RELATIONSHIP BETWEEN NUTRIENT LEVELS, PHYTOPLANKTON BIOMASS AND ZOOPLANKTON COMPOSITION, BIOMASS AND ABUNDANCE IN TUDOR CREEK-MOMBASA KENYA.

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A thesis submitted in partial fulfillment for the award of the degree of

MASTER OF SCIENCE (HYDROBIOLOGY)

UNIVERSITY OF NAIROBI

1993

DECLARATION

THIS THESIS IS MY ORIGINAL WORK AND HAS NOT BEEN PRESENTED FOR AWARD OF A DEGREE IN ANY OTHER UNIVERSITY

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ACKNOWLEDGEMENTS

My interest in zooplankton ecology was initiated by Professor Victor Jaccarini and I thank him for his guidance and encouragement. I am very grateful to Dr. Els Martens for her untiring efforts to see me through the work and the critical comments and suggestions from Dr. K. Mavuti, Dr. M. Ntiba are gratefully acknowledged. I would also like to express my deep gratitude to Dr. Sharon Smith of Brookhaven National laboratory (NY) for her interest in my work and many helpful suggestions and especially for very generously sending numerous copies of much of the literature used by me. Thanks are due to M. Githaiga, Dr. Vanden Beghe and Dr. W. Karanja for their help with the statistical analyses.

I thank Dr E. Okemwa, Director, and his staff at KMFRI-Mombasa for their excellent support and co-operation. I greatly acknowledge the skillful technical assistance given by Mr N. Maroko both in the laboratory and at sea. Gratitude is due to Messers. J. Mwaluma, M. Osore, M. Kazungu, J. Kamau, P Kilonzo and M. Umani for familiarizing me with the various technical procedures in the laboratory. My thanks are extended to Irene Githaiga and Polycap who helped me in various ways.

This work was supported by grants from the University of Nairobi and the Kenya Belgium Project in Marine Sciences and facilities from the Flemish association for development co-operation and technical assistance (VVOB).

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ABSTRACT

Previous studies in Tudor creek have suggested links between variations in general environmental factors, primarily precipitation, and zooplankton distribution and abundance, but have suffered from a lack of replication of samples. The aim of this study, therefore, was to analyze, quantitatively and statistically, the relationship between nutrient levels, phytoplankton biomass, and zooplankton composition, biomass and abundance by means of replicate sampling, at three stations.

All the environmental factors monitored showed a clear response to the monsoon conditions and in addition local gradients from the mouth to the inner reaches of the creek. Maximum nutrient levels, occurred during the intermonsoon (March), that is prior to the peak of rainfall (May). This may be explained by a larger tidal prism during the equinoctial spring tides and possibly more vigorous mixing of the water column. They may also result from flushing in of litter, and consequent decomposition, at the start of the rains in March. High levels of NO_3-N could also be due to nitrogen fixation by blue-green algae.

Plankton floral biomass and faunal composition, biomass and abundance were primarily influenced by seasonal factors and to a lesser extent location in the creek. Their maxima also occurred during the intermonsoon (March). The relationship between inorganic nitrate concentration, phytoplankton biomass, as indicated by chlorophyll levels, and zooplankton abundance was clear in station 1 only. This may be explained by the fact that station 1 was dominated by holoplanktonic groups, particularly the copepods which are mainly planktotrophic. In station 2 the relationship between inorganic nitrate concentration and phytoplankton biomass as well as that between phytoplankton biomass, as indicated by chlorophyll levels, and zooplankton abundance was obscure

Despite the relatively high levels of NO_3-N in station 2, both phytoplankton and zooplankton biomass ($F_{0.05,\,2,\,59} = 3.475$, $P = 0.0038$) were generally lower in this site compared to the other two sites. Transparency depth also showed the least fluctuation in this site and this was tentatively attributed to high turbidity as a result of anthropogenic impacts such as sewage and waste disposal possibly from Coast General Hospital, the Old Mombasa Port, and the adjacent human settlements. The low phytoplankton and zooplankton biomass in this site may indicate that apart from discharges of nitrogenous wastes, which would enrich the surface waters and therefore enhance planktonic floral and faunal production, the wastes could include substantial amounts of toxic substances which inhibit phytoplankton and directly or indirectly zooplankton production.

In station 3 total zooplankton densities were highest during the intermonsoon (March) up to the early SE monsoon (May) despite the fact that peak levels of both forms of chlorophyll a occurred in March and declined sharply thereafter. The lack of correlation between zooplankton abundance and the levels of chlorophyll a and its derivatives in station 3 may be explained by the fact that the peak from March to May is largely due to the dominance of brachyuran larvae which are lecithotrophic.

Copepods and predatory groups such as hydromedusae, chaetognaths, siphonophores and ctenophores showed some indication of a predator-prey relationship in station 1 only. No such relationship was found in either station 2 or 3. Although the densities of the selected predator groups and copepods, in station 1, are significantly correlated, these relations may not be causal. The changing monsoon conditions seem to be the most important factor affecting their abundances. This is indicated by the observation that the cycles of copepods and the various predatory groups were almost in phase with one another.

1.0.0 INTRODUCTION

1.1.0 PLANKTON AND NUTRIENTS

The pelagic zone of the world marine waters is characterized by complex plankton based foodwebs. Plankton consists of those organisms, generally small in size whose swimming abilities are so weak that they can only make relatively localized movements and are transported by water currents. The plankton consists of the zooplankton and the phytoplankton which are autotrophs and together with the bactero-phytoplankton and the prokaryotic cyanobacteria form the first trophic level. Their major inorganic requirements are carbon, phosphorus and nitrogen. Silica is important for some phytoplankton notably diatoms in which it is a skeletal material. In short spatial and temporal scales, the concentration of silica seems to be controlled by biological rather than physical processes (Perkins, 1974). Due to a surplus of carbon present as dissolved carbon-dioxide, the generally limiting nutrients for phytoplankton growth are considered to be phosphorus, in freshwater ecosystems, and nitrogen in marine ecosystems. The nitrogen nutrients assimilated are preferably ammonia, urea and nitrate.

In the nitrogen cycle dissolved ammonia as ammonium ions is very important. First the production of organic matter by photosynthesis starts with the assimilation of dissolved ammonium. On the other hand degradation of particulate and dissolved nitrogen by heterotrophic activity results in the formation of ammonium, afterwards oxidized to nitrite and nitrate. Moreover zooplankton contribute directly to the enrichment in ammonium of sea water by direct excretion. Availability of these nutrients therefore plays an important role in controlling primary production . This consequently influences the productivity of the water mass as phytoplankton are the chief source of food for the diverse assemblage of zooplankton in the grazing food chain.

The importance of zooplankton in marine ecosystems is threefold. First because they exist in large numbers and are an important link in many marine food chains (Raymont,1963). A major part of the diet of many marine animals including fish and cetaceans is composed of zooplankton particularly copepods and Euphausiacea. They are also an important food source in fish and crustacean nursery grounds such as Tudor creek (Grove et al., 1986 and Wakwabi, 1988). These grounds are utilized by many species of estuarine and reef fish, crustaceans and molluscs which are either edible or of aesthetic value. Secondly, some stages of certain zooplankton species are endoparasites or ectoparasites of fish thereby reducing their market value. Lastly, some of them are utilized in ecological studies as indicator species for water masses (Raymont, 1963). Plankton may be used to detect upwelling of deep water as well as lateral water movements and areas where planktophagous fishes aggregate. The functional role of plankton communities in the oceans cannot be underestimated.

1.2.0 LITERATURE REVIEW: WORK ON TUDOR CREEK

Studies on the ecology and systematics of marine plankton communities in the inshore waters of Kenya have been initiated in the recent past. They provide baseline quantitative data on the hydrography and planktonology of Kenyan creeks with emphasis on animal plankton in Tudor creek. Reay and Kimaro (1984) and Kimaro and Jaccarini (1989) demonstrated the influence of diel and lunar cycles on zooplankton composition and abundance in surface waters during the north-east monsoon. The first complete annual cycle of the hydrography of an East African creek and zooplankton composition and abundance was furnished by Kimaro (1986). The latter study also demonstrated two opposite gradients of open coastal water and of terrestrial influences respectively on the distribution of zooplankton groups. In addition Kimaro (1986) established that the hydrography of Tudor creek was mainly influenced by tide- induced short term changes and seasonal changes induced by the monsoon. However, no clear correlation could be established between hydrographic parameters such as temperature, salinity and transparency and zooplankton composition and abundance.

Total zooplankton abundance seems to be influenced by the seasonal rainfall pattern. But some groups particularly the meroplanktonic forms like molluscan larvae, fish eggs and their larvae, crustacean decapod larvae excluding brachyuran larvae and chaetognaths do not show monsoon related seasonal abundance maxima (Kimaro, 1986). On the other hand copepods show peaks of abundance related to the monsoon seasons. The highest copepod abundance occurs in the short rains of the north-east monsoon while a secondary peak occurs in the long rains of the south-east monsoon. This difference was tentatively attributed to seasonal fluctuation in phytoplankton biomass due to influx of nutrients from terrestrial sources through inflowing rivers (Kimaro, 1986). However in the absence of a complete data set on the annual cycle of phytoplankton production in the inshore waters of Kenya it was not possible to make a sound interpretation of the seasonality of zooplankton biomass.

Of all zooplankton groups copepods have received the most attention. Okemwa and Revis (1986) and Okemwa (1988) give information on the taxonomic composition, population densities and seasonal fluctuation of copepods in Tudor creek. Recently Okemwa (1990) investigated the pelagic copepods of the same site with emphasis on community structure, biomass and productivity. All seasonal abundance maxima coincide with the monsoons confirming the results of Kimaro (1986). In April when the long rains season is at its peak, a different set of species appears and total abundance increases, which decreases during the dry season. This is tentatively attributed to the influx of nutrients and increased phytoplankton abundance (Okemwa, 1990). A further problem in the interpretation of zooplankton seasonality in the inshore waters of Kenya arises from the fact that the few studies undertaken are largely qualitative in character. The studies did not take replicate samples making statistical analysis of the data difficult. From the foregoing account it is clear that there is urgent need to obtain a proper understanding of nutrient-plankton dynamics in the inshore waters of Kenya.

Marine creeks are very productive zones and they make a substantial contribution to marine fisheries. They are inhabited by planktonic stages of numerous species of fish, crustaceans and molluscs, many of which are of commercial importance (Grove et al., 1986). In Tudor creek such fish include the bone fish Albula vulpes Linnaeus 1858, clupeids like Sardinella gibbosa Bleeker 1849, Pellona ditchela Velenciennes 1837, Herklosicthys quadrimaculatus Rueppell 1847 and the common sprat Spratelloides delicatulus Bennett 1831. Crustaceans are mainly penaeid prawns such as Penaeus indicus H.M. Edwards 1937, P. monodon Fabricius 1798, P. semisulcatus de Haan 1844, (Wakwabi, 1988), the caridean shrimp Palaemon tenuipes Henderson 1893 and the portunid crab Scylla serrata (Forsskal). The mollusca are represented by the rock oyster Crassostrea cucullata Born 1778 (Kimaro, 1986). During their residence in the nursery grounds, the planktonic stages of these groups along with other animal plankton are an important element of the temporary zooplankton fauna of creeks and estuaries.

Though the zooplankton community comprises herbivores, carnivores and omnivores, the bulk of the community is made up of herbivores which support the consumer trophic levels. Herbivores play an important role in marine pelagic food webs by transferring energy derived from particulate and possibly dissolved organic matter to higher trophic levels (Parsons et al., 1977). In East Africa gross changes in zooplankton and possibly phytoplankton community structure occur annually presumably in response to changes in environmental conditions. These phenomena are of fundamental importance in the context of aquatic productivity, particularly fisheries production and water quality.

In order to understand and perhaps achieve sustainable utilization of inshore marine resources therefore, the biological oceanographer must have a sound knowledge of the composition, structure, biomass and functional role of the plankton communities inhabiting this zone and the environmental factors involved. Due to logistical problems zooplankton studies in general have suffered from a lack of a quantitative approach. This applies also to the few zooplankton studies in Tudor creek.

In view of these facts this study was planned so as to analyze quantitatively the relationship between nutrient levels, phytoplankton biomass as chlorophyll a and zooplankton composition, biomass and abundance by means of replicate sampling. Environmental factors which are known to influence phytoplankton composition and productivity such as salinity, temperature, pH and transparency were also monitored simultaneously.

2.0.0 SAMPLING DESIGN AND METHODS

2.1.0 STUDY AREA

Tudor creek forms the North-West boundary of Mombasa island, Kenya (4° S, 4° E, Fig. 1). Towards its mouth the creek is a narrow, deep and steep-sided channel extending 5km inland. Thereafter it widens abruptly and is bordered by extensive mudflats lined with mangrove forests. These are dominated by Rhizophora mucronata and are well developed at the Western side where the two rivers, R. Tsalu and R. Kombeni, empty into the creek. Fresh water seepage also occurs at the fringes of the creek. The East African coast has semi-diurnal tides with a mean tidal level of 1.9m and a maximum tidal range of 4.1m.

At present there is little industrial development in the inner reaches of Tudor creek, nor is there substantial cutting of mangrove. The main human activity is artisanal fishing. The land surrounding the creek beyond Mombasa Island is agricultural, mainly holdings and coconut plantations with grazing land further inland, in contrast there is substantial human settlement towards the mouth. The creek is a receiver for wastes, from the Kenya Meat Commission abattoir and the Coast General Hospital, at the western side, and the Mombasa Municipality on the eastern side. It provides a variety of water-oriented recreational activities including fishing, boating and swimming.

2.1.1.1 The Climate

Eastern Africa has a monsoon type of climate with two dry and two rainy seasons. The seasonal monsoon definitions (Smith et al., 1991) are southwest or southeast monsoon (June-September inclusive), northeast monsoon (December-February inclusive) autumnal transition (October-November inclusive) and spring transition (March-April inclusive). From October to November the winds start blowing from a north easterly direction passing over the dry Somali land mass. The coastal areas therefore, receive only a small rainfall peak in November-December. These short rains may be attributed to the generation of a local land-sea breeze system. The NE monsoon is fully established from December to February and it is the driest and warmest period of the year. It is followed by a brief intermonsoon period lasting from March to April, after which the winds change direction and blow from a south easterly direction. The SE monsoon is more humid than the former and extends from May to September. The greatest amount of rainfall occurs during the SE monsoon when winds pass over the Indian Ocean. The long rains commence during the intermonsoon months of March, April and peak during the SE monsoon in May.

2.1.1.2 Sampling stations

The sampling stations were selected in the navigational channel of the creek with a view to representing gradients in oceanic influence, depth and substrate type. Station 1 was located at the mouth of the creek where there was considerable oceanic influence, a sandy substratum and a depth of 30m. Station 2 was located about 1.5 km upstream of station 1 near the Coast General Hospital. Station 3 was located about 2km upstream of station 2, where there was substantial terrestrial influence, shallow water and a substrate consisting mainly of mud, silt,detritus and organic ooze (Figs. 1 & 2)

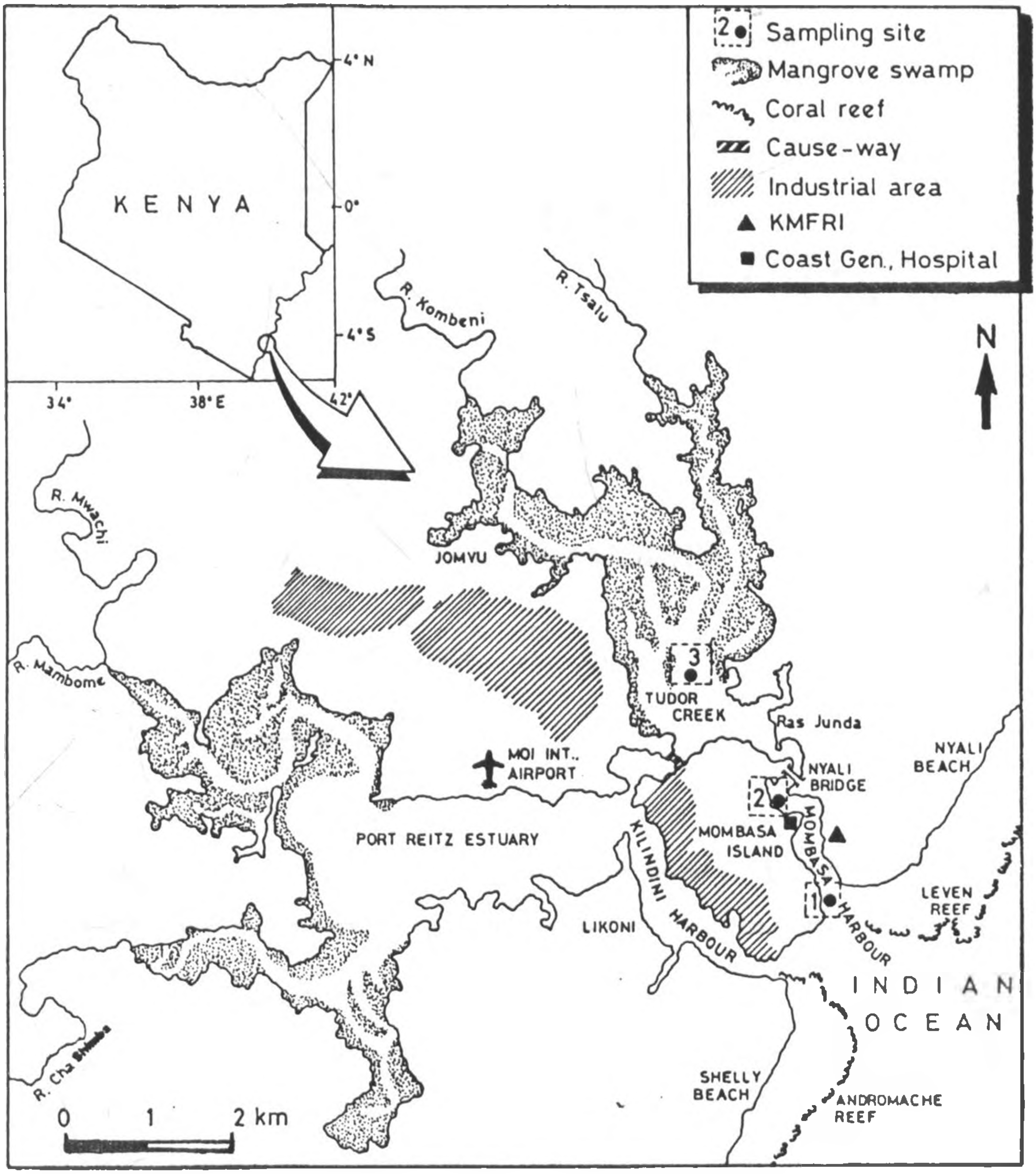


Fig. 1: Sampling stations in the study area: Tudor creek, Mombasa - Kenya.

(After Munga et al., 1993).

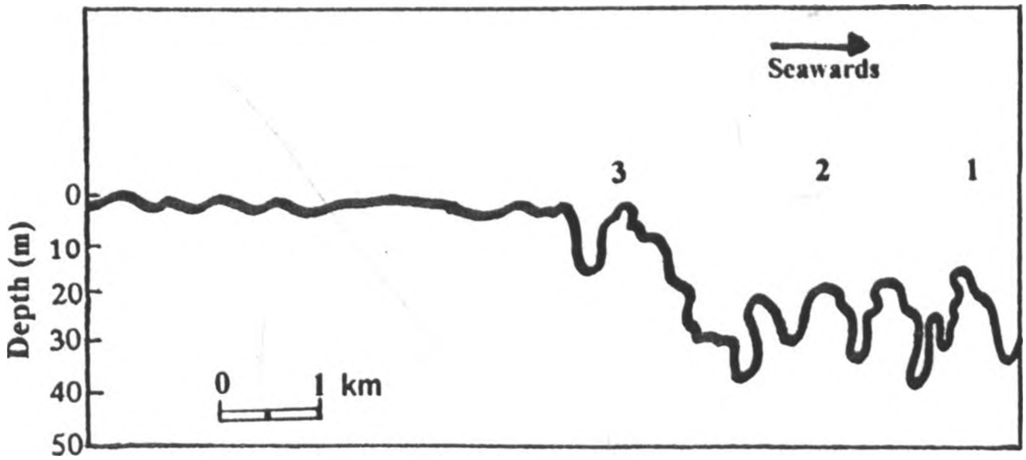


Fig. 2: Depth profile of Tudor creek, (After Revis, 1988).

2.2.0 ENVIRONMENTAL PARAMETERS

2.2.1 Physical parameters

2.2.1.1 Temperature

Near-surface sea temperature

Near-surface water temperature was measured using a mercury thermometer, with 0.5° C graduations, placed in a bucket filled with water drawn, from the towing depth of 1.4m, with a Niskin bottle.

Air temperature

Mean monthly air temperature data were obtained from the Meteorological Department, Ministry of Transport and Communications, Mombasa.

2.2.1.2 Rainfall

Data on mean monthly rainfall were obtained from the Meteorological Department, Ministry of Transport and Communications, Mombasa.

2.2.1.3 Meteorological conditions

Prevailing weather conditions such as wind direction and cloud cover were noted on the actual sampling dates. Data on sunshine hours and radiation were obtained from the Meteorological Department, Ministry of Transport and Communications, Mombasa.

2.2.1.4 Tidal amplitude

Data on tidal heights was obtained from the Kenya Ports Authority tide tables, (1992).

2.2.1.5 Transparency

A Secchi disc was lowered into the water to a depth at which it just disappeared. The depths at which disappearance and reappearance occurred were noted and the mean depth was calculated.

2.2.2 Chemical parameters

Sampling programme

Two replicate water samples were taken at each station prior to the zooplankton tows. A 2-l Niskin bottle was used to sample at 1.4m depth. They were used to quantify the concentration of phytoplankton nutrients: inorganic nitrates (NO_3-N), ammonium (NH_4-N), inorganic phosphates (PO_4-P), and reactive silicates (SiO_3-Si) with a Technicon Autoanalyser (II). These water samples were also used to analyze dissolved oxygen concentration, pH and salinity.

2.2.2.1 Dissolved oxygen

Dissolved oxygen was determined using the Winkler method (Parsons et al., 1984). The dissolved oxygen is fixed by manganous hydroxide to form an insoluble manganous hydroxide (IV) compound. The precipitated manganous hydroxide is dispersed evenly throughout the seawater sample in a stoppered glass bottle filled carefully to overflowing avoiding production of air bubbles and any trapped air. Any dissolved oxygen oxidizes an equivalent amount of divalent (2^+) manganese to form basic hydroxides of higher valency states (3^+ & 4^+). When the solution is acidified in the presence of iodide the oxidized manganese reverts to the divalent state. Iodide equivalent to the initial dissolved oxygen is liberated and its concentration is determined by titration with a standard solution of sodium thiosulphate.

2.2.2.2 pH

The pH of the sample was measured with a Schott digital pH meter (model CG 840).

2.2.2.3 Salinity

Surface water salinity was measured using a refractometer with 0.1 $^{o}/_{oo}$ graduations.

2.2.2.4 Inorganic nitrate (NO_3-N)

The nitrate in sea water is reduced to nitrite by a copper-cadmium reduction column. The nitrite ion then reacts with sulphanilamide in an acid solution. The resulting diazo compound is reacted with N-I-N, that is N-(I-Naphthyl)-ethylenediamine to form a highly coloured red azo dye read spectrophotometrically at 550nm.

2.2.2.5 Ammonium (NH_4-N)

The automated procedure for the determination of ammonia utilizes the Berthelot reaction. The dissolved ammonium salt in sea water is allowed to react with sodium phenoxide followed by sodium hypochlorite to form indophenol blue. A solution of sodium tartrate and sodium citrate is added to the sample stream to prevent the precipitation of the hydroxides of calcium and magnesium. The intensity of the blue colour is read spectrophotometrically at 630nm.

2.2.2.6 Inorganic phosphate (PO_4-P)

Dissolved inorganic phosphate in sea water occurs mainly in the ortho-phosphate form ($H_2PO_4^-$, HPO_4^{2-} and PO_4^{3-}). The determination of ortho-phosphate in sea water is based on the reaction between the phosphate and acidic ammonium molybdate to form phosphomolybdate. This compound is reduced in the presence of trivalent antimony ions, using ascorbic acid to form a phosphomolybdenum blue complex which is read spectrophotometrically at 880nm.

2.2.2.7 Silicate (SiO_3-Si)

The automated procedure for the determination of soluble silicates is based on the reduction of a silicomolybdate in acidic solution to "molybdenum blue" by ascorbic acid. Oxalic acid is introduced to the sample stream before the addition of ascorbic acid to eliminate interference from phosphates. The concentration of the blue colour is read colorimetrically at 660nm.

2.3.0 BIOLOGICAL PARAMETERS

2.3.1 Phytoplankton biomass

Sampling programme

Prior to the zooplankton tows, replicate water samples were taken at each station for analysis of phytoplankton biomass. Three replicate samples of 1 litre each were taken at the towing depth using a Niskin bottle. The amount of phytoplankton in the sample was quantified by analyzing the chlorophyll a concentration using a Shimadzu double beam spectrophotometer (UV-150-02).

Laboratory analysis

Each 1-l water sample was passed through a sieve of 200µm to remove large zooplankton. The phytoplankton was then filtered on a 0.1µm millipore filter under gentle suction. The pigment was extracted from the filter in 90% acetone and its concentration determined spectrophotometrically at 665nm and 750nm. The 650nm absorbance was corrected for a small turbidity blank by subtracting the 750nm absorbance. The extract was treated with dilute acid to enhance the degradation of all chlorophyll a to phaeo-pigments. The extinction of the acetone extract was measured again at 665nm and 750nm. The change following acidification was used as a measure of quantity of phaeo-pigments in the original sample and the combination of chlorophyll a and phaeo-pigment concentration gave the amount of chlorophyll a with phaeo-pigment. The concentration of chlorophyll a and phaeo-pigments in the sample was calculated using the following equations;

$$\text{Chlorophyll a (mg m-}^{3}) = \frac{26.7\,(665o - 665a) \times v}{V \times l}$$

$$\text{Phaeo-pigment (mg m-}^{3}) = \frac{26.7\,(1.7\,[665a] - 665o) \times v}{V \times l}$$

Where;

750 - extinction of chlorophyll extract (blank) at 750nm

665o - extinction of chlorophyll extract at 665nm before acidification.

665a - extinction of chlorophyll extract at 665nm after acidification.

v - volume of water filtered (mls).

V - volume of acetone extract (mls).

l - light path length of the cuvette.

2.3.2 Zooplankton

Sampling programme

The zooplankton fauna at the three sampling stations in Tudor creek was sampled from January to August 1992. The sampling programme was terminated during the sampling session of September 1992 due to the loss of the zooplankton sampling gear at sea. Samples were taken at monthly intervals during neap tides in the spring-neap cycle and mid-tide in the daily cycle. All samples were taken during the day, in the flow tide starting from station 3 to station 1, using one 5 minute horizontal surface tow per station, from a small boat. The approximate towing depth was 1.4m.

Sampling gear

The samples were taken using triplicate nets supported by a triangular aluminium frame (Fig. 3). Each plankton net had a mouth diameter of 0.36m and a mesh size of 335 μm. A Hydro-Bios flowmeter was mounted in the centre of the mouth of each net. The volume filtered by each net was estimated from the readings of the calibrated flowmeters. The actual towing depth was determined approximately from the length of the towing wire and the angle it made with the water surface using the equation:

Net depth = length of wire out x cosine angle of wire out with the perpendicular.

Each plankton net had a detachable container at its cod-end. After each tow the contents of the net were washed thoroughly into the container in seawater and the container detached from the cod-end. The samples were fixed in 5% formaldehyde buffered in sea water for preservation.

Laboratory analysis

2.3.2.1 Biomass

The volume displacement method described by Wickstead (1965) was used to give an index of zooplankton biomass. The sample and fixative were made up to a known volume in a graduated cylinder. The sample was then filtered off and the volume of the filtrate was measured in a graduated cylinder. The difference between these two measurements was equivalent to the zooplankton volume which is a measure of its wet biomass. Detritus and other foreign materials were carefully removed prior to the volume measurements. These measurements were always taken within 12 hours of sampling to minimize and standardize changes in volume due to fixation.

2.3.2.2 Composition

Each zooplankton sample was examined on a Bogorov tray under a Wild-Heerbrugg M3C stereo-microscope, at x10 and x40 magnification for the bigger and smaller animals respectively. Generally, copepods were identified to generic level and in a few instances to specific level and all other organisms to the lowest taxon possible, usually order or family. A list of all taxa present was compiled.

The keys and references used for identification were:-

Barnes (1988); Brodskii (1967); Buckmann (1969); Dunbar (1963); Farran (1948a, 1948b & 1948c); Farran and Vertoot (1951c); Fraser (1947a, 1947b & 1957); Greve (1975); Hannerz (1961); Isaac (1975); Kasturirangan (1963), Malt (1983); Naylor (1957a, 1957b); Newell & Newell (1973); Owre & Foyo (1967); Sewell (1929); Sewell (1932); Tregouboff and Rose (1957), Van der Spoel (1972), Wickstead (1965); and Williamson (1983).

2.3.2.3 Abundance

Total counts of all the net zooplankton present in the samples were made, by taking five sub-samples from each sample using a plankton splitter in order to provide accurate estimates of zooplankton density (UNESCO, 1968). The abundance of each taxon was expressed as number of individuals per cubic meter (No. m^{-3}).

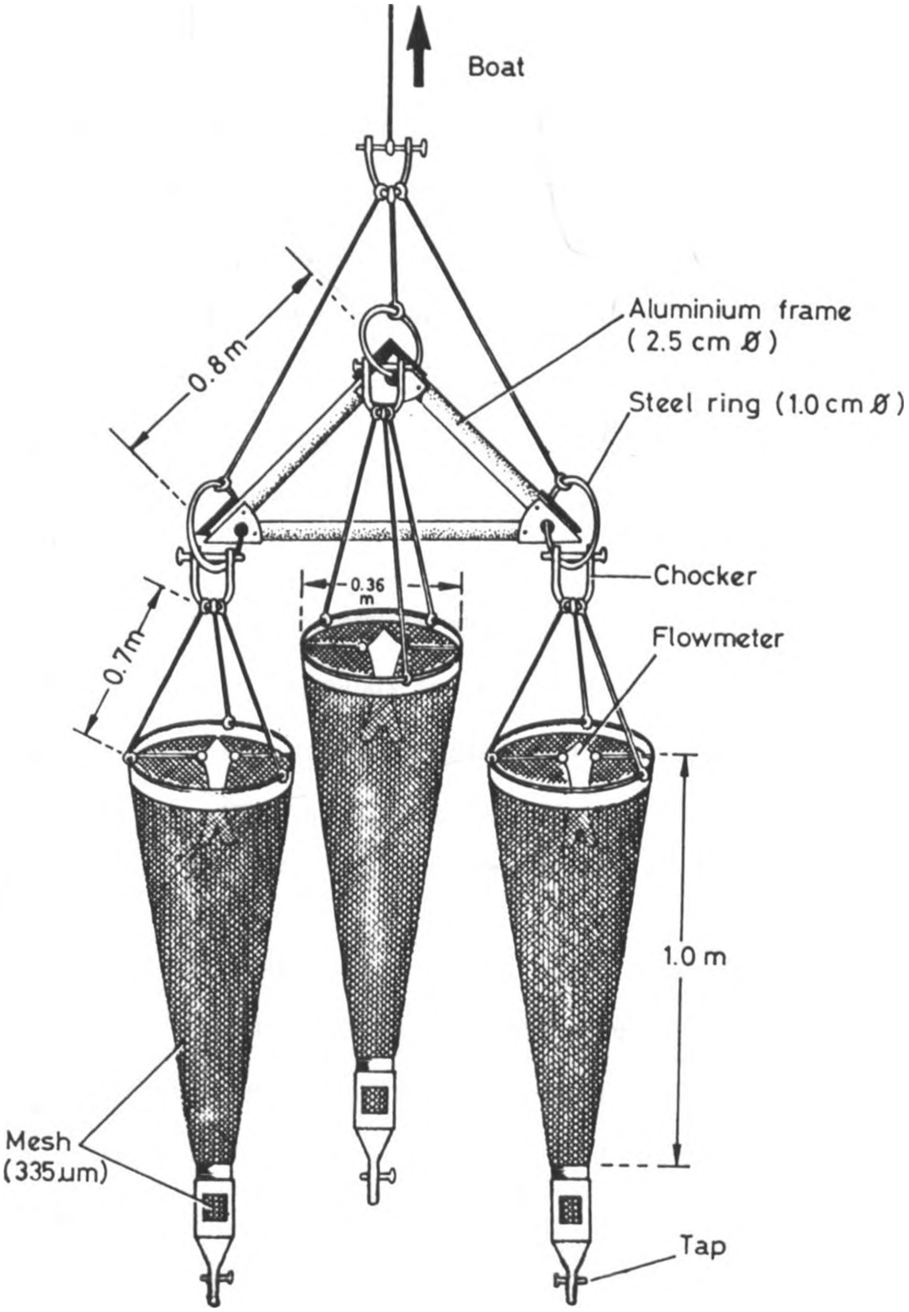


Fig. 3 Triplicate plankton net set -up.

3.0.0 RESULTS

3.1.0 ENVIRONMENTAL PARAMETERS

3.1.1 Physical parameters

3.1.1.1 Temperature

Mean near-surface sea temperature

The mean near-surface (ca. 1.4m) temperature of Tudor creek between January and August 1992 (Fig. 4) showed the widest fluctuation (± 3.3 °C) in the shallow and sheltered station 3, as expected ($\bar{x}$= 28.3 ± 0.7 SEM °C). Temperature fluctuated by only ± 2°C in the stations most under oceanic influence, ($\bar{x}$ = 27.4 ± 0.5 SEM °C and 27.3 ± 0.5 SEM °C in stations 1 and 2, respectively). Despite the differences in the mean temperature range, the three stations had similar temperatures during the sampling period ($F_{0.05\ 2,21} = 0.77$, $P = 0.472$).

But mean near-surface sea temperature was lower, during the SE monsoon compared to the NE monsoon months of January and February. The lowest temperatures occurred during the mid SE monsoon months of July (26.5 ± 0.3 SEM °C) and August (25.0 ± 0.3 SEM °C) while the rainy months of the early SE monsoon had higher temperatures ($F_{0.05\ 7,21} = 9.952$, $P = 0.0002$ and Tukey after anova $P < 0.05$).

Air temperature

Air temperature in the catchment area of Tudor creek reflects seasonal changes in the same way as sea surface temperature (Fig. 5). Mean monthly air temperature was highest during the NE monsoon in February (28.1 ± 0.1 SEM °C) while the lowest was in the mid SE monsoon in August (23.1 ± 0.1 SEM °C).

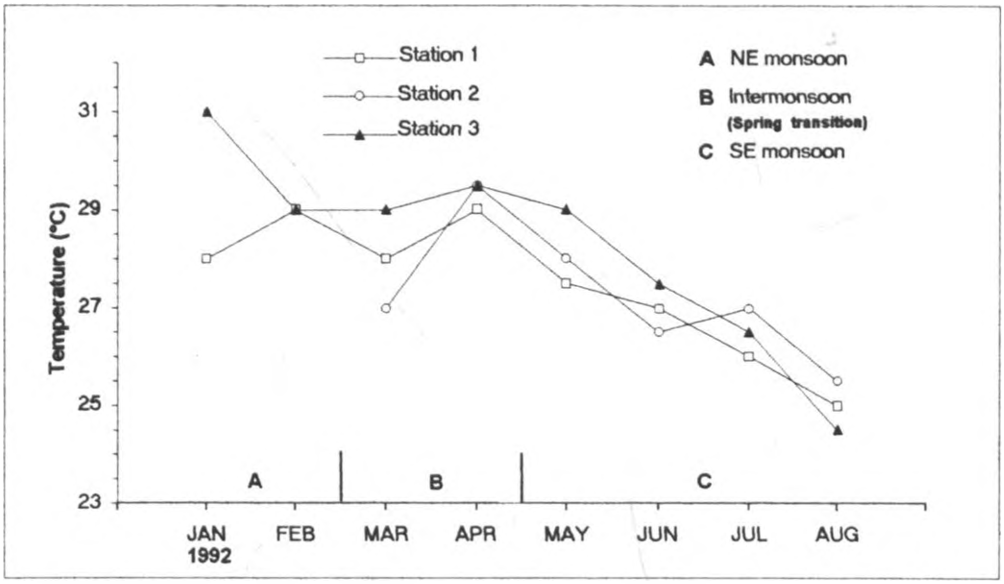


Fig. 4: Mean near-surface (ca. 1.4m) sea temperature (°C) in Tudor creek, Mombasa (N = 2 at each station). The standard errors of the mean (SEM) are small and not included.

3.1.1.2 Rainfall

Figure 5 shows the mean daily rainfall pattern for each month in the catchment area of Tudor creek as recorded at Moi International Airport, Mombasa. The trend conforms to that of the general rainfall pattern of the East African coast which is subject to a monsoon type of climate. The greatest amount of rainfall occurred during the SE monsoon in May (14.9 + 137.6mm SEM and 14.9 -1.6mm SEM) while the NE monsoon was the driest season, for instance no rain fell in February.

3.1.1.3 Meteorological conditions

The heavy rainfall during the SE monsoon was accompanied by heavy cloud cover resulting in fewer hours of sunshine, on average less than 7 per day, and a reduction in the mean radiation to less than 20 MJ m^{-2} day^{-1}, (Fig. 6). The wind speeds were also relatively higher during this monsoon season (Fig 7). These weather conditions were reversed during the NE monsoon.

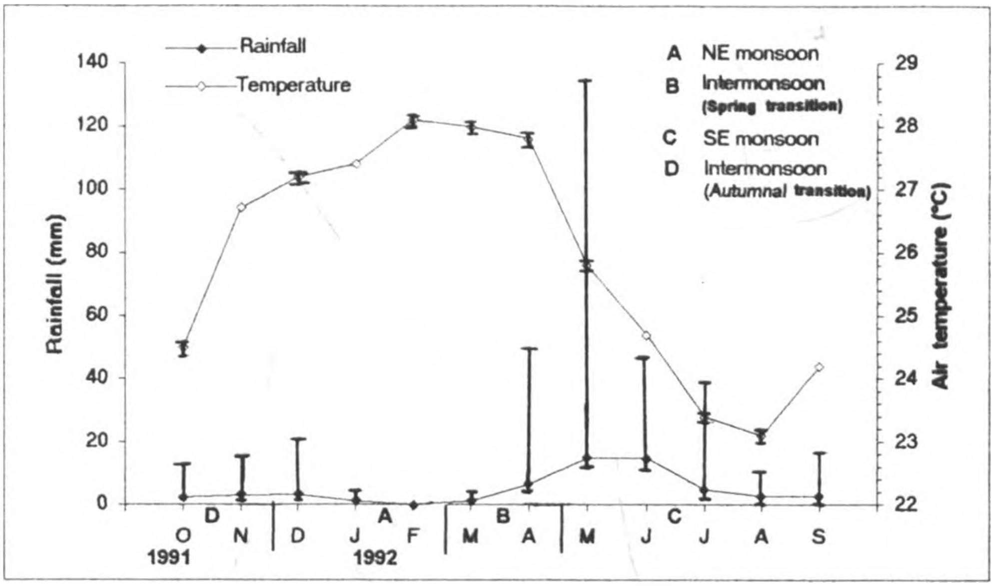


Fig. 5: Mean (± SEM) monthly air temperature and mean (± SEM) rainfall at Moi International airport Mombasa. The means are of daily temperature and rainfall for each month.

Data points for rainfall are means and SEMs of log transformed daily readings presented as antilogs. This leads to asymmetrical SEM bars.

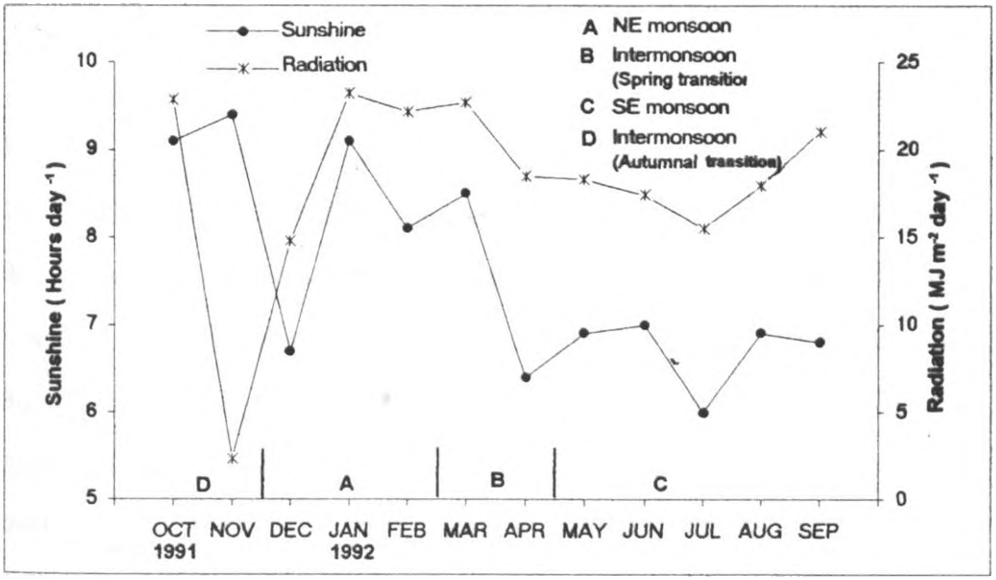


Fig. 6: Mean monthly sunshine hours and radiation per day at Moi International airport, Mombasa.

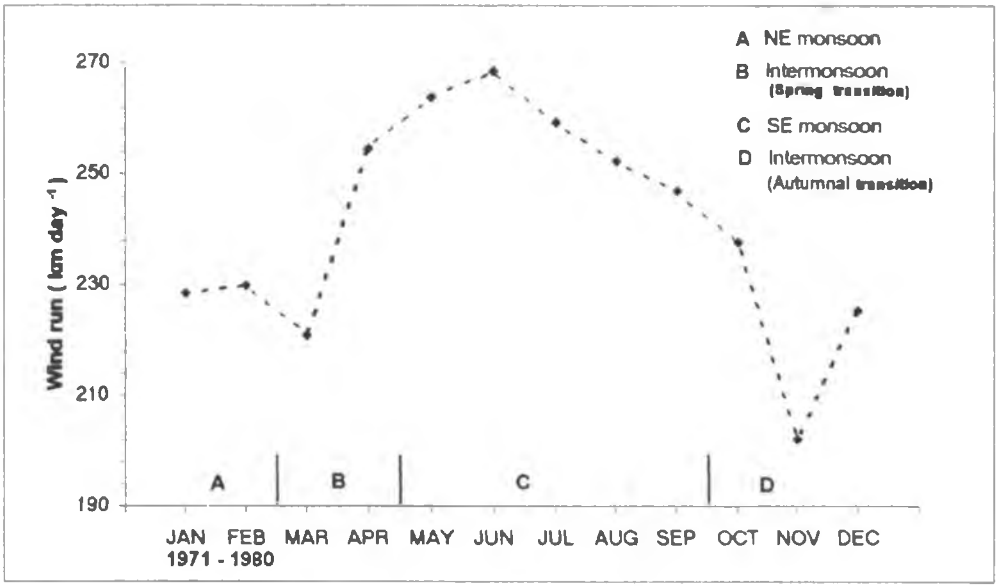


Fig. 7: Mean monthly wind speed (1971-1980) in Mombasa (after Mclanahan, 1988).

3.1.1.4 Tidal amplitude

Figure 8 gives the annual pattern of the maximum tidal height during spring tides at Kilindini Harbour in 1992. The equinoctial tidal heights were 4.0m and 3.9m in March and September, respectively.

3.1.1.5 Transparency

The depth to which light penetrates is an indicator of the amount of suspended matter in the water. Figure 9 shows a gradient of transparency decreasing from the mouth into the creek. Although stations 1 and 2 have comparable depths, transparency in station 2 only fluctuated between 4.63 ± 0.07 SEM m and 3.5 ± 0.48 SEM m as opposed to the wide fluctuation in 1 (8.01 ± 0.47 SEM m to 4.5 ± 0.3 SEM m). The highest transparency occurred during the early SE monsoon in April, in stations 1 ($F_{0.05\ 7,15} = 15.34$, $P = 0.0005$) and 3 ($F_{0.05\ 7,15} = 30.824$, $P = 0.00$). Station 2 did not show an increase of transparency in any month ($F_{0.05\ 5,15} = 3.029$, $P = 0.409$).

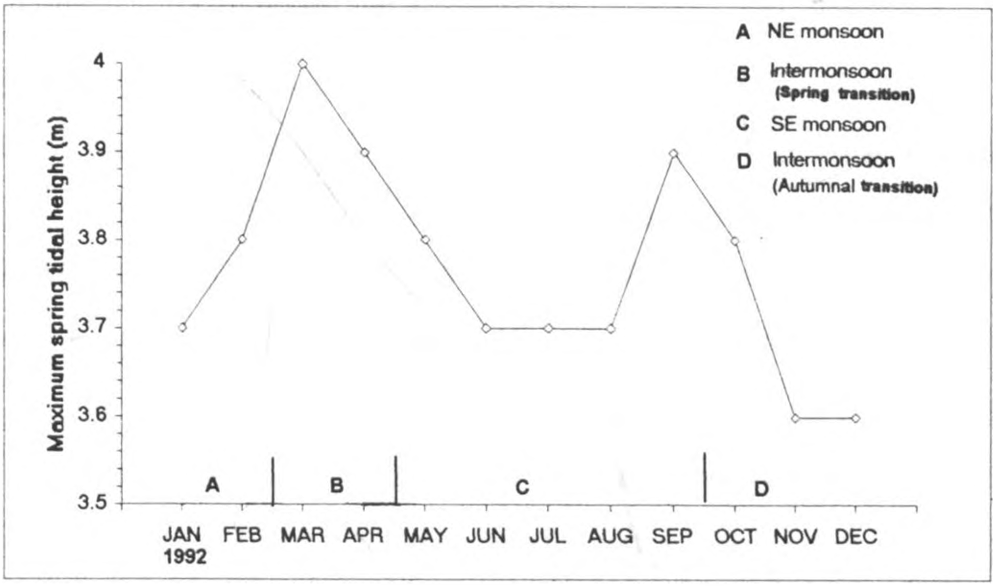


Fig. 8: Maximum tidal height during spring tides, at Kilindini harbour Mombasa.

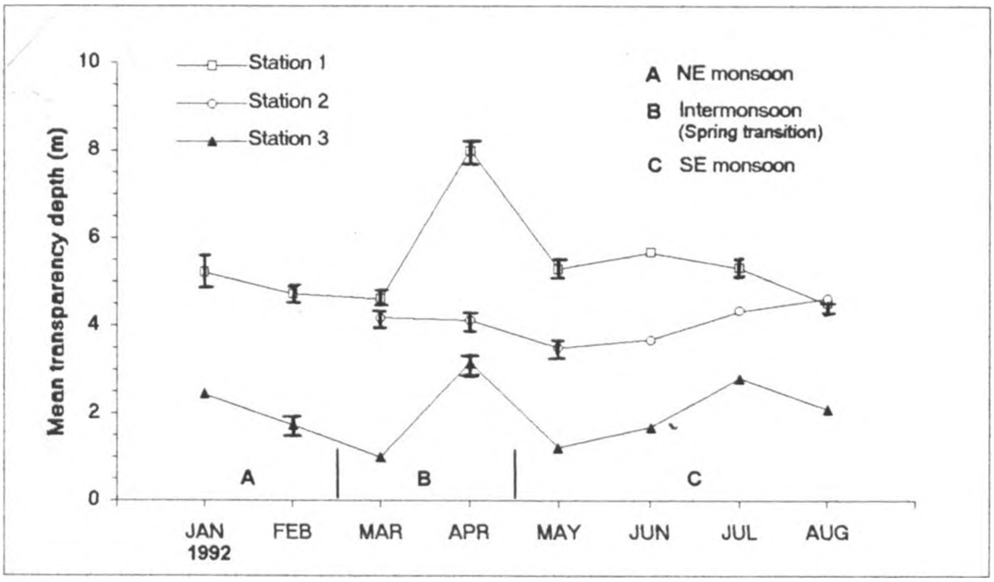


Fig. 9: Mean (± SEM) transparency depth (m) in the near-surface (ca. 1.4m) waters of Tudor creek Mombasa.

3.1.2 Chemical parameters

3.1.2.1 Dissolved oxygen

The general pattern was a gradient of dissolved oxygen decreasing from station 1 to 3 (Fig. 10). Mean dissolved oxygen had the widest fluctuation in station 1 (7.65 ± 0.22 SEM mgO$_2$ l^{-1} to 4.58 ± 0.21 SEM mgO$_2$ l^{-1}) while in stations 2 and 3 mean dissolved oxygen levels fluctuated by 2.06 and 2.22 mgO$_2$ l^{-1}, respectively. The high levels of mean dissolved oxygen during the period of monsoon reversal could indicate an incursion of well mixed neritic waters into the creek. The range of mean dissolved oxygen in the near-surface waters of Tudor creek was within the normal range of dissolved oxygen levels, (4 - 6 mgO$_2$ l^{-1}) in the near surface waters of the open oceans (Barnes, 1982), throughout the sampling period.

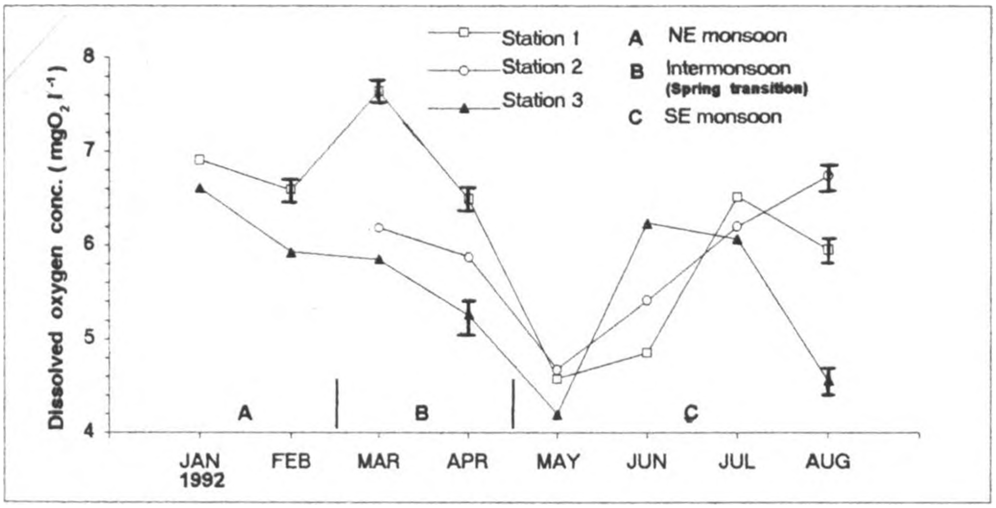


Fig. 10: Mean (± SEM) dissolved oxygen concentration in the near-surface (ca. 1.4m) waters of Tudor creek Mombasa. N = 2 at each station.

3.1.2.2 pH

The variation of mean pH levels in the near-surface waters of Tudor creek presented in figure 11 shows a gradient of pH decreasing with distance into the creek. pH levels varied within very narrow ranges in all the stations but the fluctuation in station 3 was relatively wider.

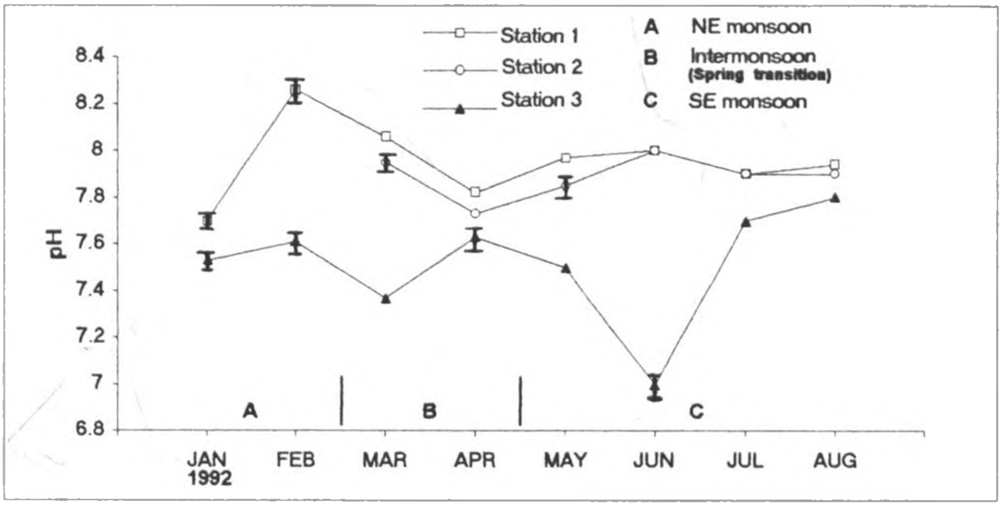


Fig. 11: Mean (± SEM) pH in the near-surface (ca. 1.4m) waters of Tudor creek Mombasa. N = 2 at each station.

3.1.2.3 Salinity

During the NE monsoon and in the intermonsoon months, salinity in the surface waters of Tudor creek averaged at 35 $^0/_{00}$ throughout the creek (Fig. 12). But as the rainy season in the SE monsoon came to a peak in May a salinity gradient with low levels upstream and higher levels at the mouth developed in the creek. Thereafter a uniform salinity of 35 $^0/_{00}$ was re-established throughout the creek.

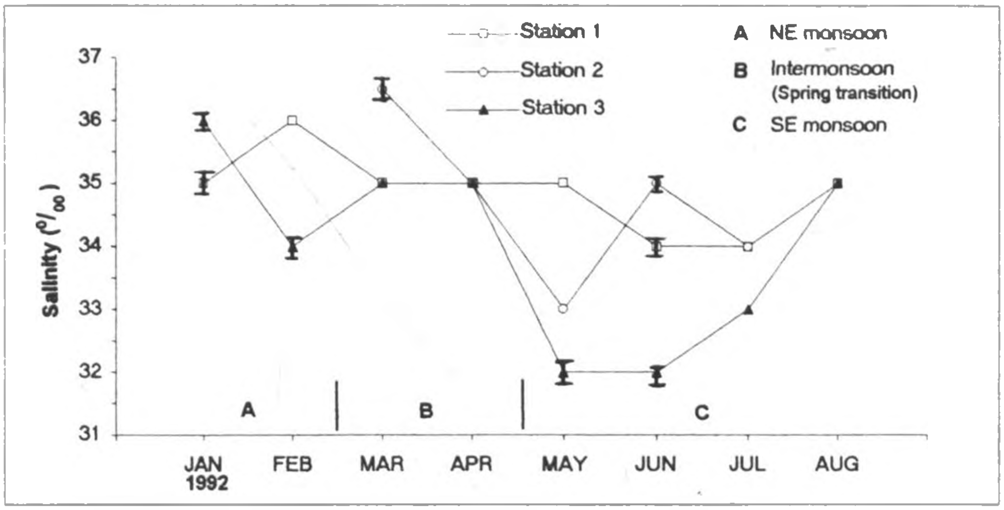


Fig. 12: Mean (± SEM) salinity in the near-surface (ca. 1.4m) waters of Tudor creek Mombasa. N = 2 at each station.

3.1.2.4 Inorganic nitrate (NO_3-N)

The pattern of inorganic nitrate (NO_3-N) concentration, in the near-surface waters of Tudor creek is presented in figure 13. The high nitrate level characteristic of the intermonsoon month of March decreased rapidly after the onset of the SE monsoon.

3.1.2.5 Ammonium (NH_4-N)

Figure 14 illustrates the variation of ammonium concentration during the sampling period. Ammonium levels were relatively high at the onset of monsoon reversal, in March and during the SE monsoon, from June to July, in all the stations. But the surface waters of Tudor creek were depleted of ammonium in April and August.

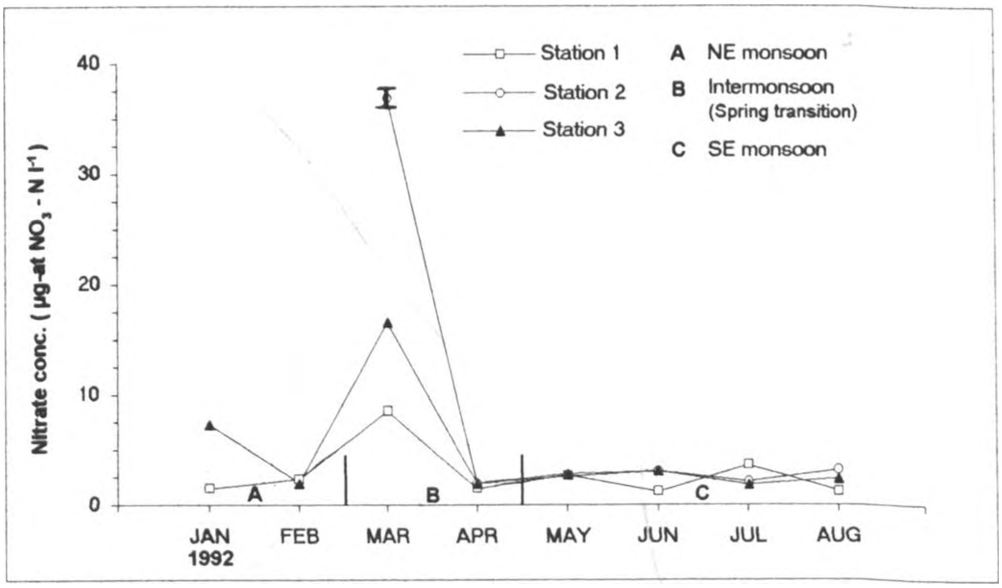


Fig. 13: Mean (± SEM) inorganic nitrate conc. at ca. 1.4m depth in Tudor creek Mombasa N = 1 at each station (2 determinations)

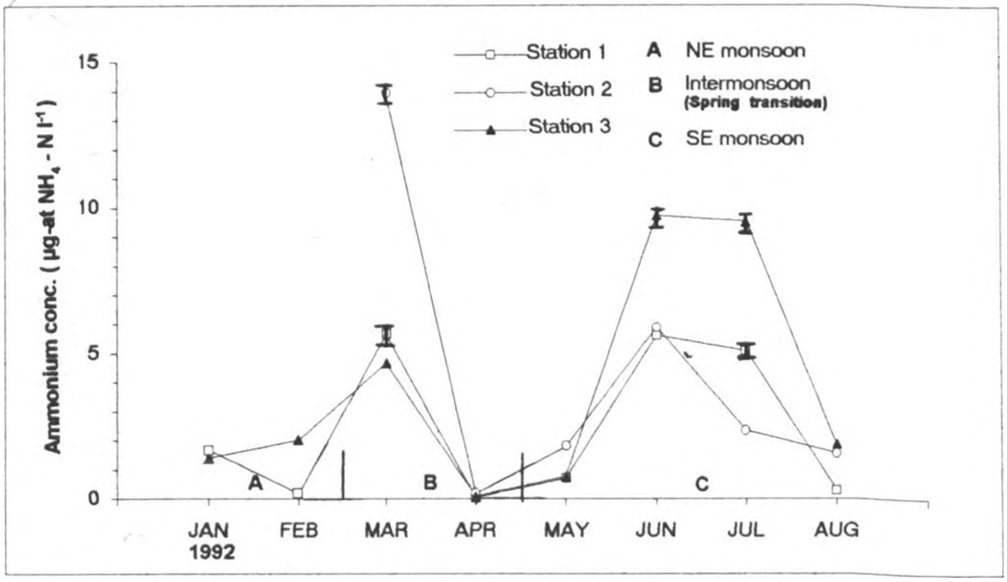


Fig. 14: Mean (± SEM) ammonium conc. at ca. 1.4m depth in Tudor creek Mombasa N = 1 at each station (2 determinations)

3.1.2.6 Phosphates (PO_4-P)

The levels of inorganic phosphates in the near-surface waters of Tudor creek were consistently higher than those of the north Indian ocean which rarely exceed 0.5 µg-at PO_4-P l^{-1} (Wyrtki et. al., 1988). Relatively high phosphate levels occurred during March in stations 1 and 3 and August in all the stations (Fig. 15).

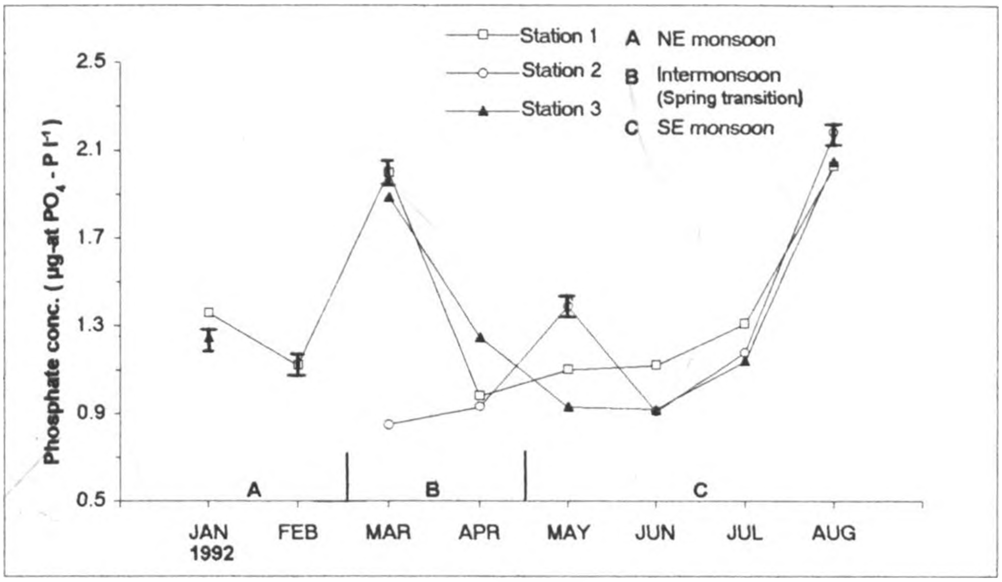


Fig. 15: Mean (± SEM) inorganic phosphate conc. at ca. 1.4m depth in Tudor creek Mombasa N = 1 at each station (2 determinations)

3.1.2.7 Silicate (SiO_3-Si)

The gradient of inorganic reactive silicate increases gradually from the mouth to the inner reaches of the creek as shown in figure 16. During the sampling period relatively high silicate levels occurred in March and from June to July. The levels of inorganic silicate in neritic waters off Mombasa range from about 3.0µg l^{-1} in the SE monsoon to 0.3µg l^{-1} during the NE monsoon (Wyrtki et. al., 1988).

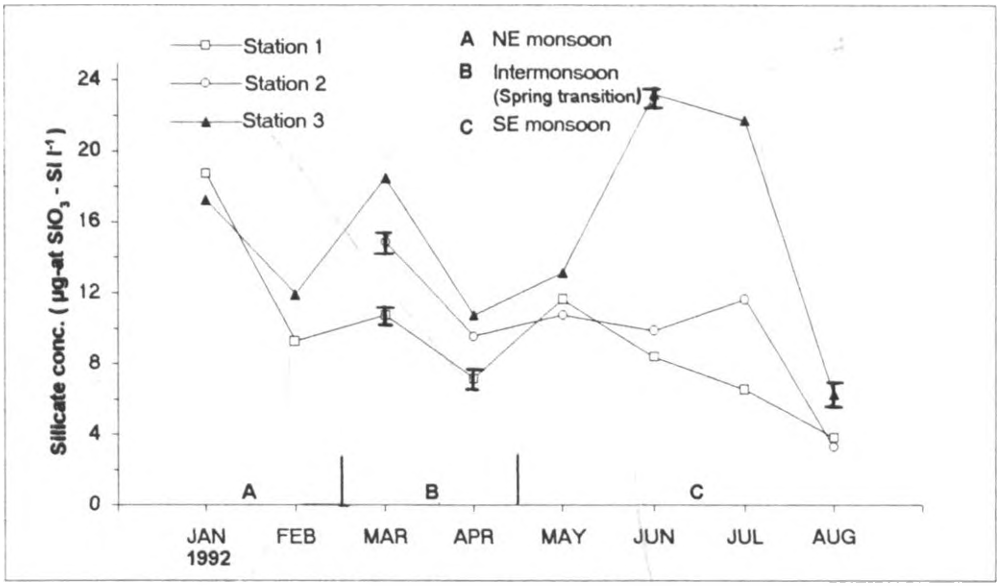


Fig. 16: Mean (± SEM) silicate conc. at ca. 1.4m depth in Tudor creek Mombasa N = 1 at each station (2 determinations)

3.2.0 BIOLOGICAL PARAMETERS

3.2.1 Phytoplankton biomass

The concentration of chlorophyll a derived from algal cells gave an indication of phytoplankton biomass in the near-surface waters of Tudor creek. A combination of this chlorophyll a with the concentration of the degradation products of chlorophyll, that is phaeo-pigments, gave the level as chlorophyll a with phaeo-pigments. The phaeo-pigments are derived from phytoplankton as well as other sources like mangrove litter. Relatively high values of both chlorophyll a (Fig. 17) and chlorophyll a with phaeo-pigments (Fig. 18) were observed during the March intermonsoon in stations 1 and 3 but thereafter declined to pre-monsoon reversal levels. In station 2 chlorophyll a levels fluctuated within very narrow ranges and no peak was discernible. Phytoplankton biomass was generally higher in station 3, throughout the sampling period, and generally lower in station 2 compared to the other two stations (Fig 17 & 18).

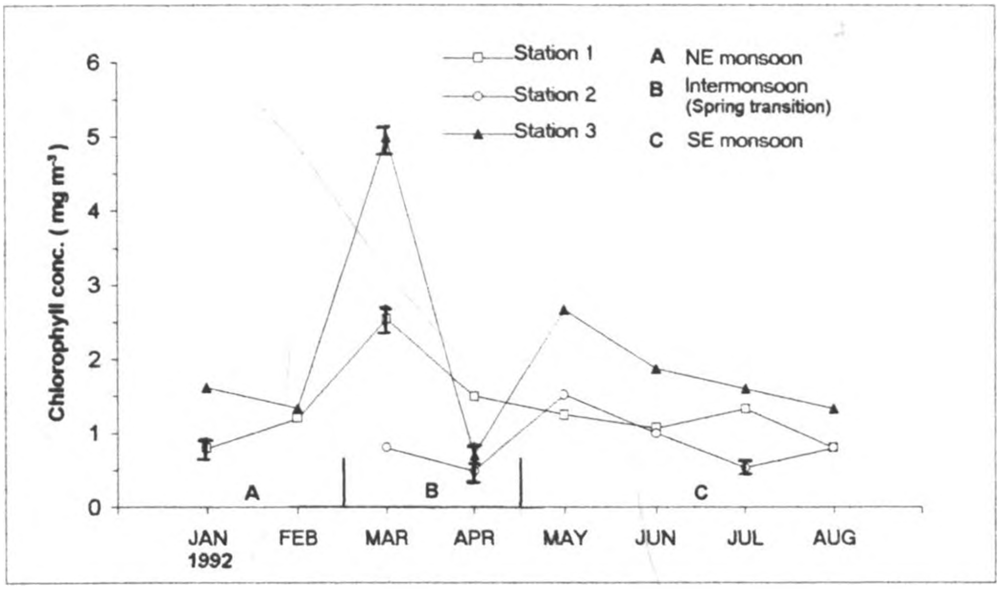


Fig. 17: Mean (± SEM) chlorophyll a concentration from 1 litre samples taken at 1.4m depth in Tudor creek Mombasa. N = 3 at each station.

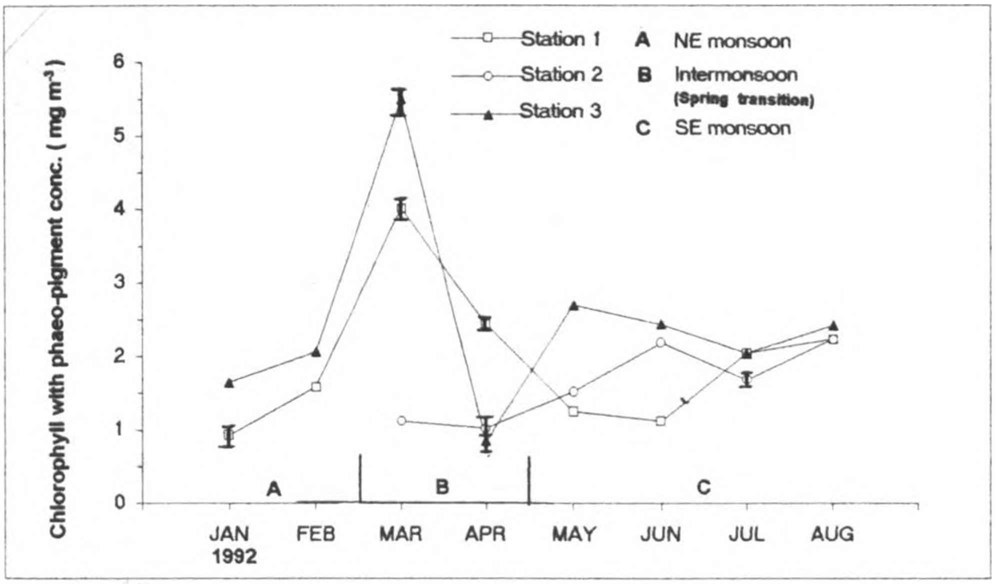


Fig. 18: Mean (± SEM) chlorophyll a with phaeo-pigment concentration from 1 litre samples taken at 1.4m depth in Tudor creek Mombasa. N = 3 at each station.

3.22 Zooplankton taxonomic composition

The major phyla in the near-surface waters of Tudor creek were Crustacea, mainly Copepoda and Decapoda, Chordata, comprising fish eggs, larvae and juveniles, Chaetognatha and the urochordates Thaliacea and Larvacea. The Cnidaria, Ctenophora and Mollusca were also conspicuous. These phyla were identified to the lowest taxon possible as listed below.

PHYLUM	**CNIDARIA**
Order	Hydroida
	Siphonophora
PHYLUM	**CTENOPHORA**
Class	Tentaculata (including Pleurobrachia sp)
PHYLUM	**ANNELIDA**
Class	Polychaeta
Family	Tomopteridae
PHYLUM	**MOLLUSCA**
Class	Gastropoda
Sub class	Prosobranchia
Order	Mesogastropoda
Super family	Heteropoda
Sub class	Opisthobranchia
Order	Thecosomata
Class	Lamellibranchia
PHYLUM	**CRUSTACEA**
Class	Branchiopoda
Order	Cladocera

Class	Copepoda
Order	Calanoida (Sars 1902)
Family	Calanidae (Dana 1853) incl. *Undinula* spp incl. *U. vulgaris*
Family	Eucalanidae (Giesbretch 1892) incl. *Eucalanus* spp and *Rhincalanus cornutus* (Dana 1849)
Family	Paracalanidae (Giesbretch 1892) incl. *Acrocalanus* sp & *Paracalanus* sp
Family	Euchaetidae (Sars 1902) incl. *Euchaeta* sp
Family	Scolecithricidae (Sars 1902) incl. *Scolecithrix danae* (Lubbock 1856)
Family	Temoridae (Sars 1902) incl. *Temora discaudata* (Giesbretch 1889), *T. turbinata* & *T. stylifera* (Dana 1849)
Family	Metridiidae incl. *Metridia* sp (Boeck, 1864)
Family	Centropagidae (Giesbretch 1888) incl. *Centropages orsini* (Giesbretch 1888), *C. furcatus* & *C. gracilis* (Dana 1849)
Family	Augaptilidae incl. *Haloptilus* sp (Giesbretch 1898)
Family	Candaciidae (Giesbretch 1892) incl. *Candacia* spp
Family	Pontellidae (Sars 1902) incl. *Calanopia* spp, *C. thompsoni*, *Labidocera* sp *L. pavo*, *Pontella* sp, *Pontellina* sp & *Pontellopsis* sp
Family	Acartiidae (Sars 1900) incl. *Acartia* spp
Family	Tortanidae (Sars 1902) incl. *Tortanus* sp

Order	Cyclopoida (Burmeister 1834)
Family	Oithonidae (Dana 1853) incl. Oithona spp
Order	Harpacticoida (Sars 1903)
Family	Ectinosomidae (Moore 1878) incl. Microsetella sp
Family	Tachidiidae (Sars 1909) incl. Euterpina sp
Family	Clytemnestridae (A. Scott 1909) incl. Clytemnestra sp
Family	Miracidae (Dana 1846) incl. Macrosetella sp
Family	Porecelliidae incl. Porecellidium sp
Order	Monstrilloida (Sars 1902)
Family	Monstrillidae
Order	Poecilostomatoida (Thorell 1859)
Family	Corycaeidae (Dana 1853) incl. Corycaeus spp
Family	Oncaeidae (Giesbretch 1892) incl. Oncaea sp
Family	Sapphirinidae (Thorell 1859) incl. Copilia sp & Sapphirina spp)
Family	Clausiidae (Embleton 1901) incl. Sapphirella spp
Class	Cirripedia (nauplii)
Class	Ostracoda
Class	Malacostraca
Super order	Hoplocarida
Order	Stomatopoda
Super order	Peracarida
Order	Cumacea
Order	Isopoda

Order	Amphipoda
Super order	Eucarida
Order	Decapoda
Infra order	Penaeidae incl. Sergestes. Lucifer and Acetes
Infra order	Caridea
Infra order	Anomura (Porcellanid larvae)
Infra order	Brachyura (larvae and megalopa)
PHYLUM	**BRYOZOA** (Cyphonautes larvae)
PHYLUM	**ECHINODERMATA** (Ophiopluteus larvae)
PHYLUM	**CHAETOGNATHA** incl. Sagitta spp & Khronitta sp
PHYLUM	**CHORDATA**
Super order	Urochordata
Class	Thaliacea
Order	Salpida
Order	Doliolida
Class	Larvacea
Family	Oikopleuridae incl. Oikopleura sp & Fritillaria sp
Sub phylum	Vertebrata
Class	Osteichthyes (incl. Family Syngnathidae)

3.23 Zooplankton biomass

Mean zooplankton biomass in the near-surface waters of Tudor creek was higher in station 1 and least in 2 ($F_{0.05,\ 2,59} = 3.475$, $P = 0.038$). The former station had the largest fluctuation of biomass ranging from 0.08 ± 0.01 SEM ml l^{-1} to 0.67 ± 0.3 SEM ml l^{-1} (Fig. 19) while the latter had the least range of zooplankton biomass (0.1 + 0.0 SEM ml l^{-1} to 0.2 + 0.0 SEM ml l^{-1}). Station 3 maintained intermediate levels ranging from 0.1 ± 0.0 ml SEM l^{-1} to 0.3 ± 0.1 SEM ml l^{-1}. Mean zooplankton biomass was highest during the intermonsoon months of March and April through to the early SE monsoon in May. Station 1, which is most under oceanic influence, attained a peak of mean zooplankton biomass in May ($F_{0.05\ 7,21} = 50.725$, $P = 0.00$), station 2 in April and station 3 in May and possibly in August.

The March-May maxima of mean zooplankton biomass was a result of increased abundance of both holoplankton, particularly copepods as well as meroplanktonic groups like crustacean decapod larvae, molluscan larvae and fish eggs. But the high biomass in station 3 during August was mainly due to high densities of these meroplankters. The maxima of mean zooplankton biomass lagged 1 to 2 months behind those of both chlorophyll a alone (Fig. 17) and of chlorophyll a with phaeo-pigments (Fig. 18). But no significant correlation could be established between mean zooplankton biomass and either types of chlorophyll a ($P > 0.05$ in all cases).

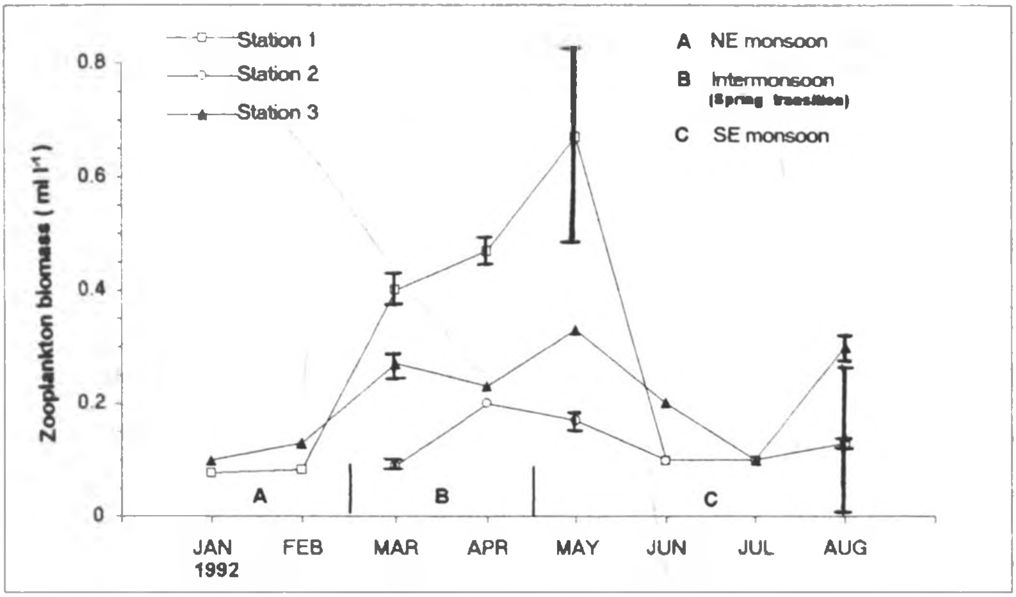


Fig. 19: Mean (+ SEM) zooplankton biomass at 1.4m depth in Tudor creek Mombasa. N = 3 at each station.

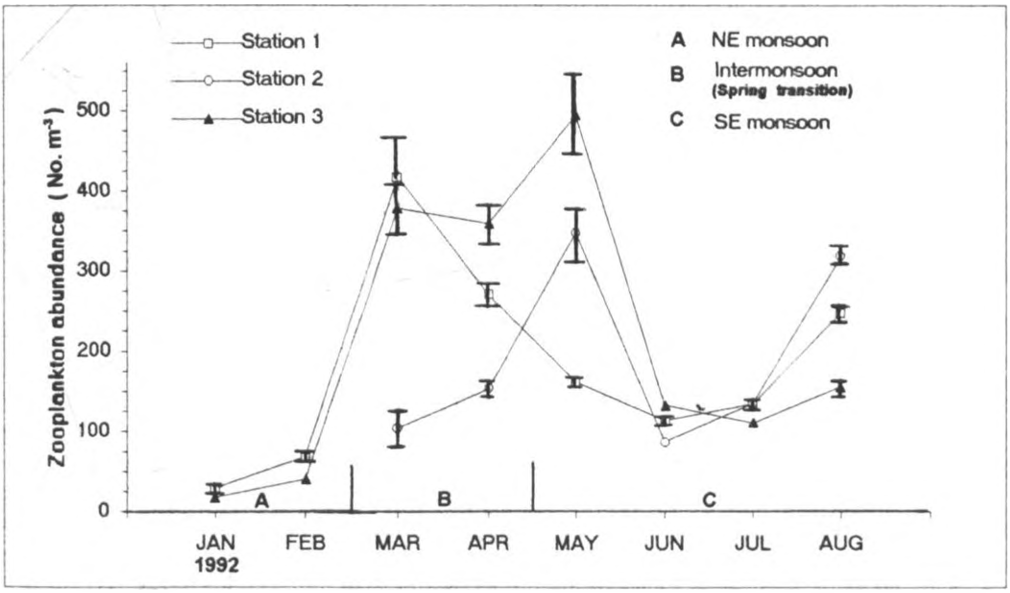


Fig. 20: Mean (+ SEM) zooplankton abundance at 1.4m depth in Tudor creek Mombasa. N = 3 at each station.

3.24 Zooplankton abundance

The triplicate plankton net (Fig. 3) provided replicate zooplankton samples in all the stations during the sampling period ($F_{0.05,\ 2,59} = 0.231$, $P = 0.795$). Therefore the zooplankton densities obtained from the samples were valid for statistical analyses.

Figure 20 gives the pattern of total zooplankton abundance at the different stations over the period of study. In station 1 zooplankton density was highest during the intermonsoon period of March reaching 417.8 ± 1.5 SEM. A possible minor peak with 248.5 ± 25.1 SEM m^{-3} occurred in August ($F_{0.05,\ 7,21} = 9.94$, $P = 0.0002$). As will be detailed in the following sections groups such as Salpida, Larvacea, Chaetognatha, Ctenophora, Siphonophora and Hydromedusae particularly the Narcomedusae showed an increase in abundance in March. Typical oceanic copepods like Rhincalanus, Metridia, and Euchaeta appeared while calanoids such as Undinula, Eucalanus, Acartia, Centropages and Temora increased in abundance. Fish eggs and fish larvae also had increased densities in March as well as in August.

Station 2 differed from 1 in that the main peak of zooplankton abundance occurred in May (347.6 ± 83 SEM m^{-3}) but a minor peak with 318.4 ± 34 SEM m^{-3} was in August ($F_{0.05,\ 5,15} = 5.4117$, $P = 0.115$ & Tukey after Anova $P < 0.05$). Meroplankters such as crustacean decapod larvae especially brachyuran larvae were responsible for the May peak and gastropod veligers for the high abundance in August. Figure 20 shows that the highest zooplankton abundance in station 3 occurred from March (378.5 ± 48 SEM m^{-3}), through April (359.5 ± 58.5 SEM m^{-3}), to May (495 ± 123.2 SEM m^{-3}, $F_{0.05,\ 7,21} = 9.9862$, $P = 0.0002$). This was largely due to increased densities of the larval stages of decapoda like Penaeidae, Caridea, Anomura and Brachyura in station 3.

Each of the zooplankton taxa showed patterns of temporal variation which differed from the general ones for zooplankton, as a whole, described above. The seasonal abundance of the two main planktonic faunal divisions, holoplankton and meroplankton, distinguished on the basis of life cycle, is discussed below.

3.2.4.1 Holoplankton abundance

Figure 21, gives the fluctuations in holoplankton abundance in the near-surface waters of Tudor creek, throughout the study period. The main peak in station 1 was during the intermonsoon months of March-April, being 204 ± 8 SEM m^{-3} and 207 ± 22.7 SEM m^{-3}, respectively. In station 3, the peak occurred in April reaching 177.9 ± 15.6 SEM m^{-3}. In contrast a possible major peak of holoplankton abundance in station 2 occurred during the SE monsoon in August with 147.4 ± 13.4 SEM m^{-3}. But the holoplankton also showed a significant increase ($F_{0.05,\ 5,15} = 6.4177$, $P = 0.0064$) in abundance during the intermonsoon in April (140.8 ± 39.4 SEM m^{-3}), in this site.

The five main holoplanktonic groups, in order of quantitative dominance were the Copepoda, Chaetognatha, Cnidaria, Ctenophora and the urochordate Thaliacea and Larvacea. Other groups such as the molluscan pteropoda and heteropoda and crustacean decapods like Sergestes, Acetes and Lucifer were not numerically important.

Copepoda

Copepods made up 65% to 85% of the holoplanktonic fauna in the near-surface waters of Tudor creek and as would be expected their patterns of abundance were similar to those observed for the general holoplankton fauna. Copepod abundance in stations 1 and 3 was highest in March-April and in station 2 during August (Fig. 22).

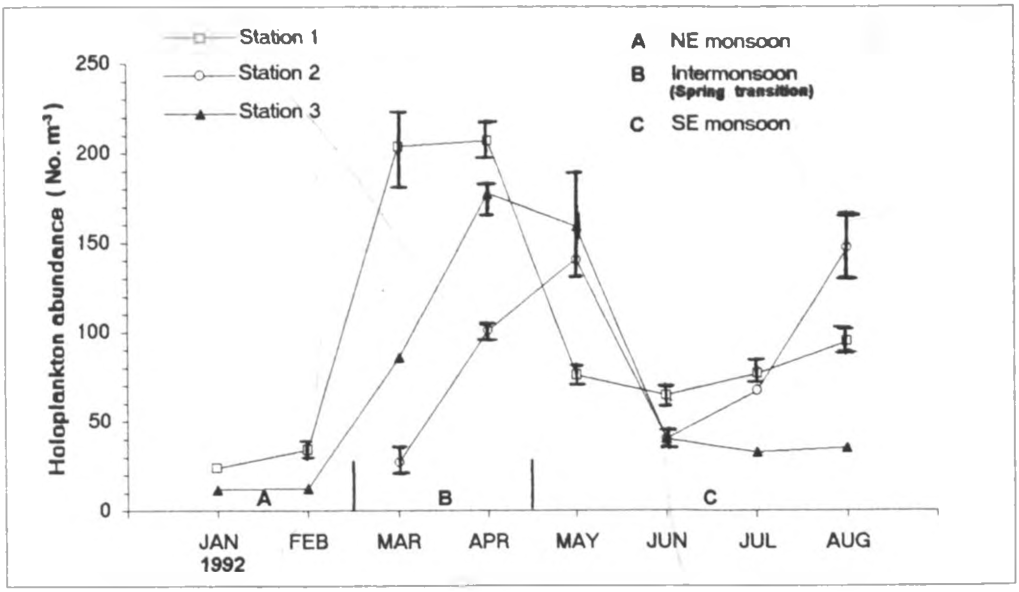


Fig. 21: Mean (± SEM) holoplankton abundance at 1.4m depth in Tudor creek Mombasa. N = 3 at each station.

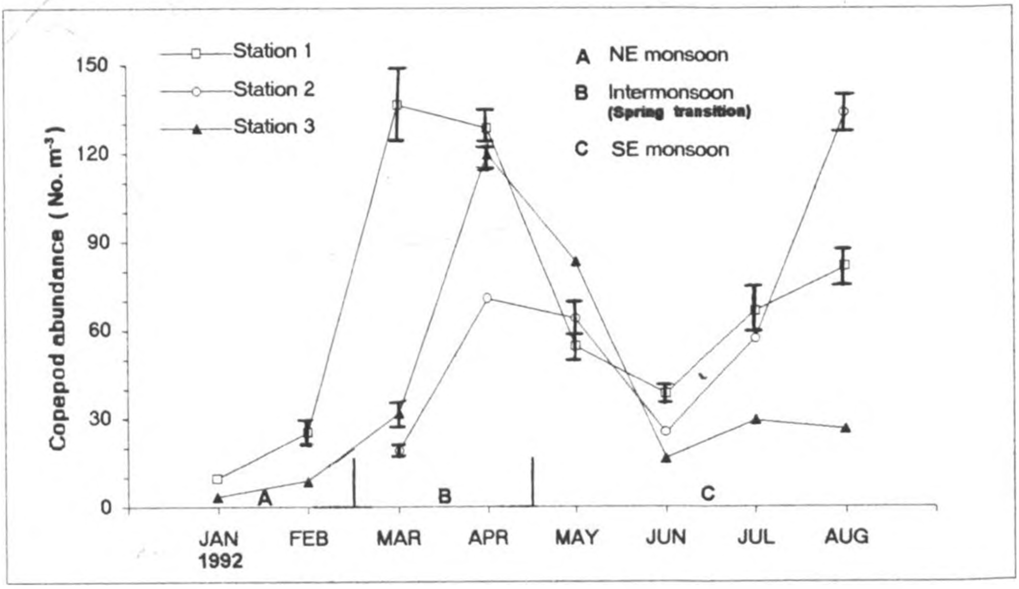


Fig. 22: Mean (± SEM) copepod abundance at 1.4m depth in Tudor creek Mombasa. N = 3 at each station.

Calanoida (Sars 1902)

As mentioned earlier this was quantitatively the most important group comprising 80-90% of the copepod fauna. In station 1 the peak of calanoid density occurred in April ($F_{0.05, 2,21} = 9.826$ $P = 0.0002$, Tukey after anova $P < 0.05$) reaching 113.9 ± 11.5 SEM m^{-3}. In the sheltered innermost station a calanoid maxima with 113.3 ± 11.1 SEM m^{-3} also occurred in April whereas calanoids were most abundant during August (115.7 ± 8.4 SEM m^{-3}) in station 2 (Fig. 23).

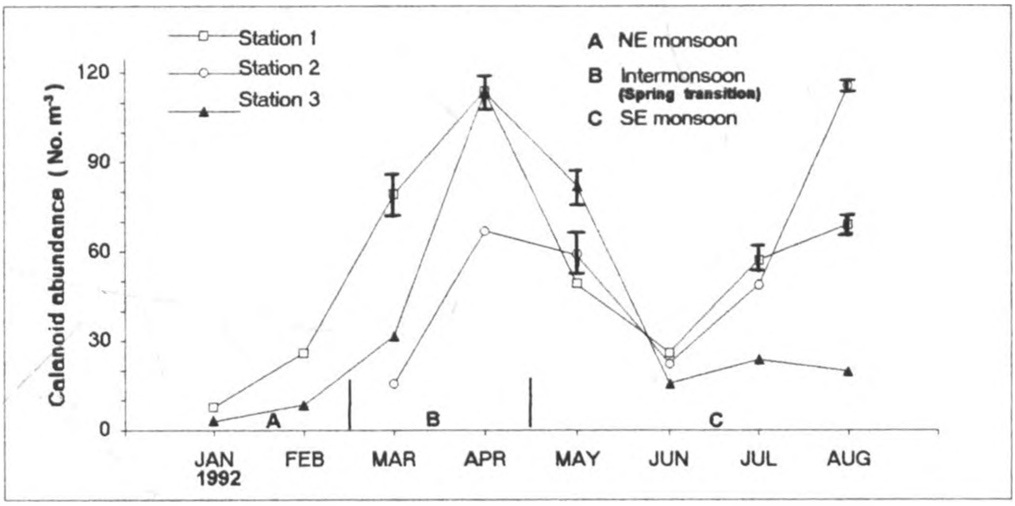


Fig. 23: Mean (± SEM) calanoid abundance at 1.4m depth in Tudor creek Mombasa. N = 3 at each station.

Poecilostomatoida

The main genera encountered were Corycaeus, Oncaea, Copilia and Sapphirina. Corycaeus spp and Oncea spp constituted 80-90% of the poecilostomatoids and were present in all the stations throughout the sampling period. Copilia sp was only abundant during March-April at all the sites, but thereafter disappeared in stations 2 and 3. The carnivores Sapphirina and Sapphirella were present in stations 1 and 2 throughout but disappeared from station 3 in April.

The major peak of poecilostomatoid abundance in station 1 occurred in March ($F_{0.05\ 7,21} = 23.99$, $P= 0.00$, Tukey after anova $P < 0.05$) with 44.7 ± 7.1 SEM m^{-3} (Fig. 24). In station 2 the possible peak in August averaged 15.1 ± 3.6 SEM m^{-3} only. Poecilostomatoid densities in the innermost station never exceeded 3 m^{-3} and no peak was discernible ($F_{0.05\ 7,21} = 2.413$, $P = 0.076$, Tukey after anova $P > 0.05$).

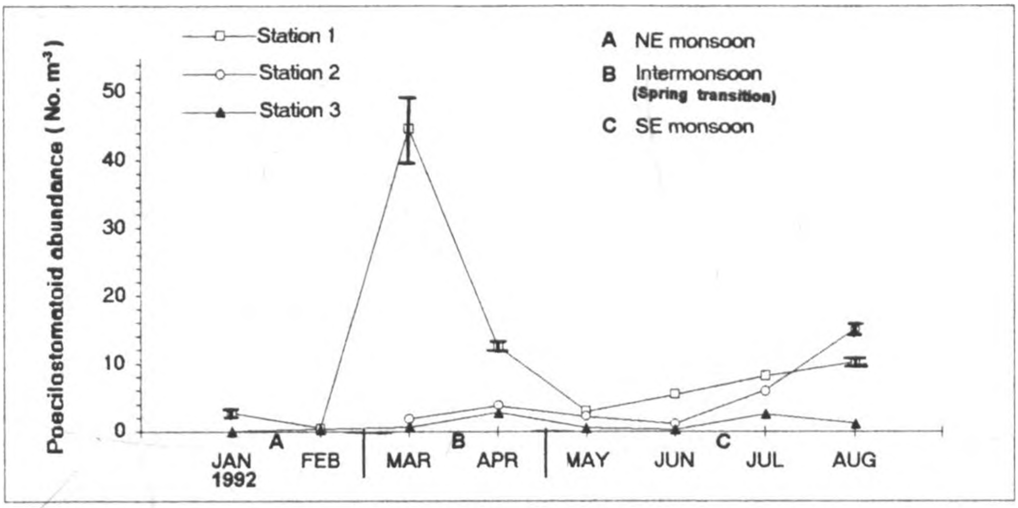


Fig. 24: Mean (± SEM) poecilostomatoid abundance at 1.4m depth in Tudor creek Mombasa. N = 3 at each station.

Cyclopoida

Oithona spp were mainly found in station 1 but in stations 2 and 3 their density never exceeded 2.0 m^{-3} (Fig. 25). The main peak in March, in station 1, had 9.4 ± 1.1 SEM m^{-3} and the minor one in June had 5.9 ± 0.2 SEM m^{-3} ($F_{0.05\ 7,21} = 40.5035$, $P = 0.00$). Station 3 had a possible peak in August with 1.6± 0.3 SEM m^{-3}.

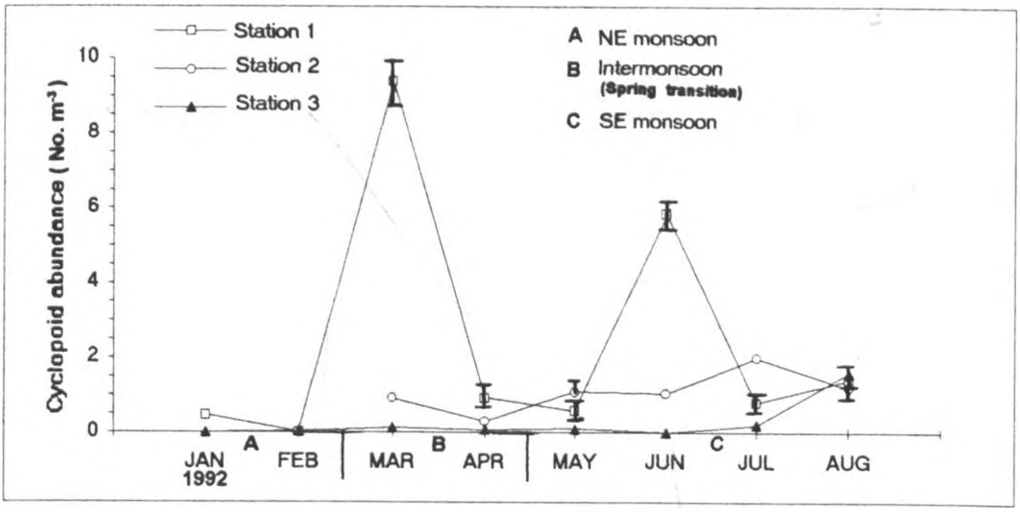


Fig. 25: Mean (± SEM) cyclopoid abundance at 1.4m depth in Tudor creek Mombasa. N = 3 at each station.

Harpacticoida

These copepods were never numerically important in any station (Fig. 26) and the main genera encountered included Porcellidium, Euterpina, Macrosetella, Microsetella and Clytemnestra. The maxima of harpacticoids in station 1, were in March and May ($F_{0.05\ 7,21} = 6.035$, P= 0.002, Tukey after anova $P < 0.05$) due to an increase of Porcellidium.

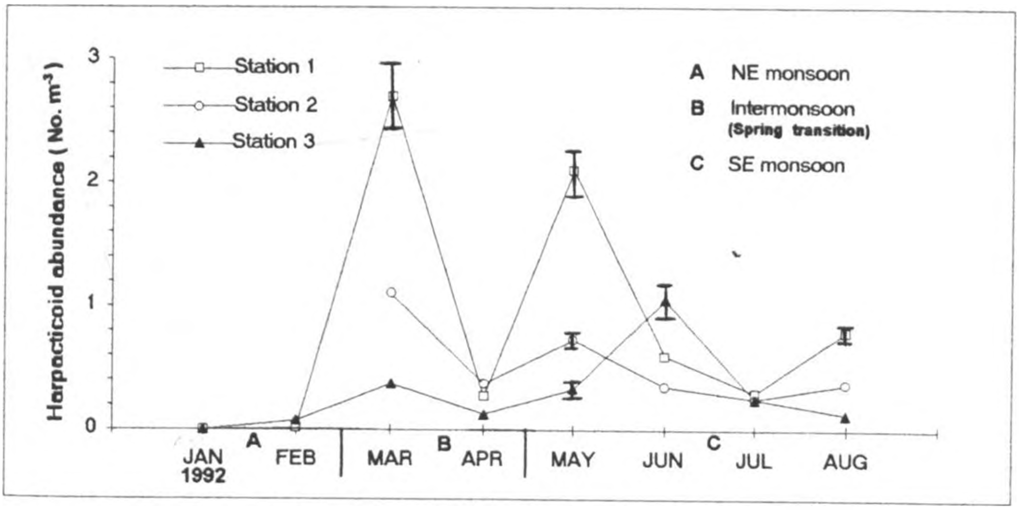


Fig. 26: Mean (± SEM) harpacticoid abundance at 1 4m depth in Tudor creek Mombasa. N = 3 at each station.

Monstrilloida

Of the five copepod orders the Monstrilloida were the least important, with densities ranging from 0.1 to 0.3 m^{-3}, in all the stations during the sampling period (Fig. 27).

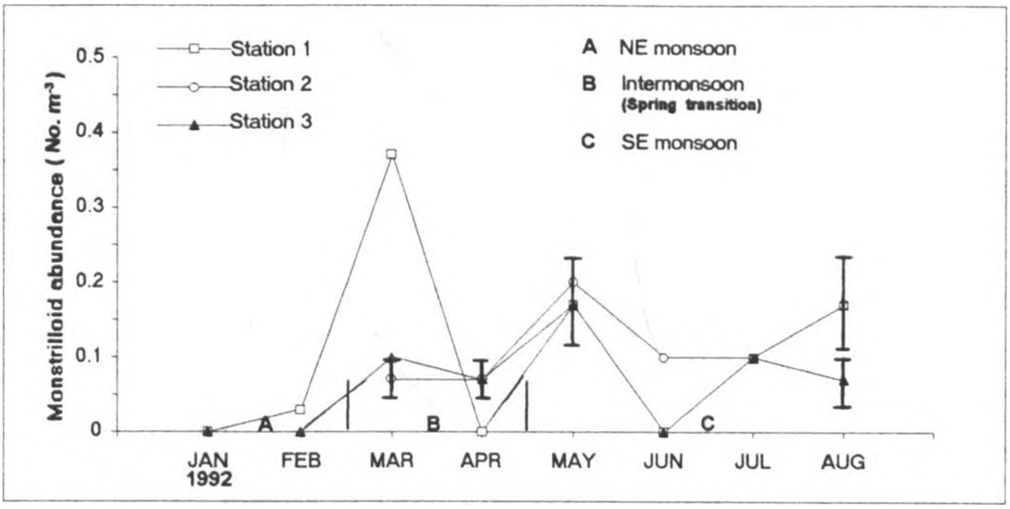


Fig. 27: Mean (± SEM) monstrilloid abundance at 1.4m depth in Tudor creek Mombasa. N = 3 at each station.

Chaetognatha

Chaetognaths appeared in all stations during the sampling period (Fig. 28), with highest abundance in station 3 and the least in station 2 as was also reported by Kimaro (1986). In stations 1 and 2, the maxima of chaetognath abundance were in April 26.9 ± 2.2 SEM m^{-3} and 9.6 ± 1.2 SEM m^{-3} in June, respectively. A possible peak also occurred during August in station 2. High chaetognath densities occurred during March in station 3 (28.1 ± 3.2 SEM m^{-3}).

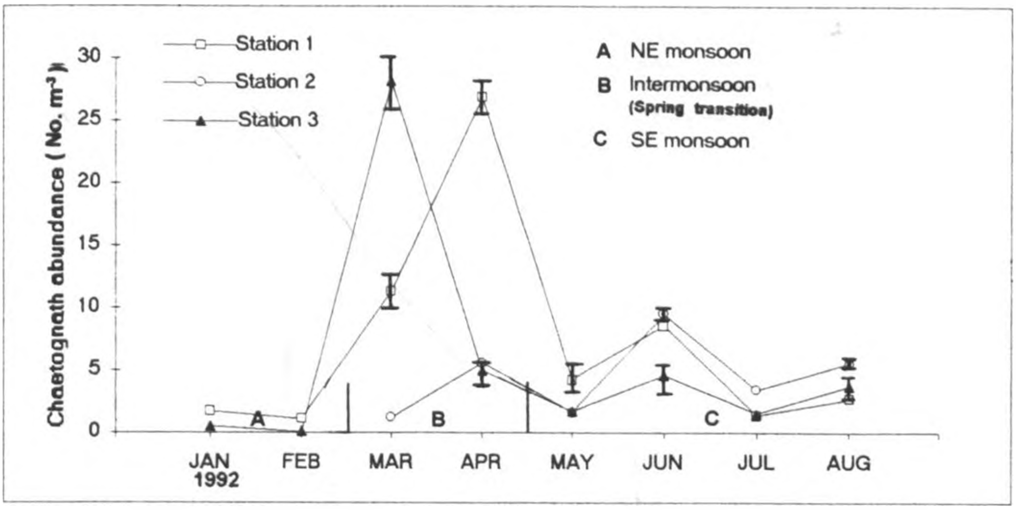


Fig. 28: Mean (± SEM) chaetognath abundance at 1.4m depth in Tudor creek Mombasa. N = 3 at each station.

Cnidaria

Hydromedusae were mostly found in station 3 ($F_{0.05\ 2,59}$ = 6.9147, P = 0.002) whereas Siphonophores were characteristic of station 1 ($F_{0.05,\ 2,59}$ = 8.9178, P =0.0004; Figs. 29 & 30). Hydromedusae occurred in maximum numbers during the intermonsoon months of March in station 1 (4.2 + 1 SEM m^{-3}) and April in station 2 (1.8 + 0.5 SEM m^{-3}). In station 3 hydromedusae were abundant throughout most of the sampling period and no peak was discernible ($F_{0.05,\ 7,21}$ = 1.7356, P = 0.1799). But relatively high densities were observed during the NE monsoon (January) and intermonsoon period (Fig. 29). The abundance of siphonophores decreased with distance into the creek and high densities occurred during the intermonsoon in all the stations (Fig. 30).

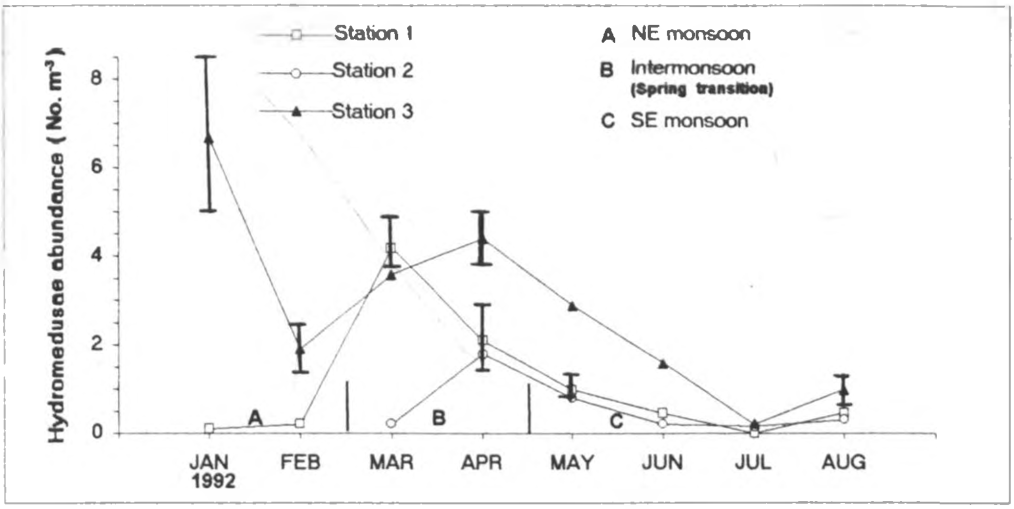


Fig. 29: Mean (+ SEM) hydromedusae abundance at 1.4m depth in Tudor creek Mombasa. N = 3 at each station.

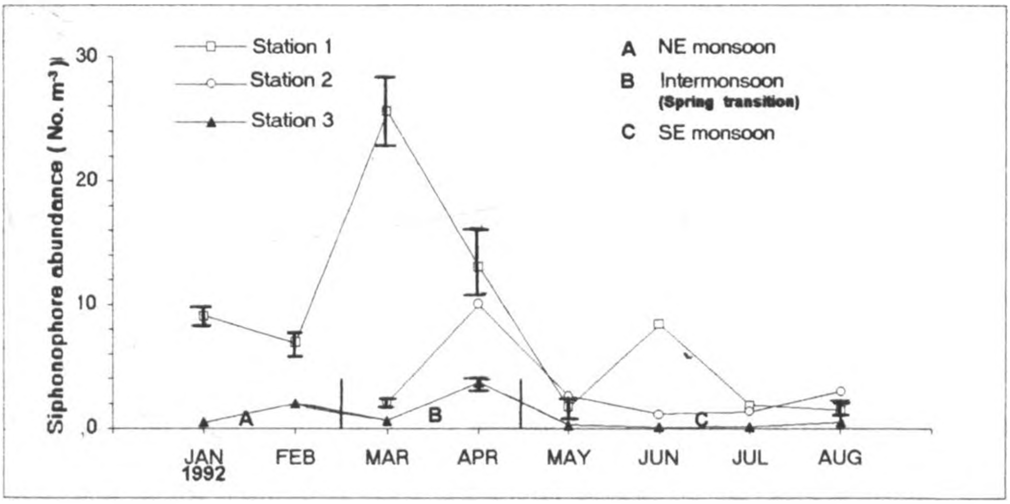


Fig. 30: Mean (+ SEM) siphonophore abundance at 1.4m depth in Tudor creek Mombasa. N = 3 at each station.

Ctenophora

The seasonal abundance of ctenophores is presented in figure 31. Ctenophores reached their highest abundance in station 1, and least in 2 which did not have a significant peak of density ($F_{0.05\ 5,15} = 2.7378$, $P = 0.0823$). The maximum density of ctenophores in stations 1 and 3 was in April with 8.9 ± 4.2 SEM m^{-3} and 6.3 ± 0.6 SEM m^{-3}, respectively. A minor peak of only 2.8 ± 0.6 SEM m^{-3} possibly occurred in station 3 during August ($F_{0.05\ 7,21} = 23.2413$, $P = 0.000$, Tukey after anova $P < 0.05$).

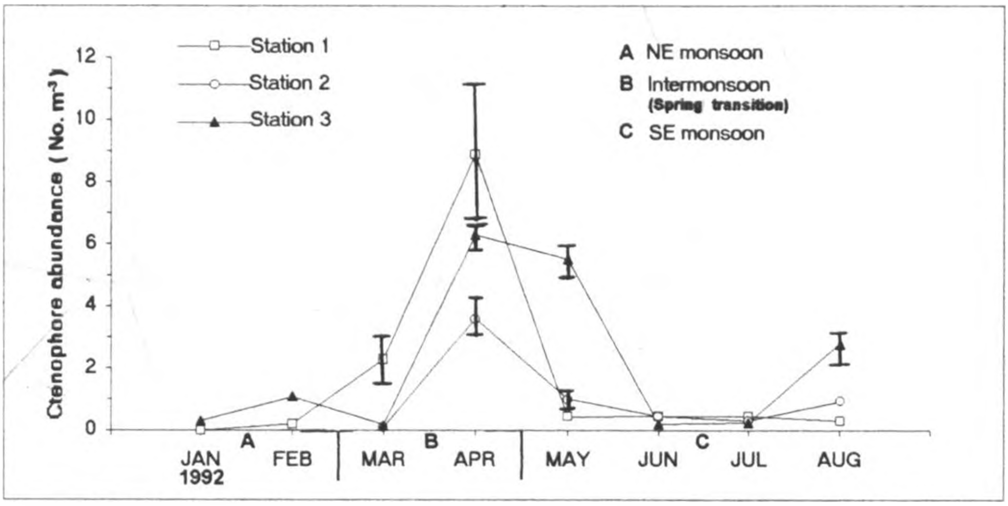


Fig. 31: Mean (± SEM) ctenophore abundance at 1.4m depth in Tudor creek Mombasa. N = 3 at each station.

Urochordata

This was the least important major holoplanktonic group, in terms of abundance, and it consisted of the thaliacean salps and doliolids and the larvaceans mainly Oikopleura sp. Thaliaceans and larvaceans were features of station 1, close to the open ocean, (Figs. 32 & 33) and were rarely found in stations 2 and 3 ($F_{0.05\ 2,59} = 14.2075$ $P = 0.00$ and $F_{0.05\ 2,59} = 4.0828$ $P = 0.022$, respectively). They appeared in large numbers during the intermonsoon, in station 1 and thereafter declined in abundance. The relatively high densities of thaliaceans in August (3.3 ± 1.4 SEM m^{-3}) were due to increased contributions of doliolids.

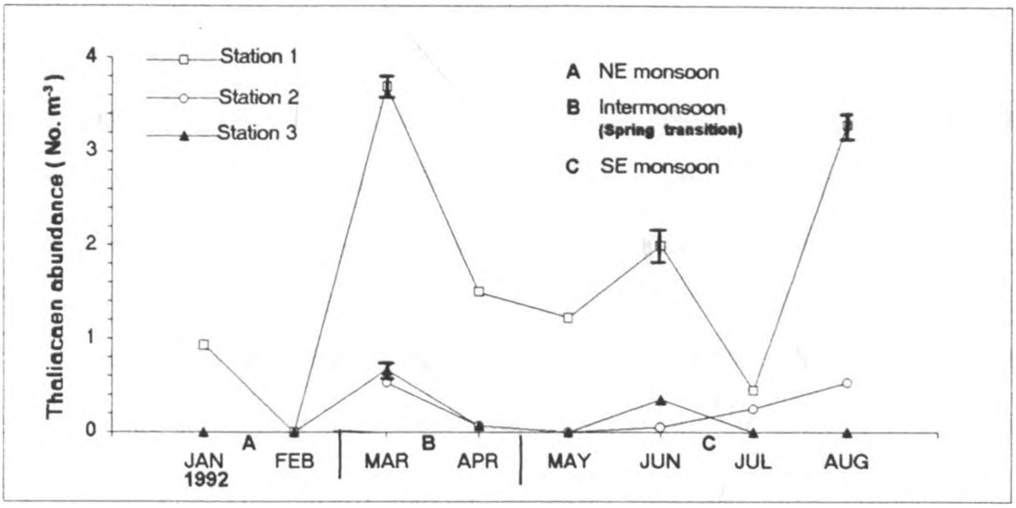


Fig. 32: Mean (± SEM) thaliacean abundance at 1.4m depth in Tudor creek Mombasa. N = 3 at each station.

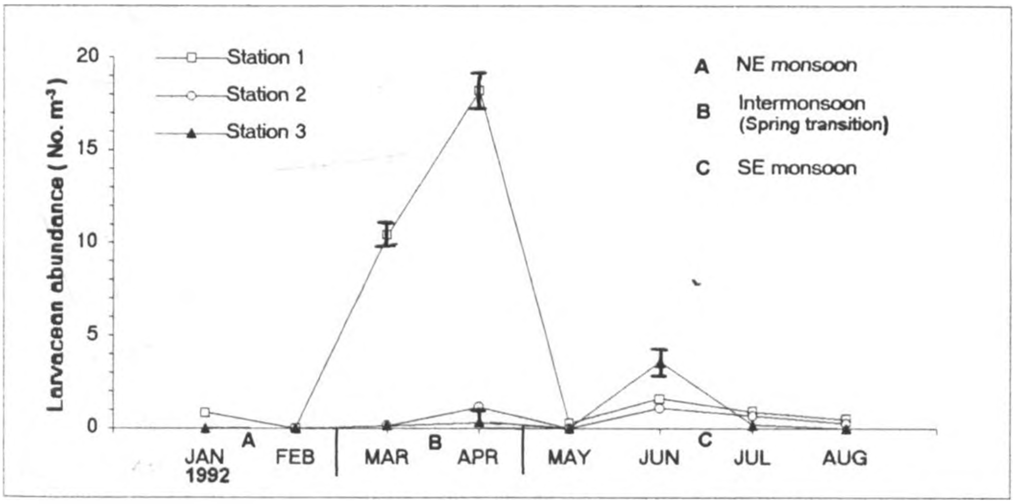


Fig. 33: Mean (± SEM) larvacean abundance at 1.4m depth in Tudor creek Mombasa. N = 3 at each station.

3.242 Meroplankton abundance

The four main meroplanktonic groups considered were the brachyuran, other crustacean decapods, molluscan larvae (mainly gastropod veligers and lamellibranch larvae) and fish eggs and larvae. Crustacean decapod larvae, excluding brachyurans consisted of larvae of the Penaeidae, Caridea, Anomura, and the Phyllosoma. As might be expected, meroplankton abundance varied according to the spawning cycles of the parental stock but there was sufficient overlapping between the various groups to ensure a substantial presence of meroplankton throughout most of the sampling period.

Meroplankton were characteristic of the inner stations and figure 34 shows a clear gradient of abundance increasing with distance into the creek. Maximum densities of meroplankton, in stations 2 and 3, occurred in May with 309.3 ± 46.6 SEM and 323.3 ± 132.8 SEM m^{-3}, respectively. These maxima were due to increased numbers of crustacean decapod larvae, particularly penaeids, carideans and brachyurans. In station 1 high meroplankton densities occurred from March to May ($F_{0.05\ 7,21} = 12.1244$, $P = 0.000$, Tukey after anova $P < 0.05$), due to increased contributions of brachyuran larvae, fish eggs and molluscan larvae.

Brachyuran larvae.

This was the most important meroplanktonic group and was a characteristic of stations 2 and 3 (Fig. 35). In station 1 relatively high abundances occurred in March (55.7 ± 8.4 SEM m^{-3}), May (33.2 ± 5.4 SEM m^{-3}) and August (72.1 ± 3.2 SEM m^{-3}). Brachyuran larvae constituted at least 50% of the meroplanktonic fauna in station 2 during May with 150.9 ± 25.7 SEM m^{-3}. In station 3 they were responsible for the relatively high densities of meroplankters observed from March to May ($F_{0.05\ 7,21} = 1.7054$, $P = 1.874$).

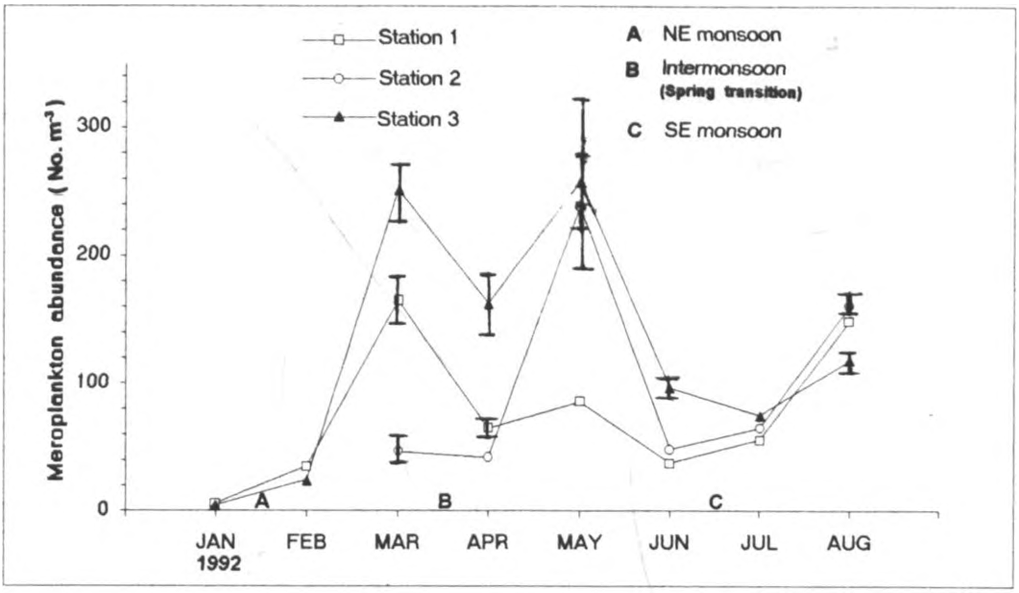


Fig. 34: Mean (± SEM) meroplankton abundance at 1.4m depth in Tudor creek Mombasa. N = 3 at each station.

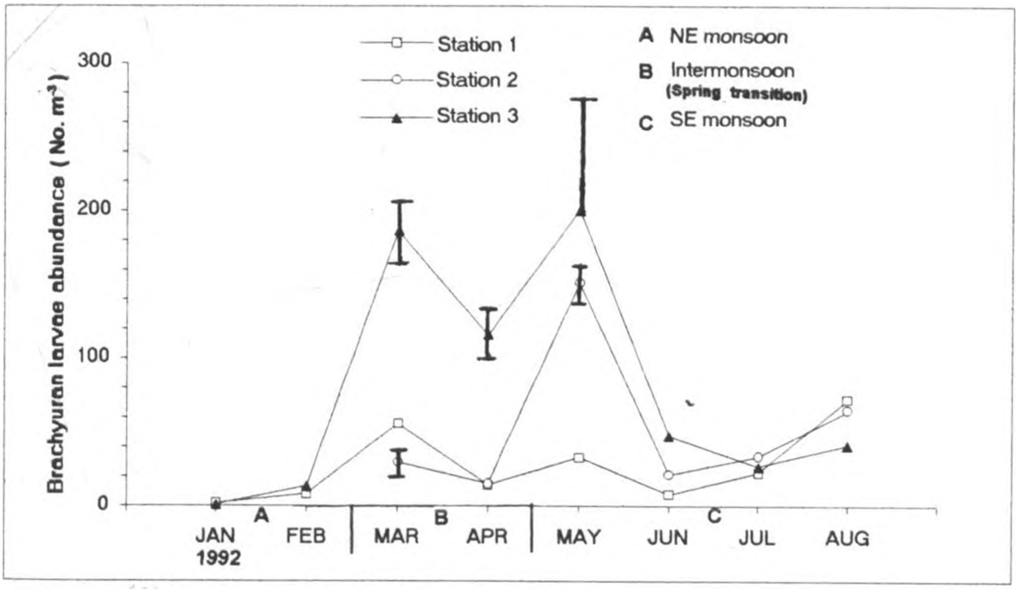


Fig 35: Mean (± SEM) brachyuran larvae abundance at 1.4m depth in Tudor creek Mombasa. N = 3 at each station.

Crustacean decapod larvae

The trend of the seasonal abundance of meroplanktonic crustacean decapod larvae is illustrated in figure 36. Meroplanktonic crustacean decapod larvae were a prominent feature of station 3 and were less abundant in stations 1 and 2. Their maximum numbers in stations 2 and 3 occurred in May with 78.4 ± 27.6 SEM m^{-3} and 246.3 ± 183.9 SEM m^{-3}, respectively. The density of meroplanktonic crustacean decapod larvae in station 1 was generally low, throughout the sampling period, therefore no peak as such was established ($F_{0.05\ 7,21} = 3.7307$, $P = 0.1073$, Tukey after anova $P > 0.05$). As mentioned earlier, crustacean decapod larvae, excluding brachyurans consisted of larvae of the Penaeidae, Caridea, Anomura, and the Phyllosoma and the most abundant were penaeids and carideans. During the peak in May up to 56.2 ± 4.8 SEM m^{-3} penaeids and 22.8 ± 4.3 SEM m^{-3} carideans were found in station 3.

Mollusca larvae

Molluscan larvae (mainly gastropod veligers and lamellibranch larvae) were the least important meroplanktonic group, and their abundance decreased with distance into the creek (Fig. 37). Gastropod veligers made up about 80% of the total molluscan larval abundance and were present throughout the sampling period. The lamellibranchs appeared intermittently in low abundances except during the intermonsoon when they made their highest contributions. In station 1 molluscan larvae occurred in maximum numbers (22.7 ± 6 SEM m^{-3}) during April ($F_{0.05\ 7,12} = 5.0831$, $P = 0.0048$, Tukey after anova $P < 0.05$). But this maximum was relatively lower than the August maximum of 43.1 ± 6.4 SEM m^{-3} in station 2. Station 3 did not have a well defined peak of molluscan larvae abundance ($F_{7,21,\ 0.05} = 2.443$, $P = 0.0734$, Tukey after anova $P > 0.05$).

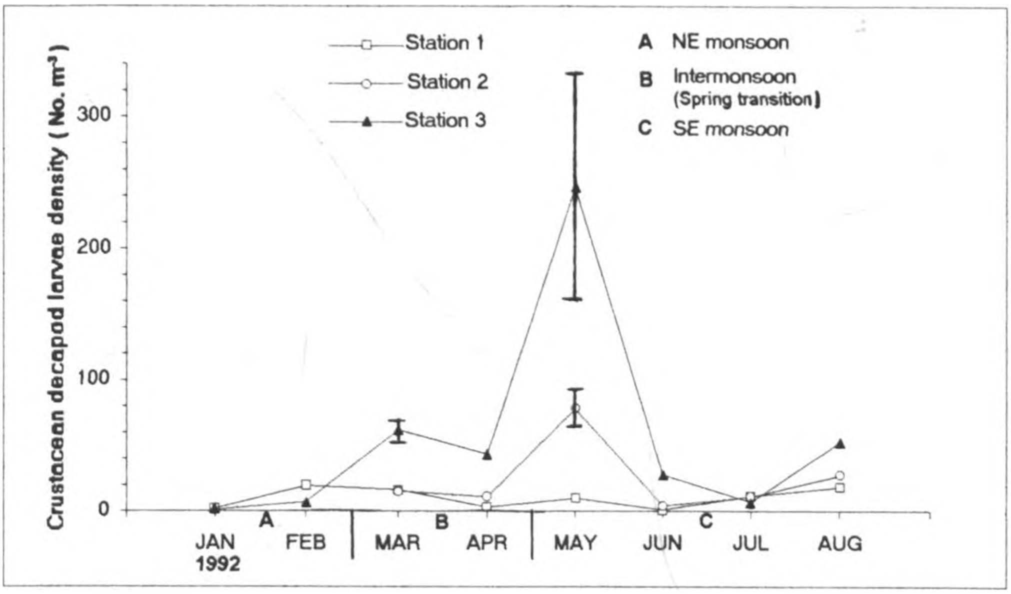


Fig. 36: Mean (± SEM) crustacean decapod larvae abundance at 1.4m depth in Tudor creek Mombasa. N = 3 at each station.

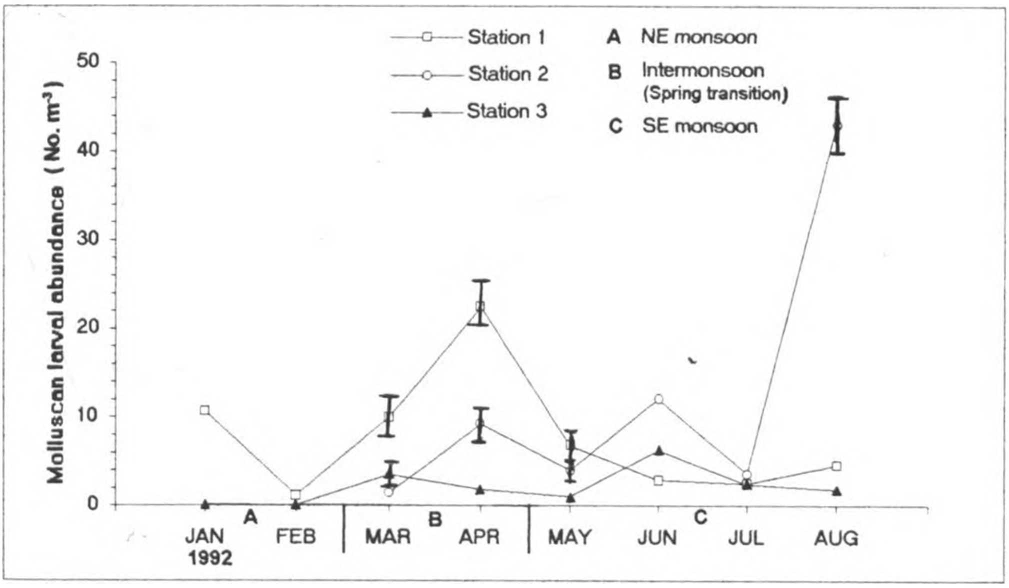


Fig. 37: Mean (± SEM) molluscan larvae abundance at 1.4m depth in Tudor creek Mombasa. N = 3 at each station.

Fish eggs abundance

Fish eggs were one of the most conspicuous element of the planktonic fauna in the near-surface waters of Tudor creek during the sampling period. Figure 38 shows a gradient of decreasing fish eggs abundance with distance into the creek. In station 1, at the mouth of the creek, a maximum of 76.3 ± 7.6 SEM eggs m^{-3} occurred during the period of monsoon reversal in March. A possible minor peak of fish egg abundance was also found in August (56.6 ± 13.1 SEM eggs m^{-3}). Fish eggs were most abundant in station 3 from June to August with densities ranging from 14.7 ± 1.9 SEM eggs m^{-3} in June to 38.6 ± 4.2 SEM eggs m^{-3} in July and to 22.4 ± 2.4 SEM eggs m^{-3} in August. Station 2 was peculiar in that fish eggs did not have a well defined peak of abundance during the sampling period ($F_{0.05\ 5,15} = 3.068$, $P = 0.0619$, Tukey after anova $P > 0.05$). Fish egg densities were generally low, and never exceeded 20 m^{-3}, but a gradual increase was observed from June to August.

Fish larvae abundance

Fish larvae were very common during March in station 1 ($F_{7,21,\ 0.05} = 3.3798$, $P = 0.025$, Tukey after anova $P < 0.05$). The high abundance of both fish eggs and larvae during the intermonsoon in this site could indicate arrival of an oceanic water mass bearing eggs and larvae of reef fishes. Fish larvae were rare in stations 2, where no peak was discernible ($F_{0.05\ 5,15} = 1.827$, $P = 0.3901$; Tukey after anova $P > 0.05$), and 3, where densities never exceeded 2.0 larvae m^{-3} (Fig. 39)

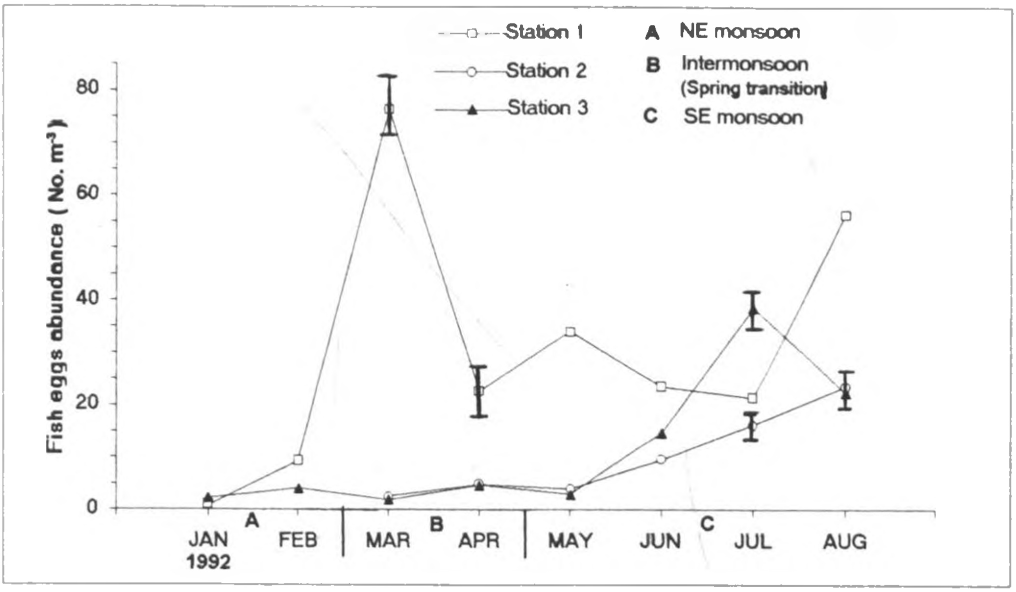


Fig. 38: Mean (± SEM) fish eggs abundance at 1.4m depth in Tudor creek Mombasa. N = 3 at each station.

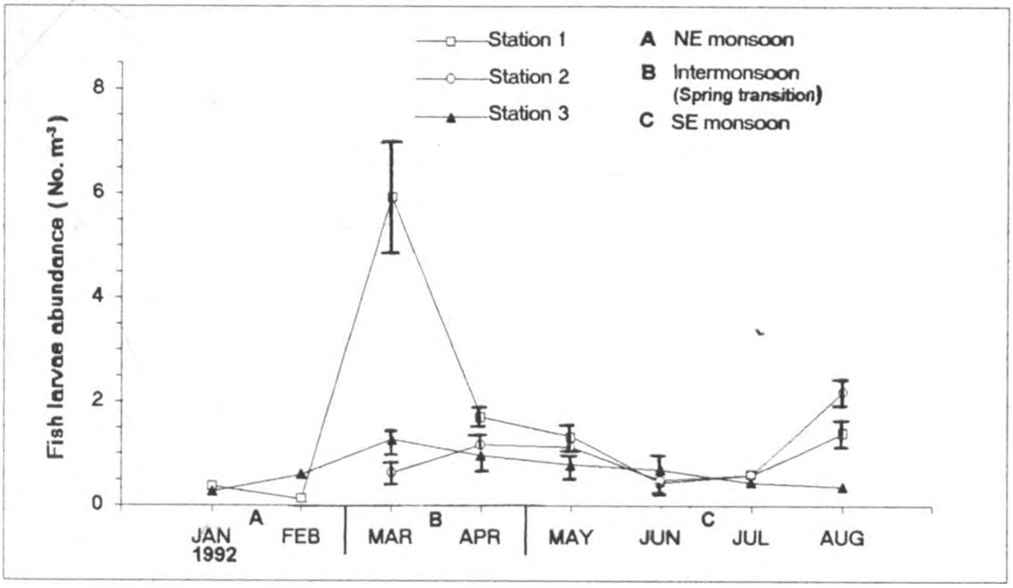


Fig. 39: Mean (± SEM) fish larvae abundance at 1.4m depth in Tudor creek Mombasa. N = 3 at each station.

4.0.0 DISCUSSION

4.1.0 ENVIRONMENTAL PARAMETERS

All the environmental parameters monitored in the catchment area and in the near surface waters of Tudor creek showed variations responding to the monsoon regime and there was a clear distinction between the wet and dry season in the catchment area of Tudor creek. The SE monsoon is the cooler and wetter season while the NE monsoon period is drier and warmer. The transition from the NE to the SE monsoon is a period of profound changes in the weather conditions and subsequently in the physico-chemical parameters of the water as seen in this study in plankton flora and fauna.

The migration of the Inter-Tropical Convergence Zone (ITCZ), is the single most important factor affecting seasonal changes throughout East Africa. In the Western Indian Ocean region the ITCZ shifts further north during the SE monsoon than in most tropical areas due to the low pressure belt created on the Asian continent during the northern summer. This shift is responsible for the greater seasonality experienced in East Africa and a greater distinction between wet and dry seasons than in many other tropical areas (McClanahan, 1988).

In addition the physico-chemical aspects of the water are also subject to tidal influences and local factors, depending on the site in the creek, such as degree of oceanic influence, depth and substrate type. Some physico-chemical parameters such as transparency, sea temperature, salinity, pH and dissolved oxygen showed gradients from the mouth to inner reaches due to the influence of local factors and their response to changes in the monsoon regime was clear. On the other hand though many of the nutrients showed a clear response to the monsoons, they did not seem to be influenced by the above mentioned local factors. For example, phosphates did not show a gradient in either direction but silicates had a gradient increasing from the mouth to the inner reaches.

Relatively high levels of NO_3-N and NH_4-N occurred in station 2, particularly in the intermonsoon period, with lower levels in stations 1 and 3. The effects of the local factors are superimposed on those of the changing monsoon to create temporal and spatial differences of the water masses in the creek but climatic conditions remain the most important influence on the environmental parameters and ultimately on the biota.

Both air and near-surface sea temperatures were higher in the NE monsoon than during the SE monsoon and as would be expected in the tropics they fluctuated within very narrow ranges. Air temperature fluctuated by $\pm$ 2.5 ^{o}C while near-surface sea temperature varied by $\pm$ 3.3 ^{o}C. The largest near-surface sea temperature fluctuation was in the shallow and sheltered station 3 ($\pm$ 3.3 ^{o}C) whereas temperature varied by $\pm$ 2 ^{o}C in the other two stations. The SE monsoon was characterized by lower air and near-surface sea temperatures, high wind speeds and increased cloud cover resulting in reduced radiation and fewer hours of sunshine. As mentioned earlier the greatest amount of rainfall occurs during the SE monsoon with peak levels in May.

The heavy rainfall in the SE monsoon caused a reduction of salinity values in all the sites. In addition to the lowered salinities a gradient with low levels upstream and higher levels at the mouth developed within the creek. But rainfall was not significantly correlated with salinity at any site ($P > 0.05$, in all cases). After the rainy season Tudor creek lost its estuarine characteristics and a uniform salinity of 35 $^{o}/_{oo}$ developed within the creek. In general this trend agrees with previous reports (Kimaro, 1986 & Okemwa, 1990) except that they recorded lower salinities in the creek during the rains than the present study.

As pointed out earlier, pH levels varied within narrow ranges and they did not seem to be influenced by the prevailing monsoon conditions. But they showed a gradient decreasing with distance into the creek and remained within the normal range of sea water pH levels (7.5 - 8.4, Hill, 1962) at all the sites. A similar gradient recorded by Okemwa (1990) was attributed to the influx of freshwater from the inflowing rivers during the rains. But in the present study the correlation between rainfall and pH was not significant in any of the sites ($P > 0.05$, in all cases).

Dissolved oxygen dynamics are affected by several factors which influence solubility such as atmospheric pressure, turbulence, temperature and salinity. Low atmospheric pressures such as in the SE monsoon, cause decreased solubility and this may account for the lower dissolved oxygen in the near-surface waters of Tudor creek found at the initiation of the SE monsoon. But as water temperature and salinities varied within narrow limits no significant influence on the concentration of dissolved oxygen could be detected at any site ($P > 0.05$, in all cases, Table 1).

Rainfall emerged as the key factor influencing dissolved oxygen levels. As presented in figure 40, relatively high dissolved oxygen levels occurred prior to and after the heavy rainfall in May whereas the lowest levels coincided with the peak of the rainfall. The Spearman correlation test also revealed significant inverse correlations between these two parameters in all the three sites (Table 1). Since the three correlation coefficients were not significantly different Fishers' (Z) transformation (Zar,1984) was used to calculate a common correlation coefficient (r_w) representing the correlation between rainfall and dissolved oxygen in the near- surface waters of Tudor creek ($r_w = -0.758$, $P < 0.05$). The decline of dissolved oxygen levels, during the peak of rainfall, may possibly be due to flushing in of leaf litter and consequent decomposition resulting in relatively high biological oxygen demand.

Table 1: Spearman correlation coefficients (r) between mean dissolved oxygen conc. and some environmental parameters in the near-surface waters (ca. 1.4m) of Tudor creek (Jan-Aug, 1992). Asterisk (∗) indicates 0.05 significance level.

Environmental parameter	Station	N	r	p
Near-surface (ca. 1.4m) sea temperature (^{o}C)	1	8	0.288	0.245
	2	6	-0.448	0.186
	3	8	0.364	0.188
Near-surface (ca. 1.4m) salinity	1	8	0.323	0.218
	2	6	0.592	0.108
	3	8	0.217	0.303
Mean monthly rainfall (mm)	1	8	-0.719	0.022*
	2	6	-0.845	0.017*
	3	8	-0.730	0.020*
Chlorophyll a (mg m^{-3}) at 1.4m depth	1	8	0.487	0.150
	2	6	-0.763	0.039*
	3	8	0.009	0.491
Chlorophyll a with phaeo-pigments (mg m^{-3}) at 1.4m depth	1	8	0.625	0.049*
	2	6	0.135	0.399
	3	8	-0.019	0.483

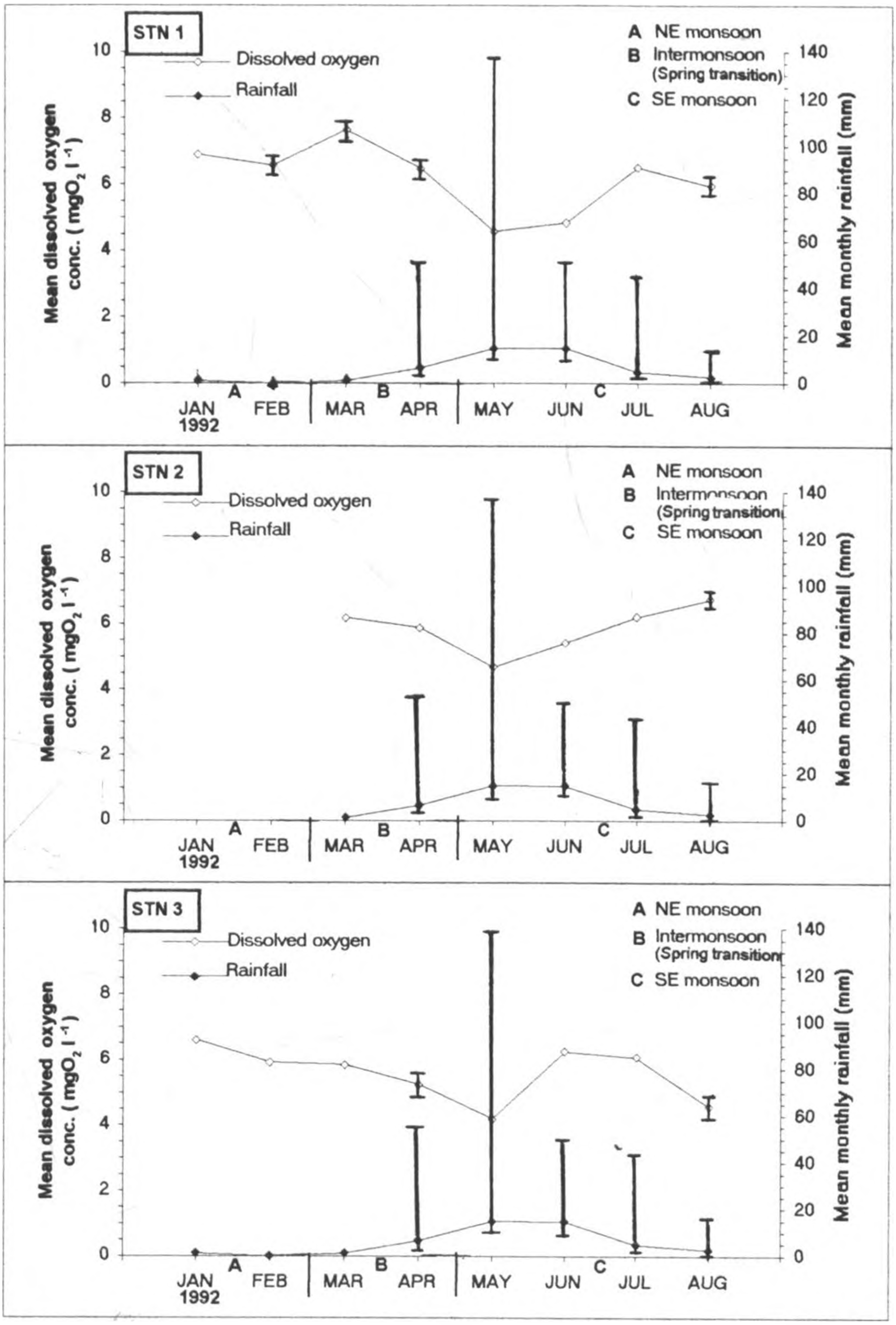


Fig. 40:Relationship between mean (+ SEM) dissolved oxygen conc. at ca. 1.4m depth in Tudor creek (N = 3 at each station) and mean (+ SEM) monthly rainfall at Moi Intl. airport, Mombasa. Data points for rainfall are means and SEMs of log transformed daily readings presented as antilogs. This leads to asymmetrical SEM bars.

Dissolved oxygen levels are altered by other biological processes such as photosynthesis and respiration thus creating local gradients. The general gradient in near-surface waters of Tudor creek was one of decreasing dissolved oxygen concentration with distance into the creek. Differences in P:R ratios would also be involved further pointing out the importance of decomposing organic matter and biological oxygen demand. Although the concentrations of both chlorophyll a and chlorophyll a with phaeo-pigments were consistently higher in station 3 than in the other two stations (Figs.17 and 18) and zooplankton biomass and density (Figs.19 and 20) were at intermediate levels in this site, the correlations between dissolved oxygen and both indicators of primary production were insignificant (Table 1). This may indicate that the oxygen consumption due to respiratory activities of the plankton is not as important as that due to decomposition in this site. Due to the close proximity of the mangroves the resulting leaf litter generates large amounts of detritus and the biological oxygen demand must be quite high.

In station 2 where phytoplankton biomass, as indicated by both chlorophyll a and chlorophyll a with phaeo-pigment (Figs.17 and 18) and zooplankton biomass and density (Figs.19 and 20) were consistently low, dissolved oxygen dynamics did not seem to be influenced by photosynthesis. Infact there was a significant inverse correlation between dissolved oxygen and chlorophyll a, pointing to a greater uptake by decomposition than contribution by photosynthesis, and an insignificant correlation with chlorophyll a with phaeo-pigments (Table 1). This contrasts with the situation in station 1 where there was a significant correlation between dissolved oxygen and chlorophyll a with phaeo-pigment concentrations (Table 1). Despite the high zooplankton density and intermediate levels of primary producer biomass it seems that community respiration does not exceed oxygen generation by photosynthesis in this site. But as mentioned earlier, many other factors influence dissolved oxygen dynamics in this site and more investigations are needed for a full understanding of dissolved oxygen variations.

Apart from possibly creating local differences in dissolved oxygen concentrations, variations of chlorophyll a concentration also altered transparency in the near-surface waters of Tudor creek. The smallest transparency depths coincided with the peak concentration of chlorophyll a and vice versa (Fig. 41). A regression analysis revealed an inverse relationship between transparency and chlorophyll a levels in station 3 but the relationship in stations 1 and 2 was insignificant (Fig. 42). Similarly, transparency depth was significantly correlated with the levels of chlorophyll a corrected for phaeo-pigments in station 3 only (Fig. 43). Although stations 1 and 2 have comparable depths (Fig. 9), transparency depth and phytoplankton biomass fluctuated within a narrower range in station 2 compared to station 1 (Fig. 41). These patterns of transparency depth and phytoplankton biomass are explained in terms of anthropogenic impacts in section 4.2.4.3.

Despite these local influences, the response of transparency to the changing monsoon conditions was evident. In stations 1 and 3 the greatest transparency occurred during the intermonsoon (April) but in station 2 transparency did not fluctuate much during the sampling period (Fig. 41). Similar works have found greater transparency depths in the near-shore surface waters of the Tanzanian coast in the SE monsoon (McClanahan, 1988). In the present study, the greater transparency in April could be attributed to the decline of phytoplankton biomass (Figs.17 and 18) as a result of increased grazing as peak zooplankton densities occurred soon after the peak of phytoplankton biomass (Figs.19 and 20). The smaller transparency depths in March may have been due to water column mixing and the subsequent increase in nutrient levels and phytoplankton biomass but there was no significant correlation between transparency and the concentration of any of the micronutrients at any site ($P > 0.05$, in all cases).

The near-surface waters of Tudor creek had the highest nutrient levels in March with minor peaks of ammonium, phosphates and silicates in July-August (Figs. 13 - 16). The high nutrient levels in all the sites during the period of monsoon reversal could be attributed to several factors such as river runoff at the beginning of the rainy season, an increased tidal prism, during the equinoctial spring tides, and possibly water column mixing. The water was highly turbid during this time indicating an increased suspended matter load. But as mentioned above nutrient levels and transparency depths were not significantly correlated at any site.

Previous studies in Tudor creek found high nutrient levels during the rainy season and attributed this to increased river runoff and erosion and washing down of fertilizers from the catchment area into the creek. It has also been suggested that in the tropics rain is an important factor in the regeneration of nutrients because at the start of the rainy season a lot of organic matter from the mangroves is washed into the creek and remineralized (Raymont, 1963). But in the present study the variation of nutrient levels did not reflect an influence of the rainfall regime. None of the nutrients had a significant correlation with rainfall in any site (Table 2).

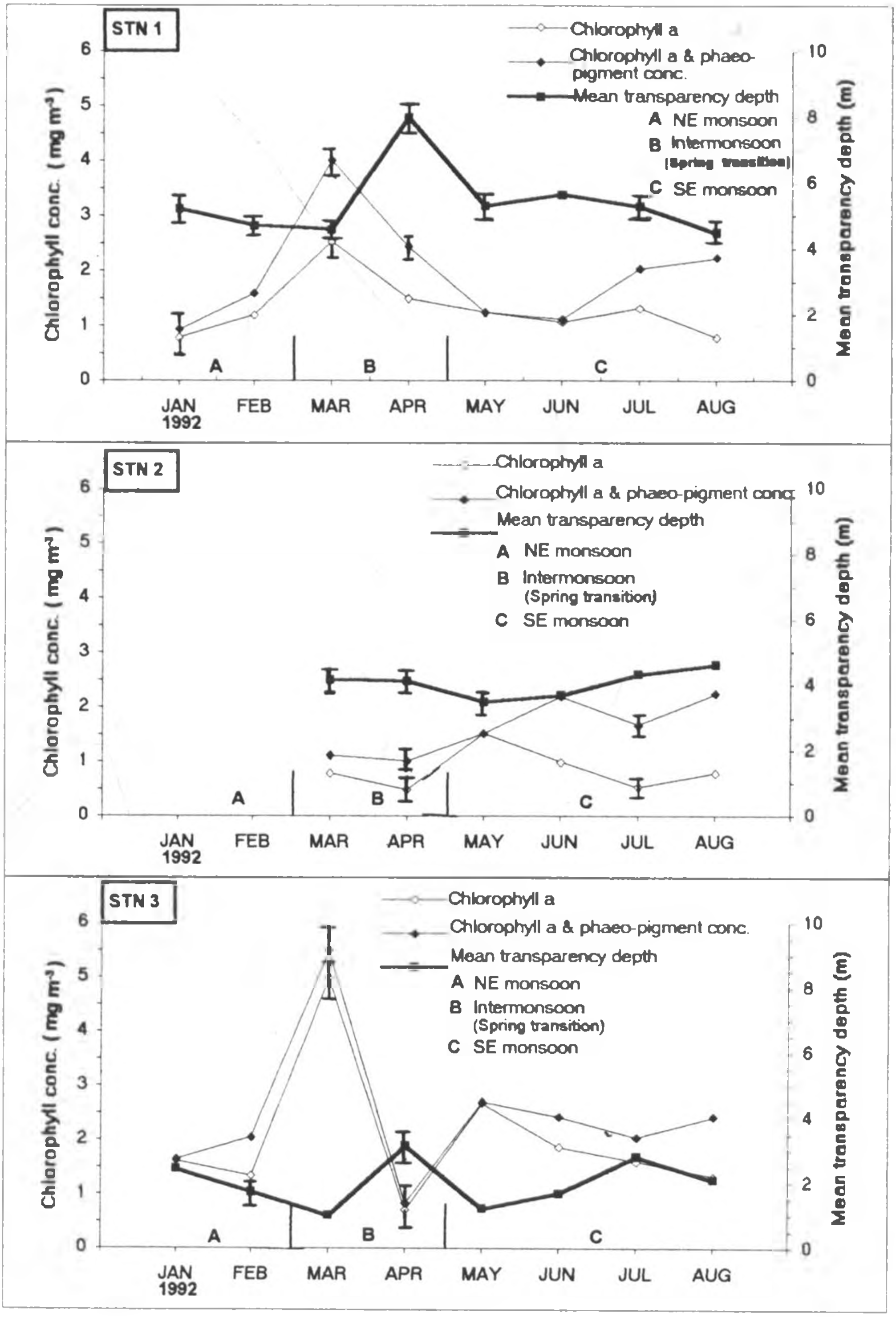
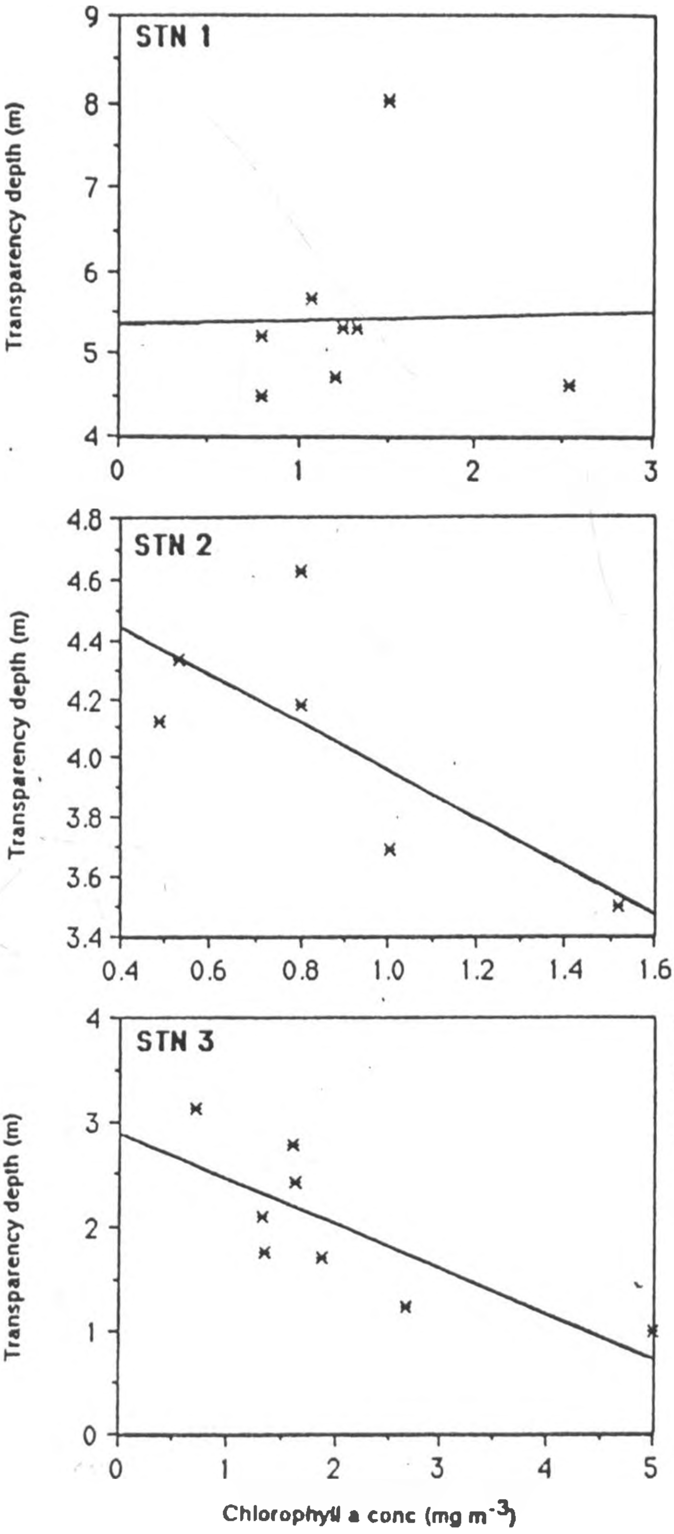


Fig. 41: Relationship between mean (± SEM) chlorophyll conc. (N = 3 at each station) and mean (± SEM) transparency depth in the near-surface waters (ca. 1.4m) of Tudor creek, Mombasa.

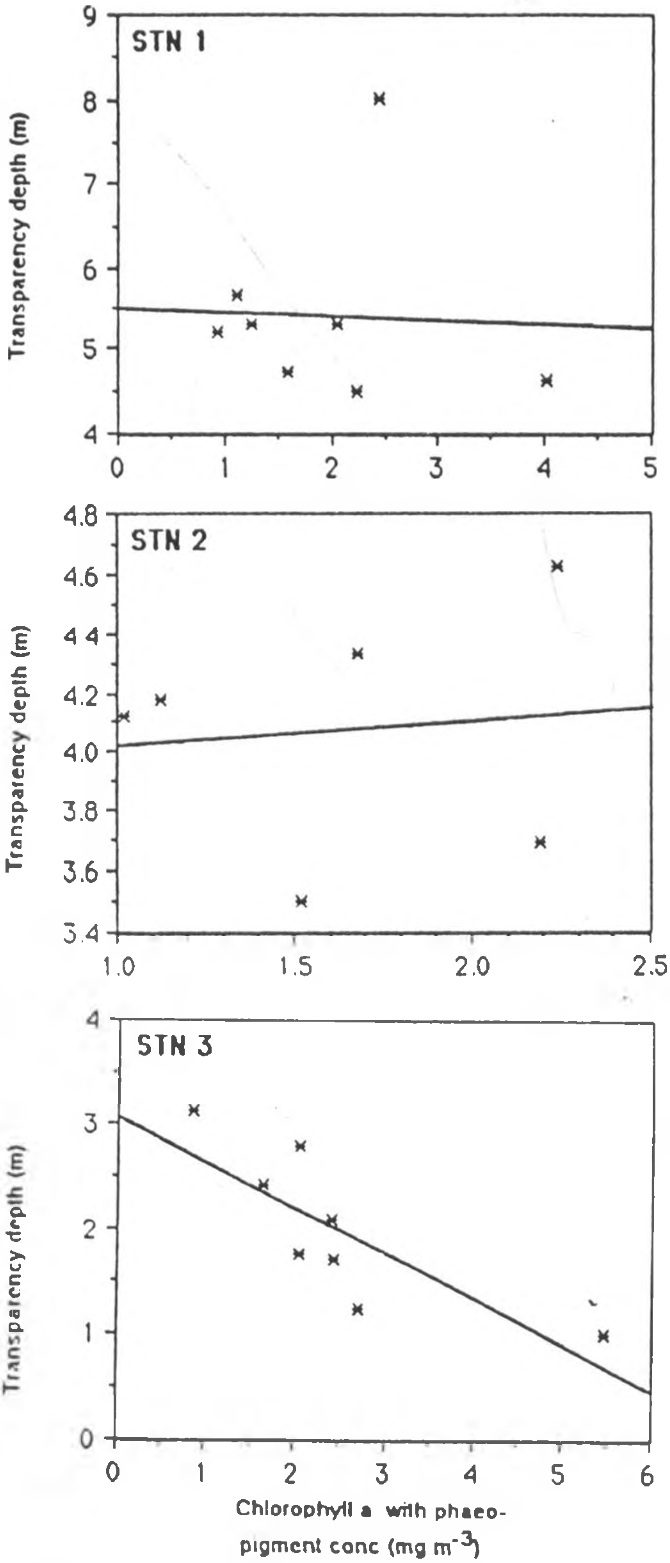


Y = 5.3551 + 4.5663e-2x
R^2 = 0.0062
P = 0.426

$\hat{Y}$ = 4.7722 - 0.81289x
R^2 = 0.5432
P = 0.094

Y = 2.8961 - 0.43575x
R^2 = 0.5898
P = 0.026*

Fig. 42: Regression plot showing the relationship between phyto-plankton biomass as chlorophyll conc. at 1.4m depth and transparency depth in Tudor creek Mombasa



STN 1:

$Y = 5.5072 - 4.7296e\text{-}2x$

$R^2 = 0.0008$

$P = 0.473$

STN 2:

$Y = 3.9354 + 8.6236e\text{-}2x$

$R^2 = 0.0036$

$P = 0.455$

STN 3:

$Y = 3.0971 - 0.43976x$

$R^2 = -0.794$

$P = 0.019^*$

Fig. 43: Regression plot showing the relationship between phyto-plankton biomass as chlorophyll a with phaeo-pigment conc. at 1.4m depth and transparency depth in Tudor creek Mombasa

Table 2: Spearman correlation coefficients (r) between mean monthly rainfall and nutrients in the near-surface waters (ca 1.4m) of Tudor creek (Jan-Aug, 1992). Asterisk (∗) indicates 0.05 significance level.

Nutrient element	Station	N	r	p
Nitrate (NO_3-N)	1	8	-0.188	0.328
	2	6	-0.408	0.211
	3	8	-0.301	0.234
Ammonia (NH_4-N)	1	8	-0.283	0.249
	2	6	-0.455	0.182
	3	8	-0.299	0.243
Phosphates (PO_4-P)	1	8	0.409	0.158
	2	6	0.016	0.488
	3	8	0.480	0138
Silicate (SiO_3-Si)	1	8	-0.076	0.429
	2	6	-0.034	0.475
	3	8	-0.211	0.308

The observation of high inorganic nitrate levels prior to the peak of rainfall contrasts with previous observations (Kazungu 1987) in which the highest levels coincided with the peak of rainfall pointing to river runoff as the main source of nitrates in the creek. But the pattern found in the present study agrees with previous observations in the near-shore surface (0.5m) waters off the Tanzanian coast. Those high nitrate levels during the NE monsoon were attributed to nitrogen fixation by blue-green algae Oscillatoria erythraea whose activities could be substantial in the NE monsoon when the water column is stable (McClanahan, 1988). In Tudor creek blooms of Oscillatoria sp have occasionally been observed during the months of March to May (Jaccarini unpublished) and more investigations on the functional role of these algal blooms may shed light on inorganic nitrate fluxes in the creek as biological nitrogen fixation by bacteria and phytoplankton is the chief mechanism for moving nitrogen from the air reservoir into the productivity cycle (Odum 1971).

It has been suggested that due to the high tidal amplitude at the East African coast, spring tides during intermonsoon times could result in periodic nutrient inputs from estuaries on a lunar and annual basis (McClanahan, 1988). Figure 44 shows the direct relationship between the maximum tidal height during high water springs and the level inorganic nitrate in Tudor creek. However a regression analysis revealed a significant correlation between inorganic nitrate concentration and maximum tidal height of water during spring tides in station 1 only (Fig. 45).

As would be expected the variation of ammonium levels was similar to that of inorganic nitrates in that high ammonium levels occurred during the intermonsoon (Fig. 14), and this may be partly the result of water mixing. But all stations had relatively high levels of ammonium during the SE monsoon (June-July) and no consistent gradient of ammonium concentrations between the stations could be detected. Furthermore the variation of ammonium was not influenced by either the rainfall pattern or the variation of the maximum tidal height during spring tides (Table 2). This could be due to the fact that the dynamics of ammonium are largely influenced by complex biological processes such as algal uptake rates and zooplankton excretion, and nitrogen fixation, nitrification and denitrification.

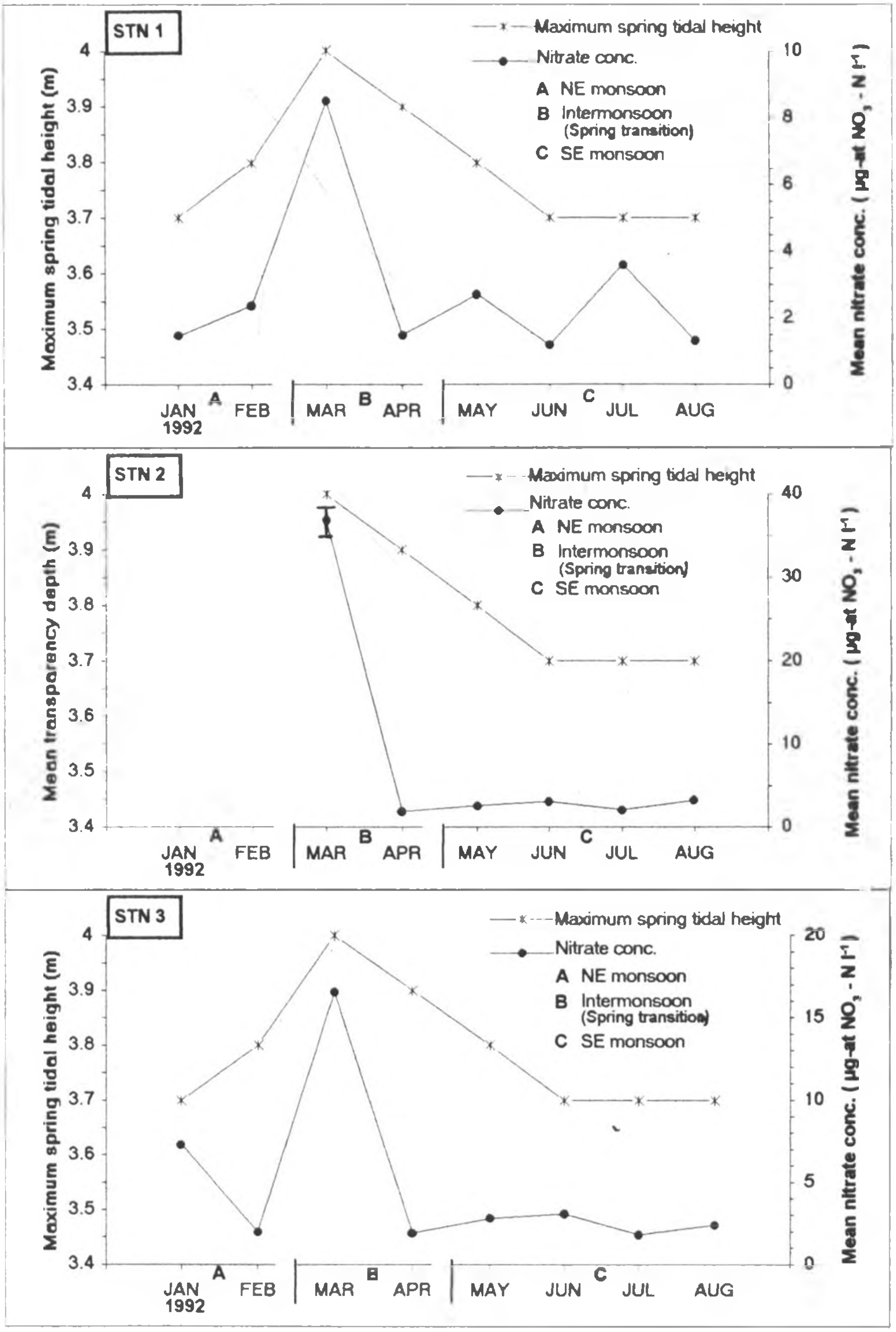
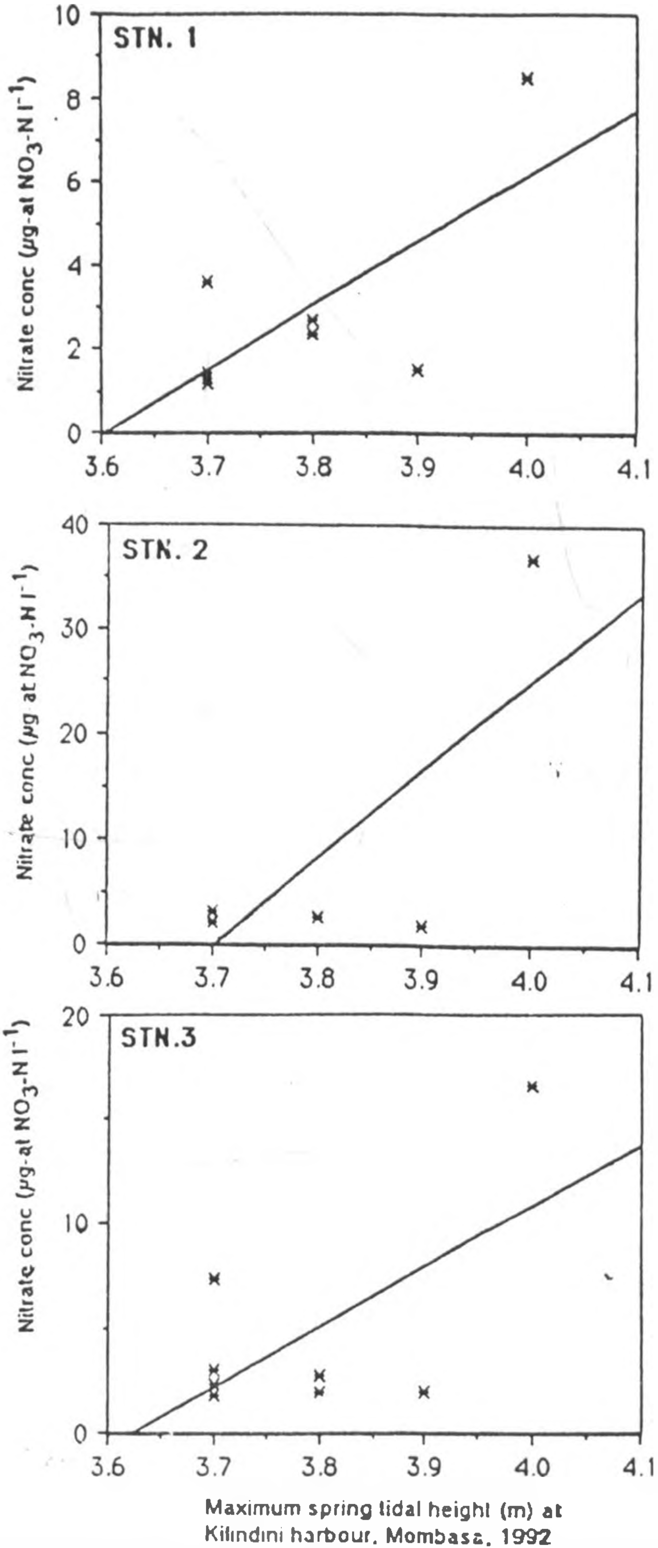


Fig. 44: Relationship between mean (± SEM) inorganic nitrate conc.in the near-surface waters (ca. 1.4m) of Tudor creek, (N = 1 at each station) and maximum spring tidal height at Kilindini Harbour.



$Y = -55.931 + 15.51x$
$R^2 = 0.516$
$P = 0.046$

$Y = -311.57 + 84.175x$
$R^2 = 0.577$
$P = 0.079$

$Y = -102.82 + 28.396x$
$R^2 = 0.392$
$P = 0.097$

Fig. 45: Regression plot of the maximum spring tidal height at Kilindini harbour and inorganic nitrate conc. at 1.4m depth (N = 1 at each station) in Tudor creek Mombasa

Ammonium is the species of inorganic nitrogen preferred by marine phytoplankton for growth and the production of organic matter by photosynthesis starts with the assimilation of dissolved ammonia. Most ammonia is supplied to the euphotic zone from biological remineralization via zooplankton excretion and metabolic processes of microheterotrophs (Dudek et al, 1986). Degradation of particulate and dissolved nitrogen by heterotrophic activity results in the formation of ammonium afterwards oxidized to nitrite and nitrate. Therefore a knowledge of the magnitudes of these biological processes is needed for a clear understanding of the variations of ammonium levels.

Like ammonium the concentration of inorganic phosphates in the near-surface waters of Tudor creek (Table 2) was not significantly influenced by either the rainfall pattern or the variation of the maximum tidal height during spring tides. The maximum levels of inorganic phosphates occurred during August in all the stations, but equally high levels occurred in March in stations 1 and 3 (Fig. 15). As with all the other parameters, station 2 did not form part of a gradient and a minor peak was observed in May.

Previous studies found maximum levels of inorganic phosphates coinciding with the peak of rainfall and attributed them to erosion of fertilizers from the surrounding banks into the creek due to increased runoff during the rains. But in the present study the correlation between inorganic phosphate concentration and rainfall was insignificant in all the sites ($P > 0.05$ in all cases). Water column mixing, in the period of the equinoctial spring tides, during the monsoon reversal in March, may therefore be a more important source of inorganic phosphates in the creek than river runoff during the rains. In the downwelling areas off the Tanzanian coast and southern Kenya coast surface phosphate concentrations peak in June soon after the initiation of the SE monsoon due to water column mixing (McClanahan, 1988).

In contrast to all other nutrient elements monitored, the variation of silicates showed a gradual increase with distance into the creek (Fig. 16). Relatively high levels occurred during the late NE monsoon (January), in the intermonsoon (March) and in the mid SE monsoon (June-July). This pattern contrasts with previous observations where high silica levels occurred during the peak of rainfall in May (Kazungu, 1990). In the present study the concentration of silicates was not significantly correlated to rainfall ($P > 0.05$ in all the cases, Table 2).

In general silicate levels are influenced by biological rather than physical processes (Perkins, 1974). Possible differences in the diatom communities in the three stations could account for the variations of silicate levels among them. Due to the close proximity of the mangroves, in station 3, detritus may be a more important energy source than diatoms hence the relatively high silicate levels observed here.

4.2.0 BIOLOGICAL PARAMETERS

4.2.1 Phytoplankton biomass

The variation of chlorophyll a and chlorophyll a with phaeo-pigments reflects seasonal changes similar to those of the physico-chemical parameters, particularly the nutrients. Peak levels of these indicators of primary production occurred during the intermonsoon in March in stations 1 and 3. As with other parameters, station 2 did not conform to this general pattern and maximum levels of chlorophyll a occurred in May and July while peak levels of chlorophyll a with phaeo-pigments occurred in April and July.

In marine waters nitrogen is the most important nutrient element and figure 46 shows the relationship between nitrate levels and the concentrations of chlorophyll a and its derivatives. The levels of both chlorophyll a and chlorophyll a with phaeo-pigments were significantly correlated with nitrate levels in stations 1 and 3 only (Table 3). Since the correlation between nitrates and chlorophyll a was not significantly different from that between nitrates and chlorophyll a with phaeo-pigments in both stations 1 and 3, a common correlation coefficient (r_W) was calculated using Fishers' (z) transformation (station 1, $r_W = 0.800$, station 3, $r_W = 0.842$).

The other nutrient elements did not show a significant correlation with either indicators of primary production at any site. This could be due to a combination of several factors acting in concert to limit phytoplankton production. Apart from nutrients especially the nitrogen nutrients in marine waters, phytoplankton production is influenced by other factors such as illumination, radiation, turbulence which would carry cells below the photic zone and grazing (Odum, 1971). Physico-chemical factors such as temperature and salinity also influence phytoplankton production.

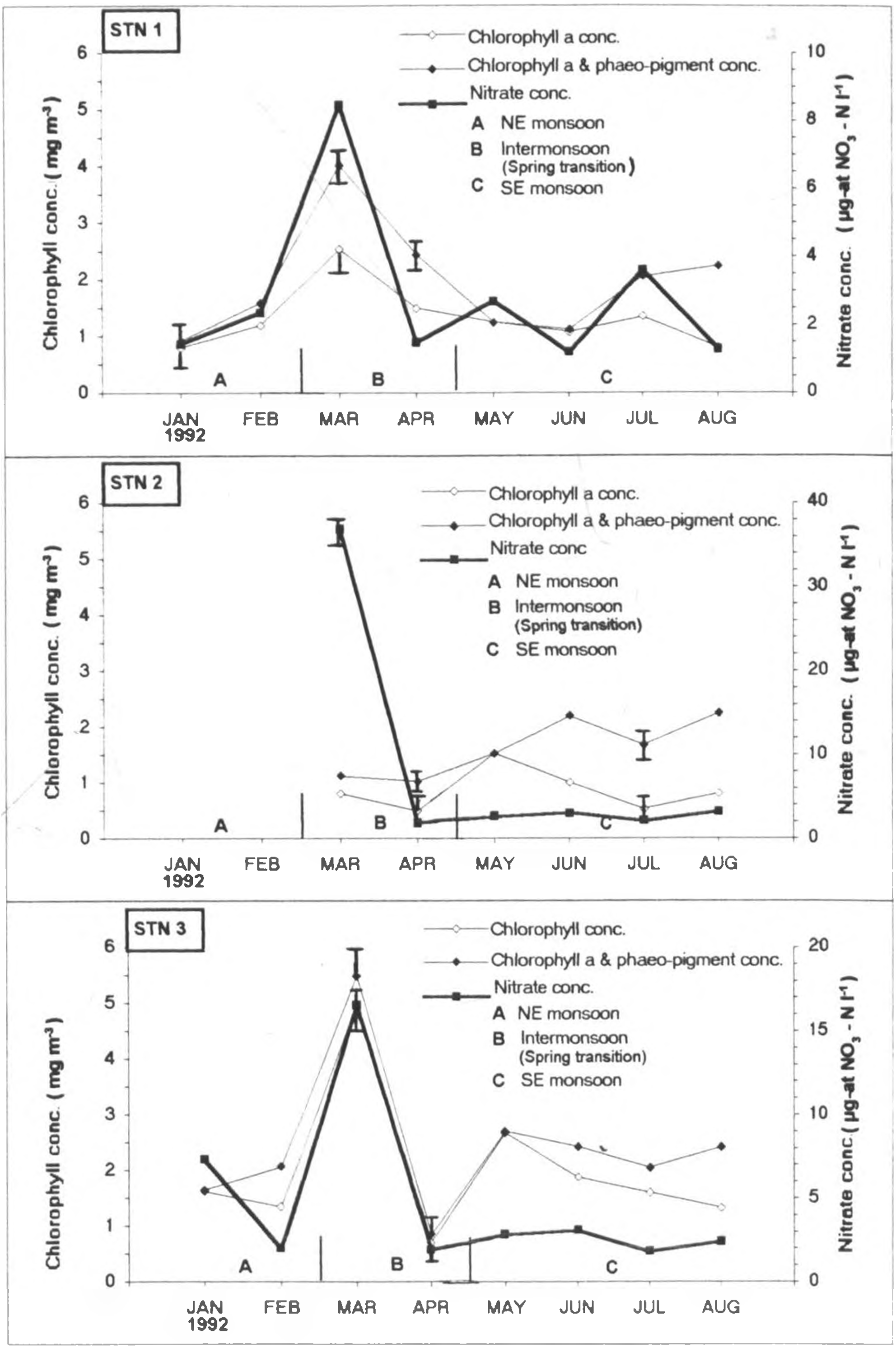


Fig. 46: Relationship between mean (± SEM) inorganic nitrate conc. (N = 1 at each station) and mean (± SEM) chlorophyll a conc. (N = 3 at each station) in the near-surface waters (ca. 1.4m) of Tudor creek.

Table 3: Spearman correlation coefficients (r) between inorganic nitrates and chlorophyll concentration in the near-surface waters (ca. 1.4m) of Tudor creek (Jan-Aug, 1992). Asterisk (*) indicates 0.05 significance level

	Station	N	r	p
Chlorophyll a (mg m^{-3})	1	8	0.795	0.019*
	2	6	-0.057	0.916
	3	8	0.877	0.004*
Chlorophyll a with phaeo-pigments (mg m^{-3})	1	8	0.805	0.016*
	2	6	0.453	0.366
	3	8	0.832	0.010*

The importance of temperature as a factor in controlling the growth of phytoplankton has been emphasized by many workers (Williams et al., 1976, Goldman, 1977, Turner et al., 1983 & Kannan et al., 1990). In the present study, maximum biomass of phytoplankton, as indicated by chlorophyll a concentration, occurred when temperatures were high but the Spearman correlation test did not find a significant relationship between near-surface water temperature and chlorophyll a concentration ($P > 0.05$, in all cases). Kannan et al., (1990) also found a coincidence of low temperature with low phytoplankton density in the Pitchavaram mangroves while Wawiye (1993) found an indication of an inverse relationship between primary productivity, in Gazi creek, and rainfall. This observation in Gazi creek points to the negative influence of low temperatures and salinities, which accompany the rains, on phytoplankton production.

However, other studies (Kannan et al., 1990) found low phytoplankton density when the water temperature was high hence the influence of surface water temperature on phytoplankton density in tropical marine environs remains obscure. Salinity also acts as a major ecological factor controlling the seasonal succession of phytoplankton. In the near-surface waters of Tudor creek a low phytoplankton biomass occurred when salinities were low during the SE monsoon. But as with temperature the correlation between chlorophyll a concentration and salinity were not significant in any site ($P > 0.05$, in all cases).

It would appear that in the near-surface waters of Tudor creek, optimum conditions for phytoplankton growth occur during the intermonsoon period when temperatures, salinities and nutrient levels are high. Relatively high concentrations of both chlorophyll a and that with phaeo-pigments occur during the intermonsoon despite the high grazing pressure exerted by the increased zooplankton biomass and density. During the NE monsoon phytoplankton biomass is low despite the high temperatures and salinities and low grazing pressure. Phytoplankton production seems to be limited by the low nutrient levels, especially the nitrogen nutrients occurring then. In the SE monsoon the low temperatures, salinities and nitrate levels may account for the relatively low chlorophyll a concentrations occurring then because grazing pressure is lower in this season compared to the intermonsoon.

4.2.2 Zooplankton taxonomic composition

The near-surface waters of Tudor creek have a highly diversified plankton fauna dominated numerically by copepods and decapods. But like the environmental parameters, the abundance of the various planktonic animals varies according to the prevailing monsoon conditions. During the NE monsoon the plankton faunal biomass is dominated by cnidarians and ctenophores and their distribution is influenced by local characteristics. For instance siphonophores were a feature of station 1 while hydromedusae were mostly found in station 3. During the period of monsoon reversal the zooplankton community underwent rapid changes from one dominated by cnidarians and ctenophores to consisting mainly of copepods and crustacean decapod larvae

The composition of the plankton fauna remained like this during the SE but there was a gradual decrease in abundance of all the groups. Similarly in Gazi creek, maximum zooplankton abundance occurred in April and declined gradually with the approach of the SE monsoon (Mwaluma et al, 1990). This decline was attributed to the dilution of seawater during the rains thus creating salinities which were unfavourable for zooplankton production.

It is also quite evident that habitat characteristics such as degree of oceanic versus terrestrial influences, depth of the water column and substrate type play a big role in the distribution of the zooplankton. It was noted that holoplanktonic groups particularly the copepods were a feature of the outermost station while the meroplanktonic forms like brachyuran larvae were concentrated in the innermost station.

4.2.3 Zooplankton biomass

Zooplankton biomass was highest in station 1 and lowest in station 2 (F(2) 0.05 2,59 = 3.475, P = 0.038). Although this pattern (Fig. 19) is similar to that of phytoplankton biomass, as indicated by chlorophyll a levels (Figs. 17 & 18), it contrasts with that found by Kimaro (1986) where biomass was highest in station 3 and least in station 1. However, zooplankton biomass was not significantly correlated with that of phytoplankton biomass either in terms of chlorophyll a or chlorophyll with phaeo-pigment at any site ($P > 0.05$, in all cases) in the present study. Maximum zooplankton biomass occurred during May in station 1, April in station 2 and from March to May and possibly in August in station 3

(Fig. 19). In addition to these peaks Kimaro (1986) observed a major peak of zooplankton biomass in December ranging from 0.48ml l^{-1} in station 1, 0.22ml l^{-1} in station 2 to 0.96ml l^{-1} in station 3.

4.2.4 Zooplankton abundance

Mean zooplankton density in the near-surface waters of Tudor creek was influenced by joint and individual effects of time of year and location in the creek ($F_{0.05,\ 2,59} = 4.238$, $P << 0.05$), but the main individual factor was time of year (Table 4).

Table 4: Anova of log transformed zooplankton abundances.

Source of variation	SOS	DF	MS	F ratio	F signif.
Main effects	7.566	9	0.841	25.304	0.000
Site	0.330	2	0.165	4.962	0.012
Month	**7.517**	7	1.074	32.324	0.000
2-Way interactions	1.168	12	0.141	4.238	0.000
(Site - Month)	1.168	12	0.141	**4.238**	**0.000**
Explained	9.256	21	0.441	13.266	0.000
Residual	1.262	38	0.033		
Total	10.518	59	0.178		

4.2.4.1 Phytoplankton relationships

The most conspicuous planktonic herbivores comprise most copepods, euphausiids, cladocera, mysids, thecosomatous pteropods and urochordates. Urochordates mainly feed on nano-phytoplankton (Barnes, 1987) while the other groups utilize net phytoplankton and their grazing activities may have a substantial impact on algal biomass. As illustrated in figure 47, the maximum zooplankton density in station 1 coincided with the peak concentrations of both forms of chlorophyll during the intermonsoon. The peaks in both phyto- and zooplankton may be attributed to either an incursion of neritic waters during the period of monsoon reversal or mixing of the water column and the subsequent increase in nutrient levels and ultimately phytoplankton and zooplankton production.

The Spearman correlation test revealed a significant correlation between zooplankton density and chlorophyll a ($r = 0.778$, $P = 0.009$) and between zooplankton density and chlorophyll a with phaeo-pigments ($r = 0.923$, $P = 0.001$). A test of equality of these two correlation coefficients using Fishers' (Z) transformation showed that they are significantly different ($Z_{0.05\ (2)} = 2.073$, $P > 0.05$). The high correlation coefficient between zooplankton density and chlorophyll a with phaeo-pigments indicates that few other factors apart from chlorophyll a levels influence zooplankton density in this site.

Since the correlation between zooplankton density and chlorophyll a with phaeo-pigments was the higher of the two it can be concluded that chlorophyll a with phaeo-pigments has a stronger influence on zooplankton density than chlorophyll a alone. This may indicate that detritus, besides phytoplankton, may form a significant part of the food of the zooplankton.

The variations of zooplankton density in stations 2 and 3 differed from those in station 1 in the timing of peak abundances and in their relation to either indicators of primary production. Maximum zooplankton abundance in station 2 occurred during the SE monsoon in May and possibly in August whereas the levels of both indicators of primary production were consistently low (Fig. 47) as compared to the levels in stations 1 and 3 and there was no significant correlation between zooplankton density and either type of primary production.

In station 3 zooplankton densities were high during the intermonsoon (March) up to the early SE monsoon (May). This is despite the fact that peak levels of either forms of chlorophyll a occurred in March and declined sharply thereafter (Fig. 47). The lack of correlation between zooplankton abundance and the concentration of chlorophyll a and its derivatives in station 3 may be explained that the peak from March to May is largely due to the dominance of brachyuran larvae which are lecithotrophic.

It was observed that holoplanktonic groups were characteristic of station 1 while the meroplankton were a feature of stations 2 and 3 (Fig. 48). This distinction was most pronounced during the period of monsoon reversal and early SE monsoon. As pointed out earlier, peak zooplankton abundance occurred in station 1 during the intermonsoon. It was mainly due to increased contributions of holoplanktonic groups, mainly copepods, such groups as salps, larvaceans, chaetognaths, ctenophores, siphonophores and medusae. However fish eggs and fish larvae also made a substantial contribution to the high zooplankton density in March in this site.

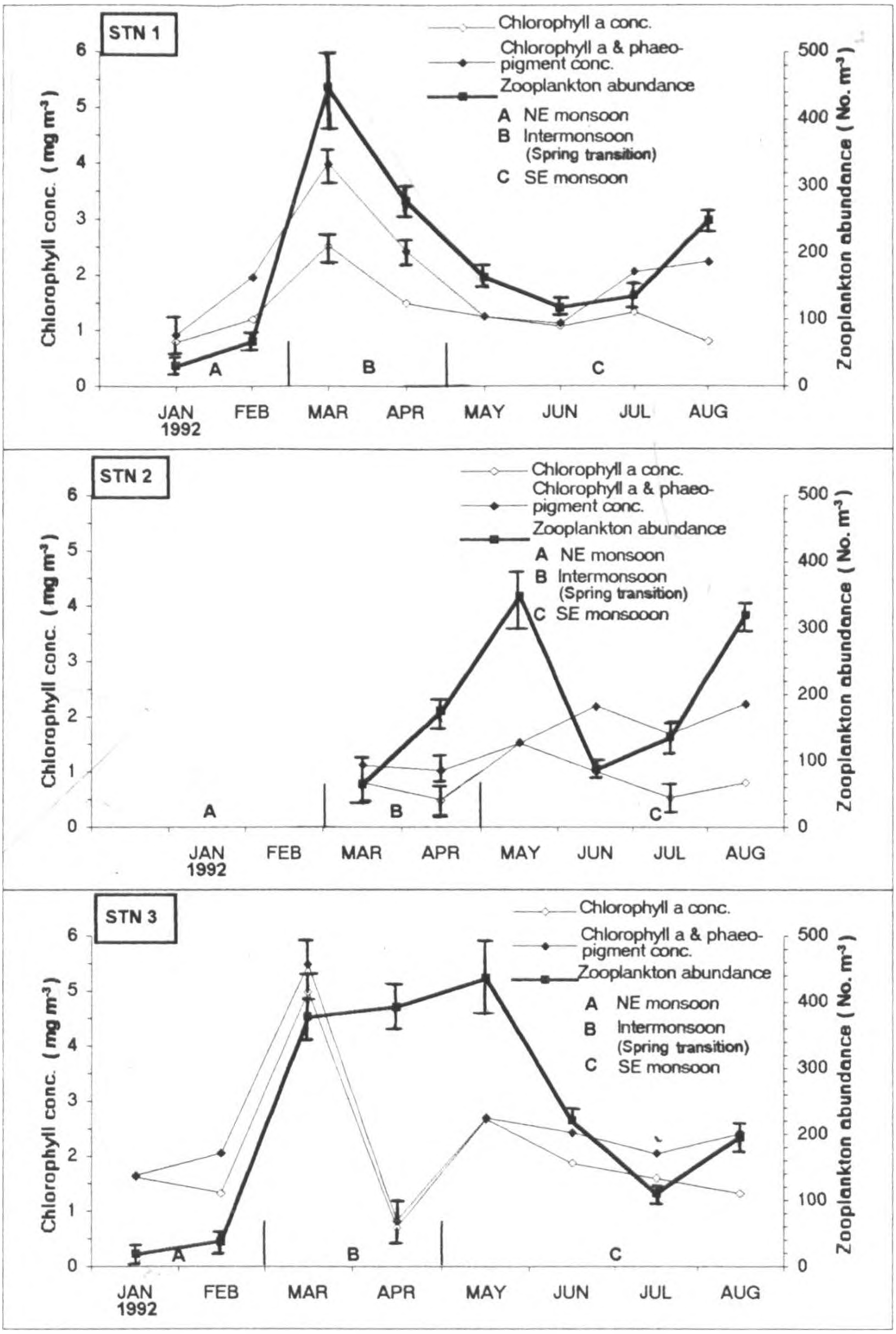


Fig. 47: Mean (± SEM) chlorophyll conc. (N = 3 at each station) and mean (± SEM) zooplankton abundance in the near-surface waters (ca. 1.4m) in Tudor creek Mombasa.

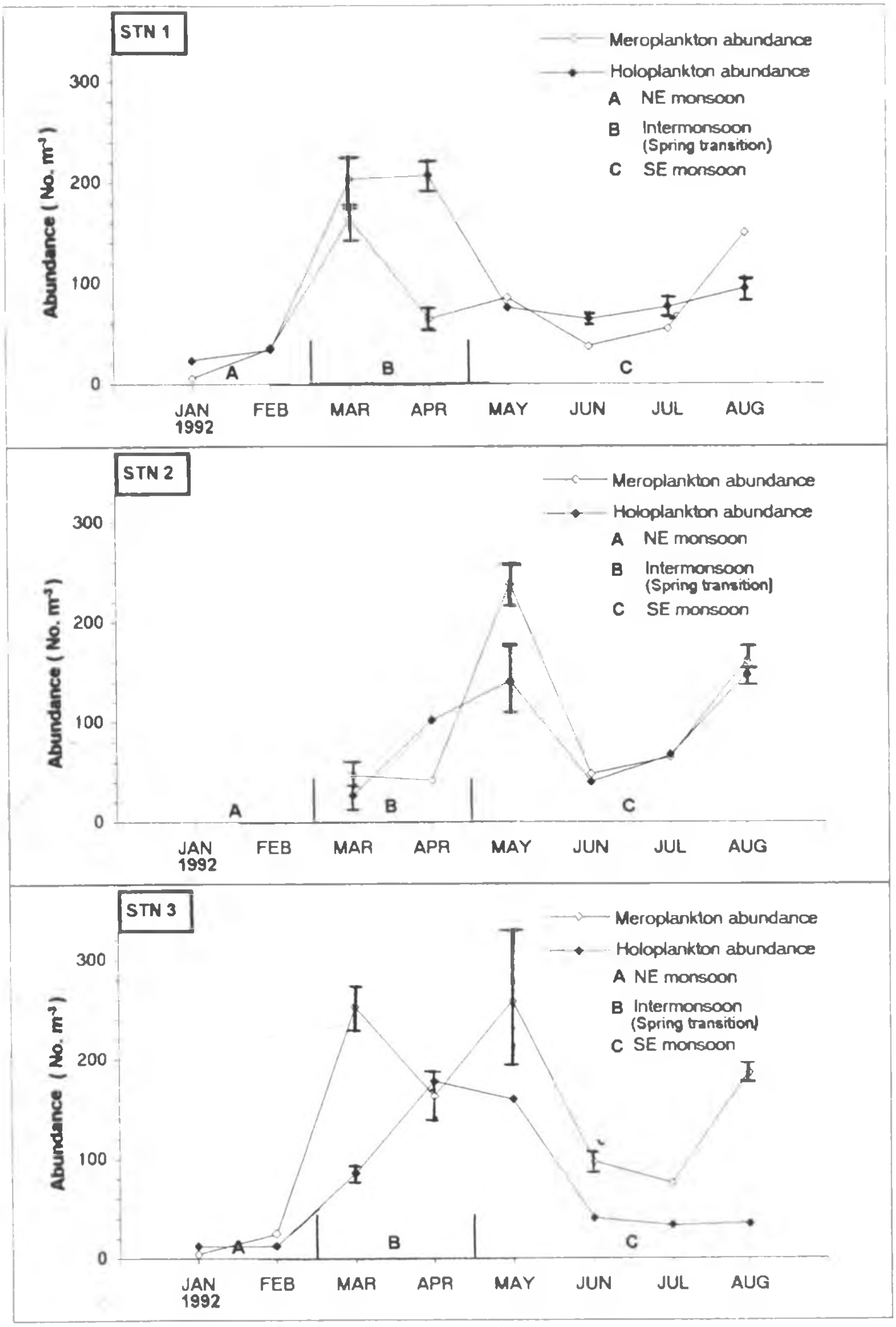


Fig. 48: Relationship between mean (+ SEM) holoplankton and meroplankton abundance (N = 3 at each station) in the near-surface waters (ca.1.4m) of Tudor creek Mombasa.

Figure 49 suggests that the increase in holoplankton density in this site was in response to increased phytoplankton biomass and furthermore the Spearman correlation test revealed that holoplankton density was positively correlated the levels of both forms of chlorophyll a (Table 5). Since the two correlation coefficients did not differ significantly, a common correlation coefficient (r_W) was calculated using Fishers' (Z) transformation ($r_W = 0.800$, $P > 0.05$).

As you move into the creek , the densities of holoplankton in the inner stations is reduced to about half of that in station 1 (Fig. 48). The relatively high densities of holoplankton during August in station 2 and April in station 3 can be almost entirely attributed to increase in abundance of calanoid copepods. The pattern of variation of holoplankton density in relation to the levels of both forms of chlorophyll a in station 3 shows a lag period of at most one month, between peak levels of chlorophyll a and holoplankton densities. But the Spearman correlation test shows that holoplankton density was not significantly correlated to the levels of either forms of primary production at either station 2 or 3 (Table 5).

Since copepods make up the bulk of the holoplankton it was not surprising that the variation of their abundance, in relation to both indicators of primary producer biomass, was very similar to that of holoplankton (Fig. 50). High copepod densities coincided with high levels of chlorophyll a, in station 1, while in station 3 there was a lag period of at most one month. As with the holoplankton, the correlations of copepod abundance to both indicators of primary producer biomass, in stations 2 and 3 were insignificant (Table 5).

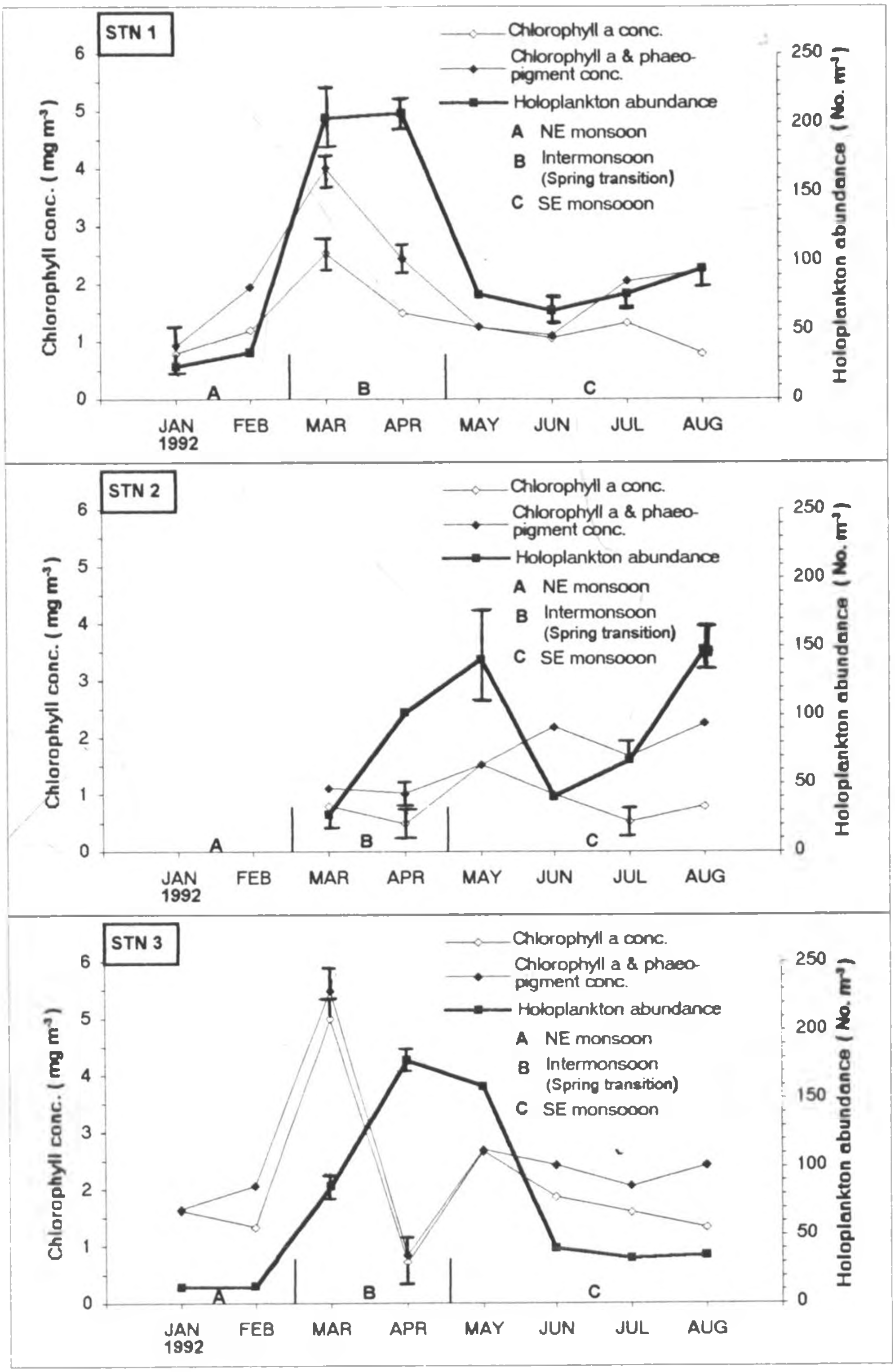


Fig. 49: Relationship between mean (+ SEM) holoplankton abundance (N = 3 at each station) and mean (+ SEM) chlorophyll conc. (N = 3 at each station) in the near-surface waters (ca.1.4m) of Tudor creek Mombasa.

Table 5: Spearman correlation coefficients (r) between holoplankton abundace and the indicators of phytoplankton biomass in the near-surface waters (ca. 1.4m) of Tudor creek (Jan-Aug, 1992). Asterisk (*) indicates 0.05 significance level.

Density (No m^{-3})	Station	N	Chlorophyll a		Chlorophyll a with phaeo-pigment	
			r	p	r	p
Holoplankton	1	8	0.756	0.030*	0.836	0.010*
	2	6	0.316	0.542	0.195	0.711
	3	8	0.114	0.788	-0.018	0.966
Copepods	1	8	0.731	0.039*	0.876	0.004*
	2	6	-0.072	0.892	0.407	0.424
	3	8	-0.122	0.774	-0.252	0.546
Calanoids	1	8	0.476	0.233	0.713	0.047*
	2	6	-0.0894	0.874	0.334	0.518
	3	8	-0.142	0.738	0.217	0.516

Holoplankton include copepods and copepods include calanoids)

Only in station 1 was copepod density significantly correlated to both chlorophyll a and its derivatives (Table 5), and a test of equality of these two coefficients showed they did not differ and therefore Fisher's (Z) transformation was used to calculate the common correlation (r_W) coefficient between copepod density and chlorophyll a and its derivatives in station 1 ($r_W = 0.816$, $P < 0.05$).

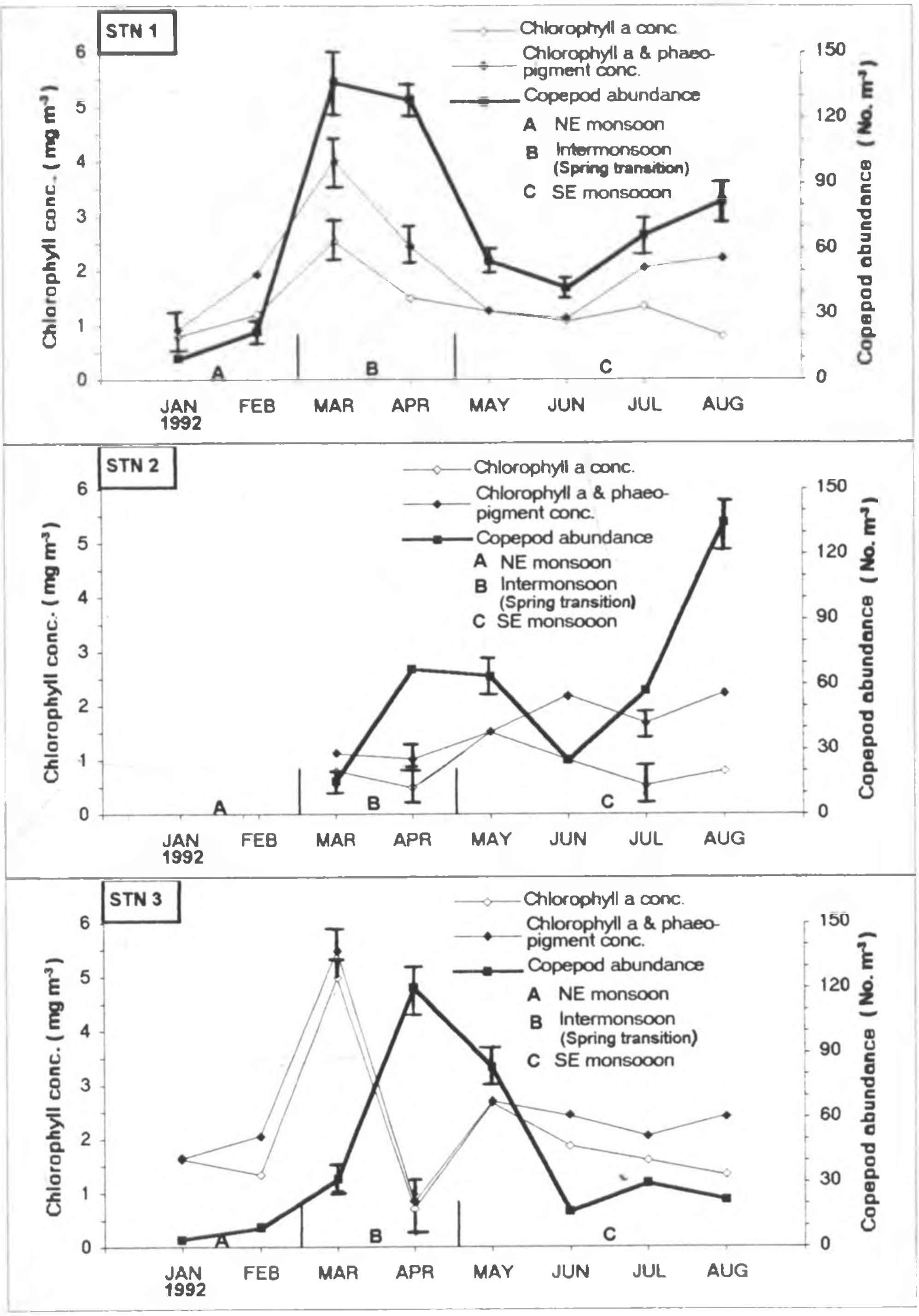


Fig. 50: Relationship between mean (± SEM) copepod abundance (N = 3 at each station) and mean (± SEM) chlorophyll conc. (N = 3 at each station) in the near-surface waters (ca. 1.4m) of Tudor creek Mombasa.

As pointed out earlier the copepods were numerically dominated by the calanoids but the variations of calanoid abundance differed from those of total copepods in two ways. First, in station 1 the maximum abundance of calanoids lagged behind that of peak chlorophyll a levels by a month (Fig. 51) while the peak numbers of total copepods coincided with levels of chlorophyll a (Fig. 50). This difference is explained by the high copepod densities in March including maxima of other copepod orders such as the poecilostomatoids and cyclopoids. Secondly, the density of calanoids was significantly correlated to that of chlorophyll a with phaeo-pigments and not with that of chlorophyll a (Table 5).

In view of these findings it can be concluded that high levels of chlorophyll a with phaeo-pigment in station 1 are strongly and positively correlated with zooplankton density and this is mainly due to increased contributions of calanoids. The relationship of calanoid abundance to both indicators of phytoplankton biomass, is similar to that of total copepods in that the correlations between calanoids and both forms of chlorophyll a were not significant in any site except in station 1 (Table 5). As mentioned earlier the holoplankton and therefore calanoids were not conspicuous in the inner stations where they maintained low densities despite the increase in phytoplankton biomass.

Although herbivorous calanoid genera such as Undinula and Acartia and the omnivores, Centropages and Temora established maximum abundances during the period of monsoon reversal and possibly in August their densities were not significantly correlated to levels of either measure of phytoplankton biomass at any site ($P > 0.05$, in all cases). This could be due the fact that each of these genera are made up of several species some of which may not be herbivorous or omnivorous.

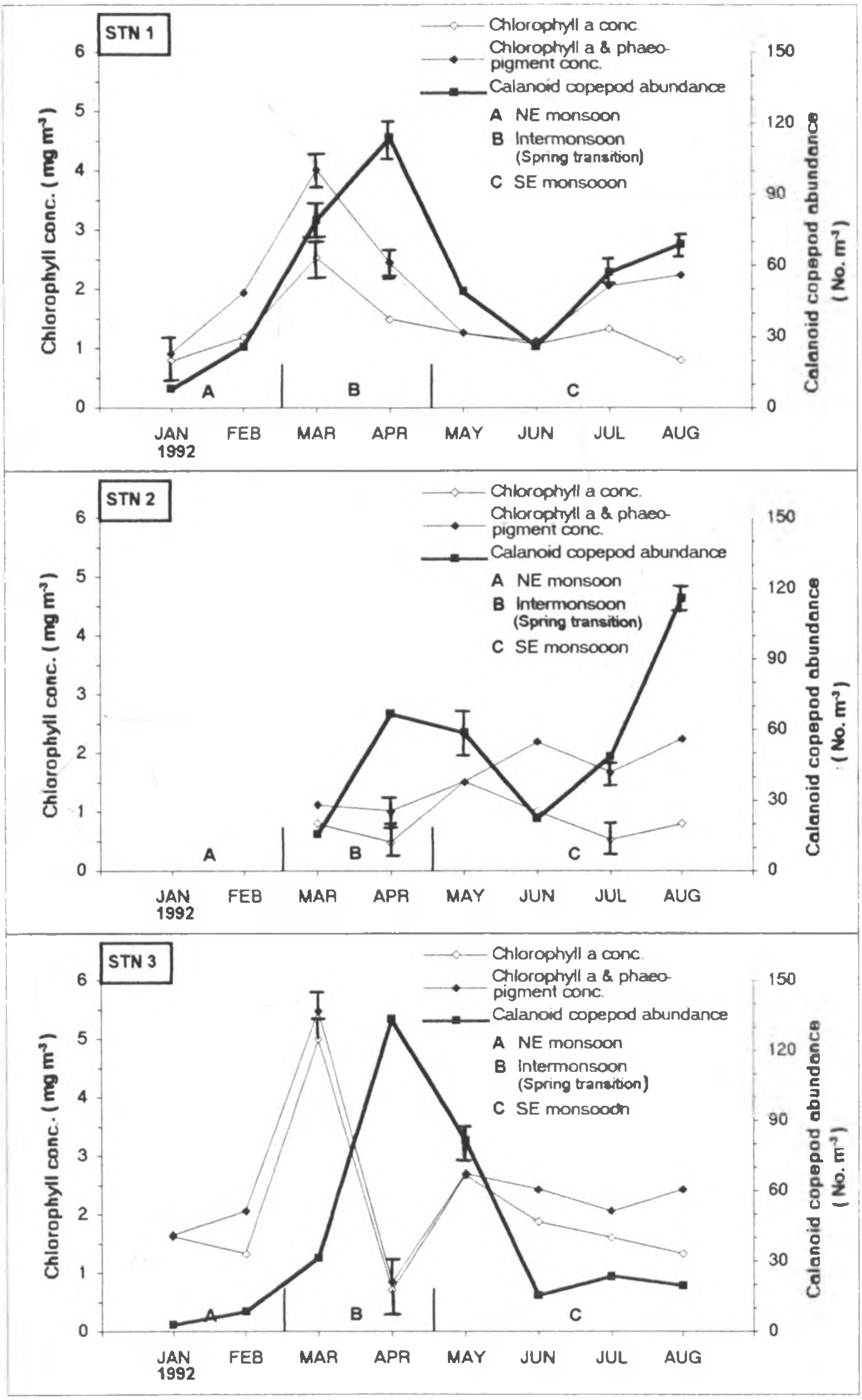


Fig. 51: Relationship between mean (± SEM) calanoid copepod abundance (N = 3 at each station) and mean (± SEM) chlorophyll conc. (N = 3 at each station) in the near-surface waters (ca. 1.4m) of Tudor creek Mombasa.

Figure 52 shows clearly that meroplankton abundances are at least twice as high in stations 2 and 3 as in station 1 and they did not seem to be dependent on chlorophyll levels in the former two stations (Fig. 52) as was confirmed by the Spearman correlation test (Table 6). In the latter station (1) meroplankton abundances were significantly correlated with chlorophyll a with phaeo-pigment levels (Table 6). In stations 1 and 3 high meroplankton densities occurred from March to May, well after the peak levels of both chlorophyll a and its derivatives. In station 2 meroplankton density was generally low except in May and in August mainly due to increased densities of brachyuran larvae and gastropod veligers, respectively.

Brachyuran larvae were the most important meroplanktonic group but the combined densities of other crustacean decapod larvae such as penaeids, carideans and anomurans was equally high. Figures 53 and 54 illustrate the variations in abundances of brachyura larvae and crustacean decapod larvae in relation to levels of both chlorophyll a and its derivatives but they were not significantly correlated at stations 1 and 3 (Table 6). Despite the consistently low levels of both forms of chlorophyll a in station 2 the abundances of brachyura larvae and crustacean decapod larvae were significantly correlated with levels of chlorophyll a (Table 6).

It is clear that the abundance of meroplanktonic groups, especially in station 3, is not as dependent on phytoplankton biomass as that of holoplanktonic groups is. This is not unexpected since a very important group of the meroplankton, the brachyuran larvae, are lecithotrophic.

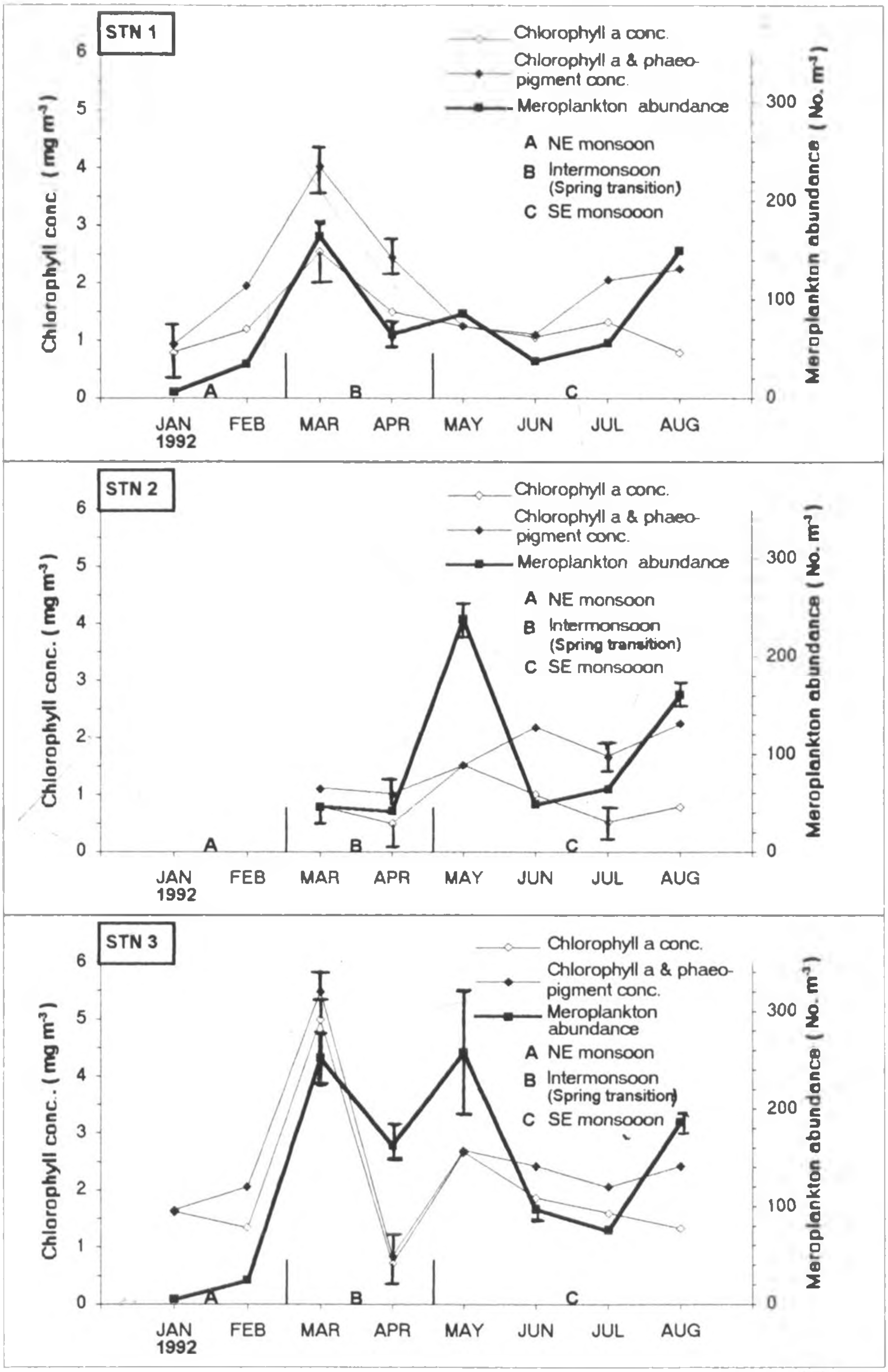


Fig. 52: Relationship between mean (± SEM) meroplankton abundance (N = 3 at each station) and mean (± SEM) chlorophyll conc. (N = 3 at each station) in the near-surface waters (ca.1.4m) of Tudor creek Mombasa.

Table 6: Spearman correlation coefficients (r) between meroplankton abundance and the indicators of phytoplankton biomass in the near-surface waters (ca. 1.4m) of Tudor creek (Jan-Aug, 1992). Asterisk (∗) indicates 0.05 significance level.

Density (No m-^{3})	Station	N	Chlorophyll a		Chlorophyll a with phaeo-pigment	
			r	p	r	p
Meroplankton	1	8	0.543	0.164	0.789	0.020*
	2	6	0.763	0.077	0.259	0.620
	3	8	0.636	0.090	0.571	0.140
Crustacean decapod larvae	1	8	0.256	0.541	0.465	0.246
	2	6	0.823	0.044*	-0.048	0.928
	3	8	0.322	0.437	0.221	0.599
Brachyuran larvae	1	8	-0.012	0.978	0.456	0.246
	2	6	0.845	0.034*	0.058	0.914
	3	8	0.655	0.078	0.546	0.162

(Meroplankton include brachyuran larvae and crustacean decapod larvae).

4.2.4.2 Predator-prey relationships

Planktonic carnivores consist mainly of chaetognaths, ctenophores, medusae, siphonophores, polychaetes, gymnosomatous pteropods and amphipods as well as many species of copepods and decapod crustacea. In the near-surface waters of Tudor creek the most important predators numerically were hydromedusae, chaetognaths, siphonophores and ctenophores in that order. Polychaete larvae were only of numerical importance during the intermonsoon in station 1, otherwise their densities rarely exceeded 2.0 m -3. Pteropods were not included as predators since the gymnosomatous and thecosomatous pteropods were not quantified as separate taxa. However the density of pteropods was generally low (< 1.0 m-3) except in stations 1 and 2 where pteropod density rose to slightly more than 5 m -3 during the intermonsoon.

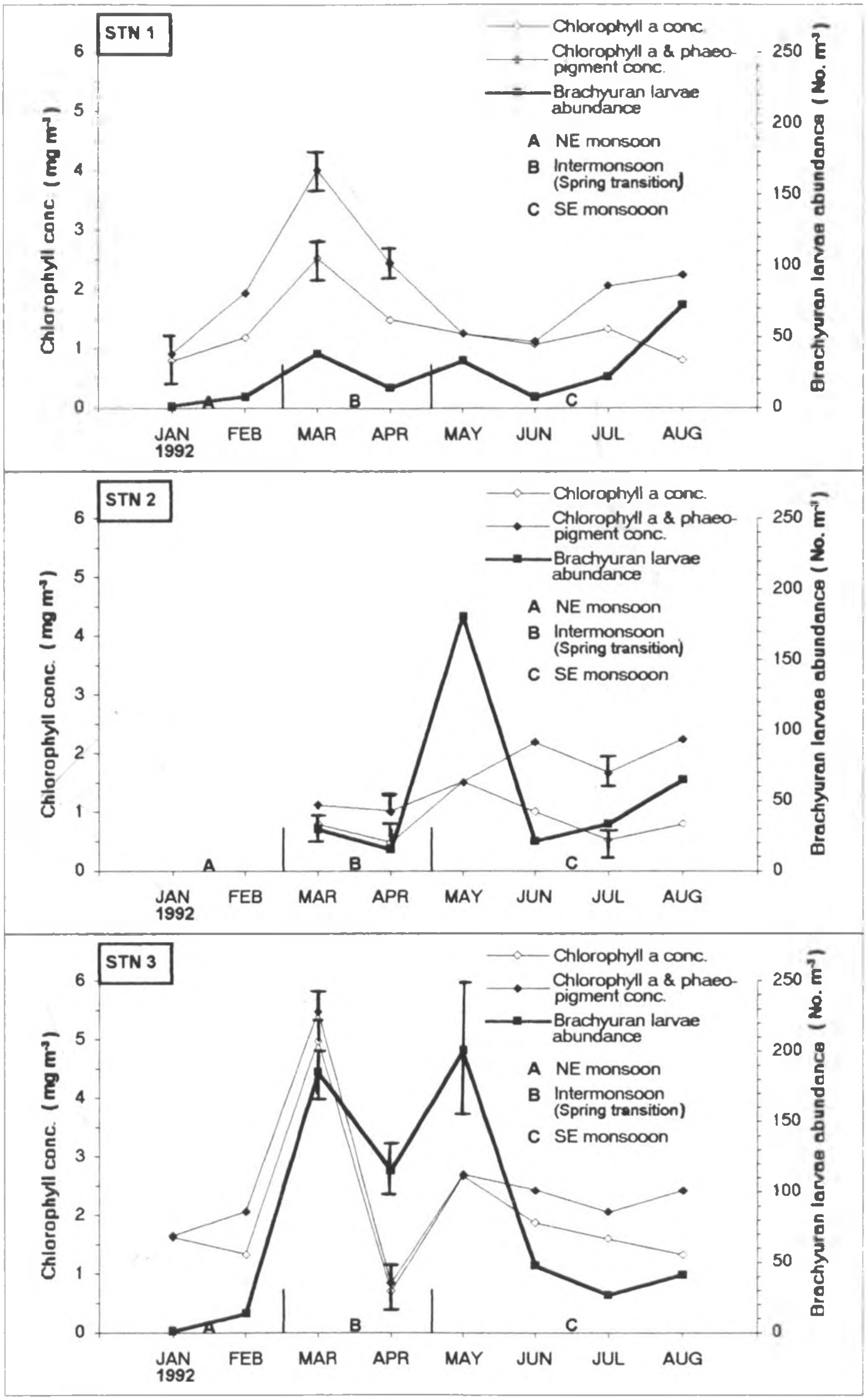


Fig. 53: Relationship between mean (± SEM) brachyuran larval abundance (N = 3 at each station) and mean (± SEM) chlorophyll conc. (N = 3 at each station) in the near-surface waters (ca.1.4m) of Tudor creek Mombasa.

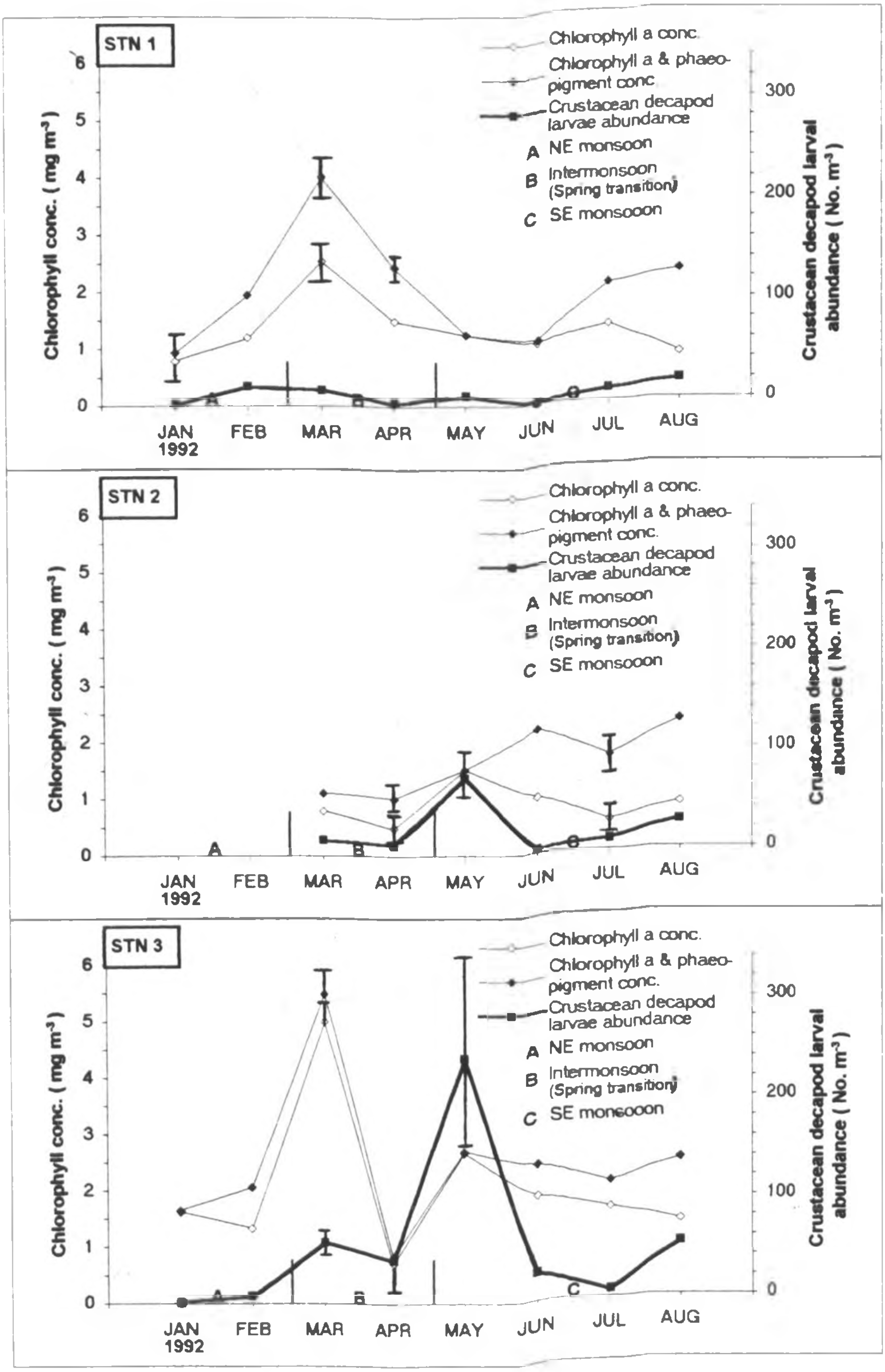


Fig. 54: Relationship between mean (± SEM) crustacean decapod larval abundance (N = 3 at each station) and mean (± SEM) chlorophyll conc. (N = 3 at each station) in the near-surface waters (ca. 1.4m) of Tudor creek Mombasa.

The variation of the combined density of each of the four main predatory groups, chaetognaths, hydromedusae, siphonophores and ctenophores, (Fig. 55) shows that the highest abundance occurred during the intermonsoon (March-April) with maximum densities in station 1 and minimum in station 2. In station 1 the maximum density of predators lagged behind the peak of copepod abundance by a month (Fig. 56) and the two were significantly correlated (r = 0.765, P = 0.026). No such relationship was found in either station 2 (r = 0.248, P = 0.636), where maximum predator density coincided with a possible peak of copepod density, or in station 3 (r = 0.128, P = 0.764), where high abundances of predators occurred prior to the peak of copepod density.

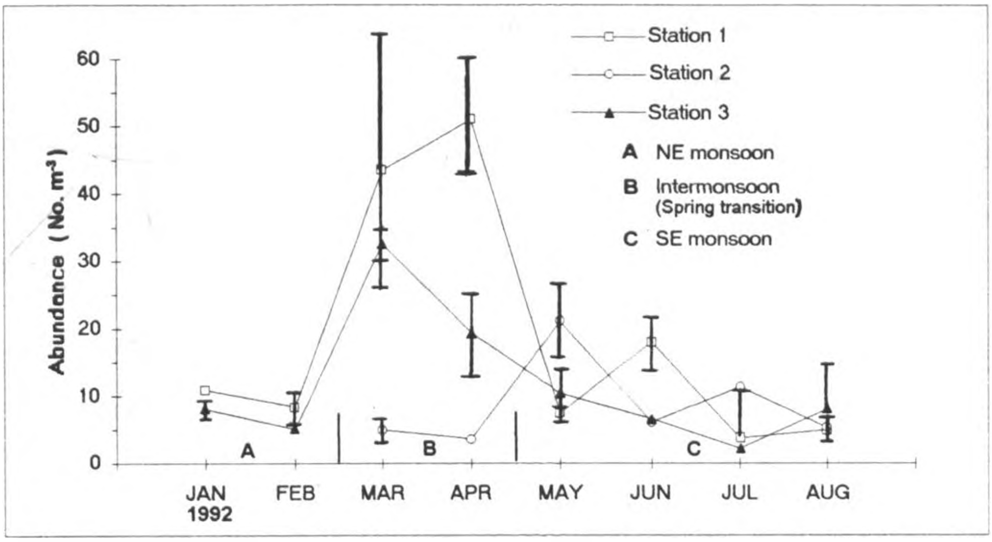


Fig. 55: Mean (+ SEM) abundance of selected predatory groups (N = 3 at each station) in the near-surface waters (ca.1.4m) of Tudor creek Mombasa.

The abundance of the two most important predatory taxa, hydromedusae and chaetognaths was not significantly correlated with copepod density in stations 2 and 3. In station 1 , the densities of hydromedusae and chaetognaths were significantly correlated with that of copepods (r = 0.851, P = 0.007 and r = 0.716, P = 0.046, respectively). A test of equality of these two coefficients using the Fisher (Z) transformation revealed that they differed significantly. It can therefore be concluded that hydromedusae were the most important predator as their correlation coefficient with copepod density was the higher of the two. As presented in figure 57, hydromedusae appeared in large numbers during the intermonsoon, at all the sites, coinciding with the high abundances of copepods. This is in contrast to the chaetognaths whose peak of abundance in station 1 lagged behind that of copepods by a month while in station 2 low densities were maintained throughout. In addition, in station 3 maximum numbers of copepods were established in April despite the high densities of chaetognaths in the previous month (Fig. 58).

Like the hydromedusae, siphonophores occurred in large numbers during the intermonsoon and there was no time lag between their peak density and that of copepods in any site (Fig. 59). But they differed from hydromedusae and chaetognaths in that their abundance was significantly correlated to that of copepods in station 3 ($r = 0.802$, $P= 0.016$) but not in station 1. Ctenophores were the most abundant predatory group, and their densities were not significantly correlated to those of copepods in any site ($P > 0.05$, in all cases). However figure 60 shows that their abundance maxima coincided with those of copepods during the intermonsoon at all the sites.

Although the densities of the selected predator groups and copepods, in station 1, are significantly correlated, these correlations may not be causal. The changing monsoon conditions seem to be the important factor affecting their abundances.

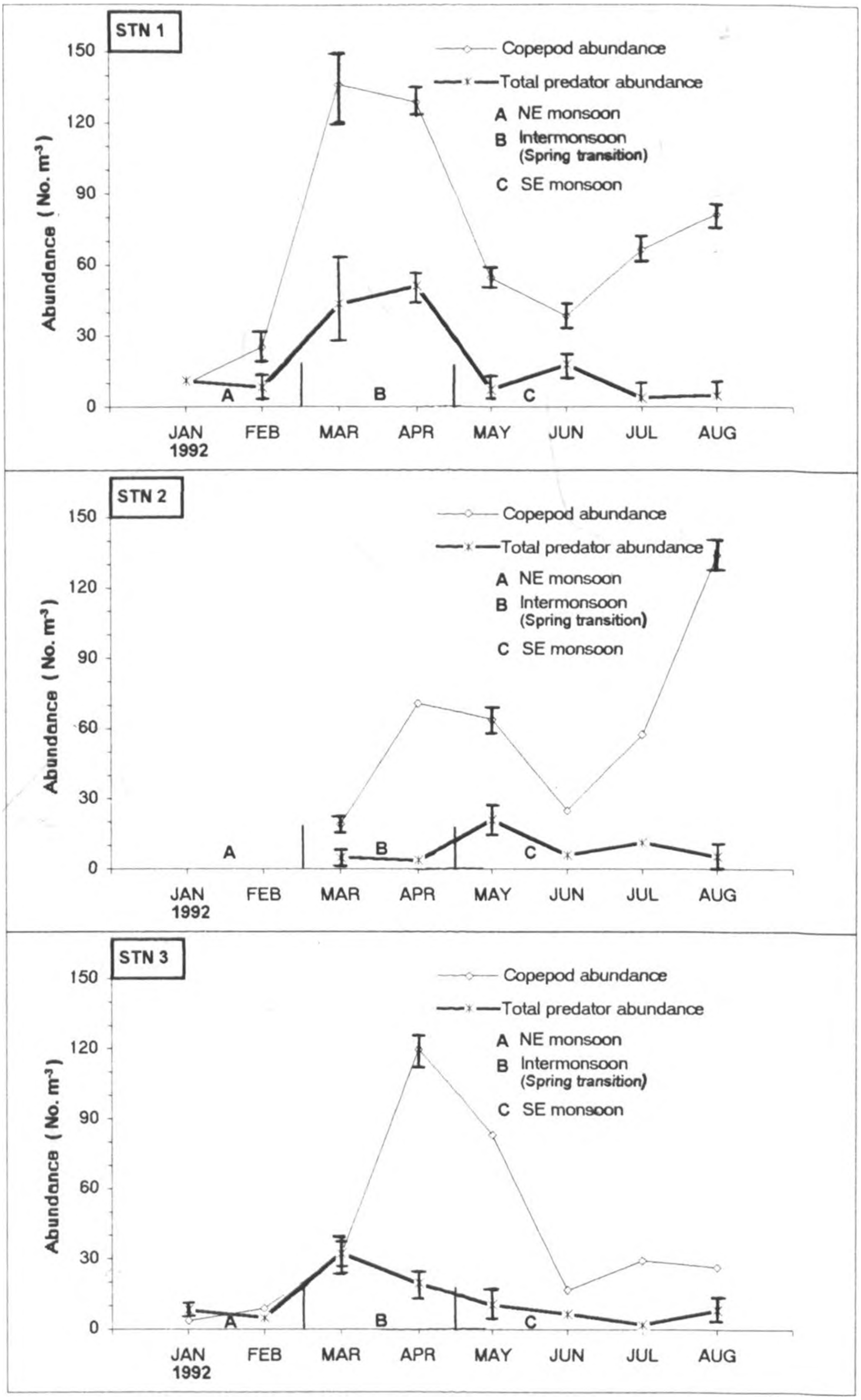


Fig. 56: Relationship between mean (± SEM) copepod abundance (N = 3 at each station) and mean (± SEM) total predator abundance (N = 3 at each station) in the near-surface waters (ca.1.4m) of Tudor creek Mombasa.

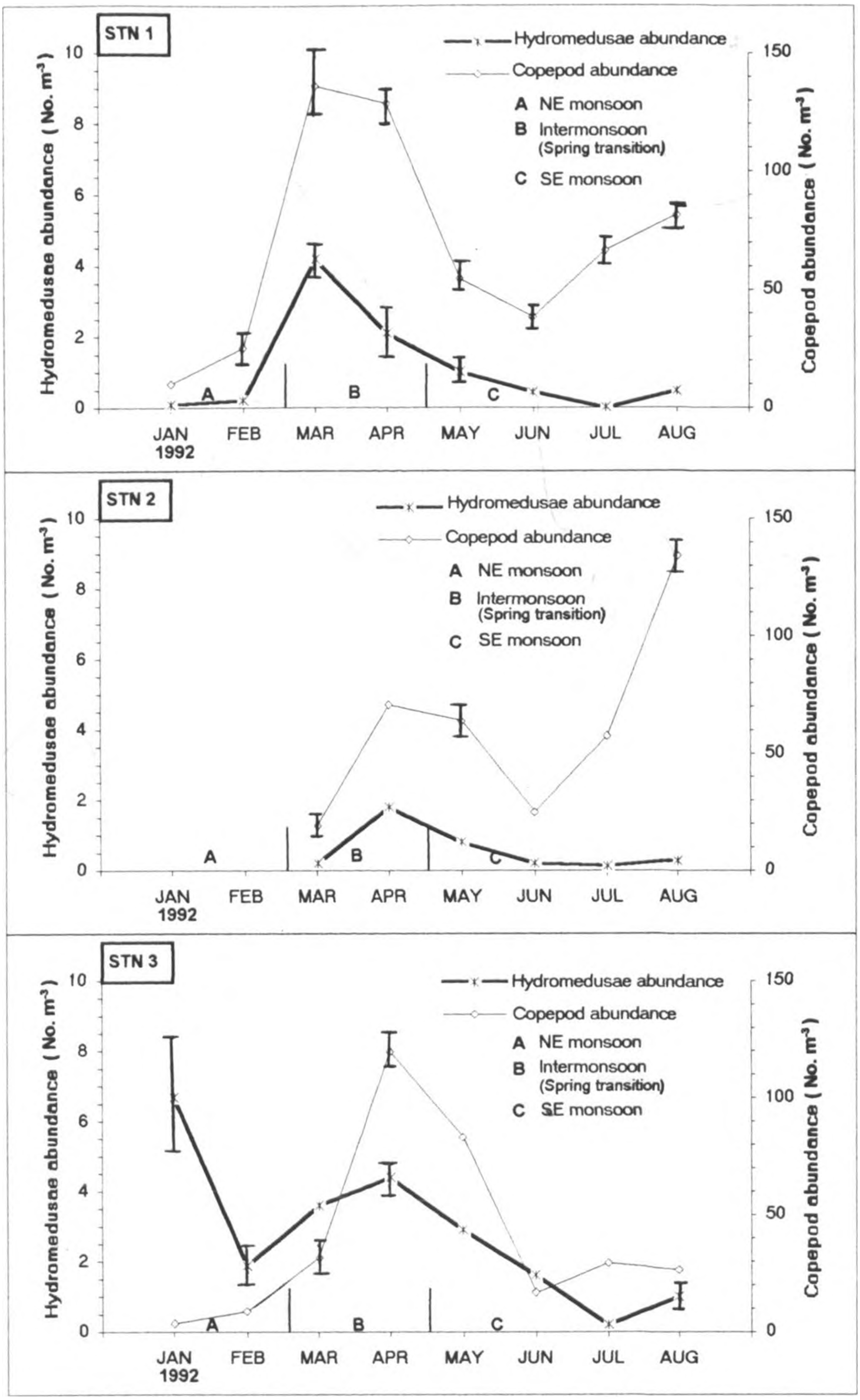


Fig. 57: Relationship between mean (± SEM) copepod abundance (N = 3 at each station) and mean (± SEM) hydromedusae abundance (N = 3 at each station) in the near-surface waters (ca. 1.4m) of Tudor creek Mombasa.

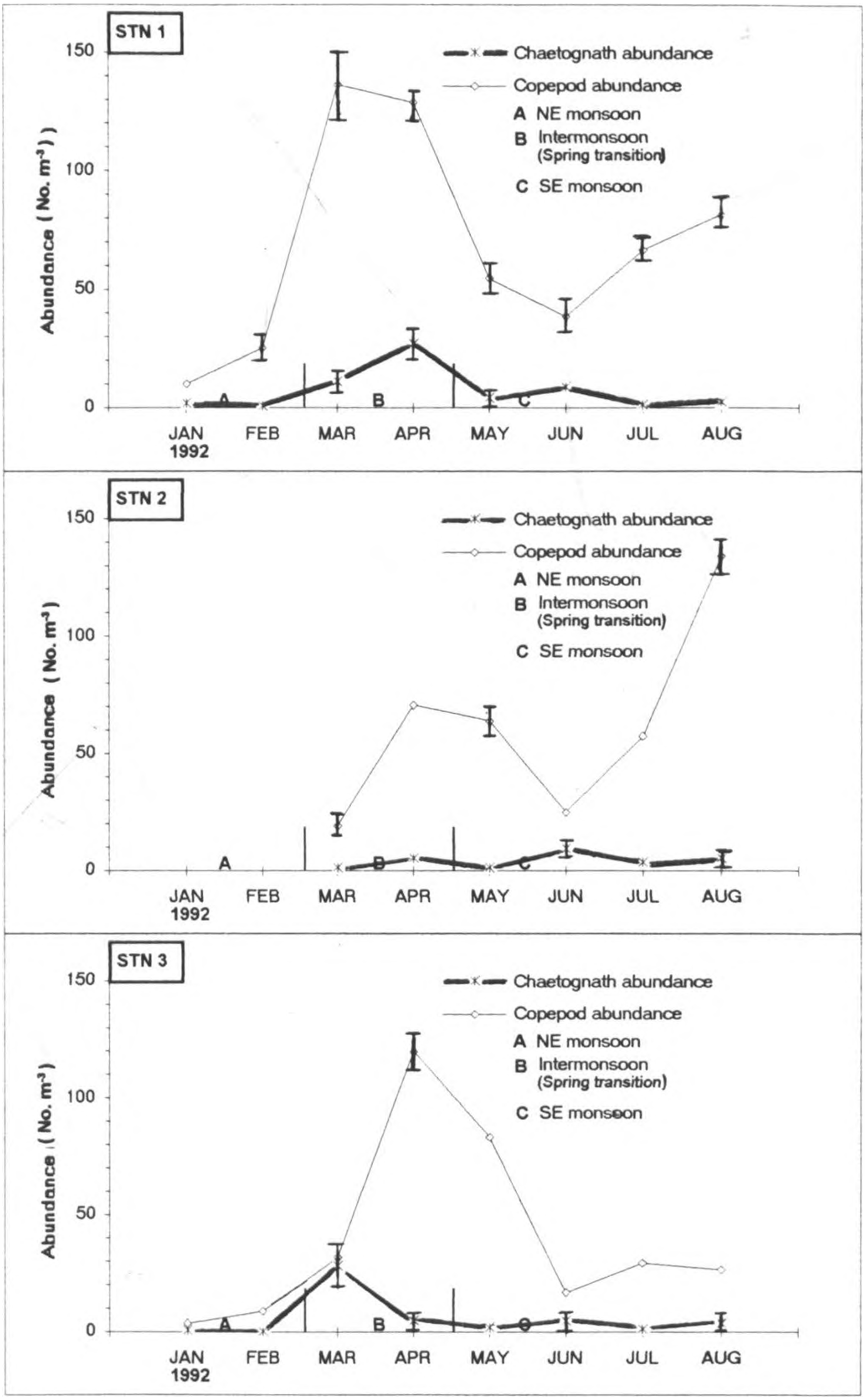


Fig. 58: Relationship between mean (± SEM) copepod abundance (N = 3 at each station) and mean (± SEM) chaetognath abundance (N = 3 at each station) in the near-surface waters (ca. 1.4m) of Tudor creek Mombasa.

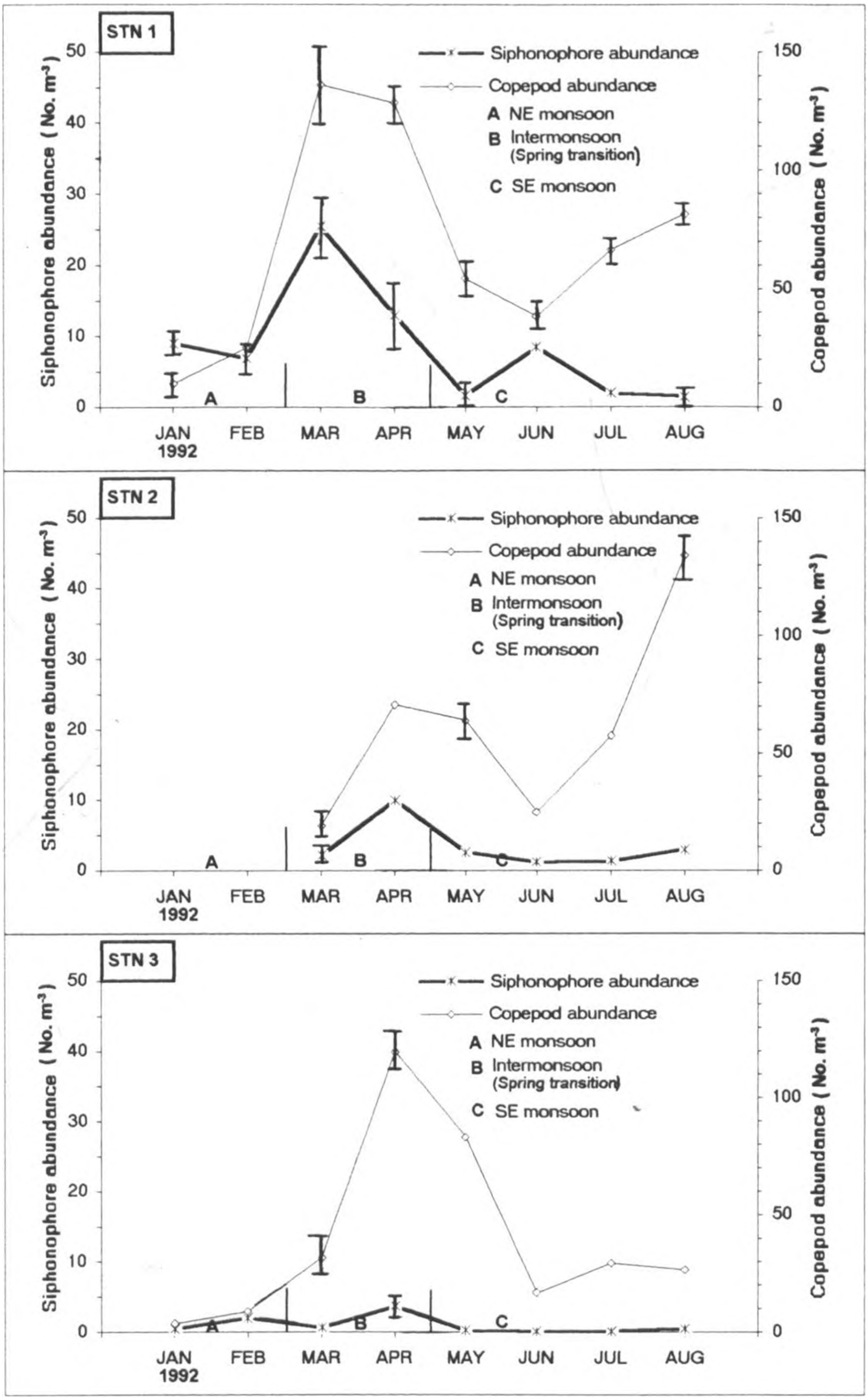


Fig. 59: Relationship between mean (± SEM) copepod abundance (N = 3 at each station) and mean (± SEM) siphonophore abundance (N = 3 at each station) in the near-surface waters (ca.1.4m) of Tudor creek Mombasa.

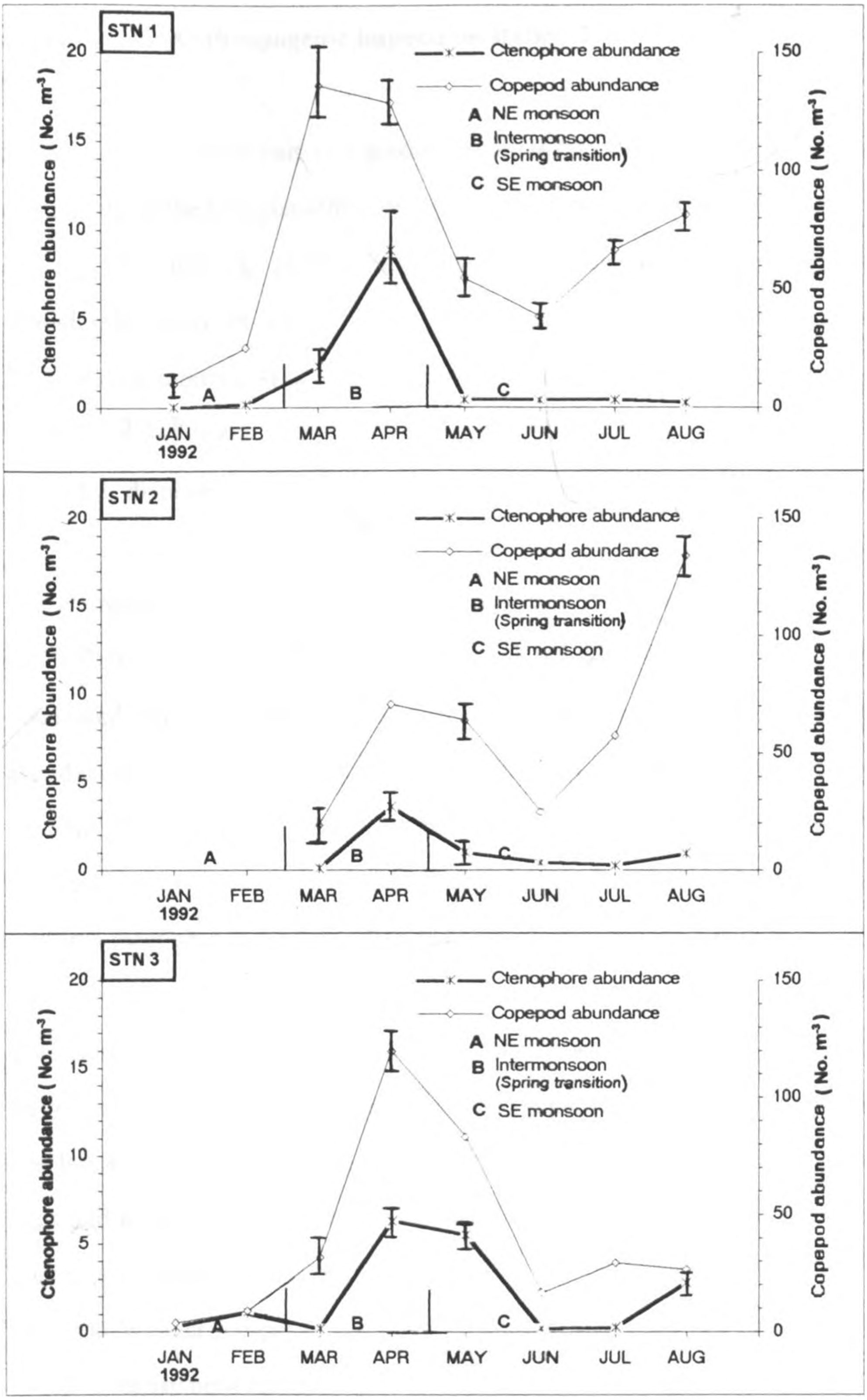


Fig. 60: Relationship between mean (± SEM) copepod abundance (N = 3 at each station) and mean (± SEM) ctenophore abundance (N = 3 at each station) in the near-surface waters (ca. 1.4m) of Tudor creek Mombasa.

4.2.4.3 Anthropogenic impacts on station 2.

Station 2 did not form part of a gradient as far as plankton biomass and faunal abundance, particularly of the holoplanktonic groups, were concerned. As pointed out in section 3.2.1 and figs. 17 and 18, phytoplankton biomass as indicated by chlorophyll levels was consistently lower in station 2 and it fluctuated within a relatively narrower range. Zooplankton biomass (Fig 19) was lowest in station 2 throughout the sampling period (section 3.2.3, $F_{0.05, 2, 59} = 3.475$, $P = 0.038$) and varied within a narrow range (0.1 to 0.2 ml l-1, displacement volume).

The abundance of zooplankton showed significant differences between the sites (section 3.2.4, $F_{0.05\ 2,59} = 4.962$, $P = 0.012$) and the holoplankton which were numerically dominated by planktotrophic species of calanoid copepods had relatively lower abundances in station 2 (section 3.2.4.1 figs. 21 to 33). The meroplankton showed a gradient of increasing abundance with distance into the creek, throughout the sampling period except, for the relatively high abundance of molluscan larvae during August in station 1 (section 3.2.4.2 figs. 34 to 39).

The groups selected to determine diversity between the three sites were copepods, ctenophores, cnidarians (hydromedusae and siphonophores), urochordates (thaliaceans and larvaceans), brachyuran larvae, crustacean decapod larvae, molluscan larvae and fish eggs and larvae. Group diversity decreases with distance into the creek (table 7) and this confirms previous reports by Kimaro, (1986) and Okemwa (1990). Comparison of the Shannon-Weaver indices of the three sites using t-tests did not detect any differences in group diversity between them ($P < 0.05$, in all cases)

Table 7: Diversity of zooplankton at ca. 1.4m depth in Tudor creek (Jan-Aug, 1992)

STATION	SHANNON-WEAVER INDEX (H')
1	0.80
2	0.71
3	0.69

$$H' = \frac{n \log n - \sum_{i=1}^{k} f_i \log f_i}{n}$$

Where: n = sample size

k = number of categories (selected zooplankton groups)

f_i = number of observations in category i

In addition, as pointed out in section 3.1.1.5 and fig. 9, although station 2 has a water column whose total depth is comparable to that of station 1, transparency in station 2 only fluctuated between 4.63 ± 0.07 SEM m and 3.5 ± 0.48 SEM m as opposed to the wide fluctuation in 1 (8.01 ± 0.47 SEM m to 4.5 ± 0.3 SEM m). Station 2 did not show a significant increase of transparency in any month ($F_{0.05\ 5,\ 15} = 3.029$, $P = 0.409$) whereas in stations 1 the highest transparency occurred during the early SE monsoon in April, in stations 1 ($F_{0.05\ 7,\ 15} = 15.34$, $P < 0.05$) and 3 ($F_{0.05,\ 7,\ 15} = 30.824$, $P < 0.05$). Among the inorganic nutrients monitored, relatively high levels of inorganic nitrates and ammonium were recorded in station 2 during the intermonsoon (sections 3.1.2.4 and 3.1.2.5, figs 13 and 14).

The relatively lower phytoplankton biomass in station 2 could be caused by reduced transparency resulting from sewage and waste discharge from the Coast General Hospital, the Old Mombasa port and the adjacent human settlements. The high levels of inorganic nitrates and ammonium, particularly in March, indicate an enrichment of the surface waters in this site from sources other than precipitation and water column mixing during the equinoctial spring tides. The absence of a concomitant peak of phytoplankton biomass suggests that these nitrogenous wastes are accompanied by large amounts of toxic substances which inhibit phyto-plankton production and directly or indirectly zooplankton production.

Parsons (1992) has evidence that sewage disposal and harbour/port activities discharge nutrients and pathogens into coastal waters and cause changes in the biological oxygen demand. Port activities also release heavy metals into these systems with deleterious effects on the aquatic communities. It appears that the effects of sewage/waste disposal and harbour activities in Tudor creek have not reached crises levels but constant monitoring would be in order.

5.0.0 CONCLUSIONS

5.1.0 Environmental parameters

5.1.1 Physical parameters

All the environmental factors monitored showed a clear response to the monsoon conditions and gradients from the mouth to the inner reaches of the creek. The lowest mean near-surface (ca. 1.4m) sea temperatures occurred during the SE monsoon (25 ± 0.3 ^{o}C) and the highest during the NE monsoon (31 ± 0.2 ^{o}C). The lower sea surface temperatures during the SE monsoon were due to heavy cloud cover resulting in fewer hours of sunshine, on average less than 7 per day, and a reduction in the mean radiation to less than 20 MJ m^{-2} day^{-1}. The wind speeds were relatively higher and the greatest amount of rain fell during this season. These changes in weather conditions were reflected in the physico-chemical characteristics of the near-surface waters and ultimately in the plankton flora and fauna. Transparency depth showed a gradient decreasing from the mouth into the creek. The widest fluctuation (ca. 8 - 4.5 m) occurred in station 1 but station 2 did not show a significant change in transparency depth (ca. 4.6 - 3.5 m) during the sampling period ($F_{0.05, 5, 15} = 3.029$, $P = 0.409$).

5.1.2 Chemical parameters

Relatively high dissolved oxygen levels (5.8 - 7.6 mg O_2 l^{-1}) occurred prior to and after the heavy rainfall in May whereas the lowest levels (4.2 - 4.8 mg O_2 l^{-1}) coincided with peak of the rainfall. The decline in dissolved oxygen levels was possibly due to the flushing in of leaf litter and consequent decomposition resulting in a high biological oxygen demand. pH levels did not seem to be influenced by the prevailing monsoon conditions and they showed a gradient decreasing with distance into the creek. They varied within narrow ranges remaining within the normal range of seawater levels (pH 7.5

- 8.4). The heavy rainfall during the SE monsoon caused a reduction in salinity values and a gradient with low levels of 32 $^{0}/_{00}$ upstream and higher levels of 34.5 $^{0}/_{00}$ at the mouth. After the rainy season Tudor creek lost its estuarine characteristics and a uniform salinity of 35 $^{0}/_{00}$ developed within the creek.

The rainfall regime did not have a direct influence on the variation of the inorganic nutrients monitored (NO_3-N, NH_4-N, PO_4-P and SiO_3-Si). Maximum levels of NO_3-N (8.5 - 36.9 µg-at NO_3-N l^{-1}), NH_4-N (4.7 - 13.9 µg-at NH_4-N l^{-1}), PO_4-P (0.85 - 2 µg-at PO_4-P l^{-1}) and SiO_3-Si (10.8 - 18.5 µg-at SiO_3-Si l^{-1}) occurred during the intermonsoon in March. Relatively high levels of PO_4-P (ca. 1.7 µg-at PO_4-P l^{-1}) and SiO_3-Si (ca. 9.1 µg-at SiO_3-Si l^{-1}) were recorded in August and June-July respectively. The peaks of inorganic nutrients during the intermonsoon may be explained by a larger tidal prism during the equinoctial spring tides and possibly more vigorous mixing of the water column. They may also result from flushing in of litter, and consequent decomposition, at the start of the rains in March. High levels of NO_3-N could also be due to nitrogen fixation by blue-green algae.

5.2.0 Biological parameters

5.2.1 Phytoplankton biomass

The variation of phytoplankton biomass as indicated by chlorophyll levels was similar to that of the inorganic nutrients, particularly NO_3-N and NH_4-N. Maximum levels of chlorophyll a (0.8 - 4.99 mg m^{-3}) and chlorophyll a with phaeo-pigment (1.12 - 5.49 mg m^{-3}) occurred during the intermonsoon (March), that is prior to the peak of rainfall in May. The levels of both indicators of phytoplankton biomass were significantly correlated to NO_3-N levels in stations 1 ($r_w = 0.800$, $P < 0.05$) and 3 only ($r_w = 0.842$, $P < 0.05$).

Despite the relatively high levels of NO_3-N in station 2, phytoplankton biomass was consistently lower in this site compared to the other two sites. This was attributed to high turbidity as a result of sewage and toxic waste disposal possibly from the Coast General hospital, the Old Mombasa port and the adjacent human settlements.

It would appear that in general, in the near-surface waters of Tudor creek, optimum conditions for phytoplankton growth occur during the intermonsoon when temperatures, salinities and nutrient levels are high. During the NE monsoon phytoplankton biomass is limited by the low nutrient levels, especially NO_3-N, while in the SE monsoon reduced temperatures, salinities and nutrient levels may be the limiting factors.

5.2.2 Zooplankton taxonomic composition and biomass

The zooplankton composition and biomass also vary with the prevailing monsoon conditions. During the NE monsoon the plankton faunal biomass was dominated by cnidarians and ctenophores at all the three stations. At the onset of the intermonsoon, in March/April the zooplankton community changed to one consisting mainly of copepods and crustacean decapod larvae. Copepods and crustacean decapod larvae remained dominant during the SE monsoon but there was a gradual decrease in the abundance of all the groups.

The distribution of zooplankton seems to be influenced by local factors. For instance, siphonophores were a feature of station 1 while hydromedusae were mostly found in station 3. In general the holoplanktonic groups such as copepods and chaetognaths were characteristic of the outer seaward station while meroplankters like crustacean decapod larvae, molluscan larvae and fish eggs and larvae were abundant in the more inland inner station.

5.2.3 Zooplankton abundance

Total zooplankton abundance in the near surface waters of Tudor creek was influenced by joint and individual effects of time of year and location in the creek, but the main individual factor was time of year.

Phytoplankton relationships

The relationship between inorganic nitrate concentration, phytoplankton biomass, as indicated by chlorophyll levels, and zooplankton abundance was clear in station 1 only. The maximum abundance of total zooplankton (417.6 ± 163.6 SEM m^{-3}) occurred during the intermonsoon, in March, and coincided with peak levels of chlorophyll a (2.54 mg m^{-3}) and chlorophyll a with phaeo-pigments (4.02 mg m^{-3}). It was significantly correlated with the levels of these indicators of phytoplankton biomass. The abundance of holoplankton was significantly correlated to phytoplankton biomass but the abundance of meroplankton was not. This could be explained by the fact that station 1 was dominated by holoplanktonic groups, particularly the copepods which are mainly planktotrophic, while the meroplankton has more lecithotrohic groups such as the brachyura.

The pattern of temporal variation of total zooplankton abundance in station 2 was somewhat similar to that of phytoplankton biomass but the two were not significantly correlated. Maximum zooplankton abundance (347.6 ± 83 SEM m^{-3}) in this site was recorded in May, due to increased contributions of crustacean decapod larvae, particularly brachyuran larvae. Relatively high zooplankton abundances (150.9 ± 25.7 SEM m^{-3}) were also recorded in August due to increased numbers of gastropod veligers.

In station 3 total zooplankton densities were highest (378.5 ± 48 SEM m^{-3} to 495 ± 123.2 SEM m^{-3}) during the intermonsoon (March) upto the early SE monsoon (May). This is despite the fact that peak levels of both forms of chlorophyll a occurred in March (4.99 mg m^{-3} and 5.49 mg m^{-3}) and declined sharply thereafter. The lack of correlation between zooplankton abundance and the concentration of chlorophyll a and its derivatives in station 3 may be explained by the fact that the peak from March to May is largely due to the dominance of brachyuran larvae which are lecithotrophic.

Predator-prey relationships

There was some indication of a predator-prey relationship between copepods and predatory groups such as hydromedusae, chaetognaths, siphonophores and ctenophores. In station 1, the maximum density of all the predators taken together lagged behind the peak of copepod abundance by a month and the two were significantly correlated ($r = 0.765$, $P = 0.026$). No such relationship was found in stations 2 and 3. The densities of individual predator groups such as hydromedusae and chaetognaths were also significantly correlated with the abundance of copepods ($r = 0.851$ $P = 0.007$ and $r = 0.716$, $P = 0.046$, respectively) in station 1.

Although the densities of the selected predator groups and copepods, in station 1, are significantly correlated, these relations may not be causal. The changing monsoon conditions seem to be the important factor affecting their abundances. This is indicated by the observation that the cycles of copepods and the various specified predatory groups were almost in phase with one another.

Anthropogenic impacts on station 2

As mentioned earlier, transparency depth showed the least fluctuation in this site and relatively high inorganic nitrate levels were recorded, during the intermonsoon. This was tentatively attributed to anthropogenic impacts such as sewage and waste disposal possibly from Coast General Hospital, the Old Mombasa Port, and the adjacent human settlements. Despite the relatively high levels of NO_3-N in station 2, phytoplankton biomass was consistently lower in this site compared to the other two sites. This may indicate that apart from discharges of nitrogenous wastes, which would enrich the surface waters and therefore enhance planktonic floral and faunal production, the wastes could include substantial amounts of toxic substances which inhibit phytoplankton and directly or indirectly zooplankton production.

5.3.0 Suggestions for future research work

Perhaps one of the most fundamental problems not resolved by the present study is what are the factors which influence nutrient levels, particularly inorganic nitrates and ammonium in Tudor creek. Is it water dynamics with a possible consequent effect on nitrogen fixing organisms? or is it terrestrial runoff and seepage? or a combination of factors? An answer to these questions would be of general importance for the ecology of creek waters not only in East Africa but further afield. Related to the above is the observation made in this study that the maxima of chlorophyll a concentration and zooplankton abundance and biomass occur in March-April before the peak of rainfall. This was also fond in Gazi creek (Wawiye,1993 and Mwaluma et al, 1990).

The present study was based on sampling only near-surface waters. (ca. 1.4 m) The question arises how the pattens observed are reflected in the rest of the water column.

One obvious problem brought out by this work is the nature of the substances depressing phytoplankton biomass as indicated by chlorophyll a levels and zooplankton biomass and abundance. Are these substances industrial pollutants? If so what are they?

Another intriguing problem remaining to be investigated is the nature of the predator - prey relationships, only hinted at in this work, for example, one would like to know which are the most important predators ? How do these interactions vary throughout the year?

The mesh size of nets used for this research was 335µm. Therefore only the larger zooplankton were sampled and naturally the picture obtained leaves out almost completely larval stages of the groups. As such the population structure is very incompletely reflected. Using finer mesh nets one can study patterns of recruitment and developmental stages of the various groups.

Lastly, the taxonomic identification of zooplankton groups in Tudor creek should be improved to species level.

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