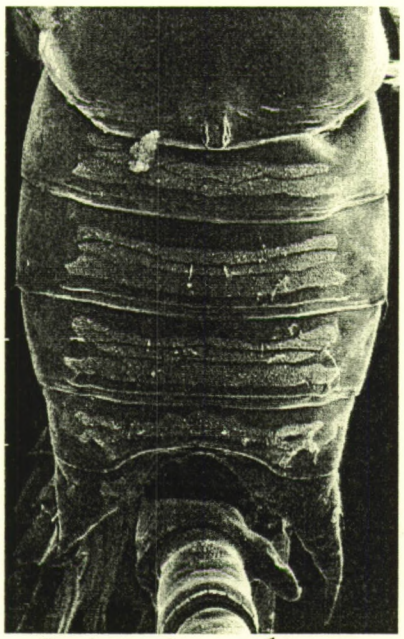
Zooplankton of the Kenya Coast: Ecology and systematics

Melckzedeck K. W. Osore

BSc Zoology & Chemistry (Kenya), MSc Marine Ecology (Belgium)



Candacia ethiopica: ♂dorsum

Prof. Dr M. H. Daro,
(Promotor)
Laboratory of Ecology & Systematics
Free University of Brussels,
Pleinlaan 2,
1050 Brussels,
Belgium

Dr Frank Fiers,
(Co-promotor)
Recent Invertebrate Section
Royal Belgian Institute of Natural Sciences,
1000 Brussels,
Belgium

A DISSERTATION

Submitted to the Faculty of Science of the Free University of Brussels in fulfilment of the requirements for the degree of

Doctor of Philosophy

Brussels, Belgium April 2003

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Dedication

To Judith and Almasi, for your patience and courage

A long time ago in Namasoli Village of western Kenya near River Yala, there lived an old man called Muhando. He brought forth a son called Atsulu. Atsulu was the father of Okumbi and the grandfather of Wellington Sakwa. Wellington Sakwa married Apelesi Omukonyi daughter of Wambululi Indetie and they had a first-born son whom they named Nathan Osore.

In a different village called Ebhukhoko there lived another old man called Washikutwa Shikunyi Waromi. He was the father of Nabucheshe, who was the father of Wamboka Nabucheshe and grandfather of Nasaye Wamboka. Wamboka was the father of Ogweli Nasaye. Ogweli's son Yafesi Shisia Ogweli married Mikali Namiba daughter of Namiba Wepiche. They had a daughter after many years of marriage and they named her Nerea Ngesa.

Years later, Nerea Ngesa and Nathan Osore met and married and were blessed with five children namely Boaz, Betty, Knight, Kennedy and Angeline. Knight met Judith, daughter of Johan and Georgette Luyckx and there came Almasi...

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The list of those to whom I am greatly indebted, without whom this research would not have been accomplished is endless. It is in fact a thesis of its own.

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I must thank those in the international organizations from whom I gained much knowledge and insight not only on plankton issues but also on various other subjects in aquatic science. They include Prof. P. Polk (VUB), Dr M. Tackx (University of P. S. Toulouse), Dr S. Ohtsuka (Hiroshima University), Dr I. Prusova (Institute of Biology of the Southern Seas), Dr M. Baars (Netherlands Institute of Sea Research), Dr Cristina Dias (University of Rio de Jeneiro), Prof. S. Piontkovski (University of New York), Dr B. Williams (Plymouth Marine Laboratory), Dr G. Boxshall (British Natural History Museum), Dr. J. Francis (WIOMSA) and Prof. S-I Uye (Hiroshima University).

I received a lot of moral and material support from Moeke Georgette, Vake Johan, Andrea and Hendrik for which I am most grateful. Last but by no means least, I would like to express my gratitude to my wife and son, my siblings and my parents for their constant support and encouragement.

Zooplankton of the Kenya Coast: Ecology and Systematics

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Summary

The Kenya coast is characterised by the half-year reversing Monsoon winds and by similarly alternating wet and dry seasons, which influence the marine and coastal environment and the flora and fauna therein. The geomorphology of the coastline comprising of creeks, bays and lagoons; and associated with various habitats of mangals, seagrass beds and coral influence the abundance, diversity and distribution of zooplankton (Chapter 1). Physico-chemical variations of the water are confined within narrow ranges except salinity, which is drastically reduced during the wet season. The hydrographical profile, climate and marine habitats of Kenya are presented in Chapter 2 including historical weather records of temperature, rainfall, humidity and evaporation. Research methodologies and material used are presented in Chapter 3.

This study reports that zooplankton population off the Kenya coast is rich, comprising more than 300 taxa of commonly occurring holoplankton and meroplankton. The zooplankton abundance varies depending on the season and the prevailing coastal geomorphology. Gazi Bay (Chapter 4) has near pristine conditions due to its location far away from major industries. Mtwapa Creek (Chapter 7) on the contrary is exposed to constant anthropogenic influence it has however, high rates of flushing resulting to efficient water exchange with the open ocean. Mida Creek (Chapter 8) lacks rivers but has substantial groundwater discharge. During the wet season, Gazi Bay and Mtwapa Creek, which have river inlets recorded high zooplankton abundances of up to 2,000 m^{-3}. Mida Creek recorded lower abundance of about 1,000 m^{-3} during the wet season, but during the dry season it increased to about 2,800 m^{-3}.

The most abundant holoplankton, which accounted for approximately 98 % of this category were Copepoda, Medusae, Chaetognatha, Appendicularia, Foraminifera, Siphonophora, Ostracoda and Cladocera. Holoplankton taxa were consistently abundant in Gazi Bay and the Mombasa Marine Park lagoon with densities ranging from about 500 to 800 m^{-3}. They were moderately abundant in Mtwapa Creek and Mida Creek with approximate densities of between 200 and 600 m^{-3}. They were often less than 200 m^{-3} in Makupa Creek (Chapters 5, 6). This creek is almost completely enclosed, has poor flushing rates and has been subjected to long term dumping of industrial and domestic wastes.

Meroplankton was mainly represented by Gastropoda, Brachyura zoea, Caridea, Pisces eggs and larvae, Decapoda and Isopoda. These taxa constituted approximately 77 % of the entire meroplankton category in numbers. They were mostly abundant in Makupa Creek (Chapters 5, 6) where they often occurred in monthly densities of between 200 and 400 m^{-3} and occasionally more than 2,000 m^{-3}.

Copepoda, whose abundance constituted more that 70 percent of the population numerically dominated the zooplankton community. *Acrocalanus*, *Oithona*, *Acartia*, *Pseudodiaptomus*, *Undinula*, *Corycaeus*, *Tortanus* and *Oncaea* were the dominant genera and accounted for more than 90% of the total copepod population.

Sixteen species of the copepod family Candaciidae were found to occur off the Kenya coast and were most abundant (up to 360 in 100 m^3) in the shelf waters (Chapter 9). *Candacia bradyi* A. Scott, 1902; *C. bipinnata* Giesbrecht, 1889; *C. curta* (Dana, 1849), *C. tuberculata* Wolfenden, 1905 and *C. ethiopica* (Dana, 1849) were reported as new records for Kenya. New morphological characters were identified and described on specimens of Candaciidae (Chapter 10), which will be valuable in taxonomic studies.

Samenvatting

Het klimaat van de Keniaanse kust wordt gekenmerkt door de half – jaarlijkse wisselende Moessonwinden en door de gelijkaardige wisselende natte en droge seizoenen, en heeft aldus een invloed op de mariene en litorale omgeving. De geomorfologie van de kustlijn met de vele kreken, baaien en lagunes, en het geassocieerd habitat van mangroves, zeegrasbedden en koralen, sterk de diversiteit en de verspreiding van het zooplankton. (Hoofdstuk 1). De fysicochemische kenmerken van het water variëren nauwelijks, met uitzondering van het zoutgehalte dat drastisch vermindert gedurende het regenseizoen. Het hydrografisch profiel, het klimaat en het marien habitat van Kenia worden besproken in hoofdstuk 2, waarin ook de historische klimatografische data betreffende temperatuur, neerslag, vochtigheidsgraad en evaporatie behandeld worden. De aangewende methodologie van het onderzoek wordt voorgesteld in hoofdstuk 3.

Deze studie toont aan dat de zooplankton populatie van de Keniaanse kust rijk is: meer dan 300 taxa werden aangetroffen in het holo- en meroplankton. De abundantie van het zooplankton varieert naar gelang het seizoen en naar gelang de plaatselijke geomorfologie van de kust. Door haar lokatie ver van industriële invloeden, is Gazi Bay (hoofdstuk 4) het meest ongerepte gebied. Mtwapa Creek (hoofdstuk 7) daarentegen, is voortdurend blootgesteld aan anthropogene invloeden en wordt gekenmerkt door een efficiente doorspoeling als resultaat van de periodieke wateruitwisseling met de open oceaan. In Mida Creek (hoofdstuk 8) ontbreekt de watertoevoer door rivieren maar er is een overvloedige input van zoetwater door grondwaterinbreng. Gedurende het regenseizoen werden in Gazi Bay en Mtwapa Creek, die beiden een riviertoevoer hebben, hoge zooplankton abundaties (tot 2,000 ind.m^{-3}) geregistreerd. In Mida Creek werden lagere waarden (rond 1,000 ind.m^{-3}) waargenomen tijdens het regenseizoen, maar deze waarden liepen op (tot ongeveer 2,800 ind.m^{-3}) tijdens het droog seizoen.

De meest abundante taxa van het holoplankton, die ongeveer 98 % van deze categorie uitmaakten, waren Copepoda, Medusae, Chaetognatha, Appendicularia, Foraminafera, Siphonophora, Ostracoda en Cladocera. Deze taxa waren constant overvloedig aanwezig in Gazi Bay en de Mombasa Marine Park lagune met densiteiten tussen 500 tot 800 ind.m^{-3}. Ze waren gematigd overvloedig in Mtwapa Creek met densiteiten tussen 200 en 600 ind.m^{-3}.

Densiteiten lagen vaak onder 200 ind.m $^{-3}$ in Makupa Creek (hoofdstuk 5, 6). Deze kreek is bijna helemaal omsloten, heeft lage doorstromingswaarden en heeft gedurende een lange periode gediend als lozingsplaats van zowel industrieel als huishoudelijk afval.

De samenstelling van het meroplankton bestond hoofdzakelijk uit Gastropoda, Brachyura zoea-larven, Caridea, viseieren en vislarven, Decapoda and Isopoda. Numeriek staan deze taxa in voor ongeveer 77 % van het gehele meroplankton. Ze waren het meest abundant in Makupa Creek (hoofdstukken 5, 6) waar ze dikwijls maandelijks densiteiten vertoonden tussen 200 en 400 ind.m^{-3}. Occasioneel werden densiteiten gemeten van meer dan 2,000 ind.m^{-3}.

Copepoda domineerde numeriek de zooplanktongemeenschap met abundaties van meer dan 70%. Acrocalanus, Oithona, Acartia, Pseudodiaptomus, Undinula, Corycaeus, Tortanus en Oncaea waren de dominanste genera en maakten meer dan 90 % van de totale copepod populatie uit.

Zestien soorten van de familie Candaciidae (Copepoda) werden gevonden langsheen de keniaanse kust en vertonen de hoogste densiteiten (tot 360 in 100 ind.m^{-3}) in het gebied van de shelf-zone (hoofdstuk 9). Candacia bradyi A. Scott, 1902; C. bipinnata Giesbrecht, 1889; C. curta (Dana, 1849), C. tuberculata Wolfenden, 1905 and C. ethiopica (Dana, 1849) werden voor het eerst gerapporteerd langsheen de keniaanse kust. Deze studie heeft eveneens een reeks nieuwe morfologische kenmerken van de Candaciidae naar voor gebracht (hoofdstuk 10). Deze kenmerken moeten als basis dienen voor een betere soortdefinitie en soortidentificatie in het taxon.

PART I

CHAPTER 1

General Introduction

1.1 Definition and importance of zooplankton and copepods

Zooplankton is commonly described as the passively floating or weakly swimming group of organisms that drift along with water currents. Zooplankton may generally be defined in function of their life history and size. Based on the life history definition, zooplankton may be categorised as holo- or mero- plankton. Holoplankton such as copepods, chaetognaths, ctenophores, cladocerans etc spend their entire life as members of the plankton. In contrast, meroplankton spend only part of their lives as plankton. They include fish eggs, brachyuran zoea and a large number of planktonic larvae, which as adults live on the bottom or form part of the nekton. Nearly every animal group and most invertebrate phyla are represented in the zooplankton (Wickstead, 1965; Raymont, 1983; Omori & Ikeda, 1984). Zooplankton is also often classified by size. Table 1.1 summarises the classification of plankton on the basis of the size range.

Table 1.1: Zooplankton classification based on size range (*After Harris et al., 2000*).

Classification	Femto-	Pico-	Nano-	Micro-	Meso-	Macro-	Mega-
Size range	.02-0.2 µm	0.2-2.0 µm	2.0-20 µm	20-200 µm	0.2-20 mm	2-20 cm	20-200 cm

The categories of femto-, pico- and nano-plankton include viruses and bacteria and are too small to be netted. They are normally sampled by centrifuging the water sample. The others are commonly referred to as 'net' plankton because they are sampled using a variety of nets. They include copepods, many larval forms and even large jellyfish.

Copepods (sub-phylum Crustacea, phylum Arthropoda) are numerically an important category and constitute a high proportion (about 70 to 90%) of the zooplankton community. They have colonised a wide variety of habitats including freshwater, sediments, subterranean (including caves), brackish water and marine water including hydrothermal vents of the deep sea (Löffler, 1968; Lescher-Moutoué, 1974; Hamner & Carleton, 1979; Itô & Burton, 1980; Burton & Hamond, 1981; Hicks & Coull, 1983; Reid, 1986; Kern & Carey, 1983). They can also live in association with plants and other invertebrates (Bell *et al.*, 1984; Por, 1984; Humes, 1990; Boxshall & Montú, 1997; Ho, 1998; Ho *et al.*, 1998). There are about 11,500 species of copepods divided between 200 families and about 1650 genera (Humes, 1994).

There are currently ten orders of copepods (Ho, 1990; 1991; 1994;) each represented by marine families, genera or species (Table 1.2). However, this systematic framework has recently become questionable (Martinez-Ibizu, Pers. Comm). For example, although not widely established yet, it is clear that Poecilostomatoida and Cyclopoida both belong in a single order Cyclopoida.

Table 1.2: Copepod orders and their habitats (*After: Ho, 1990; 1991; 1994; Huys & Boxshall, 1991; Mauchline, 1998*).

Order and authority	**Habitats**
1) Platycopioida Fosshagen, 1985	marine, benthopelagic, anchialine caves
2) Calanoida Sars, 1903	75% marine, freshwater
3) Misophrioida Gurney, 1933	marine, benthopelagic, anchialine caves
4) Cyclopoida Burmeister, 1834	marine, freshwater
5) Gelyelloida Huys, 1988	limestone deposits
6) Mormonilloida Boxshall, 1979	marine, pelagic
7) Harpacticoida Sars, 1903	80% marine, freshwater
8) Poecilostomatoida Thorell, 1859	marine, commensal/parasitic, few freshwater
9) Siphonostomatoida Thorell, 1859	marine, commensal/parasitic, few freshwater
10) Monstrilloida Sars, 1903	marine, parasitic as juveniles, pelagic as adult

Among the zooplankton, copepods are very important ecologically. The abundant Calanoida and Cyclopoida form the first vital link in the food chain that leads from phytoplankton to large fishes and mammals. Trophic levels develop leading to specialization. Primary consumers like the family Pseudocalanidae feed directly on phytoplankton. These are fed on by the secondary consumers such as Candaciidae. Others specialize as omnivorous e.g. *Centropages* or detritivorous e.g. *Scolecithrix* (Mauchline, 1998) resulting into a complex food web.

Copepods can also be devastating pest species on commercially important fish stocks and on marine plants (Boxshall & Montú, 1997; Ho *et al.*, 1998). Some copepods are also disease vectors and intermediate hosts for parasites (Huys & Boxshall, 1991).

Zooplankton plays important and diverse roles in the marine ecosystem. The key role in the ecosystem functioning is the regulation of material and energy flux in the food webs (Omori & Ikeda, 1984; Harris *et al.*, 2000). Members of zooplankton prey on phytoplankton and in turn are preyed upon. Waste products and dead material form detritus, which break down back to nutrients as described by Steele & Henderson (1981) and Oschlies *et al.* (2000) in the NPZD Model (Nutrient, Phytoplankton, Zooplankton, Detritus). As they sink, zooplankton organisms transfer net carbon from the surface to the ocean depths through biologically formed particles (biological pump) or through their skeletal structure (carbonate pump) (Lalli & Parsons, 1997).

Because many zooplankters are relatively short-lived and are capable of high growth rates, they respond quickly to environmental perturbations that influence diversity such as source-point-pollution and predation population dynamics. Since zooplankton is consumed by larger animals, changes in its community structure can provide early indication of imminent changes in the food conditions of fish, birds and mammals.

Zooplankton is also an important indicator of climatic change. This has been demonstrated off the coast of southern California where it has been found that elevation of the ocean surface temperature by 1.5 °C over 40 years caused a 70% reduction in the zooplankton biomass (Roemmich & McGowan, 1995).

Zooplankton provides food for commercially important fish, e.g. the copepod *Calanus* is the primary food for larval and juvenile cod – a commercially important fish in the North Atlantic (Keane, 1984). Therefore zooplankton studies have commercial value to mariculture and aquaculture.

Some meroplankton forms are important agents of waterborne diseases that result from ingestion of contaminated seafood (IOM, 1991). For example, because of the popularity of seafood in Japan, *Vibrio parahaemolyticus*, a virus retained by edible molluscs and gastropods, is the most common cause of gastroenteritis (IASR, 1996). Another virus *V. cholerae* (responsible for causing human cholera) can remain dormant in seawater beneath the mucous outer coat of some algae and zooplankton only erupting following elevated temperature. Certain viruses can survive in seawater for long periods (e.g. hepatitis A, poliovirus) and are concentrated by marine bivalve molluscs such as oysters and clams. Grime

(1991) has reviewed literature on plankton-associated estuarine bacteria capable of causing human disease.

1.2 Brief account of oceanographic research in the northwestern Indian Ocean

Although the Indian Ocean remains the least studied of the world oceans (Rao & Griffiths, 1998), much research effort has recently been invested especially in the northwestern Indian Ocean where the Arabian Sea was selected as one of the locations for Process Experiments under the Joint Global Ocean Flux Studies (JGOFS) (SCOR, 1987; 1995; US-GLOBEC, 1993). Development of oceanography in the Indian Ocean from early times to the late 1990s is reviewed by Rao & Griffiths (1998). Previously, very few vessels visited the Indian Ocean to conduct research, fewer still to sample for zooplankton. It is no wonder therefore that much of the present knowledge on the regional zooplankton diversity, distribution and systematics is based on collections made during cruises by the HMS Challenger (1872-1876) (Sars, 1895; Barker, 1962), Siboga Expedition (Scott, 1909), RMS Investigator (1910-1920) and the John Murray Expedition (Sewell, 1947; 1948; 1949; 1951).

The expedition that completely revolutionized the understanding of the Indian Ocean however was the multi-national, multi-disciplinary International Indian Ocean Expedition IIOE, 1959-1965 (IOBC, 1968), which resulted in numerous reports (IIOE Collected reprints, 1965-1972). Some of the results published included the zoogeographical patterns of important zooplankton taxa such as Foraminifera, Hydromedusae, Cladocera and Copepoda. It was found that in the Indian Ocean, areas with the highest copepod densities are located north of Mombasa continuing along to the Arabian coast (Rao, 1979). The copepod family Candaciidae was found to be one of the most widely distributed groups in this Ocean. Since some of the species are very similar in morphology and size and are therefore potentially strong competitors, it is documented that they avoid competition by occupying different ranges (Lawson, 1977).

Since the IIOE, there have been various other research expeditions to the northwestern Indian Ocean especially by the former USSR (Mishonov & Williams, 1998) and also by the USA, United Kingdom, Germany, France and the Netherlands.

However, this region still lacks the capacity to support and execute research offshore. In fact the only nations bordering the Indian Ocean that have demonstrated capability to conduct oceanographic research are Australia, India, Pakistan and South Africa. These have continued to conduct research even after the IIOE especially in their own territorial waters and have often been invited to team up with oceanographers from Europe and the USA to sample further offshore under auspices of JGOFS, World Ocean Circulation Experiments (WOCE), International Geosphere-Biosphere Programme (IGBP), Global Ocean Ecosystems Dynamics (GLOBEC), Biogeochemical Transport of Energy and Matter in the Deep Sea (BIGSET), etc. As a result of these, oceanographic research in the northwestern Indian Ocean has gone through dramatic expansion and over the last 10 years there have been more than 83 research expeditions directly involving more than 10 nations (see Schott & McCreary, 2001; Maghanani *et al.*, 2002).

In Kenya and within the Somali Current Large Marine Ecosystem, the most important recent expedition involving zooplankton research was the Netherlands Indian Ocean Programme (NIOP, 1992-95). During this programme, the Netherlands, Belgium, UK, USA and Germany collaborated with the nations of Kenya, Pakistan and Seychelles bringing together scientists from 27 institutions to investigate the effects of the monsoon on the marine ecosystem at different spatial and temporal scales in the northwestern Indian Ocean (Baars, 1994).

1.3 Background of zooplankton research in Kenya

Zooplankton research on the Kenya coast became active in the late 1950s during the period of colonial British East Africa. Alongside zooplankton sampling, the research involved surveying the hydrography of the East African coastline including inshore waters around Dar-es-salaam, Zanzibar and Mombasa (Wickstead, 1963; Newell, 1957). This continued to the early 1970s with inclusion of further exploratory work on ichthyoplankton (Okera, 1973), penaeid larvae (Brusher, 1974) and inshore zooplankton (Okera, 1974; Bryceson, 1984).

Momentum on zooplankton research increased towards the late 1980s during the peak of the project: Kenya/Belgium Co-operation in Marine Sciences (KBP). Much of the zooplankton sampling in the initial phase of this project was concentrated around Tudor Creek, Mombasa, which is conveniently located adjacent to the Kenya Marine & Fisheries Research Institute

(Daro, 1985). Grove *et al.* (1985) and Little *et al.* (1988) studied the distribution of ichthyoplankton in Tudor Creek and other adjacent mangrove areas. Reay & Kimaro (1984), Kimaro (1986) and Kimaro & Jaccarini (1989) described the diel, lunar and annual cycles of zooplankton. The first systematic account of the inshore copepods of Kenya (Okemwa & Revis, 1986; Revis, 1988) including the initial information on their abundance and distribution (Okemwa, 1990) were entirely based on material from Tudor Creek. Kasyii (1994) investigated the trophic relationships between the plankton and nutrients in this creek.

In the 1990s, zooplankton research extended beyond Mombasa notably to Gazi Bay in the mangrove, seagrass beds and coral reef biotopes of the south coast (Borger, 1990; Osore, 1992; 1994; Kitheka *et al.*, 1996; Osore *et al.*, 1997; Anyango, 2000). Following Kenya's participation in NIOP (1992-95) and the subsequent analyses of material from the cruises, much information about the shelf and offshore zooplankton abundance and distribution has become available not only regarding the Kenya coast (Osore *et al*, 1995; Mwaluma, 2000) but also the Somali Current ecosystem further to the north (Baars, 1994; Baars *et al.* 1995; Couwellar, 1997; Goosen *et al.* 1997). Further progress that was achieved as a result of Kenya's participation in NIOP 1992-95 is that KMFRI established research collaboration with various international institutions actively involved in plankton research in the Indian Ocean. This collaboration has enabled KMFRI to gain access and to process zooplankton collections archived at the Netherlands Institute of Sea Research (NIOZ) and Southampton Oceanographic Centre (SOC) (e.g. see Osore & Baars, 1997).

1.4 Aim, rationale and objectives

The overall aim of this study was to describe the spatial and temporal variation of zooplankton off the Kenya coast as a function of the prevailing environmental conditions. Since information on the marine zooplankton of this region is still scarce and quite scattered, this study also attempted to fill the missing gaps by providing new data. The specific aims and objectives are outlined in each chapter.

In order to provide new and useful information regarding the zooplankton of the Kenya coast, we considered the premise that the diversity, abundance and distribution of these organisms are dependent on the variable climatic, geomorphologic and environmental characteristics that

exist along the coast. First of all, the major climatic conditions are the rainy and dry seasons, which are related to the Monsoon regime. We investigated zooplankton populations that exist during the two contrasting seasons. Secondly, the main coastal geomorphological features are creeks, bays and lagoons with associated habitats of mangals, seagrass beds and coral reefs. Therefore we assessed the typical zooplankton assemblages in each of these habitats since they are representative of the rest of the coast. Thirdly, the prevailing environmental characteristics are either natural in origin (e.g. tides, ocean currents and processes etc) or as a result of anthropogenic influence (environmental degradation, agriculture, industries, over fishing etc). We integrated the human impact by using zooplankton diversity and abundance to monitor the status of water quality in the different environments.

In order to achieve the aims of this study as outlined above, our main objectives were to:

I. Describe the general taxonomic composition of the zooplankton off the Kenya coast and in particular abundance and distribution of the family *Candaciidae*, including observation of their morphological characters (fine structure) and its application in taxonomy;
II. Estimate the abundance and distribution of zooplankton including their temporal and spatial variation at selected representative sites;
III. Compile detailed data and metadata associated with the zooplankton samples including temperature, salinity, dissolved oxygen, chlorophyll-*a*, inorganic nutrients, pH, rainfall etc;
IV. Provide information regarding zooplankton of Kenya to the Darwin Initiative Data Base in order to avail it to a broader scientific and education community.

CHAPTER 2

Climatic, environmental and general characteristics of the Kenya coast

2.1 Hydrography and climate

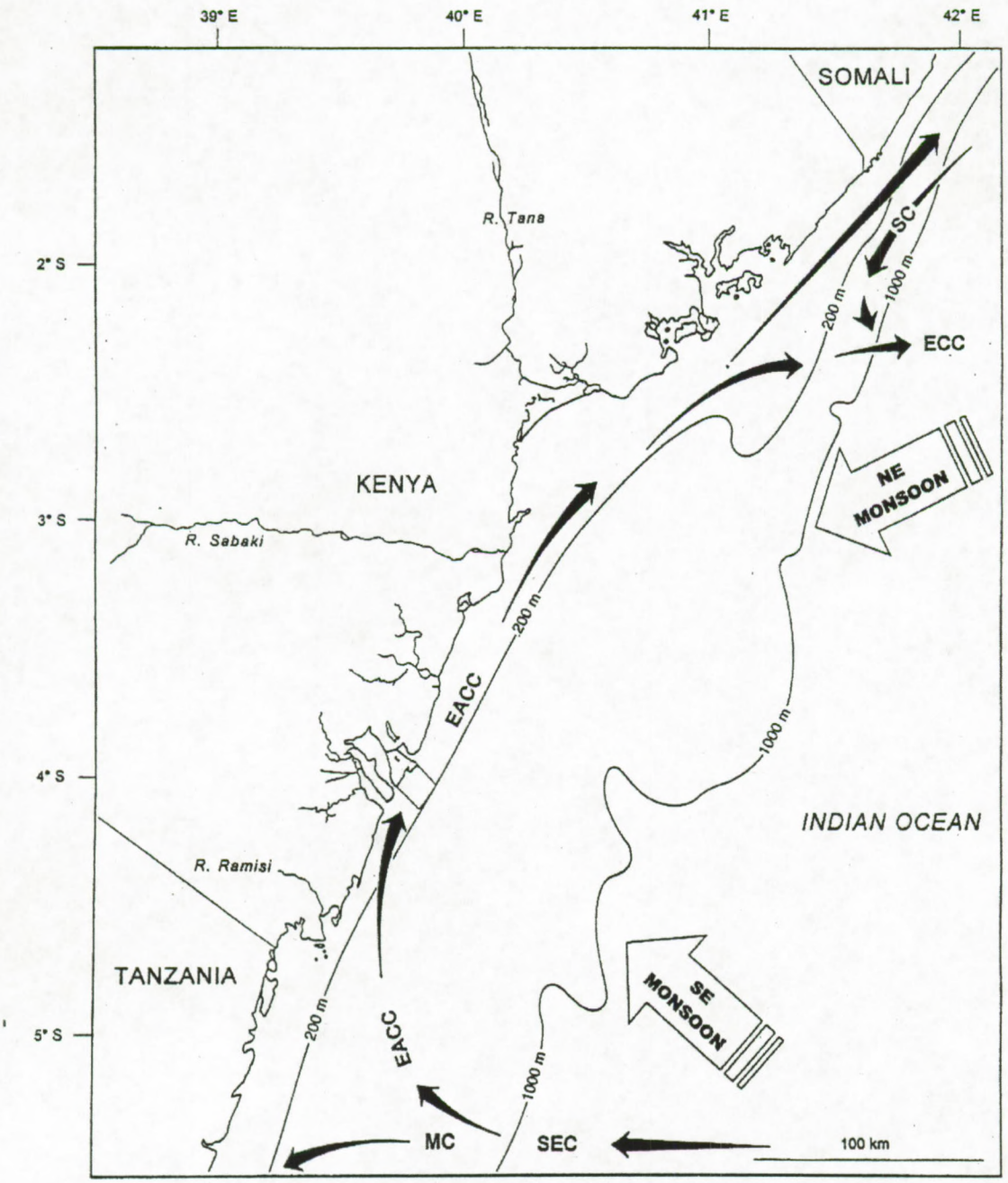


Fig. 2.1: Kenya coast: Bathymetry, direction of the monsoons and the major surface ocean currents (SEC = South Equatorial Current, MC = Mozambique Current, EACC = East African Coastal Current, ECC = Equatorial Counter Current. *Source: Newell, 1957; Johnson et al., 1982*).

The coastline of Kenya is about 536 km long and it lies between latitudes 1° 41" S and 4° 39" S. Fig. 2.1 shows the bathymetry, direction of the Monsoon winds and the major surface ocean currents off the Kenya coast. The coast is part of the Somali Current Large Marine

Ecosystem (Sherman *et al.*, 1998) and also classified as a sub-region of the Somali Coastal Current by GIWA - the Global International Water Assessment (Pernetta & Mee, 1998; UNEP, 1999). The southern coast of Kenya consists of Pleistocene reefs with a prominent intertidal platform that forms a fringing reef. The narrow coastal plain has a range of coastal hills that block inland rivers from delivering fresh water and sediments to the coast. The northern coast is formed by sedimentary plains of Quaternary and Tertiary origin and is drained by Kenya's two largest rivers the Tana (708 km long) and the Athi/Sabaki (547 km long), both transporting large volumes of fresh water and sediments to the coast. There are also submarine groundwater discharges along the coast (Ruwa & Polk, 1986; Kitheka, 1998), which influence diversity and distribution of especially mangals and seagrass beds (Tack & Polk, 1999; Kamermans *et al.*, 2002).

The continental shelf is narrow (0-3 km) except off Malindi and the River Tana mouth where it extends 15 - 60 km offshore. Beyond the 200 m depth, the shelf slopes gently to 1,000 m deep over a distance of 100 km except in the north around Lamu where it is very steep and also very productive due to the Somali coastal upwelling.

The tides of the Kenya coast are mixed semi-diurnal with two maxima and two minima per lunar day (Brakel, 1982). In each month the coast experiences two spring tides (during Full and New moon) and two neap tides. The tidal range is about 4 m and the successive pairs of high tides and low tides are unequal in height. The major coastal currents are derived from the South Equatorial Current (SEC), which divides on approaching the East African coast from central Indian Ocean (Fig. 2.1). It gives rise to the East African Coastal Current (EACC), which flows northwards along the Kenya coast and the Mozambique Current, which flows southwards. The EACC is constantly accelerated or decelerated depending on the direction of the Monsoon winds. Detailed descriptions of the ocean currents along the Kenya coast are widely published (Newell, 1957, 1959; Wyrtki, 1971; Johnson *et al.*, 1982; Woodberry *et al.*, 1989; Baars, 1994).

Monsoon winds are the dominant climatic influence on the Kenya coast, blowing from the northeast (December-March) and southeast (May-October) (Fig.2.1). The monsoon cycle is driven by the annual north-south migration of the Inter-Tropical Convergence Zone (ITCZ). During NE Monsoon (locally known as '*Kaskazi*'), inshore currents are predominantly southward and winds are light (less than 0.25 ms^{-1}) allowing for stratification of the water

column. The Somali Current influences the north coast of Kenya during this period by introducing cold upwelling waters in the area (Johnson *et al.*, 1982). During the SE Monsoon ('*Kusi*'), conditions are the opposite with high cloud cover, rain, strong winds of between 0.5 and 0.8 ms^{-1}, rough sea and decreased temperature and light.

Rainfall

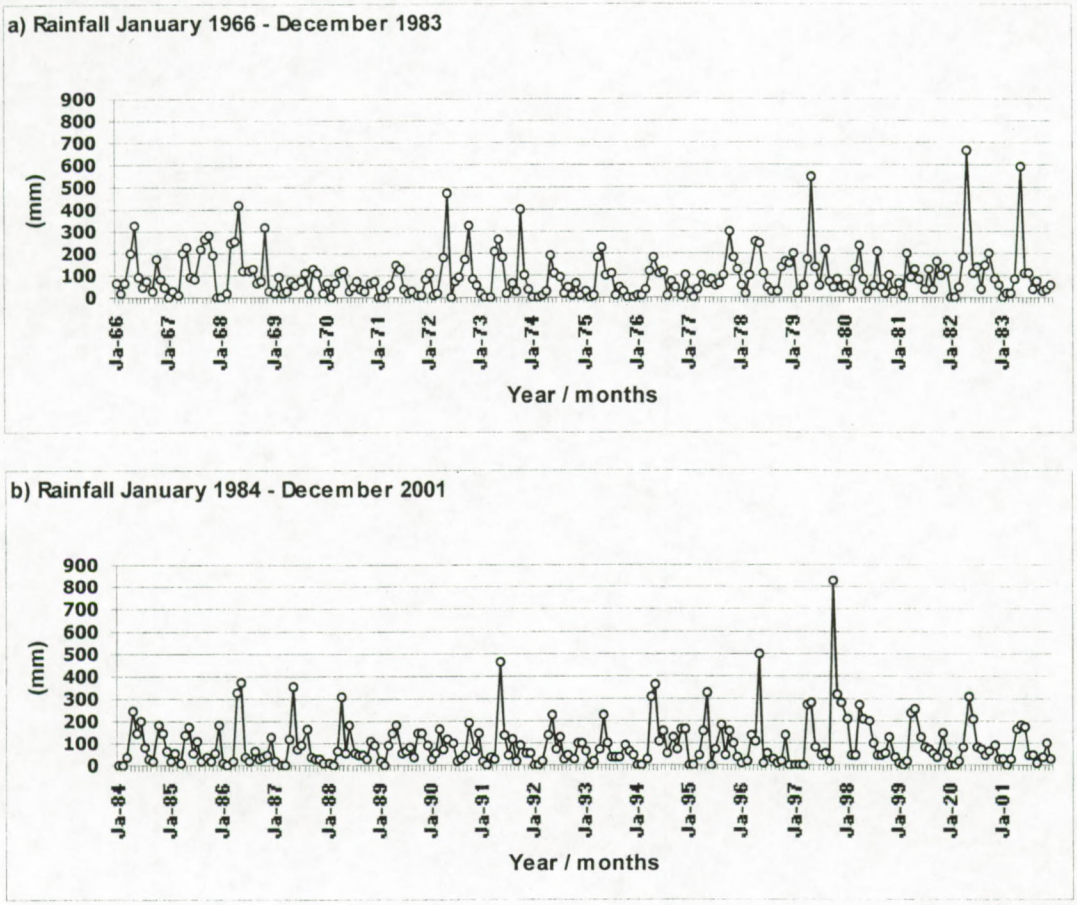


Fig. 2.2: Total monthly rainfall recorded around Mombasa **a**) from January 1966 to December 1983 and **b**) from January 1984 to December 2001(*Source: Meteo. Dept., Mombasa*).

The short intervals between the two monsoons (April-May and November-December) when the winds may be blowing from either direction are known as the inter-monsoons and they are characterised by long rains in April/May and short rains in November/December. Figs 2.2a and b show the total amount of rainfall recorded monthly around Mombasa during a period of 36 years. Total rainfall received around Mombasa averaged over the years is about 1,130 ± 40 mm each year (range: 544 mm in 1971 to 2,175 mm in 1997). The wettest months are usually April (159 ±18 mm) and May (270 ± 47 mm). However, in 1997 abnormally heavy rainfall of

up to 826 mm was received in October (Fig. 2.2 b). This was associated with the El Niño phenomena, which caused a lot of flood disasters in Kenya (see National Operations Disasters Office, 1998; Ininda, 1999; Semazzi & Indeje, 1999). There was also abnormally heavy rainfall in January 1998 (213 mm) during the month that is normally dry. The least amount of rain is normally received in February when there is usually very little (12 ± 3 mm) or no rainfall. The long-term trend of rainfall in Mombasa approximates well the pattern along the whole Kenya coast. However, north of Mombasa the coast receives slightly less rainfall than the south (Meteorological Department, Mombasa).

Humidity

Figs 2.3a and b show the trend of monthly relative humidity recorded around Mombasa for 30 years. Humidity in the afternoon is usually lower than in the morning. The average humidity in the afternoon is about 64.8 ± 1.0 % (range: 61.6 ± 4.5 to 67.6 ± 4.8%).

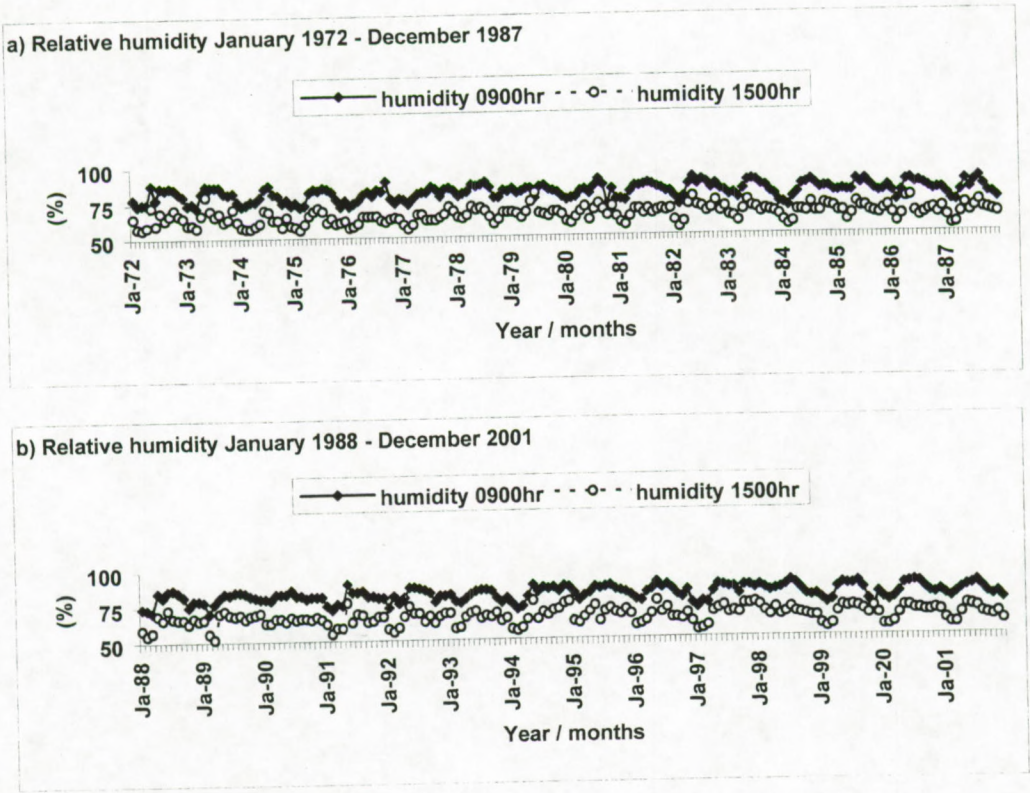


Fig. 2.3: Monthly relative humidity around Mombasa during the morning (0900hr) and afternoon (1500hr, unshaded circles) recorded **a**) from January 1972 to December 1987 and **b**) from January 1988 to December 2001. (*Source: Meteo. Dept., Mombasa*).

But this may reduce to about 58.5 ± 3.7 % during the dry season in February (Fig 2.3 b). In the morning humidity rises to about 81.0 ± 0.7 % (range: 78.0 ± 4.6 to 83.3 ± 3.4 %). Humidity is higher 83.0 ± 2.9 % (between 80.0 ± 2.5 % and 84.8 ± 3.0 %) during the rainy season in May and also during the cold months of July (85.9 ± 1.5%) and August (84.8 ± 2.1%). The daily variation of humidity is such that during the night and early morning it increases to maximum. During the late morning and afternoon it reduces again.

Temperature

Figs 2.4a and b show the minimum and maximum air temperature around Mombasa recorded over 30 years. Monthly air temperature varies between approximately 20.7 ± 0.4 and 30.6 ± 0.5 °C with a minimum during the SE Monsoon when cloud cover is high.

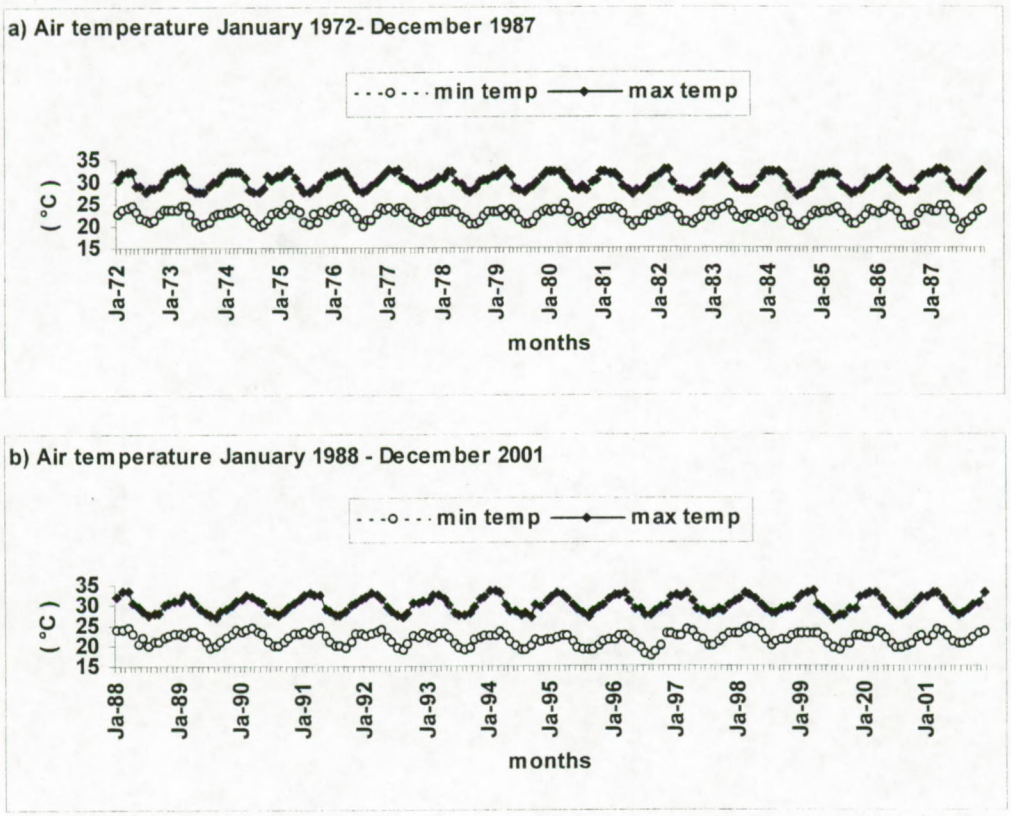


Fig. 2.4: Trend of minimum (unshaded circles) and maximum atmospheric temperature recorded around Mombasa **a**) from January 1972 to December 1987 and **b**) from January 1988 to December 2001. (*Source: Meteo. Dept., Mombasa*).

Minimum temperature is on average about 22.2 ± 0.5 °C (range: 20.7 ± 1.3 to 22.8 ± 1.5 depending on the year). The lowest average temperature (20.1°C) is during the months of July

and August (Fig. 2.4). Maximum air temperature is about 30.2 ± 0.3 °C (range: 29.7 ± 1.6 to 30.6 ± 2.0 °C). The highest monthly temperature (32.6 ± 0.3 °C) is usually during February. In such warm periods, the monsoon winds blowing from the sea can periodically raise the air temperature to 36 - 38 °C and above (Norconsult, 1975).

There are two temperature maxima, corresponding to transition periods of the inter-monsoon when the winds are light and variable and insolation is high. The first maximum occurs at the end of the SE Monsoon around October/November, which causes temperature of seawater in the lagoon to rise to 30 °C. The second maximum occurs at the end of the NE Monsoon in February/March when insolation is highest and seawater temperature can rise to 31-32 °C. During extremely warm years such as in 1994 and 1998 (see Ininda, 1999 - associated with the El Niño sea warming phenomena), temperature in the inshore water exceeded the expected by 2°C (McClanahan *et al.*, 2001).

Evaporation

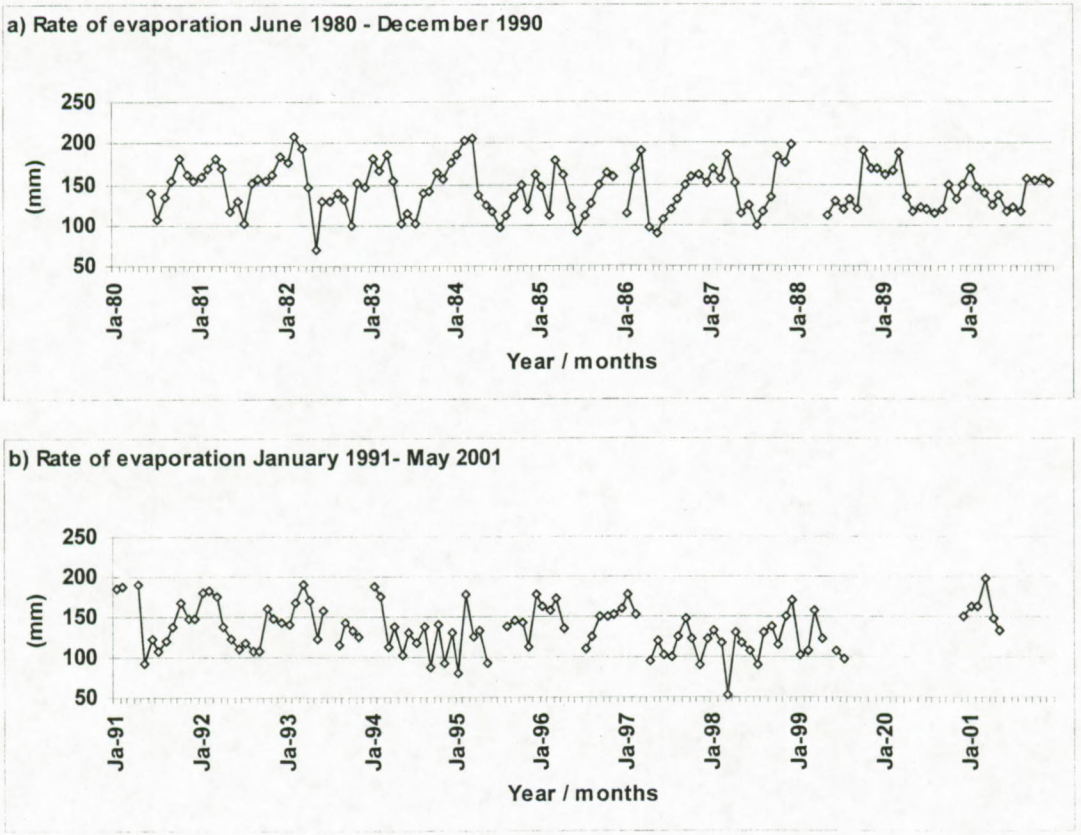


Fig. 2.5: Total monthly evaporation rates around Mombasa **a**) from June 1980 to December 1990 and **b**) from January 1991 to May 2001. (*Source: Meteo. Dept. Mombasa. Gaps mean no data collected*).

The rate of evaporation is affected by both temperature and humidity since warm air can hold more water vapour than cool air. The strength of the prevailing winds will also affect evaporation rates. Figs 2.5a and b show monthly evaporation rates around Mombasa. The monthly rates range from 116 ± 22 to 160 ± 21 mm (mean = 141 ± 10 mm) depending on the year. During the dry season in February or March the rates may exceed 200 mm (Fig. 2.5 a).

2.2 Critical habitats

The critical marine habitats that characterise the Kenya coast include the coastal mangals, seagrass beds and coral reefs, on which a variety of shore birds, fisheries and other marine fauna and flora rely for maintenance. Bays and creeks are dominated by mangals, which cover approximately 54,000 ha and are an association of nine species: *Avicennia marina*, *Bruguiera gymnorrhiza*, *Ceriops tagal*, *Heritiera littoralis*, *Lumnitzera racemosa*, *Rhizophora mucronata*, *Sonneratia alba*, *Xylocarpus granatum* and *X. mollucensis* (Kokwaro, 1985; Dahdou-Guebas *et al.*, 2000; Kairo *et al.*, 2002). Twelve seagrass species are present in Kenya (UNEP, 1998, Gullström *et al.*, 2002) occurring extensively in shallow reef slopes and lagoons. These are: *Cymodocea rotundatum*, *C. serrulata*, *Enhalus acoroides*, *Halodule uninervis*, *H. wrightii*, *Halophila balfouri*, *H. minor*, *H. ovalis*, *Syringodium isoetifolium*, *Thalassia hemprichii*, *Thallasodendron ciliatum* and *Zostera capensis*.

The extent, size and diversity of coral reef ecosystems decrease northwards along the Kenya coast due to increasingly poor conditions for reef development caused by river influence and the Somali Current system. Nearly 60 genera representing about 180 species of scleractinian and milleporid corals have been recorded in Kenya (Rosen, 1971; Hamilton & Brakel, 1984; Sheppard, 1987). However, the recent devastation of dominant coral genera and species following the 1997-98 El Niño (Obura, 2001; McClanahan *et al.*, 2001) has dramatically changed the coral community structure.

2.3 Marine fisheries

Kenya's most exploited marine resources are the fisheries located within the creeks, lagoons and reefs in the inshore waters. These include demersal fish (lethrinids, siganids, scarids, snappers etc); pelagic fish (sharks, rays, mackerel, tuna, sardines, king fish etc); Beche-de-

mer (sea-cucumbers), crustaceans (prawns, crabs and lobsters), squids and octopus (CDA/KMFRI/KWS/FD/MCM/KAHC, 1996). The estimated total number of fishermen along the entire coast is about 6500. They are mostly artisanal fishermen using non-mechanized canoes and fishing gears such as traps, gill nets, beach seines, ring nets, spear guns and hand lines. There is limited semi-industrial fishing using four government licensed commercial trawlers. However, an unknown number of unlicensed and illegal fishing vessels also operate in the area (Pers. Observation).

Nationally, the fisheries resources in Kenya are quite under-exploited and localised over-fishing occurs mostly within the reefs and shallow coastal areas where fishermen have easy access. The combined catches from rivers, lakes and marine contribute to only 0.04% of the Gross Domestic Product (GDP). Out of this, the national annual marine landing is about 12,000 tonnes (World Bank, 2001). This is minimal considering that Kenya's annual potential marine stocks are currently estimated to be between 22,000 and 34,000 tonnes (FAO, 1990; 1998; World Bank, 2001). Fig. 2.6 indicates that over the years Kenya's annual marine catches have continued to stagnate and the quantities also lag far behind those of neighbouring Somalia and Tanzania.

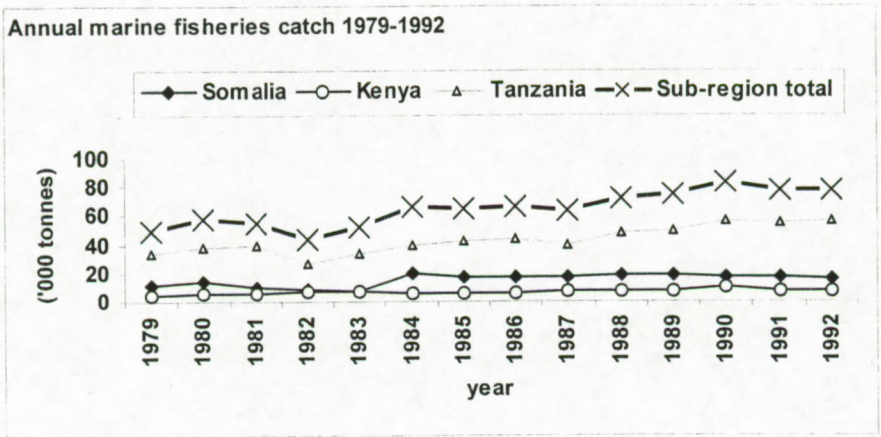


Fig. 2.6: Annual marine catches (tonnes) for Kenya and the countries in the Somali Coastal Current sub-region (*Source: FAO, 1990*).

However, it is recognised that information and data on offshore fisheries in the Kenya coast and the entire sub-region are largely unavailable (CDA/KMFRI/KWS/FD/MCM/KAHC, 1996; McClanahan *et al.*, 2000). One possible reason for this is that Kenya and the other

countries of the sub-region lack the capacity to monitor and exploit their vast marine resources and therefore leave them exposed to unscrupulous foreign fishing vessels. In Kenya, these vessels often engage in destructive fishing practices, which include excessive by-catch and discard, accidental capture of endangered species like turtles and dugongs (Alverson *et al.*, 1994; McClanahan, & Young, 1996; McClanahan *et al.*, 2000) and indiscriminate trawling.

Kenya's coastal population is estimated at 2.9 million and it is growing at an annual rate of 2.4% (Ruwa, 1998). To sustain this population growth, there must be a reciprocal increase in food production and in particular adequate fish protein. For this reason, the development and successful management of fisheries resources by the coastal inhabitants for their own benefit is therefore one of the most outstanding national challenges for the government of Kenya. There are however economic constraints facing the local fishermen, which include (i) inadequate mechanised vessels for deep-sea fishing, (ii) poor landing and storage facilities, (iii) inefficient marketing system and (iv) lack of investment capital. The physical (narrow continental shelf) and climatic (harsh SE Monsoon) conditions along the coast also contribute to constrain development of the coastal and marine fishery in Kenya.

2.4 Institutional arrangement

The Kenya government mandates three main institutions with the task of managing the country's fisheries and other living marine resources. Under the Fisheries Act (Cap 379) the Fisheries Department protects the fisheries resources by controlling all fishing activities and issuance of licences. The Kenya Wildlife Services operates under the Wildlife Conservation and Management Act (Cap 376) and is responsible for conservation of marine flora and fauna. It fulfils this mandate by creating, restoring and managing marine national parks and reserves. The Kenya Marine and Fisheries Research Institute operates under the Science and Technology Act (Cap 250). Its mandate is fisheries research, marine conservation and management, monitoring of marine pollution and promotion of aquaculture.

CHAPTER 3

Material and Methods

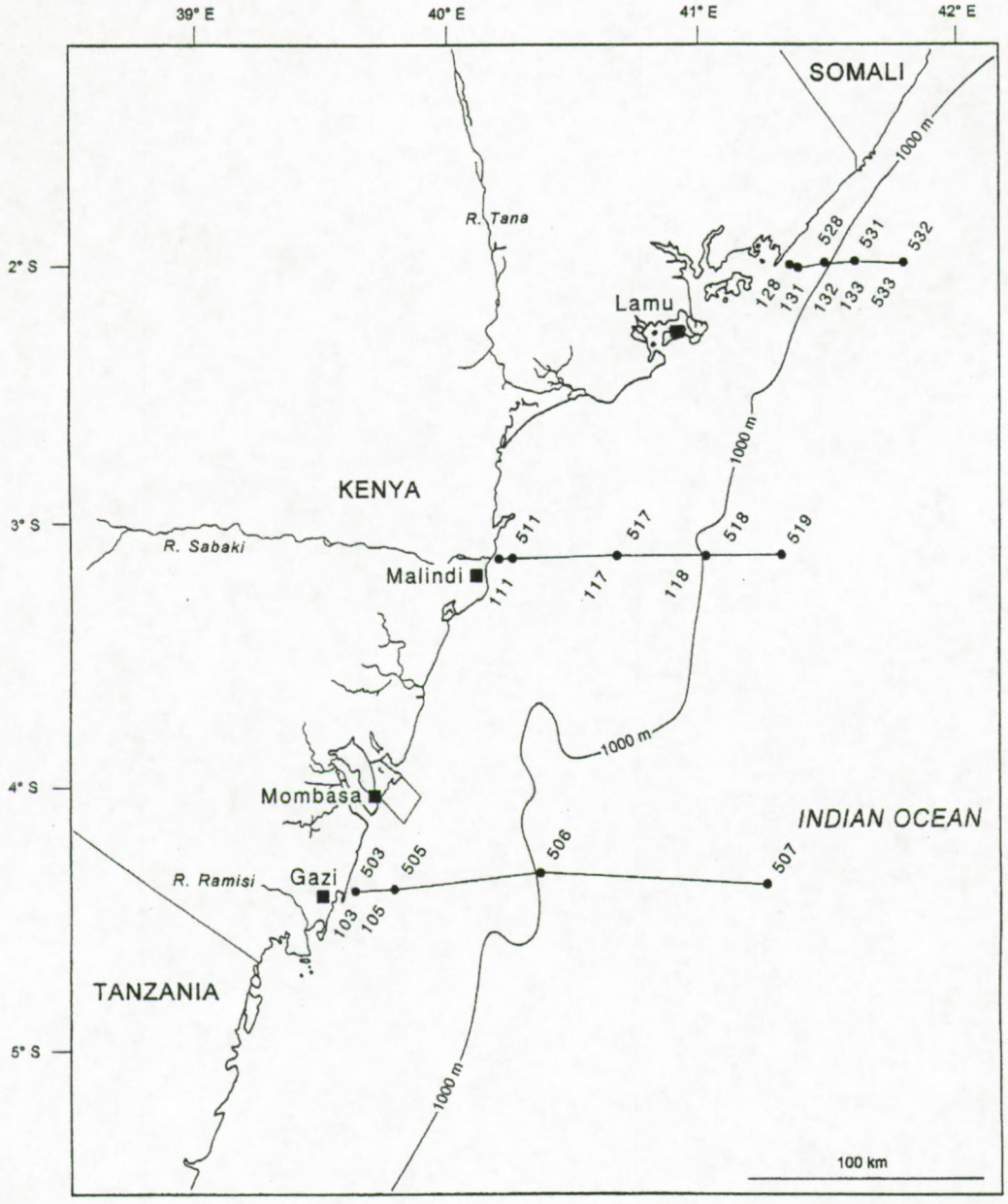


Fig. 3.1: Kenya coast: Location of the sampling sites.

3.1 General information on the study area

Samples for this study were obtained from various locations situated inshore along the coastline as well as offshore. Fig. 3.1 is a map of the Kenya coast showing location of the sampling sites. The main sampling sites during this study were Gazi Bay (GB), Makupa Creek (MkC), the Lagoon of Mombasa Marine Park and Reserve (MML), Mtwapa Creek (MtC) and Mida Creek (MdC). Other sites, which were also occasionally sampled especially for the study of the copepod family Candaciidae were Diani Lagoon (DL), Tudor Creek (TC) and Kilifi Creek (KlC). The bulk of the samples used for the study of the distribution of Candaciidae off the Kenya coast were obtained from 12 out of 14 sampling stations located on three transects running approximately perpendicular to the coastline (see Fig. 9.1 ahead).

3.2 Field sampling strategy

3.2.1 Zooplankton

Inshore and near-shore water in bays, creeks and lagoons was sampled for zooplankton using a 1.5 m long Bongo net with mouth radius of 45 cm and a mesh size of 335 μm. Standard methods for zooplankton sampling (Omori & Ikeda, 1984; Greene, 1990), fixation and preservation (Steedman, 1976) were employed. The volume of water filtered during each tow was estimated by multiplying area of the net mouth by the distance covered during each tow. Filtration efficiency was monitored by placing one calibrated flowmeter inside the net mouth and a second one on the arm extending to the side of the net. Comparison of the readings on the inside and outside flowmeters after the tow was used to indicate filtration efficiency. The net had a filtration efficiency of >85% as long as we maintained the filtered water volume (following our calibrations) of between 30 and 50 m^3 during each tow.

Three tows were made at each sampling station. The Bongo net was towed horizontally behind a rubber dinghy powered by an outboard motor at a constant speed of 0.5 ms^{-1}. After each tow, the catch was preserved in buffered 5% formalin.

Offshore sampling was conducted on board the R/V Tyro using a Hydro Bios Multinet zooplankton sampler with 200 μm mesh size plankton nets. Depth stratified sampling was done by horizontally towing the sampler at various depths. For shallow stations (0-50 m) only

one shallow cast was made. For deeper stations (500-2,000 m) three to four deep casts were made at various depth strata. A deck pump was also used to collect surface (0-3 m) zooplankton on each station. Conductivity, temperature and depth were measured simultaneously while the Multinet was in operation.

3.2.2 Environmental variables

Environmental variables were measured concurrently with each zooplankton tow. Surface water temperature and salinity were measured using an S-T Aanderaa Display unit 3315 coupled with S/T sensor 3210. Mercury thermometers and Artago salinometer were used as backup. Orion meter Research Model 231 was used to measure the pH. Secchi disc was used to determine transparency. Tidal depth and water elevations were measured using the Plastimo echo sounder and a tide pole respectively.

3.2.3 Water samples

Water was sampled from each station, prepared and treated with standard methods (Strickland & Parson, 1968; Parson *et al.*, 1984) for laboratory determination of inorganic nutrients, chlorophyll-*a* and phytoplankton.

3.3 Laboratory analyses

3.3.1 Zooplankton

Zooplankton samples were first gently filtered through a 50 μm mesh sieve to separate them from any noticeable conglomerates of detritus. Initially the whole sample was examined and all organisms larger than 1cm such as Medusae were identified, counted and removed. This initial step of scanning through the whole sample was to ensure that all the zooplankton groups present were accounted for quantitatively.

The samples were diluted to 250 ml and agitated gently. Five sub-samples of 5 ml each were pipetted into the counting chambers, total sub-sample volume being 1/10 of the total sample i.e. (5x5)/250 = 1/10. Zooplankton identification keys consulted are found in Giesbrecht (1892), Sars (1901), Scott (1909), Sewell (1929, 1932, 1947 & 1948), Rose (1933), Trégouboff & Rose (1957), Brodsky (1962), De Decker (1964), Wickstead (1965), Hulsemann (1966), Owre & Foyo (1967), Frost & Fleminger (1968), Bradford (1972) and

Greenwood (1980). Individuals in each systematic category were counted under a Wild Heerbrugg stereomicroscope at a magnification of 10x10 for bigger organisms and 10x40 for smaller ones and in situ abundance calculated as numbers of individuals per cubic meter of water filtered (ind.m^{-3}).

3.3.2 Family Candaciidae

To investigate abundance and distribution of members of the copepod family Candaciidae off the Kenya coast, 400 zooplankton samples were analysed. These samples have been collected over the years from the various sampling campaigns conducted during the Kenya Belgium Project in Marine Sciences (KBP 1985-95), the Netherlands Indian Ocean Programme (NIOP 1992-95) and the Kenya Netherlands Wetlands Project (KNWP 1996-97). During KBP and KNWP, zooplankton samples were collected using Bongo nets of radius 45 cm and mesh size of 335 μm towed horizontally in subsurface water as explained above. All individuals of *Candacia* and *Paracandacia* were isolated quantitatively from the samples. The counted individuals were represented as numbers in cubic metres of water filtering through the sampling net. The specimens were first identified and counted. Series of lengths on individual specimens (biometric measurements) were taken using a Dialux 20 microscope (maximum magnification 10 x ocular, 12.5 x adaptor and 100x objective) with phase contrast and equipped with a camera lucida. Extra identification keys specifically suitable for Candaciidae were obtained from Farran (1948), Fleminger & Bowman (1956), Grice (1961, 1962, 1963, 1981), Grice & Jones (1960), Pillai (1967), Tseng (1970), Lawson (1973a) Grice & Lawson (1978) and Das *et al.* (1982). For further species identification and confirmation, samples were also sent to Dr Susumu Ohtsuka (Fisheries Laboratory, University of Hiroshima, Japan). Materials of *Candacia pachydactyla* (Dana, 1849) from the type region were donated by Dr Cristina Dias of the Federal University of Rio de Janeiro, Brazil.

From the 400-zooplankton samples, a total of 219 Candaciidae specimens from localities along the coast of Kenya as well as from collections down to 1000 m deep and as far as 200 km off the Kenya coast (see Fig. 9.1) were studied. The specific localities sampled monthly during both the KBP (1985-1995) and KNWP (1996-97) included Gazi Bay (GB), Diani Lagoon (DL), Makupa Creek (MkC), Tudor Creek (TC), Mombasa Marine Park & Reserve Lagoon (MML), Mtwapa Creek (MtC), Kilifi Creek (KlC) and Mida Creek (MdC). Samples studied from the TYRO Expedition (NIOP 1992/95) were obtained during June-July 1992 and November-December 1992 from three transects of Gazi (off Gazi Bay), Sabaki (off Malindi)

and Kiwayu (northeast of Lamu). We obtained and studied further 160 Candaciidae specimens from a total of 48 copepod samples from the Caribbean Sea (Cruise YUC 1990) and the southern Atlantic Ocean (Mercator Cruises nos. 91 & 92 of 1938). All these samples are deposited at the laboratories of Kenya Marine and Fisheries Research Institute (KMFRI, Mombasa, Kenya), the Royal Museum for Central Africa (Tervuren, Belgium) and the Royal Belgian Institute for Natural Sciences (RBINS, Brussels, Belgium).

Processing of material and equipment used for SEM investigation on Candaciidae

The following were the main steps in the treatment of the specimens and their preparation prior to viewing under the scanning electron microscope (SEM).

Cleaning: *Candacia* and *Paracandacia* of both sexes were randomly selected from all samples from southern Atlantic Ocean and the Kenya coast. The cleanest copepods without physical distortion or missing appendages and other body parts were selected. Rinsing them in several changes of distilled water further cleaned the copepods.

Dehydration: Each specimen was transferred into a porous capsule labelled with locality, species and sex. The capsules were submerged in beakers of graded ethanol: 30%, 50%, 70%, 80% and 95% at intervals of 30 minutes and left in the final 100%. After 24 hrs, the capsules were submerged in beakers of graded Amyl acetate: 50%, 75% and 100% at intervals of 15 to 20 minutes.

Critical-point drying: The porous capsules were placed in the dryer, Model Balzers CPD 030, and subjected to CO_2 critical-point drying.
After critical-point drying, the brittle specimens were carefully fitted upon aluminium stubs with double sided adhesive. Working under the stereomicroscope and incident illumination, specimens were mounted on the stub in a particular orientation (dorsal, ventral, lateral, oblique) to ensure that the desired surface would receive optimum electron beam (Pulsfer, 1975). The specimens were placed in the sputter coater Model SCD 050 and coated with gold.

Observations were made using a Phillips electron microscope Model XL 30 ESEM at an accelerating voltage of 15.0 kV and magnifications ranging between x 500 and x 20,000.

3.3.3 Phytoplankton

Phytoplankton was collected by filtering 5 litres of subsurface water through a 25 µm sieve preserving the filtrate in 5% neutralized formalin. Enumeration was done using a Sedgwick Rafter counting cell and following methods recommended by Sournia (1978). An inverted microscope (Leica DMIL Serial no. 090-131.001-006) fitted with wWild Heerbrugg MPS camera used. Estimation of the phytoplankton standing crop was carried out by the sedimentation method (Utermohl, 1936). The different species were counted as cells per litre. Identification keys by Cleve-Euler (1955), Hasle & Fryxell (1995) and Taylor (1987) were used.

3.3.4 Chlorophyll-*a*

Chlorophyll *a*, an indication of phytoplankton biomass, was quantified in the water samples by the spectrophotometric method described by Parsons *et al.* (1984). Known volumes of seawater samples were filtered through 0.45 µm pore-size glass fibre GF/F filters (0.47cm diameter). During filtration, a few drops of a suspension of magnesium carbonate ($MgCO_3$) were added to the sample to prevent acidity on the filter. The collected pigment was extracted with ANALAR grade 90% acetone (overnight in the dark at 4°C) and the concentration of chlorophyll-*a* measured using the spectrophotometer (Shimadzu Double Beam UV-150-02).

3.3.5 Dissolved oxygen

Dissolved oxygen (DO) was determined by the modified classical Winkler titration methods (Strickland & Parsons, 1968; Parsons *et al*, 1984). At each sampling station, two clean BOD bottles were rinsed with the sampled seawater before sub-samples were carefully siphoned into each bottle. Oxygen in the samples was fixed immediately by adding manganous sulphate and alkaline potassium iodide solutions. The contents were mixed and the bottles kept in the dark. After acidification with sulphuric acid, the samples were titrated with sodium thiosulphate.

3.3.6 Nutrients

Methods described by Parsons *et al* (1984) were used to analyse nutrients in the water samples: ammonium (NH_4^+-N), nitrate/nitrite {(NO_2^- + NO_3^-)-N} and phosphates (PO_4^{3-}-P). All chemicals used were of analytical grade and all the glassware acid washed. Ammonium was determined by the modified procedure of Parson *et al.* (1984). This is an indophenol method, which relies on the measurement of an indophenol colouration formed by ammonium

in the presence of sodium nitroprusside after oxidation with hypochlorite and phenol in an alkaline citrate solution. The absorbance was read in a 1 cm cuvette at 630 nm after at least six hours. Standard curves for the analysis were prepared using analytical grade ammonium sulphate.

Dissolved nitrate/nitrite was determined using the Technicon Auto-Analyser II automated method. The procedure involved the reduction of nitrates to nitrites by the use of a reduction column containing copper coated cadmium fillings. The nitrite ion reacted with sulfanilamide under acidic condition to form a diazo compound that coupled with N(1-naphthyl)-ethylenediamine to form a reddish purple dye. This coloration was measured spectrophotometrically at a wavelength of 543 nm.

Determination of phosphates was according to the methods of Strickland & Parsons (1972). This involves the formation of a complex between soluble reactive phosphate, molybdic acid, ascorbic acid and trivalent antimony. The absorbance of the resulting blue coloured complex was measured spectrophotometrically at a wavelength of 885 nm. Potassium dihydrogen phosphate was used for the preparation of calibration standards.

3.4 Statistical analyses

The community structure of the zooplankton was analysed using TWINSPAN (Two Way Indicator Species Analysis) multivariate classification (Hill, 1974; 1979). The ordination technique Canonical Correspondence Analysis (CCA) was used for interpretation of community composition in terms of species response to environmental gradients (ter Braak & Prentice, 1988). Zooplankton data (actual abundances: ind.m^{-3}) were subjected to log + 1 transformation prior to performing the analyses in order to scale down the effect of dominant taxa (Clarke & Green, 1988).

Ecological diversity (H') and homogeneity (J) of the zooplankton taxa were calculated using the Shannon index (Magurran, 1996):

$$H' = - \Sigma p_i \ln p_i$$

where p_i, the proportional abundance of the ith taxa = (n_i/N)

$J = H'/\text{Hmax}$, where Hmax = log K

where Hmax is the maximum possible diversity of sample consisting of K taxa

Alternately, the Margalef Index was used to calculate taxa diversity (Margalef, 1951):

$H = (S-1)/\ln N$

where S is the number of encountered taxa and N the total number of individuals in the sample.

Statistical tests and co-correlations were performed using methods from Hampton (1994).

3.5 Meteorological data

Rainfall data, relative humidity, air temperature and evaporation rates were provided by the Kenya Meteorological Department and were obtained at local stations in Kwale, Mombasa and Malindi.

Table 3.1 shows a summary of the various sections within Chapter 3 (left column) and the chapters in this volume (right column) where the sections were applied.

Table 3.1: Summary of where the material and methods are used in the chapters.

Sections of Cap 3: Material & Methods	**Chapters where the sections are employed**
3.2 Field sampling strategy	
3.2.1 Zooplankton	Caps 4, 5, 6, 7, 8, 9, 10
3.2.2 Environmental variable	Caps 4, 5, 6, 7, 8
3.2.3 Water samples	Caps 4, 5, 6, 7, 8
3.3 Laboratory analyses	
3.3.1 Zooplankton	Caps 4, 5, 6, 7, 8,9
3.3.2 Family Candaciidae	Caps 9, 10
3.3.3 Phytoplankton	Caps 7
3.3.4 Chlorophyll-*a*	Caps 5, 6, 7
3.3.5 Dissolved oxygen	Caps 4, 5, 6, 7,
3.3.6 Nutrients	Caps 7
3.4 Statistical analyses	Caps 4, 5, 6, 7, 8, 9
3.5 Meteorological data	Caps 2, 4, 5, 6, 7, 8

PART II

Zooplankton Assemblages South of Mombasa, Kenya

Introduction

In part II of this study, we shall present the zooplankton assemblages of two representative areas located to the south of Mombasa Island. These are Gazi Bay, situated about 50 km south of Mombasa and Makupa Creek on the southwest of Mombasa Island.

In the south of the Kenya coast, zooplankton sampling in the past has been carried out at Shirazi/Funzi Bay, Gazi Bay, Diani Lagoon, Port Reitz Creek and Makupa Creek. In most of these however, sampling was only occasional (few days to 1 month) and mainly for exploratory purposes. Part II will therefore, only present results obtained during long-term campaigns of between 1 and 2 years.

Three chapters are presented here to describe zooplankton assemblages in Gazi Bay (Chapter 4) and zooplankton and copepod assemblages in Makupa Creek (Chapters 5 and 6).

This material is the first documentation of the zooplankton of Makupa Creek.

CHAPTER 4

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

Results reported as:

M. K. W. Osore, M. L. M. Tackx & M.H. Daro 1997. The effect of rainfall and tidal rhythm on the community structure and abundance of the zooplankton of Gazi Bay, Kenya. *Hydrobiologia* **356:** 117–126.

4.1 Summary

This chapter presents the zooplankton of the three main biotopes of Gazi Bay namely the coral reef, sea grass beds and mangrove. Variation of zooplankton densities during the wet and dry season is discussed for both spring tide and neap tide. 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. Samples obtained during spring tide did not give a clear-cut clustering pattern. CCA confirmed the following findings: a clustering together of rainy/neap tide samples and little separation (based on environmental variables) between sampling stations.

4.2 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 24hour 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 are described in Cap 3.2, 3.3.1, 3.3.5, 3.4 and 3.5.

4.3 Study area

Gazi Bay is situated 50 km south of Mombasa on the Kenya coast (4° 25'' S, 39° 30'' E) see Fig. 4.1. 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. There is freshwater input into the bay from two seasonal rivers, Kidogoweni in the northwest and Mkurumuji in the southwest. 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 Kidogoweni (Station 3) and the intermediate zone dominated by seagrass and sandbanks (Station 2).

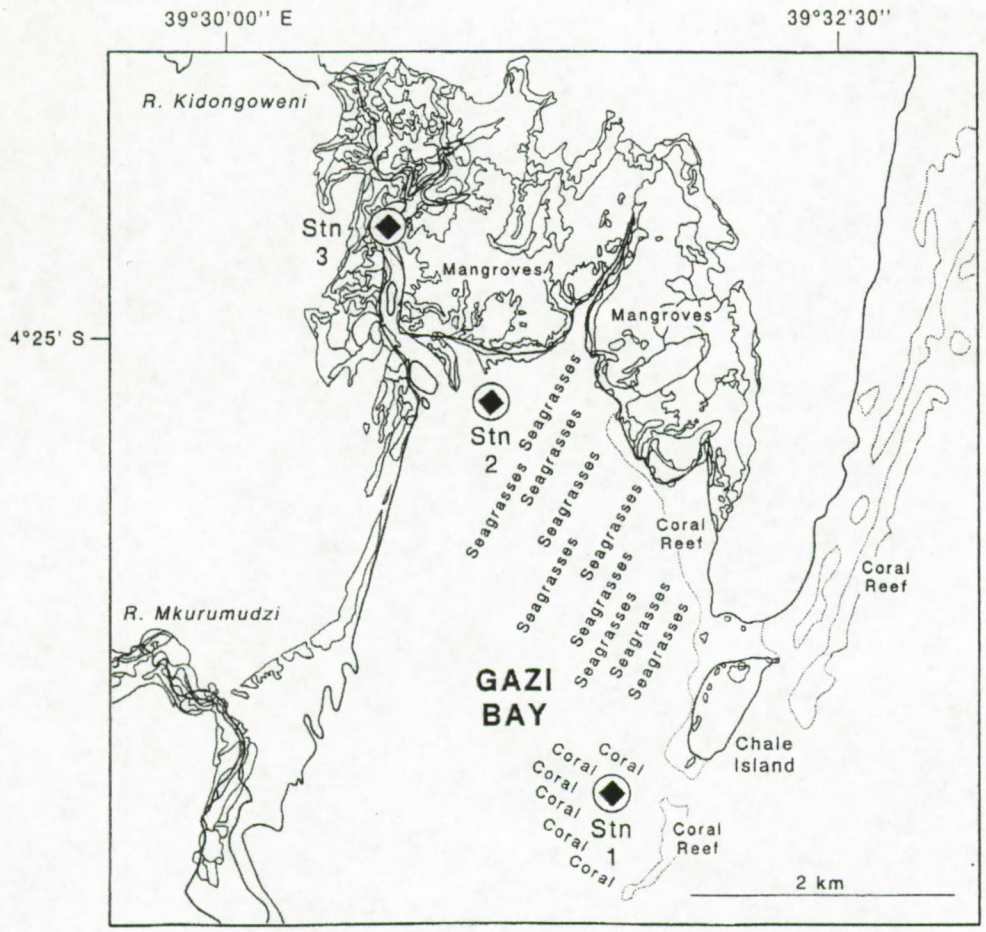


Fig. 4.1: Map of Gazi Bay showing the sampling stations and the location of the bay on the Kenya coast.

4.4 Results

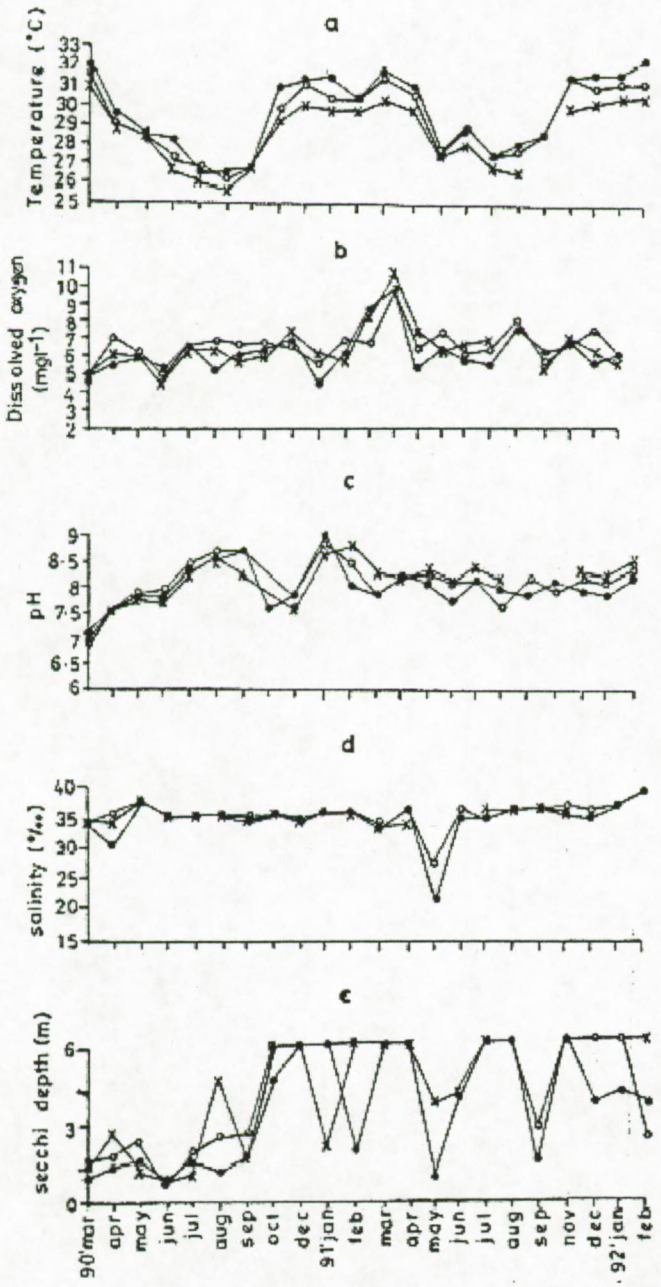


Fig. 4.2: Monthly average values of a) temperature, b) dissolved oxygen, c) pH, d) salinity and e) transparency observed in Gazi Bay during the sampling period. (No sampling in Nov. 1990 and Oct. 1991) -o- Station 1; -x- Station 2; -•- Station 3.

Abiotic factors

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.

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 Figs 4.2a - 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.

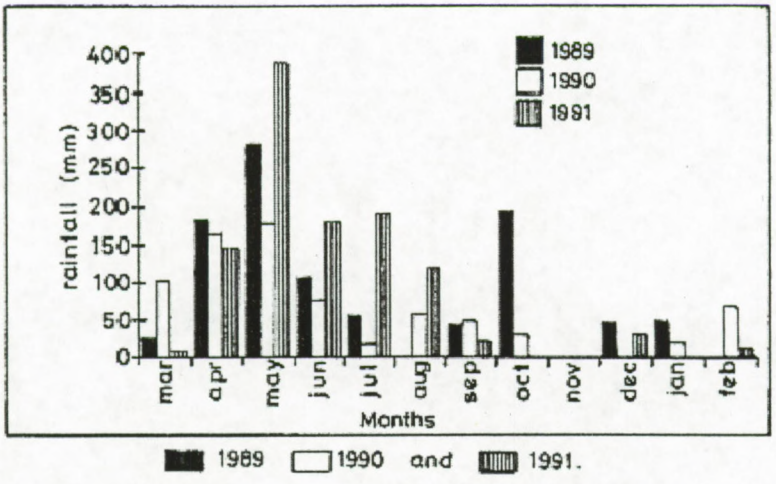


Fig. 4.3: Monthly average rainfall data for Gazi area during sampling in 1989, 1990 and 1991.

Average monthly rainfall in Gazi was highest during the months of April, May and June (see Fig.4.3). 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.

Zooplankton abundance

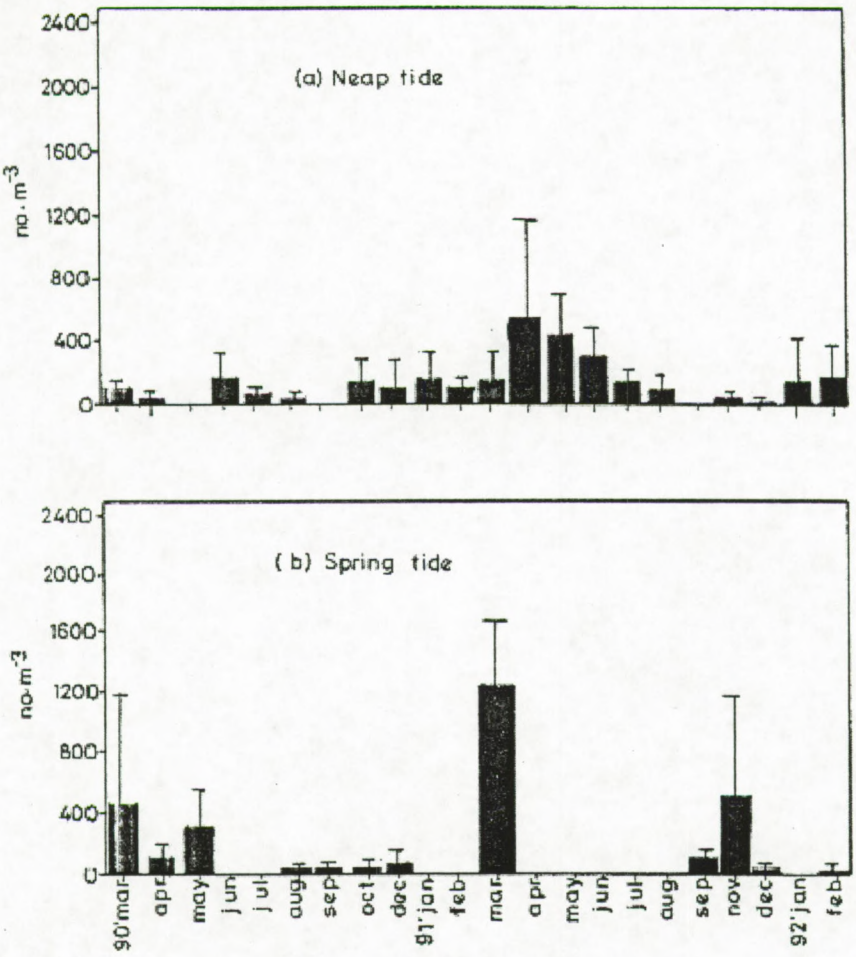


Fig. 4.4: Monthly average zooplankton abundance for Gazi Bay during (a) neap tide sampling and (b) spring tide sampling. (No sampling in Nov. '90 and Oct. '91).

Homogeneity in different zooplankton communities at the sampling stations was observed throughout the sampling period. However, monthly average abundance varied considerably (see Fig. 4.4). 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 Fig. 4.5. 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).

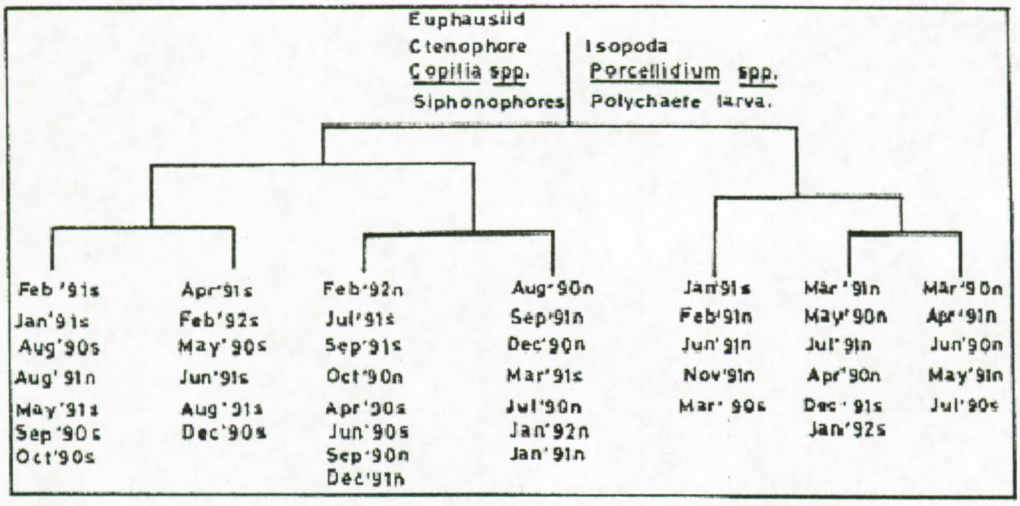


Fig.4.5: Dendrogram showing TWINSPAN results obtained for the total data set.

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 ($p<0.05$).

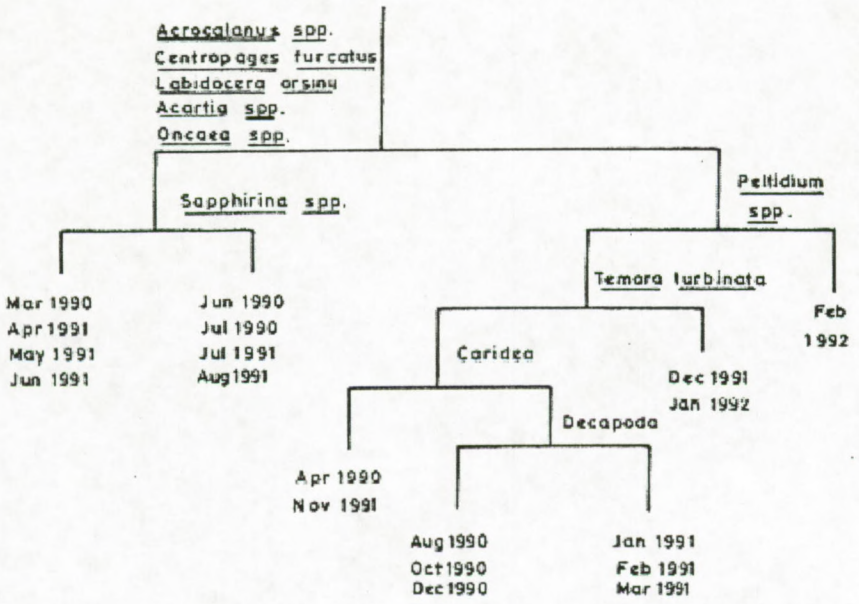
Neap tide and spring tide comparison

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 Figs 4.6a and 4.6b respectively.

For neap tide, a first split divides the year into two clusters of months: March–July and August–January (Fig. 4.6a). 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 separated 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 Fig. 4.6b), 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, November1991, 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.

(a)



(b)

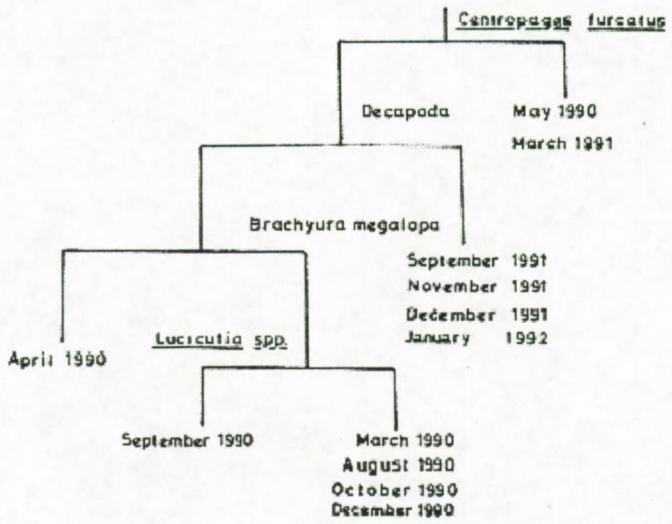
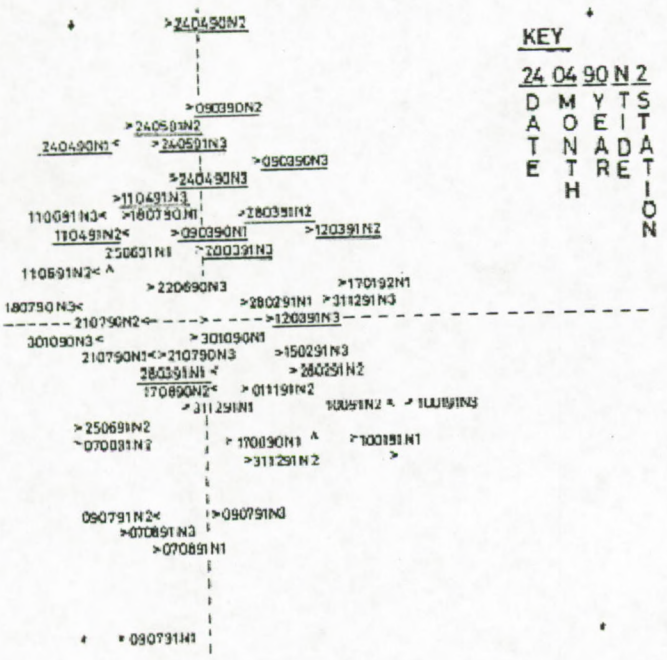


Fig. 4.6: (*a*) Dendrogram showing TWINSPAN results obtained for the neap tide samples, (*b*) dendrogram showing TWINSPAN results obtained for the spring tide samples.

(a)



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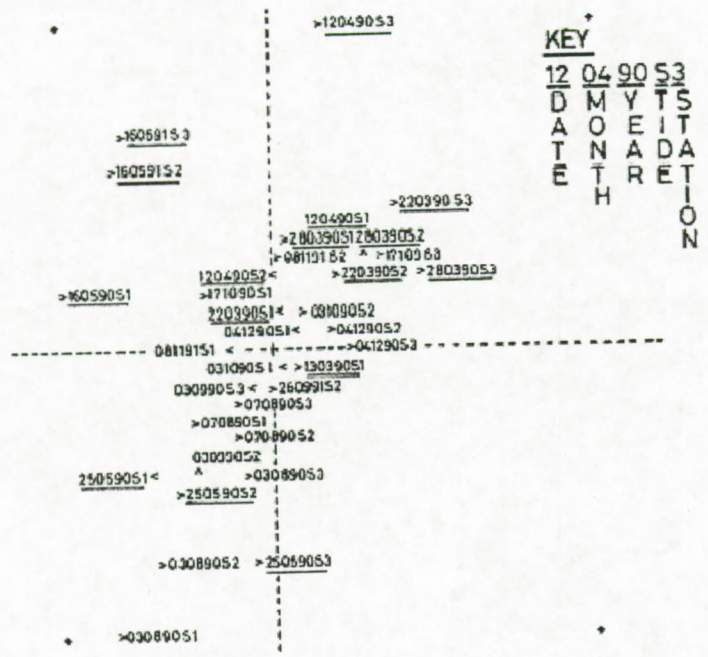


Fig. 4.7: *(a)* CCA biplot showing sample scores for the neap tide data (rainy period samples are underlined) *(b)* CCA biplot showing sample scores for the spring tide data (rainy period samples are underlined).

The interactions between environmental variables measured and the zooplankton communities were examined using CCA. 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 CCA plot (Fig. 4.7a). The clustering up of these months is not so evident for the spring tide samples (Fig. 4.7b).

To determine whether the species distribution was significantly related to the environmental parameters, a Monte Carlo permutation test was performed, only on the neap tide data (Fig. 4.8). 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. Table 4.1 displays the average abundance (separate for wet and dry months) of common zooplankton taxa obtained at Gazi Bay during both neap and spring tides.

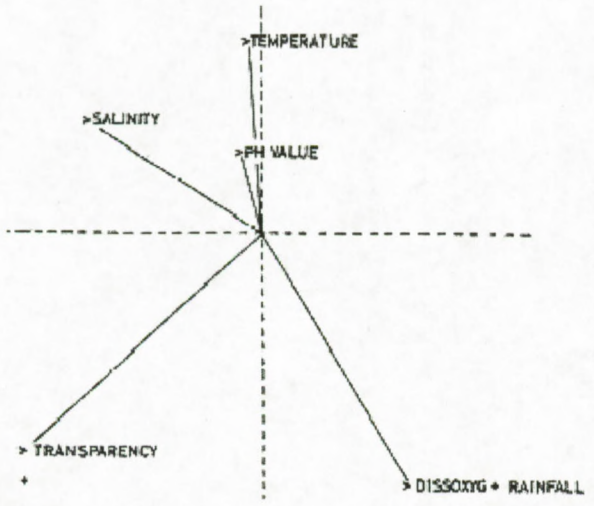


Fig. 4.8: CCA biplot of environmental variables of monthly averaged neap tide data.

Table 4.1: Seasonal occurrence of common zooplankton recorded in Gazi Bay.

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

4.5 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 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 NE 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.

CHAPTER 5

Zooplankton assemblages and some physico-chemical trends in a degraded former mangrove ecosystem, Makupa Creek, Mombasa, Kenya

Results submitted as:

M. K. W. Osore, A. M'harzi, S. Mwangi, M. Tackx & M. H. Daro (submitted). Zooplankton assemblages and some physico-chemical trends in a degraded former mangrove ecosystem, Makupa Creek, Mombasa, Kenya. *Hydrobiologia*.

5.1 Summary

Makupa Creek, formerly a healthy mangrove ecosystem, has recently been heavily exposed to crude oil, heat and domestic waste pollution from the port city of Mombasa, Kenya. In order to establish data and assess the creek's prevailing biological and physico-chemical characteristics, one year sampling survey of the water column was conducted for zooplankton, chlorophyll *a* and environmental variables.

Average zooplankton abundance ranged between 90 and 1,348 ind.m^{-3}. Brachyura zoeae, Pisces larvae, Pisces eggs, Gastropoda larvae, Cirripedia nauplii, Amphipoda, Nematoda, Mysidacea and Caridea larvae were the dominant (>70%) groups of merozooplankton. Holozooplankton were mostly abundant near the open sea and mainly composed of Chaetognatha, Appendicularia, Ctenophora and Copepoda.

Zooplankton counts showed that although the larvae (merozooplankton) of some commercially important stocks were dominant at early larval stages, the majority failed to metamorphose and develop to adulthood. Causes for this observation are suggested and linked to poor water quality. Some methods of rehabilitating the creek are proposed.

5.2 Introduction

Many studies in zooplankton ecology have been conducted in the inshore waters of Kenya especially in creeks around Mombasa Island (Grove *et al.*, 1986; Okemwa & Revis, 1986; Reay & Kimaro, 1989). Zooplankton diversity, abundance and distribution have been studied in Mida Creek to the north (Mwaluma *et al.*, 1998; Osore *et al.*, Cap 8 this Vol.) and also in Gazi Bay to the south (Kitheka *et al.*, 1996 and Osore *et al.*, 1997). All these studies have revealed that zooplankton is abundant and diverse in this locality. However, hardly any research effort has been directed towards studying zooplankton of other creeks adjacent to the island of Mombasa i.e. Port Reitz Creek and Makupa Creek. Yet these two creeks are under the direct influence of anthropogenic activities of the rapidly expanding port city of Mombasa. Only one study reports on the zooplankton sampled over a 24 hrs period across the Likoni Ferry Channel (Okemwa, 1989).

Previously, the local people living around Makupa Creek practised some subsistence economic activities including artisanal fishing, gathering of gastropods and shellfish and sustainable harvesting of mangrove and its products. During the last 15 years however, shipping activities at the port of Mombasa and its operations have drastically increased to the detriment of the ecology of this creek. Several oil leaks and accidents involving oil tankers and their storage facilities ashore have resulted in crude oil seeping into the creek, where it remains trapped (Munga *et al.*, 1993 and Kwak & Nguta, 1994). Over the years, this situation has been aggravated by the dumping of raw solid wastes and sludge on the intertidal zone adjacent to the creek. Recently, a thermal electricity generating plant was also erected at the shores of Makupa Creek and it utilises the available water as coolant. Thus, Makupa Creek is now compounded with various forms of organic, inorganic and thermal pollution.

In order to collect baseline data and information about the present health status of the creek with a view to rehabilitating it, a monthly monitoring study was begun. This study was initiated as part of multidisciplinary collaborative research between KMFRI and KWS. The specific aims of zooplankton studies within this project were to quantify zooplankton community composition and also to identify trends of important physico-chemical variables relevant to monitoring and eventual remedy of the creek.

Materials and methods are described in Cap. 3.2, 3.3.1, 3.3.4, 3.3.5, 3.4 and 3.5.

5.3 Study area

Makupa Creek is located to the west of Mombasa Island (Fig. 5.1). The main creek area occupies some 0.85 km^2. A land filling Makupa causeway separates it from Tudor Creek to the northeast, while its outlet to the Indian Ocean in the southwest is via the Port of Mombasa, Port Reitz Creek. Five sampling sites were demarcated as follows (Fig. 5.1). Stn 1 in an area with many stumps of dead mangroves is located next to a low in-come residential estate. Stn 2 also in an area with dead mangroves and some live *Avicennia marina* is situated adjacent to the municipal dumping site for solid wastes and sludge. Stn 3 is situated near the Kipevu channel and is the inlet to the Port of Mombasa. Stn 4 is next to the Kipevu Electricity Generating Plant (KEGP) while Stn 5 is inside the port.

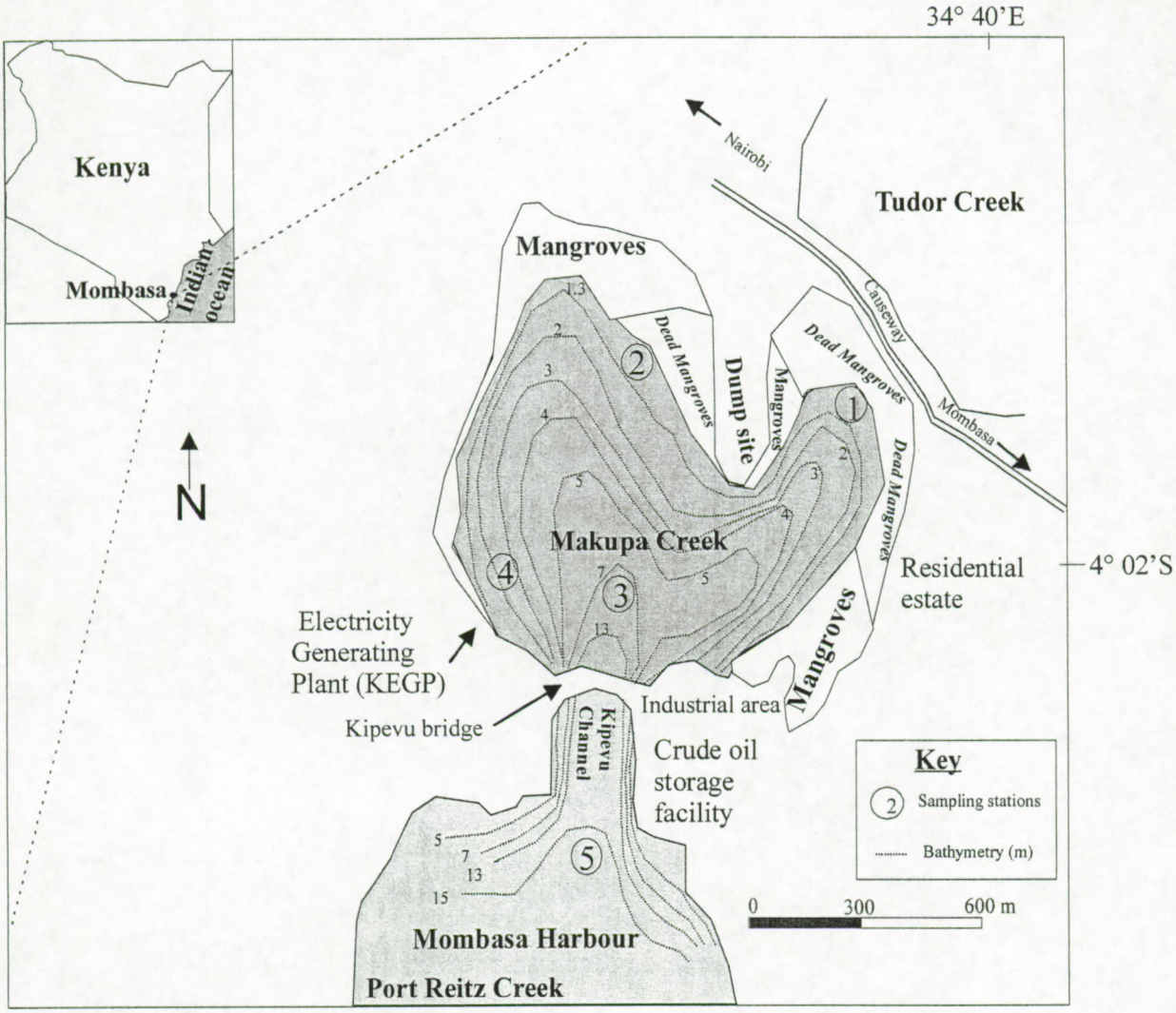


Fig. 5.1: Map of Makupa Creek showing the location of the sampling stations.

5.4 Results

Physico-chemical characteristics

The highest mean temperature of surface water (31.7±1.5°C) was recorded in March and the lowest (24.9±0.5°C) was in June (Figs 5.2a-e). The highest individual temperature (34.0°C) was recorded at Stn 3 in March while the lowest (24.5°C) was at Stns 1 and 2 in June. Generally, Stns 3 and 4 recorded higher temperature than the rest.

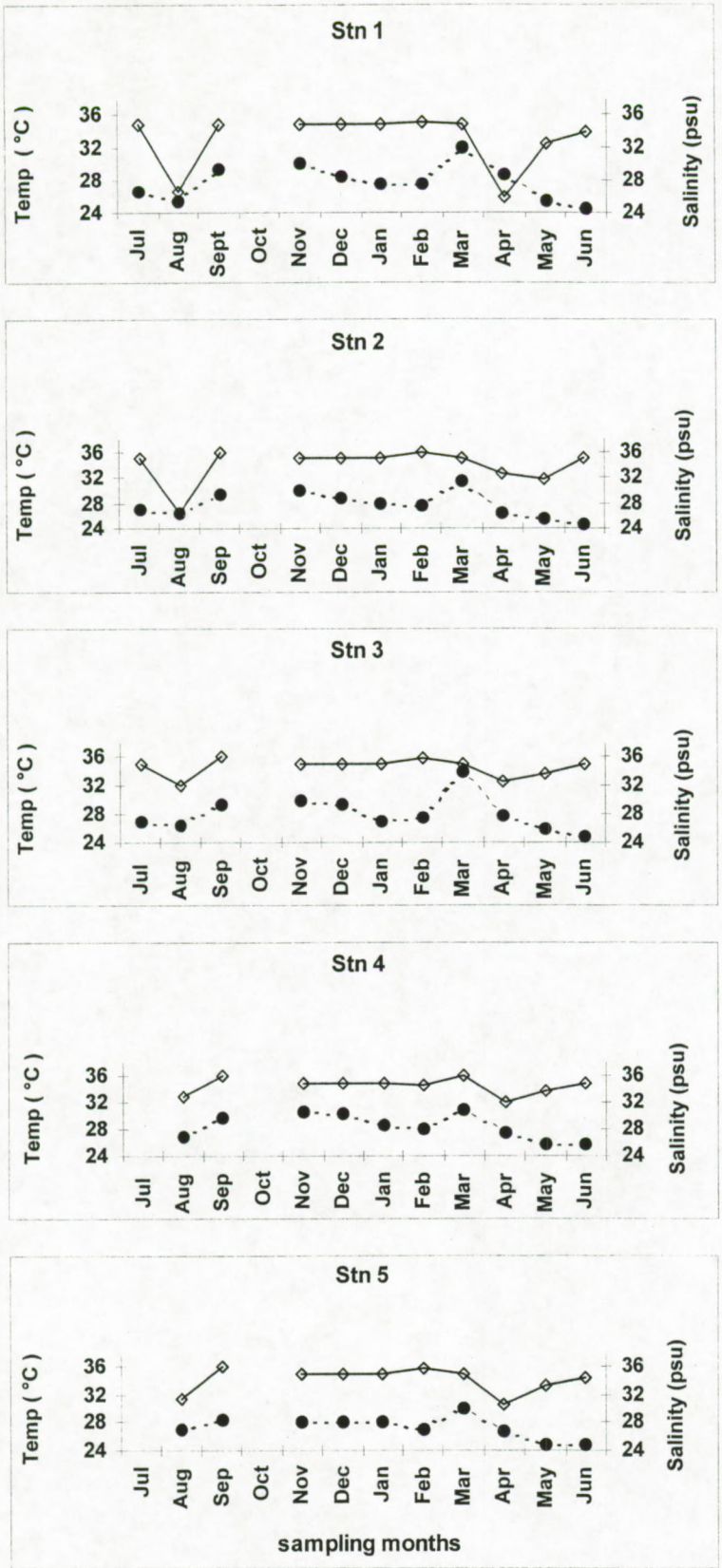


Fig. 5.2: Surface water temperature (--●--, broken line) and salinity (-○-, solid line) at the sampling stations.

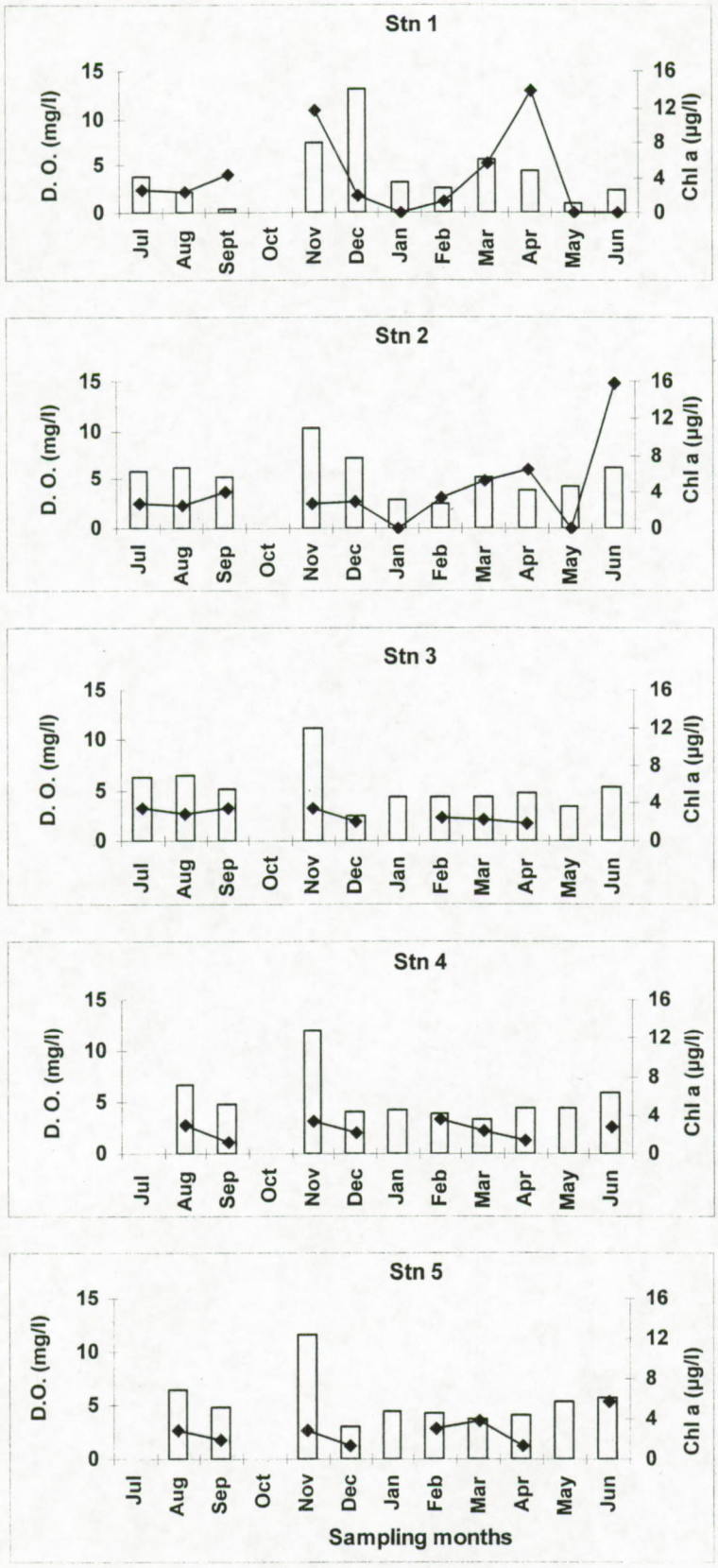


Fig. 5.3: Dissolved oxygen (bars) and chlorophyll-*a* (line) at the sampling stations.

Salinity was low in August (29.9±3.2 psu) and April (30.8±2.9 psu) but varied comparatively less (33.0±0.8 to 35.8±0.4 psu) during most of the study period (Figs 5.2 a-e). Stns 1 and 2 recorded lower monthly average salinity than the rest of the Stns.

Dissolved oxygen was generally high (10.5±1.9 $mg.l^{-1}$) in November and low (3.6±0.9 to 5.9±4.4 $mg.l^{-1}$) during the rest of the months (Figs 5.3 a-e). Stn 1 had lower average dissolved oxygen compared to other Stns. Chlorophyll *a* was higher (8.00±5.60 $\mu g.l^{-1}$) in June and lower (2.10±0.50 to 5.00±4.80 $\mu g.l^{-1}$) during the rest of the months (Figs 5.3a-e). However, Stns 1 and 2 often recorded higher levels than the rest of the Stns.

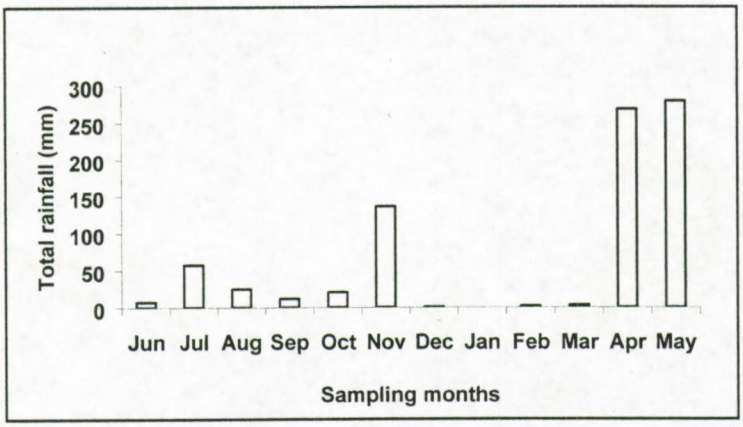


Fig. 5.4: Rainfall regime at the study area during the sampling period.

The rainfall regime displayed two main wet seasons (Fig. 5.4). The long rains occurred in April and May (268 and 297 mm respectively) and the short rains were in November (135 mm). The dry season was between December and March (0 to 3 mm).

Zooplankton composition

This study provides the first documented list of zooplankton assemblage found in Makupa Creek. Among the zooplankton taxa identified, 23 were merozooplankton whereas 61 were holozooplankton. However, merozooplankton were the most ubiquitous forms and they were widely distributed throughout the creek during the entire sampling period. On the contrary, holozooplankton were quite sparsely distributed and mainly tended to dominate in the oceanic waters of Stn 5.

Table 5. 1: Zooplankton taxa encountered at the five sampling Stns of Makupa Creek, Mombasa. (key: ++ = common, + = rare and 0 = absent).

Taxa	Stn1	Stn2	Stn3	Stn4	Stn5
Merozooplankton					
Amphipoda	+	+	+	++	+
Pteropoda	0	+	+	+	+
Gastropoda	++	++	++	+	++
Sergestidae	+	+	+	+	+
Brachyura zoea	++	++	++	++	++
Brachyura megalopa	0	+	+	+	++
Calyptopis larvae	+	+	++	+	+
Stomatopoda	+	+	+	+	+
Pisces (fish) eggs	++	++	++	+	++
Pisces (fish) larvae	+	++	+	++	++
Osteichthyes (bony fish) juveniles	+	+	+	+	0
Polychaeta	++	+	+	+	+
Tanaedacea	+	+	+	++	+
Isopoda	+	+	+	+	+
Caridea	++	++	++	++	++
Cirriped nauplii	+	+	++	++	++
Mysidacea	++	+	++	++	+
Bivalve larvae	+	+	+	+	+
Cumacea	+	0	0	+	0
Ascidian larvae	+	+	+	0	++
Insecta	+	+	+	+	+
Nematoda	+	+	0	+	+
Tintinida	0	0	+	0	0
Total merozooplankton taxa	**20**	**21**	**21**	**21**	**20**
Holozooplankton					
Copepoda					
Nannocalanus minor (Claus, 1863)	0	0	0	0	+
Canthocalanus pauper (*Giesb., 1888)	0	0	+	+	+
Cosmocalanus sp.	0	0	0	+	0
Undinula vulgaris (Dana, 1849)	0	+	++	+	++
Eucalanus attenuatus (Dana, 1849)	0	+	+	+	+
Eucalanus crassus Giesb., 1888	0	0	+	+	+
Eucalanus mucronatus Giesb., 1888	0	+	0	0	+
Eucalanus spp.	+	0	++	+	+
Mecynocera sp.	0	0	0	0	+
Clausocalanus sp.	+	+	++	+	++
Acrocalanus sp.	++	++	++	++	++
Calocalanus sp.	0	0	0	+	+
Paracalanus sp.	0	+	0	+	+
Aetideus sp.	0	0	+	0	0
Euchaeta sp.	0	0	+	0	0
Scolecithrix sp.	0	0	+	0	+

*Giesb. = Giesbrecht

Table 5. 1: (Continued)

Taxa	Stn1	Stn2	Stn3	Stn4	Stn5
Holozooplankton (continued...)					
Copepoda (continued...)					
Temora discaudata Giesb., 1889	+	0	0	0	+
Temora turbinata (Dana, 1849)	+	+	+	+	+
Centropages furcatus (Dana, 1852)	0	+	+	+	+
Centropages orsini Giesb., 1889	+	+	+	+	++
Candacia spp.	0	0	+	+	+
Calanopia elliptica (Dana, 1846)	0	0	0	+	+
Calanopia thompsoni A. Scott, 1909	+	+	0	+	0
Calanopia minor A. Scott, 1902	0	0	+	0	0
Labidocera acuta (Dana, 1849)	0	+	+	0	+
Labidocera minor Giesb., 1889	0	0	0	0	+
Labidocera pavo Giesb., 1889	0	0	+	+	+
Labidocera orsini Giesb., 1889	0	+	+	+	+
Labidocera bipinnata Tanaka, 1936	0	+	0	0	++
Labidocera spp.	+	+	+	+	+
Pseudodiaptomus sp.	++	+	+	++	0
Pontella spp.	0	+	+	+	+
Pontellina plumata (Dana, 1849)	0	+	0	+	+
Pontellopsis spp.	0	+	+	+	0
Tortanus spp.	++	++	++	+	++
Acartia spp.	++	++	++	+	++
Microsetella sp.	+	0	+	0	+
Macrosetella sp.	0	0	+	+	+
Clytemnestra sp.	+	+	0	0	+
Aegisthus spp.	+	0	0	0	0
Other Harpacticoida	+	+	+	++	+
Oithona spp.	++	++	++	++	++
Oncaea spp.	+	+	++	+	++
Pachos punctatum (Claus, 1863)	0	0	0	0	+
Corycaeus spp.	++	++	++	++	++
Copilia sp.	0	0	+	0	0
Sapphirella sp.	+	0	0	+	0
Sapphirina sp.	+	0	+	0	+
Peltidium sp.	0	+	+	0	+
Monstrilloida	0	+	0	+	+
Copepoda nauplii	+	+	+	+	+
Arachnida	+	0	0	0	0
Appendicularia	+	++	+	++	++
Siphonophora	+	+	+	+	+
Medusae	++	+	+	++	+
Ctenophora	0	+	++	+	+
Doliolida	0	0	0	+	0
Chaetognatha	++	++	++	++	++
Ostracoda	+	+	+	+	+
Euphausiaceae	+	+	+	+	+
Cladocera	0	+	0	+	+
Total holozooplankton taxa	**28**	**36**	**41**	**42**	**49**

Diversity

A list of zooplankton taxa encountered in this study and the frequency of occurrence at the sampling Stns is presented in Table 5.1. Merozooplankton taxa consistently common at all the five stations were Gastropoda, Brachyura zoea, Pisces eggs and Caridea. Holozooplankton were Chaetognatha and the Copepoda of genera *Acrocalanus, Tortanus, Acartia, Oithona* and *Corycaeus*.

Table 5.1 shows that the total merozooplankton taxa present at the various Stns were 20 to 21 and they were generally the same types per Stn. On the contrary, the total number of holozooplankton taxa progressively increased from 28 at Stn 1, to 36 at Stn 2, to 41 at Stn 3, to 42 at Stn 4 and finally to 49 at Stn 5.

Figs 5.5a-b show the trends in zooplankton taxa diversity (*H'*) and homogeneity (*J*) at the five sampling stations as averaged for the entire sampling period. On average zooplankton diversity and homogeneity were highest at Stns 5 and 3, lowest at Stns 1 and 2; and intermediate at Stn 4.

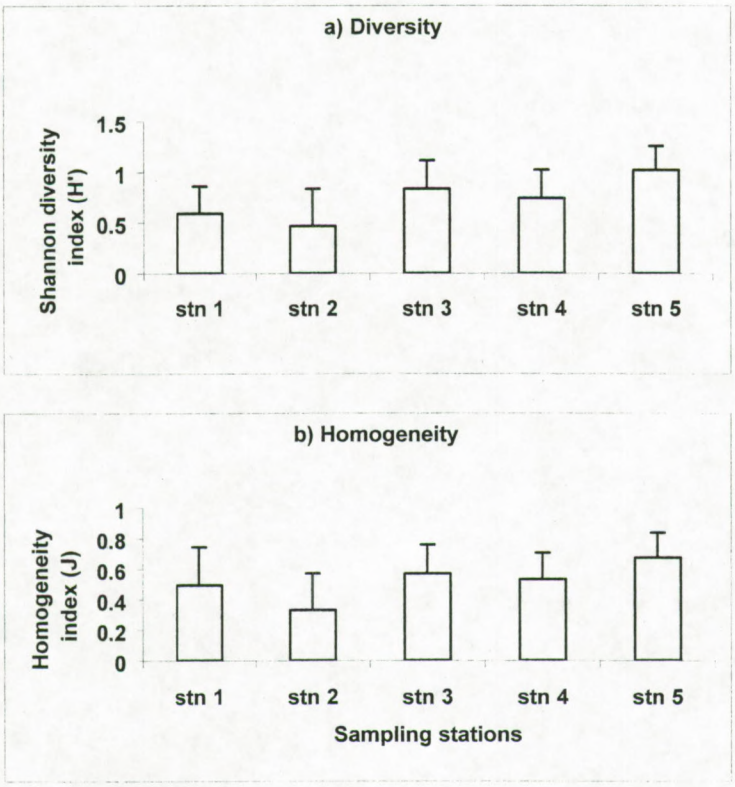


Fig. 5.5: Variation in **a**) average zooplankton diversity and **b**) homogeneity at the five sampling station in Makupa Creek. (bars are std dev).

Abundance

Monthly zooplankton abundance ranged between a minimum of 90±35 ind.m^{-3} in January and a maximum of 1348±2140 ind.m^{-3} in November (Fig. 5.6). There was a steady increase in abundance from July (102±67 ind.m^{-3}) up to November (1,348±2140 ind.m^{-3}). Thereafter, the abundance varied relatively less and ranged between 90±35 and 297±347 ind.m^{-3}. The high standard deviations in the months of August, September, November and April were due to a single or few taxa dominating the population and/or a Stn experiencing a bloom. It may also have been as a result of sheer patchiness in zooplankton distribution.

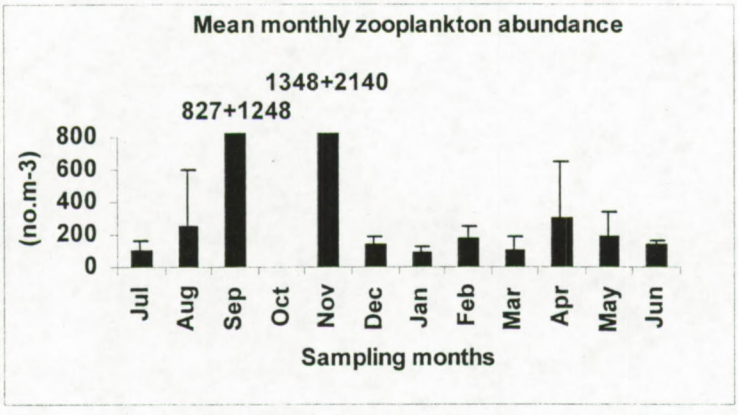


Fig. 5.6: Variation in mean monthly zooplankton abundance in Makupa Creek. (bars are std between Stns).

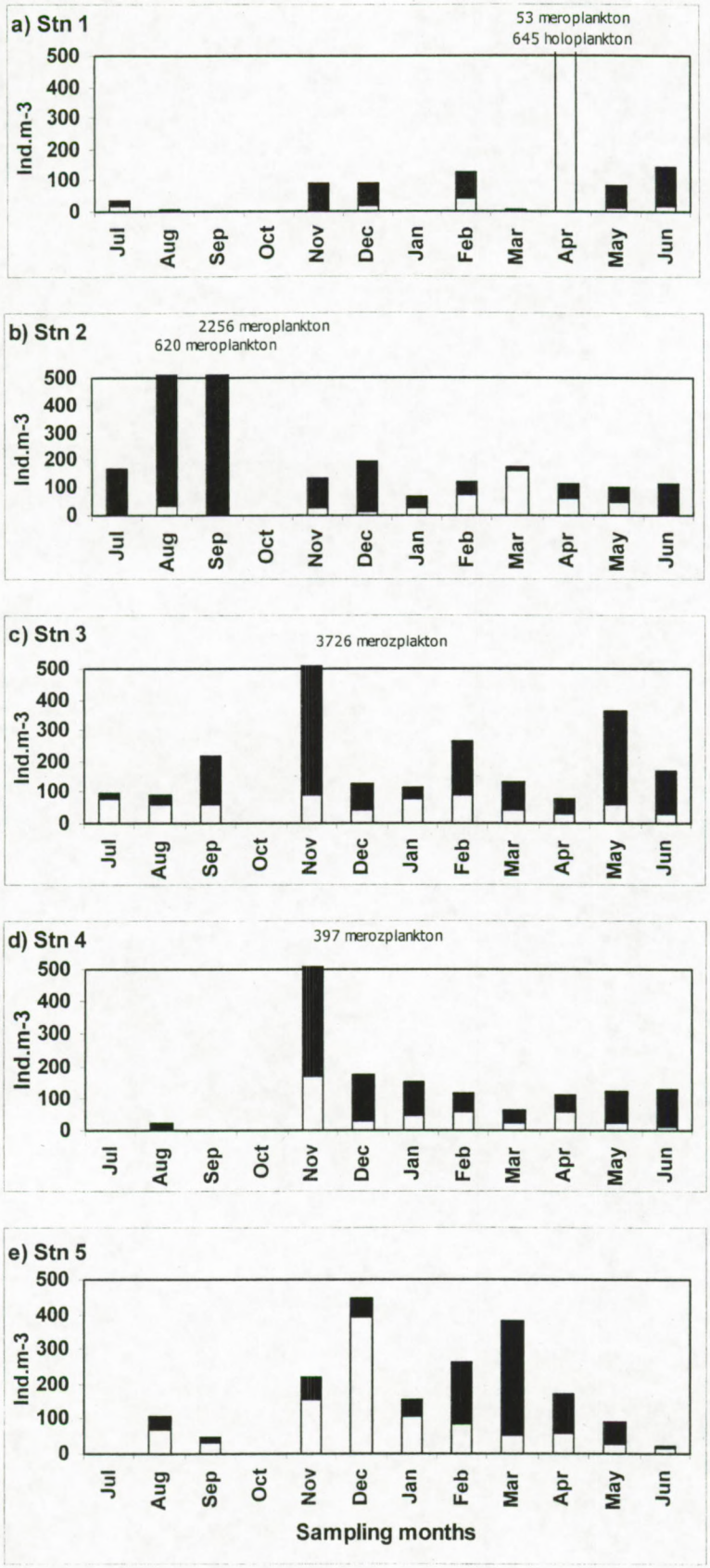


Fig. 5.7 a-e: Monthly abundance of meroplankton (black) and holoplankton (unshaded) at the five sampling stations in Makupa Creek.

Distribution

Figs 5.7a-e show mean abundance of both the merozoopankton and holozooplankton composition at the five sampling Stns.

Merozooplankton

Mean abundance of merozooplankton ranged between 1 and 3,726 ind.m^{-3}. The highest merozooplankton abundance was recorded at Stn 2 in August (620 ind.m^{-3}) and September (2,256 ind.m^{-3}); at Stn 3 in November (3,726 ind.m^{-3}); at Stn 4 in November (397 ind.m^{-3}) and at Stn 5 in March (328 ind.m^{-3}).

Holozooplankton

Mean abundance of holozooplankton varied from 0 to 645 ind.m^{-3}. The highest holozooplankton abundance was recorded at Stn 1 in April (645 ind.m^{-3}); at Stn 2 in March (160 ind.m^{-3}); at Stn 4 in November (169 ind.m^{-3}) and at Stn 5 in December (391 ind.m^{-3}).

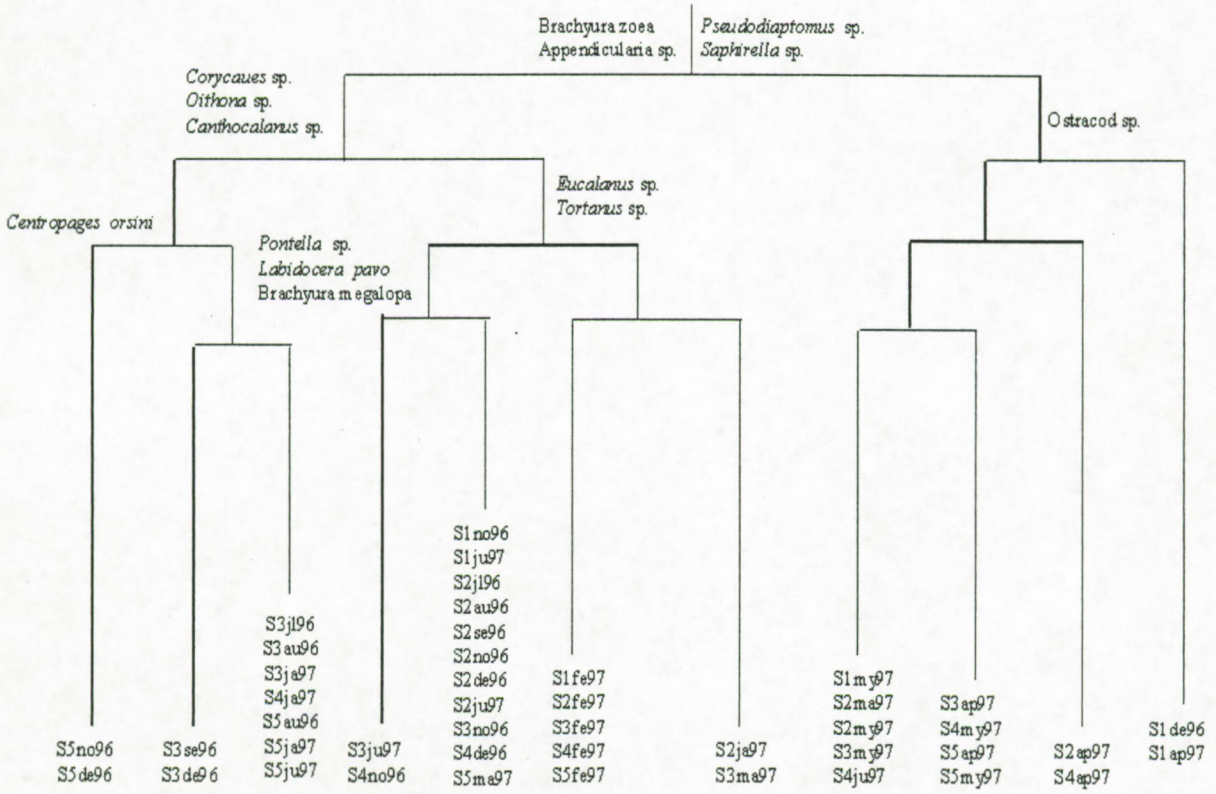
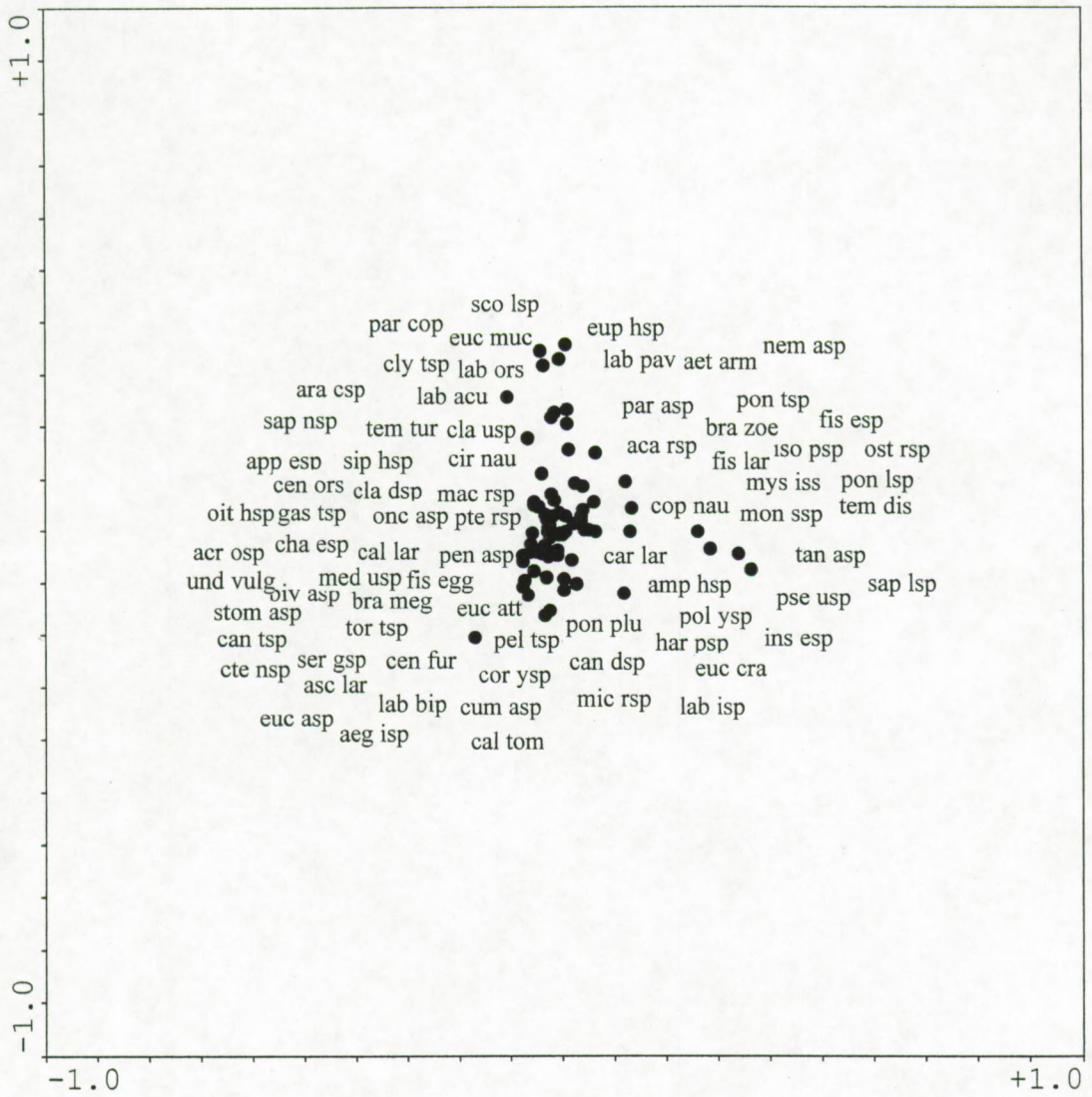


Fig. 5.8: Dendrogram showing results of the TWINSPAN for zooplankton abundance.

TWINSPAN was performed on the entire zooplankton abundance data. See Key in Fig. 5.9b for identity of the sample scores. The dendrogram for the TWINSPAN (Fig. 5.8) showed a clear splitting in the first division separating the predominantly wet season samples (right side cluster; indicator species *Pseudodiaptomus* sp. and *Sapphirella* sp.) from the rest (left side cluster; indicator species Brachyura zoea and Appendicularia).

Among these wet season samples, those collected from Stn 1 during December (s1de96) and April (s1ap97) were further separated (indicator species Ostracoda). The left side cluster constituted a mixture of samples collected during the dry season and the short rains.

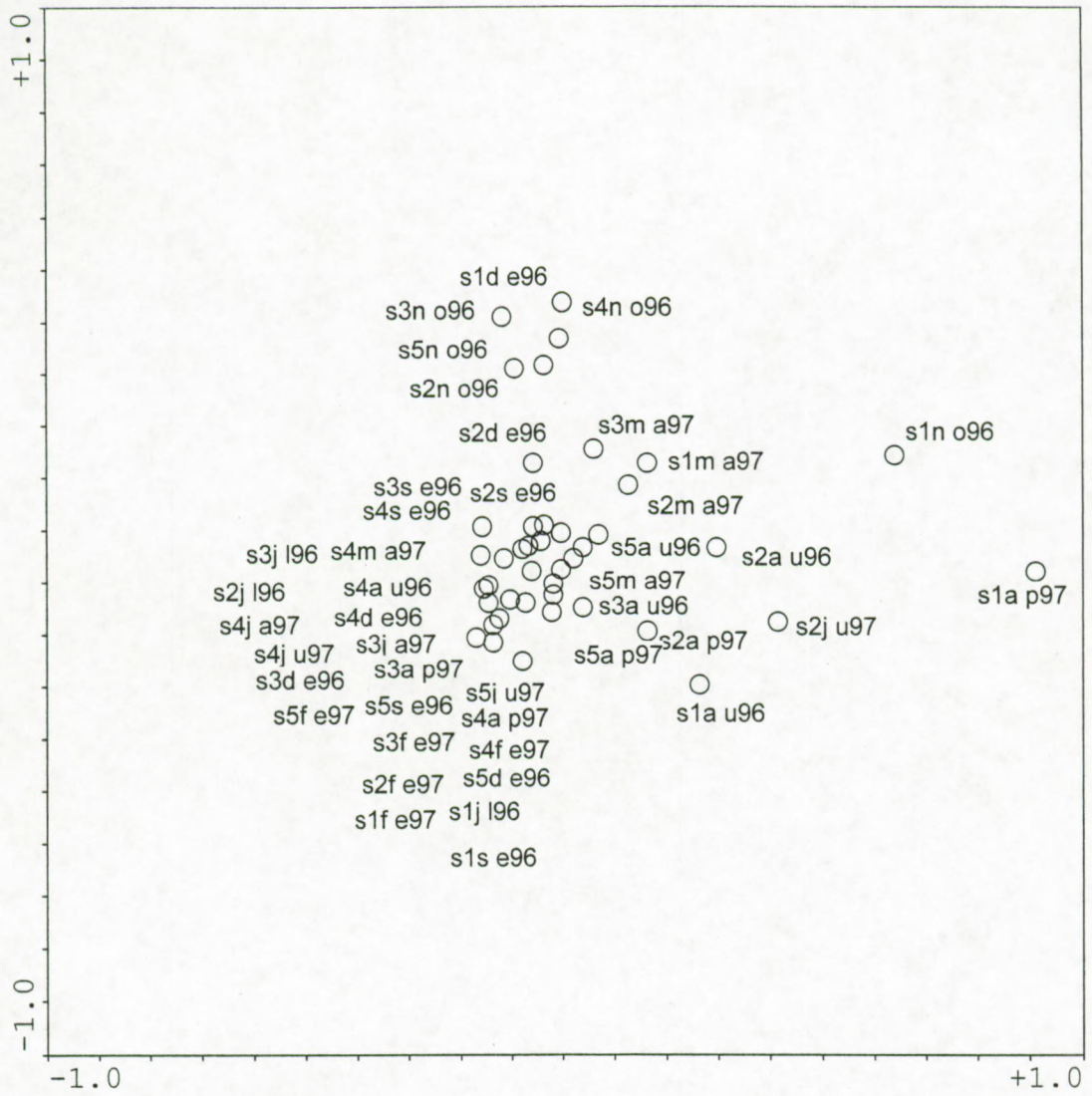
Figs 5.9 a and b show the biplot for the species and samples scores respectively in relation to environmental variables (see Fig. 5.9 c) as a result of the CCA. Chlorophyll *a* was highly correlated with axis 1. Dissolved oxygen was highly correlated with axis 2, and so was temperature to a lesser extent. Most samples were distributed below axis 1 and more so in the left quadrant (Fig. 5.9 b). Majority of species were also located close to the centre of the biplot and mainly in the left quadrant below axis 1. This quadrant is associated with decreasing values of chlorophyll *a*, dissolved oxygen and temperature. The most dominant meroplankton i.e. gastropods, brachyuran zoea, fish eggs and caridean larvae correlated positively with chlorophyll *a*, dissolved oxygen and temperature in the top right quadrant. The dominant holozooplankton i.e. *Acrocalanus* spp., *Tortanus* spp., *Oithona* spp. and Chaetognatha correlated positively with salinity and negatively with the rest of the environmental variables.



Key:

Sco lsp = *Scolecithrix sp.*, par cop = copepodite of *Paracalanus*, eup hsp = Euphasiaceae, euc muc = *Eucalanus mucronatus*, nem asp = nematode, cly tsp = *Clytemnestra* sp., lab pav = Labidocer pavo, aet arm = *Aetideus armatus*, ara csp = Aracnida, lab acu = *Labidocera acuta*, par asp = *Paracalanus* sp., pon lsp = *Pontella* sp., sap nsp = *Saphirina* sp., tem tur = *Temora turbinata*, cla usp = *Clausocalanus* sp., bra zoe = brachyuran zoea, fis esp = fish, app esp = Appendicularia, sip hsp = siphonophore, cir nau = Cirripaed nauplii, fis lar = fish larvae, iso psp = Isopod, ost rsp = Ostracoda, cen ors = *Centropages orsinii*, cla dsp = Cladocera, mac rsp = *Macrosetella* sp., mys iss = Mysidacea, pon lsp = *Pontellopsis* spp., oit hsp = *Oithona* sp., gas tsp = Gastropoda, onc asp = Oncaea sp., pte rps = Pteropoda, cop nau = Copepoda nauplii, mon ssp. = Monstrtilloida, tem dis = *Temora discaudata*, acr osp = *Acrocalanus* sp., cha esp = Chaetognatha, cal lar = Calyptopis larvae, pen asp = Penaeidae, car lar = Caridean larvae, tan asp = Tanaedacea, und vulg = *Undinula vulgaris*, med usp = Medusae, fis egg = Fish eggs, amp hsp = Amphipoda, sap lsp = *Saphirella* sp., stom asp = Stomatopoda, bra meg = Brachyuran megalopa, euc att = *Eucalanus attenuatus*, pon plu = *Pontellina plumata*, pol ysp = Polychaete, can tsp = *Canthocalanus pauper*, pel tsp = *Peltidium sp.*, har psp = Harpacticoida, ins esp = Insecta, ser gsp = Sergestidae, cen fur = *Centropages furcatus*, cor ysp = *Corycaeus* sp. can dsp = *Candacia* sp. euc cra = *Eucalanus crassus*, asc lar = Ascidian larvae, lab bip = *Labidocera bipinata*, cum asp = Cumacea, mic rsp = *Microsetella* sp., lab isp = *Labidocera* sp., aeg isp = *Aegisthus* spp., cal tom = *Calanopia thompsoni*.

Fig. 5.9 a: Canonical Correspondence Analysis (CCA) species biplot. (See key for abbreviation).



Key:

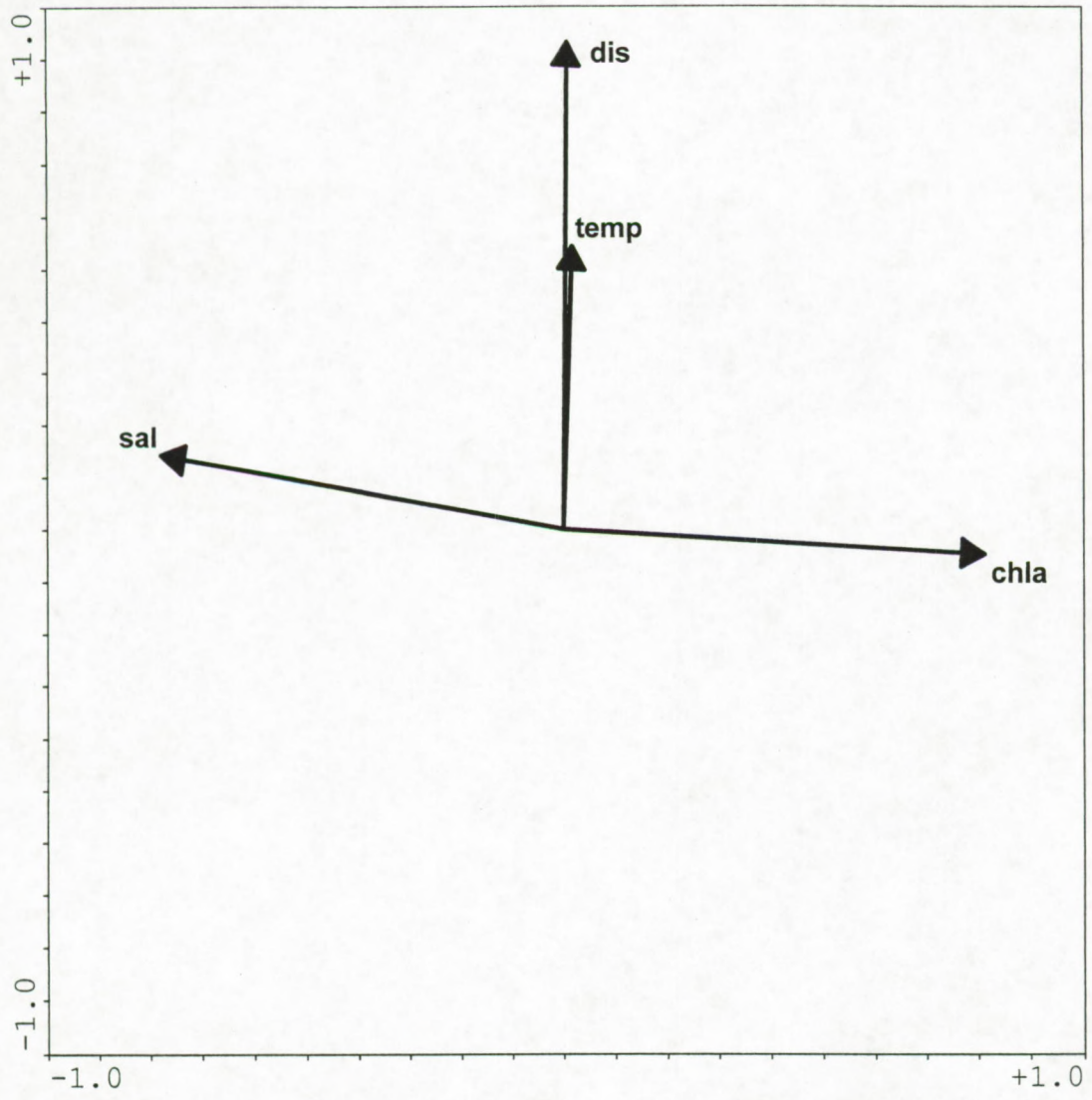
First two characters represent station of sampling.

Middle two letters represent month of sampling

Last two numbers represent year of sampling

e.g.: **s1de96** denotes sample taken from station 1 in December 1996

Fig. 5.9 b: Canonical Correspondence Analysis (CCA) samples biplot. (See key for abbreviation).



Key:
dis = Dissolved oxygen
temp = Temperature
sal = Salinity
chla = Chlorophyll *a*

Fig. 5.9 c: Canonical Correspondence Analysis (CCA) biplot for environmental variables. (See key for abbreviation).

5.5 Discussion

This study provides a first compilation of trends in surface water temperature, salinity, dissolved oxygen, chlorophyll *a* and zooplankton assemblage in the water column of Makupa Creek. Other related previous work mainly dwelt on water currents and sediment studies (Norconsult, 1975; Oteko, 1987). Kamau (2001) recorded elevated concentrations of various heavy metals (copper, cadmium, iron and zinc) in the sediments of Makupa Creek compared to those of the adjacent Port of Mombasa.

In the present study, low surface water temperature range (24.9 to 26.5°C) was recorded between the months of May and August whereas high temperature (27.4 to 31.7°C) was between September and April. Persistent high temperature of 28.4 ± 2.0°C observed at Stn 4 was probably caused by heated effluents discharged from KEGP. Elevated water temperature affects zooplankton growth positively within a certain range. Beyond that range, when temperature exceeds thermal tolerance, zooplankton growth and survival is impacted negatively. Copepod nauplii have been shown to be less abundant in areas affected by a power plant water discharge (Tsuruta & Tawara, 1975 and Le Fevre-Lehoerff *et al.*, 1993).

Dissolved oxygen concentration was usually less than 6.0 $mg.l^{-1}$, this amount is lower than what has been reported in the adjacent creeks (Mwangi *et al.*, 1998); which are better flushed and less polluted.

Low salinity values were generally preceded by heavy rainfall. For instance the heavy rainfall in April and May drastically reduced salinity especially at Stns 1 and 2. As these two Stns are also the dumping locations for domestic effluents and municipal solid wastes respectively, the runoff also carries wastes into the creek. There are no river inlets into the creek and fresh water input is mainly by direct precipitation and occasional surface runoff via temporary streams.

Chlorophyll *a* concentration ranged between 0.80 and 8.00 $\mu g.l^{-1}$. Although on average the dumping sites, Stns 1 and 2, recorded the highest levels of chlorophyll *a*, the individual monthly variations (Standard Deviation) in each Stn was very wide (5.02±4.63 and 4.62±4.22$\mu g.l^{-1}$ for Stns 1 and 2 respectively). In the rest of the Stns, chlorophyll *a* was less

(suggesting that eutrophication was lower) and its variations were narrow (between 2.25±1.03 and 2.58±1.5μg.l^{-1}).

Zooplankton abundance at Makupa Creek was generally much less than what has previously been recorded in the adjacent Port Reitz Creek and also in some healthy mangrove creeks of Kenya. Okemwa (1989) recorded an average zooplankton abundance of 236 ind.m^{-3} in Port Reitz Creek. Osore *et al.* (1997) enumerated an average of 250 ind.m^{-3} in the mangrove creeks of Gazi.

In other studied inshore waters of Kenya, the copepods and other holozooplankton constituted the bulk of the zooplankton (Okemwa & Revis, 1986; Okemwa, 1989; Kitheka *et al.*, 1996; Osore *et al.*, 1997). In Makupa Creek on the contrary, merozooplankton taxa highly dominated the zooplankton population. They constituted more than 70% of the total abundance. Common representatives were brachyuran zoea, fish eggs, fish larvae, gastropod larvae, cirriped nauplii, amphipods, nematodes, mysids and caridean larvae. However, very high standard deviations from the mean were observed during the months of August, September, November and April. The explanation for this is as follows: During August, the population at Stn 2 was completely dominated by a single taxa, brachyuran zoea, which accounted for 91% of the total zooplankton abundance. In September at Stn 2 again, 99% of the entire sample was composed of b. zoea. In November, Stn 3 had total zooplankton abundance amounting to 3,818 ind.m^{-3} (majority of them being meroplankton, 3,726 ind.m^{-3}) of which 96% were b. zoea again. Finally, at Stn 1 during the month of April, 698 ind.m^{-3} total zooplankton were recorded out of which 92% were the copepods *Pseudodiaptomus* sp.

Even though b. zoea dominated the zooplankton population in this creek, only very few members of its subsequent stage, b. megalopa, were encountered in the sample. Based solely on the present data, we cannot state with certainty whether the zoea failed to develop into the megalopa stage or whether they did and migrated elsewhere. However, Leffler (1972) reported that in laboratory experiments, ambient temperature greatly influenced growth and metabolic rate of juvenile crabs. He found that mortality was directly proportional to temperature between 13 and 34°C. Mihursky *et al.* (1974) demonstrated that smaller crabs showed greater tolerance to thermal stress at increased salinity than did larger crabs. In the present study, high water temperature and also the general poor water quality in this creek

may be contributing factors responsible for b. zoea failing to successfully metamorphose to the next stage of b. megalopa. However, detailed laboratory and field experiments need to be done to reach a conclusive answer.

Stn 2 located at the domestic waste dumping site and Stn 3, which also experiences receives heated effluents from KEGP recorded the highest mean abundance of zooplankton most of which were merozooplankton forms. However, Stn 2 was characterised by very low zooplankton diversity and homogeneity. This was caused by the single taxa, brachyuran zoea, which almost entirely dominated the whole sample. This supports the general consensus that a polluted system displays a reduction in diversity.

On average both taxa diversity and homogeneity reflected more the characteristic of the individual station rather than the sampling month. The average of all the months for each station showed a steady increase in diversity and homogeneity as one moved from the pollution prone Stn 2 towards the oceanic waters of Stn 5.

TWINSPAN results suggested that the zooplankton assemblages in Makupa Creek generally depended more on the seasonal pattern of the year rather than the location of the sampling site. Therefore, further analyses treating data as separate seasons - dry and wet, are underway and the results will be presented later on. The CCA showed that whereas chlorophyll *a* positively correlated with the primary axis (axis 1), salinity correlated negatively. Dissolved oxygen and temperature were positively correlated with the secondary axis (axis 2). Though the majority of the samples and taxa were distributed at the centre of the biplot, they were slightly negatively correlated with chlorophyll a, dissolved oxygen and temperature.

TWINSPAN and CCA did not clearly distinguish the sampling location but demonstrated that seasonality exists based principally on the rainfall regime.

Recommendations

Low concentration of dissolved oxygen in Makupa Creek is due to poor water circulation. The Kipevu Channel should therefore be widened and deepened in order to allow proper water circulation within the creek and to improve the flushing. This could also reduce the blooming of phytoplankton. At the moment, as the channel is so narrow and shallow, it tends

to impede water exchange between the open sea and Makupa Creek. However, the widening and deepening process should only begin after the dumping of raw waste has ceased and the water quality within the creek itself has been improved. Otherwise, the improved flushing and circulation may introduce new problems by distributing the polluted water widely into other nearby healthy creeks and bays.

Makupa Creek is characterised by low abundance and diversity of meiobenthic organisms (per. observation) and this is the normal situation with polluted habitats. We recommend that future pollution monitoring research along the Kenya coast should always include the study of the benthos. An effective method in benthic studies is the use of the numerical ratio of nematodes to copepods. In disturbed (polluted) conditions benthic copepods tend to predominate sediments at their trophic level while in normal (unpolluted) conditions nematodes predominate.

CHAPTER 6

Copepod composition, abundance and diversity in a degraded creek, Makupa, Mombasa, Kenya

Results submitted as:

Osore, M. K. W., F. Fiers & M. H. Daro (Submitted) Copepod composition, abundance and diversity in a degraded creek, Makupa, Mombasa, Kenya. *Western Indian Ocean Journal of Marine Sciences.*

6.1 Summary

Taxonomic composition, abundance and spatio-temporal distribution of copepods were analysed from monthly zooplankton samples collected in Makupa Creek and Mombasa Harbour, Kenya. Until recently, Makupa Creek has been subjected to considerable anthropogenic influence derived from dumping of raw domestic and industrial wastes as well as activities in and around the Harbour of Mombasa. At least 51 copepod species belonging to 38 genera (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 wet months of November and April (75 to 158 ind.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 of the year. Evenness (*J*) was however relatively constant (0.67 to 0.84) during the entire sampling period. Apparently there are suppressed copepod diversity and abundance in Makupa Creek. Possible reasons for this, which may include environmental degradation caused by pollution, are presented.

6.2 Introduction

Ongoing and recently completed marine research in Kenya and the East African coast has produced much data and information on zooplankton studies (e.g. Kimaro & Jaccarini, 1989; Okemwa, 1989; Osore *et al.*, 1993; 1995; Kitheka *et al.*, 1997; Mwaluma, 2000; etc). However, information is still quite scanty regarding ecological studies of copepods yet this taxonomic group usually comprises the major component of zooplankton in terms of abundance and diversity. Apart from the 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 Somali (Smith & Lane, 1981), very little is known about copepods of the E. African coast. The existing literature about zooplankton in 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 6.1: Major physical and chemical features of Makupa Creek, Mombasa, Kenya. Compiled from Kamau (2001), Osore *et al.*, (Cap 5, this volume) and Mwashote (In press).

Location: West of Mombasa Island (4° 02' S, 39° 38' E)

Surface area: Approximately 1 km^2 (0.85 to 1.1)

Depth: Mean 3 m (Range from 0.7 m minimum to 13 m maximum)

Water temperature range: 24.85 ± 0.50°C min to 31.70 ±1.50°C max

Salinity: 29.90 ± 3.15 psu min to 35.80 ± 0.45 psu max

Secchi transparency: 0.30 m min to 1.40 m max

Dissolved oxygen concentration: 3.60 ± 0.90 mg l^{-1} min to 5.90 ± 4.40 mg l^{-1} max

Major heavy metals (μg/g):

Sediments: Cu (56 - 114), Cd (1 - 13), Zn (223 – 1429), Fe (up to 27,718), Pb (up to 58)
Water: Cd (not detected), Pb (12)
Fish: Cd (3.9), Pb (59)

Chlorophyll *a* concentration: 2.05 ± 0.60 μg l^{-1} to 8.00 ± 6.80 μg l^{-1}

Monthly rainfall: 1.9 mm min to 279 mm max

Table 6.1 summarises the physical and chemical features documented for Makupa Creek and compiled from various 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 various forms of marine pollution. Previous studies in the creek reported that there is 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 (In press) and Osore *et al.* (Cap 5, this volume) 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 vegetations. The resultant poor water quality may also be detrimental to the recruitment of the resident fishes and invertebrates.

The present study was conducted as part of collaborative multi-institutional research between the Kenya Marine & Fisheries Research Institute (KMFRI), the Kenya Wildlife Services (KWS) and the Government Chemist Department (GCD). The overall research objective was to assess the causes and status of environmental degradation of the 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 description of the study area are presented in Cap 5, this volume. In the present chapter, copepods are singled out because they are an important secondary producer and therefore an essential link in the food chain.

This study reports on the composition, abundance and distribution of copepods in Makupa Creek and part of Mombasa Harbour. The main aim is to present the different types of copepods present and describe their seasonal trends at four sampling locations in Makupa Creek (Stns 1, 2, 3, 4) in comparison with a control site in Mombasa Harbour (Stn 5).

Materials and methods are described in Cap. 3.2, 3.3.1, 3.3.4, 3.3.5, 3.4, 3.5.

6.3 Results and Discussion

Environmental variables

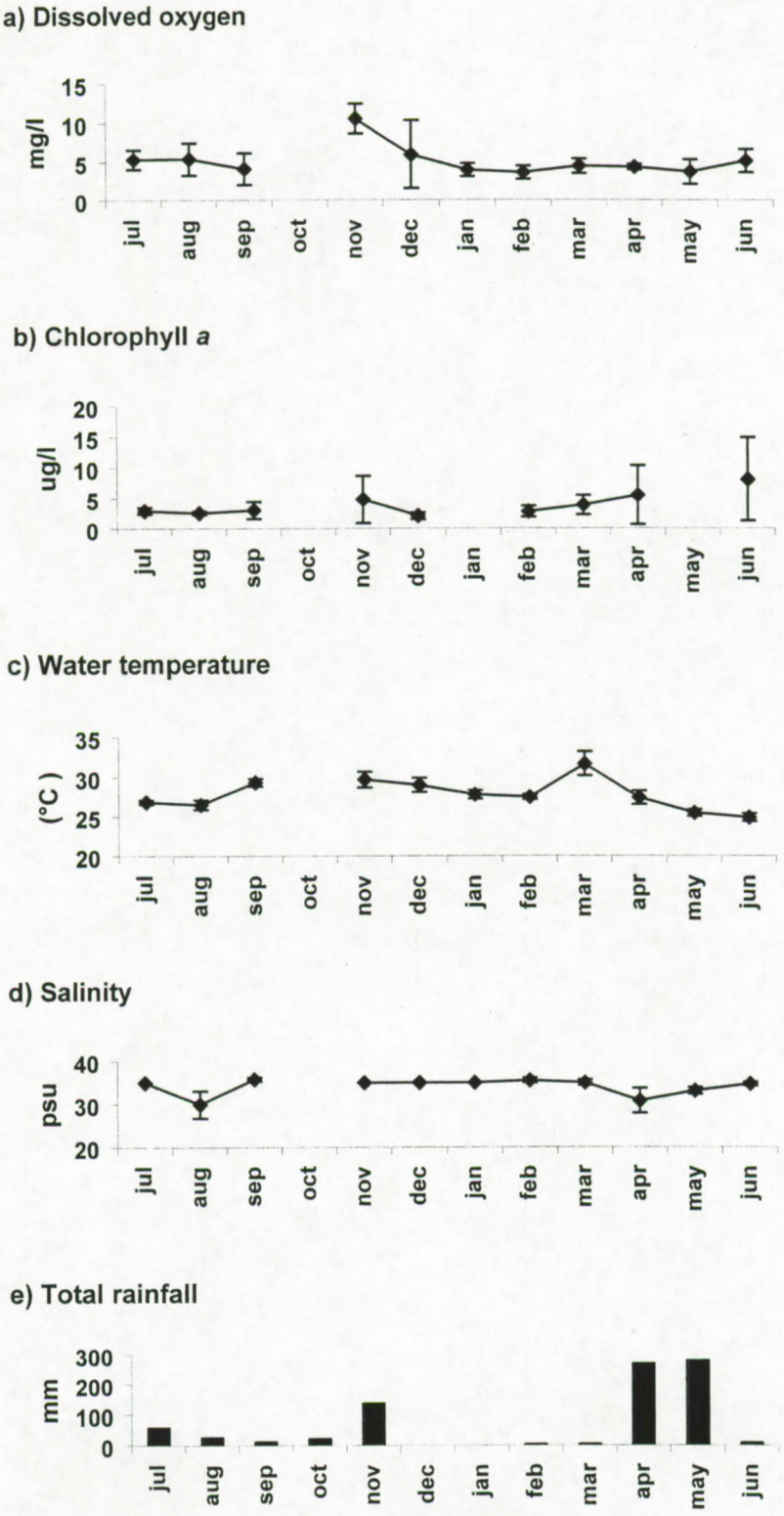


Fig. 6.1: Environmental variables recorded in the study area. Error bars are std deviation. (No sampling was conducted in October; neither was Chl-*a* sampled in January and May).

Monthly changes in average environmental variables are shown in Fig. 6.1. Average dissolved oxygen usually ranged between 3.70 and 5.31 mg l^{-1} and increased to 10.55 mg l^{-1} in November (Fig. 6.1 a). Chlorophyll *a* concentration, an indication of phytoplankton biomass, varied from 2.10 to 8.04 μg l^{-1} (Fig. 6.1 b). 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°C) in March and was relatively low (24.9 - 27.4°C) during the period from April to July (Fig. 6.1 c). Salinity varied narrowly (35.0 - 36.0 psu, Fig. 6.1 d) except in August (29.9 psu) and April (30.7 psu) due to rainfall. 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 (Fig. 6.1 e).

Copepod abundance

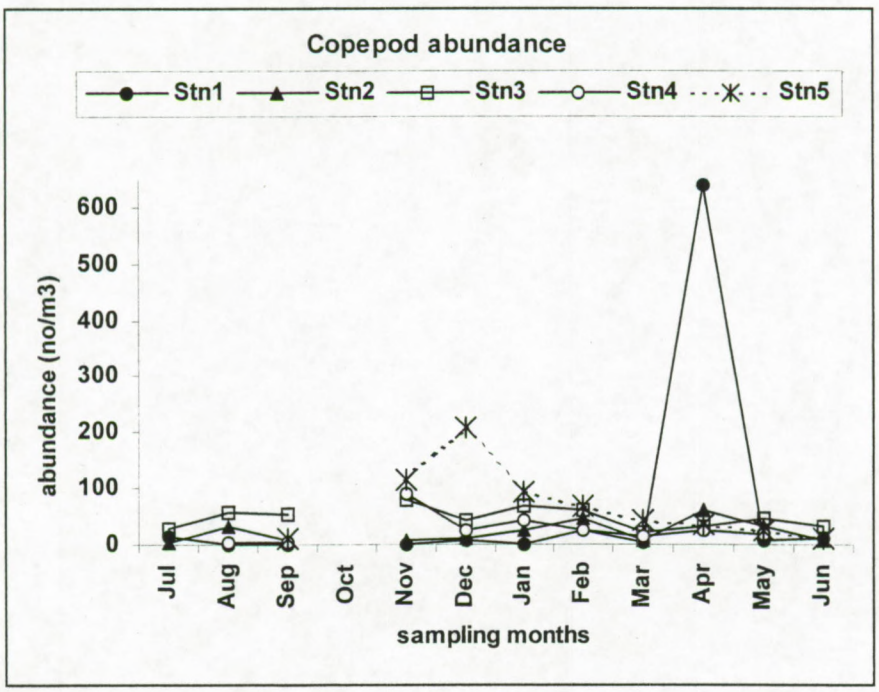


Fig. 6.2: Monthly abundance of the total copepods counted from each sampling station.

Monthly variations in copepod abundance at the five sampling stns are shown in Fig. 3. Within the creek enclosure (Stns 1- 4) abundance ranged from 3 to 88 ind.m^{-3} (Stn 4), 23 to 78 ind.m^{-3} (Stn 3), 2 to 60 ind.m^{-3} (Stn 2) and 1 to 25 ind.m^{-3} (Stn 1); but there was a major peak at this stn in April (638 ind.m^{-3}). The bloom of *Pseudodiaptomus* sp. mainly 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 ind.m^{-3}. Peak abundance (209 ind.m^{-3}) was observed in December.

Total copepod abundance for all Stns was high during the NEM period, which occurred in November, December, January, February and March. Mean value of copepod abundance was also significantly high (p = 0.001) for NEM compared to SEM period. Overall, copepod abundance peaked during the NEM period. Similarly, high densities of copepods have previously been reported in the Mombasa Harbour (Okemwa, 1992) during NEM period. In the present study, the highest monthly abundance (23 to 78 ind.m^{-3}) was recorded at Stn 3 located at the mouth of the creek and at Stn 5 (10 to 209 ind.m^{-3}), which is inside Mombasa Harbour and closer to the open ocean.

Copepod species distribution

More than 51 forms representing 5 orders, 15 families and 38 genera were identified in this study. Table 2 shows the list of copepods identified and their mean densities averaged for all the months. Numerically, the most common orders were Calanoida, Poecilostomatoida and Cyclopoida. Calanoida was mainly represented by the genera *Acrocalanus*, *Acartia*, *Centropages*, *Temora*, and *Tortanus*. *Pseudodiaptomus* only bloomed occasionally at Stn1. Poecilostomatioda was mainly represented by the genera *Corycaeus* and *Oncaea* while Cyclopoida was 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 24hr surveys within Mombasa Harbour, located in the immediate neighbourhood of Makupa Creek, yielded 100 species belonging to 29 families and 37 genera (Okemwa, 1992). The survey utilized the smaller 180µm mesh size net 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 since the water was less turbid than in the present study area.

Table 6.2: List of common copepods identified in Makupa Creek (Stns 1- 4) and Mombasa Harbour (Stn 5) and their densities of occurrence (ind.m^{-3}).

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, 1852)	0	1	1	1	2
Centropages orsini Giesbrecht, 1889	1	1	9	3	68
Candacia spp.	0	0	1	1	1
Calanopia elliptica (Dana, 1846)	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

Table 6.2: (Continued…) List of common copepods identified in Makupa Creek (Stns 1- 4) and Mombasa Harbour (Stn 5) and their densities of occurrence (ind.m^{-3}).

Species	Stn1	Stn2	Stn3	Stn4	Stn5
Calanoida (Continued…)					
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

The present 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*

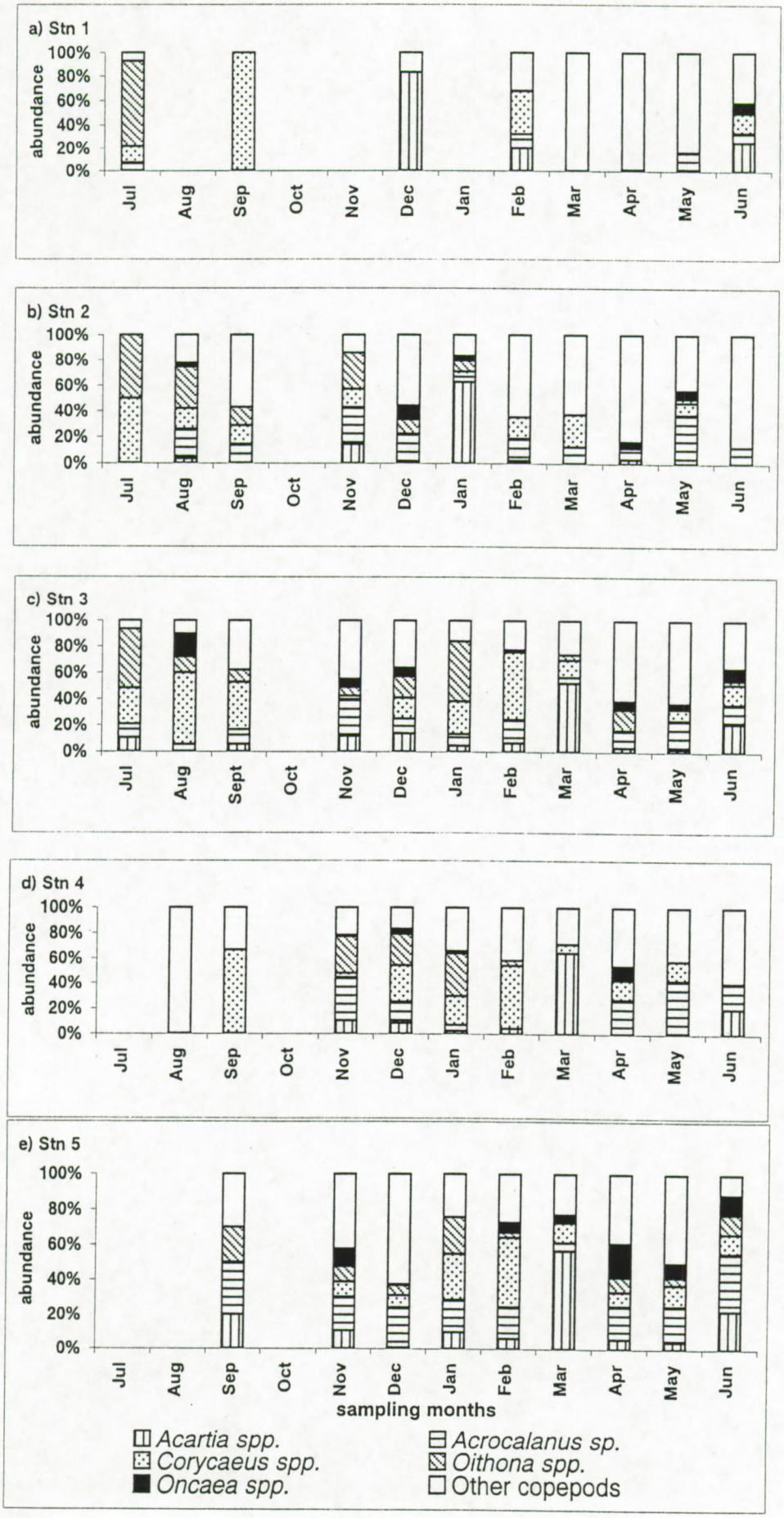
orsini Giesbrecht, 1889; *Pseudodiaptomus* sp., *Tortanus* spp., *Acartia* spp., *Oithona* spp., *Oncaea* spp. and *Corycaeus* spp. (see Table 6.2). Their combined abundance constituted 43 to 90% of the entire copepod population. Genera that comprised the most species were *Labidocera* (>6), *Eucalanus* (>4) and *Calanopia* (>3).

Characteristic copepod genera of the study area

Percentages of abundance of the five most common copepod genera in the study area namely: *Acartia*, *Acrocalanus*, *Corycaeus*, *Oithona* and *Oncaea* are presented in Fig. 6.3 a-e. These five main copepod taxa constituted an average abundance of 72% (range 45 to 90%) of the total number of copepods encountered. Table 6.2 shows that these genera occurred in all the sampling stations at maximum monthly abundance ranging from 3 to 49 ind.m^{-3} (*Acrocalanus* sp.), 6 to 25 ind.m^{-3} (*Acartia* spp.), 10 to 26 ind.m^{-3} (*Oithona* spp.) 1 to 12 (*Oncaea* spp.) and 2 to 25 ind.m^{-3} (*Corycaeus* spp.). Sampling was not conducted in October at all the Stns, in January at Stn 1, in July at Stns 4 and 5; nor in August at Stn 5.

The following is an account of the trends of occurrence and abundance of these five copepod genera at each of the sampling stations. Percent abundance in Fig. 6.3a-e demonstrates how *Acartia* and *Oithona* usually coexisted in the samples. The two genera are documented to often coexist in swarms of up to 1 m long in the shallow bays or creeks (Omori and Hamner, 1982). Since information in figs 6a-e only provides proportional abundance (%), the following account is intended to provide actual abundance (ind.m^{-3}). It also provides additional information on temporal distribution, which lacks in Table 6.2.

Fig. 6.3: Monthly variation of abundance (% of the total) of the five most common copepod genera in Makupa Creek: *Acartia*, *Acrocalanus*, *Corycaeus*, *Oithona* and *Oncaea* observed in a) Stn 1, b) Stn 2, c) Stn 3, d) Stn 4 and e) Stn 5.


a) Stn 1
b) Stn 2
c) Stn 3
d) Stn 4
e) Stn 5
abundance
100%
80%
60%
40%
20%
0%
Jul
Aug
Sep
Sept
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
sampling months
Acartia spp.
Corycaeus spp.
Oncaea spp.
Acrocalanus sp.
Oithona spp.
Other copepods

Stn 1: Although most samples from Stn 1 comprised members of the five main copepod genera mentioned above, a single genus alternately dominated in four out of the ten months sampled. *Corycaeus* dominated in September, *Acartia* in December and *Acrocalanus* in May (see Table 6.2 and Fig. 6.3 a). Only March and April were dominated by other copepods notably *Pseudodiaptomus* sp. (4 and 629 ind.m^{-3} respectively) The total number of all copepods encountered at Stn 1 (706 ind.m^{-3}) was therefore highly exaggerated by the bloom of *Pseudodiaptomus* sp. *Acartia* spp. were absent during most of the months and present only in December (5 ind.m^{-3}), February (5 ind.m^{-3}), April (6 ind.m^{-3}) and June (3 ind.m^{-3}). *Acrocalanus* sp. were also only present in July (1 ind.m^{-3}) February (3 ind.m^{-3}), May (1 ind.m^{-3}) and June (1 ind.m^{-3}). *Corycaeus* spp. were common in February (9 ind.m^{-3}) and sparsely present in July (2 ind.m^{-3}), September (1 ind.m^{-3}) and June (2 ind.m^{-3}). *Oithona* spp. were present only in July (10 ind.m^{-3}) and similarly *Oncaea* spp. only in June (1 ind.m^{-3}).

Stn 2 Compared to the others, Stn 2 was least dominated by the five main copepods (Fig. 6.3 b). Total number of all the copepods encountered at this Stn for all the months was 236 ind.m^{-3} (monthly average was 21±19 ind.m^{-3}). On many occasions, members of the five main genera were absent at Stn 2 or occurred only sparsely (1 to 8 ind.m^{-3}). *Acartia* spp. were common in January (15 ind.m^{-3}), and sparsely present in August (1 ind.m^{-3}), November (1 ind.m^{-3}), February (1 ind.m^{-3}) and April (2 ind.m^{-3}). They were absent the rest of the year. *Acrocalanus* spp. occurred during all the months except in July. They were quite common in May (12 ind.m^{-3}) and June (10 ind.m^{-3}) and also present in August (7 ind.m^{-3}), September (1 ind.m^{-3}), November (2 ind.m^{-3}), December (2 ind.m^{-3}), January (1 ind.m^{-3}), February (8 ind.m^{-3}), March (1 ind.m^{-3}), April (5 ind.m^{-3}) and June (1 ind.m^{-3}). *Corycaeus* spp. were absent in December and June but present in July (1 ind.m^{-3}), August, (5 ind.m^{-3}), September (1 ind.m^{-3}), November (1 ind.m^{-3}), January (1 ind.m^{-3}), February (8 ind.m^{-3}), March (2 ind.m^{-3}), April (1 ind.m^{-3}) and May (3 ind.m^{-3}). *Oithona* spp. were common in August (10 ind.m^{-3}) and also occurred in July (1 ind.m^{-3}), September (1 ind.m^{-3}), November (2 ind.m^{-3}), December (1 ind.m^{-3}), January (2 ind.m^{-3}), April (1 ind.m^{-3}) and May (1 ind.m^{-3}). They were completely absent in February, March and June. *Oncaea* spp. were only sparsely present (1 ind.m^{-3}) in August, December, January and April. They slightly increased in May (2 ind.m^{-3}) and were absent the rest of the months.

Stn 3: Total number of copepods encountered for all the months at Stn 3 was 526 ind.m^{-3} (monthly average was 48 ±18 ind.m^{-3}) and most of these were from the five main genera. At

least 4 of these genera co-occurred in all the months sampled, (Fig. 6.3 c). *Acartia* spp. were present during all the months except August. They were more abundant in March (12 ind.m^{-3}), November (9 ind.m^{-3}), December (6 ind.m^{-3}) and June (7 ind.m^{-3}) compared to July (3 ind.m^{-3}), September (3 ind.m^{-3}), January (3 ind.m^{-3}), February (4 ind.m^{-3}), April (1 ind.m^{-3}) and May (1 ind.m^{-3}). *Acrocalanus* spp. were abundant in November (22 ind.m^{-3}), May (10 ind.m^{-3}) and February (11 ind.m^{-3}). They were present all year round in July (3 ind.m^{-3}), August (3 ind.m^{-3}), September (6 ind.m^{-3}), December (5 ind.m^{-3}), January (6 ind.m^{-3}), March (1 ind.m^{-3}), April (4 ind.m^{-3}) and June (5 ind.m^{-3}). *Corycaeus* spp. were present during all the months except April. They were most abundant in August (31 ind.m^{-3}), September (20 ind.m^{-3}), January (17 ind.m^{-3}) and February (32 ind.m^{-3}); and common in July (8 ind.m^{-3}), November (2 ind.m^{-3}), December (7 ind.m^{-3}), March (3 ind.m^{-3}), May (4 ind.m^{-3}) and June (5 ind.m^{-3}). *Oithona* spp. were also present throughout except in May. They were common in July (13 ind.m^{-3}), abundant in January (31 ind.m^{-3}) and also present in August (7 ind.m^{-3}), September (5 ind.m^{-3}), November (5 ind.m^{-3}), December (7 ind.m^{-3}), February (1 ind.m^{-3}), March (1 ind.m^{-3}), April (5 ind.m^{-3}) and June (1 ind.m^{-3}). *Oncaea* spp. were common in August (10 ind.m^{-3}) and present in November (5 ind.m^{-3}), December (3 ind.m^{-3}), April (2 ind.m^{-3}), May (2 ind.m^{-3}) and June (3 ind.m^{-3}). They were completely absent in July, September, January, February and March.

Stn 4: Total abundance of all the copepods encountered for all the months at Stn 4 was 250 m^{-3} (monthly average was 25 ± 26 ind.m^{-3}). Fig. 6.3 d shows that the five main copepod genera co-occurred only in 3 out of the 9 months sampled. *Acartia* spp. were present only in November (9 ind.m^{-3}), December (2 ind.m^{-3}), January (1 ind.m^{-3}), February (1 ind.m^{-3}), March (9 ind.m^{-3}) and June (1 ind.m^{-3}). *Acrocalanus* sp. were abundant in November (30 ind.m^{-3}) and also present in December (4 ind.m^{-3}), January (2 ind.m^{-3}), April (7 ind.m^{-3}), May (8 ind.m^{-3}) and June (1 ind.m^{-3}). *Corycaeus* spp. were present in September (2 ind.m^{-3}), November (3 ind.m^{-3}), December (7 ind.m^{-3}), January (10 ind.m^{-3}), February (12 ind.m^{-3}), March (1 ind.m^{-3}), April (4 ind.m^{-3}) and May (3 ind.m^{-3}). They were absent in June and August. *Oithona* spp. were abundant in November (26 ind.m^{-3}) and January (15 ind.m^{-3}); sparsely present in December (6 ind.m^{-3}) and February (1 ind.m^{-3}) and absent the rest of the months. *Oncaea* spp. occurred sparsely in November (1 ind.m^{-3}), December (1 ind.m^{-3}), January (1 ind.m^{-3}) and April (3 ind.m^{-3}). They were absent the rest of the months.

Stn 5: Total abundance of all the copepods encountered for all the months at Stn 5 was 613 ind.m^{-3} (monthly average was 68 ± 65 m^{-3}). The five main copepod genera co-occurred in 6

out of the 9 months sampled and no single or even two genera of copepods dominated in any particular month (Fig. 6.3 e). *Acartia* spp. were abundant in March (25 ind.m^{-3}) and present consistently in September (2 ind.m^{-3}), November (12 ind.m^{-3}), December (1 ind.m^{-3}) January (9 ind.m^{-3}), February (4 ind.m^{-3}), April (2 ind.m^{-3}), May (1 ind.m^{-3}) and June (2 ind.m^{-3}). *Acrocalanus* sp. were very abundant in November (23 ind.m^{-3}), December (49 ind.m^{-3}) and January (18 ind.m^{-3}); and also present every month in September (3 ind.m^{-3}), February (13 ind.m^{-3}), March (2 ind.m^{-3}), April (7 ind.m^{-3}), May (5 ind.m^{-3}) and June (3 ind.m^{-3}). *Corycaeus* spp. were absent only in September and present abundantly in November (10 ind.m^{-3}), December (15 ind.m^{-3}), January (25 ind.m^{-3}) and February (28 ind.m^{-3}). They were sparsely present in March (5 ind.m^{-3}), April (3 ind.m^{-3}), May (3 ind.m^{-3}) and June (1 ind.m^{-3}). *Oithona* spp. were absent in March and abundant in November (10 ind.m^{-3}), December (12 ind.m^{-3}) and January (20 ind.m^{-3}). They were sparsely present in September (2 ind.m^{-3}), February (2 ind.m^{-3}), March (3 ind.m^{-3}), April (1 ind.m^{-3}), May (1 ind.m^{-3}) and June (1 ind.m^{-3}). *Oncaea* spp. were absent in September and abundant in November (12 ind.m^{-3}). Few individuals were present in December (1 ind.m^{-3}), February (4 ind.m^{-3}), March (2 ind.m^{-3}), April (7 ind.m^{-3}), May (2 ind.m^{-3}) and June (1 ind.m^{-3}).

Copepod diversity and homogeneity

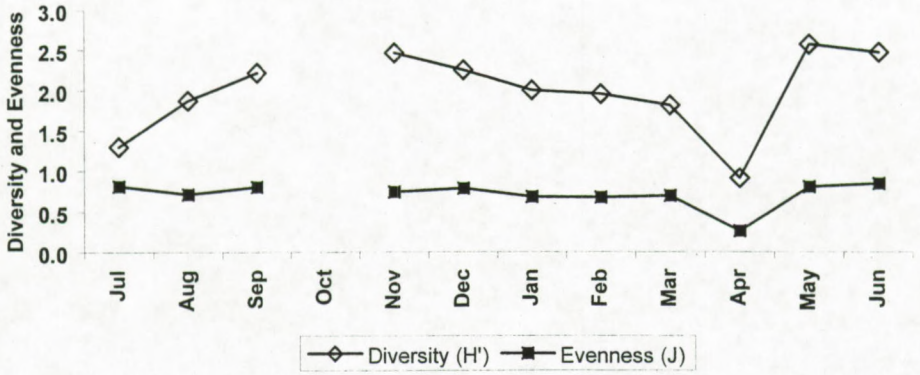


Fig. 6.4: Monthly variation of copepod diversity (unfilled diamonds) and evenness (filled squares) in Makupa Creek.

Shannon-Wiener and Pielou indices (Magurran, 1996) were used to explain the monthly diversity (*H'*) and homogeneity (*J*) of the copepod population. Fig. 6.4 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, we cannot conclusively compare results from the preset study with other in the region because data and information regarding copepod diversity for tropical creeks especially off the coast of East Africa are absent or very scarce.

6.4 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 the Mombasa Harbour, flushing is poor and thus the creek water may be expected to have extended resident times compared to water in the neighbouring creeks, lagoons and bays. But this is not entirely true, especially during spring tide.

Makupa Creek is physically unstable although it is well sheltered from the Indian Ocean. Recent hydrodynamic studies of the creek (Dr J. Kitheka, pers. com. and unpublished data) reveal that it is usually completely flushed during spring tides thus it has high rates of water exchanges 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. However, sediments trapped inside the creek may be more stable because there was usually only little re-suspension.

The temperature and salinity ranges were very narrow all the year round, which is typical of tropical creeks. Therefore, high levels of biological oxygen demand (BOD) and other chemical conditions (Mwangi *et al.*, unpublished data) were presumably the main contributing factors that caused biological/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 ind.m^{-3}) and Stn 3 (up to 78 ind.m^{-3}), which are Stns 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). Stn 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 the E. 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 domestice 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 at 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 research and other similar ones (Abuodha & Kairo, 2001; Kamau, 2001; including various unpublished data etc) 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 mainland 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 pollution 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.

PART III

Zooplankton Assemblages North of Mombasa, Kenya

Introduction

In part III of this study, we present zooplankton assemblages occurring in three representative areas located to the north of Mombasa Island. First is the zooplankton in the Mombasa Marine Park and Reserve (MMP&R), which is located to the immediate east of Mombasa mainland. Secondly the zooplankton of Mtwapa Creek located 20 km to the northeast of Mombasa. Thirdly is the zooplankton of Mida Creek, located about 100 km to the north of Mombasa (approximately 20 km southwest of Malindi town).

Apart from these three, other coastal localities that have been sampled in the past for (at least exploratory) zooplankton in the north coast are Kilifi Creek and Ungwana Bay. To the best of our knowledge, no documentation exists for zooplankton sampling around Lamu except the offshore transect during the Netherlands Indian Ocean Programme.

Two chapters are presented here on the zooplankton obtained in the lagoon of MMP&R and the adjacent Mtwapa Creek (Chapter 7) and the zooplankton of Mida Creek (Chapter 8).

CHAPTER 7

Plankton, Nutrients and Water Quality: A comparative assessment of the Mombasa marine protected area and Mtwapa Creek, Kenya

Results reported as part of:

M. K. W. Osore, S. N. Mwangi, T. Dzeha, M. Kilonzo & M. H. Daro 1999. Plankton, nutrients and water quality: a comparative assessment of the Mombasa marine protected area and Mtwapa Creek, Kenya. *In*: S. Mwangi, D. Kirugara, M. Osore, J. Njoya, A. Yobe & T. Dzeha (eds) Status of Marine Pollution in Mombasa Marine Park & Reserve and Mtwapa Creek, Kenya. KMFRI, GCD & KWS Tech. Rep. 88 pp.

7.1 Summary

In the present chapter we establish the trends of zooplankton and some related environmental factors in two adjacent marine areas. One of the areas, the Mombasa Marine Park and Reserve (MMP&R) lagoon is a Marine Protected Area (MPA) whereas the other one Mtwapa Creek is often subjected to activities that lead to environmental degradation.

Surface water temperature in Mtwapa Creek was consistently higher by about 1°C compared to the MMPR lagoon. The creek also displayed a wide monthly range of salinity (11.3 – 36.0 psu) compared to the lagoon (33.0 – 36.0 psu). The creek had slightly less dissolved oxygen than the lagoon and 2 to 4 times higher concentrations of inorganic nutrients (ammonium, nitrates and phosphates).

Although zooplankton was slightly more abundant in the creek, it was more diverse in the lagoon. Whereas chaetognaths and *Centropages* spp. were the dominant groups in the creek, the lagoon was mostly dominated by copepods belonging to genera such as *Oithona*, *Paracalanus*, *Tortanus* and *Corycaeus*.

7.2 Introduction

Kenya pioneered the concept of Marine Protected Areas (MPAs) in Africa by establishing the first marine reserve in Malindi/Watamu in 1968 (Chebures, 1989) and since then it has developed four more MPAs (Kisite, Mpunguti, Kiunga and Mombasa) along its 536 km coastline. Mombasa Marine Park & Reserve (MMP&R) was established in 1986 and it is divided into two management zones namely (i) Mombasa Marine Park, which occupies 10 km^2 and is restricted to recreational activities, scientific research and traditional fishing methods and (ii) the larger Mombasa Marine Reserve, which encompasses the park and occupies 200 km^2. Administratively, the Kenya Wildlife Services (KWS) is the governmental body responsible for the management and conservation of Kenya's MPAs while the Kenya Marine and Fisheries Research Institute (KMFRI) conducts the research.

The coastal economy of Kenya is concentrated around Mombasa, a City of 650,000 inhabitants and still growing at an annual rate of 2.6 % (World Bank, 2001). The economy is driven by port and maritime activities, manufacturing industries and most important of all

tourism. Tourism is currently the main foreign currency earner for Kenya out-performing traditional agricultural crops. The MPAs form the core attraction for coastal tourism accommodating up to 800,000 visitors annually. However, tourism and related economic activities also contribute significantly towards the degradation of the coastal environment through marine pollution and direct damage of the reef, corals and the flora and fauna therein (Viser & Njuguna, 1992). Unfortunately, the means to assess and reduce the damage and also launch remedial procedures are largely ineffective. This is partly because monitoring marine and coastal environments is often only possible when sustained external funding is available.

Traditionally, organizations like the Wildlife Conservation Society, the Wildlife Fund for Nature, World Bank, Sida/SAREC, etc. have funded specific researches to investigate the coral reef, seagrass beds, fish and sea urchins in MPAs and hence have provided useful scientific information required for awareness and education (Samoilys, 1988; McClanahan & Mutere, 1994; McClanahan & Kaunda-Arara, 1996; Muthiga, 1997; Obura *et al.*, 2000; McClanahan *et al.*, 2001; Hamilton & Brakel, 1984 etc). However, important aspects of applied research on the MPAs have often been overlooked particularly their primary productivity, the composition of important invertebrates and meroplankton essential for recruiting the fauna, the nutrient cycles and in general the role of the pelagic system and its processes. Yet these are the major ecological compartments that sustain marine life in the MPAs and knowledge of their status is therefore necessary for successful management.

In an effort to provide long-term useful data and information for current and future management strategies for Kenya's MPAs and in order to minimize further damage to the marine habitat, a monitoring project was initiated to investigate various parameters within the MMP&R and the adjacent Mtwapa Creek. The project was funded by Netherlands Wetlands Training Programme and executed by KWS, KMFRI, Coast Development Authority (CDA) and the Government Chemist Department (GCD).

The general objectives of the project were to investigate the pollution status of the MMP&R and the adjacent marine ecosystem by monitoring the concentrations of biologically active inorganic nutrients and heavy metals, determining organic contamination of the water and sediments, mapping out hydrodynamic settings and circulation patterns that affect the distribution of indicator species of pollution. The general results of this research have now been compiled in a technical report (Mwangi *et al.*, 1999).

Planktonic organisms are useful indicators of water quality because they are very sensitive to changes in toxic substances, excess nutrients and low oxygen (Clayton *et al.*, 1977; Roman *et al.*, 1993). In this chapter, we assess and compare MMP&R lagoon and Mtwapa Creek by quantifying and describing the spatial and temporal trends of (i) abundance and diversity of zooplankton, (ii) biomass of phytoplankton (iii) concentration of chlorophyll *a* and (iv) the levels of inorganic nutrients.

Material and methods are described in Cap 3.2, 3.3.1, 3.3.3, 3.3.4, 3.3.5, 3.3.6, 3.4 and 3.5.

7.3 Study area

Mombasa Marine Park & Reserve (MMP&R) about 14 km long and lies between Tudor Creek to the south and Mtwapa Creek to the north (Fig. 7.1). MMP&R is one of the largest and most popular marine protected areas in Kenya endowed with a variety of marine fauna and flora especially corals, fish and seagrass beds. It is therefore a thriving tourism hub with close to 30 beach hotels. Its shores are composed of sandy beaches and rocky cliffs that gently slope into a lagoon 1.5 to 2 km wide and 7 m maximum depth. A fringing reef to the east serves as a windbreaker and it shelters the lagoon from the open ocean, thus creating an ideal location for tourism and holiday resorts.

Mtwapa Creek is over 6 km long and up to 300 m wide with a maximum depth of 10 m near the creek mouth. Its surface area varies from 3.58×10^6 m^2 (LWS) to 1.26×10^7 m^2 (HWS) and its main fresh water input is via River Lwandani. The major economic activities around the creek include maintenance and repair work for deep-sea fishing vessels, some mangrove logging, some subsistence agriculture and artisanal fishing.

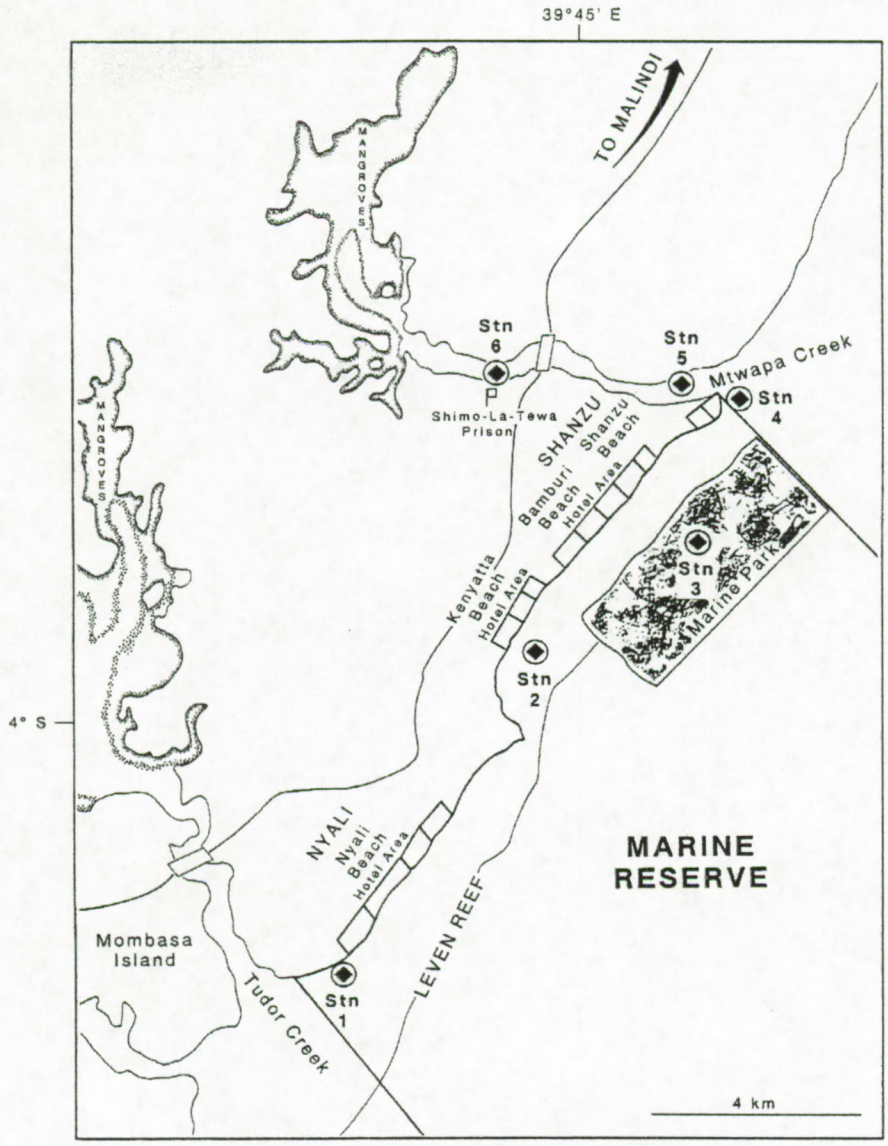


Fig. 7.1: Map of the study area showing sampling station in MMP&R lagoon and Mtwapa Creek.

The residence time of the lagoon waters is in the order of 1 to 2 tidal cycles and water exchange with the ocean is dominated by the wave induced flow over the reef and the semi-diurnal tidal forcing (Kirugara *et al*, 1998). On the contrary, water in the creek has residence time ranging from 3 days (wet season) to 12 days (dry season).

Six sampling locations were identified, three located in the lagoon (MMP&R lagoon Stns 1, 2 & 3), one at the mouth of Mtwapa Creek (Stn 4) and two inside the creek (Stns 5 & 6). Routine sampling of water and measurement of various physico-chemical variables was

conducted. The present study reports on results obtained for rainfall, surface water temperature, salinity, dissolved oxygen, inorganic nutrients, phytoplankton and zooplankton.

7.4 Results and discussion

Rainfall

Amount of rainfall recorded during the months of sampling is shown in Fig. 7.2. There were two wet seasons, the short rains occurred from October to November and the long rains from April to June. May received the highest amount of rainfall (500 mm) in 1996. There was also some substantial amount (180 mm) in August 1995. January and February were the driest months receiving between 0 and 16 mm of rainfall. Higher total rainfall amounting to 1,343 mm was recorded within the first year of the study period (August 1995 – July 1996) compared to 869 mm during the subsequent year.

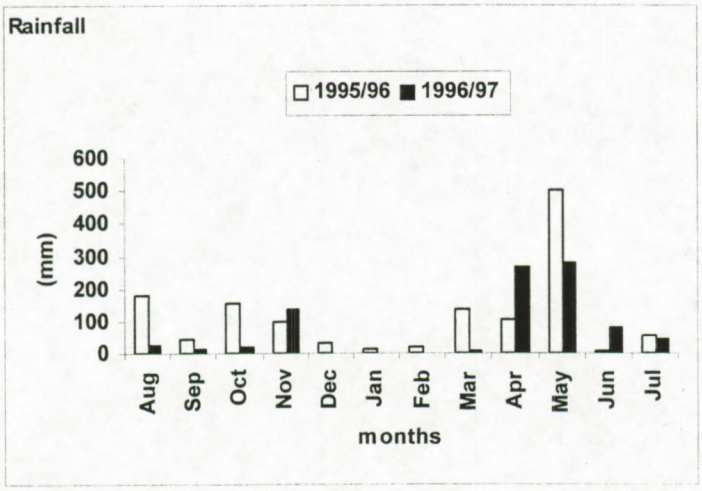


Fig. 7. 2: Total monthly rainfall in the area during the study period.

Surface water temperature

Figs 7.3a and b show the monthly variation of surface water temperature in the study area. The mean annual surface water temperature recorded within the MMP&R lagoon was higher by about 1°C during the first period of sampling compared to the second (Fig. 7.3a). Temperature varied between 26.0 and 29.9°C (mean = 27.9°C) during 1995-1996. It was between 25.2 and 28.4°C (mean = 26.9°C) during 1996-1997.

In Mtwapa Creek (Fig. 7.3 b), the temperature recorded during 1995-96 ranged between 26.4 and 31.0°C (mean = 28.4) and during 1996-97 it was between 25.9 and 29.0°C (mean = 27.5°C). Lower temperature was recorded between June and September (SE Monsoon) when the weather was cool while higher temperature was recorded between November and April. There was, however, a temperature drop in February 1996/97.

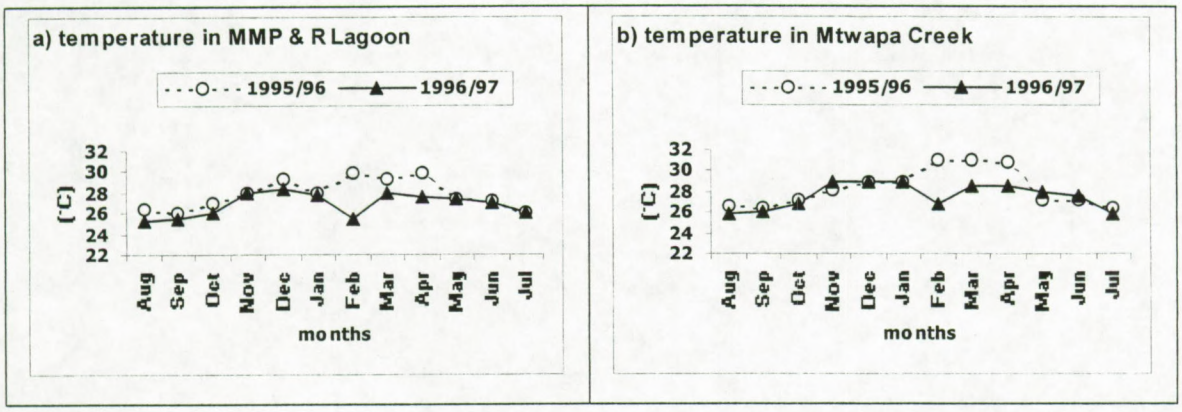


Fig. 7.3: Monthly variation of surface water temperature in **a**) MMP&R lagoon and **b**) Mtwapa Creek.

Salinity

Figs 7.4a and b illustrate monthly changes in salinity of MMP&R lagoon and Mtwapa Creek respectively. Surface water salinity in the lagoon ranged between 33.0 and 35.6 psu (mean = 34.6 psu) while in the creek it was between 11.3 and 36.0 psu (mean = 33.1 psu). The lowest salinity measured in the creek was during May 1996 (Fig.7.4 b), which was attributed to the brackish water plume formed when freshwater mainly from River Lwandani and also surface runoff entrained denser seawater. Salinity in the lagoon was relatively stable (Fig. 7.4 a) except during the rainy season when direct precipitation and storm water slightly reduced it. In the hot season, evaporation was responsible for salinity higher than 35 psu. Hence, the lagoon water was mainly oceanic without large-scale density driven circulation much unlike in the creek system.

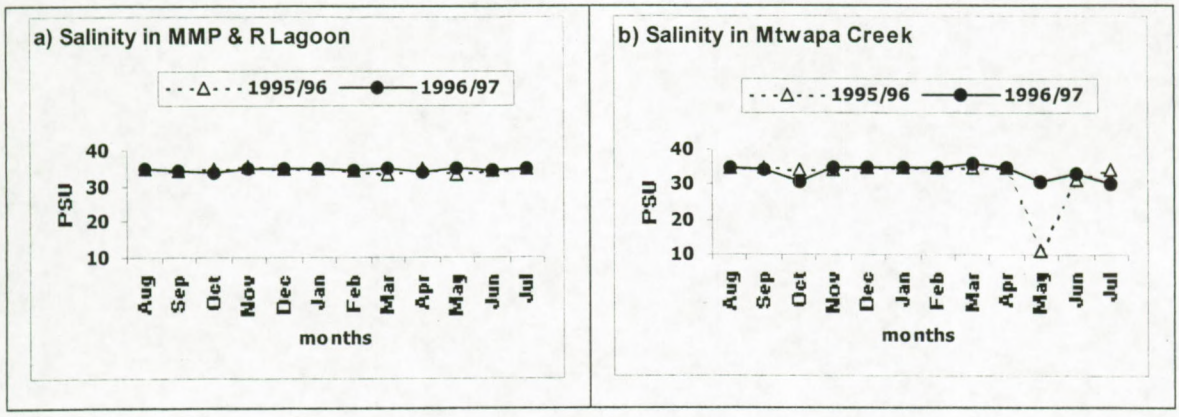


Fig. 7.4: Monthly variation of salinity in **a**) MMP&R lagoon and **b**) Mtwapa Creek.

Dissolved oxygen

Figs 7.5a and b show the concentration of dissolved oxygen (DO) recorded in the MMP&R lagoon and Mtwapa Creek respectively. Within the lagoon, DO range was between 4.36 ± 1.57 and 8.17 ± 0.40 mg l^{-1} (mean = 5.99 ± 0.63 mg l^{-1}) during 1995/96 while it was between 3.56 ± 0.44 and 8.18 ± 1.11 mg l^{-1} (mean = 5.81 ± 0.61 mg l^{-1}) during 1996/97 (Fig. 7.5 a). Within the creek, DO range was between 4.89 ± 0.10 and 7.58 ± 0.10 mg l^{-1} (mean = 5.73 ± .20 mg l^{-1}) during 1995/6, while it was between 4.04 ± 0.20 and 7.75 ± 0.20 mg l^{-1} (mean = 5.52 ± 0.34 mg l^{-1}) during 1996/97 (Fig. 7.5 b).

In both the lagoon and creek, higher DO was recorded from May to November (during the SE Monsoon). This was attributed to increased turbulence during this period often accompanied by strong wave action on the reef, which encouraged mixing of water. Besides, the general seasonal trends in dissolved oxygen showed higher saturation during the cool months between May and July and less saturation from January to February. This is a typical situation since oxygen saturation is temperature dependent and cooler waters facilitate the dissolution of oxygen to saturation.

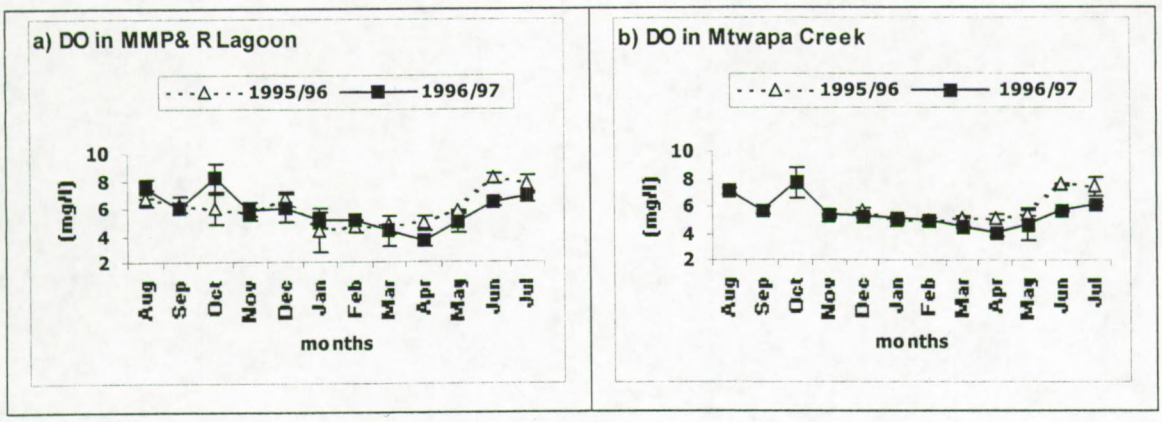


Fig. 7.5: Monthly average concentration of dissolved oxygen in **a**) MMP&R lagoon and **b**) Mtwapa Creek (bars represent std deviation of measurements between Stns).

Nutrients

Monthly average concentrations of ammonium, nitrate/nitrite and phosphate are presented in Figs 7.6 a-f. Average concentration recorded for these nutrients are described as follows:

Ammonium. Within the MMP&R lagoon (Fig. 7.6 a), the concentration varied between 0.31 ± 0.06 and 2.12 ± 0.92µM (mean = 0.65 ± 0.22µM) during 1995/96. It was between 0.32 ± 0.30µM and 6.91 ± 0.16µM (mean = 1.61 ± 0.36µM) during 1996/97. In Mtwapa Creek (Fig. 7.6 b) the concentration was between 0.82 ± 0.1 and 3.82 ± 0.55µM (mean = 2.51 ± 051µM) during 1995/96 and it was between 0.60 ± 0.28 and 5.89 ± 1.20µM (mean = 2.19 ± 0.47µM) during 1996/97.

Nitrate/nitrite. Within the lagoon (Fig. 7.6 c), the concentration was between 0.32 ± 0.65 and 3.71 ± 0.71µM (mean = 1.06 ± 0.50µM) during 1995/96. It was between 0.48 ± 0.65 and 8.06 ± 2.90µM (mean = 2.32 ± 1.13µM) during 1996/97. In the creek (Fig. 7.6 d) the concentration was between 0.42 ± 0.21 and 9.12 ± 4.17µM (mean = 4.14 ± 0.90µM) during 1995/96 and it was between 1.25 ± 0.42 and 20.63 ± 5.63µM (mean = 5.57 ± 1.33µM) during 1996/97.

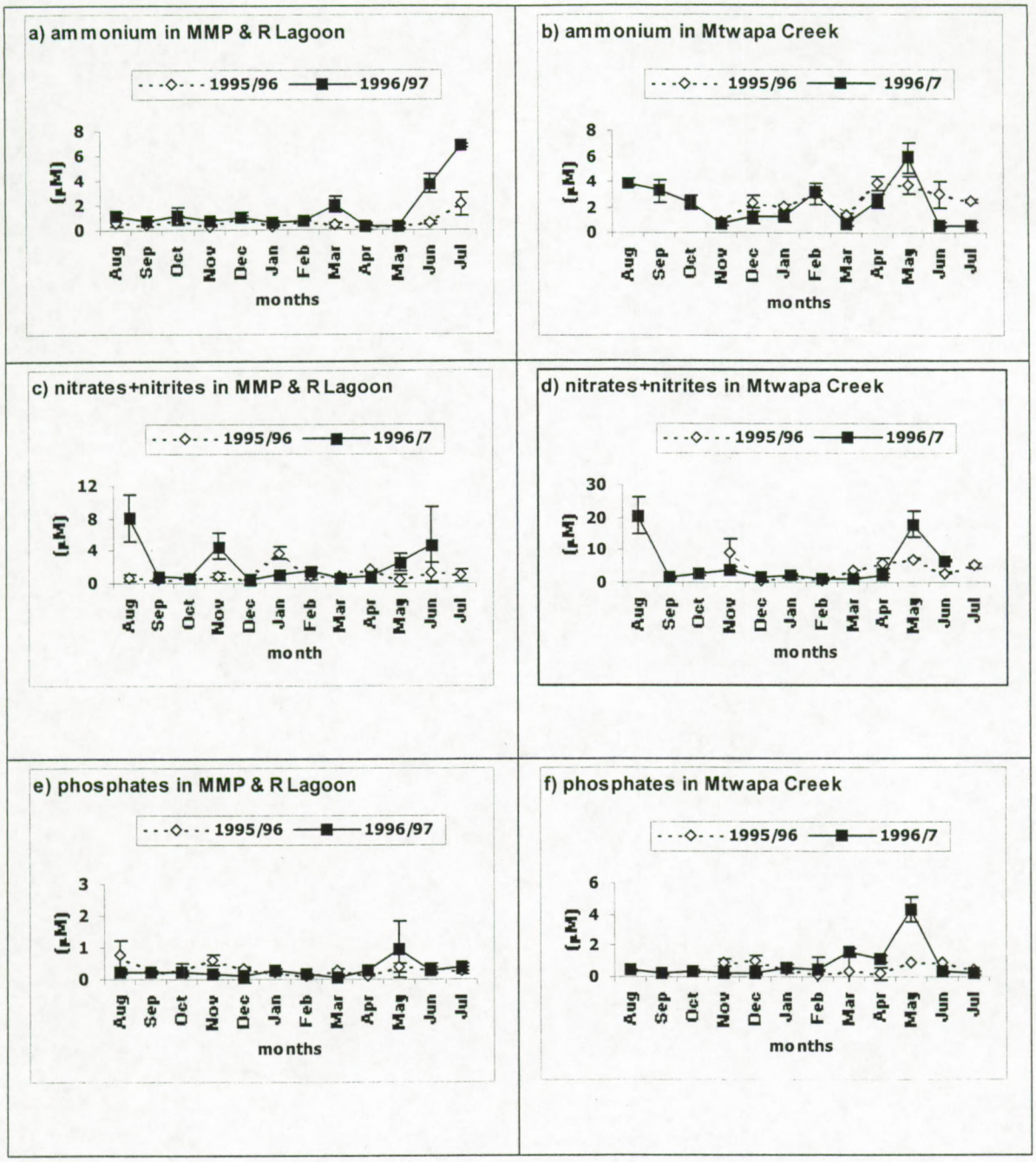


Fig. 7.6: Monthly average concentration of ammonium (Figs **a**, **b**), nitrates/nitrite (Figs **c**, **d**) and phosphates (Figs **e**, **f**) in MMP&R lagoon (left) and Mtwapa Creek (right). Bars represent std deviation.

Phosphates. Within the lagoon (Fig. 7.6 e), the concentration was between 0.09 ± 0.05 and 0.77 ± 0.45µM (mean = 0.32 ± 0.13µM) during 1995/96. It was between 0.08 ± 0.03 and 0.95 ± 0.89µM (mean 0.28 ± 0.15µM) during 1996/97. In the creek (Fig. 7.6 f) the concentration

was between 0.15 ± 0.20 and 1.00 ± 1.04μM (mean = 0.58 ± 059μM) during 1995/96 and it was between 0.20 ± 0.12 and 4.28 ± 0.76μM (mean = 0.82 ± 0.16μM) during 1996/97.

MMP&R lagoon contained relatively low nutrient levels as expected of coral reef lagoons (Odum, 1971) compared to Mtwapa Creek. These nutrients were also relatively stable in the lagoon except for nitrates that were variable (standard deviations commonly of similar magnitude as their means). Slightly elevated levels of all nutrients were observed during the wet seasons caused by local effects near the mouths of Tudor Creek and Mtwapa Creek (at Stns 1 and 4 respectively). The fact that during the wet season, nutrient concentrations were elevated at both Stns 1 and 4 suggests that additional nutrients were derived from riverine sources and transported through the creek systems during ebb currents.

Nutrient levels were significantly higher in the 1996/97 period than in 1995/96 ($p < 0.05$), a strong indication that the levels were not entirely a function of terrestrial runoff (since 1996/97 was less wet). This was a clear demonstration of the complexity of nutrient dynamics in a coral reef lagoon as reported by Bell (1990).

Generally, nutrient levels in the lagoon were slightly higher but comparable to those reported by Ohowa *et al* (1997) at the coral reef zone in Gazi Bay (about 0.97 μM for nitrate/nitrite and 0.90 μM for ammonium) and much lower than those recorded in the open waters of the western Indian Ocean as reported by Smith & Codispoti (1980). Phosphate concentrations were also lower than the 0.5 μM reported for the northern Indian Ocean by Ryther & Menzel (1965).

Compared to the lagoon, nutrient levels in the creek were conspicuously higher and had marked distinct seasonal signals. The highest values were recorded during the wet season. Similarly, Kazungu *et al.* (1989) reported higher nitrate/nitrite values (2.80 ± 0.1 to 28.50 ± 0.09 μM) in Tudor Creek during the wet season.

Chlorophyll *a*

The amount of chlorophyll *a* observed monthly in the study area is illustrated in Fig. 7.7. Mean monthly chlorophyll *a* values observed in MMP&R lagoon were in the range of 0.31 ±

0.04 to 0.81 ± 0.11μg l^{-1} (mean = 0.54 ± 0.09μg l^{-1}) suggesting that the lagoon was not eutrophicated.

Such concentrations were comparable to the overall mean monthly values observed in adjacent localities of Diani, Kanamai and Vipingo during 1993 to 1994 (Muthiga, 1997).

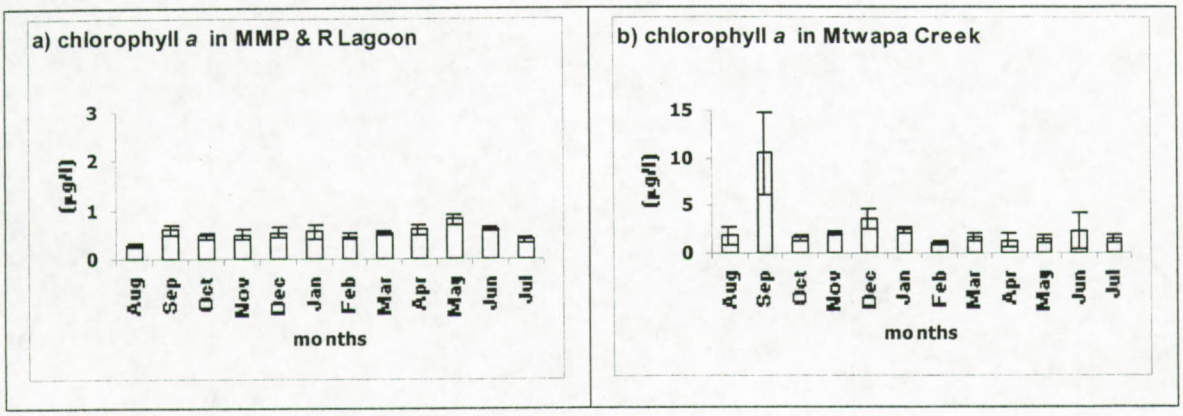


Fig. 7.7: Monthly average concentration of chlorophyll *a* in **a**) MMP&R lagoon and **b**) Mtwapa Creek (bars represent standard deviation).

Relatively higher chlorophyll *a* concentrations were observed in the lagoon during the long rains (May-June) when a maximum value of 0.92 μg l^{-1} was recorded (Fig. 7.7 a).

In Mtwapa Creek chlorophyll *a* concentrations were high and variable (Fig. 7.7 b). A mean of 2.62 ± 0.95 μg l^{-1} was recorded over the study period and ranged between 1.09 ± 0.22 and 10.53 ± 4.34 μg l^{-1}.

In general, poor correlation was observed between nutrient concentration and chlorophyll *a*. Thus implying that the distribution of chlorophyll *a* was patchy and non-homogeneous.

Phytoplankton

Only the total phytoplankton counts rather than individual taxa were availed to us by the third author who analyzed these samples. Therefore data on species diversity is not presented here.

Microscopic counting as a method of measuring biomass is both time consuming and imprecise (Lund *et al.*, 1958; Ilmavirta, 1974; Hallegraeff, 1977). However, it is the only way in which details of species composition may be determined. Besides, data on cell numbers are scanty, hardly comparable and generally biased by an underestimation of pico- and nano-planktonic components. In this study 40 samples were enumerated for phytoplankton biomass during the SE Monsoon period and 27 during NE Monsoon.

Figs 7.8a and b show monthly abundance of phytoplankton enumerated in both MMP&R lagoon and Mtwapa Creek. Total phytoplankton abundance was low in the lagoon and high in the creek. Abundance in the lagoon was between 44 and 9,561 cells l^{-1} while in the creek it was between 85 and 26,382 cells l^{-1}.

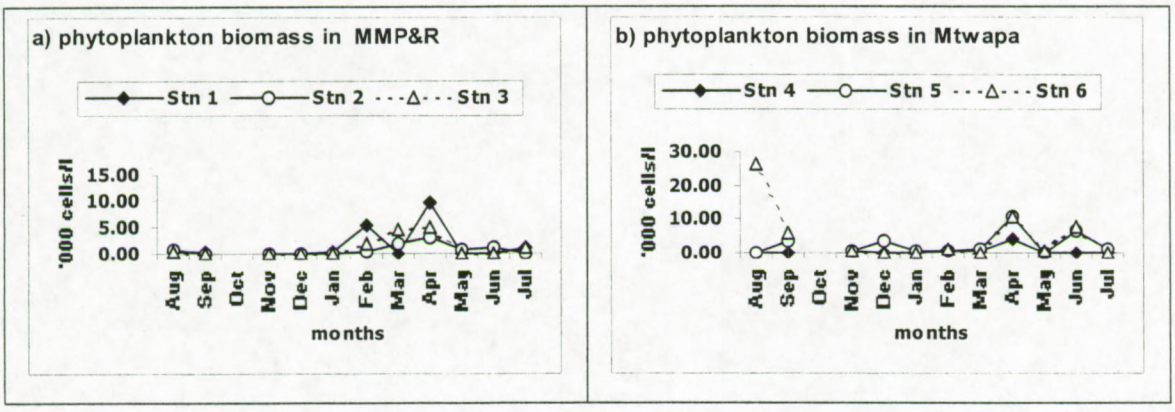


Fig. 7.8: Total phytoplankton biomass in **a**) MMP&R lagoon and **b**) Mtwapa Creek.

Phytoplankton abundance was significantly lower during the NE Monsoon than the SE Monsoon period. The highest count during the NE Monsoon period was 5,400 cells l^{-1} observed in February at Stn 1 (Fig. 7.8 a). In both monsoons, the order of dominance was diatoms > dinoflagellates > cyanophyceae and observed species proportions varied greatly from sample to sample. McGowan (1974) suggested that such variability decreases the relative importance of interspecific interactions in regulating the overall species proportions of the system.

The phytoplankton biomass indicated by abundances was generally higher for the creek Stns. The highest phytoplankton cell count (26,382 cells l^{-1}) was recorded in August at Stn 6 (Fig.

7.8 b), which is located adjacent to a sewage effluent point and was dominated by *Coscinodiscus* and *Chaetoceros*. During that period, diatoms dominated the population and constituted 87.9% followed by the dinoflagellates (6.8%) and cyanophyceae (0.8%).

The high phytoplankton counts observed in the creek were indicative of nutrient enrichment (of up to 26.26 μM, 6.09 μM and 5.64μM for nitrate/nitrite, ammonium and phosphates respectively) from terrestrial input and/or possible sewage discharge. The increased amounts of nutrients enabled the environment to support a larger population of phytoplankton with a greater number of species (Torrington-Smith, 1974). Significantly high correlation between phytoplankton and nutrients was only achieved with nitrate/nitrite ($r = 0.51$, $P < 0.05$) particularly in the creek. Correlations between phytoplankton and the other nutrients were weak and insignificant.

Zooplankton abundance and diversity

Figs 7.9a-f show average zooplankton abundance, number of taxa encountered and diversity at each sampling Stn in the MMP&R lagoon and Mtwapa Creek during the study period.

Abundance ranged from 71±20 to 128±102 ind.m^{-3} in MMP&R lagoon and from 91±48 to 122±34 ind.m^{-3} in Mtwapa Creek (Figs 7.9a and b). The number of taxa encountered ranged from 26±2 to 33±3 in the lagoon and from 26±4 to 29±10 in the creek (Figs 7.9 c and d respectively).

Taxon diversity ranged from 5.8±1.3 to 6.7±1.7 in the lagoon and from 5.5±1.0 to 5.8±0.9 in the creek (Fig. 7.9 e and f respectively). Diversity was higher than in the adjacent inshore waters of Tudor Creek (Okemwa, 1990; Osore, 1994) and also the surface offshore waters of the Kenya coast (Osore *et al.*, 1995; Mwaluma, 2000).

The highest number of zooplankton taxa in the lagoon (up to 36) was recorded at Stn 2 and this also coincided with an equally high abundance (up to 229 ind.m^{-3}) and diversity (max 8.4). Stn 5 recorded a very wide range of taxa (29±10) and high abundance (up to 159 ind.m^{-3}) but with relatively low diversity (max 6.5). Stns 3 and 4 recorded the lowest taxa diversities (5.8±1.3 and 5.5±1.0 respectively), the lowest number of encountered taxa (26±2 and 26±4

ind.m^{-3} respectively) and also the lowest zooplankton abundances (71±20 and 91±48 ind.m^{-3} respectively).

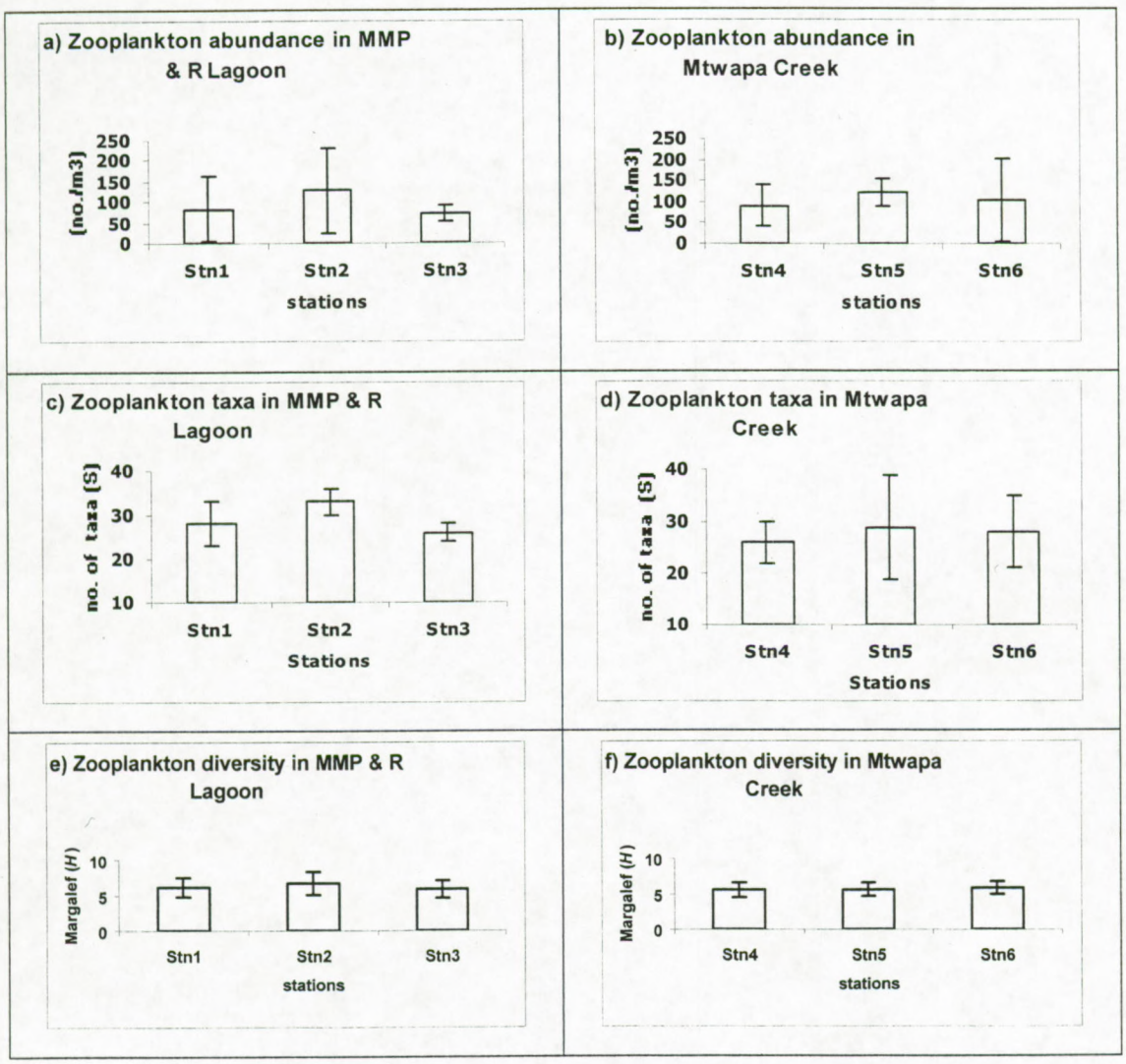


Fig. 7.9: Average zooplankton abundance, number of taxa encountered (S) and Margalef diversity (*H*) in the MMP&R lagoon (**a**, **c** and **e** respectively) and Mtwapa Creek (**b**, **d** and **f** respectively).

Generally, zooplankton was slightly more abundant in the creek than in the lagoon whereas diversity seemed higher in the lagoon than in the creek.

Figs 7.10a and b show the spatial variation, distribution and abundance of important zooplankton taxa in the surface water at all the six sampling Stns. Based on the abundance

and frequency of occurrence of zooplankton in the study area, Chart 7.1 was compiled to indicate the characteristic taxa for each sampling Stn. From the chart, gastropods and the following copepods: *Paracalanus* spp., *Acartia* spp., *Undinula vulgaris* (Dana, 1849), *Centropages* spp. and *Oithona* spp. were always present at all the sampling Stns. However, they varied in abundance among the Stns and period of sampling. Several taxa were only present at particular Stns e.g. *Tortanus* spp. (at Stn 1) *Peltidium* spp. (Stn 2), *Temora* spp. (Stn 3), *Oikopleura* spp. (Stn 4) and Polychaeta (Stn 6).

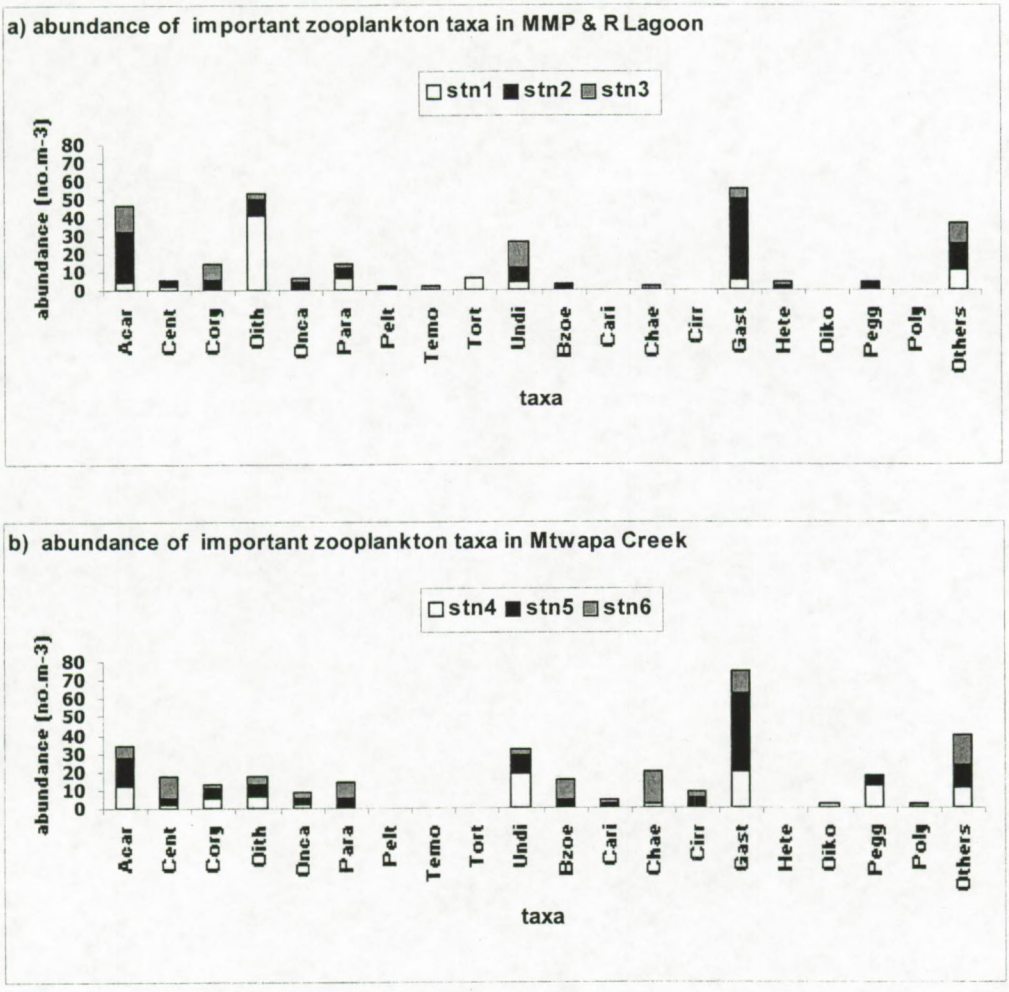


Fig. 7.10: Abundance of important zooplankton taxa in different sampling Stns located in a) MMP&R lagoon and b) Mtwapa Creek. (Key: Acar = *Acartia*, Cent = *Centropages*, Cory = *Corycaeus*, Oith = *Oithona*, Onca = *Oncaea*, Para = *Paracalanus*, Pelt = *Peltidium*, Temo = *Temora*, Tort = *Tortanus*, Undi = *Undinula*, Bzoe = Brachyura zoea, Cari = Caridea, Chae = Chaetognatha, Cirr = Cirriped nauplii, Gast = Gastropoda, Hete = Heteropod, Oiko = Oikopleura, Pegg = Pisces eggs and Poly = Polychaeta).

The abundance of commonly occurring taxa usually ranged between 2 and 20 ind.m^{-3} but where single taxa dominated, the abundance often increased to 44 ind.m^{-3}. The rarity of

young planktonic stages such as nauplii, zoea etc that are usually more sensitive to stress than adults, attested that the water quality in Mtwapa Creek is generally poor. Studies by Kingzett & Pirquet (1995) show that domestic sewage is typically associated with the presence of gastropods and other molluscs in seawater and the related possibility of typhoid, hepatitis, cholera or other illnesses especially when raw contaminated shellfish is consumed.

Total zooplankton abundance in the study area (71±20 to 129±102 ind.m^{-3}) was considerably lower than what is observed in inshore waters along the Kenya coast. Stn 3 (location of the marine park) recorded low zooplankton abundance compared to either Stns 1 and 2, (which are within the marine reserve) or the adjacent Mtwapa Creek. Usually planktonic copepods are diverse and abundant in coral gardens (such as the marine park Stn 3) and they associate in nutrition with the coral polyps (Bell, 1990; 1992). However, the plankton population discussed here is mainly derived from the surface water nowhere near the coral matrix so the abundance may not reflect the true population count in the whole water column.

Indicator species characteristic of each sampling Stn did not reveal a clear-cut boundary between Stns. There was a lot of overlapping. Nevertheless, copepods dominated all the Stns in the lagoon while chaetognaths (the arrow worms) and gastropods tended to dominate in the creek. Gastropods and the copepod species of *Acartia* were the most prevalent taxa in the study area and they commonly occurred in four Stns out of all the six (see Chart 7.1). Gastropods and copepods are the main planktonic groups that have adapted to the constantly changing environment of lagoons and creeks. Calanoid copepods were the dominant members of the zooplankton at MMP&R lagoon and the holoplankton community in the lagoon can therefore be described as an assortment of calanoid copepods.

Chart 7.1: The characteristic zooplankton of MMP&R lagoon and Mtwapa Creek.

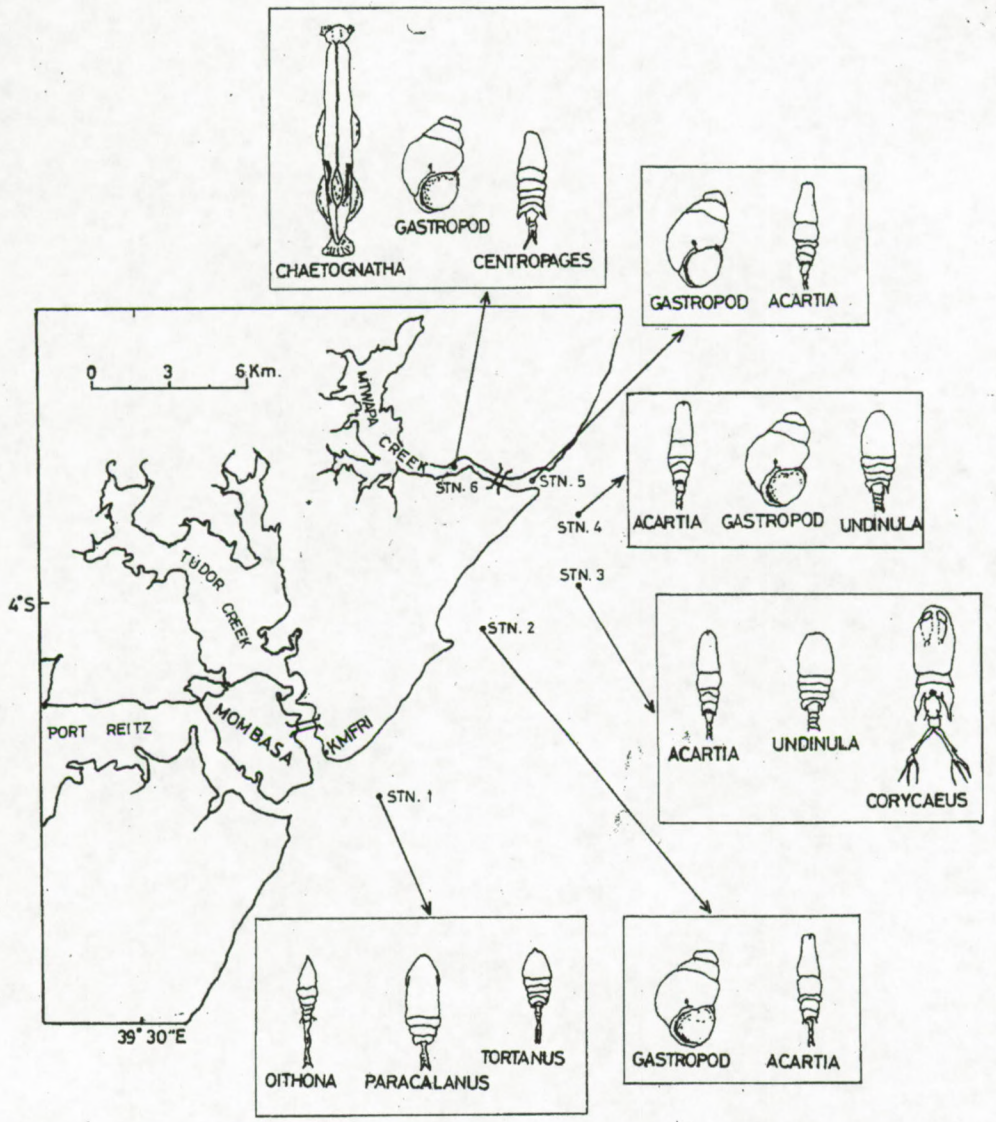


Chart 1. Zooplankton taxa characteristic of each sampling station in the Mombasa marine park/reserve and the adjacent Mtwapa creek.

24 hr variability of zooplankton and tide

Figs 7.11 & 7.12 show bi-hourly variations of surface zooplankton abundance, number of taxa encountered and the tidal height recorded during two 24 hr sampling cycles at Stn 2. The first cycle was conducted on 28-29 May 1996 (Figs 7.11 a and b). The lowest zooplankton abundance (25 to 100 ind.m^{-3}) was recorded during daytime between 0700hr and 1900hr. High abundance (120 to 240 ind.m^{-3}) was recorded at night between 2100hr and 0300hr (Fig. 7.11 a). There was a major increase in zooplankton abundance between 1700hr and 2100hr (from 25 to 160 ind.m^{-3}) and also between 2300hr and 0300hr (from 120 to 240 ind.m^{-3}).

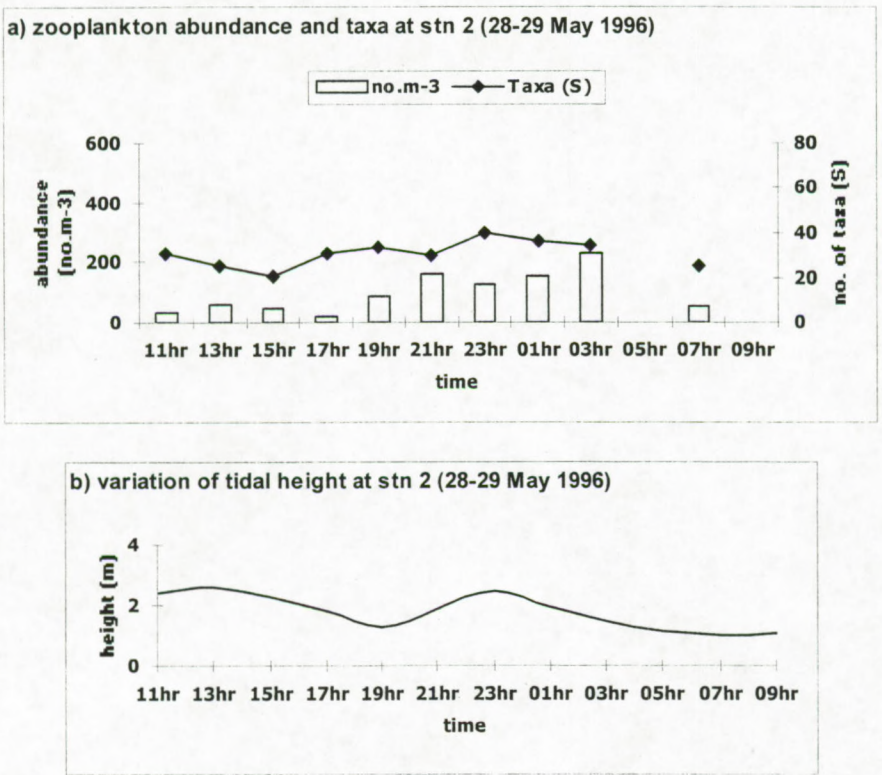


Fig.7.11: a) Total zooplankton abundance and the number of taxa encountered and b) variation of tidal height over 24hr period (28-29 May, 1996) conducted at Stn 2 in the MMP&R lagoon. (Zooplankton sampling was not conducted at 0500hr and 0900hr).

The number of encountered taxa reduced from 31 at 1100hr to 25 at 1500hr and then increased again to 33 at 1900hr. There was a steady decrease down from 40 at 2300hr to 27 at 0700hr. Correlation between abundance and the number of taxa was weakly positive and insignificant ($r_s = 0.4817$, $df = 8$, $p = 0.0798$). Zooplankton sampling was not conducted at 0500hr and 0900hr.

Fig. 7.11 b shows that high tide was observed at 1300hr (2.58 m) and 2300hr (2.48 m) whereas low tide was at 1900hr (1.27 m) and 0700hr (0.98 m). Flooding phase was already underway as sampling began (at 1100hr) and lasted till 1300hr, and also between 1900hr and 2300hr. Ebbing phase occurred between 1300hr and 1900hr and also between 2300hr and 0700hr. The tide weakly correlated negatively and insignificantly with abundance (r_s = *-0.115; df = 8; p= 0.3749*) and also with the number of taxa (r_s = *-0.0366; df = 8; p= 0.4614*).

Figs 7.12a and b show results obtained during the second 24 hr sampling cycle conducted on 18-19 July 1997. The lowest zooplankton abundance (between 21 and 163 ind.m^{-3}) was recorded during the daytime between 1100hr and 1900hr (Fig. 7.12 a).

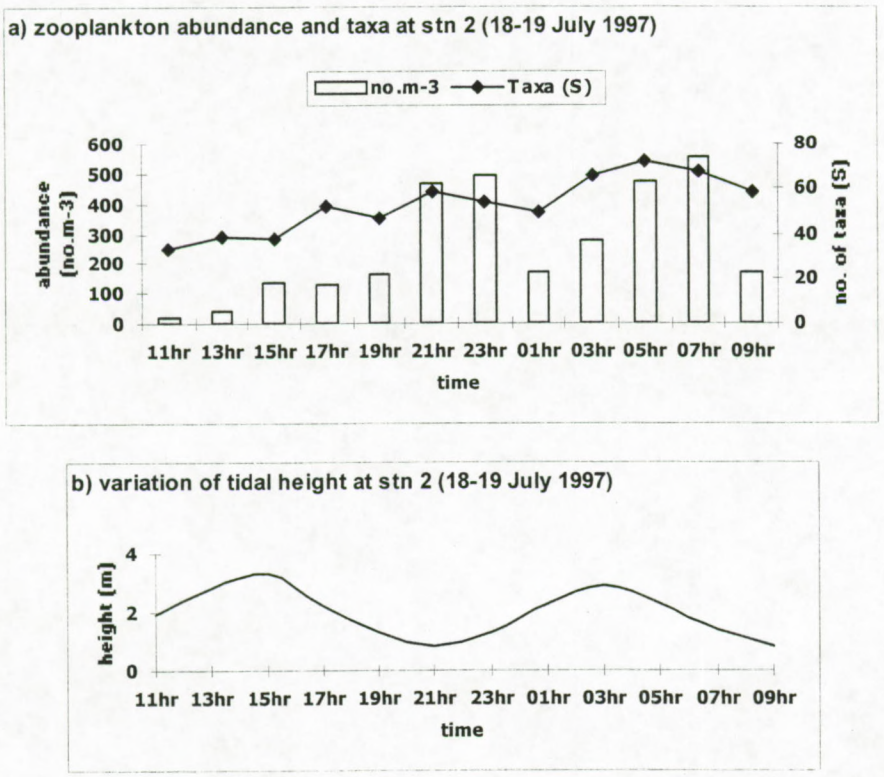


Fig.7.12: **a**) Total zooplankton abundance and the number of taxa encountered and **b**) variation of tidal height over 24 hr period (18-19 July, 1997) conducted at Stn 2 in the MMP&R lagoon.

High abundance was recorded at night between 2100hr and 2300hr (463-495 ind.m^{-3}) and early morning between 0500hr and 0700hr (474-551 ind.m^{-3}). The number of taxa increased slightly from between 33 and 52 during the day to between 54 and 72 at night. There was a

significant and strong positive correlation between abundance and number of taxa ($r_s = 0.836$; $df = 10$; $p = 0.0003$).

Fig. 7.12 b shows that high tide was observed at 1500hr (3.30 m) and 0300hr (2.94 m) whereas the height of low tide at both 2100hr and 0700hr was 0.80m. Flooding was underway at the beginning of sampling at 1100hr and lasted till 1500hr, and also between 2100hr and 0300hr. Ebbing was between 1500hr and 2100hr and also between 2000hr and 0900hr. The tidal rhythm weakly correlated negatively and insignificantly with both the abundance ($r_s = -0.3134$; $df = 10$; $p = 0.1614$) and also the number of taxa ($r = -0.2212$; $df = 10$; $p = 0.2440$).

Results from both 24 hr sampling surveys show that zooplankton abundance increased by a factor of up to 4 times at night. The number of encountered taxa also increased in response to high abundance. The raising tide did not result in an increase in abundance (or number of taxa); in fact it slightly had the opposite effect.

7.5 Conclusion

This study has established and compared the status of the plankton population, the main nutrients and the water quality of the MMP&R lagoon and Mtwapa Creek. The shallow and well-flushed lagoon consists of mainly oceanic waters rich in DO owing to the wave breaking action on the reef edge and reef top. In contrast, the creek has less DO. Water in the lagoon is replenished within one or two tidal cycles as compared to 3-12 days in the creek. Therefore, nutrients and pollutants tend to be retained for longer periods in the creek.

The wettest months were April and May and the driest ones January and February.

High nutrient and chlorophyll *a* levels recorded in Mtwapa Creek indicated that the creek is relatively polluted and, as observed from studies in similar environments (Bryceson, 1982; Verlencar, 1984), it may in future become eutrophic. The high nutrient levels were a response of direct discharge of raw sewage, and input of materials from seasonal rivers and non point sources especially through surface runoff during the wet seasons. Enhanced nutrient levels were in turn responsible for the high phytoplankton biomass reported in the creek compared to the lagoon.

Nutrients in the lagoon were characteristically low as expected of localities adjacent to coral reefs (Crosslands, 1983; Bell, 1992). This indicated that the environment is still conducive for coral reef development. Based on studies of the local coastal circulation (Norconsult, 1975; Magori, 1997) strong tides and currents around Stn 4 are directed northward. Therefore it appears that currents tend to wash away and dilute any pollutants from the creek that may tend to accumulate in the lagoon.

In general, zooplankton abundance was not much different between the lagoon and the creek. However, the diversity seemed to be lower in the creek. Based on composition of the zooplankton taxa, the type of pollution experienced may be categorised as domestic- mainly due to dumping of raw sewage (Ryther *et al.*, 1972; Kingzett & Pirquet, 1995).

Copepods belonging to several species of *Oithona* (Cylopoida), *Paracalanus* (Calanoida), *Tortanus* (Calanoida) and *Corycaeus* (Poecilostomatoida) were the most common taxa in the lagoon. Chaetognatha and *Centropages* spp. were dominant in the Creek. Taxa that were consistently common in both localities were Gastropoda and the copepods *Acartia* spp. and *Undinula vulgaris*.

During the 24 hr cycle, zooplankton abundance substantially increased at night compared to daytime as expected (Richard *et al.*, 1996; Manuel & D'Or 1997; Gray, 1998; Shaw & Robinson, 1998). The ebbing and flooding of the tide did not show a strong correlation with the trends of zooplankton abundance and diversity, but it is possible that tidal fluctuations may exert some influences that were not detectable in this study. However, it has recently been documented (Hays *et al.*, 1996; Queiroga *et al.*, 1997; Osore *et al.*, Cap 8 this volume) that the orientation (ebb or flood) and phase (neap/spring) of the tide may be among the main contributory factors that influence diel displacement of some crab zoea as well as copepods.

CHAPTER 8

Zooplankton composition and abundance in Mida Creek, Malindi, Kenya

Results submitted as:

Osore, M. K. W., J. M. Mwaluma, F. Fiers & M. H. Daro (Submitted). Zooplankton composition and abundance in Mida Creek, Malindi, Kenya. *Zoological Studies*.

8.1 Summary

In order to establish the resident assemblages of zooplankton in Mida Creek, Kenya, a survey was conducted from May 1996 to April 1997 to study their seasonal composition, abundance and distribution. 27 major zooplankton taxa were identified. Order Copepoda was the most abundant taxon dominated mainly by genera *Acartia*, *Paracalanus*, *Labidocera*, *Temora*, *Centropages* and *Calanopia*. Other common zooplankton taxa were Medusae, Ctenophora, Brachyura larvae and Chaetognatha. The highest abundance (1,961 ± 540 to 2,856 ± 788 ind.m^{-3}) was recorded during the dry season from February to March while the lowest (77 ± 21 to 352 ± 98 ind.m^{-3}) was in the wet season from May to July.

Vertical migration and the tidal cycle were the main factors affecting variation in diel zooplankton abundance and diversity. However, monthly composition of the taxa varied only minimally.

8.2 Introduction

Mida Creek (03° 23' S, 39° 56' E) is unique because, unlike other creeks and bays along the Kenya coast, it has no river inflow. It is now evident that a substantial amount of fresh water inflow into the creek is via ground water seepage (Kitheka, 1998; Tack & Polk, 1999). From literature, coastal ecosystems similar to Mida with limited drainage canals and natural streams are documented to derive much freshwater input from groundwater flow (Valiela *et al.*, 1978, Bokuniewuicz, 1980; Johannes, 1980). However, information related to the phenomena of groundwater outflow, coastal water circulation and their linkages in the tropical marine ecosystems is only beginning to emerge (Bokuniewuicz, 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 & Hockey, 1997; Ouko & Manohar, 1998) in the adjacent Arabuko Sokoke Forest, which is itself sustained by ground water 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 done on the hydrology, mangroves and the general marine ecology of Mida Creek (e.g. Gang & Agatsiva, 1992; Messana *et al.*, 1993; Vezzosi *et al.*, 1995; Hockey *et al.*, 1995; Ruwa, 1996;

Dahdouh-Guebas *et al.*, 1998, 1999; 2000; 2002; Vaninni *et al.*, 1997, 2001; Kitheka, 1998; Kitheka *et al.*, 1999; Gherardi *et al.*, 1999; Kairo *et al.*, 2002), published information on zooplankton composition is completely lacking.

This chapter presents results on the seasonal composition and abundance of zooplankton in Mida Creek collected during one year of multidisciplinary research entitled: Mida Creek Biodiversity Research Project. The research was conducted in the framework of the Kenya Netherlands Wetlands Programme. The programme's overall objective was to collect information on the biodiversity of Kenya's wetlands with a view to assessing the natural and anthropogenic threats and impacts on them. Zooplankton is an essential component of the Mida Creek biodiversity since this group constitutes most crustaceans and larval stages of many larger marine animals.

Materials and methods are described in Cap. 3.2, 3.3.1, 3.4 and 3.5.

8.3 Study Area

Mida Creek is located 20 km southwest of Malindi town along the Kenya coast (Fig. 1) and occupies a total area of 32 km^2 including the mangrove cover. There is no river drainage into the creek and fresh water input comes mainly from ground water 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 at the centre (1,500 to 2,000 m) and narrow again further inland. Depth varies from 4 m in the shallow basin inland to 7 m at the centre 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, 3) and the water within the sheltered mangroves and the sand flats (Stn 4).

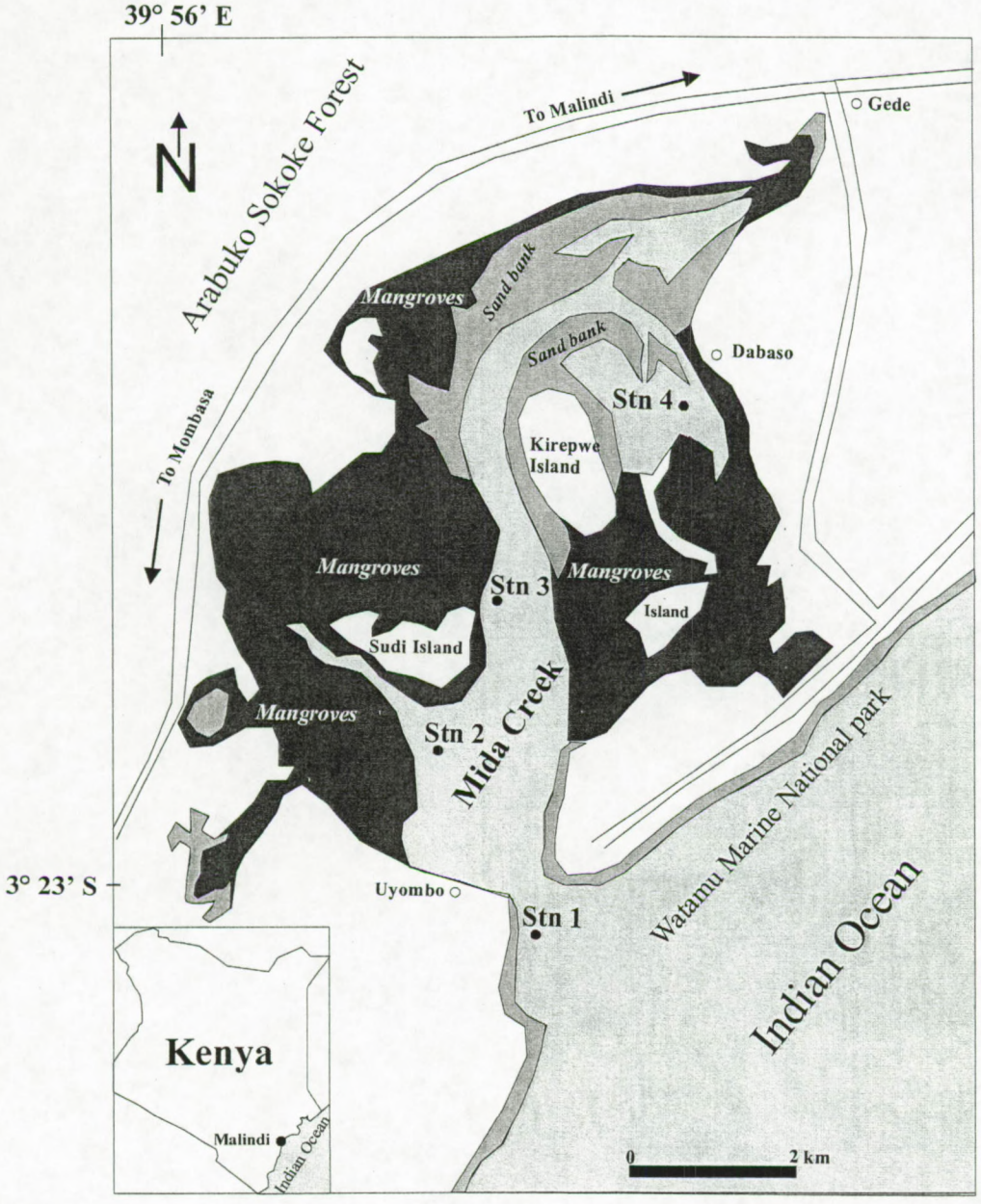


Fig. 8.1: Map of the study area showing location of the sampling Stns in Mida Creek, Malindi, Kenya.

8.4 Results

Rainfall, temperature and salinity

Monthly variations of total rainfall, surface water temperature and salinity recorded during the sampling period are shown in Figs. 8.2, 8.3 and 8.4 respectively. Each monthly temperature and salinity on the graph is the average reading for the four Stns. Total annual rainfall around Mida Creek area was 1,418 mm with most of it (76%) falling in April and May (Fig. 8.2). The highest rainfall recorded was 760 mm in May and there was minimum or no rain from December to March.

The lowest surface water temperature (24.4 - 26.9 °C) was recorded between July and October and the highest (28.6 - 30.9 °C) between November and March (Fig. 8.3).

Increasing salinity (Fig. 8.4) was recorded in December (35.2 psu), January (35.9 psu), February (37.0 psu) and peaked in March (37.4 psu). It reduced in April (34.2 psu) and May (32.9 psu). The lowest salinity was recorded in August (25.8 psu).

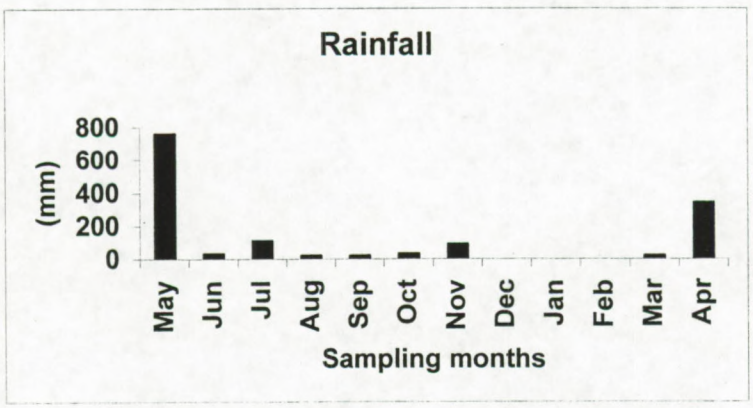


Fig. 8.2: Variation in total monthly rainfall recorded around Mida Creek.

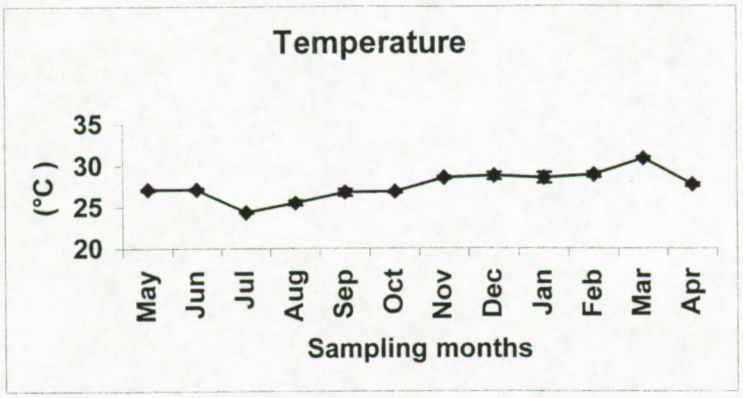


Fig. 8.3: Variation in average monthly surface water temperature in Mida Creek. (Error bars represent standard deviation).

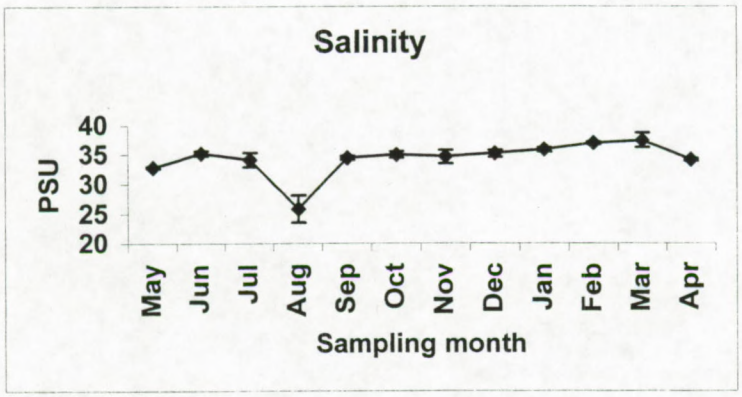


Fig. 8.4: Variation in average monthly salinity in Mida Creek. (Error bars represent standard deviation).

Zooplankton abundance

Variation in zooplankton collected monthly from each of the sampling Stns is shown in Fig. 8.5. The highest mean zooplankton abundance was collected in February (2,856 ± 788 ind.m^{-3}) and March (1,961 ± 540 ind.m^{-3}). Abundance was also appreciably high in January (851 ± 239 ind.m^{-3}), April (879 ± 242 ind.m^{-3}) and May (1029 ± 283 ind.m^{-3}). Abundance was minimum from June to December (between 77 ± 21 and 352 ± 98 ind.m^{-3}). Stn 3 always recorded the highest zooplankton abundance ranging from 108 ind.m^{-3} in June to 3,998 ind.m^{-3} in February. The rest of the Stns recorded comparatively lower monthly abundance as follows: Stn1 (62 to 2284 ind.m^{-3}) Stn 2 (65 to 2,398 ind.m^{-3}) and Stn 4 (74 to 2,741 ind.m^{-3}).

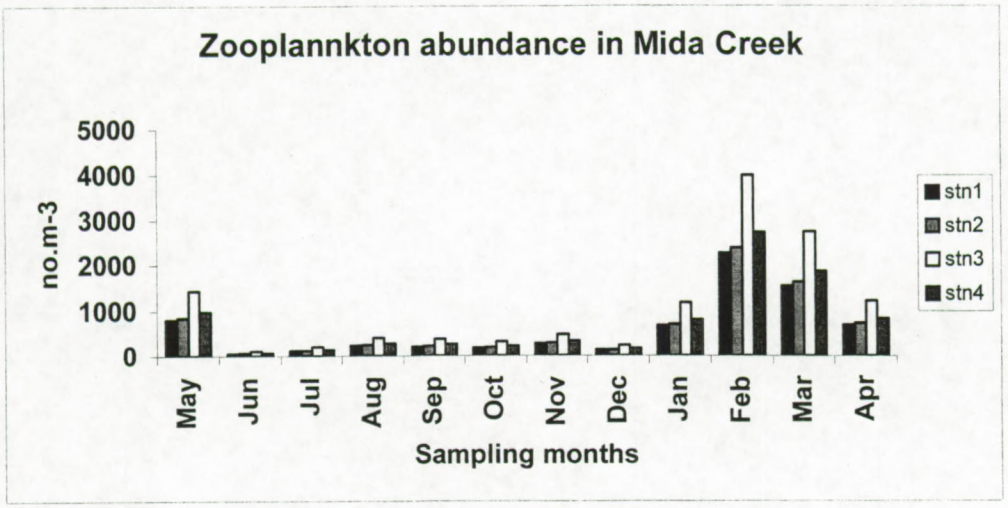


Fig. 8.5: Monthly variation of zooplankton abundance at the four sampling stns in Mida Creek.

Zooplankton composition and diversity

Table 8.1 shows zooplankton taxa encountered in Mida Creek and their relative abundance at the sampling Stns. Twenty-seven major zooplankton taxa were identified in this study. Copepoda consistently occurred at all Stns and was the most dominant taxon in terms of abundance and diversity. Other common taxa included Mollusca, Caridea, Brachyura zoea, Chaetognatha, Appendicularia and Pisces.

Table 8.1: List of major zooplankton taxa in Mida Creek and relative abundances at each Stn.

Taxa	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
Mysiidacea		x		
Cirripaedia			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^{-3})

xx - Abundant (between 100 and 500 ind.m^{-3})

xxx - Most Abundant (500 ind.m^{-3} and above)

Monthly variation of zooplankton diversity is averaged for the four sampling Stns and is shown in Fig. 8.6. Generally, diversity was highest in June (1.27 ± 0.12) and July (1.33 ± 0.15) and it was lowest in March (0.66 ± 0.02). However, individual Stns displayed diversity gradients such that zooplankton taxa at the mouth of the creek (Stn 1) were more diverse than in the main basin upstream (Stns 2, 3 and 4). Although Table 8.1 shows that most taxa were obtained at Stn 3 followed by Stn 4, Stn 2 and lastly Stn 1, the actual species richness within individual taxa (especially within Copepoda) was higher at Stn 1 in comparison with the rest of the Stns.

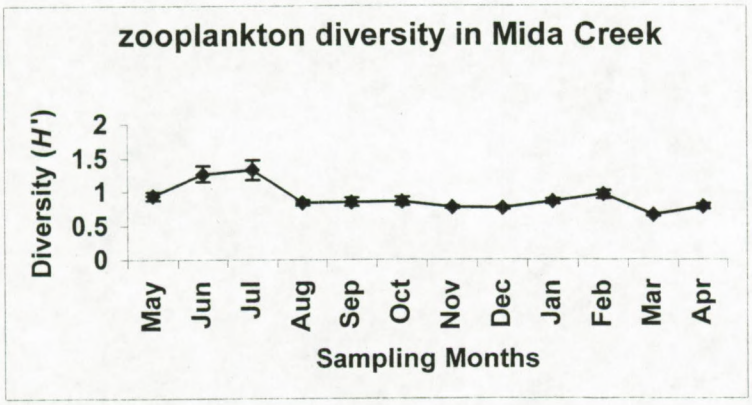


Fig.8.6: Variation in average monthly zooplankton diversity in Mida Creek (Error bars represent std deviation).

Zooplankton temporal distribution

Temporal distribution for zooplankton taxa that contributed relative abundance of more than 100 ind.m^{-3} is described below.

Foraminifera: Foraminifera were present throughout the year and peaked in February with a total abundance of 314 ind.m^{-3}. January also recorded a high abundance of 184 ind.m^{-3}. During the rest of the year, abundance was comparatively reduced (0 to 74 ind.m^{-3}). Foraminifera were represented mainly by *Globigerina* sp., encountered especially at Stns 1, 2 and 3.

Medusae: Medusae were found throughout the year except in June. The highest abundance of 242 ind.m^{-3} occurred in May during the rainy season. A smaller peak of 170 ind.m^{-3} occurred

in March during the dry spell. They were mostly encountered at Stns 3 and 4 and were absent at Stns 1 and 2.

Ctenophora: Ctenophores like Medusae were found at Stns 3 and 4. They occurred throughout the year, recording peak abundance of 296 ind.m^{-3} in September. *Pleurobranchia* was the main representative genus.

Mollusca: These occurred at all Stns throughout the year with peak total abundance of 1,530 ind.m^{-3} in February. During this period, the molluscs completely dominated zooplankton composition at Stn 3 (828 ind.m^{-3}). They were mainly 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 most dominant calanoids were *Acartia* sp., *Paracalanus* sp., *Centropages orsinii* Giesbrecht, 1889 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 peak abundance of 1,183 ind.m^{-3} at Stn 4 during the rainy season, whereas *Paracalanus* sp. peaked during the dry season (February) with abundance of 332 ind.m^{-3}. Other notable species of copepods that occurred seasonally in the creek were *Pseudodiaptomus* sp., *Eucalanus* sp. and *Tortanus gracilis* (Brady, 1883). *Pseudodiaptomus* sp. dominated at Stns 3 and 4. *T. gracilis* was also abundant here during the rainy season in May and April. *Eucalanus* sp. completely dominated copepod abundance at Stn 1 during the dry season in February.

Majority of the cyclopoids were *Oithona* sp. Poecilostomatoids constituted mainly of *Oncaea venusta* Philippi 1843 and *Corycaeus gibbulus* (Giesbrecht, 1891). Other members of this group such as *Sapphirina* sp., *Saphirella* sp., *Porcellidium* sp. and *Peltidium* sp. were found at all Stns in the creek though comparatively few. *Metis* sp., *Setella* sp. and other representatives of harpacticoids were mainly found distributed in the inner parts of the creek especially at Stns 3 and 4.

Caridea: Caridean larvae were found throughout the year with peak abundance in February when high counts were recorded at Stn 1 (463 ind.m^{-3}) and Stn 2 (420 ind.m^{-3}) as compared to

Stn 3 (70 ind.m^{-3}) and Stn 4 (55 ind.m^{-3}). 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 was 157 ind.m^{-3} in February. Hyperiids, gammarids and caprellids were the main representatives. They occurred more in the upper reaches (Stns 3 and 4) of the creek.

Sergestidae: Sergestiids were present throughout the year and experienced peak abundance in May (101 ind.m^{-3}) and April (122 ind.m^{-3}). Sergestiids were mainly composed of calyptopis larvae and adult lucifer. Other peak months were February (55 ind.m^{-3}) and March (67 ind.m^{-3}). Abundance reduced between June and January (down to 9 ind.m^{-3}). Sergestiids were commonly encountered at Stns 3 and 4.

Brachyura larvae: Brachyura larvae was the second most abundant taxon in Mida Creek after Copepoda. They occurred throughout the year and recorded peak abundance of 2,335 ind.m^{-3} at Stn 3 during the dry season in March. On many occasions, they were abundant in the upper reaches of the creek (Stns 3 and 4). However in February, high abundance of 724 ind.m^{-3} was observed at Stn 1 compared to 202 ind.m^{-3} at Stn 2 and 685 ind.m^{-3} at Stn 4. Larvae of portunids, porcellanids and grapsiid crabs were the main representatives of Brachyura.

Chaetognatha: Chaetognaths were found throughout the year with peak total abundance of 301 ind.m^{-3} in February. Another observable peak was in May (84 ind.m^{-3}) during the rainy season. Chaetognaths were abundant at Stn 1(222 ind.m^{-3}) and also at Stns 3 and 4.

Appendicularia: Appendicularia occurred throughout the year with peak abundance of 123 ind.m^{-3} in December. *Oikopleura*, *Fritillaria* and larvae of tunicates were the main representatives. Appendicularia mainly occurred at Stns 2, 3 and 4.

Pisces: This taxon comprised of fish eggs and fish larvae. They occurred throughout the year and had a peak total abundance of 283 ind.m^{-3} in February. This peak was caused by high numbers of fish eggs at Stn 1 that amounted to 167 ind.m^{-3} compared to 7 ind.m^{-3} of fish larvae. Another peak was observed in January (234 ind.m^{-3}) and again this was due to the dominance of fish eggs that amounted to 122 ind.m^{-3} as compared to 1 ind.m^{-3} of fish larvae at

the same Stn. Fish larvae on the other hand were comparatively abundant (56 ind.m^{-3}) at Stn 3 as compared to the other Stns, which recorded between 3 and 7 ind.m^{-3}. 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 seagrass zones.

Zooplankton diel cycles

Zooplankton samples were collected over three different twenty-four hours (24 hr) periods during July, October and January in order to study diel zooplankton variation in abundance and diversity. Samples were collected off Sudi Island (Stn 3) at intervals of 2 hours. Temperature, salinity and tidal height were recorded con-currently during each zooplankton sample haul in order to relate their variations with zooplankton abundance and diversity.

17-18/7/96: Diel variations in zooplankton abundance and diversity, tidal height, temperature and salinity are shown in Figs 8.7 a, b and c respectively. Sampling at Stn 3 was conducted during 24 hr (from 17 to 18 July 1996). This period of sampling coincided with spring tide and new moon. Fig. 8.7a shows that zooplankton abundance increased steadily with nightfall from 1800 hr (173 ind.m^{-3}) and attained peak abundance at 0200 hr (3,782 ind.m^{-3}). This peak coincided with the flooding phase just after low tide (Fig. 8.7 b). Abundance declined slightly at 0400 hr (2,391 ind.m^{-3}) and sharply thereafter (<587 ind.m^{-3}). The next daytime low tide occurred at 1400 hr coinciding with minimum (<266 ind.m^{-3}) zooplankton abundance (Fig. 8.7 a). Temperature varied minimally (24.30-25.50°C) in rhythm with the diurnal air temperature. Salinity was quite constant (35.2-35.7 psu) except at 1400 hr (34.4 psu), see Fig 8.7c. Zooplankton abundance at night was almost four times higher compared to daytime. This may be attributed to vertical migration of zooplankton to the surface water at night.

Spearman correlation analyses returned insignificant negative relationship between zooplankton abundance and tidal height (r_s = - 0.15; df = 11; P = 0.3). This suggested that there was no bulk lateral importation of zooplankton into Stn 3 by the incoming tide. However, there was 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. 8.7 a, b).

24 hr Sampling Spring Tide 17 – 18/7/96

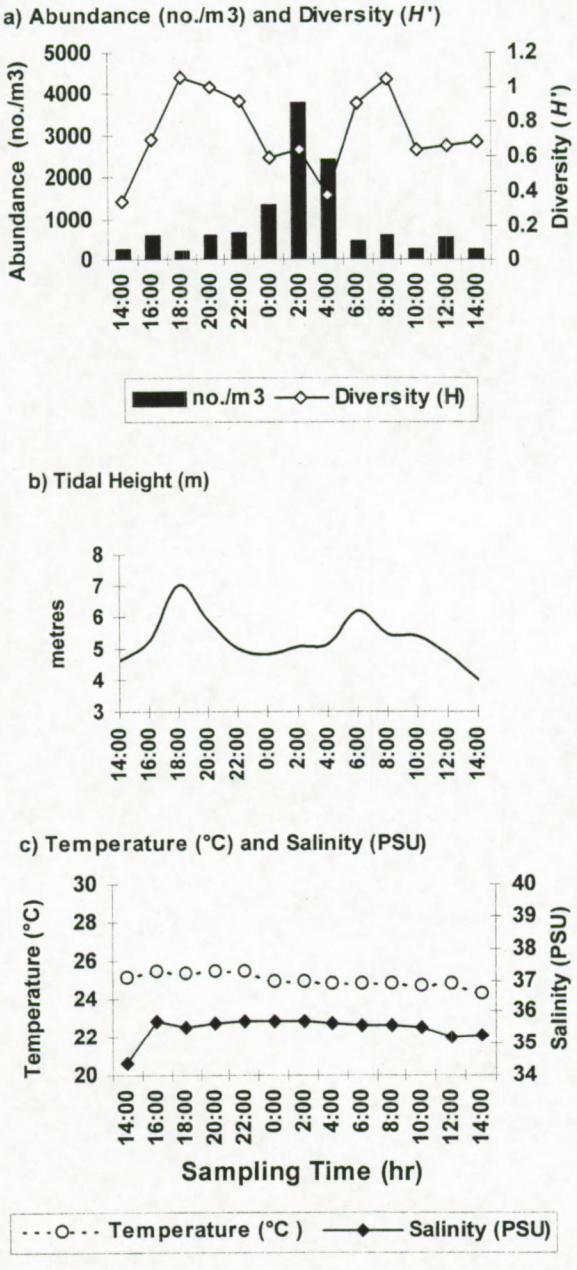


Fig. 8.7: Diel variation in **a**) zooplankton abundance and diversity, **b**) tidal height and **c**) temperature and salinity at Stn 3 Mida Creek during 24 hr sampling from 17 to 18 July 1996.

Dominant zooplankton taxa identified during this period were the copepods *Acartia* sp. *Paracalanus* sp., *Pseudodiaptomus* sp., *Oithona* sp. and *Temora turbinata* Dana, 1849. Other common zooplankton were Caridea, Brachyura larvae, Chaetognatha, Medusae, Ctenophora, and Formainifera. These taxa peaked at different times over the 24 hours. The most

dominant was the copepod *Acartia* sp., which constituted between 29 and 77% of total zooplankton abundance during the 24 hr cycle. *Acartia* sp. was dominant at 1800 hr, 2200 hr, 2400 hr, 0200 hr, 0400 hr (peak abundance of 77% of total zooplankton), 1000 hr, 1200 hr and 1400 hr. The other important copepods that dominated were *Oithona* sp. at 1700 hr (66% of total zooplankton), 0600 hr (50%) and 0800 hr (38%).

28-29/10/96: Figs 8.8 a, b and c show diel variations in zooplankton abundance and diversity, tidal height and temperature and salinity respectively during the 24 hr sampling conducted at Stn 3 (from 28 to 29 October 1996). This sampling period coincided with spring tide and full moon. Fig. 8.8 a shows that zooplankton abundance displayed peaks at 1400 hr (2,000 ind.m^{-3}, 3,582 ind.m^{-3}) and at 0600 hr (1,846 ind.m^{-3}). The lowest abundance was at 1600 hr (351 ind.m^{-3}) when the tide was flooding in (Fig. 8.8 b). During low tide at night between 2200 hr and 0600 hr zooplankton increased albeit slightly (ranging from 593 to 1,846 ind.m^{-3}). From 0800 hr to 1200 hr during high tide, abundance reduced (between 615 and 484 ind.m^{-3}). Abundance at night was almost 1.4 times more than during the day.

Zooplankton abundance and tidal height correlated negatively (r_s = -0.43; df = 11; P = 0.5) but insignificantly. Tidal height and zooplankton diversity also showed insignificant negative correlation (r_s = -0.14; df = 11; P = 0.3) see Fig. 8.8 a, b.

The lowest temperature (26.36 - 26.76 °C) was recorded between 0200 hr and 0800 hr. It was higher (27.33 - 28.98 °C) the rest of the period (Fig. 8.8 c). Salinity sharply increase at 00 hr (35.8 psu) and 0200 hr (36.8 psu), the rest of the period it was stable at 34.9 psu.

The most dominant taxa on this occasion were the copepods *Temora turbinata*, *Pseudodiaptomus* sp., *Acartia* sp. and *Oncaea venusta*. Other zooplankton were Gastropoda larvae, Caridea, Foraminifera, fish eggs and Medusae. Brachyura larvae were dominant at 1400 hr attaining 72 to 95% of total zooplankton abundance. *T. turbinata* dominated in samples of the early morning hours at 0400 hr (50%), 0600 hr (86%), 0800 hr (36%); and early evening at 1800 hr (62%). Gastropoda larvae, were abundant during the daytime at 1600 hr (37%), 1000 hr (57%) and 1200 hr (66%).

24 hr Sampling Spring Tide 28-29/10/96

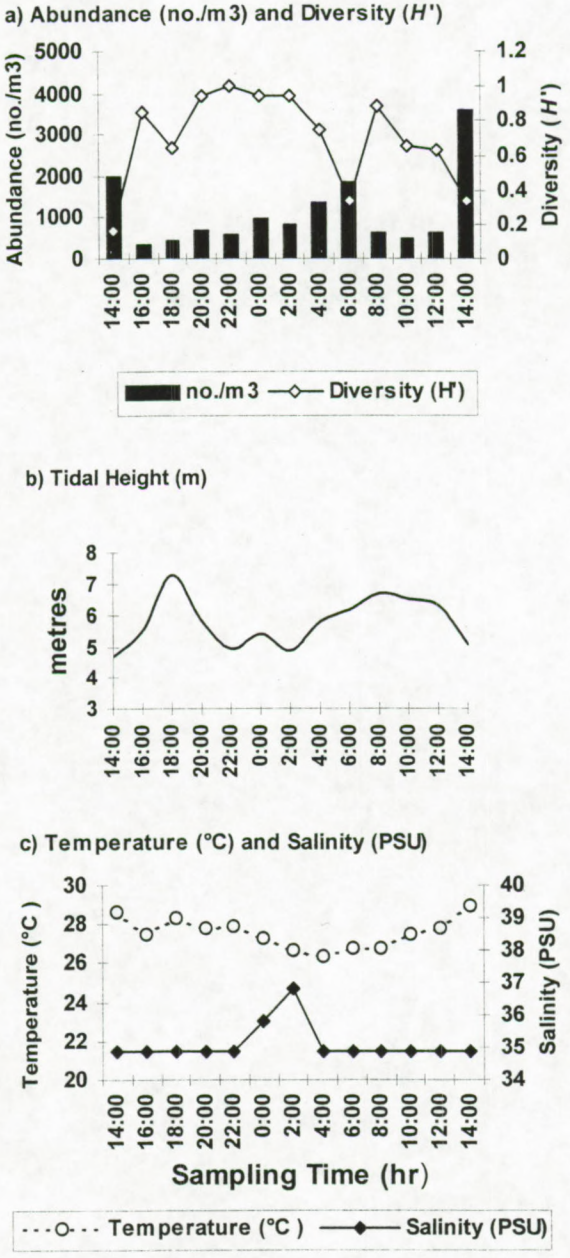


Fig. 8.8: Diel variation in **a**) zooplankton abundance and diversity, **b**) tidal height and **c**) temperature and salinity at Stn 3 Mida Creek during 24 hr sampling from 28 to 29 October 1996.

28-29/1/97: Diel variations in zooplankton abundance and diversity, tidal height, temperature and salinity during the 24 hr sampling from 28 to 29 January 1997 are shown in Figs 8.9 a, b, c respectively. Time of sampling at Stn3 coincided with neap tide and full moon. Fig. 8.9 a shows that similar to the other two 24 hr sampling sessions, zooplankton abundance peaked only at low tide. The peak at night was during flood phase (Fig. 8.9 b) at 0300 hr (4,025 ind.m^{-3}) and 0500 hr (3,675 ind.m^{-3}) and daytime peak was during ebbing at 1300 hr (2,475 ind.m^{-3}) and 1500 hr (1,450 ind.m^{-3}). Low abundance was recorded at high tide from 1900 hr to 2100 hr (450 to 500 ind.m^{-3}) and also during the flood phase of the next high tide from 0700 hr to 1100 hr (100 to 300 ind.m^{-3}). The abundance at night was about twice as high as during the day.

Zooplankton abundance showed significant negative correlation with the tidal height (r_s = -0.73; df = 10; P = 0.005), whereas diversity correlated positively and significantly (r_s = 0.72; df = 10; P = 0.004) with the tidal height (Fig. 8.9 a, b).

Fig. 8.9 c shows that salinity was higher between 1700 hr (37.93 psu) and 0500 hr (38.3 psu) and lower thereafter (ranging between 36.6 and 37.7 psu). Temperature reduced gradually after 1700 hr (28.68 °C) and reached a minimum at 0300 hr (26.57 °C) then increased 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 taxa were copepods *Acartia* sp. *Oithona* sp. *Tortanus* sp., *Pseudodiaptomus* sp. and *Labidocera acuta* (Dana, 1849).

Brachuyra larvae were dominant at 1700 hr (75%), 2300 hr (37%), 0700 hr (26%), 0900 hr (41%), 1100 hr (42%) and 1500 hr (37%). *Acartia* sp. dominated at 0100 hr (31%), 0300 hr (19%), 0500 hr (70%) and at 1300 hr (38%). Chaetognatha and *Oithona* sp. were only dominant at 1900 hr (20%) and 2100 hr (53%). *Acartia* sp. was dominant during peak zooplankton abundance that occurred between 0300 hr and 0500 hr.

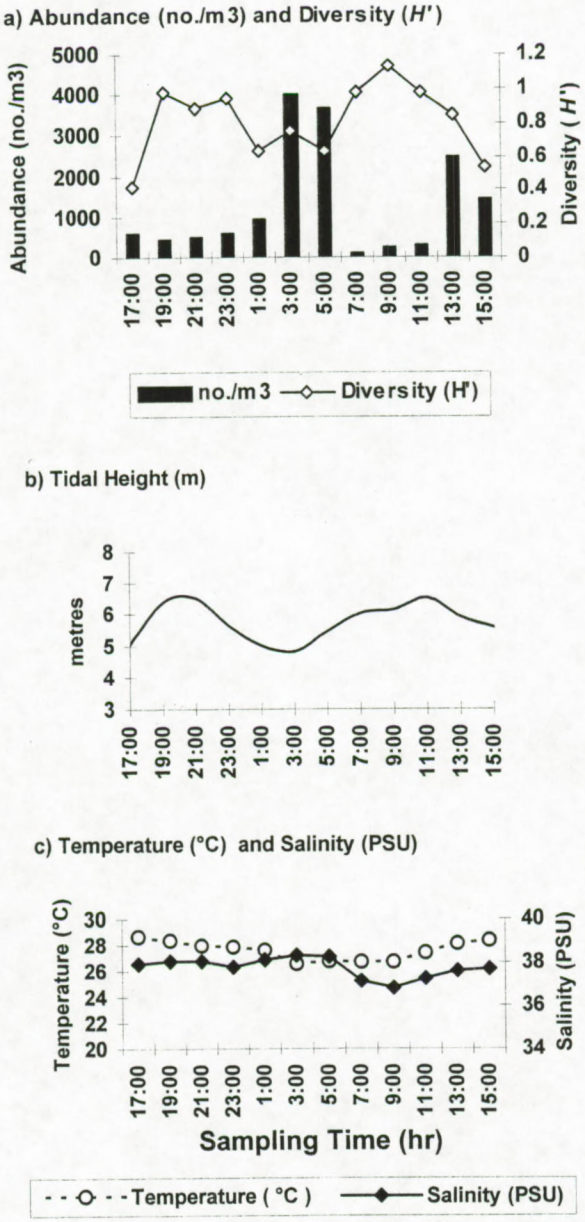


Fig. 8.9: Diel variation in **a**) zooplankton abundance and diversity, **b**) tidal height and **c**) temperature and salinity at Stn 3 Mida Creek during 24 hr sampling from 28 to 29 January 1997.

8.5 Discussion

Related zooplankton data in this region that would be most appropriate to compare with the present results are largely unavailable. Nevertheless, the present results indicate that Mida Creek is rich in zooplankton and has at least 27 major taxa. The present study has shown that the zooplankton composition is almost similar to what has been reported in the 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 seasonality that was somewhat different from that observed in Tudor Creek and Gazi Bay. This is probably because Mida Creek does not experience any direct river influence as compared to the others 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 fresh water discharge from rivers. This happens during the wet season or immediately thereafter and it is often accompanied by peak zooplankton abundance.

In Mida Creek on the other hand, the highest zooplankton abundance occurred during the dry season in January, February and March. Mean peak abundance of 2,856 ± 786 ind.m^{-3} was recorded in February. During the rainy season in May, the abundance substantially reduced to 1,029 ± 283 ind.m^{-3}, and thereafter in June to the lowest abundance (77 ± 21 ind.m^{-3}). In Tudor Creek, Reay & Kimaro (1984) and Okemwa (1990) reported increase of zooplankton in the rainy season owing to high amounts of nutrients washed into the creek, which in turn ameliorate 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) and the lowest was at the mouth of the creek (Stns 1 and 2) adjacent to the open ocean.

During the rainy season in April and May, the decline in salinity in most parts of the creek was only minimum since there are no drainage rivers. It declined from about 37.4 psu in March to about 34.2 psu in April and 32.9 in May. However, underground seepage and input from surface runoff (Kitheka pers. comm.), which occurred in the inner parts of the creek (Stns 3 and 4), caused a substantial drop in bottom water salinity (25.8 ± 2.3 psu) at these

Stns. This change in salinity occasionally altered zooplankton composition, introducing estuarine species like *Acartia* sp. and *Pseudodiaptomus* sp. However, this was a rare occurrence. Therefore, absence of river input in Mida Creek has caused a somewhat steady zooplankton population that is more or less present throughout the year.

Major zooplankton taxa recorded abundantly throughout the year included Copepoda, Medusae, Ctenophora, Brachyura larvae and Chaetognatha. Dominant Copepoda were *Acartia* sp., *Paracalanus* sp., *Temora turbinata*, *Centropages orsinii* Giesbrecht, 1889, *Labidocera* sp. and *Calanopia thompsonii* A. Scott, 1909.

Some zooplankton taxa were observed to occur at particular sampling Stns. 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 high abundance of Brachyura larvae was recorded at Stn 1. Fish larvae were predominantly found at Stns 2, 3 and 4. Chaetognaths, which mostly feed on copepods, were evenly distributed in the creek and mostly found in areas of high copepod abundance. Amphipods were abundant at Stns 3 and 4, these were areas predominantly occupied by seagrass and mangroves.

In general, almost all zooplankton taxa attained peak abundance in February. Pisces was no exception (Mwatha *et al.*, 1998), fish eggs were most abundant at the mouth of Mida Creek (Stn 1) during January and February in the dry season. Kimaro (1986) and Okemwa (1990) reported similar observations in Tudor Creek, and Osore (1994) in Gazi Bay. Kimaro (1986) recorded high abundance of fish eggs and larvae at the mouth of Tudor Creek between November and January, while Okemwa (1990) reported high abundance at the creek mouth although it was during the rainy season (March to June). Osore (1994) reported fish eggs abundance of up to 90 ind.m^{-3} at the mouth of Gazi Bay during the rainy season, and only 7 ind.m^{-3} within the mangrove zone upstream.

Increased zooplankton diversity in June (1.29 ± 0.12) and July (1.33 ± 0.15) was accompanied with low abundance (77 ± 21 and 154 ± 42 ind.m^{-3} respectively). During this period no particular zooplankton taxa was dominant. In February, diversity was low (0.9 ± 0.6) possibly

due to high abundance of zooplankton dominated by *Eucalanus* sp., Brachyura larvae and fish eggs.

Mean zooplankton diversity among the sampling stations was highest at the oceanic Stn 1 ($H' = 1.15 \pm 0.11$) and reduced gradually (down to $H' = 0.8 \pm 0.5$) towards Stns 3 and 4 located in the inner parts of the creek. This observation of zooplankton diversity gradient in bays and creeks is well documented and it is not new in the coast of 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 showed that the catches at night were always higher than those at daytime. Ratios of night to day abundance were 1.98 (January), 3.78 (July) and 1.39 (October). 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 low, whereas at low tide the situation was the reverse. The influence was more pronounced during neap tide full moon than during either spring tide full moon or spring tide new moon.

Although vertical migration within the creek itself is limited due to minimal depth, the phenomenon is unhindered in the deeper oceanic water beyond Stn 1. Therefore, it is possible that the incoming tide imports zooplankton horizontally into the creek.

During the 24 hr sampling, gelatinous zooplankton like (jellyfish) ctenophores 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. The 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, the intertidal pools which are permanently surrounded by sand banks at Stns 3 and 4 retain gelatinous zooplankton thus making these taxa typical of those Stns.

The 24 hr sampling partly 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 by zooplankton to counteract fish predation (Masson *et el.*, 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 possibly few other taxa may have been trans-located horizontally by the tide towards Stn 3.

PART IV

Family Candaciidae (Calanoida, Copepoda): General distribution and morphology

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Introduction

This part consists of two chapters and deals exclusively with the calanoid genera *Candacia* Dana, 1846 and *Paracandacia* Grice, 1963; which belong to the family Candaciidae Giesbrecht, 1892. This group was selected because it is widely distributed in the Indian Ocean as well as in the other oceans and seas worldwide. Therefore information emanating from research on this group has the potential of application on wide geographical scales.

Chapter 9 deals with the distribution and abundance of the different species of this group off the Kenya coast. In Chapter 9, we also document the status of the current knowledge on this family especially in the Indian Ocean and we provide new distribution records for the Kenya coast.

In Chapter 10 we present results of morphological research conducted on individuals of the family Candaciidae. The results were obtained by examining the fine structure (ultrastructure) on the tegument of members of this group. We document some previously undetected microcharacters and explore their possible usefulness in taxonomy.

CHAPTER 9

Candacia Dana, 1846 and *Paracandacia* Grice, 1963 (Copepoda, Calanoida, Candaciidae): Distribution and abundance off the Kenya coast

Results to be published as:

Osore, M. K. W., F. Fiers & M. H. Daro (In Preparation). *Candacia* Dana, 1846 and *Paracandacia* Grice, 1963 (Copepoda, Calanoida, Candaciidae): Distribution and abundance off the Kenya coast.

9.1 Summary

This chapter presents the distribution and abundance of copepods belonging to the genera *Candacia* and *Paracandacia* (family Candaciidae) within the inshore, shelf and offshore waters of the Kenya coast. Results indicate that Candaciidae are more abundant during the SE monsoon period and less in the NE monsoon. They are widely distributed off the Kenya coast in the following pattern: abundance is less (9 to 240 ind./100m^3) within the inshore waters. It increases to maximum within the shelf waters (40 to 360 ind./100m^3) and decreases again to minimum (10 to 40 ind./100m^3) in the open ocean. Abundance also decreases with increasing depth from a maximum of 880 ind./100m^3 at the surface to a minimum of 10 ind./100m^3 in the deep layers. Candaciidae are least abundant at the depth range of 400 to 800 m, which also coincides with the depth of minimum oxygen concentration.

Candacia bradyi A. Scott, 1902; *C. bipinnata* Giesbrecht, 1889; *C. curta* (Dana, 1849); *C. tuberculata* Wolfenden, 1905 and *C. ethiopica* (Dana, 1849) are reported as new records for the Kenya coast. Based on new information and previous studies off the Kenya coast, this study attempts to describe the distribution pattern of Candaciidae in this region.

9.2 Introduction

The family Candaciidae Giesbrecht, 1892 is one of the most widely distributed copepod groups in the Indian Ocean. It comprises two genera of carnivorous copepods, namely *Candacia* Dana, 1846 and *Paracandacia* Grice, 1963. The current systematics of Candaciidae has remained stable since the revision by Grice (1963) and was recently further reinforced thanks to results from the study of character phylogenies in this group by von Vaupel Klein & Gassmann (1998). There are currently 31 species ascribed to genus *Candacia* and 4 to *Paracandacia* (Mauchline, 1998). However, information from literature including unpublished reports estimates that the total number of species and subspecies of these genera worldwide may rise to about 80. Apart from the Indian Ocean where they are most common, Candaciidae are also found in the Atlantic and Pacific. They are also represented in restricted localities such as the Mediterranean Sea, Red Sea, Antarctic, etc where some of the species are considered as endemic.

Grice & Hulsemann (1967), Lawson (1977) and Rao (1973, 1979) compiled much of the known information about Candaciidae and its zoogeography in the Indian Ocean. The information was primarily based on the samples collected during the International Indian Ocean Expedition (IIOE 1960-1965) and the various atlases, handbooks and other publications compiled thereafter (IOBC, 1968; Stephen et al., 1992; Desai, 1992). Since IIOE, there have also been a number of other expeditions in the western Indian Ocean organized by the former Soviet Union (with documentation mainly in Russian and therefore previously inaccessible) whose results obtained between 1973 and 1990 are just emerging (Darwin Initiative for Survival of Species; Mishonov & Williams, 1998). During the past decade, there has been concerted effort in oceanographic research in the Indian Ocean by the regional leaders in oceanography i.e. India, Pakistan, South Africa and Australia mainly in collaboration with internationally renown counterparts such as France, Germany, Japan, the Netherlands, United Kingdom and the USA notably in the framework of the World Ocean Circulation Experiment (WOCE) and the Joint Global Ocean Flux Study (JGOFS). Unfortunately, most of these initiatives and sampling cruises did not extend their transects further inshore to sample coastal waters along the East African shoreline. This was only achieved during the Netherlands Indian Ocean Programme (NIOP 1992/95) TYRO Expedition to the western Indian Ocean when both the inshore and offshore waters of Kenya, including the Exclusive Economic Zone, were sampled.

Earlier, from 1985 to 1997 Kenya participated in long-term bilateral initiatives on zooplankton sampling in the creeks and bays along the coast. Two important initiatives during that period were between the Governments of Belgium and Kenya on the one hand (Kenya Belgium Project in Marine Science, KBP 1985-1995) and the Governments of the Netherlands and Kenya on the other hand (Kenya Netherlands Wetland Project for Conservation of Biodiversity, KNWP 1996-97).

The study by Lawson (1977) is widely believed to be the most thorough IIOE-based species level work on *Candacia* and *Paracandacia* in the Indian Ocean. The study described and distinguished the niches of these copepods and proposed possible evolutionary explanations. Because they have morphological and size similarity, these copepods are potentially strong competitors, so they occupy different niches.

Specimens used for the present study of the distribution of Candaciidae were obtained from zooplankton sampled during the two NIOP cruises off the Kenya coast as well as samples collected in the framework of the KBP and the KNWP mentioned above.

The objective of this study was to identify the common Candaciidae of the inshore, neritic and oceanic waters of Kenya and describe their distribution.

Material and methods are described in Cap 3.2.1, 3.3.1, 3.3.2 and 3.4

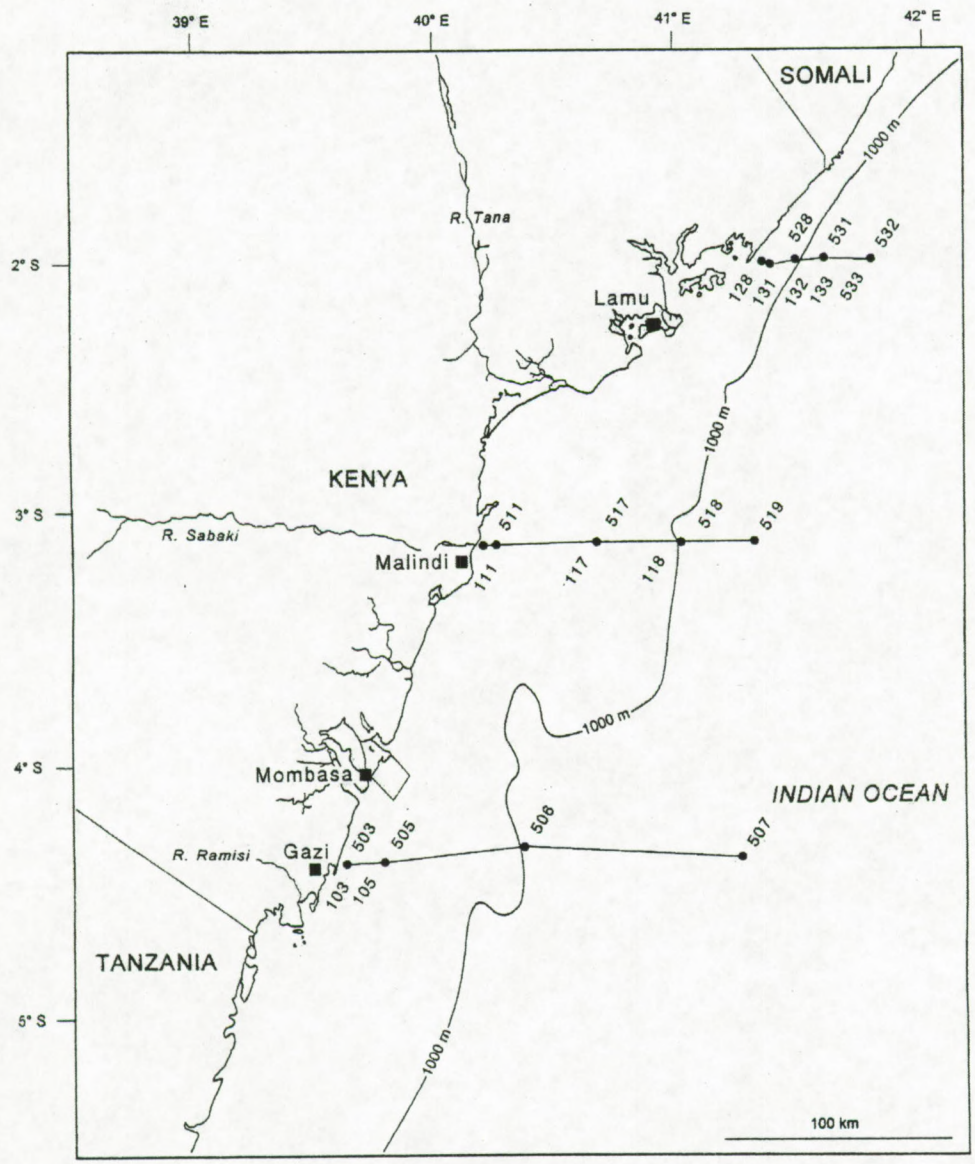


Fig. 9.1: Transects and sampling stations from where Candaciidae specimens were obtained.

9.3 Study area

Fig. 9.1 shows the location of transects and the sampling stations from where specimens of Candaciidae were obtained during the TYRO expedition (NIOP 1992/95). Other sampling locations along the Kenya coast from where further specimens were obtained during the other projects (KBP, KNWP) are indicated in Fig. 3.1.

9.4 Results

Based on our taxonomic literature search, the most cited Candaciidae worldwide that we encountered are *C. pachydactyla* and *C. bipinnata* followed by *C. bradyi*, *C. curta* and *C. longimana* in that order (Table 9.1). Results obtained from identifying and counting Candaciidae in our samples indicated that these species are also commonly encountered off the Kenya coast and, according to Lawson (1977) they are also common in the western Indian Ocean.

Table 9.1: The most commonly cited species of *Candacia* and *Paracandacia* in the taxonomic literature (cited from various literature in the reference list).

> 40 citations	31-40 citations	21-30 citations	11-20 citations
C. pachydactyla	*C. bradyi*	*C. catula*	*C. varicans*
C. bipinnata	*C. curta*	*C. armata*	*C. elongata*
	C. longimana	*C. norvegica*	*C. tenuimana*
			C. ethiopica
			C. cheirura
			C. columbiae
			P. bispinosa
			P. simplex

Since the revision of the family Candaciidae by Grice (1963), several new species have been described and are currently accepted e.g. *C. grandis*, *C. caribbeanensis*, *C. giesbrechti*, *C. guinensis*, *P. worthingtoni*, etc. (Table 9.2). Still many more have been mentioned in literature including unpublished reports, thesis etc which require confirmation. With the exception of *C.*

guinensis, *P. truncata* and *P. worthingtoni* whose males are yet to be discovered and described, both sexes of the rest of the commonly cited Candaciidae listed in Table 9.2 have now been identified and described.

Table 9.2: Some *Candacia* and *Paracandacia* and their common synonyms.

Species	Synonym	References
C. armata (Boeck, 1873)	*C. pectinata* Brady, 1878	1, 2
C. bipinnata Giesbrecht, 1889		
C. bradyi A Scott, 1902		
C. caribbeanensis Park, 1974		
C. catula (Giesbrecht, 1889)		
C. cheirura Cleve, 1904	*C. chirura* Cleve, 1905	6
C. columbiae Campbell, 1929	*C. pacifica* Mori, 1937	2b,
C. curta (Dana, 1849)	*C. bicornuta* Mori, 1932	4
C. discaudata A. Scott, 1909		
C. elongata (Boeck, 1873)	*C. inermis* Cleve, 1904	2, 4
C. ethiopica (Dana, 1849)	*C. melonopus* Claus, 1963	4
	C. aethiopica (Dana, 1849)	5
C. falcifera Faran, 1929		
C. giesbrechti Grice & Lawson, 1977		
C. grandis Tanaka, 1964		
C. guggenheimi Grice & Jones, 1960		
C. guinensis Chahsavar-Archad & Razouls, 1983♀		
C. ketchumi Grice, 1961		
C. longimana (Claus, 1863)		
C. magna Sewell, 1932		
C. maxima Vervoort, 1957		
C. nigrocincta (Thompson, 1888)		
C. norvegica (Boeck, 1865)		
C. pachydactyla (Dana, 1849)		
C. paenelongimana Fleminger & Bowman, 1956		
C. parafalcifera Brodsky, 1950		
C. pofi Grice & Jones, 1960		
C. rotunda Wolfenden, 1904		
C. samassae Pesta, 1941		
C. tenuimana (Giesbrecht, 1889)	*C. gracilimana* Faran, 1908	2, 4
C. tuberculata Wolfenden, 1905	*C. curva* Mori, 1932	7
C. varicans (Giesbrecht, 1892)		
P. bispinosa (Claus, 1863)	*C. bispinosa* Claus, 1863	4
P. simplex (Giesbrecht, 1889)	*C. simplex* (Giesbrecht, 1889)	3
P. truncata (Dana, 1849)♀	*C. truncata* (Dana, 1849)	2b
	C. *turgida* Wilson, 1950	2b
P. worthingtoni Grice, 1981♀		

1= Hure & Krsinic, 1998; 2 = Grice, 1962, 2b = Grice, 1963; 3= Brodsky, 1962; 4 = Vervoort, 1965; 5= Sazhina, 1982; 6= Fleminger & Bowman, 1956; 7 = Mori, 1964.

Occurrence of Candaciidae off the Kenya coast

Inshore and nearshore distribution

Table 9.3 shows the densities of Candaciidae that were recorded at the various inshore sampling locations during the different months.

Table 9.3: Maximum abundance (ind.m^{-3}) of Candaciidae obtained in monthly zooplankton samples collected from various localities (creeks, bays, lagoons) comprising the inshore waters of the Kenya coast.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
GB	0	0	0.51	0	0.48	0.54	0	0	0	0	0	0
DL	0	0	0.24	0.8	0.2	0.4	0	0.8	0	0	0.92	0
MkC	0	0	0	0.63	0	0	0	0	0.52	0	0	0.67
TC	0.43	0	0.18	0	0	0	0	0.21	0	0	0	0
MML	1.9	0	nd	nd	3.0	0.5	0.5	0.43	0.32	0.90	0	2.11
MtC	0	0.22	0	0	0	0	0.21	0	0.19	0	0	0
KlC	0.11	.09	0	0	0	0	0	0	0	0.20	0.1	0
MdC	0.3	2.4	0	0.3	0	0	0.24	0.23	0	0	0	0

GB= Gazi Bay, DL= Diani Lagoon, MkC=Makupa Creek, TC=Tudor Creek, MML = Mombasa Marine Park Lagoon, MtC=Mtwapa Creek, KlC=Kilifi Creek, MdC= Mida Creek, 0 = no Candaciidae, nd = No Data sampled.

In the inshore waters of Kenya including creeks, bays and lagoons, our results indicated that where Candaciidae were present, their monthly abundance ranged from 0.09 to 2.40 ind.m^{-3} (i.e. 9 to 240 ind./100m^3), see Table 9.3. Inshore water in sheltered systems such as creeks and bays recorded somewhat a lower abundance range (0.09-2.40 ind.m^{-3}) in comparison to the lagoon systems adjacent to the open ocean (0.20-2.11 ind.m^{-3}).

There was no apparent seasonality of abundance detected for Candaciidae in the creeks, bays and lagoons sampled. The common species encountered in the creeks and bays were *C. catula*, *C. magna* and *C. tuberculata*. However, few individuals of other species like *C. bipinnata*, *C. bradyi*, *C. discaudata*, *C. tenuimana* and *C. varicans* were found in Mombasa Marine Park lagoon (MML) and Diani lagoon (DL). Occasionally, *P. truncata* was also observed in samples obtained from these lagoons.

Off shore distribution

Tables 9.4a and b show the abundance and distribution of Candaciidae in both the surface and the deep-water strata off the Kenya coast during the SE and NE Monsoon period of 1992.

Table 9.4 a: Abundance of Candaciidae in the various depth strata along the Kenya coast during the SE Monsoon June/July 1992.

SE Monsoon (Jun/Jul 1992)

Transect	Stn	Position	Depth (m)	Depth interval (m)	Ind./100m^3
GAZI	Gazi (103)	4° 26" S, 39° 33" E	50	0-45	40
	Gazi (105)	4° 17" S, 41° 48" E	500	0-50	360
				50-150	120
				150-250	40
				250-450	560
SABAKI	Sabaki (111)	3° 09" S, 40° 13" E	50	0-40	58
	Sabaki (117)	3° 09" S, 40° 42" E	500	0-100	208
				100-200	32
				200-300	0
				300-450	26
	Sabaki (118)	3° 08" S, 41° 00" E	1000	0-200	31
				200-400	0
				400-600	66
				600-800	7
KIWAYU	Kiwayu (128)	2° 04" S, 41° 17" E	50	0-45	60
	Kiwayu (131)	2° 00" S, 41° 27" E	500	0-100	880
				100-200	80
				200-300	20
				300-425	20
	Kiwayu (132)	1° 56" S, 41° 37" E	1000	0-200	200
				200-400	5
				400-600	0
				600-800	3
	Kiwayu (133)	2° 00" S, 41° 48" E	2000	0-200	40
				200-400	0
				400-600	4
				600-800	4

Table 9.4 b: Abundance of Candaciidae in the various depth strata along the Kenya coast during the NE Monsoon November/December 1992.

NE Monsoon (Nov/Dec 1992)

Transect	Stn	Position	Depth (m)	Depth interval (m)	ind./100m^3
GAZI	Gazi (503)	3° 09" S, 40° 14" E	50	0-40	130
	Gazi (505)	4° 24" S, 39° 45" E	500	0-136	80
				136-300	40
				300-450	0
	Gazi (506)	4° 19" S, 40° 21" E	1000	0-200	40
				200-400	30
				400-600	10
	Gazi (507)	4° 21" S, 41° 12" E	2000	0-400	10
				400-800	0
				800-1000	20
SABAKI	Sabaki (511)	2° 05" S, 41° 18" E	50	0-45	260
	Sabaki (517)	3° 09" S, 40° 41" E	500	0-200	50
				200-300	0
				300-450	14
	Sabaki (518)	3° 08" S, 40° 59" E	1000	0-200	20
				200-400	40
				400-800	22
	Sabaki (519)	3° 09" S, 41° 16" E	2000	0-400	40
				400-800	13
				800-1000	0
KIWAYU	Kiwayu (528)	2° 05" S, 41° 18" E	50	0-45	100
	Kiwayu (531)	2° 00" S, 41° 26" E	500	0-200	0
				200-300	0
				300-450	3
	Kiwayu (532)	1° 55" S, 41° 37" E	1000	0-200	25
				200-400	10
				400-800	0
	Kiwayu (533)	2° 01" S, 41° 47" E	2000	0-200	30
				200-400	13
				400-800	11

Table 9.4c: *t*-Test results for abundance of Candaciidae during southeast Monsoon (SEM) & northeast Monsoon (NEM) periods.

Transect & Depth Strata	Abundance SEM	Abundance NEM
GAZI (50m) 0-45m	40	130
GAZI (500m) 0-50m	360	80
50-150m SE &136-300m NE	120	40
150-250mSE & 300-450 m NE	40	0
250-450 m SE	560	0
SABAKI (50m) 0-40m	58	260
SABAKI (500m) 0-200m	208	50
300-450 m	26	14
SABAKI (1000m) 0-200m	31	20
200-400m	0	40
KIWAYU (50m) 0-45	60	100
KIWAYU (500m) 0-200m	880	0
300-450m	20	3
KIWAYU (1000m) 0-200m	200	25
200-400m	5	10
KIWAYU (2000m) 0-200m	40	30
200-400m	0	13

Summary Data

	SEM	NEM	Total
n	17	17	34
ΣX	2648	815	3463
ΣX^2	1329090	108999	1438089
SS	916625.0588	69926.9412	1085372.2647
mean	155.7647	47.9412	101.8529

Mean $_{SEM}$ — Mean $_{NEM}$	t	df	P
107.8235	1.71	16	0.053292

SE Monsoon period

Along the Gazi transect in the south of Kenya, the near shore waters (Stn Gazi 103) recorded abundance of 40 Candaciidae per 100 m^3 in the upper (0-45 m) layer. Further off shore and in the deeper water (Stn Gazi 105) abundance in the upper layer (0-50 m) was 360 ind./100m^3. In the deeper layers, the abundance decreased to 120 ind./100m^3 (50-150 m), 40 ind./100m^3 (150-250 m) and increased again to 560 ind./100m^3 in the deepest layer (250-450 m) of this station.

Along the Sabaki transect, in the near shore shallow water (Stn Sabaki 111), abundance recorded at the upper (0-40 m) layer was 58 ind./100m^3. Further offshore along this transect (at Stn Sabaki 117) abundance was 208 (in the 0-100 m upper layer), 32 ind./100m^3 (100-200 m), 0 (200-300 m) and 26 ind./100m^3 (300-450 m). The next offshore station of this transect (Stn Sabaki 118) recorded 31 ind./100m^3 (in the upper 0-200 m layer), 0 (200-400 m), 66 ind./100m^3 (400-600 m) and 7 ind./100m^3 (600-800 m).

Along the Kiwayu transect, the near shore waters of this transect (Stn Kiwayu 128) recorded abundance of 60 ind./100m^3 in the upper (0-45 m) layers. Further offshore, the next station (Stn Kiwayu 131) recorded abundance of 880 ind./100m^3 in the upper (0-100 m) layer. In the subsequent deeper strata of this station, abundance was 80 ind./100m^3 (100-200 m), 20 ind./100m^3 (200-300 m) and 20 ind./100m^3 (300-425 m). At the next station (Stn Kiwayu 132) located even further offshore in the 1,000 m depth range, abundance of Candaciidae with increasing depth was as follows: 200 ind./100m^3 (in the upper 0-200 m), 5 ind./100m^3 (200-400 m), 0 (400-600 m) and 3/100m^3 (600-800 m). At the furthest station of this transect (Stn Kiwayu 133), located within the 2,000 m depth range, abundance was 40 ind./100m^3 (in the upper 0-200 m), 0 (200-400 m), 4 ind./100m^3 (400-600 m) and 4 ind./100m^3 (600-800 m).

From the results above, it appears that during the SE Monsoon period members of Candaciidae were less abundant in the upper layers of the near shore waters compared to similar layers offshore. At each station, abundance reduced as the sampling depth increased until a certain minimum depth stratum and thereafter increased again. This depth stratum (about 200-600 m) of minimum abundance of Candaciidae coincided with the layer of minimum oxygen concentration recorded by Heip *et al.* (1995) at the time of sampling.

NE Monsoon period

On the Gazi transect the near shore waters within 50 m deep (Stn Gazi 503) recorded abundance of 130 ind./100m^3 in the upper (0-40 m) depth stratum. Further offshore (Stn Gazi 505) abundance was 80 ind./100m^3 (0-136 m), 40 ind./100m^3 (136-300 m) and 0 (300-450 m). Further offshore within the 1,000 m depth (Stn Gazi 506), abundance was 40 ind./100m^3 in the upper depth stratum (0-200 m), 30 ind./100m^3 (200-400 m) and 10 ind./100m^3 (400-600 m). The furthest station (Stn Gazi 507) on this transect, recorded 10 ind./100m^3 (0-400 m), 0 (400-800 m) and 20 ind./100m^3 (800-1,000 m).

On the Sabaki transect the near shore waters (Stn Sabaki 511) recorded 260 ind./100m^3 in the upper depth (0-45 m). The next station located offshore (Stn Sabaki 517) recorded 50 ind./100m^3 in the upper layer (0-200 m) and the subsequent deeper layers recorded 0 (200-300 m) and 14 ind./100m^3 (300-450 m). The next (Stn Sabaki 518) recorded 20 ind./100m^3 (0-200 m), 40 ind./100m^3 (200-400 m) and 22 ind./100m^3 (400-800 m). The furthest station offshore (Stn Sabaki 519) recorded 40 ind./100m^3 in the upper (0-400 m) depth stratum. The rest of the deeper strata at this station recorded 13 ind./100m^3 (400-800 m) and 0 (800-1,000 m).

Finally on the Kiwayu transect in the north, the near shore waters (Stn Kiwayu 528) recorded 100 ind./100m^3 in the upper (0-45 m) layer. At the next station (Stn Kiwayu 531), the upper strata (0-200 and 200-300 m) did not record any Candaciidae. The bottom depth stratum (300-450 m) recorded 3 ind./100m^3. Further off shore, the next station (Stn Kiwayu 532) recorded 25 ind./100m^3 (0-200 m), 10 ind./100m^3 (200-400 m) and 0 (400-800 m). The furthest station offshore overlying 2,000 m deep waters (Stn Kiwayu 533) recorded 30 ind./100m^3 in the upper (0-200 m) layers. The subsequent depth strata at this station recorded 13 ind./100m^3 (200-400 m) and 11 ind./100m^3 (400-800 m).

During the NE Monsoon contrary to observations in the SE Monsoon, the upper layers (0-45 m) in the near shore stations recorded a substantially higher abundance of Candaciidae compared to the off shore stations of similar depth strata. Similar to the SE Monsoon period, abundance decreased with increasing depth except at Stn Kiwayu 531, which did not record any Candaciidae in the upper 0-300 m. Also, at Stn Sabaki 518 more Candaciidae were recorded in the deeper strata compared to the preceding layers. The stratum of minimum

abundance observed during SE Monsoon was still present during the NE Monsoon period but had shifted deeper (to layers of about 200-800 m).

To compare the two Monsoon periods, we considered abundance of Candaciidae for similar depth strata (see Tables 9.4a and b) during both the SE and NE Monsoon periods. Results in Table 9.4c shows that from the statistical analysis, abundance of Candaciidae was significantly higher ($t = 1.71$, $df = 16$, $p = 0.05$) during the SE Monsoon period.

Species composition of Candaciidae in the inshore and offshore waters of Kenya

During previous taxonomic studies of copepods and zooplankton in the creeks and bays off the Kenya coast (Okemwa, 1990; Osore, 1994), the 8 commonly observed species of Candaciidae were: *C. catula*, *C. longimana*, *C. magna*, *C. pachydactyla*, *C. tenuimana*, *P. bispinosa*, *P. simplex* and *P. truncata*. Following analysis of copepods from zooplankton samples collected in the shelf and deep waters of Kenya during NIOP 1992/93 TYRO expedition (Mwaluma, 2000; Osore *et al.*, 1995), all the species mentioned above were also commonly encountered. However, *C. bradyi* is a new record for this locality.

In the present study, we also identified *C. bipinnata*, *C. curta*, *C. tuberculata* and *C. ethiopica* as new records for Kenya. These species, previously unknown to occur in inshore and near shore waters of Kenya, were encountered by Lawson (1977) in offshore samples (working on IIOE 1960-1965 samples) within the 0-200 m depth. However one species, *C. ethiopica,* is a completely new record in the Kenya coast. Table 5 shows the updated list of all the Candaciidae identified in Kenya and their horizontal and vertical distribution.

Table 9.5: List of Candaciidae sampled from the Kenya coast and their approximate range of distribution and abundance. Data was obtained from the present study and others.

Species	Distribution	Abundance (ind./100m^3)	Ref
C. bipinnata	near shore (0-100 m)	50-800	1,5
C. bradyi	near shore	100-500	1,3,4
C. catula	lagoon, near shore	200-900	1,2,5
C. curta	off shore (deep 200-400 m)	50-800	1,3,4,5
C. discaudata	near shore	76-225	1,5
C. ethiopica	off shore, rare	1-15	1
C. guggenheimi	off shore (0-200 m)	26-75	1,5
C. longimana	off shore (deep 500 m)	1-75	1,2,3,4,5
C. magna	mouth of creek, lagoon	40-300	1,2,6
C. pachydactyla	off shore (surface 0-50 m)	70-2,000	1,2,3,4,5
C. tenuimana	near shore (deep 0-100 m)	10-100	1,2,5
C. tuberculata	mouths of creek, bay	10-40	1
C. varicans	near shore surface (0-50 m)	10-75	1,5
P. bispinosa	off shore (deep 400-800 m)	20-60	1,2,5
P. simplex	offshore (surface 0-200 m)	76-225	1,2,5,
P. truncata	near shore, off shore	200-2,000	1,2,3,5

1=Present study, 2=Okemwa (1990), 3=Osore 1994, 4=Mwaluma (2000), 5=Lawson (1977), 6=Sewell (1932).

9.5 Discussion

This study has established that sixteen species of the family Candaciidae occur along the coast of Kenya. Thirteen species of *Candacia* and three of *Paracandacia* appear to be characteristic of the shelf waters of the Kenya coast and were commonly found in the epipelagic zone and, to a lesser extent, at depths of down to 1,000 m. Close to the shores and in the inshore waters the abundance ranged from 9 to 240 ind./100 m^3. In the shelf waters abundance was higher and ranged from 40 to 360 ind./100 m^3. Offshore, abundance was quite low ranging from 10 to 40/100 m^3 in the surface layers and from 11 to 20 ind./100 m^3 in the deep bottom layers. Quite often, the abundance in the mesopelagic zone (400-800 m) reduced substantially, this was most probably in response to the minimum oxygen concentration at these depths. Most copepod species are known to avoid water with oxygen content below 0.1-0.2 ml.l^{-1} (Longhurst, 1967; Judkins, 1980; Sameoto, 1986; Sameoto et a. 1987). At the time of sampling offshore Kenya, low oxygen levels (0.1-1.5 ml.l^{-1}) were recorded especially at depths of 400-800 m (Heip *et al.*, 1995). It has also been shown by Vinogradov & Voronina (1962) that the Arabian Sea in the neighbouring northern Indian Ocean region similarly

experiences zones of low oxygen concentration at depths of 150 to 1,500 m which influences zooplankton biomass distribution and alters species composition in the area.

The monsoonal currents in the Kenya coast created by the yearly reversing SE and NE Monsoon winds affected abundance and distribution of Candaciidae in the offshore zone and deep waters. Abundance was higher during SE Monsoon and the population was more concentrated in the offshore areas. During the NE Monsoon, there were more Candaciidae towards the shore. The oxygen minimum layer had also shifted deeper. Therefore, the reverse in the flow of the monsoon winds seems to have influenced the abundance and distribution of Candaciidae as well.

The wet and dry seasonal regime at the coastal strip is responsible for the distribution of Candaciidae and other copepods within the creeks, bays and near shore waters. Climatic changes and other environmental variables play a key role in the abundance, diversity and distribution of zooplankton (of which Candaciidae are a part) of the inshore waters of Kenya (Okemwa, 1990; Osore, 1994; Mwaluma, 2000). During the wet season, Kenya's main rivers alone, i.e. R. Tana and R. Galana/Sabaki discharge over 5,000 $m^3 s^{-1}$ to the near shore and this is expected to cause drastic changes in salinity, nutrient type and concentration, primary productivity and the general hydrography of the near shore waters.

From our study, the population of Candaciidae may be geographically distributed off the Kenya coast in the following pattern: those that prefer creeks, bays, lagoons and inshore waters are *C. catula*, *C. magna* and *C. tuberculata*. Those with preference for near shore waters above the continental shelf include *C. bipinnata*, *C. bradyi*, *C. discaudata*, *C. tenuimana*, *C. varicans* and *P. truncata*. The rest prefer the offshore zone or even deep-water layers, they include *C. curta*, *C. ethiopica*, *C. guggenheimi*, *C. longimana*, *C. pachydactyla*, *P. bispinosa* and *P. simplex*. However, these are not strict boundaries and that is why Candaciidae are known to occupy wide geographical regions in the Indian Ocean.

This study is the first attempt to describe the distribution of family Candaciidae from the shelf waters of Kenya and offshore localities of such great depths in the region. A previous study of Candaciidae in the Indian Ocean by Lawson (1977) was based on IIOE samples collected only within the upper 200 m of mainly the oceanic provinces of this ocean.

CHAPTER 10

Introduction to the microcharacters of the integument: a potential tool for future species recognition

Results partly presented as:

M. K. W. Osore, F. Fiers & J. Cillis 2000. Microcharacters as tool for taxonomy in the future: case study *Candacia* and *Paracandacia* (Copepoda: Calanoida). 7th Benelux Congress, Nov., 2000. VUB, Belgium.

10.1 Summary

This chapter reports on the occurrence of integumental organs (sensilla and pores) and integumental structures (spinules and spinular pattern) on the body somites of *Candacia* Dana, 1846 and *Paracandacia* Grice, 1963. We present observations made on the genital somite, the first pair of swimming legs, the dorsal hump, the antennule and the rostrum.

- Two types of rostra exist in Candaciidae, one with a single protrusion, the other with double.
- A pore was observed on the right foot of the first pair of swimming legs of all specimens.
- A dorsal hump was observed to occur in all female as well as male specimens. The arrangement of the associated sensilla and pores on the hump was uniform.
- Four different patterns of integumental ornamentation on the genital somite were classified.

These are the first such observations to be documented on members of the copepod family Candaciidae.

10.2 Introduction

Much information is emerging on the various types of integumental organs and structures on copepods. By definition, the **integumental organs** are small in size relative to the thickness of the integument. They involve distinct perforation on the integument and lack any direct relationship to an organ system of more than local extension (Vaupel-Klein, 1982b). **Integumental structures** are superficial modifications of the outermost layer, they occur in groups, do not involve perforation and they completely lack structural relation with other larger organ systems.

Like other copepod groups, Candaciidae possess a variety of integumental structures and organs (Fleminger, 1973; Mauchline, 1977; 1998). However, the main focus in the current study is the presence and pattern of sensilla (pit-sensilla, peg-sensilla, spine-sensilla, hair-sensilla) pores (spinular-pore, circular-pores), warts and granules. These were routinely

investigated on the tegument of the prosome, the urosome and the appendages of Candaciidae specimens. Vaupel-Klein (1982b) provides further descriptions, definitions and functions of these and similar organs and structures on the copepod *Euchirella messinensis* (Claus, 1863).

The number, pattern and variability of these organs and structures have demonstrated their value in systematic studies from local populations to higher taxonomic levels (Fleminger, 1973; Fleminger & Hulsemann, 1977; Mauchline, 1977; 1988; Hulsemann & Fleminger, 1990). Integumental perforations (i.e. pore pattern structure), which usually become visible once the integumental organs have procedurally been dissolved in chemicals, are now documented to be species specific and therefore represent a powerful tool in species discrimination (Ianora *et al.*, 1992; Park, 1995). However, there are still many structures and organs on the copepod integument whose presence, location and morphology are either ignored or unknown due to their minute sizes.

Observation of minute characters on specimens at very high magnification is currently achievable using the scanning electron microscope (SEM) technique. We applied this technique to investigate a selection of body teguments on species of the family Candaciidae. In our study we documented the presence of the fine morphological structures (microstructure).

In order to investigate separate geographical regions, specimens used for this study were obtained not only from locations off the Kenya coast but also from the southern Atlantic Ocean (samples from the Mercator cruises in the nineteen thirties as well as from more recent expeditions).

The objective of this study was to identify and locate the types and distribution of microcharacters on the tegument of members of the family Candaciidae. Thus, provide fundamental information as the basis for systematic and phylogenetic studies of these two calanoid taxa. In the following section, we first briefly observe the diagnostic features of the family Candaciidae and its distinction from the other families of the order calanoida. Consequently, we present a selection of different morphological observations dealing with the integumental structures and organs.

Materials and methods used here are described in Cap 3.2.1 and 3.3.2.

10.3 Results

General morhphology

Fig. 10.1 illustrates the general morphology of Candaciidae depicting the location of some of the features investigated. Members of this family have a rectangular shaped cephalosome (see also *Plate* 49), which is separated from the first pedigerous somite. Viewed laterally, the shape of the posterior corner of the prosome is often rounded, acutely pointed or triangular. In dorsal view, the female urosome is symmetrical and is composed of three free somites. The male urosome dorsal view is either symmetrical or asymmetrical and has five free somites. Pedigerous somites 4 and 5 are separate in females and fused or partly fused in males.

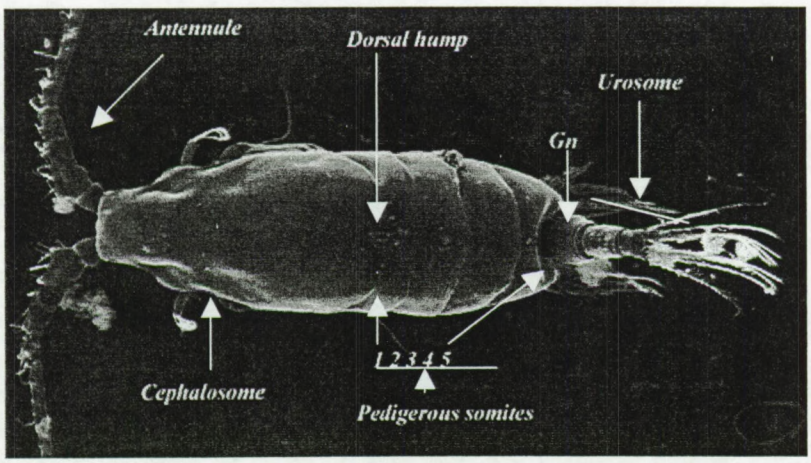


Fig. 10.1: Some characteristics of the family Candaciidae (*C. elongata* ♀) in dorsal view.

Antenna 1 (antennule, A1) is discussed below in details. Antenna 2 has an exopod with 7 free segments composed of 7-8 inner setae, 2 terminal setae and fused basis and endopod. Mandible basis has no setae while the endopod terminal has 6 setae. Maxilla 1 lacks basal exite seta and its exopod extends short of endopod distal border. Maxilla 2 lacks the coxal epipodite seta and its endopod setae are shaped like a claw. The female maxilliped coxal endite 2 has 1 seta whereas in the male maxilliped endopod segments 5 and 6 have outer setae.

In the first pair of swimming legs (P_1) the basis inner distal seta is absent (*Plate* 26); the outer seta is present; endopod is 2-segmented; exopod is 3-segmented; exopod segment 1 has an

outer distal spine; exopod segment 3 has 4 inner setae. P_2 endopod is 2-segmented and the exopod is 3-segmented. Exopod segment 3 has 3 outer spines. P_3 basis lacks the outer distal spine. Both P_3 and P_4 have 2-segmented endopods and 3-segmented exopods; exopod segment 3 has 3 outer spines and 5 inner setae. Surfaces of P_2, P_3 and P_4 are naked and the terminal spine is serrated on the outer border.

P_5 is very dissimilar from P_1-P_4. In females (see Fig. 10.2) it is uniramous, not natatory, usually symmetrical and the inner border of the coxa has no seta. The coxae and intercoxal sclerite are fused; the basis has 1 outer seta; the exopod is 1-segmented, long and may end in spine-like processes, finger-like processes or single long seta. Seta may be present or absent along the inner margins.

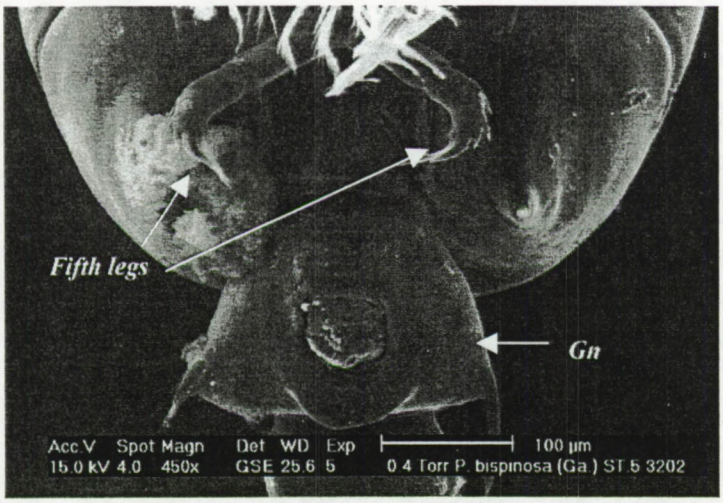


Fig. 10.2: Ventral view of the posterior region showing the female P_5 and the genital somite of *P. bispinosa*.

In *Candacia* males the right P_5 is uniramous; the exopod short and 2-segmented and usually set in opposition to long, wide, terminally rounded expansion of basis. In *Paracandacia* males (see Fig. 10.3) this expansion is absent and the exopod segment 2 terminates by a long, plumous seta. The left P_5 is uniramous; exopod is elongate and 2-segmented; segments are narrow and the terminal segment is rounded distally. The segments are also variously decorated with small outer border spines and rows of hairs.

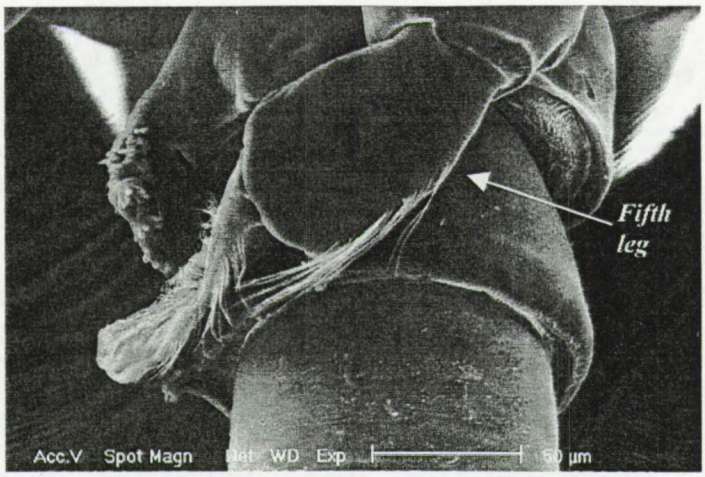


Fig. 10.3: Ventral view of the posterior region showing the male P5 and the first urosomites of a *Paracandacia* sp.

Distinction between Candacia and Paracandacia

Dana described the first species of this group, *Candace ornata*, in 1849. Unfortunately, the description was based on immature specimens and the species is unrecognisable. Therefore, Grice & Vervoort (1963) requested the International Commission on Zoological Nomenclature to replace *C. ornata* with *C. pachydactyla* Dana, 1849, the second species to be attributed to this group by Dana. The original description of *C. pachydactyla* is based on a male specimen collected from the type locality in the Atlantic Ocean (1° - 11° S, 14° - 30° W) and deposited in the US National Museum (Cat. No. 107602) and has been designated as the neotype (Grice, 1962).

In both sexes of *Candacia*, the basal tooth of the mandible is usually divided into one or two pointed cusps. The two spines on the second basal segment of the second maxillae are variable in length and thickness. In females, the terminal segments of the fifth pair of feet (P_5) may end in one or more spine-like processes or a single long seta. In males, the right P_5 is chelate. A 'comb structure' is also present on one or more segments in the geniculated region of the male right first antenna (A1). At present, thirty-one species are referable to the genus *Candacia* (see Table 9.2 and references cited therein).

As in the case of *Candacia*, Dana mentioned no type species for *Paracandacia*. A female specimen of *Paracandacia truncata* collected in the Pacific Ocean (0° 35'N, 170° 11'E) and

deposited in the US National Museum (Cat. No. 107600) has been designated as the neotype (Grice, 1962).

In both sexes of *Paracandacia*, the basal tooth of the mandible is simple except in *P. simplex*, which has a minute point arising from the external side of the basal tooth near the tip. The proximal spine on the second basal segment of the second maxillae is approximately one-half the length of the distal spine and considerably thinner than the distal spine. In the females, the terminal segments of the P_5 end in a finger-like process, which maybe finely serrated along one or both margins. There are two setae on the inner lateral margins of these segments. In the male, segment 17-18 (ancestral segment XIX – XX) and 19-20 (XXI – XXII) of the right A1 are fused and there is no "comb structure" in the geniculated region. At present four species are referable to genus *Paracandacia* (see Table 9.2).

The following are species of family Candaciidae that we routinely investigated during this study: *Candacia pachydactyla*, *C. longimana*, *C. elongata*, *C. ethiopica*, *C. bradyi*, *C. curta*, *C. bipinnata*, *C. catula*, *C. tuberculata*, *Paracandacia bispinosa*, *P. simplex* and *P. truncata*. Fig. 10.4 shows the position of some of the investigated sites on the tegument of Candaciidae. Details of the fine structures observed on these sites are illustrated in *Plates* 1- 59.

Description of the general distribution of some fine structures on Candaciidae

On the entire body of all the Candaciidae specimens (Fig.10.4), we observed series of integumental organs and structures similar to those reported on other copepods by various workers (e.g. Fleminger, 1973; Mauchline, 1977; Saraswathy & Bradford, 1980; Vaupel-Klein, 1982b). These included aesthetascs (*Plate* 1) and Setae (*Plate* 2) on the antennules. Aesthetascs are described as hollow structured sensory filaments, which can detect chemical information. Setae are closed integument outgrowths, which detect physical disturbance. Others were sensilla, pores, pegs, warts, spines (*Plate* 3) occurring on the pleural surfaces of the fourth pedigerous somite; spinules (*Plate* 4) occurring on the dorsal cephalosome and granules (*Plate* 5) on the dorsal surfaces of the pedigerous somites. Often a double sensillum (*Plate* 6) possessed an associated pore adjacent to it (*Plate* 7). Pairs of double sensilla and adjacent pores lined the entire dorsal and pleural surfaces of the somites at regular intervals. There was also pit and pore (*Plate* 8). Setae were sunken in a pit or on the surface of

appendages (*Plate* 9) etc. Some of these integumental structures were distributed in bilateral symmetry on the tegument of Candaciidae.

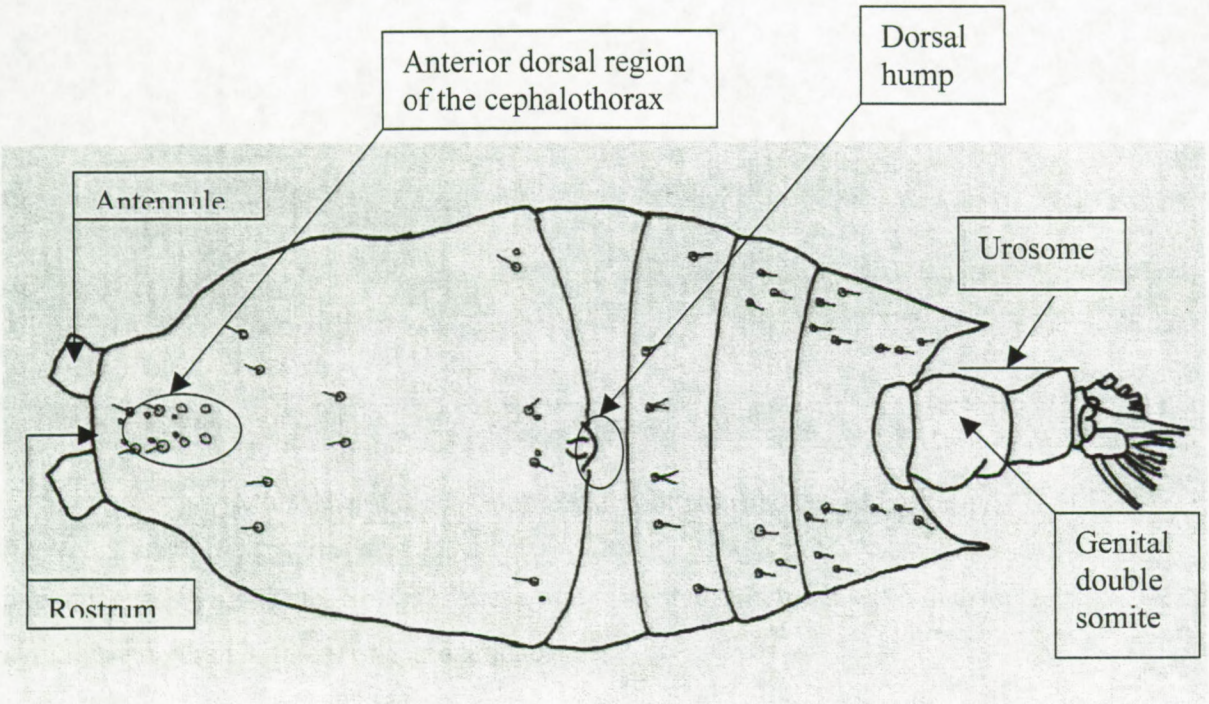


Fig. 10.4: Habitus of a specimen of Candaciidae (dorsal view of female) illustrating the position of some of the investigated sites.

Antennule

Out of the 28 ancestral segments of the A1, our Candaciidae specimens had 24 free segments. The ancestral segments II, III and IV were fused and so were segments XXVI, XXVII and XXVIII (Huys & Boxshall, 1991). In both sexes the ancestral segments X and XI were separate. The A1 of the female are typically bilaterally symmetrical. In males, segments II and III were fused in some species e.g. in *C. pachydactyla* and separate in others e.g. *C. longimana*. The male A1 was geniculated on the right side only, the left side resembled that of the female. A1 of both sexes were also furnished with setae, sensilla and aesthetascs (*Plate* 1). Aesthetascs detect food, water disturbance and predators (Mauchline, 1998). Each ancestral segment I, IV, VI, VIII-XXI, XXV and XXVIII had a single aesthetasc whereas each of the segments III, V and VII had a pair of aesthetascs. Segments II, XXI, XXII and XXVI had no aesthetasc.

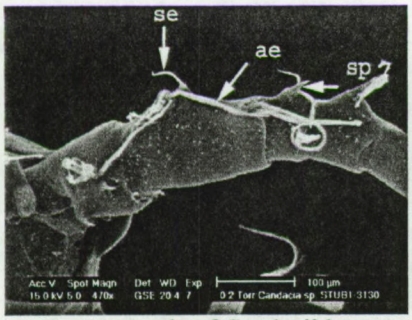


Plate 1: Antennule of Candaciidae showing aesthetascs (ae), sensilla (se) and spines (sp).

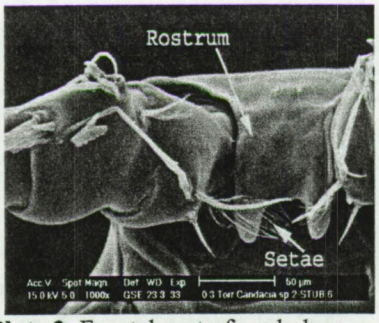
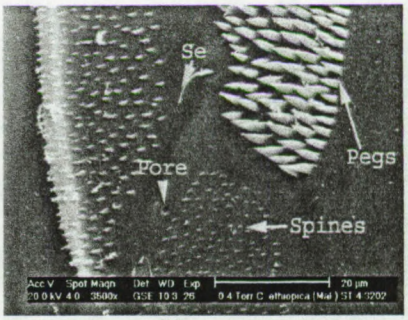


Plate 2: Frontal part of cephalosome showing rostrum, some setae and the attachment of right antennule.



Pate 3: A sensillum (se), a pore, patches of pegs and spines discerned on the tegument of Candaciidae.

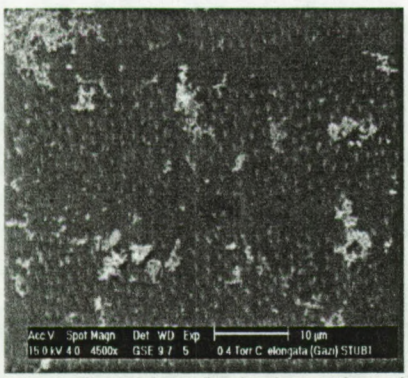


Plate 4: Examples of spinules and a pair of pores on the tegument of Candaciidae.

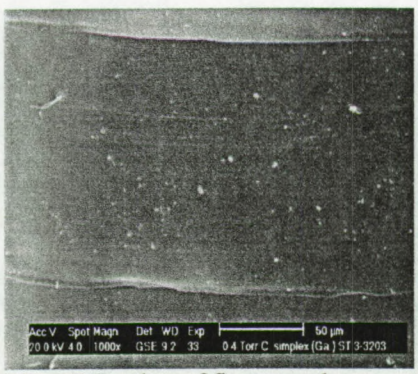


Plate 5: Patches of fine granules on the tegument of Candaciidae.

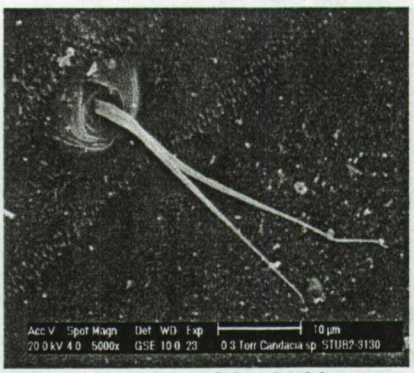


Plate 6: Example of the double sensillum observed on Candaciidae.

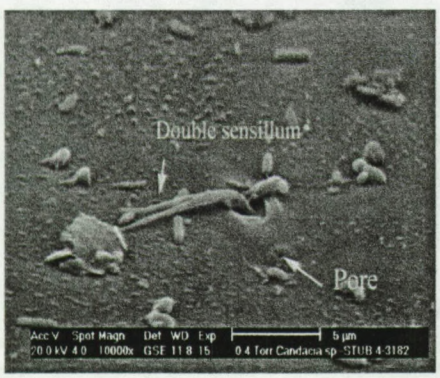


Plate 7: Double sensillum and an adjacent pore.

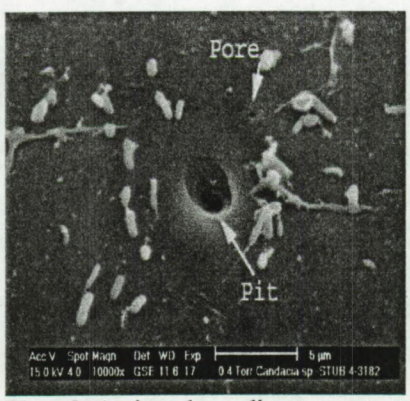


Plate 8: A pit and an adjacent pore.

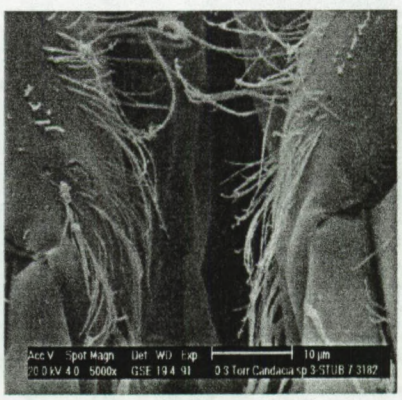


Plate 9: Hairs on the swimming legs.

Plates 1-9: Scanning electro micrographs of some general fine structures discerned on Candaciidae specimens.

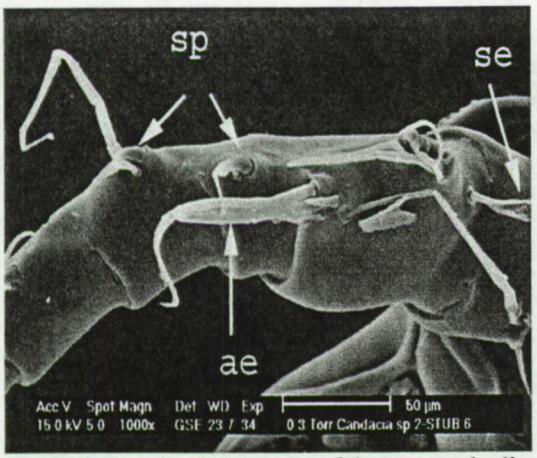


Plate 10: Proximal segments of the antennule display aesthetascs (ae), spines (sp) and setae (se).

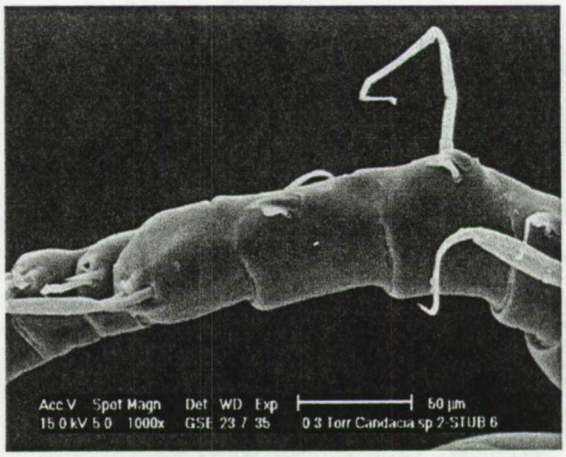


Plate 11: Further antennullar segments showing aesthetascs and spines.

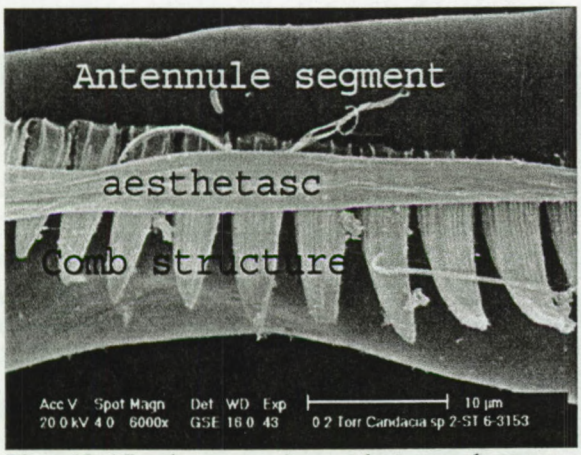


Plate 12: 'Comb structure' on male antennule segment no. 18. Notice aesthetasc resting on the teeth of the comb structure.

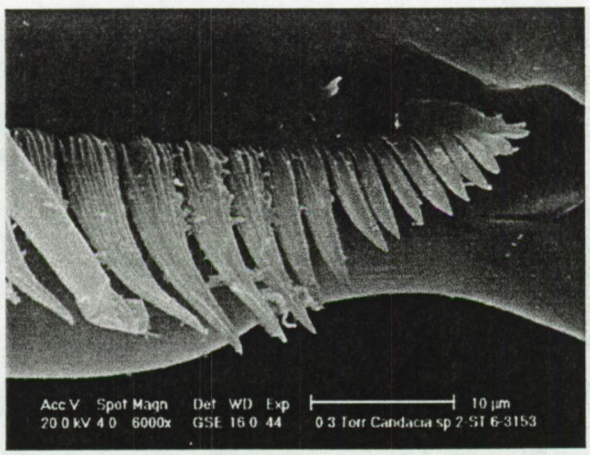


Plate 13: Detail of the 'comb structure' on segment 19.

Plates 10-13: Scanning electron micrographs of the fine structures on the segments of the Candaciidae antennule.

The geniculate right A1 in the male is a secondary sexual adaptation for grasping the female copepod during copulation. According to Glatzel & Schminke (1996), this appendage also plays an important role in male-female recognition during the initial phase of the mating behaviour of some harpacticoid copepods. Consequently, new information that we detected and described about the A1 of Candaciidae in our investigation may provide important value in behavioural observations and future studies of the systematics of this group.

All the aesthetascs, sensilla (both hair and pegs) and setae observed on the antennules of *Candacia* and *Paracandacia* though highly magnified under SEM (up to x 6,000 see *Plate 10*, *Plate 11*) appeared more or less as observed under light microscopy (LM up to x1250). However, the 'comb structure' on segments 17, 18 and 19 of the right male antennule of *Candacia bradyi, C. pachydactyla* and *C. curta* was not as smooth as it appears under LM. SEM revealed that each unit of the "comb structure" had longitudinal groves radiating from apex to base (see *Plate*12 and *Plate* 13). Similar modifications of the antennular segments have also been observed and described by Corni *et al.* (2001) on the right antennule of the male of *Temora stylifera* Dana, 1849. These workers attributed the antennular modifications to secondary sexual characters and concluded that males use them during mating.

Rostrum

The copepod rostrum is defined as a median extension of the anterior margin of the dorsal cephalosomic shield that carries a rostral sensory complex (Huys & Boxshall, 1991). It is further described as a multiple sensory organ complex significant to the Crustacea (Hosfeld, 1996). Viewed ventrally using LM, the rostra of all Candaciidae specimens we observed were typically continuous with the dorsal shield and directed posteroventrally between the proximal segments of the antennules. There were two types of rostrum structures that we observed. The first type that we observed on *C. elongata* from Kiwayu, Kenya (*Plate* 14) and *P. bispinosa* from Gazi, Kenya and the southern Atlantic (*Plate* 15) had a rostrum that extended into a single blunt protrusion tapering to a rounded tip.

The second rostral type we observed on specimens of *C. ethiopica* from Malindi, Kenya (*Plate* 16, *Plate* 17 and *Plate* 18). It extended into a pair of rostral protrusions beneath the ventral cephalosome (Ce). Although the rostra appeared to be quite smooth when observed under LM, SEM observations revealed they posses a pair of double hair sensilla (bifurcated)

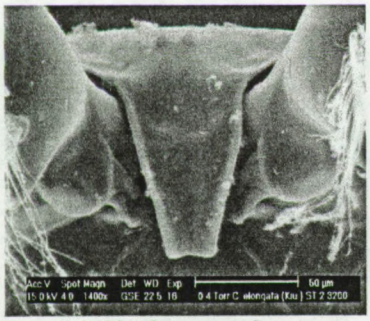


Plate 14: Single protrusion rostrum type observed on *C. elongata.*

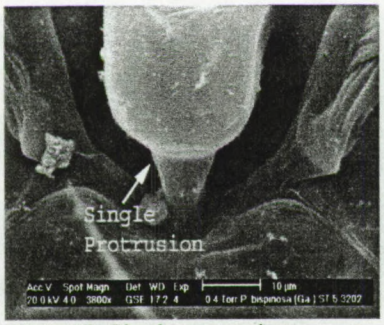


Plate 15: Single protrusion rostrum type observed on *P. bispinosa.*

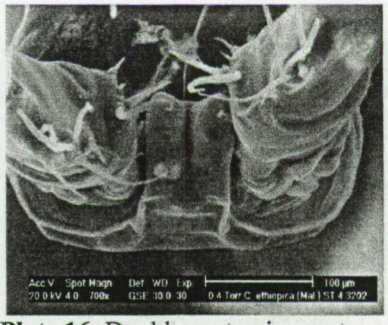


Plate 16: Double protrusion rostrum type observed on *C. ethiopica.* Ventral oblique view.

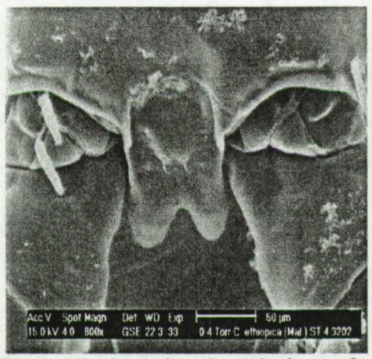


Plate 17: Anterior dorsal view of the double protrusion rostrum.

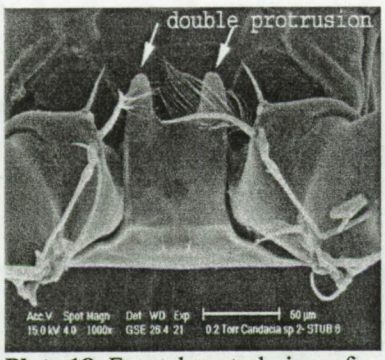


Plate 18: Frontal ventral view of double protrusion rostrum type.

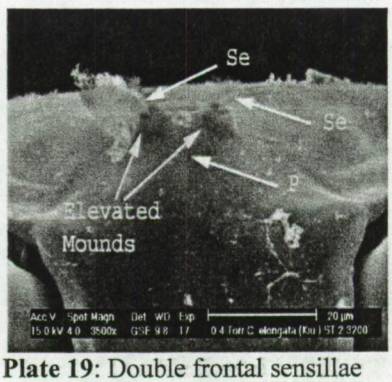


Plate 19: Double frontal sensillae (se) on elevated mounds on the rostrum and a median pore (p).

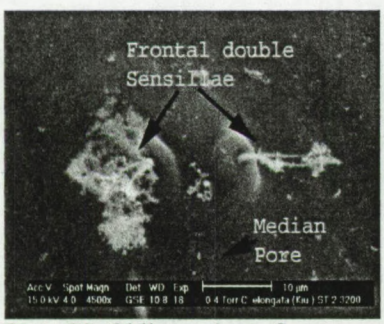


Plate 20: Oblique view of rostrum displaying frontal sensillae and median pore.

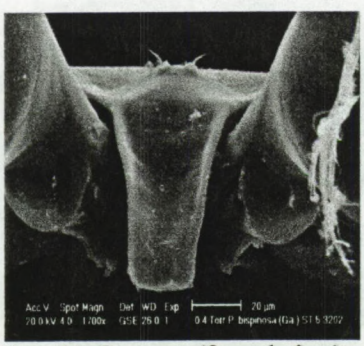


Plate 21: Rostrum (frontal view) with a pore and double sensillae.

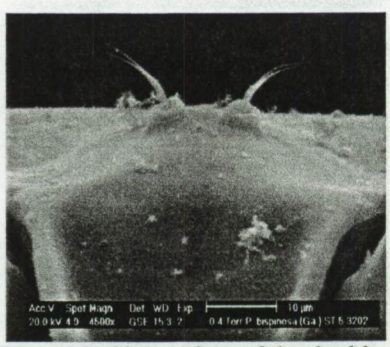


Plate 22: Closer view of the double sensillae and pore in *P. bispinosa.*

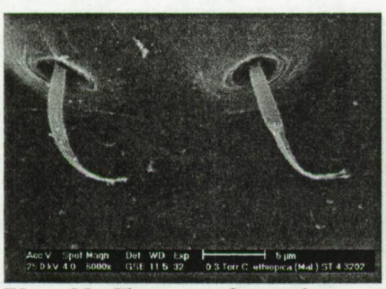


Plate 23: Close-up of rostral double sensilla of *C. ethiopica* from the Sabaki Transect, Kenya.

Plate 24: Rostral double sensilla of *P. simplex* from Gazi Bay, Kenya.

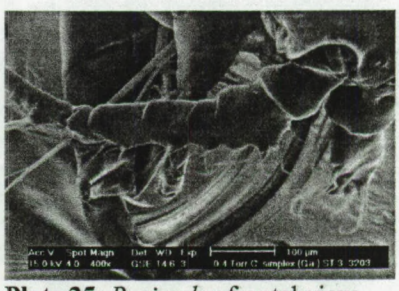


Plate 25: *P. simplex* frontal view showing rostrum and the attachment of antennules.

Plates 14-25: Scanning electron micrographs showing the two shapes and types of rostra possessed by Candaciidae and the fine structures discerned on them.

at the apical position and a single median pore just below them (*Plate 19*). The base of each frontal double sensillum was an elevated mound.

The other figures illustrate further observations we made on the rostra of *C. elongata* from Kiwayu, Kenya (*Plate* 20); *P. bispinosa* from Gazi, Kenya and the southern Atlantic (*Plate* 21 and *Plate* 22); *C. ethiopica* from Sabaki, Kenya (*Plate* 23) and *P. simplex* from Gazi, Kenya and the southern Atlantic (*Plate* 24 and *Plate* 25).

The general characteristics of the various copepod rostra have been discussed by Huys & Boxshall (1991). Hosfeld (1996), investigating the ultrastructure and anatomy of the rostrum of the harpacticoid copepod *Canuella perplexa* T. & A. Scott, 1893 concluded that studying such characters could provide information for phylogenetic relationships within copepods. The present study, however, is a series of preliminary observations we have made that will contribute towards a better understanding of the structure of the Candaciidae rostrum. It is also the first documented investigation on this structure for Candaciidae.

First swimming legs (P_1)

A pore occurs at the anterior surface of segment 3 of the exopods of the right leg of the first pair of swimming legs (Ex_3P_1) as illustrated in *Plate* 26 and *Plate* 27. This pore was surrounded with and almost entirely obscured by strands of fine setae. In his work on factor analysis of variation in the first pair of swimming legs of 27 species of Candaciidae, Lawson (1973b) indicated the position of this pore by shading of the area but neither mentioned nor described its morphology and location. A similar pore has been observed on both legs of the first four swimming legs of the calanoid *Euchirella messinensis* and described by Vaupel-Klein (1982a) and Koomen (1992). A similar pore may be observed on the swimming legs of harpacticoid copepods (Dr Frank Fiers, Pers. Comm.), but it always occurs on both legs.

The present study revealed that the pore was only present on the P_1 and not on other swimming legs in all the candaciids examined. Examples illustrating the pore are presented for the following species: *C. elongata* from Gazi, Kenya (*Plate* 28), *P. bispinosa* from southern Atlantic (*Plate* 29), *C. ethiopica* from Sabaki, Kenya (*Plate* 30) and *P. simplex* from Gazi, Kenya (*Plate* 31). Since it is present in both sexes, the pore is not a sexual character. However, its actual function is unknown.

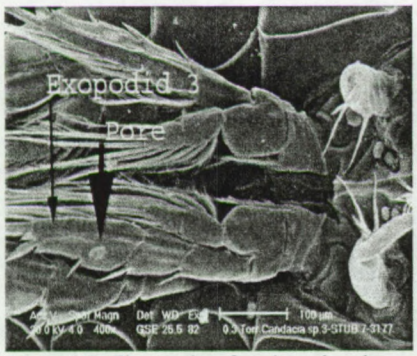


Plate 26: First pair of swimming legs (P_1) showing location of the pore on the third segment of the exopod (Ex_3).

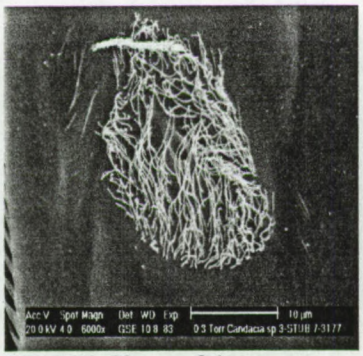


Plate 27: Shape of the pore surrounded by hairs and its location on the Ex_3 of the right P_1.

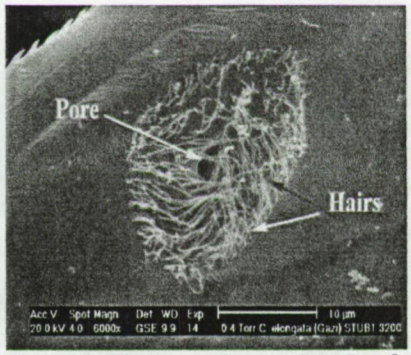


Plate 28: The pore observed on P_1 of *C. elongata.*

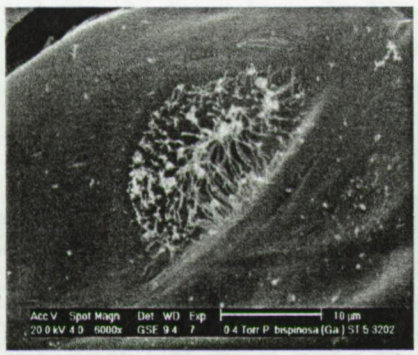


Plate 29: The pore observed on P_1 of *P. bispinosa.*

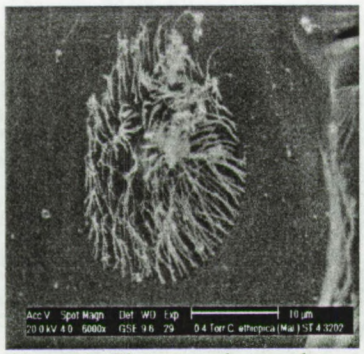


Plate 30: The pore observed on P_1 of *C. ethiopica.*

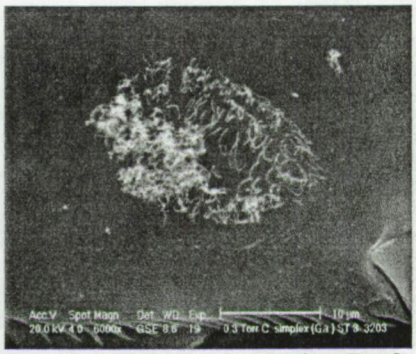


Plate 31: The pore observed on P_1 of *P. simplex.*

Plates 26-31: Scanning electro micrographs of shape and position of the pore observed on the first pair of swimming legs of Candaciidae.

Dorsal Hump

In family Candaciidae a dorsal hump structure was present in all species of both sexes. The hump structure was located dorsally at the posterior edge of the cephalosome (*Plate* 32). Structurally, the hump was preceded by a pair of hair sensilla and associated pores (see also the general dorsal view *Plate* 33, *Plate* 34 and lateral view *Plate* 36). Posterior to these sensilla, on the surface of the hump were 5 more pairs of sensilla and associated pores arranged in bilateral symmetry (*Plate* 35). Examples of the detailed features we observed on the hump are illustrated (using elecrtomicrographs) for *C. elongata* from Gazi, Kenya (*Plate* 37) and Kiwayu, Kenya (*Plate* 38); and for *P. bispinosa* obtained from Gazi, Kenya and the southern Atlantic (*Plate* 39).

Copepods possess some specialised organs and structures hitherto unknown due to their extremely minute sizes. For example the "cephalic dorsal hump" (CDH) solely present on the males of families Calanidae, Megacalanidae, Mecynoceridae and Paracalanidae suggests that this organ plays an important role in mate recognition (Nishida, 1989). Matsuura & Nishida (2000) investigated the fine structure of another organ - the "button setae" on the maxilla and maxilliped of genus *Euaugaptilus* and they related it to the specialised mode of feeding practised by these copepods. Hulsemann & Fleminger (1990) observed that the pattern and arrangement of integumental organs and patches of spinules on the genital segment of *Pontellina* females were species-specific and therefore they determine successful courtship and copulation. Another example is the morphological adaptation to a neustonic existence developed in some members of family Pontellidae. A structure consisting of two semicircles of closely spaced setules is present on a flattened area in the anterior dorsal surface of the cephalosome of these copepods (Ianora *et al.*, 1992). It functions to attach the copepod to the surface film of water, and thus conserves energy. This is a functional adaptation for pontellid copepods living in the hyponeuston.

Since the dorsal hump structure in our study occurred in both sexes, it is unlikely to be homologous to the CDH mentioned above. The CDH is documented to be always located within the anterior margin of the prosome whereas the hump in our study was located further posterior on the dorsal edge of the cephalosome. Furthermore, in the present study we could not postulate on the possible functional properties of the hump since we did not conduct further investigations e.g. by using TEM (Transmission Electron Microscopy), CLSM (Confocal Laser Scanning Microscopy) and other similar techniques (e.g. see Galassi *et al.*,

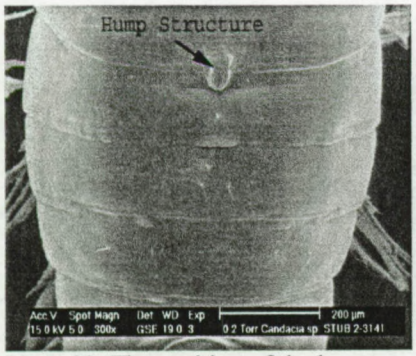


Plate 32: The position of the hump structure on the cephalosome of Candaciidae.

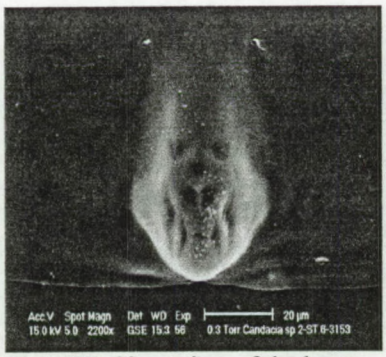


Plate 33: Close view of the hump structure.

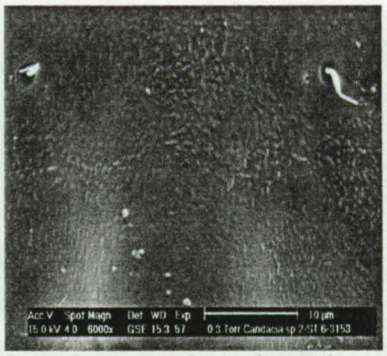


Plate 34: Located anterior to the hump structure is a pair of double sensillae each with an adjacent pore.

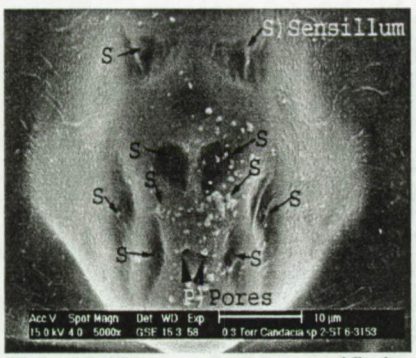


Plate 35: Hump structure magnified to show location of sensillae (s) and pores (p) as they occur in bilateral symmetry.

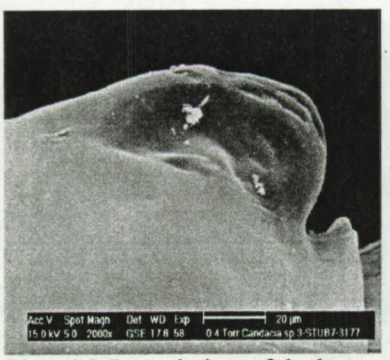


Plate 36: Lateral view of the hump structure.

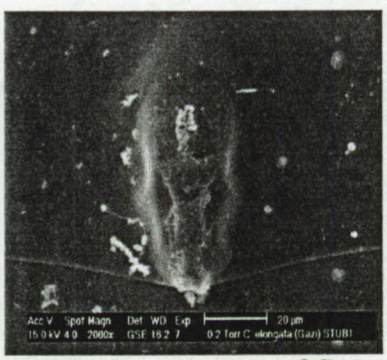


Plate 37: Hump structure of *C. elongata* from the Kenya coast.

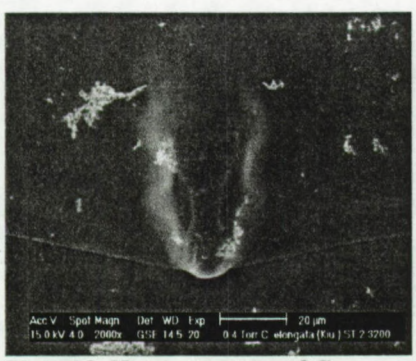


Plate 38: Hump structure of *C. elongata* from the southern Atlantic Ocean.

Plate 39: General hump structure of *P. bispinosa*.

Plates 32-39: Scanning electro micrographs showing the morphology of the hump structure of Candaciidae and the fine structures on it.

1998), which are usually recommended for such detailed analyses of the internal anatomy. The function of this structure is unknown, however, we hypothesise that it may be a useful adaptation of the Candaciidae for their type of environment.

Urosome (Ur) and female genital somite (Gn)

The urosome comprises three principal somites: the genital somite (double somite in females), the anal somite and caudal rami (furca). The genital double somite of female copepods is vital in reproduction because it is the site of the genital aperture, which provides entry for spermatozoa and exit for fertilized eggs (Huys & Boxshall, 1991; Mauchline, 1998). The genital segment is typically sought out by the male for placement of the spermatophores in order to ensure the spermatozoa access to the copulatory pore. The general genital structures of Candaciidae as well as those of other families of superfamily Centropagoidea have been described by Barthélémy *et al.* (1998a, b).

Plates 40-48 show examples of some ornamentation observed on the urosomes of the Candaciidae specimens. The ornamentation appeared in various patterns depending on the species and the somite observed on the urosome. *Plate* 40 and *Plate* 41 show the patterns on the first and second male urosome somite (Ur_1, Ur_2 respectively) for *C. elongata* from Kiwayu, Kenya. *Plate* 42 shows the pattern on the female of the same species. *Plate* 43 and *Plate* 44 show the pattern we observed on Gn and Ur_2 respectively of female specimens of *P. bispinosa* from Gazi, Kenya and southern Atlantic. The pattern on the male *C. ethiopica* from Malindi, Kenya is shown in *Plate* 45 and *Plate* 46. Ornamentation pattern on the urosome of male *P. simplex* is shown in *Plate* 47 and *Plate* 48.

The urosome and in particular the genital somite displayed patches of small spinules ornamenting the integument both dorsally and laterally. *Plate* 40 shows rectangular patches of spinules observed on the Ur_1 of male *C. elongata*. *Plate* 41 shows square patches on the Ur_2 of *C. elongata* male. Other patterns observed were the continuous bands of spinules on the genital double somite of *C. elongata* female (*Plate* 42) and the hexagonal patches of spinules on Ur_1 of *C. pachydactyla* male (*Plate* 59).

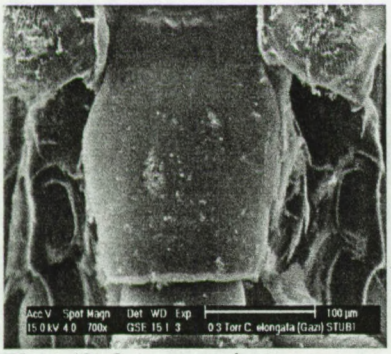


Plate 40: Ornamentation pattern on the first urosome segment (Ur_1) of *C. elongata* male.

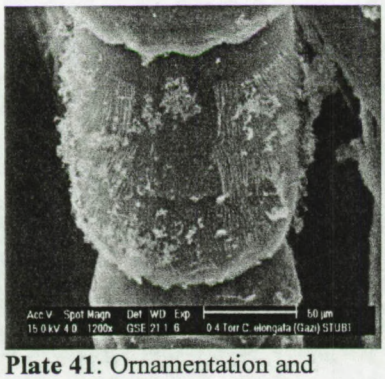


Plate 41: Ornamentation and pattern of arrangement of setae on the Ur_2 of *C. elongata* male.

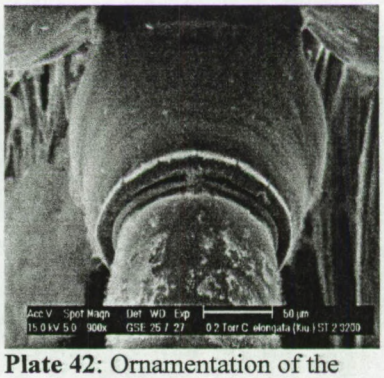


Plate 42: Ornamentation of the genital double somite (Gn) and Ur_2 of *C. elongata* female.

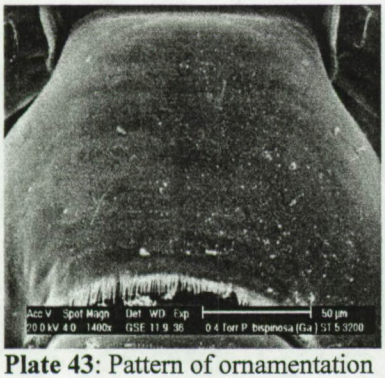


Plate 43: Pattern of ornamentation on the Gn of *P. bispinosa* female.

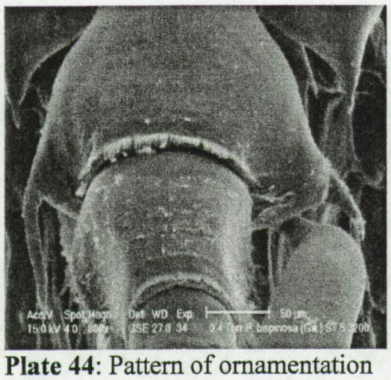


Plate 44: Pattern of ornamentation on the Gn and Ur_2 of *P. bispinosa*. Also visible at the bottom right is the attached spermatophore.

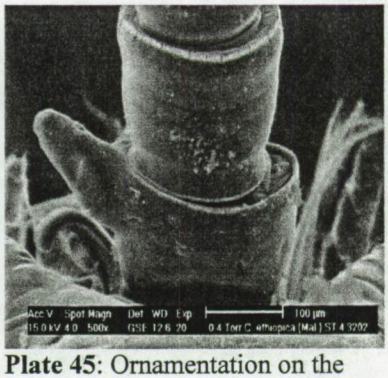


Plate 45: Ornamentation on the first and second urosome segments (Ur_1 & Ur_2) of *C. ethiopica* male.

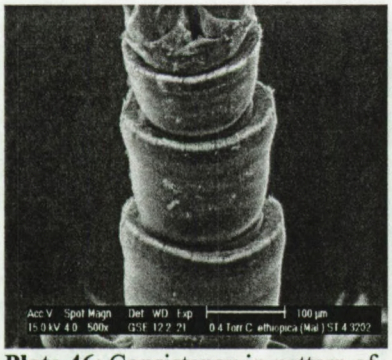


Plate 46: Consistency in pattern of ornamentation on the rest of the urosome segments of *C. ethiopica* male.

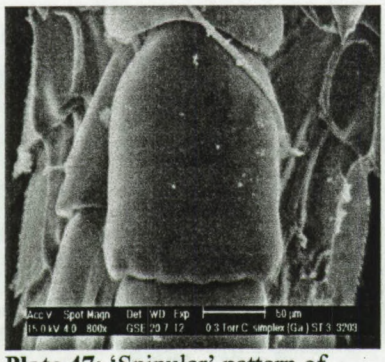


Plate 47: 'Spinular' pattern of ornamentation on the Ur_1 of *P. simplex* male.

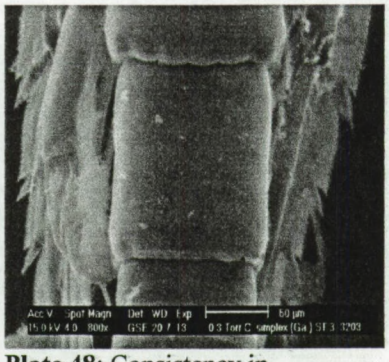


Plate 48: Consistency in ornamentation on the rest of the urosome segments of *P. simplex* male.

Plates 40-48: Scanning electro micrographs of urosome segments of Candaciidae showing type and pattern of ornamentation.

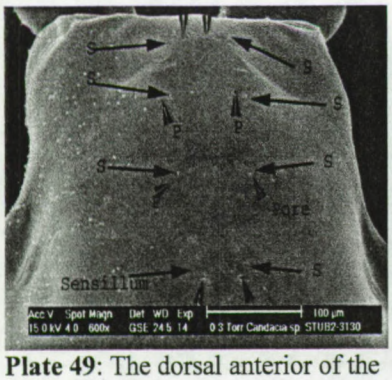


Plate 49: The dorsal anterior of the cephalosome has a row of pairs of sensillae (s) each with an adjacent pore (p).

Plate 50: Closer view of the cephalosome sensillum with adjacent pore.

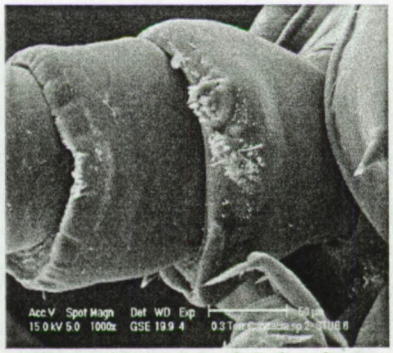


Plate 51: Urosome of *C. bradyi* showing granular structure on the right side of the Ur_1.

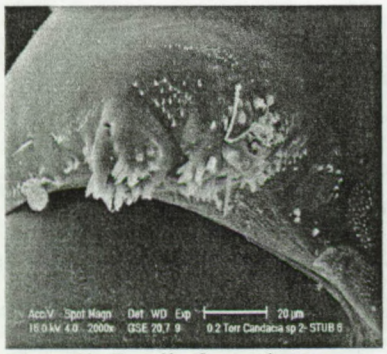


Plate 52: Detail of protuberances on the granular structure on the Ur_1 of *C. bradyi*.

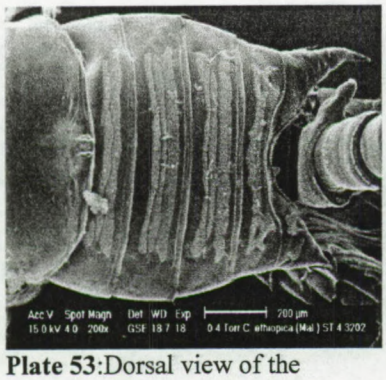


Plate 53:Dorsal view of the metasomes of *C. ethiopica* (from M_1 to M_{4+5}) showing an elaborate ornamentation pattern.

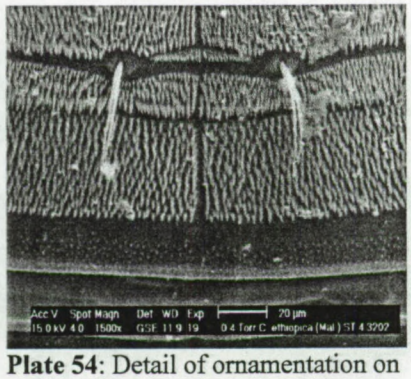


Plate 54: Detail of ornamentation on M_2 revealing bilateral symmetry in the pattern of sensillae and spinules.

Plates 49-54: Scanning electro micrographs of other fine structures and pattern of ornamentation observed on the cephalosome, urosome and metasome of Candaciidae.

Other observations

The anterior dorsal region of the cephalosome of candaciids was occupied by a set of 4 pairs of hair sensilla (Plate 49), each with an associated pore (*Plate* 50). Details on the surface of each species also reveal ornamentation of a continuous pattern of warts.

Our observations using SEM revealed other detailed structures that are characteristic for the individual species. *Plate* 51 and *Plate* 52 show in detail the structure on the urosome of a male *C. bradyi* from Mombasa, Kenya. The granular structure on the first 2 abdominal segments (Ur_1, Ur_2) has been illustrated in literature (Grice, 1963) and considered as a diagnostic character for the species but there is no further detail provided.

Viewed dorsally, the surfaces of each of the first four metasomes (Me_{1-4}) of *Candacia* and *Paracandacia* have sensillae arranged in a bilaterally symmetrical pattern. For example in addition to sensilla, the male *C. ethiopica* has a spectacular bilaterally symmetrical pattern of ornamentation (see *Plate* 53 and *Plate* 54). In comparison, the ornamentation on *C. simplex* is less pronounced. SEM examination revealed regular patches of spinules arranged in a uniform pattern of ornamentation. On each metasome of *C. ethiopica*, the patches occur in pairs each separated by two sensillae. The spinules can be described as rigid structures rising from the integument and pointing obliquely posteriad.

Biometric measurements

Various body lengths were measured on several specimens of *Candacia* and *Paracandacia* as defined and illustrated in Fig. 10.5. Results of these measurements are compiled in Table 10.1. These copepods are characterised by long antennules that extend beyond the total body length (Lt). The main observation from the body measurements was that the sizes of different species of *Candacia* and *Paracandacia* tended to approximately lie within a defined size range. The species can be categorised as large, small or intermediate. The Lt of larger candaciids such as *C. magna*, *C. curta*, *C. bipinnata* and *C. elongata* ranged from 2.25 mm to more than 3.00 mm. Total lengths of the smallest ones such as *C. bradyi*, *C. guggenheimi*, *P. bispinosa* and *P. simplex* ranged from less than 1.55 mm to 2.00 mm. The rest are intermediate.

Due to the wide overlap in the sizes of individual specimens, it is evident that such classical biometric measurements on their own are not entirely reliable to accurately distinguish and identify Candaciidae.

10.4 Discussion

Candacia and *Paracandacia* are very rare in zooplankton samples obtained from creeks and bays of Kenya (Okemwa, 1990; Osore, 1994). They are however, common and widely distributed near shore and offshore in the western Indian Ocean (Jones, 1966; Lawson, 1977). Apart from being strict carnivorous (Arashkevich, 1969; Itoh, 1970) members of the two genera comprise some of the most selective feeders of all the known copepods. For example *C. bipinnata* predate on other copepods, larvacea (Ohtsuka & Onbé, 1989; Ohtsuka & Kubo, 1991) and even on the larger Chaetognatha. The nauplii of *Candacia,* however, do not feed (Sekiguchi, 1974). Observations using SEM indicate that the sharp mandibular blades of Candacia are suitable for piercing and cutting rather than crushing and grinding as is the case with other carnivorous copepods (Ohtsuka & Onbé, 1989).

Results obtained from using SEM have provided substantial new information that can be interpreted in function of copepod ecology and systematics. Examples of this information include the feeding habits of genera *Candacia* and *Euaugaptilus,* which was investigated by Matsuura & Nishida (2000) and the discovery of minute structures of taxonomic value on the genital segments of females of genus *Pontellina* in the study by Hulsemann & Fleminger (1990). Other studies include identification and description of previously undetected integumental structures on the antennule of the copepod *Gaussia* by Saraswathy & Bradford (1980). Paffenhöffer & Loyd (1999; 2000) also reported their observations of the cephalic appendages of some copepod species of *Centropages*, *Eucalanus*, *Paracalanus* and *Temora* using both SEM and TEM and described possible functions of the newly observed fine structures.

We are convinced that some of the fine structures reported here on Candaciidae will contribute towards future taxonomic studies of this group. Several species of copepods possess integumental microcharacters or specialised regions on the cuticle whose function is still unknown. The first task we have accomplished in our investigations is to establish the

presence of these specialised integumental characters and to describe them in detail prior to suggesting their possible functions. In our present work, we have illustrated and described some of these characters. In some cases we have made comparisons and references to similar characters that have been observed on other copepods. In the next step we hope to compile a list of the character states that are possessed by each species and thereafter attempt to distinguish the species based on these characters.

In copepods and generally in crustaceans, there are various types of rostra. In decapods, they all posses a common structure composed of the sensory pore X organ (SPX-organ) whose three constituents are: the main sensory part, the lateral sensory pore and the independent organ of Bellonci (Hosfeld, 1996; Mauchline, 1998). Early workers were unable to detect the rostrum on Candaciidae and explicitly stated that is was absent (e.g. Mori, 1964 pp. 77, 78). Later, subsequent work has confirmed that these copepods indeed posses a rostrum (Bradford-Grieve, 1994; 1999). However, prior to our investigations there was no mention of the existing types and their structural appearance. We observed two types of rostra – one ending with a single protrusion and the other with two. On the surface, both types were composed of a pair of frontal double-sensilla situated above a median pore; this pattern was consistent in all the specimens we observed. It has been suggested (Hosfeld, 1996) that in copepods, a bifurcated rostrum with paired filaments seems to be the plesiomorphic state whereas the unpaired rostrum represents the modified and derived state. We did not test this hypothesis in our study but the importance of the rostrum in copepod phylogeny and systematics has been demonstrated elsewhere. Studies on the rostral structure of the cyclopoid copepods have revealed important results in the systematics of this group. The rostral pore signature together with the pattern of the integumental ultrastructure has recently been used to distinguish species and generic pattern in Cyclopidae (Baribwegure *et al.*, 2001).

Sexual dimorphism in Candaciidae is expressed in various secondary sexual characters. The characteristics in the males include the specialised fifth pair of thoracic legs (P_5) that have evolved into copulatory appendages (the right foot ending in either a chela as in *Candacia* or a long seta seen on *Paracandacia*). Secondly, the urosome comprises of five somites with, as we have also shown, distinct patterns of ornamentation. Thirdly, a pair of asymmetrical antennules (A1) with geniculation (hinge) on the right antennule, one or more segments indented or swollen and sometimes with a 'comb structure' on segments 17, 18 and 19.

Closer observations of the 'comb structure' revealed that they are not simple structures but possibly modified hyaline membranes that coalesce to form a broad base and narrow apex (*Plate* 12, *Plate* 13). According to observations by Corni *et al.* (2001) the "comb structure" of male *T. turbinata* that come into contact with the female urosome during copulation not only perform purely mechanical function "...but may also detect chemical cues that stimulate spermatophore transfer...". Most probably it is the presence of the aesthetascs adjcacent to the "comb structure" (see *Plate* 12 and *Plate* 13) that enable the detection of the chemical cues.

Apart from a vague indication of the presence of the pore on the P_1 in drawings of Candaciidae provided by Lawson (1973b), neither the shape nor the functions of this pore are explicitly documented anywhere else in literature to the best of our knowledge. Vaupel-Klein (1982a) observed similar pores on swimming legs of various species of the calanoid *Euchirella*. Such pores are also noticeable on harpacticoid copepods (Dr Frank Fiers, Pers. Comm.) but they lack the structural distinctiveness and are not surrounded by setae. It is possible that the pore is a common feature in copepods and is only visible at such high magnifications. However, in the case of our specimens of Candaciidae, it was uniquely present on the right first swimming leg (P_1) and only at a particular location (En_3P_1).

The general morphology of the female external genital area in Candaciidae varied in shape from regular cylindrical, cuboidal or trapezoid. The female specimens we observed here have a ventral genital double somite, typical of most calanoids (*Plate* 55, *Plate* 56 and *Plate* 57). They have gonopores close together and totally covered by a single genital operculum. They lack seminal receptacles but instead they possess genital atria, which according to Barthélémy *et al.* (1998) perform a similar function of storing seminal products discharged from the spermatophores. From the dorsal view, the genital double somite was symmetrical in some species (*Plate* 58) and asymmetrical or slightly asymmetrical in others (*Plate* 40). On the contrary, the males' first urosome (Ur_1) was always asymmetrical (e.g. *Plate* 45, *Plate* 59). The genital field, located ventrally on the genital double somite was positioned either posteriorly (as in *P. simplex*) or medially (*C. elongata*). The present study did not examine the internal genital area, however, from our literature survey, some previous SEM observations by Cuoc *et al.* (1997) revealed that female *Candacia simplex* have paired egg-laying ducts under the genital operculum. It would be of taxonomic value and interest in studies of phylogeny to investigate whether this arrangement of the genital field is similar in *Paracandacia* as well. Examination of the fine structures of the female genital segment is

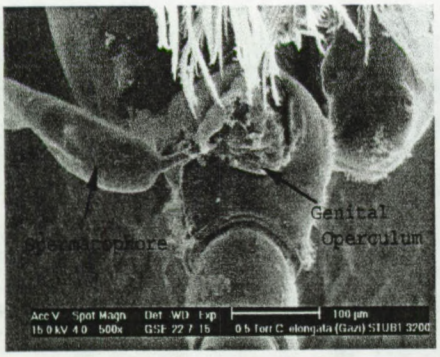


Plate 55: The external genital structure of *P. simplex* female displaying the genital operculum and direct placement of the male spermatophore.

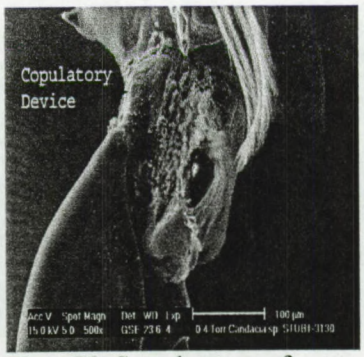


Plate 56: Complex type of spermatophore with coupling device attached to female genital double somite.

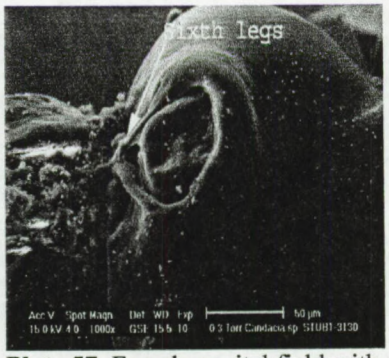


Plate 57: Female genital field with remnants of the sixth legs forming part of the genital apparatus.

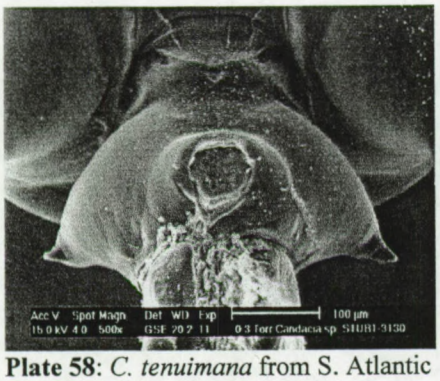


Plate 58: *C. tenuimana* from S. Atlantic Ocean presents symmetrical genital double somite observed in females.

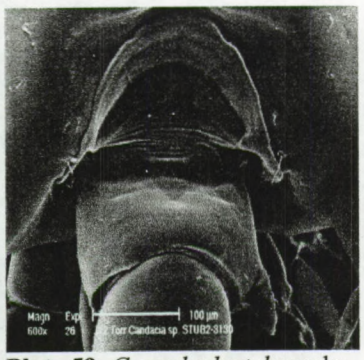


Plate 59: *C. pachydactyla* male from S. Atlantic shows example of asymmetrical Ur_1 observed in all male Candaciidae.

Plates 55-59: Scanning electron micrographs showing the urosome and the genital double somite of some Candaciidae.

now becoming routine procedure in copepod taxonomic studies and producing useful information (see e.g. Barthélémy *et al.*, 1998a, b; Barthélémy, 1999).

Information on the importance of the cuticular pattern on the female genital somite in relation to successful copepod mating and reproduction is well documented by Hulsemann & Fleminger (1990) and Cuoc *et al.*, (1997). During mating the male must position the spermatophore correctly. Therefore, the morphology of the genital double somite and the presence and pattern of integumental structures play an essential role in the recognition of the spermatophore fixation site close to or on the copulatory pores (Vaupel-Klein, 1982a; Hulsemann & Fleminger 1990). In Candaciidae, therefore, the different patterns of ornamentations that we observed on the female genital somite may provide some form of species-recognition to the potential mate that result in successful mating.

From our SEM observations, spinules occur virtually everywhere on the dorsal, ventral and pleural surfaces of the urosome of Candaciidae. Workers in this field of study have often viewed the spinular pattern of the urosome with importance in females for reasons of mate recognition and successful reproduction as outlined above. An example is the study by Hulsemann & Fleminger (1990) on spinular pattern on the urosome of *Pontellina* females. In our study however, we observed that characteristic spinular patterns also occurred on the male urosome and we would propose the possible usefulness of this pattern in identification and/or for confirmatory purposes of individual species of Candaciidae. Indeed Lawson (1973a) using SEM techniques was able to distinguish *C. tuberculata*, which had erroneously been reported as *C. bradyi* from the Persian Gulf by Pesta (1941) and from the Sea of Japan by Tanaka (1964). This was achieved by successfully differentiating details of the fine structure of the protuberances of the male Ur_1 and the P_5 through SEM.

Candaciidae is among the most widely distributed group in the Indian Ocean (Lawson, 1977) with each species tending to occupy a particular niche or sympatric species sharing a niche. Morphological differences (at the ultrastructure scale) observed on the various species of Candaciidae in our study may present alternative barriers to hybridisation. This augments to the role mainly played by hormones as obstacle to hybridisation (Fleminger, 1973; Jacoby & Youngbluth, 1983; Vaupel-Klein, 1982a, b).

Like many other fine structures on Candaciidae, the dorsal hump is not specifically documented in literature although it is visibly indicated in drawings. Grice (1963), however, did not indicate it on drawings of *Candacia catula,* C. *bispinosa* and *P. simplex* (his Plate 31 no. 17 and Plate 32 nos. 7 and 15 respectively). Likewise, Owre & Foyo (1967) excluded the structure on drawings of females of *C. longimana*, *P. bispinosa*, and *P. simplex* (their Figs 662, 679 and 681 respectively) thus suggesting that females of these species lack the hump structure. Our investigations present the first description and documentation of this structure on Candaciidae (also according to Susumu Ohtsuka, Pers. Comm.). In our specimens, both the males and females of these species possessed the hump structure. The structure is unique because it presented a consistent pattern of pores and sensilla in all the specimens observed. In our observations there was high consistency in the number and location of pores and setae on this structure in both males and females specimens. This deserves further detailed investigations on the internal morphology of the structure with a view to establishing its biological importance to these copepods and its taxonomic relevance. The hump structure was present on individuals in late copepodid stages (CIV – CV) of our specimens but we did not investigate the presence of pore and pattern of setae on these stages. In studying developmental stages of some Candaciidae, Bernard (1964), did not indicate on his illustrations any evidence of the dorsal hump on the nauplii of *C. armata* and *C. bipinnata* up to stage CI. So we assume it may be absent at these early stages.

This is not, by any means, the complete list of all the possible characters we could observe on the Candaciidae specimens, there were many more but we have chosen to discuss these ones as preliminary results. Other similar fine structures that other workers have observed on copepods include "button setae" (Matsuura & Nishida, 2000) on the maxilla and maxillipeds of genus *Euaugaptilus,* which is also carnivorous like members of family Candaciidae. The caudal ramus of the copepods has also been proposed as another potential area of study especially in regards to the pore pattern of cyclopoids (Baribwegure *et al.*, 2001). In our study we did not investigate the fine structure of maxillipedes or the caudal rami.

Currently the most reliable and widely quoted species list of Candaciidae and key for species identification is the one based upon the revision of this group by Grice (1963) in which he recognised 34 species in the genus *Candacia* and 4 in *Paracandacia*. Our literature review revealed that there are now close to 80 species and sub-species of Candaciidae worldwide reported including unpublished reports and websites. Many of these are in fact synonyms of

the main species reported by Grice (1963), Jones (1966) and Lawson (1977). Indeed some like *C. aucta, C. clausii, C. nigrocincta, C. ornata* have been declared *nomino dubia* while others such as *C. violaceus, C. aethiopica* are *nomina nuda*. New information emanating from our study of the fine structure on the morphology of this group may suggest that if these microstructures are species specific then there are more species of Candaciidae than what we know at present. However, after completion of this investigation additional supportive information possibly from other sciences like molecular biology (Mauchline, 1998) must be included before any conclusions can be drawn. We would like to recognise the fact that it is becoming increasingly evident that future studies in copepod taxonomy will be enhanced by involving all the three useful methodologies widely available namely the classical description, the high resolution optical techniques and molecular biology. Unfortunately, the three are often used independently today.

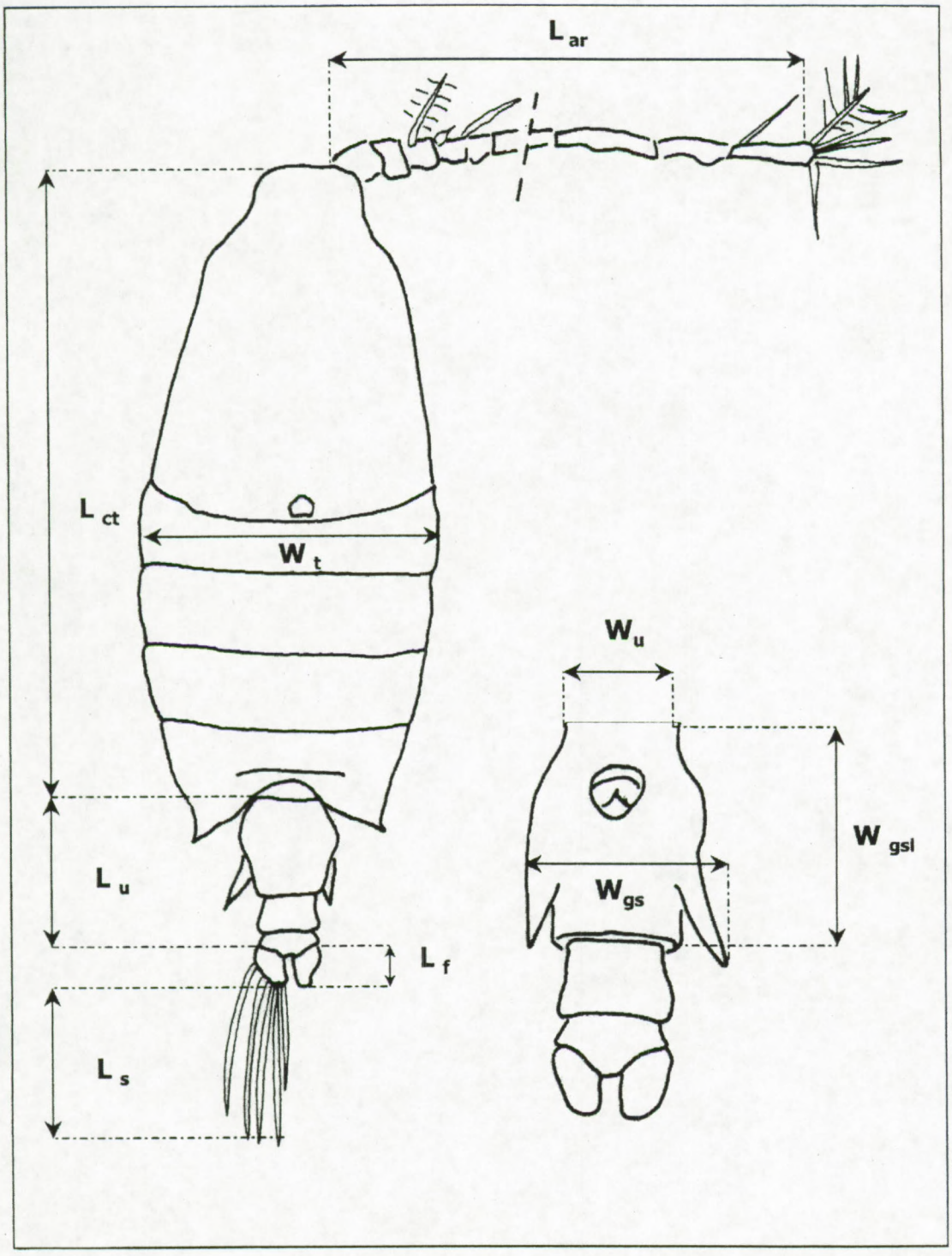


Fig. 10.5: Dorsal view of *Candacia pachydactyla* adult female showing lengths of measurements taken (Further information in the text).

Table 10.1 - BIOMETRY

BODY MEASUREMENTS OF CANDACIIDAE OBTAINED FROM VARIOUS LOCALITIES ALONG THE KENYA COAST(WESTERN INDIAN OCEAN) AND IN SOUTHERN ATLANTIC OCEAN

Key:

Lt = total body length (Lct+Lu)
Lct = cephalothorax length
Wt = widest cephalothorax width
Lu = urosome length
Wu = urosome width
Lf = furcal length
Ls = setal length
Lar = right antenula length
Lal = left antenula length
Wgs = genital segment width
Wgsl = genital segment length

ND = Not determined/measured
C = Copepodid stage
F, M = Female, Male

Sample ID & Locality		Lt	Lct	Wt	Lu	Wu	Lf	Ls	Lar	Lal	Wgs	Wgsl	Sex	Species
Atlantique Sud # 92 (southern Atlantic)														
	1	2.01	1.56	0.7	0.45	0.13	0.06	0.56	2.12	ND	0.23	0.12	ND	*C. ethiopica*
	2	2.21	1.82	0.9	0.39	0.2	0.11	0.39	2.24	ND	0.35	0.24	ND	ND
	3	2.19	1.76	1.1	0.43	0.25	0.09	0.52	2.46	ND	0.41	0.26	ND	ND
	4	2.02	1.52	0.74	0.5	0.16	0.05	0.5	2.12	ND	0.44	0.16	ND	ND
	5	2.19	1.81	1.05	0.38	0.19	0.09	0.24	ND	2.26	0.38	0.24	ND	ND
	6	2.26	1.83	1.22	0.43	0.24	0.15	0.45	ND	2.3	0.43	0.29	ND	*C. curta*
	7	2.08	1.63	0.73	0.45	0.14	0.07	0.52	ND	2.45	0.25	0.19	ND	ND
	8	2.1	1.75	1	0.35	0.21	0.09	0.39	2.1	ND	0.4	0.24	ND	ND
	9	2.11	1.78	0.88	0.33	0.2	0.1	0.45	2.26	2.34	0.34	0.18	ND	ND
	10	2.25	1.78	0.95	0.47	0.18	0.09	0.56	2.44	2.5	0.38	0.25	ND	*C. curta*
	11	2.16	1.63	0.68	0.53	0.15	0.09	0.45	2.43	2.5	0.24	0.12	ND	ND
	12	2.02	1.6	0.75	0.42	0.17	0.1	0.6	2.24	2.19	0.25	0.1	ND	ND
	13	2.21	1.86	0.78	0.42	0.19	0.14	0.33	2.47	2.7	0.35	0.26	ND	*C. curta*
Atlantique Sud # 91														
	1	2.19	1.66	0.71	0.53	0.18	0.13	0.66	2.57	2.32	0.26	0.18	ND	ND
	2	2.14	1.63	0.73	0.51	0.17	0.11	0.58	2.44	2.35	0.26	0.21	ND	ND
	3	2.23	1.8	1.01	0.43	0.21	0.08	0.5	2.59	ND	0.22	0.21	ND	*C. ethiopica*
	4	2.06	1.66	0.8	0.4	0.11	0.11	0.48	2.08	2.3	0.25	0.14	ND	*ND*
	5	1.75	1.33	0.78	0.42	0.14	0.1	0.49	ND	1.69	0.18	0.21	ND	*P. bispinosa*
	6	1.42	1.16	0.75	0.26	0.13	0.1	0.31	1.62	1.82	0.18	0.15	ND	*P. bispinosa*
	7	2.18	1.68	0.77	0.5	0.16	0.13	0.66	2.29	2.24	0.25	0.16	ND	*P. bispinosa*
	8	2.4	1.9	1.1	0.5	0.18	0.12	0.48	2.4	2.54	0.38	0.23	ND	ND
Mombasa Marine Park & Reserve stn 3														
	1	1.46	1.24	0.52	0.22	0.11	0.08	0.22	1.63	1.66	0.17	0.19	ND	*C. bradyi*
	2	2.04	1.62	0.68	0.42	0.12	0.09	0.42	1.92	1.88	0.15	0.16	ND	*C. bradyi*
	3	1.82	1.23	0.48	0.59	0.11	0.1	0.4	1.83	1.55	ND	ND	ND	*C. bipinnata*
	4	1.62	1.19	0.54	0.43	0.1	0.07	0.43	1.61	1.77	0.17	0.16	ND	*C. catula*
	5	1.99	1.59	0.73	0.4	0.13	0.08	0.36	ND	ND	0.19	0.25	ND	*C. bradyi*
	6	2.35	1.82	0.88	0.53	0.16	0.1	0.55	ND	ND	0.26	0.31	ND	*C. bipinnata*
	7	1.07	0.76	0.39	0.31	0.13	0.1	0.38	ND	ND	0.13	0.11	ND	*C. bradyi*
	8	1.62	1.19	0.48	0.43	0.12	0.07	0.38	ND	ND	0.18	0.12	ND	*C. catula*
	9	1.39	1.03	0.42	0.36	0.1	0.06	0.37	1.41	1.31	0.13	0.11	ND	*C. bradyi*
	10	1.52	1.18	0.5	0.34	0.1	0.08	0.42	ND	1.48	0.18	0.19	ND	*C. bradyi*
Atlantique Sud IG 1153 9/II/38														
	1	2.7	2.06	0.84	0.64	0.15	0.11	0.41	2.71	ND	0.26	0.33	ND	ND
	2	2.48	1.97	0.79	0.51	0.18	0.08	0.33	2.01	1.89	0.28	0.25	ND	*C. paenelongimana*
	3	2.67	2.05	1.01	0.62	0.17	0.04	0.6	2.68	2.69	0.26	0.37	ND	*C. elongata*
	4	2.2	1.68	0.99	0.55	0.17	0.1	0.4	2.03	1.9	0.24	0.3	ND	ND
	5	2.74	2.19	0.64	0.55	0.23	0.07	0.63	2.55	ND	0.26	0.38	ND	*C. elongata*
	6	2.35	1.99	1.2	0.36	0.18	0.09	0.5	2.14	1.93	0.31	0.28	ND	*C. pachydactyla*
	7	2.34	1.87	0.82	0.57	0.17	0.09	0.61	2.28	1.85	0.28	0.5	ND	*C. tenuimana*
	8	2.34	1.76	0.84	0.58	0.16	0.06	0.54	2.43	2.29	0.22	0.23	ND	ND
	9	2.39	1.81	1.08	0.43	0.2	0.09	0.5	1.9	1.86	0.25	0.27	ND	*C. paenelongimana*
	10	1.56	1.24	0.63	0.32	0.14	0.08	0.39	1	1.43	0.18	0.2	ND	ND
	11	2.07	1.6	0.68	0.47	0.19	0.07	0.48	ND	2.23	0.26	0.14	ND	ND
	12	2.5	1.92	1.1	0.58	0.18	0.09	0.6	2.09	2	0.36	0.31	ND	ND
	13	2.28	1.78	0.92	0.5	0.16	0.12	0.45	2.03	2	0.29	0.3	ND	*C. tenuimana*
	14	2.19	1.73	0.88	0.46	0.24	0.08	0.49	2.07	2.16	0.27	0.27	ND	*P. truncata*

Table 10.1 - BIOMETRY(continuation)

Sample ID & Locality	Lt	Lct	Wt	Lu	Wu	Lf	Ls	Lar	Lal	Wgs	Wgsl	Sex	Species
Atlantic Sud IG 1153 9/II/38 (Continuation...)													
15	1.6	1.3	0.71	0.3	0.17	0.07	0.48	1.43	1.4	0.2	0.23	ND	*P. truncata*
16	2.5	1.94	0.79	0.56	0.19	0.09	0.68	2.66	2.59	0.36	0.23	ND	ND
17	2.29	1.76	0.86	0.53	0.2	0.08	0.52	1.98	1.96	0.47	0.34	ND	*C. pachydactyla*
18	2.29	1.78	0.86	0.51	0.18	0.07	0.57	1.98	2.09	0.29	0.35	ND	*C. pachydactyla*
19	2.4	1.83	0.85	0.57	0.21	0.09	0.52	2.28	1.96	0.31	0.33	ND	ND
20	2.5	1.92	0.81	0.58	0.21	0.07	0.64	2.41	ND	0.31	0.21	ND	ND
21	1.98	1.58	0.69	0.4	0.19	0.08	0.45	ND	ND	0.32	0.16	ND	ND
22	2.48	1.97	0.84	0.51	0.19	0.06	0.61	2.24	2.14	0.29	0.34	ND	*C. elongata*
23	2.94	2.27	1.18	0.67	0.22	0.08	0.69	2.46	2.72	0.24	0.39	ND	*C. elongata*
24	2.28	1.82	0.92	0.46	0.24	0.11	0.59	2.7	1.57	0.31	0.29	ND	*C. bipinnata*
25	1.89	1.39	0.6	0.5	0.12	0.11	0.44	ND	1.08	0.19	0.14	ND	*P. bispinosa*
26	2.4	1.92	0.97	0.48	0.19	0.11	0.58	ND	ND	0.29	0.33	ND	ND
27	2.14	1.71	0.97	0.43	0.24	0.1	0.53	2	1.94	0.3	0.27	ND	*C. pachydactyla*
28	2.37	1.83	0.96	0.54	0.54	0.07	0.51	1.98	ND	0.3	0.3	ND	*P. truncata*
29	2.39	1.78	0.91	0.61	0.19	0.11	0.56	2.02	1.99	0.33	0.33	ND	*P. truncata*
30	2.4	1.92	0.98	0.48	0.23	0.09	ND	2.09	ND	0.3	0.26	ND	*C. bipinnata*
31	1.57	1.29	0.66	0.28	0.14	0.05	0.38	1.34	1.36	0.13	0.14	ND	ND
32	2.11	1.7	0.88	0.41	0.18	0.08	0.52	1.99	1.85	0.25	0.27	ND	*C. ethiopica*
33	2.48	1.86	0.98	0.62	0.13	0.1	0.59	ND	ND	0.3	0.36	ND	ND
34	2.43	1.94	0.91	0.55	0.23	0.07	0.54	1.99	2.09	0.34	0.49	ND	*C. varicans*
35	2.39	1.91	0.8	0.48	0.18	0.08	0.46	ND	2.03	0.31	0.38	ND	*C. varicans*
36	2.21	1.85	0.91	0.36	0.23	0.12	0.56	2.08	1.61	0.26	0.29	ND	*C. varicans*
37	2.56	1.87	1.06	0.69	0.17	0.14	0.59	ND	ND	0.28	0.31	ND	*C. bipinnata*
Yucatan IX sEst viii.60 19/07/90 (southern Atlantic)													
1	2.08	1.6	0.72	0.48	0.18	0.06	0.47	2.06	2.1	0.19	0.17	ND	*C. longimana*
Yucatan VIII 80 (36) 20/07/90													
1	2.84	1.99	1.43	0.85	0.2	0.07	0.63	2.25	2.44	0.28	0.34	F	ND
2	2.69	1.84	0.85	0.65	0.16	0.08	0.62	2.42	2.57	0.27	0.3	M	ND
3	2.42	1.73	0.69	0.79	0.18	0.07	0.53	2.07	2.35	0.23	0.18	M	ND
4	1.87	1.28	0.52	0.59	0.13	0.05	0.45	1.73	1.68	0.28	0.33	M	ND
5	2.46	1.93	0.63	0.53	0.2	0.08	0.63	ND	ND	0.28	0.31	F	ND
6	2.78	2.25	0.87	0.53	0.19	0.08	0.53	2.42	2.46	0.28	0.31	F	ND
7	2.5	1.96	0.78	0.54	0.14	0.09	0.58	2.5	2.37	0.23	0.29	F	ND
8	2.08	1.68	0.7	0.4	0.14	0.09	0.56	2.09	2.23	0.22	0.25	F	*C. longimana*
9	1.4	1.13	0.51	0.27	0.1	0.04	0.33	1	1.09	0.14	0.17	F	ND
10	1.73	1.39	0.48	0.34	0.13	0.06	0.04	1.46	1.54	0.23	0.18	ND	*P. simplex*
11	1.76	1.33	0.59	0.48	0.14	0.05	0.42	1.68	1.78	0.17	0.09	M	*P. simplex*
12	1.62	1.32	0.4	0.3	0.11	0.04	0.41	1.32	1.52	0.21	0.17	F	*P. simplex*
13	1.74	1.28	0.43	0.46	0.12	0.04	0.46	1.62	1.76	0.13	0.13	M	*P. simplex*
14	1.68	1.3	0.58	0.38	0.1	0.04	0.38	1.58	1.66	0.16	0.14	M	*P. simplex*
15	2.16	1.33	0.83	0.33	0.11	0.06	0.41	ND	ND	0.22	0.19	F	*P. simplex*
16	1.71	1.24	0.43	0.47	0.09	0.05	0.44	1.72	1.78	0.14	0.08	M	*P. simplex*
17	1.85	1.44	0.57	0.41	0.13	0.04	0.34	ND	1.47	0.21	0.19	F	*P. simplex*
18	1.72	1.39	0.8	0.33	0.13	0.05	0.36	1.37	1.47	0.23	0.18	F	*P. simplex*
19	1.51	1.16	0.35	0.39	0.11	0.04	0.43	1	1	0.15	0.15	ND	*P. simplex*
20	2.23	186	0.83	0.48	0.17	0.09	0.53	2.28	2.28	0.24	0.23	F	ND
21	2.18	1.87	0.69	0.65	0.14	0.08	0.59	2.23	2.55	0.2	0.17	F	ND
Yucatan IX 60 (47) 22/07/90 hora 2:53													
1	2.52	1.87	0.69	0.65	0.14	0.08	0.59	2.23	2.55	0.2	0.17	M	*P. truncata*
2	1.85	1.4	0.7	0.45	0.13	0.04	0.48	1.67	1.77	0.16	0.12	M	*P. truncata*
3	2.07	1.5	1	0.57	0.17	0.07	0.53	1.94	1.94	0.29	0.33	F	*P. truncata*
4	1.7	1.25	0.84	0.45	0.16	0.07	0.23	1.58	1.64	0.19	0.26	F	*P. truncata*
5	1.85	1.46	0.7	0.39	0.12	0.07	0.35	1.71	1.71	0.21	0.27	F	ND
6	2.44	1.88	0.84	0.56	0.17	0.06	0.54	2.36	ND	0.25	0.23	M	ND
7	1.97	1.56	0.72	0.41	0.11	0.08	0.37	1.88	1.73	0.24	0.23	F	*P. bispinosa*
8	1.85	1.43	0.67	0.42	0.13	0.07	0.46	ND	ND	0.28	0.2	M	*P. bispinosa*
9	1.77	1.34	0.66	0.42	0.11	0.06	0.34	1.54	1.62	0.25	0.2	F	*P. bispinosa*
10	1.68	1.31	0.63	0.38	0.13	0.06	0.36	1.54	1.57	0.21	0.21	F	*P. bispinosa*
11	1.65	1.3	0.54	0.35	0.14	0.05	0.38	1.54	ND	0.21	0.18	F	*P. bispinosa*
12	1.91	1.42	0.64	0.49	0.1	0.04	0.44	1.7	ND	0.16	0.16	M	*P. bispinosa*
13	1.65	1.27	0.6	0.38	0.11	0.05	0.44	1.56	ND	0.21	0.17	F	*P. bispinosa*
14	1.9	1.38	0.53	0.52	0.1	0.06	0.41	1.8	1.8	0.14	0.15	M	ND
15	2.02	1.62	0.7	0.4	0.15	0.18	0.24	1.73	1.61	0.23	0.25	F	ND
16	2	1.54	0.78	0.46	0.13	0.07	0.41	ND	ND	0.23	0.25	F	ND
17	1.89	1.49	0.53	0.4	0.13	0.08	0.45	1.62	1.64	0.21	0.23	F	ND
18	1.96	1.45	0.56	0.51	0.11	0.06	0.42	1.62	ND	0.15	0.13	M	ND
19	1.84	1.4	0.75	0.44	0.13	0.06	0.43	1.61	1.48	0.23	0.25	F	ND

Table 10.1 - BIOMETRY(continuation)

Sample ID & Locality	Lt	Lct	Wt	Lu	Wu	Lf	Ls	Lar	Lal	Wgs	Wgsl	Sex	Species
Bottle 48 stn 117 100 - 0m NIOP 1992/93 Kenya coast													
1	2.01	1.58	0.61	0.43	0.13	0.04	0.38	ND	ND	0.18	0.18	F	*P. truncata*
2	2.04	1.51	0.58	0.53	0.1	0.06	0.42	ND	2.04	0.15	0.14	C	*P. truncata*
3	2.06	1.46	0.62	0.6	0.12	0.08	0.47	1.85	2.04	0.14	0.15	M	*C. tenuimana*
4	1.64	1.58	0.54	0.6	0.12	0.06	0.18	1.44	ND	0.16	0.15	M	*P. truncata*
5	1.83	1.51	0.86	0.32	0.11	0.06	0.38	0.71	ND	0.19	0.26	F	*P. simplex*
6	1.89	1.51	0.86	0.38	0.16	0.06	0.31	ND	ND	0.19	0.18	M	*P. truncata*
7	2.34	1.87	0.67	0.47	0.1	0.08	0.41	1.86	ND	0.22	0.2	M	*P. truncata*
8	1.83	1.58	0.65	0.25	0.12	0.06	0.44	ND	1.8	0.17	0.21	F	*P. simplex*
9	1.91	1.39	0.45	0.52	0.11	0.08	0.41	1.82	ND	0.14	0.11	M	ND
10	1.45	1.06	0.44	0.39	0.09	0.09	0.28	1.22	1.25	0.11	0.09	C	ND
Bottle 11 stn 533 NIOP 1992/93 Kenya coast													
1	1.92	1.44	0.72	0.48	0.15	0.09	0.23	ND	ND	0.18	0.17	CV M	*C. curta*
2	1.83	1.46	0.63	0.37	0.14	0.08	0.3	1.73	1.66	0.6	0.15	F	*P. bispinosa*
3	3.09	2.64	0.62	0.45	0.14	0.06	0.35	1.82	1.39	0.19	0.21	F	*C. magna*
4	1.87	1.44	0.72	0.43	0.14	0.07	ND	ND	ND	0.2	0.25	CV F	*P. bispinosa*
5	1.99	1.6	0.64	0.39	0.13	0.05	0.45	ND	ND	0.19	0.2	F	*P. truncata*
6	2.13	1.6	0.53	0.53	0.12	0.06	0.46	ND	ND	0.15	0.15	M	*C. longimana*
7	1.74	1.3	0.57	0.44	0.11	0.07	0.42	ND	ND	0.17	0.26	F	*P. bispinosa*
Bottle 27 stn 518 200-0m NIOP 1992/93 Kenya coast													
1	1.94	1.41	0.78	0.53	0.16	0.08	0.45	1.7	1.78	0.19	0.42	C	*C. guggenheimi*
2	1.76	1.36	0.68	0.4	0.14	0.09	0.44	1.61	1.68	0.18	0.26	C	*P. simplex*
3	1.98	1.54	1.1	0.44	0.18	0.08	0.59	1.87	1.88	0.24	0.27	C	*C. guggenheimi*
4	1.54	1.26	0.62	0.28	0.14	0.1	0.27	1.49	1.49	0.17	0.23	C	*C. discaudata*
5	2.32	1.75	0.7	0.57	0.12	0.09	ND	1.46	1.29	0.21	0.3	C	*C. longimana*
6	1.31	0.98	0.6	0.33	0.12	0.07	0.3	1.1	1.25	0.1	0.13	C	*C. longimana*
7	2.13	1.7	0.74	0.43	0.17	0.05	0.43	1.39	1.9	0.23	0.22	F	*P. simplex*
8	2.16	1.56	0.58	0.6	0.14	0.05	0.42	1.92	2.06	0.17	0.14	M	*P. truncata*
9	1.684	1.344	0.49	0.34	0.1	0.07	0.36	1.22	1.49	0.156	0.21	F	*C. discaudata*
10	1.639	1.272	0.58	0.367	0.12	0.06	0.39	ND	ND	0.137	0.104	C	*P. simplex*
11	1.767	1.32	0.735	0.447	0.141	0.85	0.396	1.66	1.63	0.184	0.165	C	*C. guggenheimi*
12	1.957	1.56	0.433	0.397	0.104	0.523	0.32	1.39	1.42	0.122	0.104	M	*C. catula*
13	2.022	1.632	0.725	0.39	0.155	0.85	0.367	1.9	1.82	0.226	0.245	F	*P. truncata*
14	1.51	1.2	0.5	0.31	0.104	0.57	0.377	1.57	ND	0.17	0.16	F	*C. longimana*
Bottle 46 stn 507 400-0m NIOP 1992/93 Kenya coast													
1	2.03	1.64	0.89	0.39	0.166	0.09	0.37	ND	ND	0.31	0.18	M	*C. curta*
2	2.13	1.54	0.71	0.59	0.12	0.1	0.3	ND	1.66	0.21	0.22	M	*C. curta*
3	2.06	1.52	0.56	0.54	0.13	0.17	0.21	1.01	0.93	0.15	0.28	F	*C. longimana*
Bottle 18 stn 528 NIOP 1992/93 Kenya coast													
1	2.67	1.94	0.97	0.73	0.26	0.18	0.71	3.01	2.66	0.29	0.23	M	*C. bipinnata*
2	2.38	1.72	0.89	0.66	0.2	0.07	0.66	1.94	ND	0.28	0.34	F	*C. bipinnata*
3	2.7	2.01	0.95	0.69	0.27	0.15	0.66	2.38	ND	0.37	0.24	M	*C. bipinnata*
Bottle 11 stn 105 50-150 m NIOP 1992/93 Kenya coast													
1	1.86	1.39	0.73	0.47	0.59	0.08	0.46	1.68	1.87	0.21	0.15	M	*C. bradyi*
2	1.78	1.39	0.64	0.39	0.13	0.06	0.53	ND	1.51	0.22	0.23	ND	*C. bradyi*
Bottle 69 stn 131 300-200 m NIOP 1992/93 Kenya coast													
1	1.4	1.03	0.41	0.37	0.12	0.08	0.48	1.49	1.39	0.21	0.25	F	*C. tenuimana*
Bottle 75 stn 132 200-0 m NIOP 1992/93 Kenya coast													
1	1.99	1.46	0.83	0.53	0.15	0.09	0.35	ND	1.9	0.48	0.3	M	*P. simplex*
2	1.91	1.51	0.8	0.4	0.12	0.08	0.45	2.01	1.8	0.55	0.31	F	*P. simplex*
3	1.36	1	0.52	0.36	0.09	0.08	0.29	1.32	ND	0.31	0.11	M	*P. bispinosa*
4	1.95	1.56	0.8	0.39	0.13	0.09	0.4	ND	1.78	0.53	0.39	F	*P. simplex*
5	1.45	1.15	0.66	0.3	0.09	0.06	0.09	1.22	1.22	0.36	0.1	CV	*P. simplex*
6	1.98	1.58	0.85	0.4	0.14	0.06	0.39	ND	ND	0.6	0.3	F	*P. simplex*
7	1.87	1.48	0.93	0.39	0.15	0.1	0.38	1.8	1.63	0.67	0.33	F	*P. simplex*
8	1.43	1.2	0.63	0.23	0.12	0.11	0.27	1.39	ND	0.48	0.23	CV	*P. bispinosa*
9	1.76	1.46	0.65	0.3	ND	ND	ND	1.87	ND	ND	ND	ND	ND
10	1.91	1.56	0.9	0.35	0.13	0.08	0.41	ND	1.87	0.65	0.25	F	*C. guggenheimi*
11	1.04	0.84	0.52	0.2	0.09	0.07	0.2	ND	0.93	0.36	0.15	CV	ND
12	1.69	1.22	0.65	0.47	0.13	0.09	0.43	1.39	1.46	0.55	0.16	M	*P. truncata*
13	2.05	1.58	0.9	0.47	0.12	ND	ND	ND	1.84	0.6	0.26	F	*C. pachydactyla*
14	1.6	1.17	0.65	0.43	0.11	0.09	0.43	1.41	1.51	0.5	0.36	M	*P. simplex*
15	1.31	1	0.56	0.31	0.08	0.06	0.31	1.22	ND	0.36	0.24	M	ND

Table 10.1 - BIOMETRY(continuation)

Sample ID & Locality	Lt	Lct	Wt	Lu	Wu	Lf	Ls	Lar	Lal	Wgs	Wgsl	Sex	Species
Bottle 75 stn 132 200-0 m NIOP 1992/93 Kenya coast (Continuation ...)													
16	1.37	1.1	0.73	0.27	0.09	0.09	ND	1.29	1.2	0.43	0.21	CV	*P. simplex*
17	1.25	1	0.59	0.25	0.09	0.06	0.25	1.12		0.41	0.23	F	*P. simplex*
18	1.44	1.15	0.64	0.29	0.13	0.11	0.28	1.46	1.46	0.54	0.24	F	*P. simplex*
19	1.49	1.17	0.65	0.32	0.13	0.14	0.25	1.99	1.53	0.52	0.23	F	ND
20	2.06	1.46	0.92	0.6	0.13	0.09	0.37	ND	ND	0.25	0.23	F	*C. pachydactyla*
21	1.53	1.1	0.72	0.43	0.14	0.09	0.49	ND	ND	0.31	0.28	F	*P. simplex*
22	1.99	1.56	0.96	0.43	0.14	0.09	0.49	ND	ND	0.31	0.28	F	*C. catula*
23	1.36	1.1	0.65	0.26	0.11	0.1	0.25	1.48	1.32	0.19	0.18	F	*C. guggenheimi*
Bottle 41 stn 117 200-100 m NIOP 1992/93 Kenya coast													
1	1.77	1.41	0.74	0.36	0.13	0.08	0.36	1.75	1.76	0.23	0.26	F	*C. bradyi*
2	2.02	1.63	0.69	0.39	0.13	0.14	0.29	1.53	1.63	0.27	0.27	CV F	*C. bipinnata*
3	2.13	1.56	0.75	0.57	0.14	0.16	0.21	1.65	ND	0.23	0.23	CV F	*C. bipinnata*
Bottle 54 stn 506 600-400 m NIOP 1992/93 Kenya coast													
1	2.81	2.23	0.82	0.58	0.28	0.16	0.59	2.92	2.9	0.46	0.2	M	*C. catula*
Bottle 32 stn 117 200-100 m NIOP 1992/93 Kenya coast													
1	2.02	1.53	0.71	0.49	0.11	0.1	0.5	1.94	1.92	0.2	0.23	M	*C. bipinnata*
Bottle 10 stn 105 50-0 m NIOP 1992/93 Kenya coast													
1	1.91	1.44	0.61	0.47	0.19	0.11	0.51	1.37	ND	0.2	0.12	M	*C. varicans*
2	1.43	1.1	0.6	0.33	0.19	0.14	0.38	1.48	1.46	0.21	0.21	F	*C. discaudata*
3	1.46	1.15	0.5	0.31	0.1	0.13	0.28	ND	1.45	0.22	0.17	F	*C. bradyi*
4	1.96	1.58	0.65	0.38	0.12	0.1	0.42	2.02	1.82	0.28	0.2	F	*C. discaudata*
5	1.68	1.22	0.54	0.46	0.14	0.08	0.48	1.9	1.87	0.19	0.11	M	*C. discaudata*
6	1.38	1.1	0.51	0.28	0.12	0.09	ND	ND	1.17	0.2	0.15	CV F	*C. catula*
Bottle 55 stn 505 300-136 m NIOP 1992/93 Kenya coast													
1	1.98	1.58	0.72	0.4	0.16	0.11	0.5	1.68	2.14	0.32	0.25	M	*C. bradyi*
Bottle 8 stn 106 500-0 m NIOP 1992/93 Kenya coast													
1	1.92	1.37	0.72	0.55	0.08	0.11	0.49	1.7	2.13	0.24	0.21	M	*P. bispinosa*
2	2.24	1.75	0.74	0.49	0.16	0.09	0.52	1.92	2.06	0.21	0.12	M	*C. ethiopica*
3	1.74	1.39	0.66	0.35	0.13	0.16	0.24	1.68	ND	0.23	0.25	F	*C. ethiopica*
4	2.89	2.33	0.89	0.56	0.19	0.11	0.59	2.47	2.76	0.29	0.28	F	*C. magna*
5	2.21	1.82	0.81	0.39	0.17	0.15	0.51	2.21	1.78	0.24	0.27	F	*C. curta*
Bottle 42 stn 503 50-0 m NIOP 1992/93 Kenya coast													
1	1.83	1.49	0.62	0.34	0.17	0.1	0.41	ND	1.73	0.24	0.2	F	*P. truncata*
2	2.02	1.58	0.63	0.44	0.15	0.07	0.56	2.09	1.99	0.17	0.11	M	*P. truncata*
Bottle 13 stn 532 400-200 m NIOP 1992/93 Kenya coast (KIWAYU)													
1	1.86	1.44	0.64	0.42	0.16	0.1	0.43	1.63	1.73	0.17	0.13	CV	*C. curta*
2	1.89	1.46	0.64	0.43	0.18	0.1	0.51	ND	1.58	0.19	0.1	M	*C. curta*
3	1.77	1.46	0.74	0.31	0.16	0.15	0.35	2.02	1.56	0.2	0.23	F	*C. curta*
Bottle 28 stn 117 24hr NIOP 1992/93 Kenya coast (MALINDI)													
1	1.39	1.18	0.57	0.21	0.13	0.11	ND	ND	1.22	0.16	0.15	CV	*C. discaudata*
2	1.79	1.42	0.62	0.37	0.16	0.12	0.39	1.68	1.58	0.18	0.21	F	*C. tuberculata*
3	1.92	1.54	0.64	0.38	0.15	0.1	0.48	1.92	1.94	0.16	0.1	F	*C. tuberculata*
4	1.88	1.51	0.66	0.37	0.15	0.12	0.49	1.75	1.7	0.18	0.2	F	*P. truncata*
5	1.97	1.58	0.65	0.39	0.15	0.12	0.44	1.82	1.8	0.19	0.2	F	*C. tuberculata*
6	1.81	1.44	0.63	0.37	0.15	0.11	0.31	1.78	1.73	0.22	0.23	F	*C. varicans*
Bottle 9 stn 106 100-0 (GAZI) NIOP 1992/93 Kenya coast													
1	1.84	1.49	0.68	0.35	0.16	0.13	0.47	1.82	1.85	0.18	0.24	F	*C. tuberculata*
2	1.78	1.39	0.61	0.39	0.13	0.07	0.41	1.62	1.66	0.2	0.2	F	*C. tuberculata*
3	1.91	1.51	0.61	0.4	0.13	0.08	0.42	ND	ND	0.18	0.2	F	*C. varicans*
4	1.89	1.54	0.66	0.35	0.16	0.12	0.46	1.87	1.9	0.23	0.22	F	*C. tuberculata*
5	1.93	1.54	0.69	0.39	0.15	0.07	0.43	ND	1.9	0.2	0.22	F	*C. tenuimana*
6	1.93	1.49	0.64	0.44	0.14	0.08	0.47	ND	1.78	0.17	0.19	F	*C. tuberculata*
7	1.84	1.46	0.64	0.38	0.12	0.07	0.43	ND	1.92	0.2	0.17	F	ND
8	1.83	1.34	0.55	0.49	0.13	0.08	0.46	ND	ND	0.15	0.13	F	*C. tenuimana*

PART V

CHAPTER 11

General discussion and conclusions

General discussion and conclusions

Climatic conditions especially the seasonality of rainfall and the Monsoon winds as well as the ocean currents have great influence on the abundance and diversity of zooplankton off the Kenya coast.

The Kenya coast receives an annual rainfall of about 1,200 mm. The months of January and February, which are usually the driest, receive less than 15 mm of rainfall each. April and May, which are the wettest, receive about 200 mm of rainfall each. The rest of the months in the year receive an average of 50 – 100 mm each. During the hot months, the temperature in the coastal zone rises to over 32°C, while during the cool months the temperature is about 22°C.

Rainfall has strong impact not only in the functioning of Kenya's coastal marine environment but also on the national economy. Kenya experienced extraordinarily heavy rainfall between May 1997 and February 1998 due to the El-Niño weather phenomena. Normally, mid December to late March is the driest and hottest season. However, during this period the season turned out to be the wettest ever recorded in the country in the past several decades. This caused floods and landslides, which destroyed human and animal life, fertile farmlands, roads, railways and bridges and relocated telephone and power lines. The national economic loss has been estimated as about US $ 1 billion (Ngecu & Mathu, 1999).

The variations of the temperature of the ocean surface water reflect that of the prevailing atmospheric temperature. The ocean temperature is low (25 – 28°C) between May and September and it is high (29 – 32°C) from October to April. Dissolved oxygen ranges between 4 and 7 mg l^{-1} with low values recorded in Makupa Creek and occasionally in Mtwapa Creek. Both creeks receive considerable inputs of domestic and industrial wastes.

Among the measured environmental variables, salinity had the most significant influence on zooplankton abundance and distribution. Fresh water from rivers feeding into Gazi Bay and Mtwapa Creek were responsible for reducing salinity by a very wide range of up to 25 psu units (from 35 to 10 psu). This salinity decrease was often accompanied by a drastic reduction in the number of taxa and species present. Only those that could tolerate such low salinities were retained e.g. *Pseudodiaptomus* spp.

Usually the inter-monsoon period in April and the beginning of the SE Monson in May signalled the start of the long rains in Kenya. The rains rejuvenated the rivers and also caused streams of temporary rivers and surface runoff that carried nutrients from agricultural farmland to the shallow coastal areas. This general scheme of events was often followed by an increase in nutrients concentrations, phytoplankton and zooplankton. Peak zooplankton abundance in many areas was therefore expected around the rainy season. However, this was not the case in areas that lack rivers and considerable surface run off such as Mida and Makupa creeks.

The zooplankton community of the Kenya coast is very rich in terms of taxonomic groups and species. Seasonal variation in zooplankton abundance ranged from a maximum of 2,800 m^{-3} during the most productive period to around 200 m^{-3}. Based on information from the present study and others (e.g. Okemwa, 1990; Osore, 1994; Mwaluma, 2000) at least 300 zooplankton taxa have now been recorded off the Kenya coast since 1990. These have accordingly been updated in the databases (see section on Synopses). The main holoplanktonic and meroplanktonic groups and their relative abundance are shown in Fig. 11.1.

The most abundant and widely distributed holoplankton groups are Copepoda, Medusae, Chaetognatha, Appendicularia, Foraminifera, Siphonophora Ostracoda and Cladocera. The meroplankton groups are Gastropoda, Brachyura zoea, Caridea, Pisces eggs, Pisces larvae, Decapoda, Polychaeta and Isopoda.

Copepods are the most important group in terms of species richness, persistence, abundance and ecological significance. Their abundance comprised about 70% of all the zooplankton population. At least 200 species of pelagic copepods have been recorded in the inshore, near shore and offshore waters of the Kenya coast. Despite this high diversity, usually eight main copepod genera characterise this region, and accounted for more than 90% of the total copepod abundance. These are *Acrocalanus*, *Oithona*, *Acartia*, *Pseudodiaptomus*, *Undinula*, *Corycaeus*, *Tortanus* and *Oncaea*.

Copepods are present throughout the seasons in all the localities whereas other holoplankton and meroplankton groups have a marked temporal and spatial distribution. In the mangrove

dominated areas with seasonal rivers such as in Gazi Bay there was a marked increase in zooplakton abundance during the rainy season.

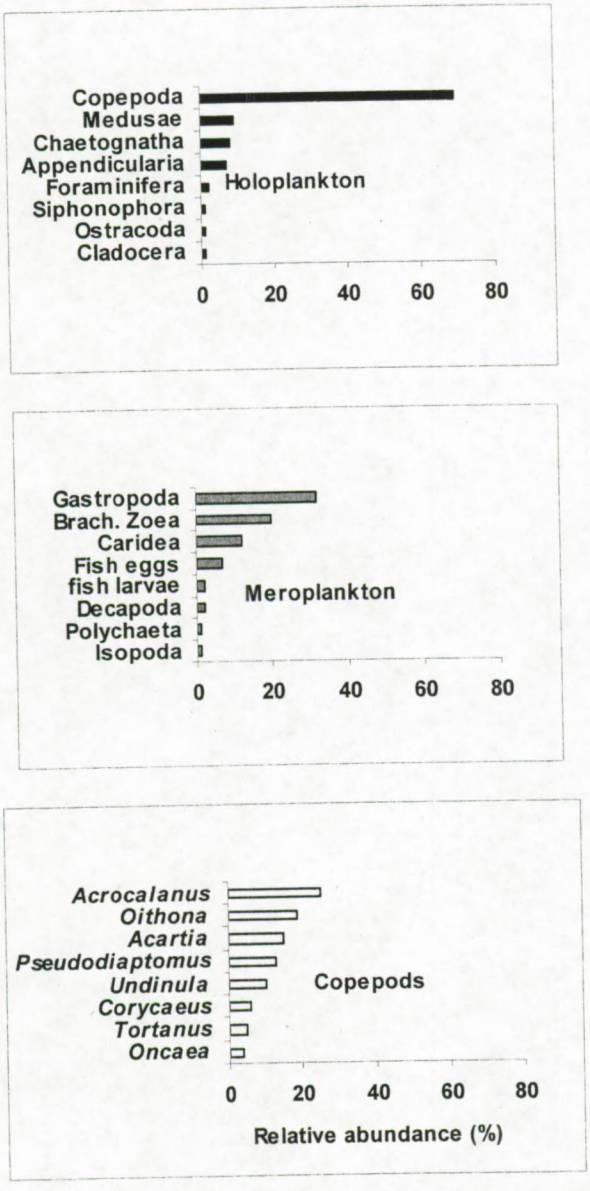


Fig.11.1: Relative abundance of the eight major taxa and species of holoplankton, meroplankton and copepods off the Kenya coast.

Much of the zooplankton was dominated by copepods of genera *Oithona*, *Acartia*, *Pseudodiaptomus* and *Undinula*. In degraded localities such as Makupa Creek zooplankton abundance was comparatively less. Meroplankton such as Brachyura zoea, Gastropoda larvae, Caridea larvae, Pieces eggs and larvae dominated the zooplankton population whereas copepods were relatively few and their diversity was less. In Mtwapa Creek, which also

experiences considerable degradation from human activities the zooplankton abundance was more than in Makupa and diversity was also higher. The geomorphology of Mtwapa Creek enables it to quickly and effectively exchange water with the adjacent open ocean. The Mombasa Marine Protected Area supports a high abundance and diversity of zooplankton as well as other fauna and flora. In Mida Creek there are no rivers, however there is abundant underground water seepage, which acts as a source of freshwater input. Therefore, unlike in the other mangrove creeks and bays off the Kenya coast, zooplankton abundance in Mida does not peak during the wet season.

Zooplankton abundance at night was up to four times higher in comparison with the daytime. Some of the areas studied during 24 hours sampling are too shallow for Diel Vertical Migration (DVM) to be the sole cause of high abundances at night. Therefore, Diurnal Horizontal Migration (DHM) was also proposed as a contributory factor responsible for the daily variation in zooplankton abundance. Results from studies in Gazi Bay, Mombasa Marine Park and Reserve lagoon and Mida Creek indicated that the diurnal variation in zooplankton abundance as well as diversity also depended on the orientation and phase of the prevailing tidal cycle.

Various zooplankton taxa exhibited gradients in abundance and diversity within the creeks and bays. These gradients were mainly attributed to variations in salinity and to a lesser extend other environmental variables. The abundance, diversity and distribution of calanoid copepods *Candacia* and *Paracandacia* were extensively investigated. Table 11.1 shows the characteristic species and their range in abundance in each oceanic zone off the Kenya coast. These copepods displayed peak abundance and high diversity in the shelf area of the coast and showed minimal abundance inshore and offshore. Of the 16 species that were found to occur off the Kenya coast, 6 were characteristic of the shelf waters.

Table 11.1: Distribution of *Candacia* and *Paracandacia* off the Kenya coast

	Inshore	**Shelf**	**Offshore and deep**
Characteristic Species	*C. catula, C. magna, C. tuberculata*	*C. bipinnata, C. bradyi, C. discaudata, C. tenuimana, C. vericans, P. truncata*	*C. curta, C. ethiopica, C. guggenheimi, C. longimana, C. pachydactyla, P. bispinosa, P. simplex*
Abundance range (no.100m^{-3})	9 to 240	40 to 360	10 to 40 and 11 to 20

The SE Monsoon tended to relocate these copepods offshore and also to increase their abundances. Abundance was substantially reduced during the NE Monsoon. This study reported for the first time the occurrence of *Candacia bradyi*, *C. bipinnata*, *C. curta* and *C. tuberculata* off the Kenya coast. Observed structural details of the rostrum, the antennule, the first pair of swimming legs and the genital segment provided ample additional information for distinguishing between species of *Candaciidae*. These and other minute details are most likely to be useful discriminatory feature in future taxonomic studies of this copepod group.

This study has broadly achieved its objectives. The conclusions can thus be summed up as:

- The assemblages of zooplankton that occur off the Kenya coast during different season and at various spatial scales have been described. Their abundance, diversity and distributions have been estimated. New information on the morphology and the local distribution of members of the copepod family Candaciidae has now been obtained.

- Zooplankton species lists, and the accompanying environmental variables and related information has been disseminated to the broader scientific and education community via the Darwin Initiative databases, scientific publications and via other fora.

- Results obtained from this research are currently in application locally, regionally and internationally.

Synopses: Practical application of the results of this Ph.D work

Application of results obtained from this Ph.D work is now in progress under several local, regional and international programmes. Below are examples of these programmes, their objectives and summaries of the status or the level of application of our zooplankton results.

1. Darwin Initiative on Conservation of Marine Biodiversity: Zooplankton biovariability in the Atlantic and Indian Ocean – CD ROM of zooplankton data from the Kenya coast

Following the United Nations Conference on Environment and Development (UNCED, the Earth Summit), held in Rio de Janeiro in June 1992, one of the outcomes of concerted efforts by nations of the world to promote environment protection was the agreement on Biodiversity Convention – also known as Convention on Biological Diversity (CBD). The aim of the CBD is to conserve the complete variety of life on earth. Under this Convention, one of the roles and prime responsibility of each nation is to provide strategies and plans for conservation and sustainable of their species and habitats. This is achieved through various ways including public education, information exchange between nations and technical and scientific co-operation.

The Darwin Initiative for the Survival of Species was formed to promote activities of the Biodiversity Convention. In this programme, which is managed by the UK government, British experts work in collaboration with developing country partners to build up biodiversity knowledge and expertise.

In 1999 I was invited to participate in the Darwin Initiative programme to contribute data and information that I was collecting for my PhD work regarding the zooplankton of the Kenya coast. This task involved processing zooplankton data from the Indian and Atlantic Oceans in collaboration with scientists from Plymouth Marine Laboratory (UK), Institute of Biology of the Southern Seas and Marine Hydrophysical Institute (Ukraine) and Smithsonian Tropical Research Institute (Panama). Inventories of zooplankton and related data have now been compiled and produced on CD ROM. These are also accessible at the following websites:

http://www.pml.ac.uk/diocean/gallery.html
http://www.pml.ac.uk/diocean/data.html

2. Marine Species Database for Eastern Africa (MASDEA): Database provides systematic list of species records and publications thereof in eastern Africa and the western Indian Ocean

This database is maintained in partnership between the Flanders Marine Institute (VLIZ) and the Kenya Marine and Fisheries Research Institute (KMFRI). It was conceived to fill the need for a comprehensive species register for the western Indian Ocean. Edward Vanden Berghe, currently working with the Flanders Marine Data and Information Centre, which is part of VLIZ, originally developed the database.

Data and information on species and distribution records from this Ph.D work will contribute to MASDEA.

Further information on this database may be obtained from:
http://www.vliz.be/vmdcdata/Masdea/about.htm#MASDEA

3. Global International Water Assessment (GIWA) through the United Nations Environment Programme (UNEP)

The Global International Water Assessment (GIWA) was formed in 1999 to assess the status of the world's marine, freshwater and ground water resources in order to protect them and make recommendations for their sustainable use. The Global Environment Facility (GEF) through the United Nation Environment Programme (UNEP) funds GIWA.

The aim of GIWA is to produce a comprehensive and integrated global assessment of international waters in relation to ecological status and the causes of environmental problems. Based on the GIWA criteria, the world is divided into 66 water areas called sub-regions. The Kenya coast is part of the Somali Coastal Current (SCC) Sub-region no. 46.

Currently, the GIWA Somali Coastal Current sub regional Task Team is compiling the available literature in the sub-region. This is for purposes of identifying root causes of key issues and concerns regarding water resources in order to prioritise them. I was appointed a member of the SCC Task Team to compile and assess information on the sub-region's marine biodiversity and productivity (primary and secondary).

Zooplankton abundances calculated in the course this Ph.D work have been used to derive information on biomass, which is component of productivity. Measurements of zooplankton diversity have now also enhanced the available information on the biodiversity of the sub-region.

The present status of GIWA in my sub-region and the relevant contribution from this PhD work is provided at these web sites:

http://www.giwa.net/areas/area46.phtml#taskteam
http://www.giwa.net/areas/area46.phtml

4. Contribution in other local marine researches

Distribution records of some target zooplankton taxa are proving to be useful in other marine research programmes in Kenya. Our results of the distribution and seasonal abundances of isopods in creeks and bays of Kenya have provided some indication on suitable sites for studying the infestation of wood-borer isopods on the mangroves of East Africa. Some achievements in this linkage have recently been published (Svavarsson *et al.*, 2002 see abstract below).

Does the Wood-borer *Sphaeroma terebrans* (Crustacea) Shape the Distribution of the Mangrove *Rhizophora mucronata*?

Jörundur Svavarsson, Melckzedeck K.W. Osore & Emil Ólafsson

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http://www.ambio.kva.se

Abstract

Field surveys were conducted to evaluate the occurrence of the isopod borer *Sphaeroma terebrans* (Crustacea) in aerial roots (prop roots) of the red mangrove *Rhizophora mucronata* on several different spatial scales (m to 100 km) in East Africa. In 6 out of 17 sites studied in Kenya and on Zanzibar Island, Tanzania, no signs of the isopods were found. When the isopods were present the frequency of infestation was high. Trees in muddy substrates in the lower intertidal, in particular at fringing channels or the open sea, showed high prevalence and intensity of infestation, with large part of their roots damaged or dead. Trees at the upper range of *Rhizophora*, in sandy and muddy areas, showed no signs of isopod infestation. This pattern recurred in mangrove forests on large spatial scales and there was no indication that island forests differed from the mainland forests. This indicates that sediment characteristics, vertical height in the tidal zone, and direct exposure to incoming water are the major factors controlling the abundance of *S. terebrans*. The isopod may play an important role in determining the lower intertidal limits of *R. mucronata*. Trees with numerous dead or nongrowing roots, as result of *Sphaeroma* attack, are likely to tumble due to a lack of root support and this is most likely to occur along channels at the lower, muddy intertidal. Tumbled trees were frequently observed along channels in the lower, muddy intertidal, but rarely in the mid or high intertidal. Implications for management of mangrove forests are discussed.

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Wyrtki, K. 1971. Oceanographic atlas of the International Indian Ocean Expedition. National Science Foundation, Washington DC. 531 pp.

APPENDICES

- **Workshop and training attended in the course of and with relevance to this Ph.D**
- **Publications and reports produced in the course of and with relevance to this Ph.D**

Workshop and training attended in the course of and with relevance to this Ph.D

1998/1999

4th - 13th December 1998. Zanzibar, Tanzania.
Workshop on Mangrove Ecology & Physiology, Paper presented: Ecology and Impact of Mangrove Borer Isopod.
Organized by Sida/SAREC

5th - 16th January 1999. Mombasa, Kenya.
Field survey on the boring activities of the woodboring isopod *Sphaeroma terebrans* and their impact on the health conditions of the Mangroves.
Organised by UNESCO.

18th - 23rd March 1999. Zanzibar, Tanzania.
Regional course on the biology of marine phytoplankton and cyanobacteria.
Organised by Sida/SAREC.

1999/2000

11th – 16th April 1999. Naivasha, Kenya.
Shallow Tropical Water and Humans Conference
Presentation: Use of Zooplankton to monitor degradation in marine ecosystems

25th - 31st July 1999. Curitiba, Brazil.
7th International Conference on Copepoda
Organised by the World Association of Copepodologists (WAC) and Centre of Marine Studies - Federal University of Parana, Brazil (UFPR).

24th - 26th November 1999. Bonn, Germany
International Conference on Understanding the Earth System: Compartments, Processes and Interactions
Organised by German National Committee on Global Change Research in cooperation with University of Bonn.

2000/2001

25th - 28th November 2000. Brussels, Belgium.
7th Benelux Conference on Zoology
Theme: Back to the Future
Organized by the Zoological Association of Belgian, Netherlands and Luxemburg. Vrije Universiteit Brussels, Belgium.
Presentation : Microcharacters as tool for taxonomy in the future

23rd – 27th April 2001, Plymouth Marine Laboratory, United Kingdom.
Project Conference: Darwin Initiative on Conservation of Marine Biodiversity. Presented data and information on zooplankton abundance and diversity on the Kenya coast for compiling CD ROM.

18th – 20th July 2001, Mombasa, Kenya.
Global International Water Assessment (GIWA)
Training workshop on the GIWA methodology: Guidance to Scaling and

Scoping Methodology and its use for Somali Coastal Current Sub-region no. 46.Organized by GIWA on behalf of the United Nation Environment Programme (UNEP) and funded by the Global Environment Facility (GEF).

2001/2002

22nd – 26th October 2001, Dar-es-Salaam, Tanzania.
Second Western Indian Ocean Marine Science Association (WIOMSA) Scientific Symposium and General Assembly.
Presentation: (I) Activities of the Project Ocean Data and Information Network for Africa.

14th – 17th November 2001, Nairobi, Kenya.
Second Annual Review and Planning Workshop for the Ocean Data and Information Network for Africa – ODINAFRICA
Presented Report on the activities of the ODINAFRICA Information Services Centre located in Mombasa, Kenya.
Sponsored by Intergovernmental Oceanographic Commission of UNESCO.

8th – 12th April 2002, Kisumu, Kenya.
Global International Water Assessment (GIWA) meeting for the sub-Saharan Africa mega-region
Presented progress report on the scaling and scoping results for the Somali Coastal Current sub-region (Somali, Kenya and Tanzania)
Organized by Pan African START Secretariat/UNEP-GIWA Co-ordination Office

2002/2003

15th-19th July 2002, Kaohsiung, Taiwan, R.O.C
National Museum of Marine Biology and Aquarium
Training workshop on Copepod Morphology and Systematics
Organized & Sponsored by the World Association of Copepodologists (WAC)

21st-26th July 2002, Taipei, Taiwan, R.O.C
National Taiwan Ocean University
8th International Conference on Copepoda (8th ICOC)
Presentations: Zooplankton composition and abundance in Mida Creek, KenyaOrganized by WAC and co-sponsored by government of Taiwan R.O.C

25th-27th November 2002, Brussels, Belgium
Colour of Ocean Data
Presentation: Functioning of the ODINAFRICA Info Centre, Mombasa, Kenya
Organized & Co-sponsored by: Flanders Marine Institute (VLIZ), Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO) and Census of Marine Life (OBIS)

6th-10th January 2003, Plymouth, England
Training workshop on statistical analysis and interpretation of community data from ecology/environmental science using PRIMER (Plymouth Routines in Multivariate Ecological Research) version 5 for Windows.
Hosted at the Marine Biological Association, Plymouth, UK
Conducted by PRIMER-E Ltd
Marine Biological Association, UK

Publications and reports produced in the course of and with relevance to this Ph.D

Torres, G., J. Landivar, Q. L. Burgos, A. M'Harzi, **M. K. W. Osore**, X. Irigoien, M. Tackx & M. H. Daro 1998. Phytoplankton and zooplankton community structure in the Guayaqil estuary and the Estero Salado, Ecuador. Proceedings of the ICES Symposium on Brackish Water Ecosystems.Helsinki, Finland. 48 pp.

Osore, M. K. W & M. O. Odido (eds) 1999. IOC-LUC-KMFRI Workshop on RECOSCIX-WIO in the year 2000 and beyond. IOC Workshop Report No.156.

Mwangi, S., D. Kirugara, **M. K. W. Osore**, J. Njoya, A. Yobe & T. Dzeha 1999. Status of marine pollution in Mombasa marine park & reserve and Mtwapa Creek, Kenya. Kenya Marine & Fisheries Research Institute, Government Chemist Department, Kenya Wildlife Services. Technical Report. 88 pp.

Osore, M. K. W. 2000. Interviewing Copepodologist. Monoculus Copepod Newsletter.38: 16-18.

Osore, M. K. W., F. Fiers & J. Cillis 2000. Microcharacters as tool for taxonomy in the future: case study *Candacia* and *Paracandacia* (Copepoda : Calanoida). Poster presentation. 7th BENELUX Congress. November 2000. VUB Belgium.

Plymouth Marine Laboratory, **Kenya Marine & Fisheries Research Institute**, Institute of Biology of the Southern Seas, Marine Hydrophysical Institute, Smithsonian Tropical Research Institute 2002. Plankton Biodiversity and Biovariability in the Indian and Atlantic Ocean. Darwin Initiative for the Survival of Species. Project no.162/8/251 CD ROM 1 and 2.

Osore, M. K. W. 2002. Interview with Geoff Boxshall. Monoculus Copepod Newsletter. 44: 9-11

Svavarsson, J., **M. K. W. Osore** & E. Olafsson 2002. Does the wood-borer *Sphaeroma terebrans* (Crustaceana) Shape the Distribution of the Mangrove *Rhizophora mucronata?* Ambio. 31:(7-8) 574-579.

Osore, M. K. W., A. M'Harzi, S. Mwangi, M. Tackx & M. H. Daro (Submitted). Zooplankton assemblages and some physico-chemical trends in a polluted former mangrove ecosystem, Makupa Creek, Mombasa, Kenya. Hydrobiologia.

Osore, M. K. W., J. M. Mwaluma, F. Fiers & M. H. Daro (Submitted) Zooplankton composition and abundance in Mida Creek, Malindi, Kenya. Zoological Studies.

Osore, M. K. W., F. Fiers & M. H. Daro (Submitted). Copepod composition, abundance and diversity in a polluted creek, Mombasa, Kenya. WIO Journ. Mar. Sci.