INTER-UNIVERSITY POST-GRADUATE TRAINING COURSE ON FUNDAMENTAL AND APPLIED MARINE ECOLOGY

(F.A.M.E)

Free University of Brussels

Brussels, Belgium

October, 1990

A study of the Pelagic Copepods (COPEPODA; CRUSTACEA) in a tropical marine creek Tudor, Mombasa, Kenya, with a special reference to their community structure, biomass and productivity.

by

EZEKIEL OKEMWA

B.Sc (Hons), M.Sc, Cert. Post-grad. Mar. Ecol.

A Thesis submitted for the fulfillment for the degree of Doctor of Philosophy.

Promotors:

Dr. M. Daro & Prof. Dr. Ph. Polk

(Free University of Brussels, Laboratory of Ecology and Systematics, Peinlaan 2, 1050 Brussels, Belgium)

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DEDICATION

To my Parents

Rebecca Basweti

and

Dishon Okemwa Kereri,

on their 45th Wedding Anniversary.

TABLE OF CONTENTS

CHAPTER 2

CHAPTER 3

CHAPTER 4

CHAPTER 6

CHAPTER 7

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

I thank my supervisors, Dr. M. N. Daro and Prof. Dr. P. Polk, for their tireless, critical and keen supervision throughout the period of this study. This study was financed from the Kenyan/Belgian Marine Sciences Research Project (KBP) grant to Kenya Marine and Fisheries Research Institute (KMFRI), Mombasa, Kenya by the Belgian Government to whom I am very grateful.

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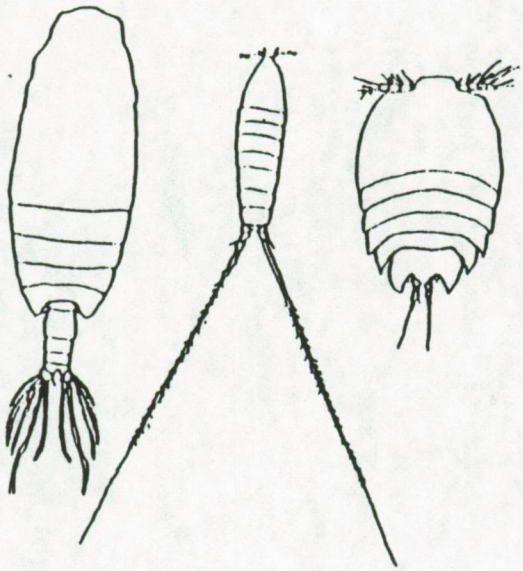
Last, but not least, I express my gratitude to my family, my wife and our children, without whose cooperation and understanding I would not have been able to complete this study.



ABSTRACT

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This study was undertaken with a view to: (a)describe the species composition and the community structure of copepods in the Tudor Creek; (b) describe the spatio-temporal distribution of pelagic copepods as well as estimating their abundance, and finally to estimate both primary production, biomass and respiration in Tudor Creek.

The first quantitative study of the pelagic zooplankton community of the Tudor Creek, Mombasa, Kenya, was undertaken from December 1984 to December 1987. Using a Bongo plankton net of 335 µm mesh from R.V. Maumba from December to March 1985. From April 1985 to December 1987 a small canoe with an outboard engine was used. A conical plankton net having a mesh aperture size of 335 µm fitted with a flow-meter at the mouth of 45 cm diameter and a length of one meter long was used for sampling.

Surface-plankton samples were taken using a small canoe at each of the five permanent stations during day- time and night-time during one neap and one spring of every month from September 1985 to August 1986. Thereafter only day-time neap and spring samples were taken from September 1986 to December 1987 in five stations. 24-hours cycle sampling was occasionally done at stations 1 and 5 simultaneously.

The neap tide sampling of the 24-hour cycle started at 0900 h on 23rd September 1985 and the last samples were taken at 0900 h the following day. Sampling during the spring tide started at 0900 h on 1st October 1985 to 0900 h on 2nd October 1985. Every two hours zooplankton was collected by horizontal hauls at 1.3 m depth with a 335 µm mesh net. Simultaneously the following abiotic parameters were measured: for information on salinity, temperature, transparency, oxygen concentration and pH. Fresh zooplankton was sampled from January 1986 to February 1986, in February 1987 and from February 1988 to March 1988 every morning with a plankton net of 335 µm mesh aperture on board of the small canoe at very low speed during about 2 hour. Live sample was put in a bucket with fresh sea water and brought to the laboratory, for respiration experiments, length and weight measurements.

Hydrographic parameters, including surface water salinity and temperature, turbidity, dissolved oxygen and pH were also monitored during this study. Photosynthesis of phytoplankton biomass was measured in the field, using light and dark glass bottles and using oxygen methods.

Results from the study have shown that zooplankton is rich and abundant and over 51 taxa were recorded. Close to 74% of zooplankton comprised copepods of which the most important were calanoids followed by cyclopoids, poecilostomatoids, harpacticoids and monstrilloids in that order. Calanoids were the dominant group of copepods in all the samples, followed by poecilostomatoids, cyclopoids, harpacticoids and lastly Monstrilloids. The most commonly encountered calanoid species included:

Centropages orsinii, Acrocalanus longicornis,Clausocalanus farrani, Temora turbinata, Paracalanus aculeatis, Canthocalanus pauper, Undinula vulgaris, Acartia danae, Paracalanus simplex, Euchaeta marina, and Eucalanus spp..

The most common cyclopoid species encountered were Corycaeus specious, Oncaea venusta , Copilia mirabilis Dana, and Sapphirina lactens, Oithona plumifera, O.setigera, and O.simplex. Three harpacticoids, Microsetella rosea, Euterpina acutifrons, and Macrosetella gracilis were the commonest. Only occasionally did copepods of the order Monstrilloida show up in the samples.

Some 99 copepod species, representing 41 genera and 30 families, have been identified. Amongst these 17 species are dominant but 6 species including Calanus darwini, Labidocera laevidentata, Paracalanus crassirostris, P.indicus, P.tropicus and Sapphirina lactens, have been recorded in Western Indian Ocean off Kenya coast for the first time.

Both diel and seasonal changes in the abundance of zooplankton catches occur. While night catch numbers are higher than day ones the seasonal changes seen appear to be strongly associated with the dry and wet periods. Mean annual total copepod biomass was 308, 90 and 149 mg dw $10\,m^{-3}$ for the first, second and third years of study, respectively. Peaks

biomass of copepods as well as Primary production in the Tudor Creek were recorded in May-June and again in November-December which are the rain months in Kenya.

Respiration rates per unit weight of copepods is higher at night than day time.

SAMENVATTING

Studie van de pelagische copepoden (Copepoda: Crustacea) in een tropische mariene kreek (Tudor, Mombasa) met speciale aandacht voor de gemeenschapstructuur, biomassa en productiviteit.

Deze studie werd ondernomen met de volgende doestellingen:

(a) beschrijven van de soortensamentelling va de copepoden gemeenschapstructuur in Tudor creek; (b) het beschrijven van zowel de verspreiding der pelagische copepoden in ruimte en tijd als het schatten van hun aantallen, en tenslotte het schatten van primarie en secundaire produktie in Tudor creek.

De eerste kwantitatieve studie van pelagische zooplankton gemeenschappen in Tudor Creek, Mombasa, Kenya werd ondernomen tussen december 1984 en december 1987. Voor de staalname werd gebruik gemaakt van een Bongo planktonnet met een maaswijdte van 335µm en uitgerust met een flow-meter van 45 cm diameter en een lengte van 1 meter.

Oppervlakte zooplankton stalen werden genomen met een kleine kano en dit op elk van de vijf stations gedurende zowel de dag als nacht en tijdens een doodtij en een springtij. Dit elke maand vanaf september 1985 tot augustus 1986. Hierna werden nog enkel stalen genomen op vijf stations gedurende de dag tijdens doodtij en spingtij en dit van september 1986 tot december 1987. 24-Uur cyclus staalname werd uitgevoerd in Tudor Creek, tegelijkertijd op stations 1 en 5.

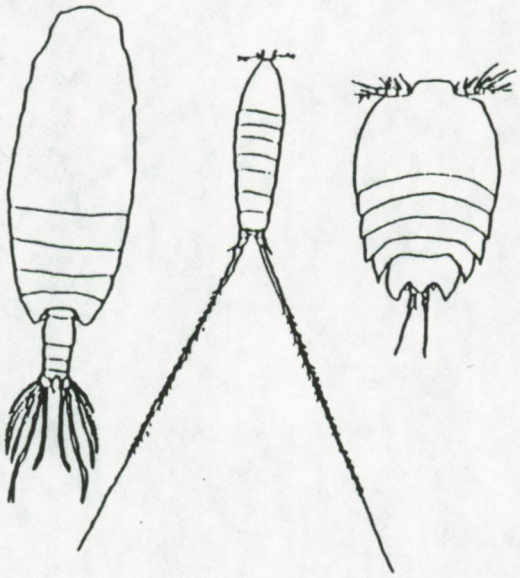
De doodtij staalname van de 24-uur cyclus werd gestart om 0900 u op 23 september 1985 en de laatste stalen werden genomen om 0900 u de volgende dag. Staalname gedurende springtij werd uitgevoerd om 0900 u op 1 oktober 1985 tot 0900 u op 2 oktober 1985. Zooplankton werd elke twee uur verzameld door middel van horizontale slepen en dit op 1.3 m diepte met een net met een maaswijdte van 335µm . Tegelijkertijd werden de volgende abiotische parameters gemeten: saliniteit,

meest voorkomenden. In zeldzame gevallen werden copepoden van de orde Monstrilloida aangetroffen.

Ongeveer 99 copepodesoorten werden geidentificeerd, toebehorend aan 41 genera en 30 families. Van dezen zijn 17 soorten dominant, doch zes soorten zijn nieuw voor de West Indische Oceaan: Calanus darwini, Labidocera laevidentata, Paracalanus crassirostris, Paracalanus indicus, Paracalanus tropicus en Sapphirina lactens.

Zowel dag- als seizonale fluctuaties in de abondantie van zooplanktonvangsten komen voor. Terwijl nachtvangsten hoger zijn dan dagvangsten, lijken de seizonale fluctuaties verbonden te zijn met de droge en natte periodes. Jaarlijkse gemiddelde totale copepode biomassa bedroeg 308, 90 en 149 mg dw $10\,m^{-3}$ voor respectievelijke het eerste, tweede and derde jaar van de studie. Copepode biomassa pieken vielen samen met de regenseizonen in de kustzone. Biomassa pieken van zowel -xxxv- copepoden als primaire produktie in de Tudor creek werden waargenomen in mei-juni en opnieuw in november-december. Dit zijn de regenmaanden in Kenya. Respiratie per eenheid gewicht van copepoden is hoger gedurende de nacht dan gedurende de dag.

INTRODUCTION



CHAPTER 1

CHAPTER 1

1.0. Introduction

The animal plankton consists of those organisms living in water whose weak swimming ability are so weak that they drift with the prevailing currents. The subclass Copepoda '(Class Crustacea)' is one of the predominant groups of marine zooplankton. Although copepods are generally minute, most ranging from less than 1 mm to several millimeters in length, their enormous numbers make them one of the quantitatively most important zooplankton into animal tissue.

The importance of copepods in the economy of the marine ecosystem is three fold. First, because they exist in enormous numbers, they are an important link in many marine food chains (Newell and Newell, 1956; Okera, 1973). A major part of the diet of many marine and freshwater animals for example fish is composed of copepods (Wickstead, 1965), and are an important secondary consumer food source in fish nursery grounds such as Tudor creek (Little et al., 1988). Second, they constitute parasites of fish, both as in the ectoparasitic and endoparasitic forms, thereby reducing the market value of fish.

Third, they are also parasites of crustaceans and dugongs, whales etc. Last, because of their great species diversity, some of them have been utilized in ecological studies, as indicator species for water masses.

These few remarks demonstrate the importance of copepods in aquatic ecosystems for example the role they play in aquatic food webs.

1.1. Literature review

1.1.2 Previous studies on plankton in Indian Ocean.

Since the beginning of the 19th century, several 'European' Scientific Expeditions and numerous individuals have collected and described zooplankton from the Indian Ocean (Sewell, 1912, 1929a, 1932, 1940, 1947, 1949; Scott, 1909).

Although Dana (1853) made the earliest attempts to provide an adequate explanation on the distribution of the Copepoda and other crustaceans. This work included many forms of crustacea some of which are not planktonic, except in their larval stages.

Studying the distribution amongst the Copepoda, Giesbrecht (1892) recognizes three zones. One of these is the warm tropical and sub-tropical zone characterized by high species diversity and the other two characterized by low species diversity are the Arctic and Antarctic zones extending from about lat. 47° N to lat. 44° S respectively.

Our present knowledge of the systematics and spatial distribution of the copepods in the Indian Ocean is largely based on the report of plankton collections by **R.I.M.S. "Investigator"** (1910 - 1925) the **"Siboga"** and **"John Murray"** expeditions (Sewell, 1912, 1929a, 1932, 1940, 1947, 1948, 1949) and **Siboga** (Scott, 1909).

Such studies have shown that the copepod fauna in the deeper waters of the Indian Ocean is similar to that of the Pacific to the east and the Atlantic Ocean to the west (Sewell, 1929). However, while the surface faunistic compositions are the same for the Indian and the Pacific Ocean they are different between the Indian and the Atlantic Ocean. One of the probable reasons for this difference could be the formation of a strong boundary at the meeting point of the warm Mozambique and Agulhas currents with cold Atlantic current of the West-wind drift off the west coast of South Africa (Sewell, 1929).

The systematics of the copepods around Maldive and Laccadive islands has been described by Wolfenden (1906). While Krishnaswamy (1951, 1951a,b, 1953 a,b,c; 1956) has made invaluable contribution to the systematics of the species found in the Bay of Bengal.

The seasonal distribution of copepods in the Indian Ocean has been studied. Ganapati and Rao (1954) describe similar phenomenon for the copepods off the waters of Waltair and also bring some light on the spatio-temporal distribution of copepods off Visakhapatnam Coast in relation to salinity and temperature. Kartha (1959) gave similar account of the distribution of copepodites and adult copepods in the Gulf of Mannar and Palk Bay. This study showed differences in the species composition as well as in the population of the adults in the two areas. Further work in this area (Prasad and Kartha, 1959) showed a close relation between the breeding of the copepods with the diatom cycles. Dakin et al., (1948) report on the systematics of the copepod fauna in the Australian estuarine systems.

Marichamy and Siraimeetan (1979) discuss the hydrological and meteorological factors which influence the distribution of zooplankton off Tuticorin Coast in the Gulf of Mannar.

Recent studies on the distribution and abundance of zooplankton in tidal creeks in Bengal Bay shows that zooplankton distribution has a major peak in March - April and a minor during November - December period Baidya and Choudhury (1984). Copepods were the principal components contributing 81 to 91% of the total plankton population.

Klekowski and Sazhina (1985), determine oxygen consumption for 18 pelagic species of copepoda from the northern and southern boundaries of the Equatorial Counter-current of the Indian Ocean. Regression equations were computed of the relationship between metabolism, body weight, energetic equivalent and daily cost of maintenance for the period of ontogenesis.

Deevey (1960) shows that copepod length is inversely correlated with environmental temperature for several copepods in the North Sea.

Studying the ecology of copepods from Hooghly Estuary, West Bengal, India Sarkar et al., (1986) showed that there was a higher diversity and abundance of most copepods during high saline pre-monsoon period.

First study on structure and ecology of plankton communities of the Indian Ocean include that of the Timonin 1971 and Tranter 1977.

While in other seas a lot of research appears to have been done on zooplankton in the nearshore and estuarine waters concerning ecology of plankton, seasonal study, zooplankton dynamics, food chain structure and plankton communities (Davis, 1950; Davis and Williams, 1950; King, 1950; Pierce, 1951; Grice, 1956; 1960a, b; Deevey, 1960; Hopkins, 1966; Evans, 1981; Bakker and Van Rijswijk, 1987; Williams et al, 1987; Robertson et al, 1988; Nielsen and Richardson, 1989). Comprehensive surveys on taxonomic analysis and quantitative estimates of standing crop both in terms of weight and numbers are very scanty and completely lacking in the West Indian Ocean area.

1.1.3. Related work from the East African coast

Where studies on the hydrography of the East African waters have been made there appear to exclude creek waters (Newell, 1959). The only information on seasonal and tidal cycles in the abiotic factors in the creeks around Mombasa is that provided in the report of Norconsult (1975). In addition this report describes the phytoplankton communities in these Kenyan creeks but fails to give, at all, similar information on zooplankton from these creeks. Recently, however, Brakel (1982) analyzed the tidal patterns of the area with emphasizes on the influence they have on the intertidal biota. Only the work of Wickstead (1963) attempts to provide a systematic study on the ecology of the inshore zooplankton on this part of Indian Ocean. The work of Okera (1974) examines the diversity of the night zooplankton in one coastal stretch of Tanzania. In this work he also gives the temporal trends in the numerical abundance of nearly all the major zooplanktonic groups in this area.

Brusher (1974) examined the distribution and abundance of penaeid prawn post-larvae in Port Reitz. Kuranty 1983 investigated seasonal changes in the abundance of prawn larvae and other plankton entering the culture ponds at Malindi, Kenya.

The literature available indicates that the zooplankton off the East African Coast is little known (Wickstead, 1965, 1968; Timonin, 1971; Okera, 1974; Tranter, 1977; Smith & Lane, 1981).

Tudor Creek makes an important contribution to the marine fisheries of Kenya coast Grove et al (1985) and Little et al (1988a, b & c). Despite the importance of Tudor Creek, very little information is available on the coastal zooplankton communities. The few studies which have been carried out on the inshore zooplankton of Tudor Creek include those of Reay and Kimaro (1984), and Kimaro (1986) who identified the diel, lunar and annual cycle. Studies carried out on planktonic copepods from coastal and inshore water of Tudor Creek include that of Okemwa and Revis (1986). This study was the first systematic account on copepods reported from the coastal and inshore water of Kenya. Fifty-two free swimming plankton copepod species were identified. Revis (1988) studied the copepods from Tudor Creek and gave information on densities and their seasonal fluctuations. From the foregoing it is clear that every effort is needed to have proper understanding of zooplankton community in this part of the Indian Ocean waters.

1.1.4. Plankton studies in other Seas

While it is a fact that plankton research dates well over one hundred years ago, during which time numerous studies on seasonal and diel changes have been done, it is clear that recently studies on biomass and production of pelagic copepods have been taken up especially in the North Atlantic Ocean.

Some of these studies amongst others, the works of Riley (1946, 1947), Riley and Bumpus (1946), Harvey (1950), Cushing (1955, 1959) and

Raymont (1963) contribute in a major way towards the understanding of the biomass and production of the entire plankton community in the North Sea. Later work tends to look at the finer division, for example Adams (1963), Aron (1962) and Tranter (1962), restricted themselves to zooplankton, dealt with it only in its entirety. While Cushing and Vucetic (1963) confined themselves to herbivorous zooplankton. Even this is limited to a comparison between Calanus sp and all other herbivores combined. Herbivore zooplankton is important for understanding the food chain in the sea. This fact is recognized by Bogorov (1959) when he discusses and emphasizes the importance of studying the biomass of the components within the herbivore trophic level.

Daro (1973) studied the role of zooplankton in the ecological situation in the Sluice-Dock at Ostend (Belgium). Research on phytoplankton has left the stage of extrapolation from Chlorella and Phaeodactylum at all phytoplankton, and many marine species are now routinely cultured and studied in the laboratory. In contrast, only a few species of zooplankton have been intensively studied, the outstanding work being that of Marshall and Orr (1955) on Calanus sp. The most common group of marine, zooplankton organisms - the calanoid copepods have been cultured beyond a single generation in the laboratory and in situ conditions (Zillioux & Wilson, 1966; Mullin & Brooks, 1967; Klein Breteler, 1980; Klein Breteler & Gonzalez, 1982, 1986, 1988; Klein Breteler et al 1982; Vijverberg, 1989).

1.2. The rationale of the study

The composition, structure, and functional role of zooplankton communities in the sea are issues of fundamental concern in the context of water quality, aquatic productivity, and particularly in fisheries production.

During excretion and respiration, zooplankton can play a major part in recycling organic matter to nutrients (Podamo, 1975). In view of their activity as grazers and in recycling to nutrients, zooplankton actually can affect phytoplankton populations in some specific ecosystems.

Talking about energy flow, one has to look at zooplankton playing different roles: first as herbivores removing phytoplankton by grazing and considering them as carnivores they eliminate some of the zooplankton grazing activities (Podamo, 1975). Daro (1980) showed that zooplankton plays a major role in the decline of phytoplankton in pelagic area. Joiris et al (1982) found that zooplankton plays a minor role in shallow coastal areas in the grazing on phytoplankton.

Copepods, a major component of zooplankton marine aquatic ecosystem, form a major food source for many fishes and prawns.

In Tudor Creek, Mombasa, Kenya, one would expect this to be a common biological phenomenon and if this is the case zooplankton indirectly represent an important component of the human diet in Kenya. And, indeed, this is probably the case since Okera (1974) showed Sardinella gibbosa (Bleeker) and S. albella (Valenciennes) of the inshore waters of Tanzania feed on zooplankton.

In order to understand how many copepods are available as food for larval and juvenile fish in the estuary, we first have to know something about copepod species composition and their seasonal cycles of reproduction and growth.

Of course one would expect to find many copepod species in zooplankton samples from the Kenyan Coastal waters. Until recently the information on their identity, abundance as well as their population dynamics are really scanty or virtually non existent. Bearing this in mind, this study was planned to provide some of this information in the Tudor Creek with a view to expanding the work to cover other creeks and a majority of the inshore waters of Kenya in the future. Because in the sampling design it was found necessary to take measurements of the various parameters as frequently as was necessary, the choice of the Tudor Creek as the sampling area was quite obvious due to its close proximity to the Institute in Mombasa. The study is, therefore, planned with a view to:

(i) describe the species composition and structure of the copepod community in the Tudor Creek.

(ii) describe the spatial and temporal distribution in terms of numbers and weight of pelagic copepods in Tudor Creek in order to elucidate the patterns of their seasonal occurrence.

(iii) estimate primary and secondary production in Tudor Creek.

(iv) give general approach of qualitative and quantitative estimation of the copepods, excluding possible micro-distributions due to fronts, gyres etc.

The information gathered will provide the baseline data necessary for the future development and management of the Tudor Creek fishery and mariculture.

1.3. Study area

1.3.1. An overview of the Tudor Creek ecosystem

The topography of the East African Coast strip shows clear evidence of pleistocene reef growth and erosion (Caswell, 1953; Thompson, 1956). Two major episodes of reef growth occurred during periods of elevation along the shore. This is due to uplift and faulting which formed underwater notches in the limestone and deeply cut river valleys which later were covered by the rising sea and have formed sheltered mangrove-lined inlets known locally as creeks (Sikes, 1930; Thompson, 1956; Alexander, 1968).

The geology of the Kenyan coast is characterized by the mostly submerged reef flats along the shores, the raised reefs of the coastal plain and the various sedimentary formation further inland generally running parallel to the coast (Norconsult, 1975).

Tudor Creek lies to the north and west of Mombasa Island, Kenya (approximately latitude 4° S, longitude 40° E) and comprises an estimated 20 km^2 of shallow channels, mud-banks and mangrove forest (Figure 1.1). As can be seen it cuts through the reef complex into the sandy and shelly beds of the sedimentary formations. Sediments of Tudor Creek are predominantly mud and some parts are covered with sand.

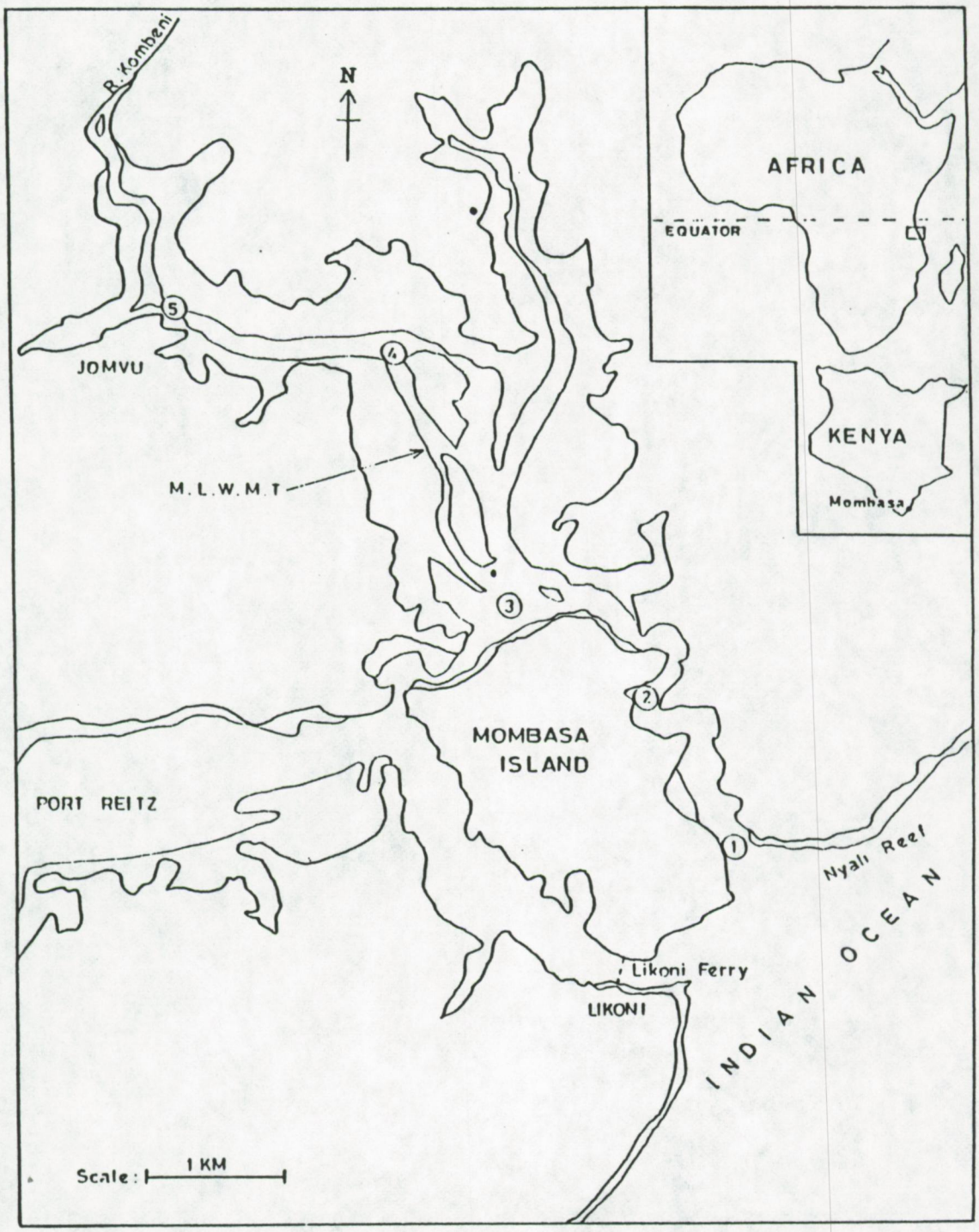


Fig.1.1.The study area and sampling locations in Tudor Creek, Mombasa, Kenya (__ Boundary of the system, M.L.W.M.T.) .

The topography of Tudor Creek is diverse and presents a very mixed pattern. The Mombasa Island has a steep sea front and in some areas cliffs towards Tudor Creek. Port Reitz and Tudor Creek surround Mombasa Island. From port Tudor the entrance to the ocean is under the Nyali bridge and through the narrow waters of Mombasa Island, where they join the Indian Ocean.

The characteristic of Tudor Creek is the narrow deep waters at the entrance and shallow waters towards the inner parts. The wide, shallow inner parts of Tudor Creek take more than 80% of its total surface area.

No information on the types of habitats occurring at the top of the creek after station 5 (fig.1.1) is available. However, there is a freshwater input by the Kombeni River, which could conceivably result in the concentration of organisms at a "salt - wedge" (Grove et al, 1986). Freshwater seepage probably also occurs at the fringes (Ruwa, pers. comm).

The edges of the creek are lined by mangrove forests mainly Rhizophora mucronata which are best developed on the western side of the creek where river Kombeni drains into the creek.

At present there is little obvious industrial development in Tudor, nor is there any substantial cutting of mangrove. The main human activity in Tudor Creek is artisanal fishing. The land surrounding the creek beyond Mombasa island is mainly agricultural, largely small-holdings and coconut plantations with rough grazing land further inland. At the Western side of Tudor Creek is Kenya Meat Commission slaughter-house, and a point where waste is disposed from Coast General Hospital. The maximum tidal range in Tudor Creek is approximately 4m and the mean tidal prism for the creek is 40×10^{10} m^3 (Norconsult,1975). Tudor Creek makes an important contribution to the marine fisheries of kenya coast as a breeding and nursery grounds for fish and prawns Grove et al (1985) and Little et al (1988a,b & c).

1.3.2 Tides

The tides of Kenya coast are semi-diurnal,two low and two high tides per day. Tidal exchange in Tudor Creek is considered with a mean tidal level of 1.9 m and a tidal range of 4.0 m. (Brakel,1982). These cause strong, localized currents in breaks around the reefs which are superimposed onto the overall longshore current.

1.3.3 Ocean currents

Currents are derived from the South Equatorial Current, which divides on reaching the African Coast. It gives rise to the East Africa Coastal Current (EACC), which flows

northwards along the Kenya coast causing a northward water movement for most of the year. Current velocity is very high, averaging between two and four knots. The Mozambique current, which flows southwards from the northern coast of Mozambique to join the Madagascar current, which flows along the eastern and southern coast of Madagascar, to form the Agulhas stream (fig. 1.2).

A general feature of the water circulation in the region is the seasonal switch of the flow direction caused by the monsoon winds. From November until March, the north east monsoon (NEM) is dominant and from mid- April until September the south east monsoon (SEM) blows from the southeast direction. During the later, the East African Coastal Current (EACC) flows northward and is responsible for the

Somali upwelling (Woodberry et al., 1989). During the north east monsoon the southward Somali current and the northward (EACC) meet off North Kenyan Coast and then they flow eastward as the Equatorial Counter Current. Further information is given in Hove (1981) and Newell (1957).

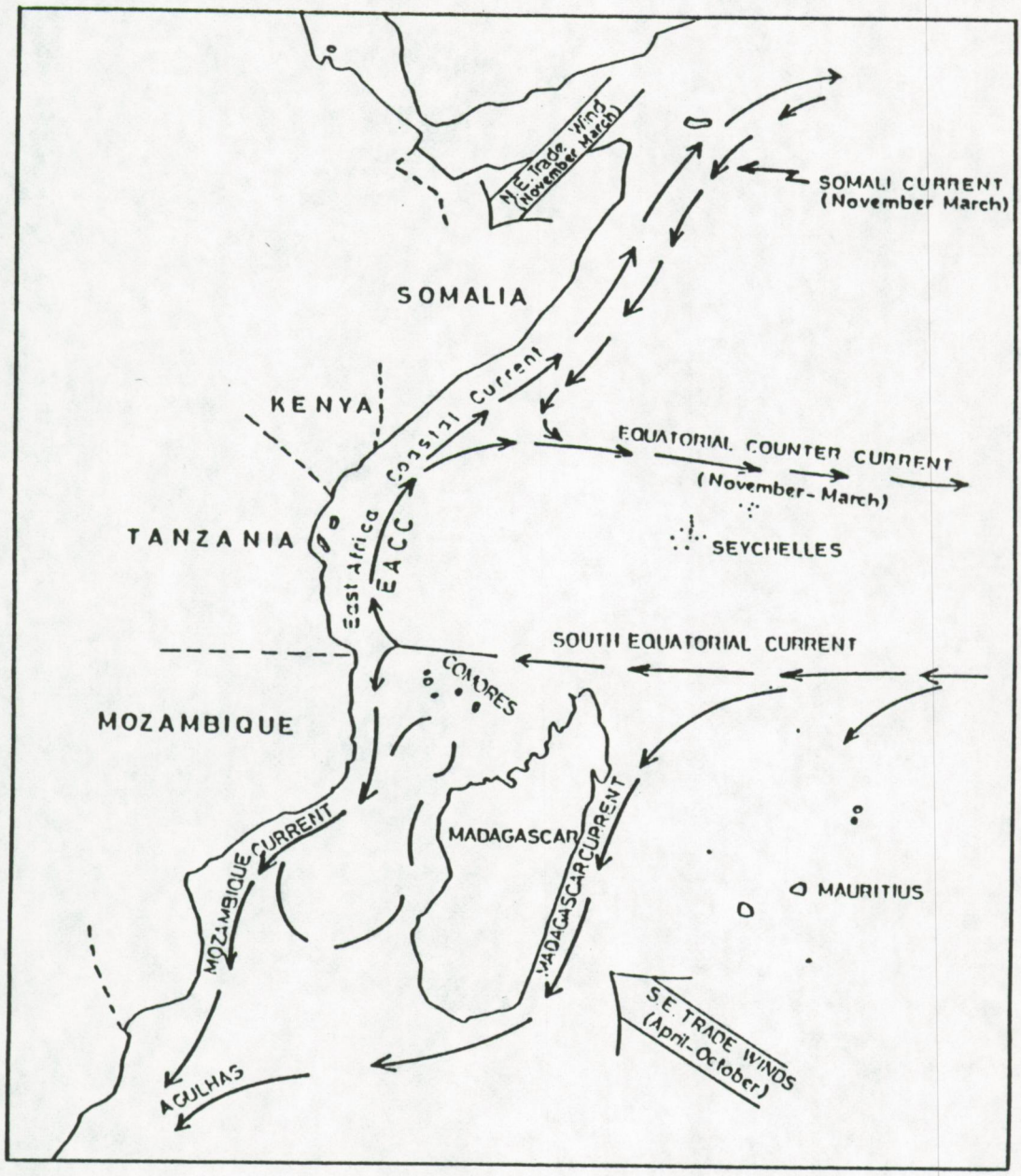


Fig.1.2.Ocean currents and winds in the Eastern African regional sea .

1.3.4. The climate

The micro-climate in the Tudor Creek is a result of the area's coastal location near the equator with alternate but continuously blowing monsoon winds. Generally the climate is hot and humid throughout the year. The shifting monsoons result in two distinct rainy seasons and two dry seasons. The wet season occurs in April - May when the wind shifts to southeast. The warmest period occurs from November to March. Tudor Creek experiences two alternating seasons, the North-East and South-East monsoons. The former extends from about November to about the end of March, during this period the winds are mainly north-easterly and light. The South-East monsoon starts about April and ends about October-November, during this period the winds are south-easterly and strong). The short period between the two monsoons (March - April and October - November), when the winds may be blowing from either direction are known as in the inter-monsoons. The inter-monsoon periods are characterized by short rains in November and long rains in April - May.

Humidity in Tudor Creek shows marked daily variations, but is almost constant throughout the year. During the day, the humidity is normally 60 - 70% in the afternoon. During the night and early in the morning, the humidity increases to reach 92 - 94%. The temperature in Tudor Creek shows small seasonal variations. The mean monthly temperature ranges from 24° C during the coldest months of July and August to 29° C in the warmest months of February and March. During warm seasons, the monsoon winds blowing from the sea keep the air temperature from increasing above 36 to 38° C (Norconsult, 1975).

1.3.5. Sampling stations

Five sampling stations were selected in the center of the main channel of the creek. Station 1 was located at the mouth of the creek where the water depth was approximately 30 m (Fig. 1.3) and where considerable tidal incursion of "clear" coastal water was apparent on flood tides. Station 5 was located in the upper reaches of the creek where the water was shallow

(1 -2 m at low water, Fig. 1.3). Station 2 - 4 were intermediate in position and character between station 1 and 5 as shown earlier in Figure.1.1.

The substrata sediments at station 1 and station 2 were basically sand, whereas station 3, 4, 5 were characterized by mud, silt, detritus and organic ooze.

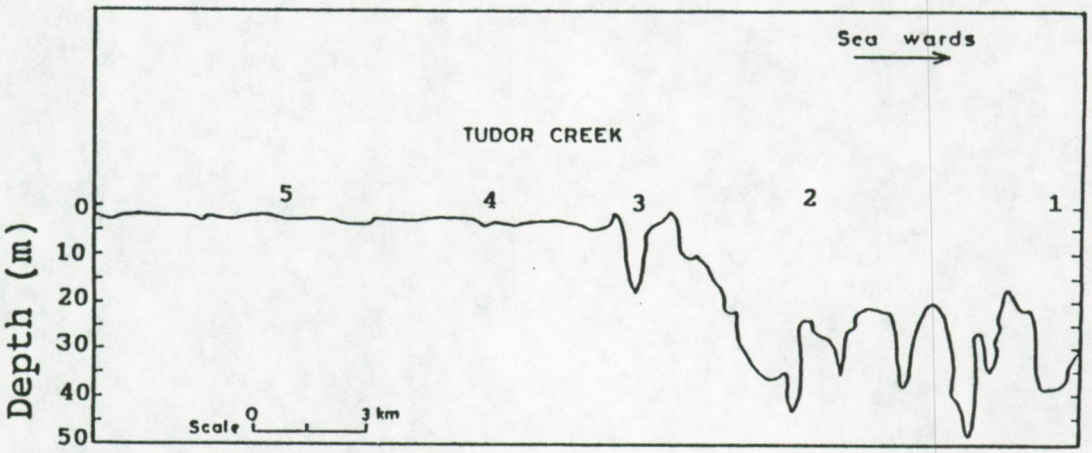
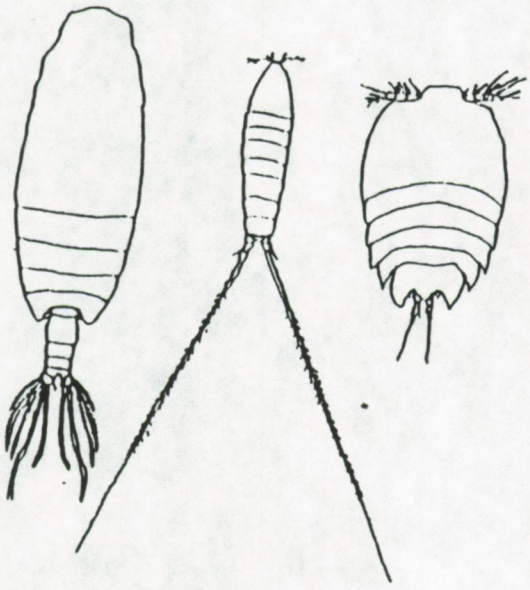


Fig.1.3. Depth pattern in sampling stations 1 - 5 in the Tudor Creek, Mombasa Kenya. Scale bar refers to horizontal distance. After Revis (1988) .

MATERIALS AND METHODS



CHAPTER 2

CHAPTER 2

2.0 METHODS AND MATERIALS

The sampling was done at monthly intervals from December 1984 to August 1985, and always half-way between a spring and a neap tide, in the lunar cycle, and half-way between a high and low tide. Samples were taken only during the day time and one tow principally being taken at each station. All tows were taken horizontally at an approximate depth of 1.4 m.

From December 1984 to March 1985 a Bongo plankton net was used to collect plankton samples from R.V. Maumba. A Bongo towing frame consists of two circular frame each 0.6 m in diameter, connected by a central yoke to which the towing wire is attached. The towing frame is fitted with two cylindrical conical nets of (mesh diameter 335μm and 500μm) each. (Fig.2.1). The samples used for this study were collected by the 335μm net and towed at 4 ms^{-1} for fifteen minutes. A flow meter was mounted at the center of the net's mouth for measurement of the flow of water through the net UNESCO (1968).

At the end of March 1985 **R.V Maumba** broke down, which necessitated a change of the sampling gear. From April 1985 to December 1987 a small canoe with an outboard engine was used. For sampling a conical plankton net of mesh aperture size of 335μm fitted with a flow-meter at the mouth of 45 cm diameter and a length of one meter long. The towing time and the speed of the boat were adjusted so that the smaller net could filter approximately the same range of volume of water as had been filtered by the Bongo net Kimaro (1986).

The basic shape of the plankton net to be used is a cone (Fig.2.2). This comprises a cone of nylon mesh which is left open and is reinforced by a simple mesh bag of mesh size 200 μm tied to a reinforced plastic ring at the tapered end of the net with sewn in ties. After each tow, the mesh bag is untied from the net and transferred directly to a jar containing a formalin 5%. A new bag is fitted in its place ready for the next tow.

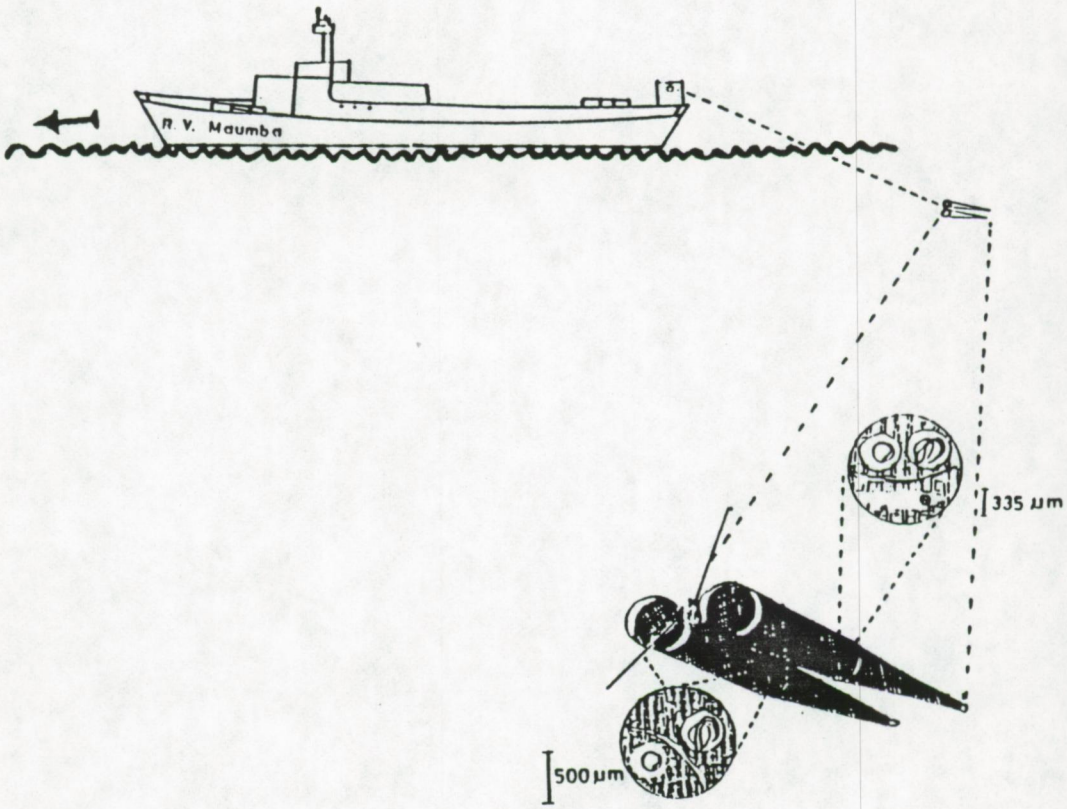


Fig.2.1.Plankton surface water sampling using Bongo net at Tudor Creek.

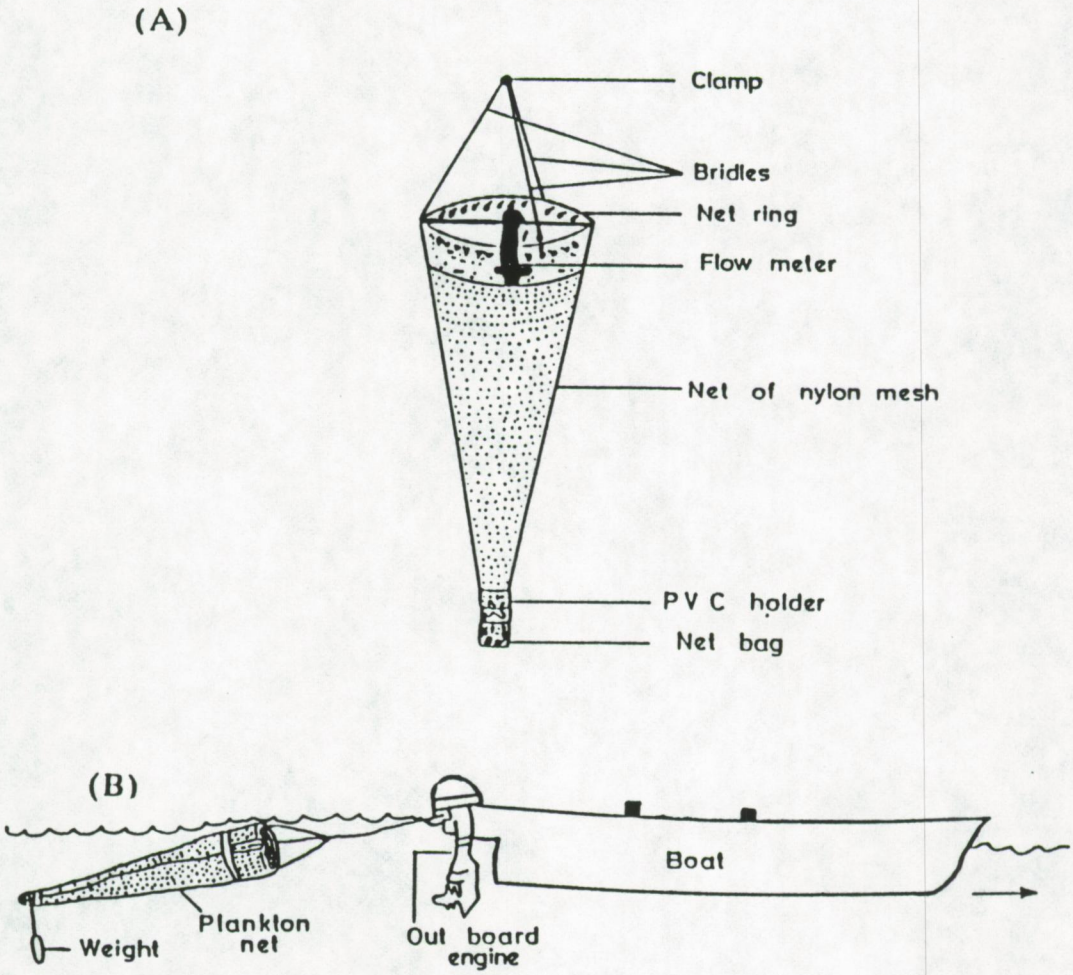


Fig.2.2.Plankton sampling in Tudor Creek (A) Plankton net used (B) The way towing was carried out. Systematic diagram of the plankton net (A) in this study and how it was towed (B). Arrow direction of tow.

2.1. Collection and preservation of the plankton samples

2.1.1. Sampling zooplankton

Surface-plankton samples were taken using a small canoe at each of the five stations during day-time and night-time during one neap and one spring of every month from September 1985 to August 1986. Thereafter only day-time neap and spring samples were taken from September 1986 to December 1987. Samples were taken using a simple plankton net with a mouth area of 0.173 m^2 and a mesh size of 335µm.The net was towed behind a small boat at approximately 0.5 m s^{-1} for 5 min, resulting in about 34 m^3 being filtered during each tow, if 100% efficiency is assumed. In fact, there is evidence from independent trials with the net, using a Braystroke current meter, that this was effectively the case Grove (1985). The actual volume filtered was calculated from the mouth area of the net, the duration and speed of the tow, (as determined from the Braystroke current meter routinely suspended from the side of the boat). The validity of surface sampling was confirmed by trials on vertical distribution at station 1 in Tudor Creek by Little et al., (1988). Only surface tows were feasible in the shallow waterways of the mangroves.

The conical plankton net had a detachable cod-end opposite the mouth. After each tow the net was thoroughly washed with sea water, and the cod-end was untied from the net and fixed directly to a jar containing 5% formaldehyde in sea-water. The fixed samples were labelled and then transported to the laboratory for analysis.

2.1.2. Live samples (used for dry weight and respiration)

Fresh zooplankton was sampled from January 1986 to February 1986 and February 1987 every morning with a plankton net of 335µm mesh aperture on board of the small canoe at every low speed during about 2 hours. Live sample was put in a bucket with fresh sea water and brought to the laboratory.

2.1.3. Laboratory methods

The formalin samples were passed through a 42 µm mesh sieve and the residue was placed in a round bottomed flask. Subsample were taken by withdrawing 5ml volume quickly from the well-stirred sample by stempel pipette. Each subsample was sorted out under a binocular microscope and copepods were put in separate petri dishes UNESCO (1968).

The Copepods were identified to species level by dissecting the animal and drawing the antennae, antennules, mouth parts, thoracopods and furca. The keys and reference books used in the identification were got from Giesbrecht (1892); Sars (1901); Scott (1909); Sewell (1929, 1932, 1947 and 1948); Rose (1933); Decker De (1964); Hulsemann (1965); Brodsky (1967); Owre & Foyo (1967); Frost & Fleminger (1968); Bradford (1972); Fleminger (1973); Wells (1976) and Greenwood (1979).

One sample from each station was diluted to 250 ml. and agitated until it was well mixed. 10 subsamples of 5 ml each were taken with Stempel pipette. The zooplankton of each systematic category were counted using a stereo microscope at a magnification of X10 and X40 for the bigger and the smaller animals, respectively. The sum of the 10 subsamples was multiplied by 5 to give the total number for the sample. The abundance of the zooplankton groups was expressed as the number of individuals per cubic meter by dividing by thirty four.

2.1.4. 24-Hours cycle sampling

24-hours cycle sampling was carried in Tudor Creek at stations 1 and 5 (Fig.1.1) simultaneously. The neap tide sampling of the 24-hour cycle started at 0900 hr on 23rd September 1985 and the last samples were taken at 09 00hr the following day. Sampling during the spring tide started at 09 00 hr on 1st October 1985 to 0900 hr on 2nd October 1985.

Every two hours zooplankton was collected by horizontal hauls at 1.3 m depth with a 335µm mesh net, simultaneously with hydrographic parameters (see 2.2.1). For the tidal range, data from Kilindini Harbor

(Port Reitz) were used. Zooplankton samples were immediately preserved in 5% formaldehyde. Subsamples were taken and sorted out under a binocular stereo microscope, zooplankton counted and identified and counted to the lowest taxonomic level practicable. Abundance was calculated.

2.2 Measurements of physical and chemical parameters

2.2.1. Hydrographic parameters

The hydrographic parameters monitored during this study were surface water salinity and temperature, transparency, dissolved oxygen and pH. These parameters were measured simultaneously with the zooplankton sampling.

Surface water salinity was measured using a refractometer with 1 ‰ graduations. Surface water temperature was measured using a mercury thermometer with 0.5° C graduations placed in a bucket filled with water drawn from the surface water. Turbidity was measured using a Secchi disc.

2.2.2. Determination of dissolved Oxygen

The Winkler method was used to determine dissolved oxygen as described by Strickland and Parsons (1968). The Winkler method involves first the fixation of oxygen by allowing manganous hydroxide to react with the DO (oxidation) to produce an insoluble brown manganese (IV) compound. When the resulting solution is acidified, in the presence of excess potassium iodide, iodine is formed quantitatively and may be titrated with a standard solution of sodium thiosulphate.

2.2.3. Determination of pH

Surface water sample was taken in a bucket of water, filled in plastic bottles, and taken to the laboratory for the analysis of pH. The pH was determined by an Orion Research Model 231 digital pH meter.

2.3 Phytoplankton

2.3.1. Primary production

2.3.1.1. Incubator measurements

Photosynthesis was measured in the field. The procedure designed by Strickland and Parsons (1968) was followed. Pairs of light, transparent glass bottles (50 or 100 ml) filled with surface water were suspended in the water at the depth of sampling station 0, 3, 5, 7, 10 m. Another 2 dark bottles at a place without shadow during 6 hours (Fig.2.3).

At the time of sampling and filling the bottles (time O of the experiment) 2 supplement bottles were filled with the same surface water and the oxygen fixed immediately by adding manganese sulphate and potassium iodide in order to get the oxygen concentration at the time 0 of the experiment. It was found that the best time of the day to carry out primary production experiments would be between 0800 hrs and 1800 hrs. Different incubation times were tried and the conclusion was that a minimal time would be 6 hours, and 8 hours would be ideal at the upper limit Daro (1985).

Secchi-disc readings were taken. After the incubation period (6-8) hours the oxygen of the samples was fixed and determined in the laboratory by Winkler method. Daily photosynthesis below a square meter of sea surface was then calculated by graphic integration of the values of daily photosynthesis ($mgCm^{-2}day^{-1}$) obtained for each depth.

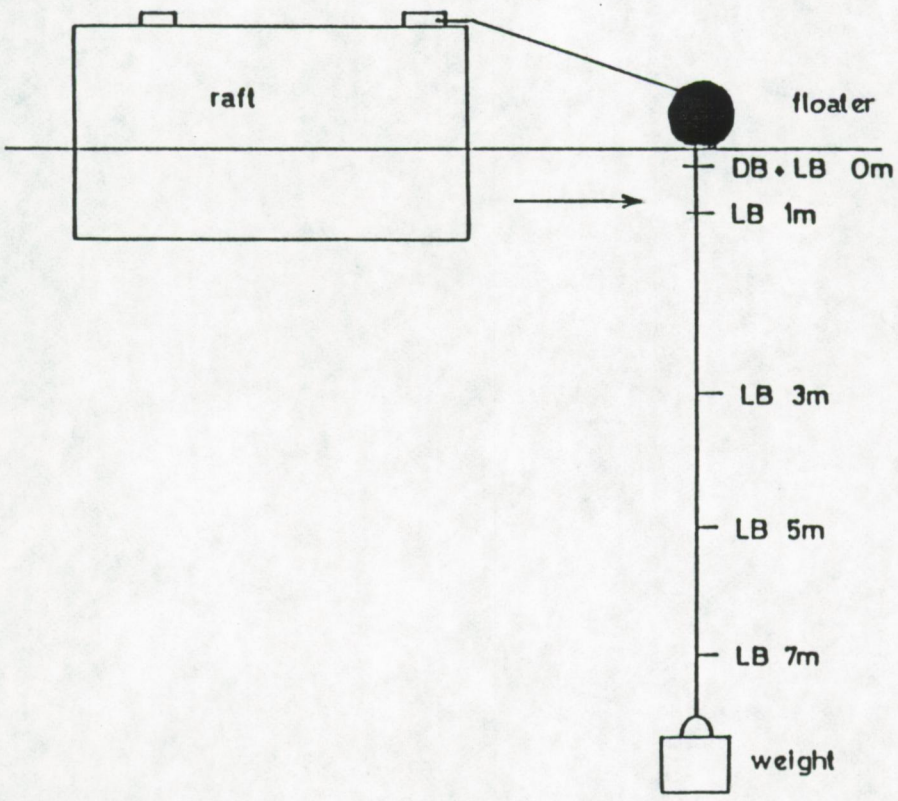


Fig.2.3. Incubation device for primary production measurements.

2.3.2. Determination of chlorophyll a

Water samples of one liter were taken from the sea surface and used for the extraction of pigments from the phytoplankton following the method of Strickland and Parsons (1968).

The water sample was passed through a nylon net of 200μm mesh size to remove large zooplankton and then the phytoplankton was filtered on a membrane filter of 0.1 μm. The membrane filters containing the algae were folded in half (with the plankton innermost). Membrane filters were stored in a desiccator and kept in the dark at -20° C.

The chlorophyll a concentration was determined by the acetone extraction method with a spectro- photometer with wavelength settings at 750, 665, 645 and 630 nm. The chlorophyll a content was calculated using the formula in Strickland (1968). That is:

$$C = 11.6(E665-E750)-1.31(E645-E750)-0.14(E630-E750)$$

where C is the Chlorophyll a concentration and E is the extinction of the sample used.

Having obtained the value C, then

$$\text{mg Chl.a m}^{-3} = \frac{C \times 2.5}{V}$$

where V is the volume of sea water filtered in litres.

Because a 4 cm cuvette cell was used instead of a 10 cm cell, the values obtained by the above procedure were multiplied by

$$\frac{10}{4} = 2.5.$$

2.4. Zooplankton Biomass Determination

2.4.1. Length measurements

Live Copepods were also collected during the period 1985, 1986 and 1987. By sampling twice monthly it was possible to catch most copepodites and adults of the common copepod species alive. To ensure that they got to the laboratory alive net samples were released into a bucket containing fresh filtered sea water. Back in the laboratory an aliquot of the sample was anesthetized using Lithium carbonate ($LiCO_3$) solution or 3-aminobenzoate methane-sulphonic acid (Ms 222) or sprite or club soda and single specimens picked out of the sample, identified, and the length of the cephalothorax was measured using an ocular micrometer under stereo microscope. This measurement was chosen as the easiest to make quickly and that also it is the most least likely to be distorted in plankton net samples.

2.4.2. Regression assessment

To establish the regression equations of weight on length, it was necessary to transform these data so that the relationship between length and weight is approximately linear. Huxley (1932) showed that, when two parts of an animal grow at different rates, the relation between the sizes of the two can be expressed thus:

$$W = aL^k$$

where W = the size of one of the parts,

a = a constant,

L = the size of the other part, and

k = the growth ratio of the two parts.

This equation can be applied to the present situation by setting W equal to the weight per individual and L equal to the length per individual. Then, assuming k is constant and taking logs, the resulting equation is linear and given by:-

$$\log_{10} W = \log_{10} a + k \log_{10} L$$

2.4.3. Dry weights

Copepods were freed from their egg-sacs if they had some and separated into groups depending on their identity and length. All copepods were rinsed briefly in distilled water before being placed in pre-weighed aluminium foil microtrays and dried for 24 hours in an oven at 60° C as described by Vollenweider (1969), Winberg (1971) and Razouls (1977). The drying temperature of 60° C guards against possible loss of fats which occurs at higher temperatures resulting in erroneously low weights (Winberg,1971).

After drying, the microtrays were cooled in a desiccator for about an hour and weighed to the nearest microgram using a Cahn milli-electro-micro balance which has an absolute error of $\pm 0.1\mu g$. Individuals whose weight loss was less than 1 μg were weighed in batches to keep the error less than 10%. Larger individuals were weighed individually. It was necessary to ensure that samples did not increase in weight, owing to absorption of atmospheric humidity. Therefore silica gel was put inside the weighing chamber. The mean dry weight per individual was calculated and the total biomass of the copepods was calculated by simple multiplication of the abundance of the various copepods species, by their corresponding mean dry weight (i.e. mean weight of an individual).

2.4.4. The relation between length and weight

Bogorov (1959), pointed out that it is very difficult to obtain weights for separate components of the zooplankton. Some indirect method was needed if studies on the biomass of the separate copepods were to be made. Kamshilov (1951) showed that this can be done by establishing the regression equation for weight on length for the different organisms and then, from direct length measurements, estimate the mean weight at any time and place. Regression equation of weight on length had therefore to be determined for several individuals in each group of common copepods encountered in the Tudor Creek in the period of this study.

To establish the length-weight relationships, the mean length and mean dry weight were determined for each of several groups of individuals from

each of the copepods under study. The method of catching, measuring length and dry weight has been explained above. The effect of formalin on the animals was also determined by measuring and weighing the animals that have stayed in formalin for different times.

2.5. Metabolism of respiration of selected copepod species

2.5.1. Introduction

Knowledge of the respiratory rates of animals and the way they vary in weight is basic to a complete analysis of production. Copepod respiration is a very good approximation of the total metabolism of the animals.

Allee & Oesting (1934), concluded that the Winkler technique is sufficiently accurate for use in respiration studies on aquatic organisms. The water bottle technique has been used by a number of investigators to measure respiration of zooplankton (Marshall, 1935; Conover, 1956, 1959; Richman, 1958 and Daro et al., 1989).

A considerable number of respiration measurements are available for temperate and boreal plankton. Exception of report made by Daro (1985), there seems to be no such work reported for zooplankton from tropical waters where a high rate of oxygen consumption probably occurs.

2.5.2. Material and methods

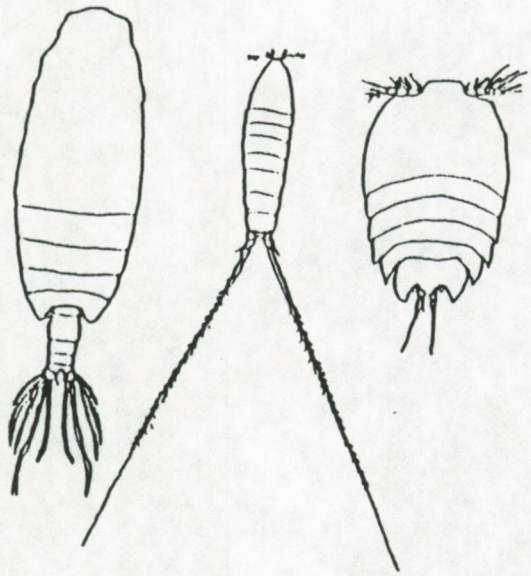
Plankton was obtained from Tudor Creek during different 24 hours experiments at station 1, with 335μm mesh size net as described before. This net was used in order to avoid phytoplankton and plant materials.

The sample, in a water bucket with fresh sea-water, was brought to the laboratory and kept standing for a half to one hour. During this time the living and not damaged zooplankton, swims to the surface and the remaining detritus and big plant materials sinks to the bottom of the jar. Swimming zooplankton at the surface of the water was collected and transferred to petri dishes containing fresh sea-water. Under microscope known copepod genera were picked (10-50 in number) and a suitable number were transferred to a known volume of fresh filtered sea-water in

the glass BOD bottles. A series of experiment bottles were filled with fresh sea-water and when 10-50 number of copepods had been gathered, 5 ml. of the water containing them were transferred to the BOD bottles. A control for the time 0 and another one without zooplankton were also taken. The bottles were incubated in the dark, to avoid production of oxygen by photosynthesis at sea-water temperature. The oxygen of some bottles was fixed at different times from 3 to 6 hours.

Respiration measurements were done by the measurement of dissolved oxygen concentration in water directly by the Winkler technique. After titration the rest of the sample was put in a petri dish and examined under a microscope to ascertain the identity of the zooplankton and the number counted. The sample was then filtered on a pre weighted GFC filter paper, dried for 1 hour at 60° C, cooled and weighed, in order to know the weight of the zooplankton of the experimental bottles. Five 24 hours measurements of respiration of selected copepod species was performed. Each experiment was carried out with a fresh sample taken from the sea.

ENVIRONMENTAL PARAMETERS IN TUDOR CREEK



CHAPTER 3

CHAPTER 3

3.0 THE ENVIRONMENTAL PARAMETERS IN THE TUDOR CREEK

3.1. Seasonal variation of Oceanic conditions

3.1.1. Temperature

The temperature fluctuations during the period of study at the three stations were small (4° C) which is characteristic of tropical waters.

Lower temperatures were encountered during the Southeast monsoon than during the northeast monsoon. Temperature in the inner creek is higher than at the mouth of the estuary (Fig.3.1).

More details in figure 3.2 show that the average surface water temperature found in the study area lies between 28.0 - 30.0° C for shallower waters in station 5, and 28.0 - 29.5° C for deeper waters (30m) in station 1. It must be borne in mind, however, that these values hold for the period of the N.E - monsoon, which is warmer than the subsequent S.E - monsoon.

The maximum value 32° C was recorded at all stations from January to March. The minimum water temperature value 22° C was recorded in June at station 5 and in July to September the value 23.3 - 25.4° C at station 1. The same minimum value range was recorded from June to August at stations 2,3, and 4 (Fig.3.2). The data presented in this figure also shows both seasonal and diurnal changes in water temperature in the Tudor Creek. It is clear from these figures that water temperature at day in neap tides throughout the study period September 1985 to August 1986, was generally higher than at night time with the exception of August at stations 1,2 & 3. This trend of temperature change provides clear evidence of an influence of spring and neap tides on temperature, and also the influence of day and night conditions.

The temperature gradient can be explained by the important role that tides play in these coastal water.

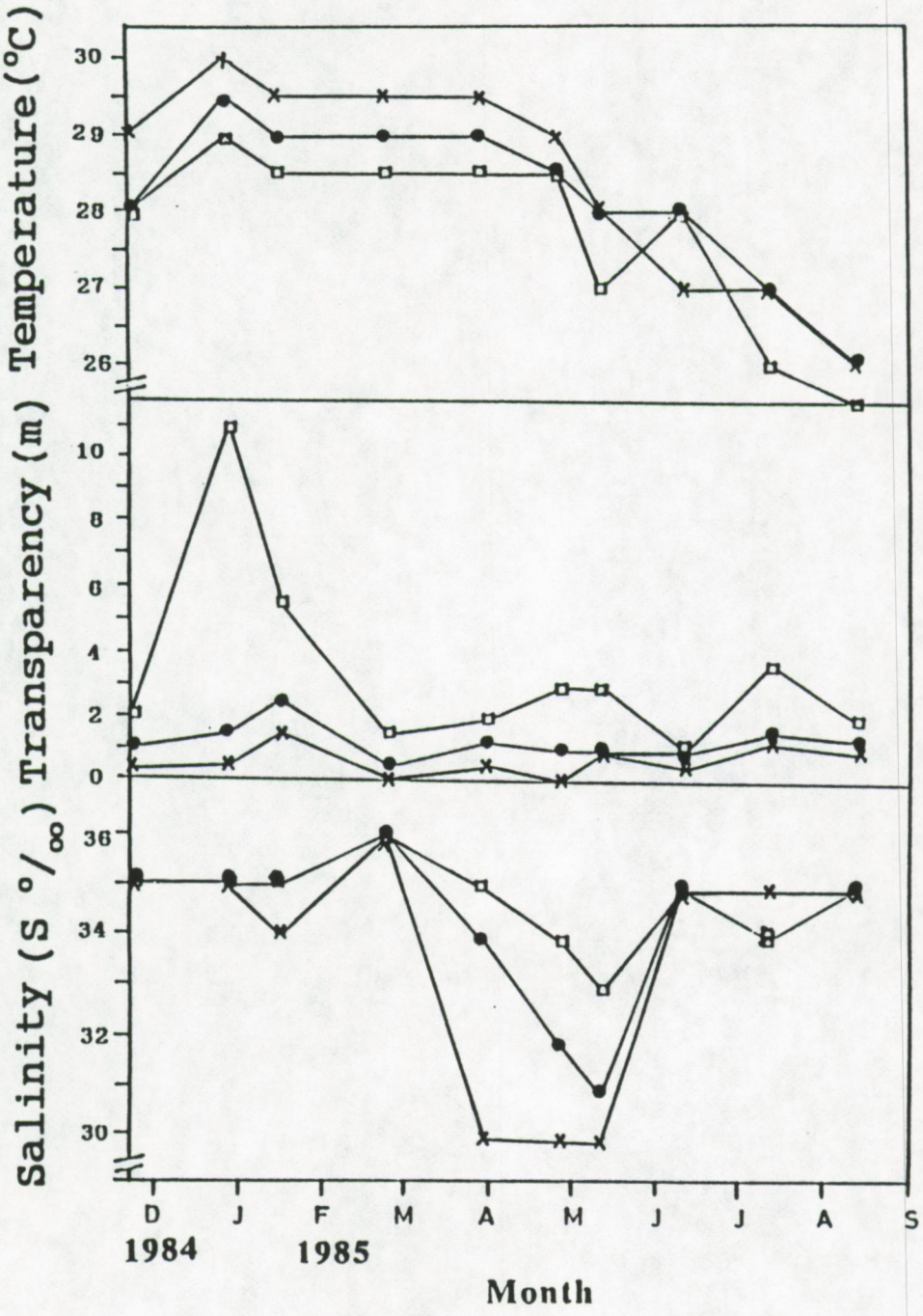


Fig.3.1.Seasonal changes of temperature, transparency and salinity at some stations in Tudor Creek from December 1984 to September 1985. -▫- station 1;-●-station 2; -*- station 3.

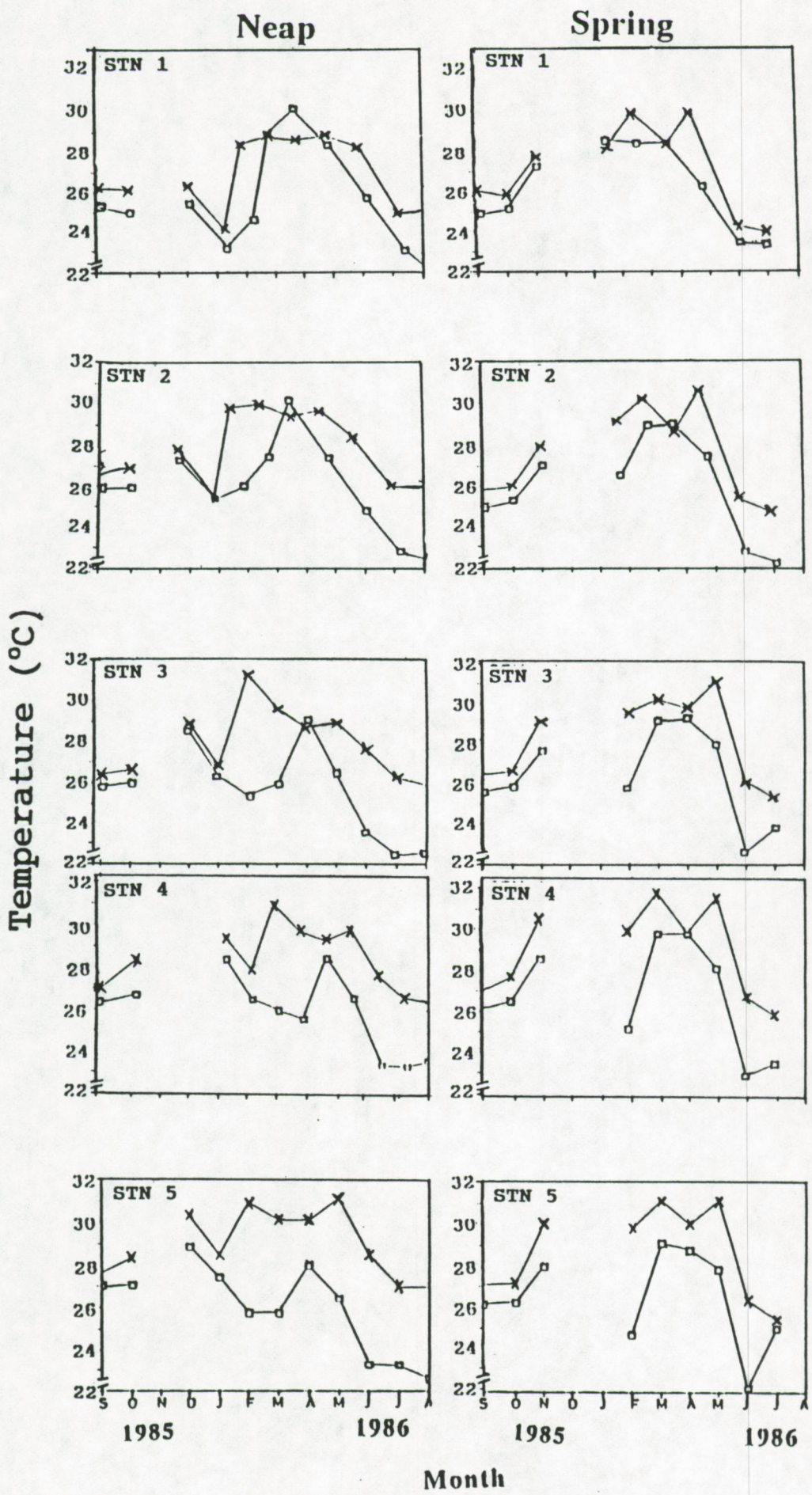


Fig.3.2.Mean monthly surface water temperature in Tudor Creek from September 1985 to August 1986 at spring and neap tides.(▫ Night, ⋆ Day) (Gaps indicate months in which no data was taken).

Sea-water temperatures are further more seen to be closely related to topography and depth since higher water temperature was recorded in shallow parts of the creek e.g at station 5 where a temperature of 32.0° C, was observed in March, 1986. Conversely the lowest water temperature were recorded in the deeper water of the Creek (Cf. stn 1).

The surface water temperature gradient was apparent from station 1 to station 5 (Fig 3.3); being higher, at station 5 than at station 1 by about 4° C . This difference was high enough to believe that the temperature gradient seen is phenomenal in the Tudor Creek.

As was stated earlier, the NE - Monsoon period, is characterized by higher air temperatures than the SE -Monsoon. This agrees with reports by Kimaro (1986) and Grove et al., (1985) who reported temperatures of 29.0° C in the Tudor Creek during the NE-Monsoon and 26.0° C during SE-Monsoon.

The higher surface water temperatures during the NE Monsoon are caused by both oceanic and local effects. The surface waters of the Southern Indian Ocean are warmer in the Southern summer and the South Equatorial current thus brings warmer water to the East African coast (Donguy, 1974). The surface waters of the East African Coastal current are in contact with warmer air temperatures, higher relative humidity (less cooling due to evaporation) and slower current speeds with a more stable water column and shallower thermocline (Newell, 1959; Leetmaa & Truesdale, 1972). In the Southern Monsoon these conditions are reversed and generally lower temperatures are observed with a deeper thermocline and an acceleration of the northward coastal current.

3.1.2 Salinity

Salinity generally decreased from station 1 to station 5 (Fig.3.3). Seasonal changes in salinity in Tudor Creek for the five stations (Fig. 3.4) indicates marked fluctuations in stations 4 and 5 particularly during the long rain months (April to June) and short rain months (November to December) Fig.3.4.

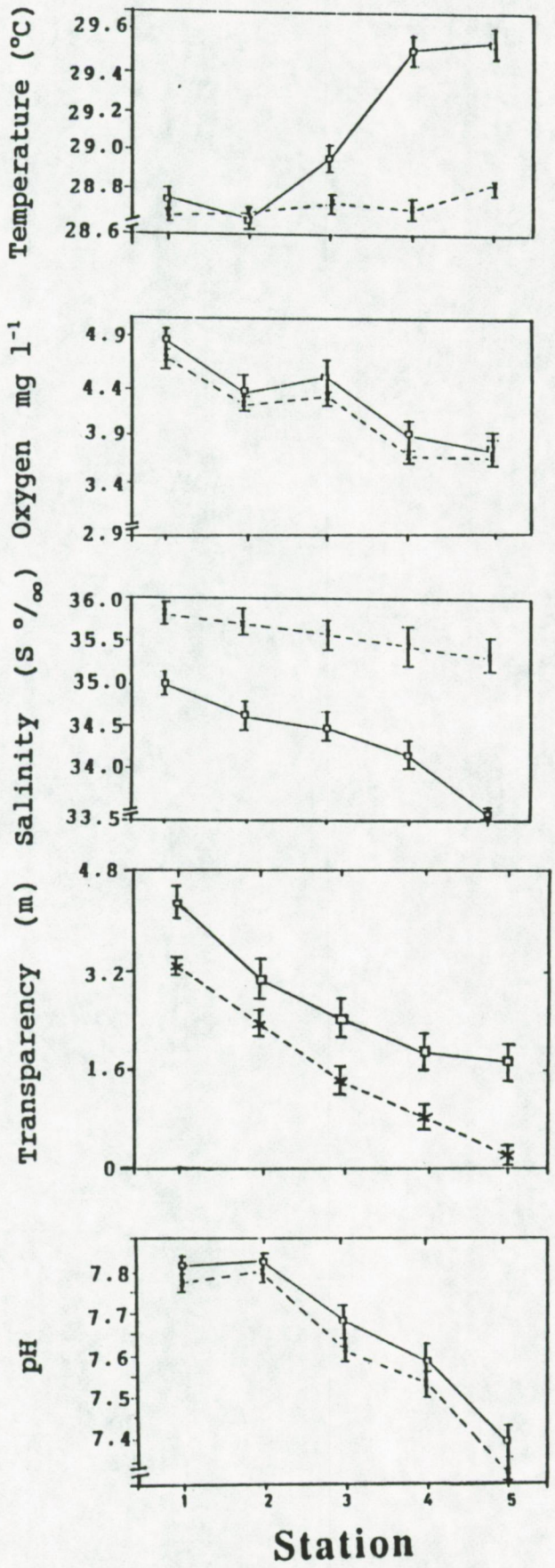


Fig.3.3.Summary of environmental data for stations 1-5 in Tudor creek, Sept.1986 - Dec. 1987. The experiment was carried out during day time spring (▫) and neap (⋆) tide. Vertical bars show 95% CI.

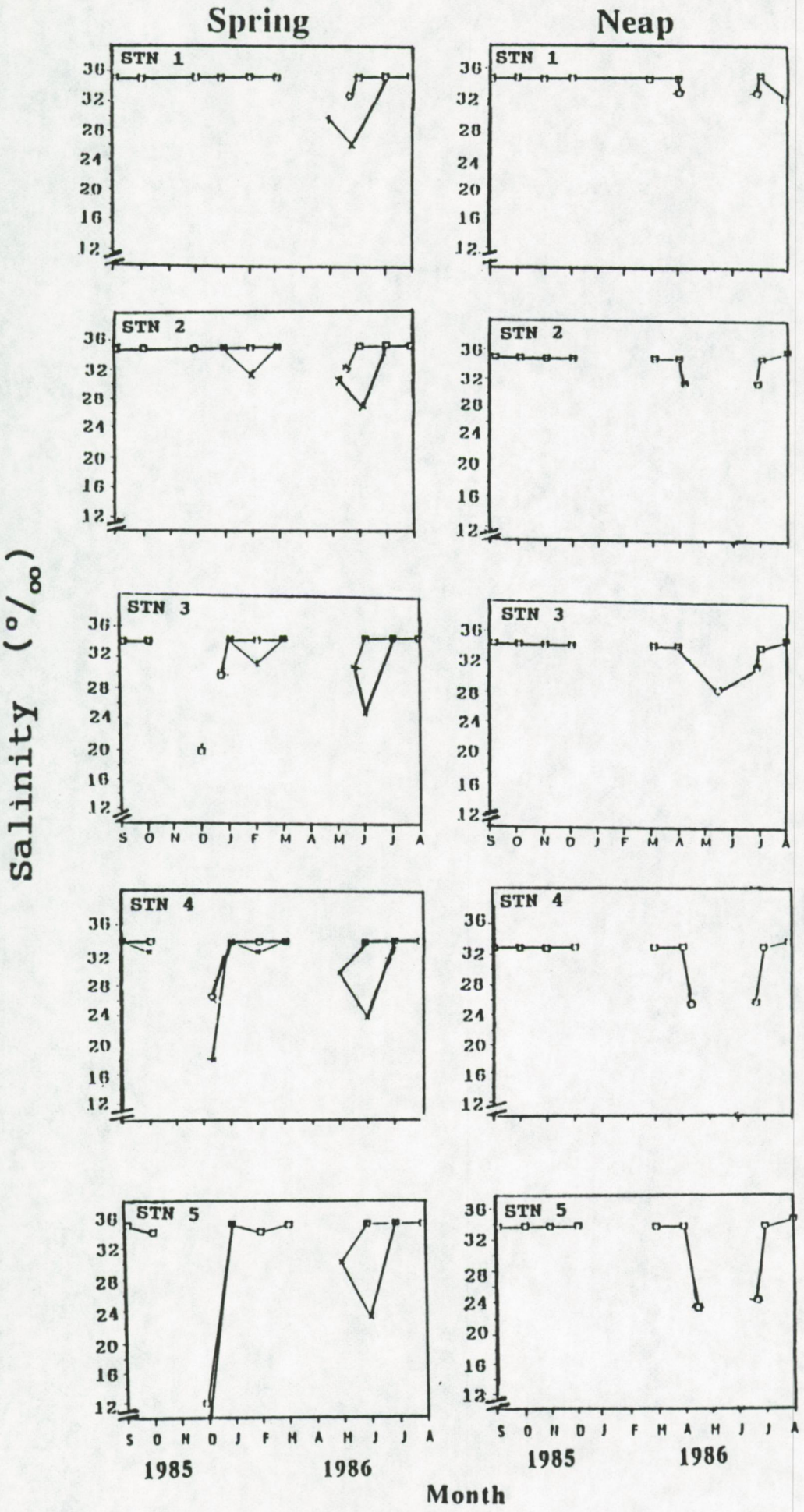


Fig.3.4.Surface water salinity changes in Tudor Creek from September 1985 to August 1986. (▫ night; ⋆ day) (Gaps indicate months in which no data was taken).

It appears like during long and short rain season months, following spring and neap of each month, similar salinity pattern changes occurred, although the effects for short rains were not as marked compared to the long rains season. Because of fresh water inflow, salinity ranges were greatest in the upper estuary in stations 4 and 5. The results in this figure also imply that seasonal changes in salinity in the Tudor Creek show wide variations, during times of rain.

Table 3.1. Salinity (‰) changes in the Tudor Creek.

Lowest	Highest	Station
30	35	1
28	35	2
27	35	3
18	35	4
10	35	5

The salinity from July to October in all stations was 35‰. Except during times of rain season a marked salinity gradient was present in Tudor Creek.

In years with less rain over the first part of the year salinities above 36‰ have been recorded, especially in station 5 because of evaporation of sea water. In June, the salinity gradient decreased considerably while in July, salinities throughout the creek were more or less uniform at 35‰.

The seasonal changes of salinity in the Tudor Creek are presented together with those of temperature and turbidity in Figure 3.1 for the period December, 1984 to August 1985. Data used are from stations 1 to 3. The salinity varied from 30‰ to 36‰. The minimum value 30‰ was recorded from April to June at station 3. Influence of freshwater from River Kombeni is not there in station 1, however, it is felt in the upper reaches of the Tudor Creek.

3.1.3. Secchi Disc readings

The measurement of turbidity represents a rough measure of the concentration of suspended matter in the water column.

The suspended material present in the Tudor Creek in the form of organized or unorganized matter and of mineral particles strongly influences primary production. Turbidity reduces light penetration in the water column and, consequently, carbon assimilation. These measurements are shown in Figs.3.1 and 3.5.

Turbidity generally increased from station 1 to station 5 (Fig.3.3), but was very variable, depending principally on the extent of recent tidal and wind - induced mixing.

Throughout the study period station 1 showed the largest secchi disk reading which was (8.2 m) recorded in January. The lowest Secchi disk readings were recorded in December and again in April to June. The lowest turbidity readings were recorded at station 5.

Results in Figure.3.5, show that Secchi measurements were higher during the neaps than in the spring period for all stations in the Tudor Creek. Turbidity was influenced by the strength of local winds and tidal currents.

3.1.4 pH

Figure 3.6 shows seasonal variations in pH in the stations studied in Tudor Creek. It also shows day and night influence on pH. It can be seen, for example, that the pH of day was lower than that of the night time for stations 1, 2 & 3 and in nearly all the months, but showed a similar pattern. There was no difference in pH between spring and neap in all stations.

The pH ranged from as high as 8.6 in June to as low as 7.0 in the months of April and December. It also showed a tendency to decrease towards the shallower upper reaches of the creek due to the influence of freshwater, but consecutive station differences did not exceed 0.5 (Fig.3.3).

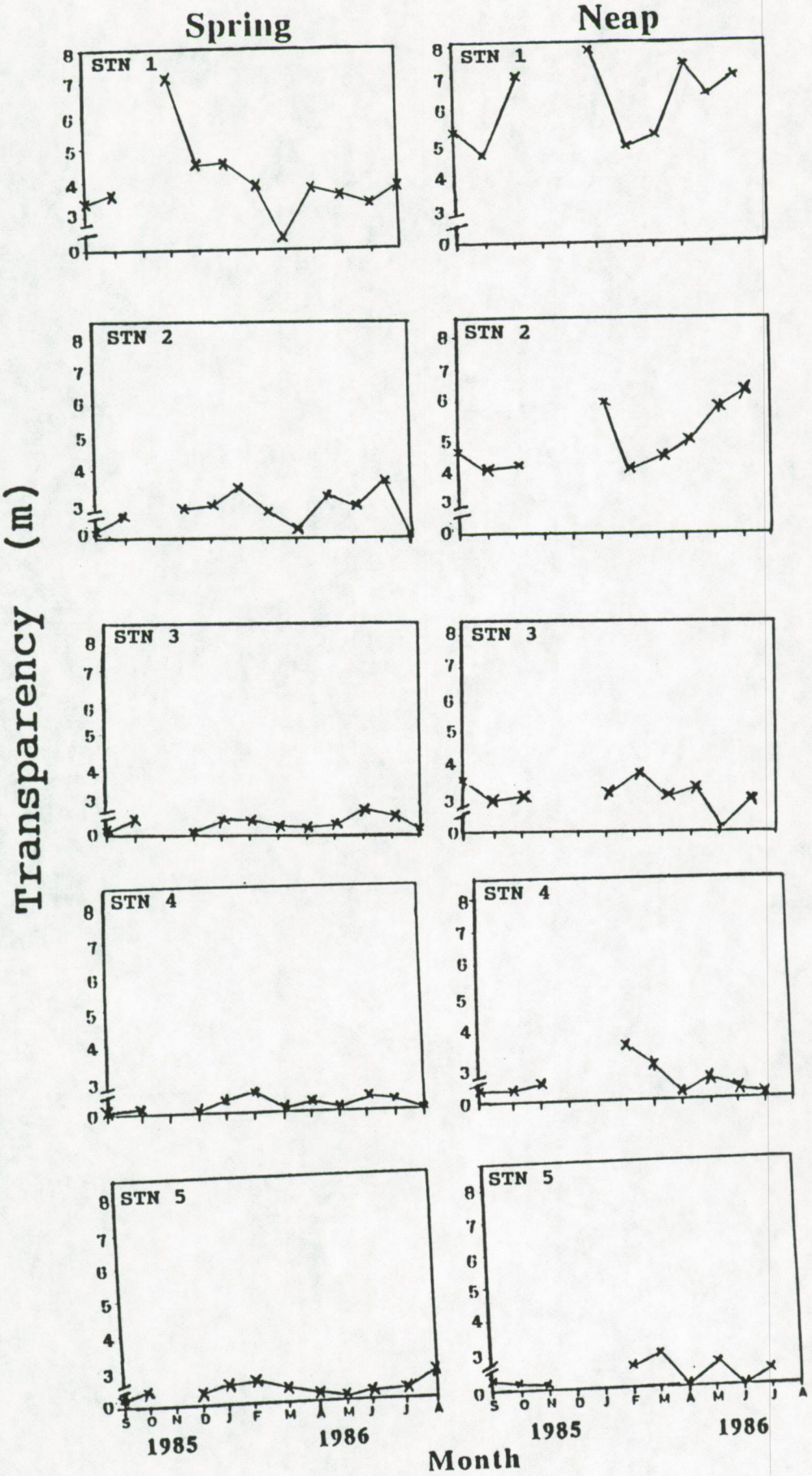


Fig.3.5.Transparency in Tudor Creek to show seasonal and tidal influence during the period from September 1985 to August 1986 (Gaps indicate months in which no data was taken).

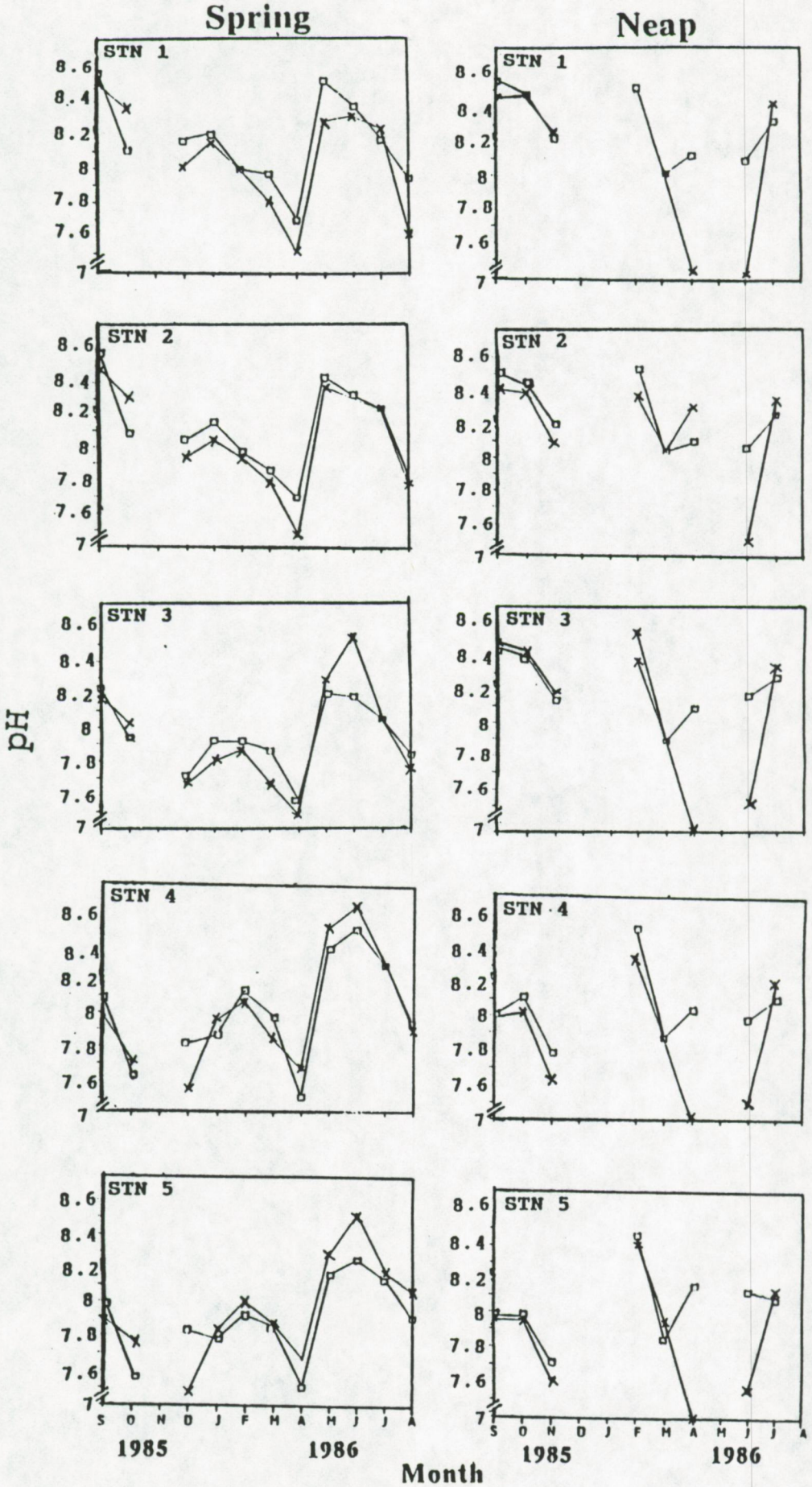


Fig.3.6.Surface water pH in Tudor Creek, to show seasonal and tidal influence during the period from September 1985 to August 1986. (▫ night; * day) (Gaps indicate months in which no data was taken).

3.1.5. Rainfall

Rainfall data were kindly provided by meteorological Department, Ministry of Transport and communication Kenya as recorded at Old Fire Station, Kilindini, Mombasa, for the period 1985 and 1986. Figure.3.7 shows the monthly total rainfall in Tudor Creek from Old Fire Station Kilindini, Mombasa, in 1985 and 1986. The data show that the long rains were in April and May in both years while the short rains were in November and December. This data also points to the fact that the total annual rainfall in Tudor Creek ranges between 1,000 and 1,200 mm but 40% of this falls in April and May. During the short rains season most of the precipitation occurs in November (fig. 3.7). This annual pattern is, however, subject to considerable variations.

3.1.6 Oxygen

Some changes in dissolved oxygen in the Tudor Creek for the five stations are shown in Figure 3.8. Although data for some months were missed out due to unavoidable circumstances, it is clear that the amount of dissolved oxygen in the creek waters is higher during the day than at night.

In the Tudor Creek dissolved oxygen concentration increases with depth of the station during day time on both the spring and the neap tides (Fig. 3.3). Mean levels of dissolved oxygen ranged from 4.8 to 3.7 mgl^{-1} and from 4.6 to 3.5 mgl^{-1} between stations 1 and 5 for each of these tides respectively. There is more dissolved oxygen in station 1 than station 5 because of mixing of oceanic water.

3.1.7. Nitrate - Nitrogen

The seasonal fluctuation of nitrate - nitrogen in Tudor Creek is shown in Figure 3.9. Although the highest concentrations of nitrate-nitrogen were

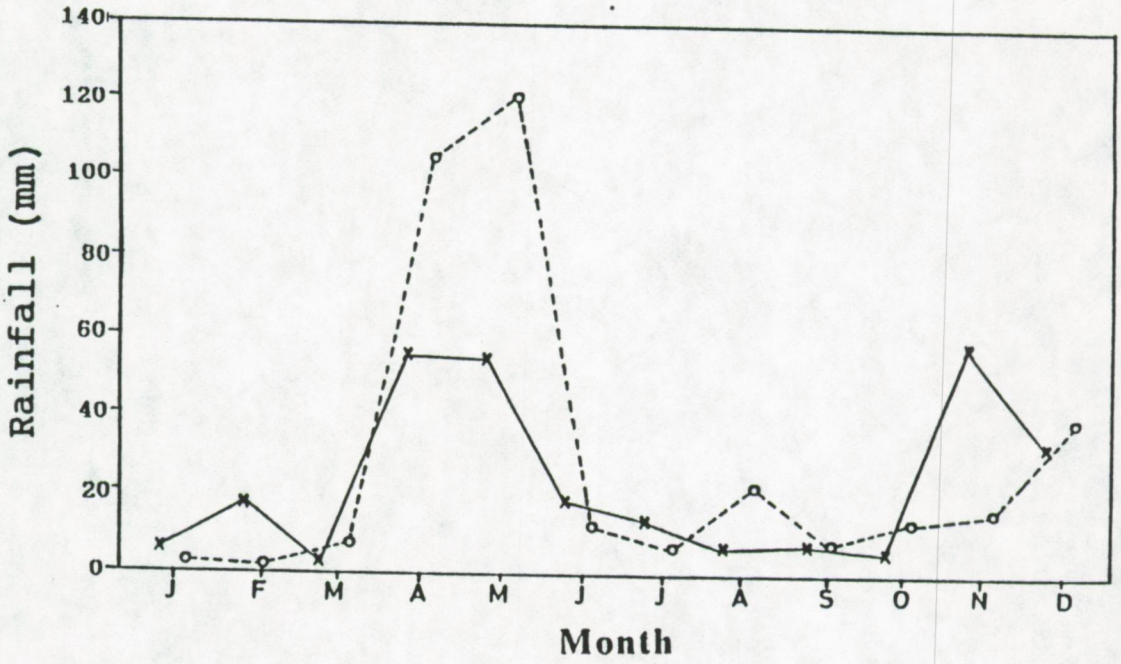


Fig.3.7.Mean monthly total rainfall in Tudor creek from Old Fire station, Kilindini, Mombasa, as in 1985 and 1986. By courtesy of the Meteorological Department, Ministry of Transport and Communications.

------ 1985, o------o 1986 .

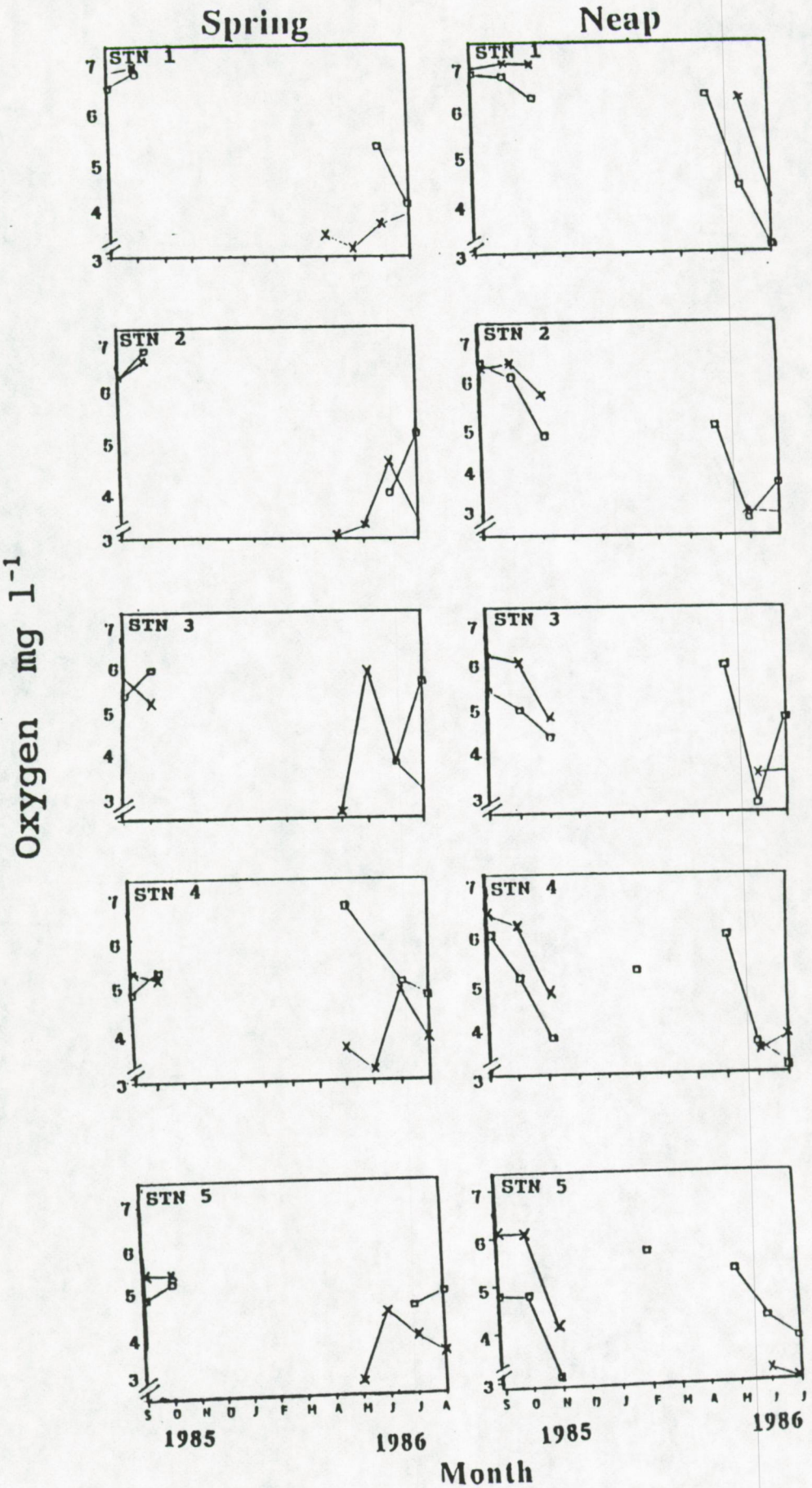


Fig.3.8.Surface water Dissolved Oxygen concentration in the seawater in the Tudor Creek, from September 1985 to August 1986. (▫ night; * day) (Gaps indicate months in which no data was taken).

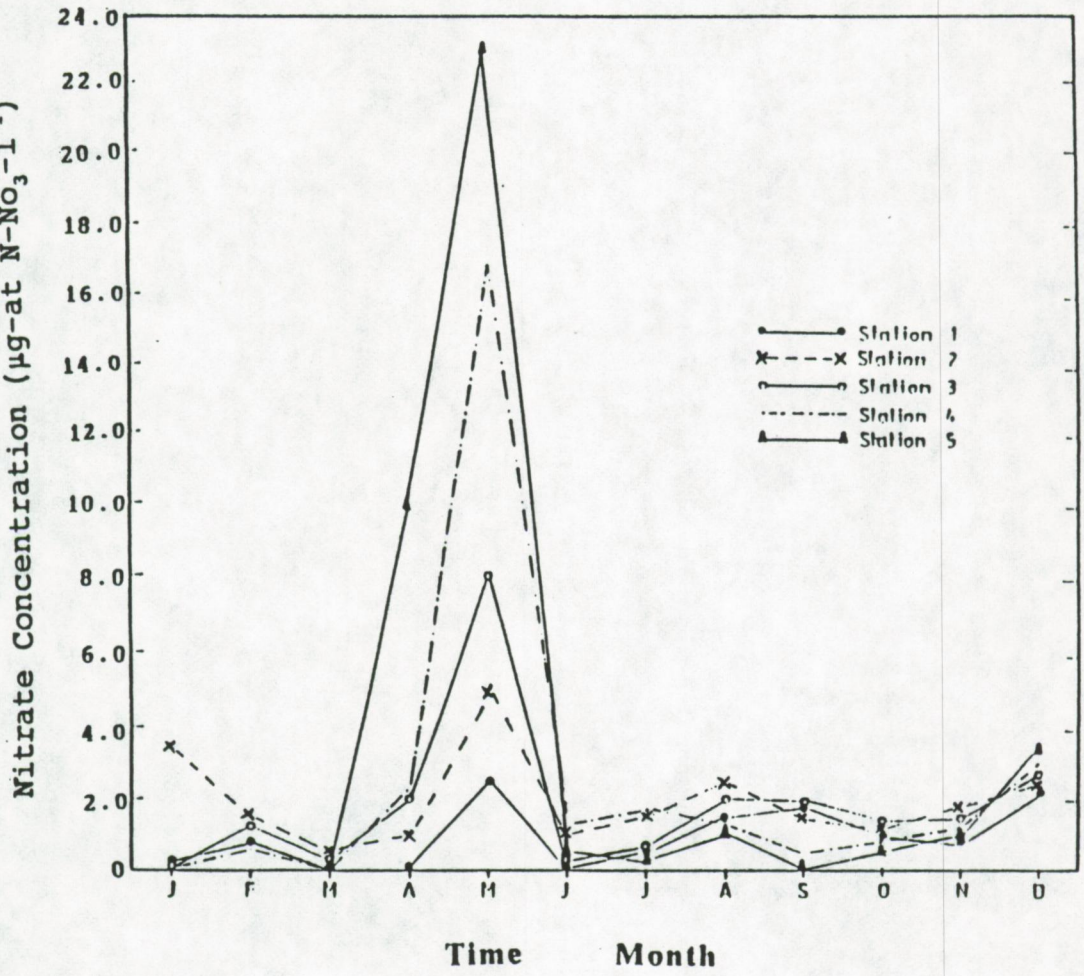


Fig.3.9.Seasonal nitrate-nitrogen values from five stations in Tudor Creek. Data from Kazungu (1990).

recorded during the period April to May a peak was observed in May at all stations, but predominantly at stations 4 & 5.

It may be that the tendency for nitrate-nitrogen to rise during rain season, towards the shallower upper reaches of the Creek is due to the effect of river Kombeni (Fig.3.10).

Small peaks of nitrate - nitrogen concentrations were detected in station 2 during dry season and this is probably due to the sewage discharge from the Coast General Hospital (Kazungu, et al., in press).

Levels of nitrate - nitrogen were generally high during the southern monsoon with below levels being detection during the northern Monsoon.

3.1.8 Phosphate

The distribution of phosphate distribution in five stations in Tudor Creek is shown in Figure.3.10. These results indicate that higher phosphate concentrations were recorded during the long rains season in all stations. A gradient of increasing phosphate concentration was found from a mean level of 8.0 µg- at P/l at station 1 to 41.0 µg- at P/l at station 5 (Fig.3.10).

Phosphate concentration showed a peak in June at station 2 whereas thst probably due to the sewage drainage system (near station 2) from the Coast General Hospital (Kazungu,et al., in Press).

3.1.9 Silicate

The seasonal pattern of silicate concentration in the Tudor Creek is shown in Figure.3.11. At the start of the long rainy season in April the highest concentration was about 71.0 µg- at Si l^{-1} at station 5 while the lowest concentration of 3.5 µg- at Si l^{-1} was recorded at station 1. The silicate profile seems to implicate that for the month of May river runoff strongly influences the levels of silicate in the Tudor Creek.

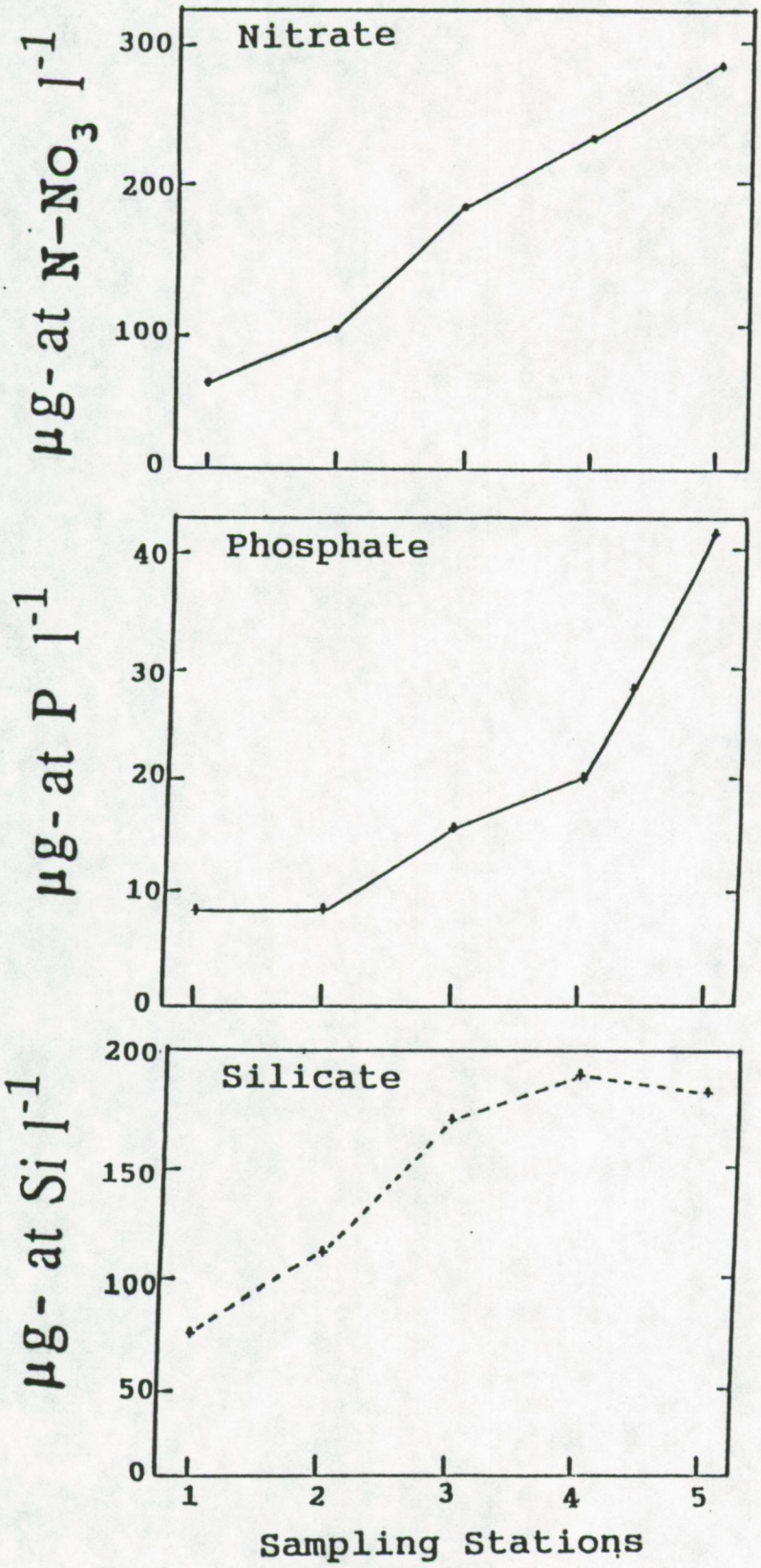


Fig.3.10.Distribution patterns (22nd May 1986, Spring) of phosphates, nitrates and silicates from five stations in Tudor Creek. Data from Kazungu (1990).

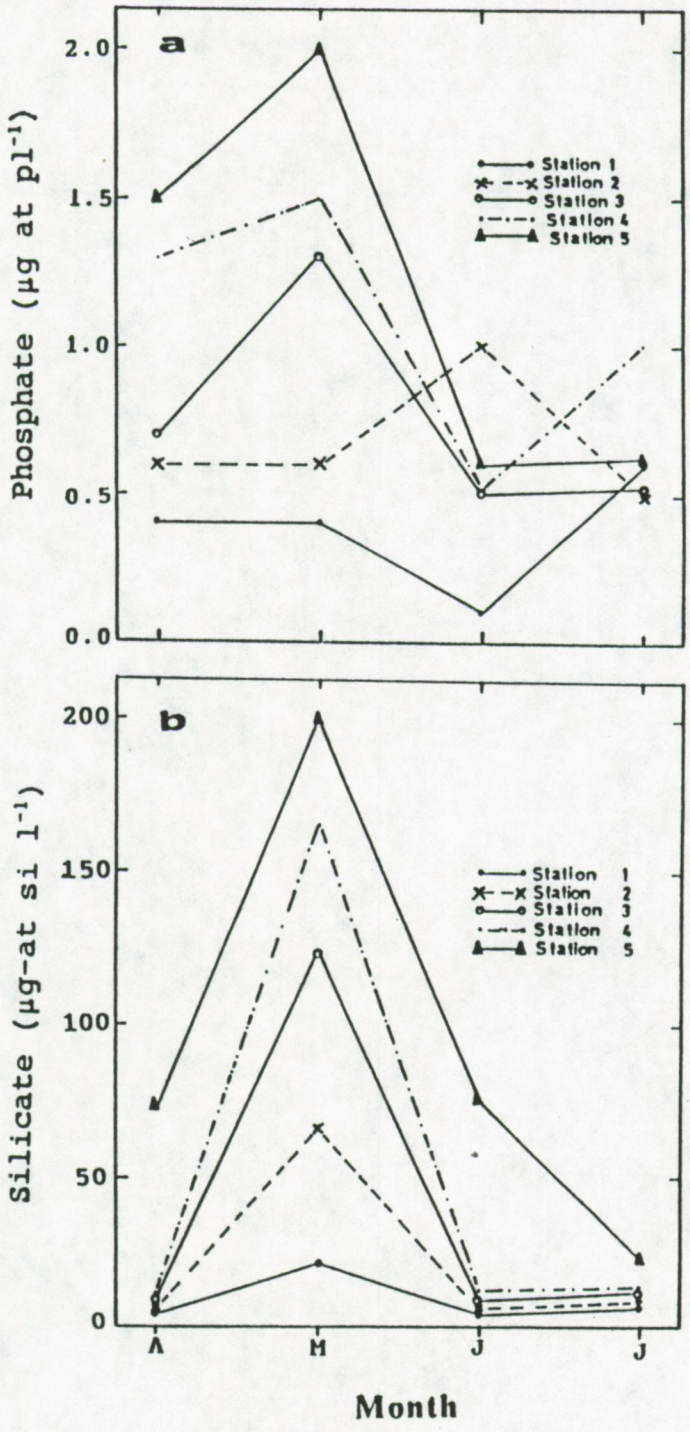


Fig.3.11.Seasonal pattern of (a) phosphate and (b) Silicate from five stations in Tudor Creek. Data from Kazungu (1990).

Silicate concentrations of above 100 µg at Si l^{-1} were recorded at stations 3, 4 and 5. Relatively high silicate concentration (22.0 µg-at Si l^{-1}) were also got at station 1 during rain seasons. In June and July, after the end of the long rainy season, silicate concentrations dropped very sharply (Kazungu, et al in Press).

Silicate concentrations generally increased from station 1 to station 5. Silicate concentration gradient is shown in Figure 3.10. This may be due to occurrence of probably more diatoms and river run-off in station 5 than station 1. Future research is needed to show why there is more silicate in station 5 than station 1.

3.2. Diel changes in physical factors

The diel changes in temperature, oxygen, pH and turbidity at station 1 collected during 24 hr cycle experiment on 25th March 1985, 24/25th June 1985, 23/24th September 1985, 16/17th February 1987 and 24/25th June 1987 are shown in Figure 3.12.

3.2.1. Temperature

Figure.3.12(a) shows that surface temperature fluctuated between 25.5 and 29.9° C and the lowest values were recorded during the night. It also shows temperatures were generally higher in February and March than those recorded in June and September (Fig.3.12(a)). The diel range of surface water temperature was smaller (about 2.1° C) during February and March and about twice as large for June and September when this range was 4.4° C. All this data suggests that temperatures were higher during ebb tide, probably because of the warm inshore water, than during the flood tide when cold oceanic water influences the creek water.

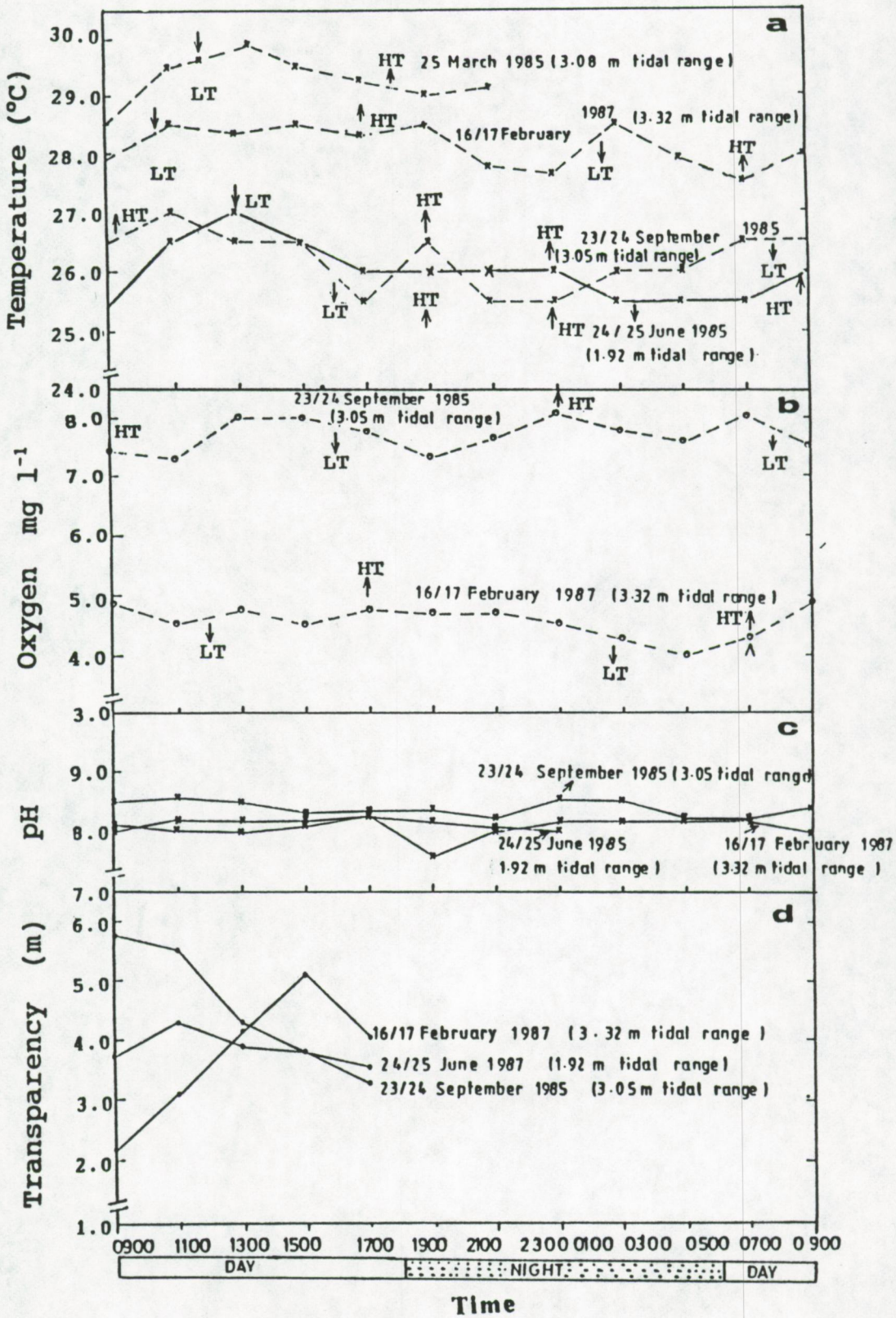


Fig.3.12.Environmental data for station 1 in Tudor Creek on three 24-hr cycle experiments in 1985 and 1987 (LT = lowtide; HT = Hightide).

3.2.2. Oxygen

The concentration of dissolved oxygen during the two 24-hr cycle experiments was higher in September than in February when it ranged from 7.3 - 8.0 mgl^{-1} and 4.1 - 4.9 mgl^{-1}, respectively (fig. 3.12b). Dissolved oxygen concentration is more or less constant and did not correspond to the tidal variations (Fig.3.12(b)). The tidal influence seems to be much more important than the biological activities.

Dissolved oxygen values varied according to temperature and salinity (which influence solubility).

3.2.3. pH

The pH content of the surface water ranged from 7.5 to 8.5 in February, 8.0 to 8.1 in June and 8.2 to 8.5 in September. The pH values were higher in September than in February (Fig.3.12(c)). There is no clear influence either from tidal movements.

3.2.4. Transparency

Transparency ranged from 2.1 m to 5.2 m in February, 3.6 m to 4.2 m in June, and 3.3 m to 5.8 m in September (Fig.3.12d) indicating that transparency rose with incoming tide.

3.2.5 .Comparison of diel regime of temperature, oxygen, salinity, pH and transparency between station 1 and 5

Since station 1 is found at the mouth of the Tudor Creek and station 5 at inner most part of the Creek it was decided to compare them. Four 24-h cycle experiments were carried out in Tudor Creek, firstly on 16-17th February 1987, secondly on 4-5th June 1987, and thirdly, two 24-h series

were carried out simultaneously at stations 1 and 5 in Tudor Creek on the 23-24th September 1985 and 1-2nd October 1985 during neap and spring tides respectively. From these series of samples it was hoped to gain some insight into the effect of the diel and tidal cycles.

Figures 3.13 and 3.14 show a comparison of environmental data between stations 1 and 5 in Tudor Creek on the 24 hr cycle experiments of 16-17th February 1987 and 4-5th June, 1987. The factors considered include temperature, Oxygen, pH and transparency. The tidal level fluctuations are shown in these figures.

It can be seen that temperature was higher at station 5 than station 1 during the sampling period (Fig.3.13 and 3.14) while on the contrary dissolved oxygen concentration was higher at station 1 than station 5 (Fig.3.13). Similarly pH and transparency were also higher at station 1 than station 5 (Fig.3.13b, c & d and 3.14b, c & d).

For station 1 (Fig.3.15) the temperature fluctuated between 25 and 27^{o} C, with lower values during the night. The salinity varied from 34 to 36‰. Transparency varies from 5.8 to 2.9 meters. This trend was not an artifact of the increasing darkness, because during the 24-hour cycle at spring tide, the transparency increased (outgoing tide) towards the evening (unpublished data for similar simultaneously taken 24 hours cycles at spring tide). Transparency rose with incoming tide. The pH fluctuated between 8.56 and 8.30. The oxygen concentration was in- between 8.1 and 7.2 mgl^{-1}. Oxygen concentration and pH fluctuation corresponded with the tidal variations, increased with incoming tide and decreased with outgoing tide.

For station 5, as shown in figure 3.15, the temperature showed a diurnal fluctuation rising to 28.6^{o} C in the afternoon and falling to 26.8^{o} C during the night. The salinity varied between 34 and 35‰ the lowest values were recorded at low tide. Transparency fluctuated between 2.2 and 1.2 m, diminished at outgoing tide and rose at incoming tide. The pH varied between 8.04 and 8.20 and oxygen concentration between 4.3 and 5.7

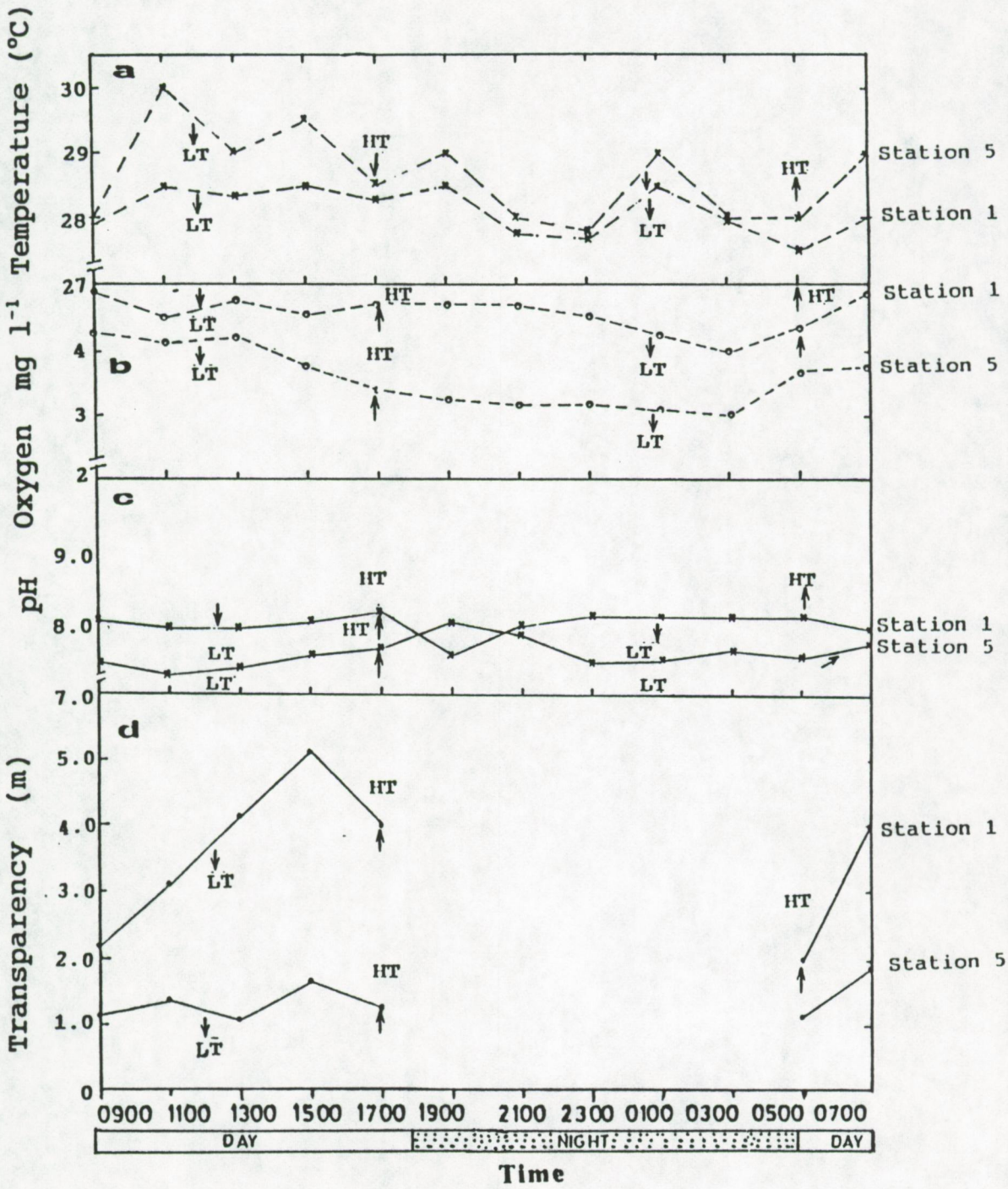


Fig.3.13.Comparison of environmental data between stations 1 & 5 in Tudor Creek on the 24 hr cycle experiment of 16/17 February 1987.

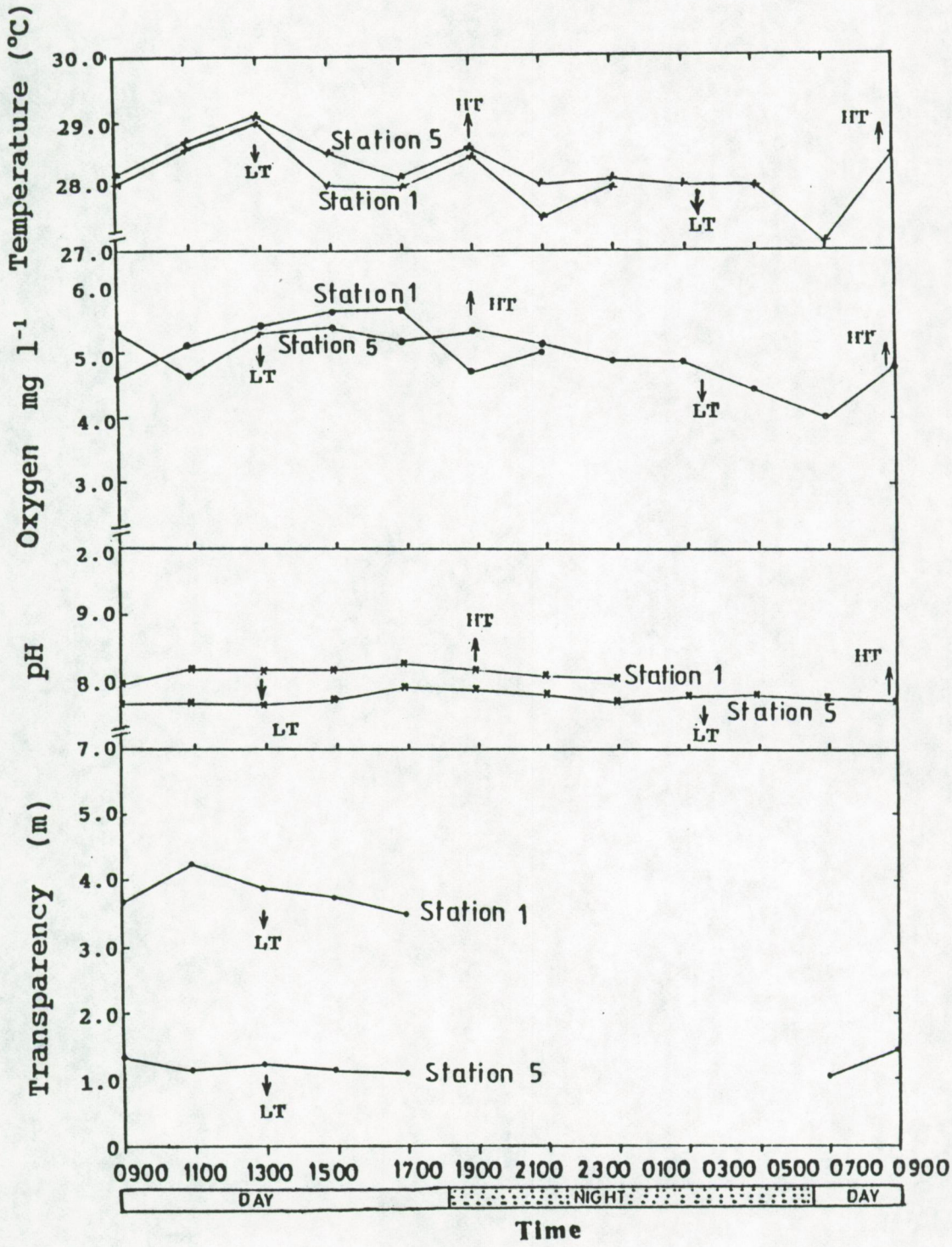


Fig.3.14.Comparison of environmental data between station 1 & 5 in Tudor Creek on the 24-hr cycle experiment of 4/5 June 1987.

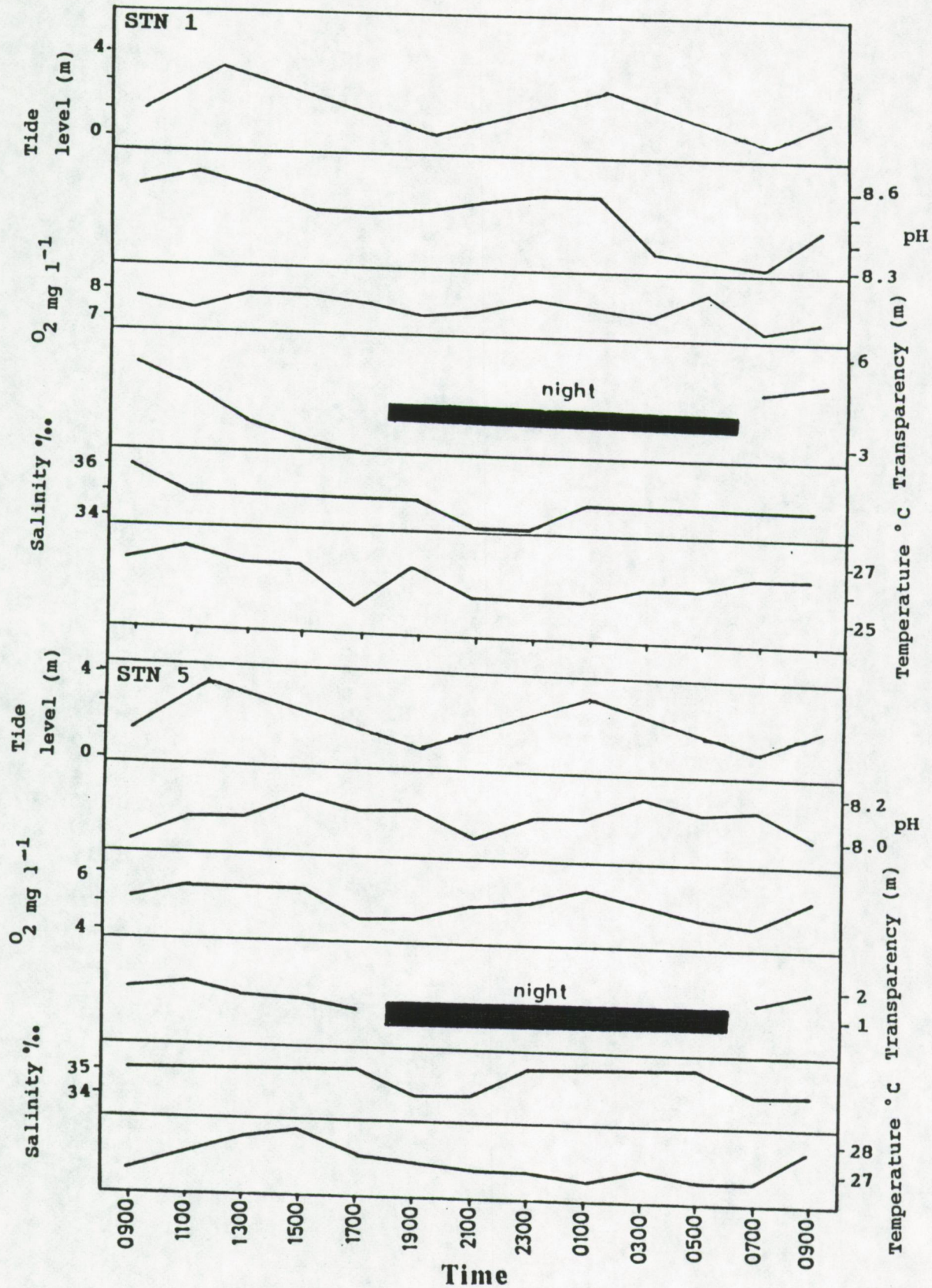


Fig.3.15. Comparison of environmental data between stations 1 and 5 on 24 hr cycle experiment of 23rd - 24th Sept 1985 which were carried out simultaneously in Tudor creek.

mgl^{-1}. Oxygen concentration fluctuations corresponded to the tidal variations increased during high tide and decreased during low tide. pH followed the tidal cycle somewhat delayed.

Figure 3.16 shows a comparison of environmental data between stations 1 and 5 in Tudor creek on the 24-hr cycle experiment of Spring on 1/2-10-1985. Same pattern was observed for temperature, oxygen, pH and transparency as in Fig. 3.15.

Comparing the two stations it can be seen that the temperature was higher at station 5 than at station 1 at any moment of the sampling period. Transparency, pH and oxygen concentration on the contrary were higher at stn 1 than 5.

3.2.6. Discussion

Grove et al., (1985) reported that during the wettest months (April and May) the input of freshwater is less than 2,000 l sec^{-1}; in the driest months (August and September) it is little more than 200 l sec^{-1}, which is barely worth considering, except on a very local scale, when compared to the volume of sea-water in Tudor Creek as a whole.

Kimaro (1986) Revis (1988) and Okemwa and Revis (1989) reported minimum salinity in April to June in Tudor Creek while in this study the mean monthly minima agrees with them.

On 25 March 1985 salinity in the tidal channel at Tudor Creek were 35‰ at the incoming tide and 32‰ at outgoing tide.

Along the Coast salinity varies from 34.4‰ to 35.3‰. The salinity reaches the lowest value of the year in May. This is because low salinity water is drawn into the South Equatorial Current from the Malayan region in the N.E.M. and arrive in Kenya Coast towards the end of N.E.M. coinciding with the long rains at the onset (April - May) of the S.E.M. (Morgan, 1959). During N.E.M the Somali Current draws seawater of low temperature and high salinity from Somalia into the Kenyan coast with

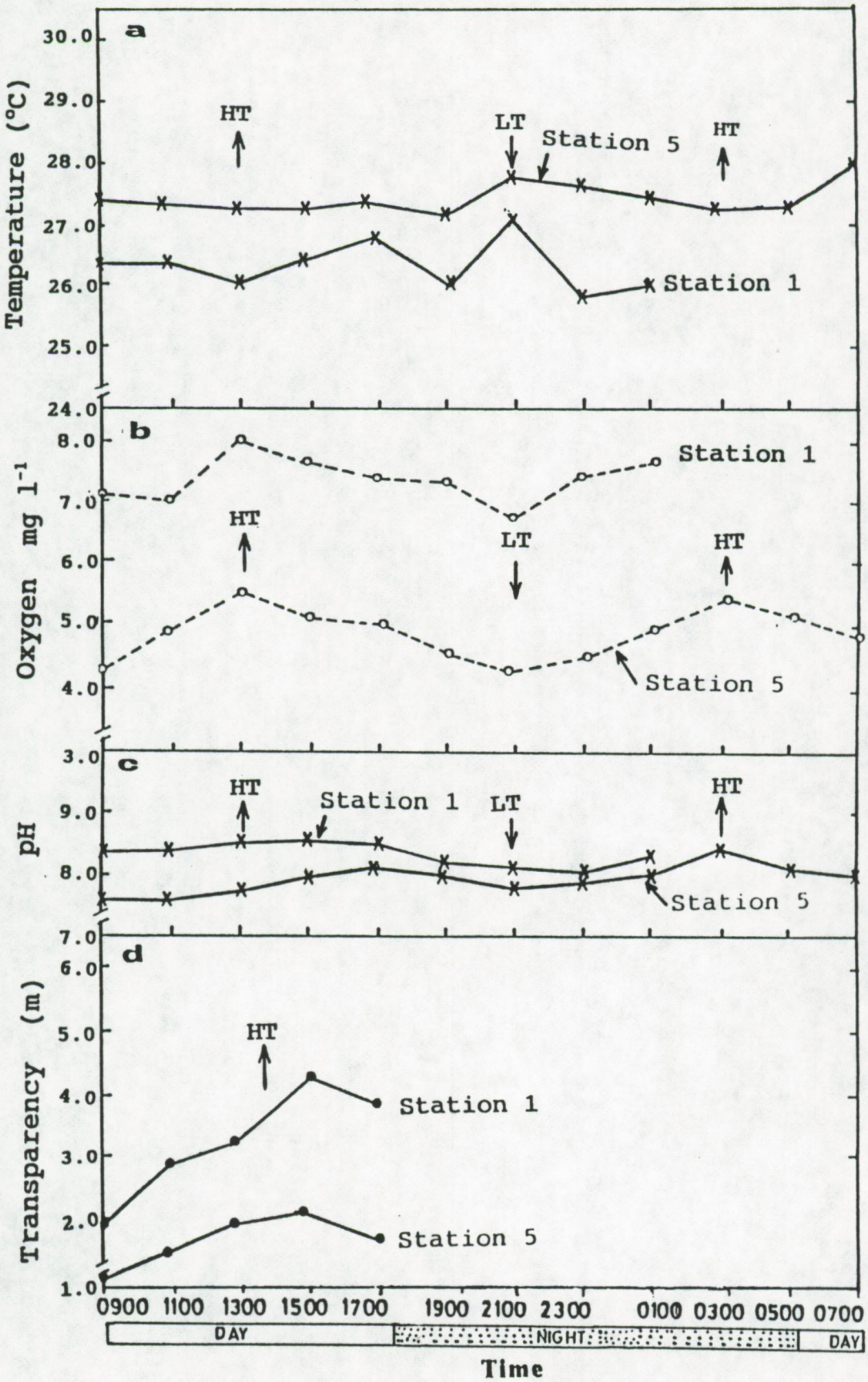


Fig.3.16. Comparison of environmental data between stations 1 and 5 in Tudor creek on the 24 hr cycle experiment of 1/2nd Oct 1985.

maximum salinity (35.3‰) occurring in December (Williams, 1970). The seawater temperature along the Kenyan coast varies from 29.5° C to 25.5° C with the highest value occurring in February - March in N.E.M. and lowest in August - September in S.E.M. (Johnson, 1980)

Lower salinities from April to June are also due to the combined effects of oceanic and local, or regional effects; the South Equatorial Current brings water of lower salinity from the central Indian Ocean (Rochford, 1964), while simultaneously rainfall in the Southern part of Kenya causes increased runoff and dilution of the slowed East African Coastal current. Higher salinities during August to November are as a result of reversed conditions.

McClanahan (1988) stated that nitrogen has 3 important sources, namely biogenic sources formed from nitrogen fixation, break down of nitrogenous compounds, terrestrial run off and upwelling. In non-upwelling pelagic areas nitrogen fixation is likely to be the main nitrogen source. Bryceson (1982) suggests that nitrate in nearshore waters of Tanzania reflect the breakdown of nitrogenous compounds from nitrogen fixing planktonic Cyanophyte Oscillatoria erythraea. Particularly high nitrate levels were found in the vicinity of surface blooms (Fig.3.17).

A seasonal study of the Tudor Creek in Mombasa (Norconsult, 1977 and Kazungu 1990) showed that nitrate - nitrogen was highest during the SE monsoon suggesting that run-off was the main nitrogen source in this creek.

Bryceson (1977) working on the inshore waters of Dar-es-Salaam found phosphate concentrations greater during the Southern Monsoon than during the northern monsoon. These results agree with those of Rochford (1967) and are slightly lower than those recorded by Newell (1959) although showing similar pattern of seasonality. McClanahan (1988) indicated that the main sources of mineral elements such as phosphorus

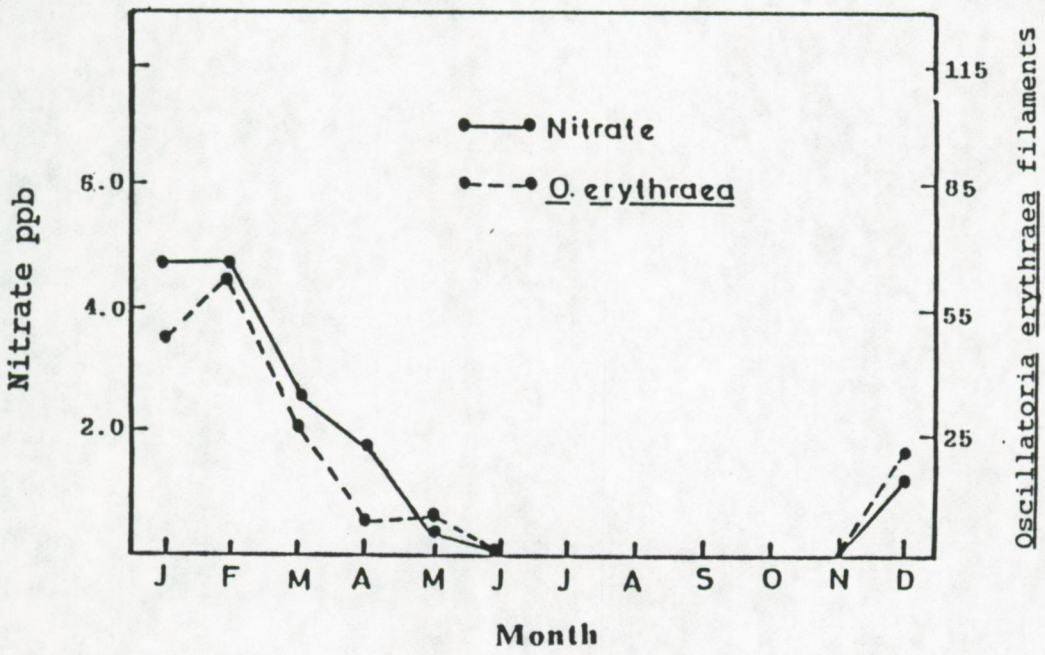


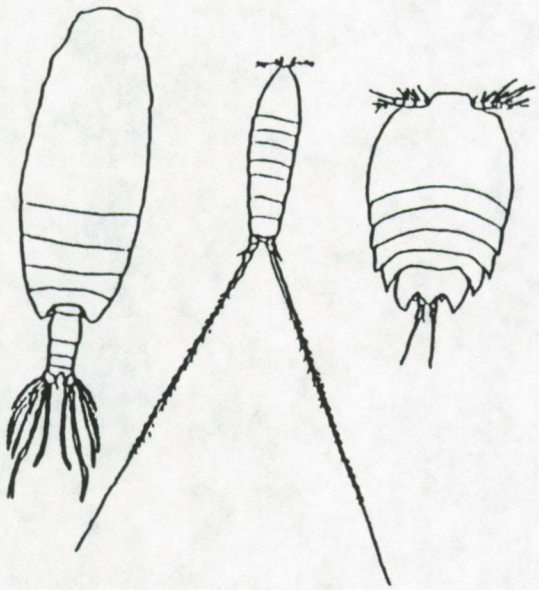
Fig.3.17. Seasonal nitrate-nitrogen values and the abundance of nitrogen-fixing alga from nearshore waters off the Tanzanian coast. Data adopted from Bryceson (1982).

are water column mixing, upwelling, river discharge and run off. In down-welling areas off Tanzania and Southern Kenya the main sources of phosphorus are water-column mixing, discharge and runoff occurring during rainy seasons (Newell, 1959; Bryceson, 1982). Phosphate may be mixed up at a greater rate from the nutrient rich deeper waters during the Southern Monsoon due to greater turbulence in the water column. It would appear that phosphate is not limiting phytoplankton growth since it is present at all times Bryceson (1982).

Nutrients are as important as illumination (Ricard, 1984). Phosphate and nitrate seem to be the limiting nutritional factors, while concentrations of silicate, often limited in oceanic waters, are replenished through run off (Ricard, 1984). Phytoplankton peaks frequently occur at the same time as nitrate and especially, phosphorus, peaks, i.e. during the rainy seasons (Qasim et al., 1969; Sankaranarayanan & Qasim, 1969). These input of nutrients, together with a sudden lowering of salinity, initiates growth of phytoplankton.

It can be emphasized here that tidal movements in Tudor Creek are great and may affect salinity, temperature, transparency. There is a large difference in tidal movements between stations and seasonality in Tudor Creek. Other ecological factors which had little fluctuations in Tudor Creek are pH and Oxygen. These very different environmental conditions between the stations may probably affect plankton communities as we will show in the next chapter.

COMPOSITION AND STRUCTURE OF THE ZOOPLANKTON COMMUNITY



CHAPTER 4

CHAPTER 4

4.0 COMPOSITION AND STRUCTURE OF THE PLANKTON COMMUNITY

4.1. Species composition and community structure.

The zooplankton is rich and abundant and over 51 taxa were recorded (Table 4.1). Close to 74% of zooplankton comprised copepods of which the most important were calanoids followed by cyclopoids, poecilostomatoids, harpacticoids and monstrilloids in that order. Because copepods dominated amongst the other zooplankton groups in the samples, it was decided to attach greater attention to them from this point of the study onwards as regards to composition and community structure.

An overall rank order and percentage composition for the main taxonomic groups from the samples collected twice monthly from the five stations from Tudor Creek from September, 1985 to December, 1987 is shown in table 4.2.

A brief description of the composition and temporal trends of the taxa in the Tudor Creek is given in table 4.2.

Okemwa and Revis (1986) and Revis & Okemwa (1989) identified more than fifty two free swimming plankton copepod species from three stations in Tudor Creek.

From all stations, shown in table 4.3, 99 copepod species were identified. 83 species were found at station 1, and 37 of those were specific to this station. In station 2, 54 species were found of which 4 were specific. In station 3, only 50 species were found, of which 3 were specific. In station 4, 15 species were found, of which none was specific. In station 5, only 8

Table 4.1 Zooplankton taxa collected from five stations of Tudor Creek from December, 1984 to December, 1987.

Taxa	Stn1	Stn2	Stn3	Stn4	Stn5
Cnidaria					
Hydromedusae		XX	XXX	XX	X
Siphonophora	XX	XX	X	X	X
Acnidaria					
Ctenophora	X	X	XX	X	X
Plathyhelminthes					
Notoplana(flatworm)	X	X			
Proboscis-worm	X				X
Annelida					
Polychaete Larvae	XX	X	X	X	X
Aphroditidae Larvae	X	X	X	X	
Pycnogonida					
Pycnogonid	X				
Branchiopoda					
Cladocera		X		XX	XX
Ostracoda					
Ostracoda	X	XX	XX	XX	X
Copepoda					
Calanoida	XXX	XXX	XXX	XXX	XXX
Poecilostomatoida	XXX	XX	XX	XX	X
Cyclopoida	XX	XX	XX	XX	X
Harpacticoida	XXX	XX	XX	XX	X
Monstrilloida			X	X	X
Cirripedia					
Cirripedia nauplii	XX	XXX	XX	XX	X
Mysidacea					
Mysids		X	X	XX	XXX
Cumacea					
Cumacean		X	X	XX	XX
Isopoda					
Anilocra	X				
Cryptoniscids	X		X	X	
Paragnathia Larvae	X			X	
Amphipoda					
Gammaridea	X	XX	X	XXX	X

Hyperiidea	X	XX	XX	X	X
Penaeidae					
Lucifer Juvenile	X	XX	XXX	XX	X
Penaeid mysis	X	XXX	XX	XX	XX
Decapod larvae					
Anomuran zoeae			XX	XX	
Brachyuran zoeae	X	XXX	XXX	XXX	XX
Brachyuran megalopae	X	X	XXX	XX	X
Caridean Larvae	X	XX	XXX	XXX	XX
Acetes	X	X	X	XX	
Stomatopoda					
Stomatopod alima	X	X	X		
Mollusca					
Bivalve veligers	X	X	XX	XXX	XXX
Pteropoda	XX	X			
Gastropod veligers	XX	XX	X	X	X
Heteropods (atlantid)	X	X			
Lophophorates					
Bryozoan cyphonautes	X				
Chaetognatha					
Sagitta spp.	XX	XX	XXX	XXX	XX
Echinodermata					
Echinoderm larvae	X				
Appendicularia					
Larvacea	XXX	XX	X	XX	X
Salpida					
Thalia	XXX	XX	X		
Doliolida					
Doliolum spp.	XXX	XX	X	X	X
Cephalocordata					
Amphioxus		XXX	XX	X	X
Insecta					
Halobates	X		X		X
Pisces					
Fish eggs	XXX	XXX	XX	X	X
Fish larvae	X	X	XX	XX	XX

(51 taxa were identified: XXX = abundant, XX = common, X = rare).
(Stn = Station)
(Zooplankton taxa with XXX show local population where they are found).

Table 4.2 Annual percentage contributions of the Copepoda and other zooplankton groups arranged in descending order in all stations in the Tudor Creek during neap and spring tides.

Percentage contributions											
	1985-1987										$\bar{X}$ Years
Station	1		2		3		4		5		
Tide	Neap	Spring	Neap	Spring	Neap	Spring	Neap	Spring	Neap	Spring	Mean
Copepoda	73	77	65	80	69	75	59	82	79	81	74
Molluscan Larvae	3.7	3.7	3.1	0.7	3.2	2.9	l9.8	1.8	5.4	9.0	5.33
Brachyuran Zoeae	4.2	4.2	11.9	6.2	6.1	5.1	5.2	1.6	1.8	1.2	4.75
Chaetognath	3.4	3.4	2.4	3.6	3.5	3.4	4.3	5.8	2.2	2.1	3.41
Caridea	2.7	2.7	4.7	1.5	3.8	2.6	1.5	0.7	0.7	0.1	2.10
Appendicularians	2.4	2.4	1.5	0.5	1.4	1.3	1.6	1.0	1.7	0.8	1.46
Fish eggs	1.7	1.7	1.6	1.1	1.0	0.7	1.2	0.3	0.1	0.0	0.94
Euphausiids	0.7	0.7	1.8	0.7	1.6	1.0	0.6	0.2	0.1	0.0	0.74
Sergestids	0.7	0.7	0.6	0.9	0.9	1.4	0.3	0.6	0.1	0.3	0.65
Mysids	0.3	0.3	0.1	0.2	0.1	0.2	0.1	1.0	0.5	3.2	0.60
Medusae	0.1	0.1	1.2	1.2	0.2	0.7	1.1	0.8	0.4	0.1	0.59
Fish larvae	0.5	0.5	0.7	0.3	0.9	0.6	0.4	0.3	0.3	0.3	0.48
Amphipods	0.6	0.6	0.1	0.2	0.1	1.2	0.1	0.6	0.1	0.1	0.37
Polychaetes	0.5	0.5	0.3	0.3	0.4	0.3	0.2	0.7	0.3	0.2	0.37
Brachyuran megalopa	0.2	0.2	0.1	0.2	0.1	0.2	0.0	0.2	0.0	0.1	0.13
Siphonophores	0.4	0.4	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.11
Pteropods	0.3	0.3	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.09
Penaeids	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.0	0.0	0.09
Ctenophores	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.1	0.0	0.0	0.04

species were found, of which none was specific to the station and this supports the gradient hypothesis reported by Okemwa & Revis (1986).

In this study a complete list of all the copepod species encountered and their occurrence in Tudor Creek during the study period is given in Table 4.3. The species marked with asterisks were the most common and numerically dominant. The species with two asterisks were the most dominant in both biomass and numbers.

Up to now 102 copepod species have been identified, belonging to 41 genera and 30 families Revis (1988). About 17 species are dominant. Six species are new in Western Indian Ocean. Calanus darwini Lubbock 1860, Labidocera laevidentata Brady 1883, Paracalanus crassirostris Dahl 1894, Paracalanus indicus Wolfenden 1905, Paracalanus tropicus Andronov 1977 and Sapphirina lactens Giesbrecht 1892. Three new species have been encountered and their descriptions are in preparation: Tortanus sp.; Kelleria sp. and Harpacticella sp. This agrees with Revis (1988) who worked on the same samples.

4.2. Individual taxa

4.2.1. Cnidaria

4.2.1.1. Hydrozoan medusae:

Liriope tetraphylla Chamisso & Eysenhardt 1821 and Solmundella bitentaculata Quoy & Gaimard 1833 were recorded at densities up to 1 and 3 m^{-3} in sampling of February and March 1985 respectively.

4.2.1.2. Siphonophores:

A number of some Calycophorae which are include in the genera Diphyes Chun 1897 were present in few samples; collectively they formed in average about 1%of the total non-copepod fauna,and the highest recorded density was 1 m^{-3} at station 1 in December.

Table 4.3 Classified copepod species and their occurrence in five stations of Tudor Creek.

				STN1	STN2	STN3	STN4	STN
CALANOIDA	Sars 1902							
Calanidae	Dana 1853	Calanus darwinii	(Lubbock 1860)	X				
		Calanus minor	(Claus 1863)	X	X	X		
		Canthocalanus pauper*	(Giesbrecht 1888)	X	X	X	X	
		** Undinula vulgaris*	(Dana 1849)	X	X	X		
Eucalanidae	Giesbrecht 1892	Eucalanus spp.		X	X	X		
		Rhincalanus cornutus	(Dana 1849)	X	X			
Paracalanidae	Giesbrecht 1892	Acrocalanus gibber*	Giesbrecht 1888	X	X	X	X	
		Acrocalanus gracilis	Giesbrecht 1888	X	X	X		
		Acrocalanus longicornis	Giesbrecht 1888	X	X	X		
		Acrocalanus monachus	Giesbrecht 1888	X				
		Bestiola sp.		X	X	X	X	
		Paracalanus aculeatis	Giesbrecht 1888	X	X	X	X	
		Paracalanus crassirostris*	Dahl 1894	X		X		
		Paracalanus indicus	Wolfenden 1905	X	X	X		
		Paracalanus tropicus	Andronov 1977		X	X		
Calocalanidae	Bernard 1958	Calocalanus sp.	Giesbrecht 1888	X	X			
		Ischnocalanus sp.	Bernard 1963			X		
Clausocalanidae	Giesbrecht 1888	Clausocalanus arcuicornis	(Dana 1849)	X				
		Clausocalanus farrani	Sewell 1929	X				
		Clausocalanus furcatus	(Brady 1883)	X				
		Clausocalanus minor	Sewell 1929	X				
		Clausocalanus sp.1		X				
		Clausocalanus sp.2		X				
Euchaetidae	Sars 1902	Euchaeta marina	(Prestandra 1833)	X				
		Euchaeta pubera	Sars 1907	X	X			
		Euchaeta indica	Wolfenden 1905	X				
Scolecithricidae	Sars 1902	Scolecithrix danae	(Lubbock 1856)	X	X			
Temoridae	Sars 1902	Temora discaudata	Giesbrecht 1888	X	X	X	X	
		Temora stylifera	Dana 1849	X				
		Temora turbinata*	Dana 1849	X	X	X		
Metridiidae	Sars 1902	Pleuromamma indica	Wolfenden 1905	X				
		Pleuromamma piseki	Farran 1929	X				
Centropagidae	Giesbrecht 1892	Centropages calaninus	Dana 1849		X	X		
		Centropages elongatus	Giesbrecht 1846	X				
		Centropages furcatus	(Dana 1849)	X	X	X		
		Centropages gracilis	(Dana 1849)	X				
		**Centropages orsinii*	Giesbrecht 1889	X	X	X		
Pseudodiaptomidae	Sars 1902	Pseudodiaptomus stuhlmani	Poppe & Mrazek 1895	X	X	X	X	
Lucicutiidae	Sars 1902	Lucicutia flavicornis	(Claus 1863)	X	X			
Candaciidae	Giesbrecht 1892	Candacia catula	(Giesbrecht 1889)	X	X	X		
		Candacia longimana	(Claus 1863)	X				
		Candacia magna	(Sewell 1932)	X				
		Candacia pachydactyla	(Dana 1849)	X				
		Candacia tenuimana	(Giesbrecht 1889)	X				
		Paracandacia bispinosa	(Claus 1863)		X			
		Paracandacia simplex	(Giesbrecht 1889)	X				
		Paracandacia truncata	Dana 1849	X				
Pontellidae	Sars 1902	Calanopia elliptica	(Dana 1849)	X	X	X		
		Calanopia minor	A. Scott 1909	X	X	X		
		Calanopia parathompsoni	Gaudy 1969		X	X	X	
		**Labidocera acuta	Dana 1849	X	X	X		
		Labidocera kroyeri	(Brady 1883)		X	X		
		Labidocera laevidentata	(Brady 1883)	X				
		Labidocera madurae	A. Scott 1909	X	X	X	X	
		Labidocera minuta	Giesbrecht 1892	X	X	X		
		Pontella sp.1				X		
		Pontellina morii	Fleminger & Hulsemana 1974	X				
		Pontellina plumata	Dana 1849	X				
		Pontellopsis herdmani	Thompson & Scott 1903		X		X	
Acartiidae	Sars 1900	Acartia amboinensis*	Carl 1907	X	X	X		
		**Acartia bispinosa	Carl 1907	X	X	X		
		Acartia danae	Giesbrecht 1889	X	X			
		Acartia natalensis	Connell & Grindley 1974	X		X	X	
		Acartia negligens	Dana 1849	X	X	X		

		Acartia pietschmani	Pesta 1912	x	x		
Tortanidae	Sars 1902	**Tortanus barbatus*	(Brady 1883)	x	x	x	x
		Tortanus gracilis	(Brady 1883)	x	x	x	
		Tortanus sp.			x		
POECILOSTOMATOIDA	Thorell 1859						
Corycaeidae	Dana 1853	Corycaeus(O) agilis	Dana 1849		x	x	
		Corycaeus(D) asiaticus	F. Dahl 1894	x	x	x	
		Corycaeus catus	F. Dahl 1894	x			
		Corycaeus(C) crassiusculus	Dana 1849			x	
		Corycaeus(D) dubius	Farran 1911		x		
		Corycaeus(O) pacificus	F. Dahl 1894		x	x	
		Corycaeus(C) speciosus	Dana 1849	x			
		Corycaeus(D) subtilis	M.Dahl 1812		x	x	
		Farranula gibbulus	(Giesbrecht 1891)	x			
Oncaeidae	Giesbrecht 1892	Oncaea conifera	Giesbrecht 1891	x			
		**Oncaea venusta*	Philippi 1843	x	x	x	x
		Lubbockia squillimana	Claus 1863	x		x	
Sapphirinidae	Thorell 1859	Copilia mirabilis	Dana 1849	x			
		Copilia quadrata	Dana 1849	x			
		Sapphirina auritens	Claus 1863	x			
		Sapphirina lactens	Giesbrecht 1892	x			
		Sapphirina nigromaculata	Claus 1863	x		x	
		Sapphirina opalina	Dana 1849	x			
		Sapphirina ovatolanceolata	Dana 1849	x			
Clausidiidae	Embleton 1901	Sapphirella sp.		x			
Lichomolgidae	Kossmann 1877	Kelleria pectinata	(A.Scott 1909)				x
		Kelleria sp.			x		
CYCLOPOIDA	Burmeister 1834						
Oithonidae	Dana 1853	Oithona plumifera	Baird 1843	x	x	x	
		Oithona setigera	Dana 1849	x			
		Oithona simplex	Farran 1913			x	
		Oithona spp.		x	x	x	
HARPACTICOIDA	Sars 1903						
Ectinosomatidae	Moore 1878	Microsetella rosea	Dana 1846	x		x	
Tachidiidae	Sars 1909	Euterpina acutifrons	(Dana 1846)	x	x	x	
Clytemnestridae	A. Scott 1909	Clytemnestra	Dana 1847		x		
Miracidae	Dana 1846	Macrosetella gracilis	Dana 1846	x	x		
Harpacticidae	Dana 1846	Harpacticella sp.		x			
Porcellidiidae				x	x	x	
Harpacticoida sp.					x	x	x
MONSTRILLOIDA	Sars 1902						
Monstrillidae				x		x	x

4.2.2. Acnidaria

4.2.2.1. Ctenophores:

Pleurobrachia sp. Fleming 1822 was encountered in April sampling abundance is (1 m^{-3}) at station 3.

4.2.3. Polychaete Larvae:

Lopadorhynchus henseni (Reibisch, 1893), Vanadis minuta Treadwell 1906 and Travisiopsis Lanceolata Southern 1910 occurred in the few of the samples. The eggs of nereid were abundant in the sample collected during the February samples. September and March samplings are found to have the highest numbers of polychaete larvae the two periods having an abundance of 9 and 1 m^{-3} respectively.

4.2.4. Crustacea

4.2.4.1. Branchiopoda

4.2.4.2. Cladocera

Evadne tergestina Claus 1864 was found sporadically in all the samples, but more were found in August samples. The highest densities (3 m^{-3}) occurred in April at station 3.

4.2.4.3. Ostracoda

4.2.4.4. Ostracods

Pyrocypris and Euconchoecia appeared in few of the samples and mainly in the night. Their maximum density 1 m^{-3} occurred in June and March samples.

4.2.4.5. Copepoda:

4.2.4.5.1. Calanoida

Calanoids were the dominant group of copepods in all the samples, followed by poecilostomatoids, cyclopoids, harpacticoids and lastly mostrilloids. The most commonly encountered calanoid species included: Centropages orsinii Giesbrecht 1888, Acrocalanus longicornis Giesbrecht 1888, Clausocalanus farrani Sewell 1929, Temora turbinata Dana 1849, Paracalanus aculeatis Giesbrecht 1888, Canthocalanus pauper Giesbrecht 1888, Undinula vulgaris Dana 1849, Acartia danae Giesbrecht 1889, Paracandacia simplex Giesbrecht 1889, Euchaeta marina Prestandra 1833 and Eucalanus spp. Dana 1848.

4.2.4.5.2. Poecilostomatoida

The most common poecilostomatoid species encountered were: Corycaeus specious Dana 1849, Oncaea venusta Philippi 1843, Copilia mirabilis Dana 1849 and Sapphirina lactens Giesbrecht 1892. The highest density (140 m^{-3}) occurred in December 1985 at station 1.

4.2.4.5.3. Cyclopoida

The most common cyclopoid species encountered were: Oithona plumifera Baird 1843, Oithona setigera Dana 1849 and Oithona simplex Farran 1913. The highest densities (380 and 300 m^{-3}) occurred in March 1986 in stations 3 and 5 respectively.

4.2.4.5.4. Harpacticoida

Harpacticoids were found in some samples, and the common species were: Microsetella rosea Dana 1846, Euterpina acutifrons Dana 1846, and Macrosetella gracilis Dana 1846. They occurred sporadically.

4.2.4.5.5. Monstrilloida

On rare occasions copepods of the order Monstrilloida were encountered.

4.2.4.6. Cirripedia:

Nauplii and cyprid larvae of barnacles were in the samples of February, August, October and December.

4.2.4.7. Mysidacea:

Siriella sp. and Anchialina agilis Sars, 1877 were caught in abundance of 4 m^{-3} in the sampling of October and December, respectively, and in the rest of the sampling the catch was scarce.

4.2.4.8. Euphausiacea:

Euphausia Dana 1848 appeared in most of the samples of June, August, October and December 1985 with abundance of 6, 1, 5 and 18 m^{-3} respectively.

4.2.4.9. Cumacea:

The cumacea, Siphinoe truncata were recorded in October samples in abundance of 1 m^{-3}.

4.2.4.10. Isopoda

Cryptoniscid isopod larvae, Idotea Sars 1897 were taken in the sampling of April, August, October and February.

4.2.4.11. Amphipoda

Hyperia Stephensen 1942 and Synopia ultramarina were sparsely collected in all the sampling with maximum numbers 1 m^{-3} in October sampling.

Paragnathia formica appeared regularly and were of little importance quantitatively. In general the holoplanktonic forms dominated the meroplanktonic forms.

4.2.4.12. Penaeidae

Penaeids were well represented, they included: Penaeus indicus H. Milne Edwards 1837, Penaeus simisulcatus de Haan 1844, Penaeus monodon Fabricius 1798 and Metapenaeus monocerus Fabricius 1798; Sergistidae: Acetes erythraeus Menon 1933, Lucifer typus H. Milne Edwards 1837 and Sergestes crassus Hansen 1919;

4.2.4.13. Decapod Larvae

Decapod larval stages were well represented.

Brachyuran zoeae appeared in large numbers in the sampling of December, January and April in abundance of 741, 885 and 188 m^{-3} respectively. Anomuran zoeae occurred in August and October at abundance of 21 and 15 m^{-3}.

Acetes erythraeus (Menon, 1933) and Lucifer typus Edwards 1837, all reached maxima in April 1985. Lucifer typus has high abundance of 3 and 1 m^{-3} at station 1 and station 2 in April respectively.

4.2.4.14. Stomatopoda

Larva of Alima type was in the samples of october 1985 in abundance of 1 m^{-3}.

4.2.5. Mollusca

4.2.5.1. Pteropoda:

Creseis Rang 1828 was commonly taken in the plankton of the five stations of December and February during the North-East monsoon, but were rare in the other months during the South-East monsoon.

4.2.5.2. Gastropod veligers

Gastropod veligers were collected in all 5 stations from the Tudor Creek during the period from September, 1985 to August, 1986, and were at a maximum in October 1985 and August 1986 series in abundance of 3 m^{-3} respectively.

Lamellibranch larvae were found in maximum numbers in the sampling of January in abundance of 6 m^{-3}.

4.2.6. Chaetognatha

4.2.6.1. Chaetognaths:

The numerical importance of Sagitta enflata Grassi 1881 and Sagitta elegans Verrill 1873 was high with a maximum value of 144 m^{-3} during North-East monsoon on the December sampling.

Chaetognath were one of the most consistent and conspicuous components of almost all samples and several species, including those of the genera Sagitta and Krohnitta spp. were clearly present in the zooplankton community.

4.2.7. Tunicata

4.2.7.1. Appendicularia

In the sampling of December, Appendicularia made the major contribution to non-copepod zooplankton with about 60% followed by brachyuran zoeae and fish eggs.

4.2.7.2. Salpida

Salps were observed sporadically in very low numbers in all samples. Thalia democratica Metcalf 1918 was recorded in high numbers in the samples of August 1985.

4.2.7.3. Doliolida

Doliolum sp. appeared more frequently and with highest mean density 2 m^{-3} on the December, sampling during the North-East monsoon.

4.2.8. Cephalocordata

4.2.8.1. Amphioxus:

Amphioxus Yarrell 1836 though rare was recorded in the August and October samples in station 2.

4.2.9. Insecta

4.2.9.1. Halobates:

The hemipteran insect, Halobates which was a conspicuous inhabitant of the water surface in Tudor Creek, occasionally appeared in the plankton samples.

4.2.10. Pisces

4.2.10.1. Fish eggs

Fish eggs occurred principally during the months of April and May time for long rains. More fish eggs was caught in station 1 and 2 (15 m^{-3} and 13 m^{-3}) respectively. Fish larvae were also frequently seen in April, May and December though usually in lower concentrations in station 3 in December (Max: 7 m^{-3}) than eggs.

The mean monthly abundance of fish eggs at station 1 during the study period was 5 m^{-3}. Station 2 and 3 had lower numbers of fish eggs during the North-East Monsoon than during the Southeast Monsoon.

The highest number of fish larvae was recorded at station 2 (20 m^{-3}) in December. The mean monthly abundance of fish larvae was lower in station 1 than in stn 2 and 3.

4.2.10.2. Fish larvae

The families dominating the Tudor Creek are the Serranidae, Lethrinidae, Albulidae, Stolephoridae, Clupeidae and Lutjanidae. The following fish species were encountered: Spratelloides delicatulus Bennett 1831, Stolephorus heterolobus Rüppell 1837, Albula vulpes Linnaeus 1958, Harklosichthys quadrimaculatus Ruppell, 1837 and Sardinella gibbosa Bleeker 1849.

4.3. Discussion

The seasonal occurrence of the zooplankton groups appeared to be higher during the northeast monsoon period.

The Copepod species were comparatively more in station 1 than in station 2 and 3. The salinity gradient may be the limiting factor in their distribution.

Every station has a more or less typical copepod fauna. There exist a gradient in copepod species, which decreases from station 1 to station 5. Okemwa and Revis (1986) working in the same area indicated the species that were specific to stations 1, 2 and 3 respectively.

Okera (1974), working in the neritic waters of Dar es Salaam made observation on the temporal variation of the numbers of zooplankton and suggested that there is an annual cycle of zooplankton production in East African Inshore water, although the elucidation of the nature of this cycle requires future work.

Surveys of zooplankton in the same Tudor Creek have reported communities which are similar in species composition to those found in this study (Reay & Kimaro, 1984; Kimaro, 1986; Okemwa & Revis, 1986, 1988).

The zooplankton assemblages observed in Tudor Creek are probably characteristic of tropical creek waters and are similar to subtropical zooplankton communities. Tudor Creek experiences wide fluctuations in temperature and salinity throughout the year. It has consistency of prevailing monsoon winds and wide tidal prism. Normally this must act to stabilize the events which underline the relatively brief seasonal growth of some populations, e.g. copepods, brachyuran larvae, cirriped larvae, penaeid larvae, hydromedusae and caridean.

It has to be noted that vertical depth migrations may influence the surface densities sampled. Investigations in other water regions suggest that there is diel shifts in density and also changes on vertical depth distributions of Zooplankton (Reeve & Cosper, 1973; Trinast, 1975; Stickney & Knowles, 1975).

The occurrence of species, their distributional patterns, and variations in plankton communities and assemblages are influenced to some extent by environmental factors that were measured.

The primary biogeographical classification of a copepod species is based on its regional distribution range and is characterized in terms of both its near- shore versus offshore occurrence.

The gross patterns of geostrophic oceanic circulation form the basic for these different biological provinces (in station 1 and station 5 in Tudor Creek).

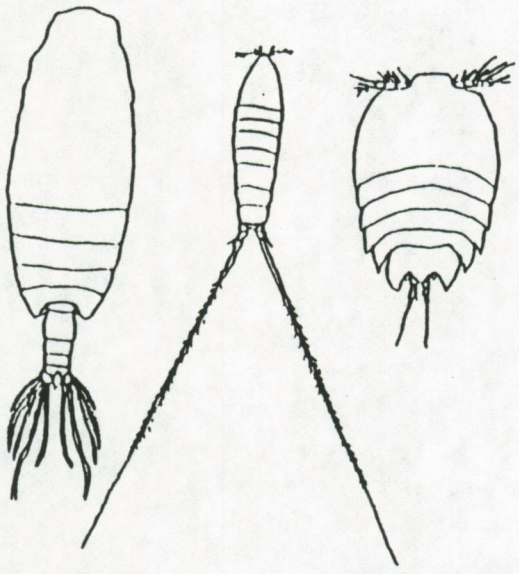
The surface water in Tudor Creek is warm, low in nutrients, and has less seasonal variations than occurs at higher latitudes. The species diversity is high but the community biomass is small.

Seasonal fluctuations in the abundance of zooplankton observed in this study were determined from monthly sample collections. Weekly or shorter intervals would have revealed more information about the coupling of environmental events and population growth. Monthly collections, however, sufficed to demonstrate that major changes in density and community structure occur annually. Fish eggs were more common at the mouth of the creek, probably due to the pelagic eggs of reef fishes which spawn within the reef outside the creek.

The major peak in numbers of fish larvae in Tudor Creek in December and March - May was also accompanied by a concomitant peak in numbers of large copepods. Thus, our data supports the hypothesis of Greve &. Parsons (1977), that larval fishes often coincide in nature with large copepods.

Tidal exchange has been suggested as the single most important factor controlling the distribution of estuarine plankton (Grindley, 1981). Finally, the survival of plankton depends on population reproduction rates as well as the exchange rate of the water.

POPULATION DYNAMICS AND TEMPORAL VARIATION PATTERNS OF COPEPODS



CHAPTER 5

CHAPTER 5

5.0 POPULATION DYNAMICS OF COPEPODS IN TUDOR CREEK

5.1 Total Copepods

5.1.1. Numeric abundance

The seasonal changes in numerical abundance of copepods in three stations in Tudor Creek between December 1984 and November 1985 is shown in figure 5.1.

Typically, highest copepod abundances occurs in the long rains from march to June in all stations, and relatively small peak in short rain season from November to December (Fig.5.1). While lowest abundance of all copepods in all stations occurs during the dry seasons. This annual trend in abundance of copepods in the Tudor Creek appears to be related very closely to the seasonality of the monsoon. The abundance copepods is the highest in Tudor Creek during SE monsoon.

It is evident from these results that the total copepod community showed marked seasonal changes in abundance. These changes were mainly influenced by density fluctuations of the dominant species: Canthocalanus pauper Giesbrecht 1888, Undinula vulgaris Dana 1849, Eucalanus spp. Giesbrecht 1892, Acrocalanus spp Giesbrecht 1888, Paracalanus crassirostris Dahl 1894, Temora discaudata Giesbrecht 1888, Temora turbinata Dana 1849, Centropages orsinii Giesbrecht 1889, Centropages furcatus Dana 1849, Labidocera acuta Dana 1849, Acartia pietschmani Pesta 1912, Acartia amboinensis Carl 1907, Acartia bispinosa Carl 1907, Tortanus barbatus Brady 1883, Corycaeus spp. Dana 1853, Oncaea venusta Philippi 1843 and Oithona spp. Dana 1853. Figure 5.2 provides information about abundance of the common copepod species with respect to season, and location.

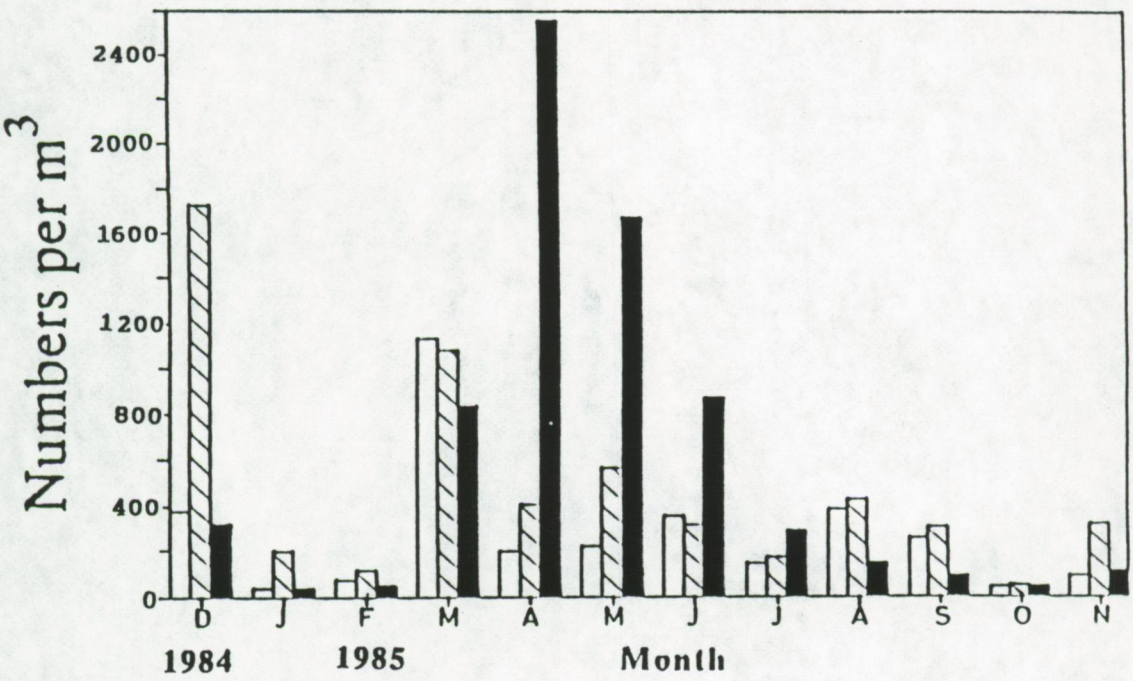


Fig.5.1.Annual variation of Copepod numbers in three stations in Tudor Creek from December 1984 to November 1985. ▫ station 1; ▪ station 2; ■ station 3.

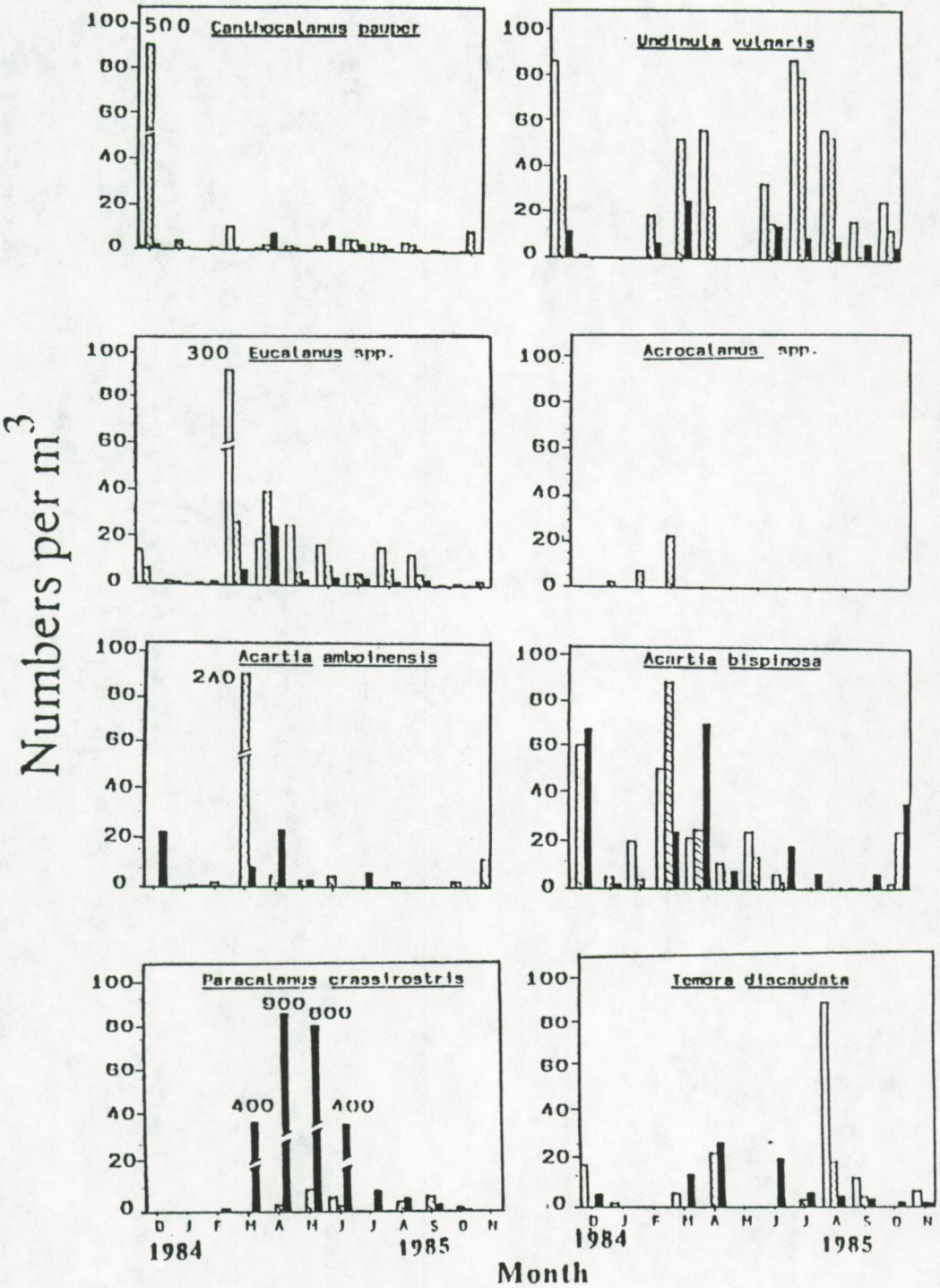
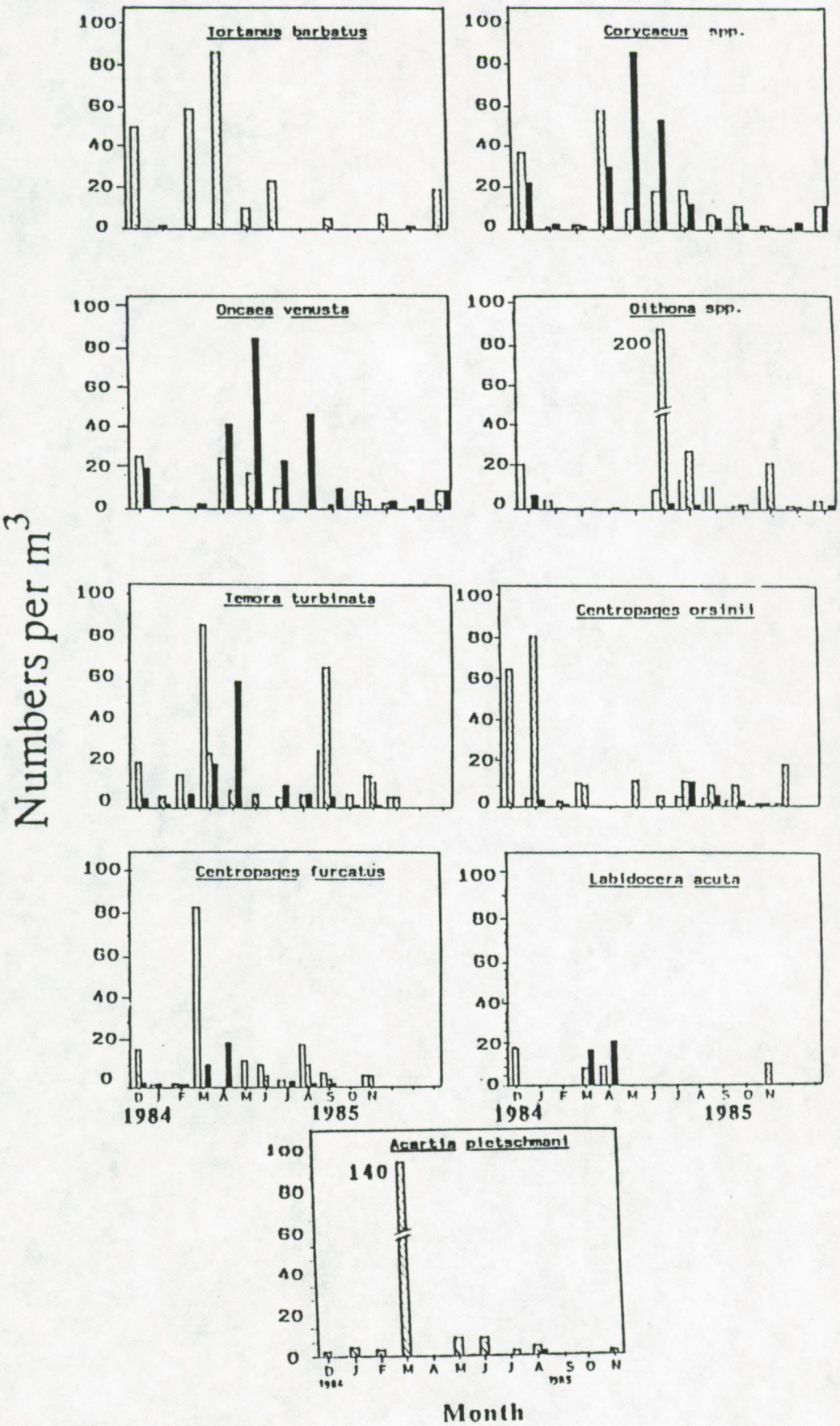


Fig.5.2. Temporal changes in abundance of the common copepod species in three stations in Tudor Creek from December 1984 to November 1985. (Stn= Station). ☐ Stn 1 ▨ Stn 2 ■ Stn 3 (continued)

Fig.5.2. (Continued)



These copepod species constituted 90% of the total numeric abundance of copepods in Tudor Creek. Illustrations are given for only the common copepod species.

Figures 5.3 to 5.11 illustrate seasonal changes in abundance of 10 copepod species in Tudor between September 1985 and November 1986. Figure 5.12 shows seasonal changes in zooplankton abundance in near-shore waters off the Tanzanian coast (Okera 1974).

Revis 1988 reported 12 copepod species in Tudor Creek which were the most numerically abundant and categorized them into 5 main groups (Table 5.1).

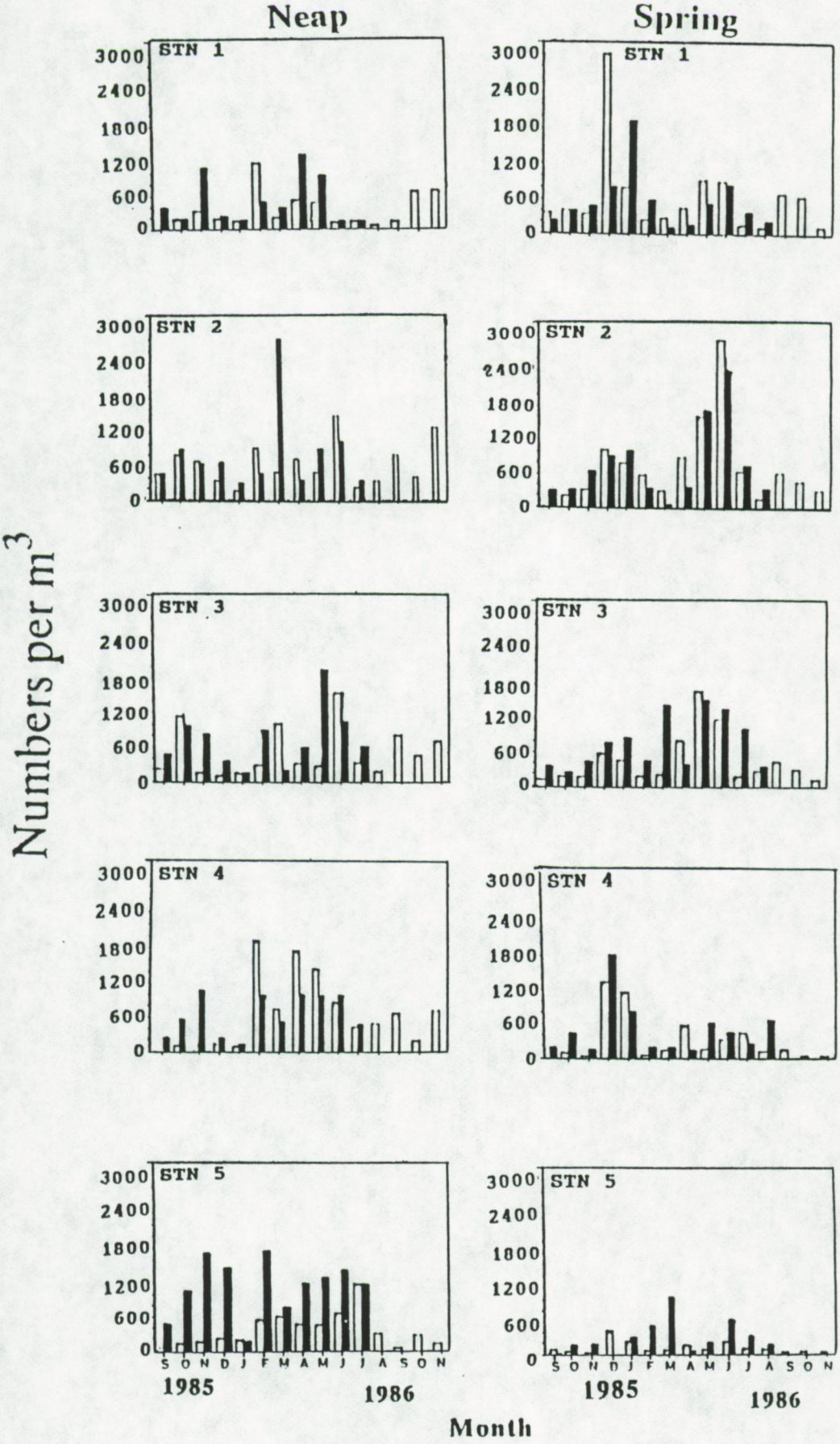


Fig.5.3. Seasonal changes in abundance of Zooplankton in five stations in Tudor Creek from September 1985 to November 1986: for day and night in one neap and one spring in each month. (▫ day; ▪ night).

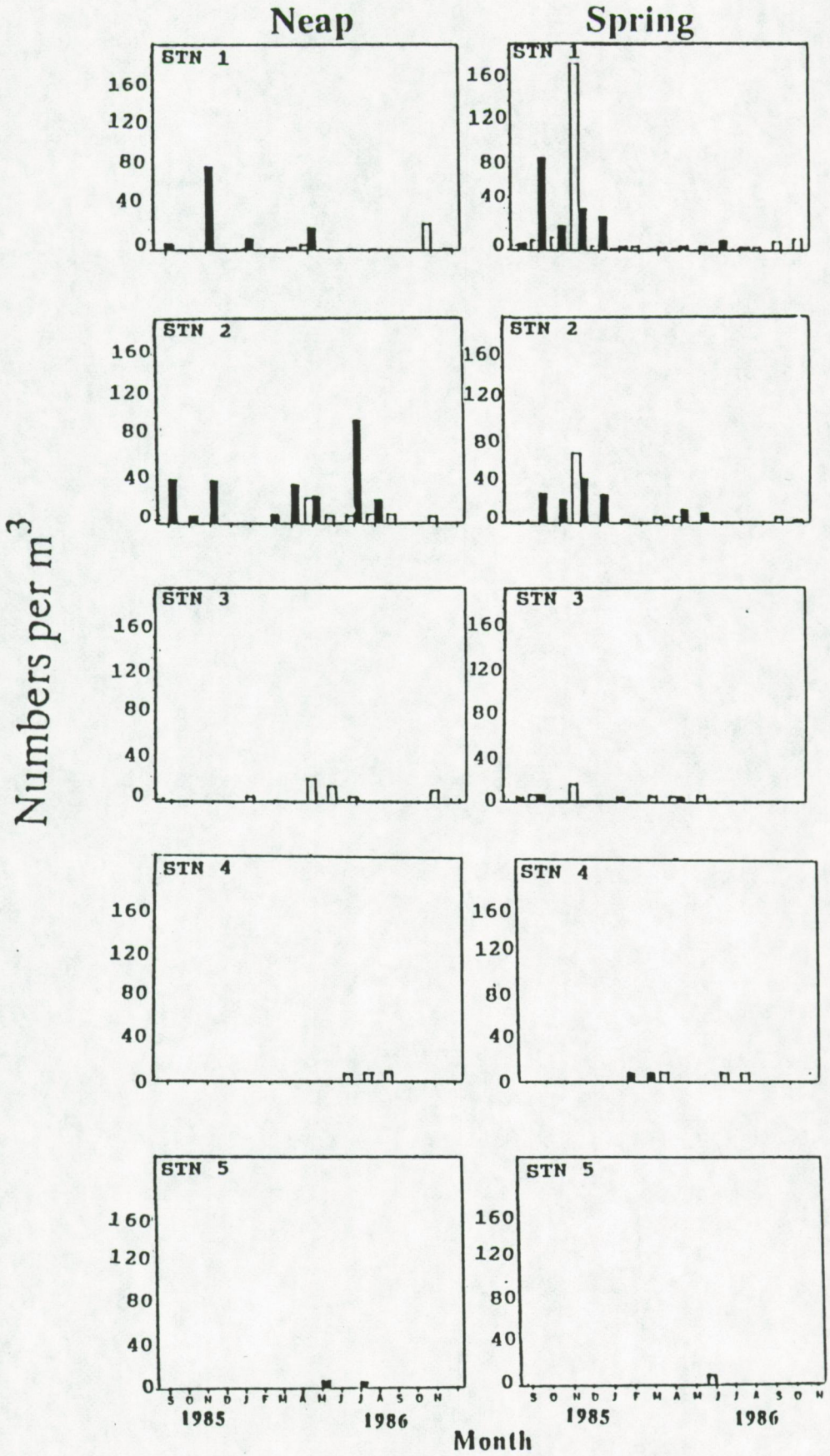


Fig.5.4. Seasonal changes in abundance of Undinula vulgaris in five stations in Tudor Creek from September 1985 to November 1986 for day and night in one neap and one spring in each month. (▫ day; ▪ night).

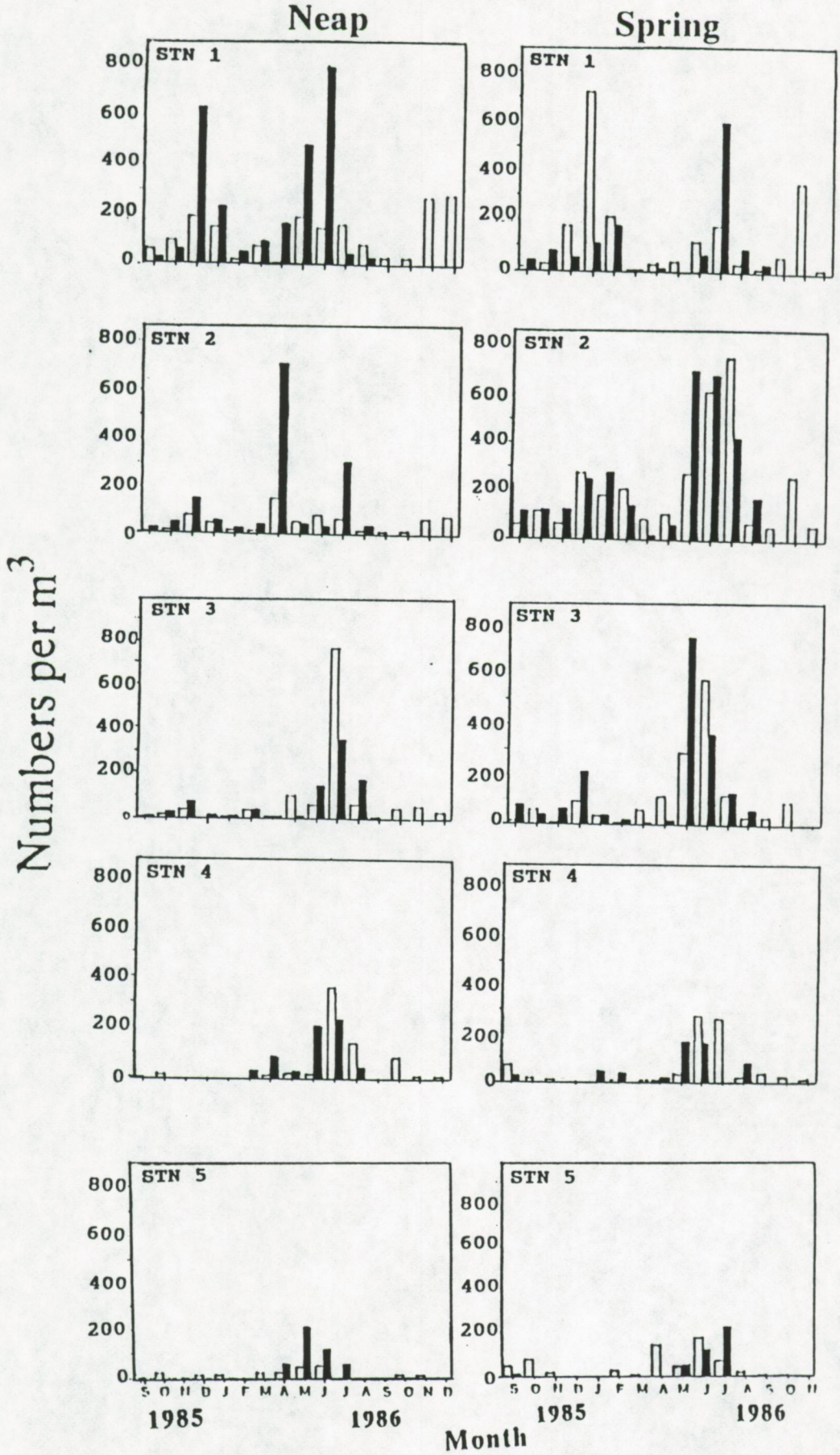


Fig.5.5. Seasonal changes in abundance of Acrocalanus spp. in five stations in Tudor Creek from September 1985 to November 1986: for day and night in one neap and one spring in each month. (▫ day; ▪ night).

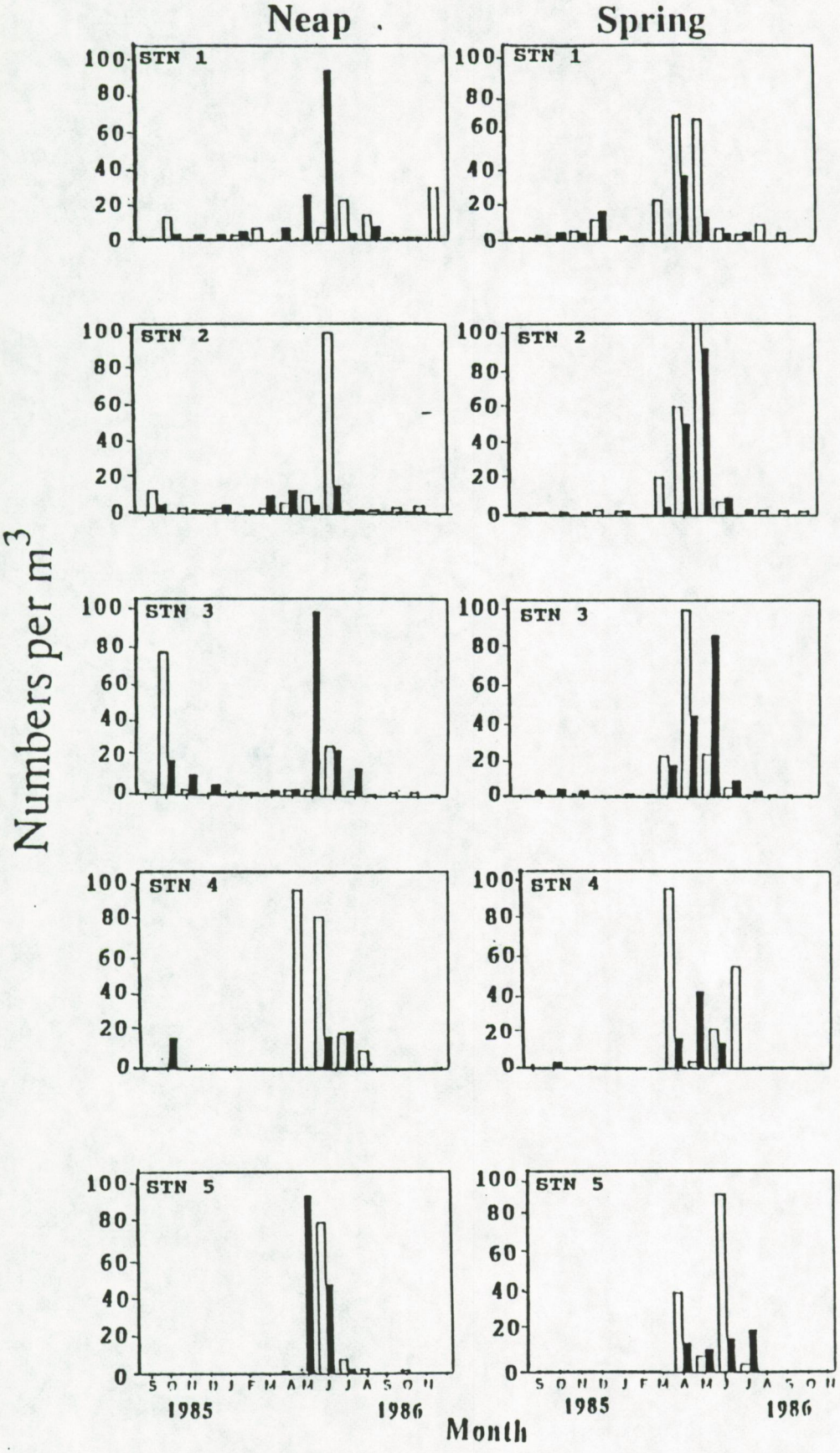


Fig.5.6. Seasonal changes in abundance of Paracalanus spp. in five stations in Tudor creek from Sept 1985 to Nov 1986: for day and night in one neap and one spring in each month. (▫ day; ▪ night) .

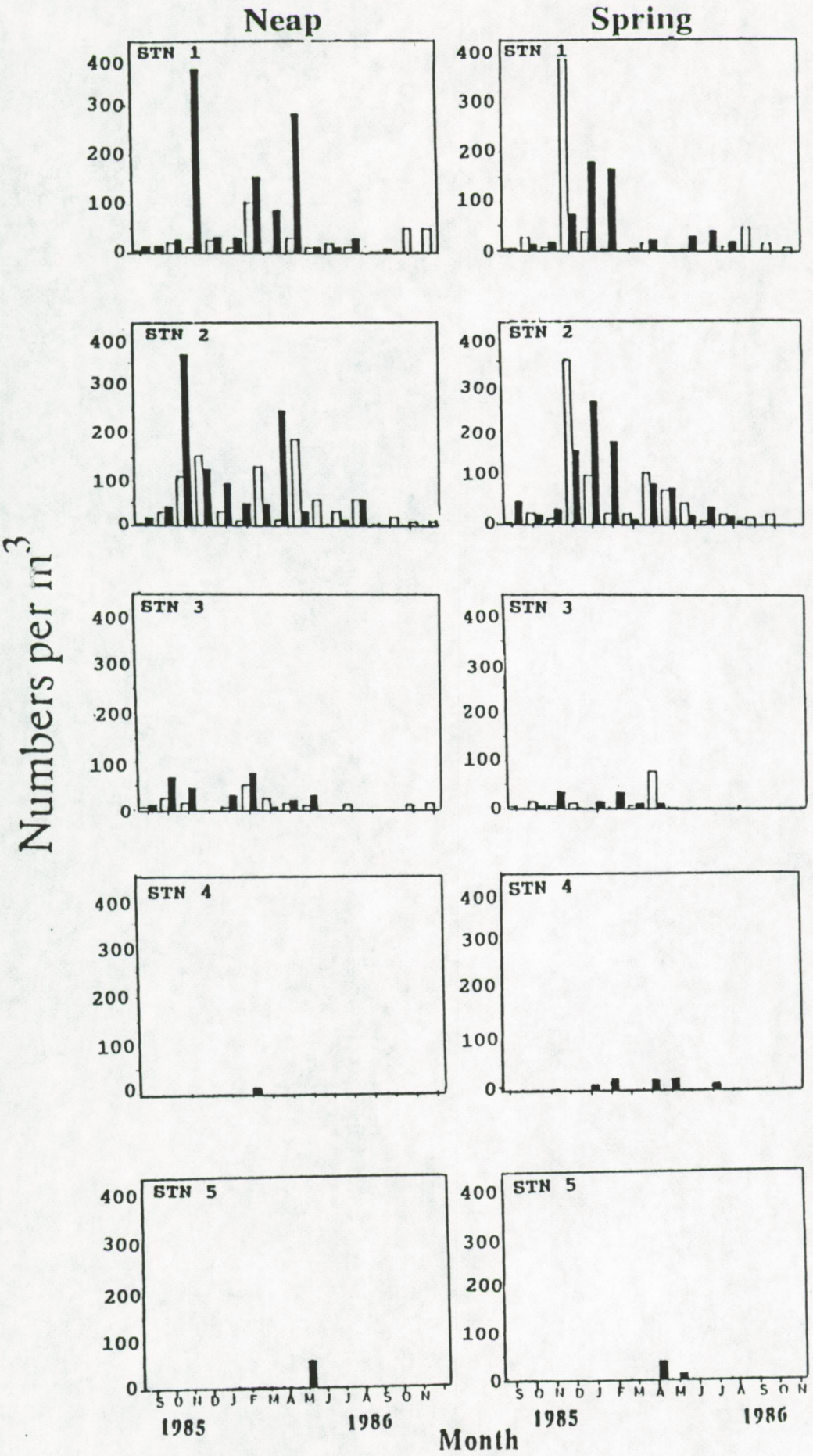


Fig.5.7. Seasonal changes in abundance of Temora spp. in five stations in Tudor Creek from September 1985 to November 1986: for day and night in one neap and one spring in each month. (▫ day; ▪ night).

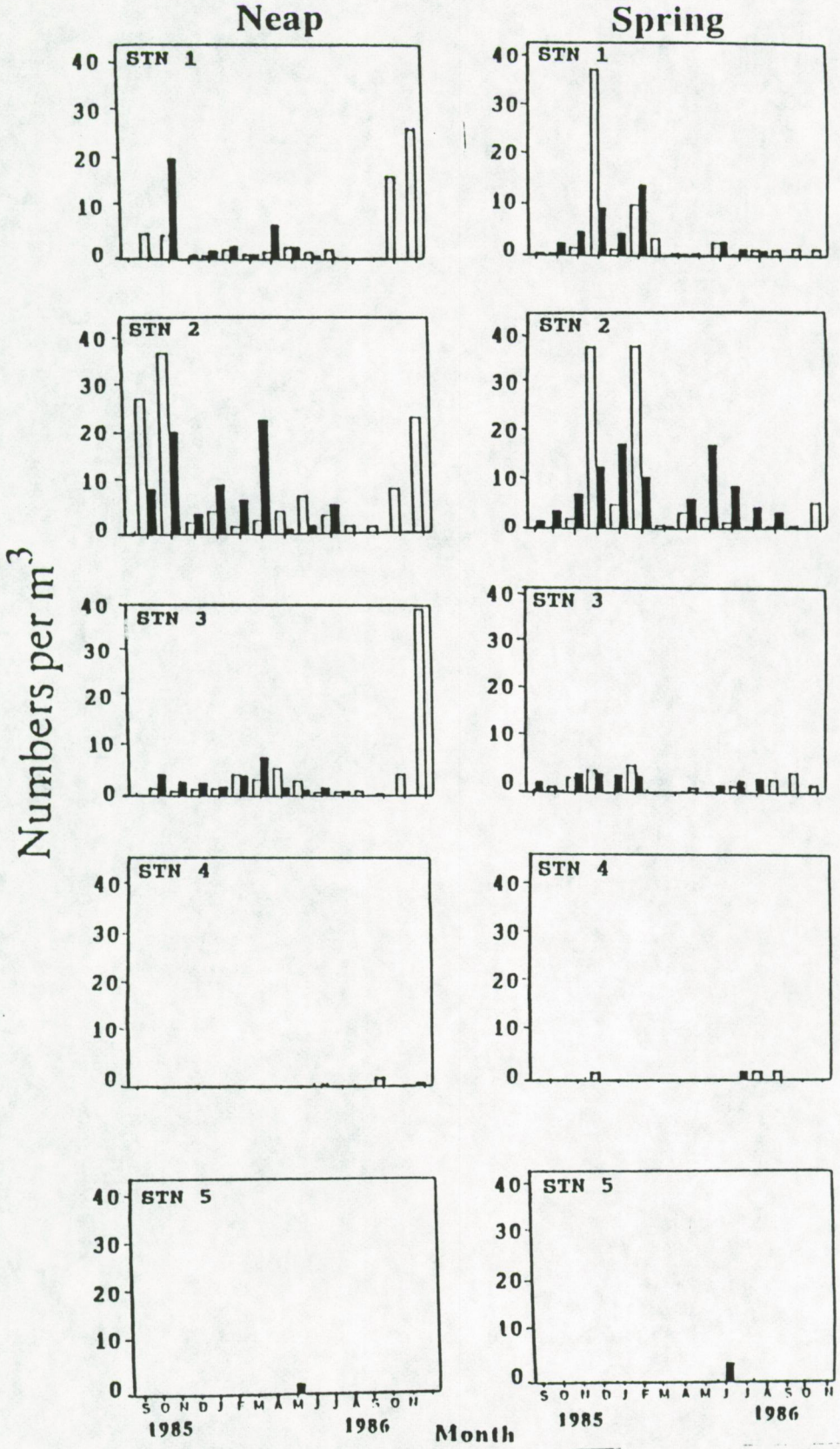


Fig.5.8. Seasonal changes in abundance of Centropages spp. in five stations in Tudor Creek from September 1985 to November 1986: for day and night in one neap and one spring in each month. (▫ day; ▪ night) .

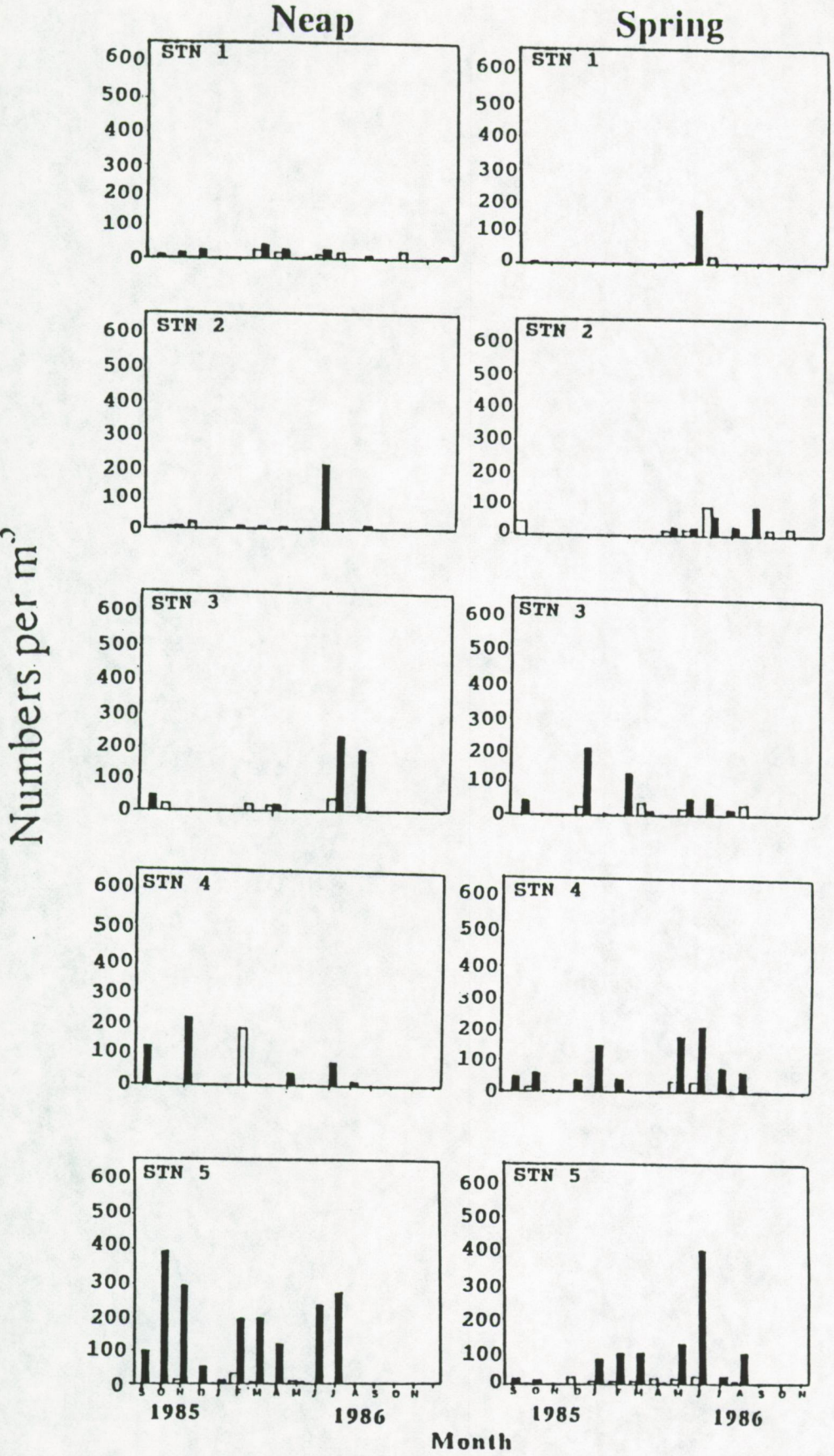


Fig.5.9.Seasonal changes in abundance of Pseudodiaptomus spp. in five stations in Tudor Creek from September 1985 to November 1986: for day and night in one neap and one spring in each month. (▫ day; ▪ night).

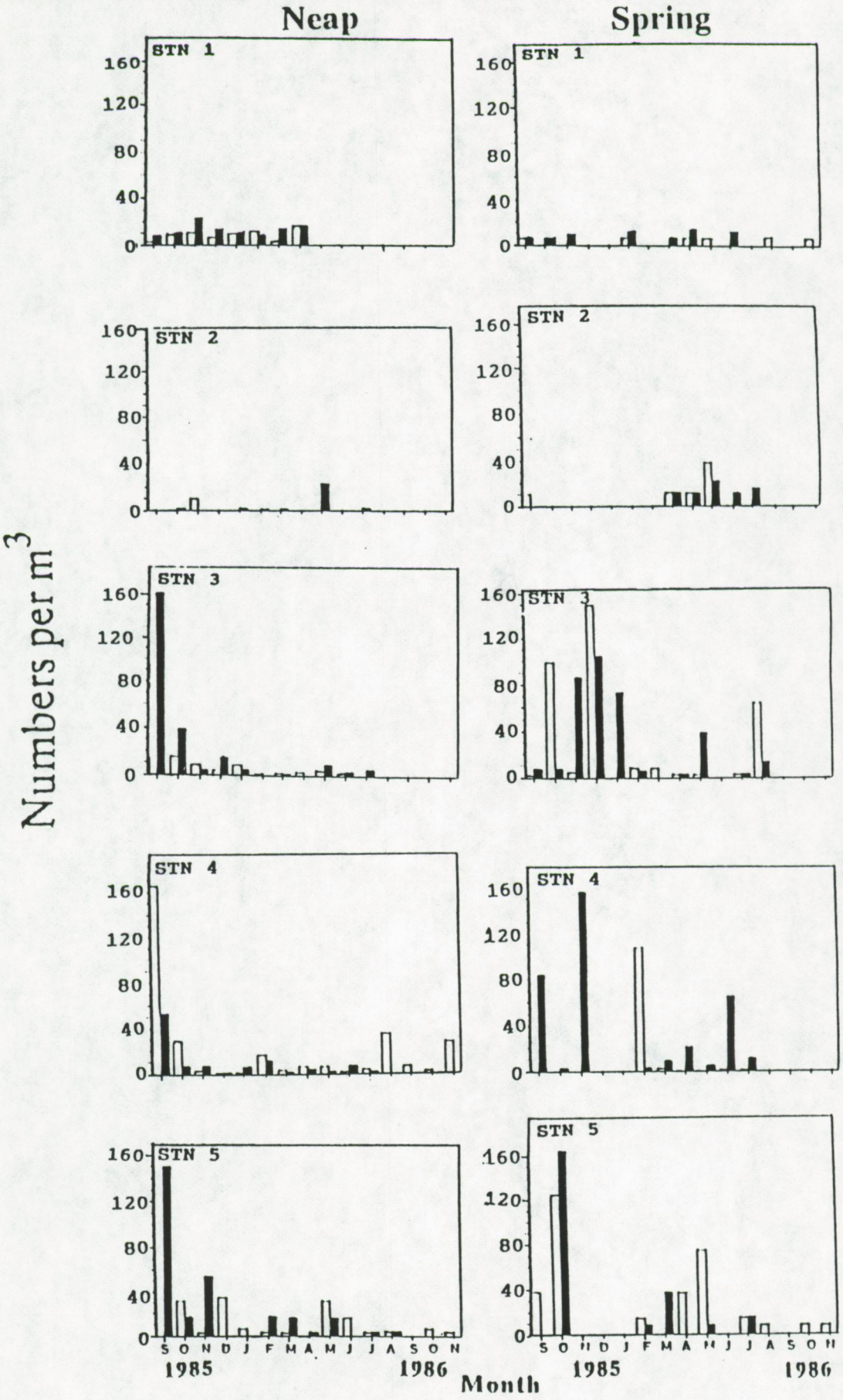


Fig.5.10. Seasonal changes in abundance of Labidocera spp. in five stations in Tudor Creek from September 1985 to November 1986: for day and night in one neap and one spring in each month. (▫ day; ▪ night).

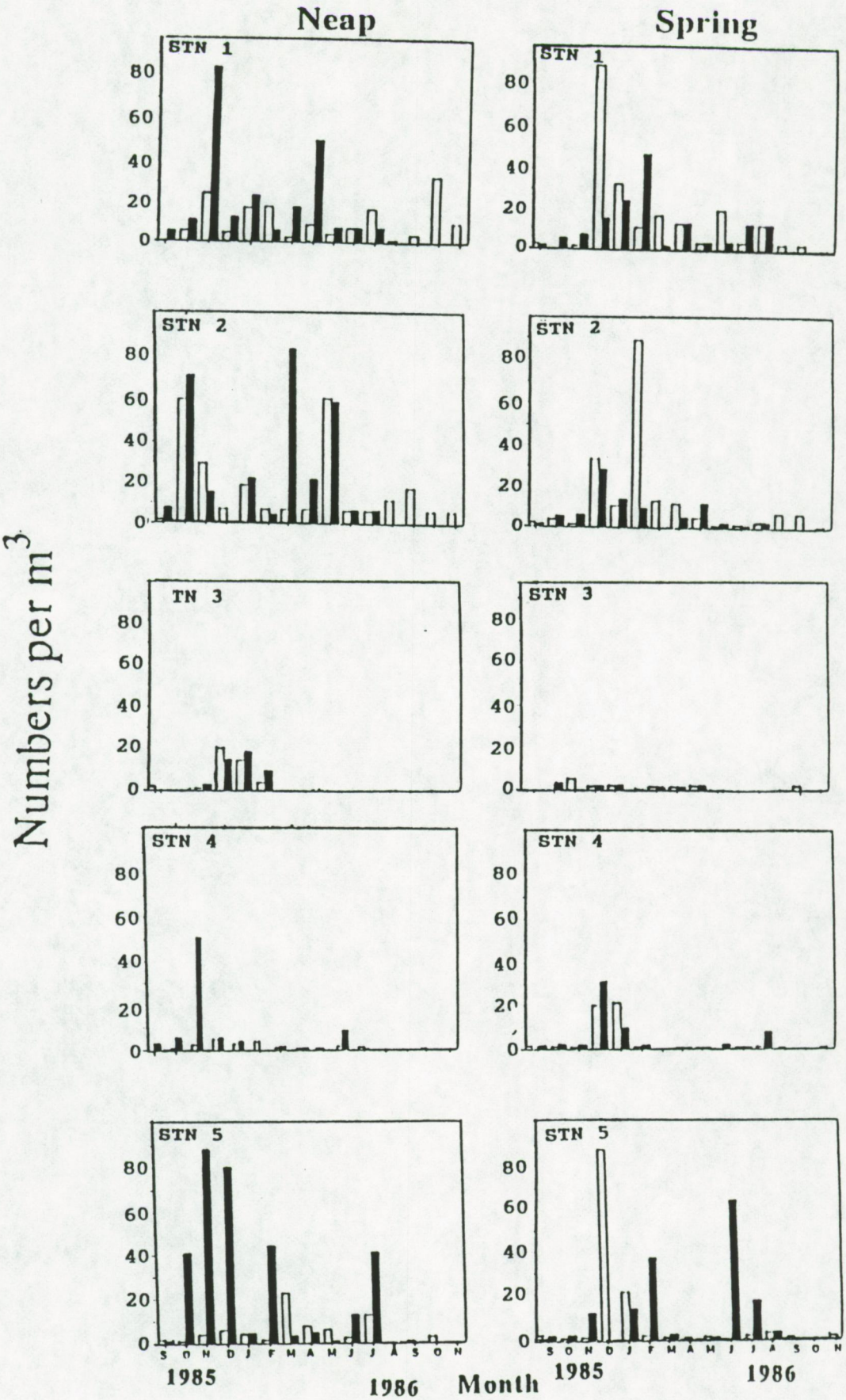


Fig.5.11. Seasonal changes in abundance of Acartia spp. in five stations in Tudor Creek from September 1985 to November 1986: for day and night in one neap and one spring in each month. (▫ day; ▪ night).

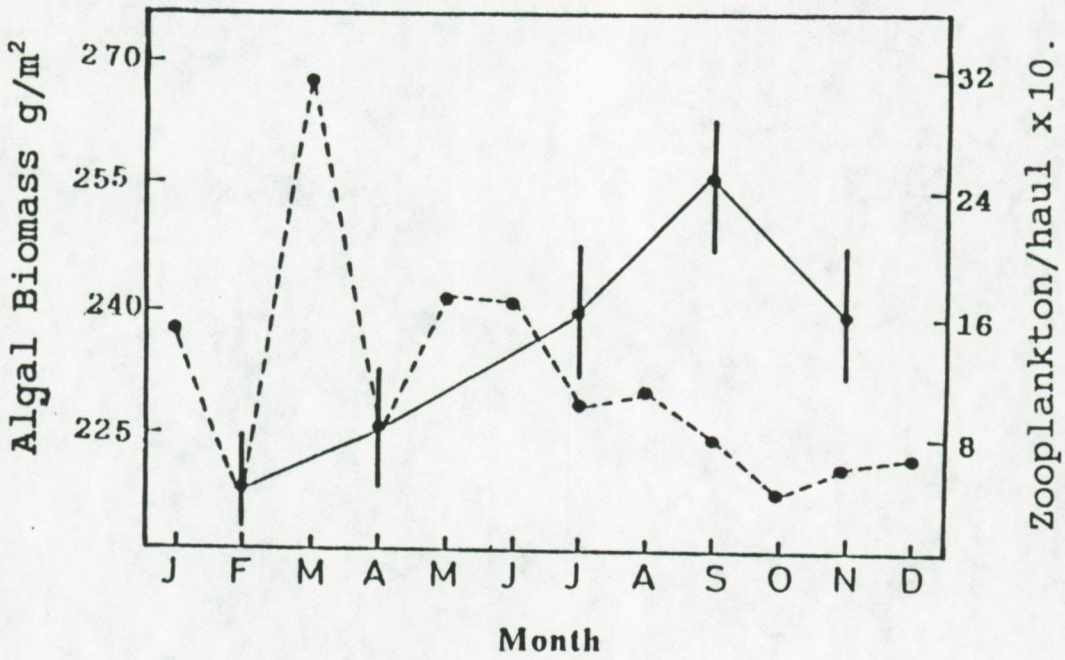


Fig.5.12. Seasonal changes in Zooplankton abundance in near-shore waters off the Tanzanian coast (1969) and average seasonal biomass (1973-74, 0.5 SE) of benthic algae from 13 sites on 2 Kenyan reef platforms. Adopted data from Okera (1974) and Moorjani (1979).-
•-• benthic algae; •—• zooplankton.

Table 5.1: Revis (1988) categorization of the common copepod species which are numerically abundant in the Tudor Creek during the period Nov. 1984 to Oct.1985

Copepod group	Key species	Station found	Time of occurrence
1	Acartia amboinensis	2	March
	Acartia pietschmani	2	March
	Centropages furcatus	1	August
	Acartia bispinosa	1,2,3	December
			March
2	Acrocalanus gibber	1	March
		2	December
	Tortanus barbatus	1,2	December
			February
			March
	Canthocalanus pauper	1,2	July
			December
			March
3	Oncaea venusta	1	December
	Undinula vulgaris	1	May
		2	August
			December
4	Temora turbinata	1	March
		2	August
		3	April
	Paracalanus crassirostris	1,2,3	May,June,
			September
			October
5	Centropages orsinii	2	December
			January

5.1.2 Spring and neap patterns in the plankton

Grove et.al., (1985) illustrated the amplitude of spring tides at Mombasa showing variation with season and the differences between new and full moon.

Annual and tidal abundance are shown for stations 1 to 5 in Tudor Creek in Figs. 5.13 to 5.17. Greatest abundance occur in the long and short rain seasons. While greatest abundance of all copepoda regularly peaks in the rainy months, individual taxa or species may reach their greatest abundance at other times of the year.

Individual copepoda genera and species which show high abundance during rain season and/or reach greatest abundance at other times of the year are shown in Figs 5.18 - 5.25.

The majority of all the high catches occurred on springs. Figs 5.18 - 5.25 show tidal changes in abundance of copepoda species in five stations from Tudor Creek from December 1986 to December 1987. They show that some copepoda species have their greatest abundance during spring tides, while others have theirs in neap tides, and at different months of the year. Figures 5.13 - 5.17 show the densities of zooplankton and copepoda taken from five stations in Tudor Creek. Table 5.2 shows the average abundance of copepoda from five stations in the Tudor Creek for spring and neap tides for the period December 1986 to December 1987.

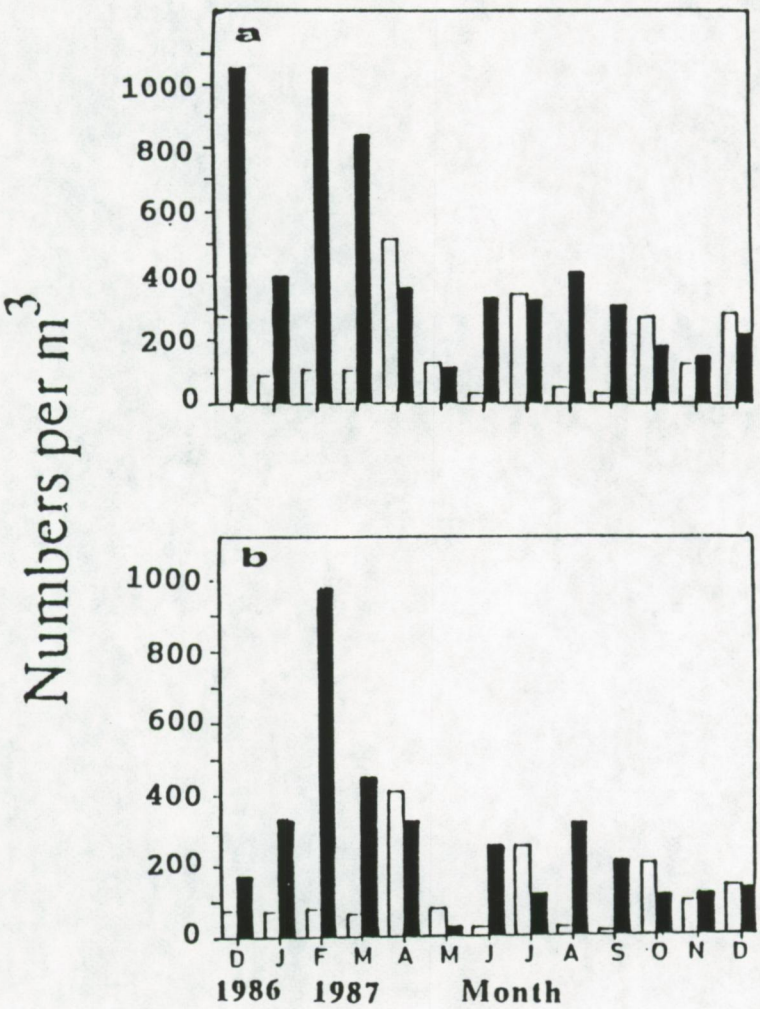


Fig.5.13. Annual variation of (a) Zooplankton and (b) Copepod numbers in station 1 in Tudor Creek from December 1986 to December 1987: for one neap and one spring in each month. (▫ neap, ▪ spring).

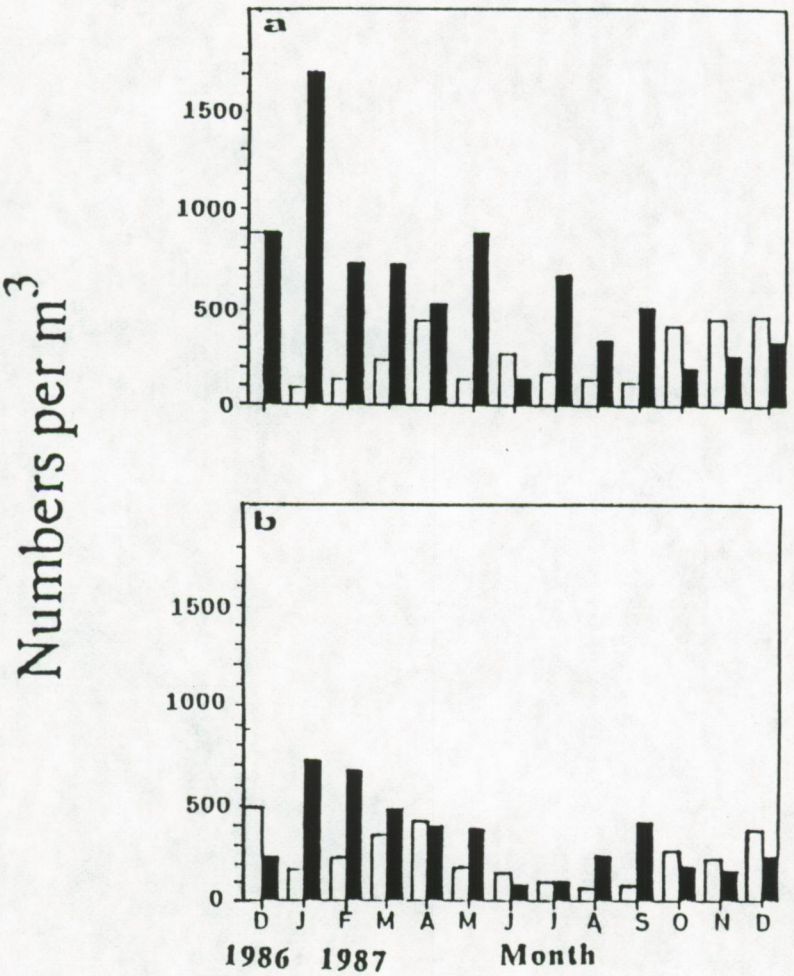


Fig.5.14. Annual variation of (a) Zooplankton and (b) Copepod numbers in station 2 in Tudor Creek from December 1986 to December 1987: for one neap and one spring in each month (▫ neap, ▪ spring).

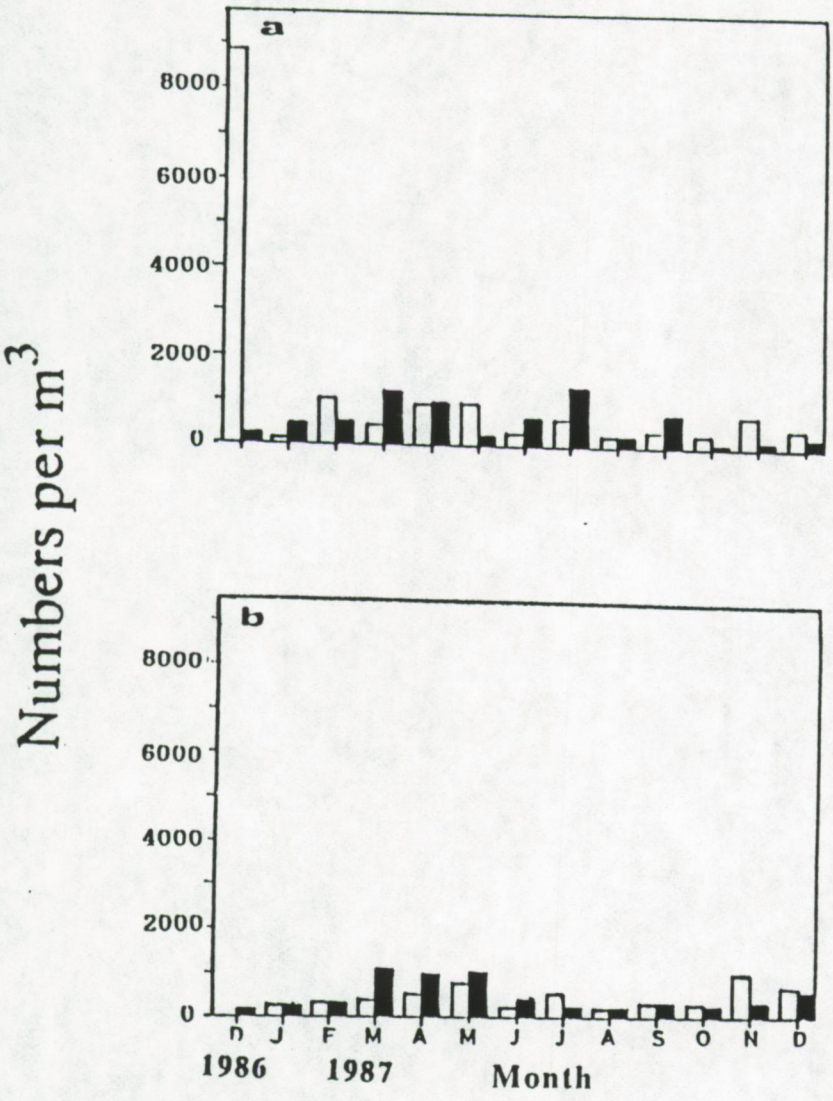


Fig.5.15. Annual variation of (a) Zooplankton and (b) Copepod numbers in station 3 in Tudor Creek from December 1986 to December 1987: for one neap and one spring in each month. (▫ neap, ▪ spring).

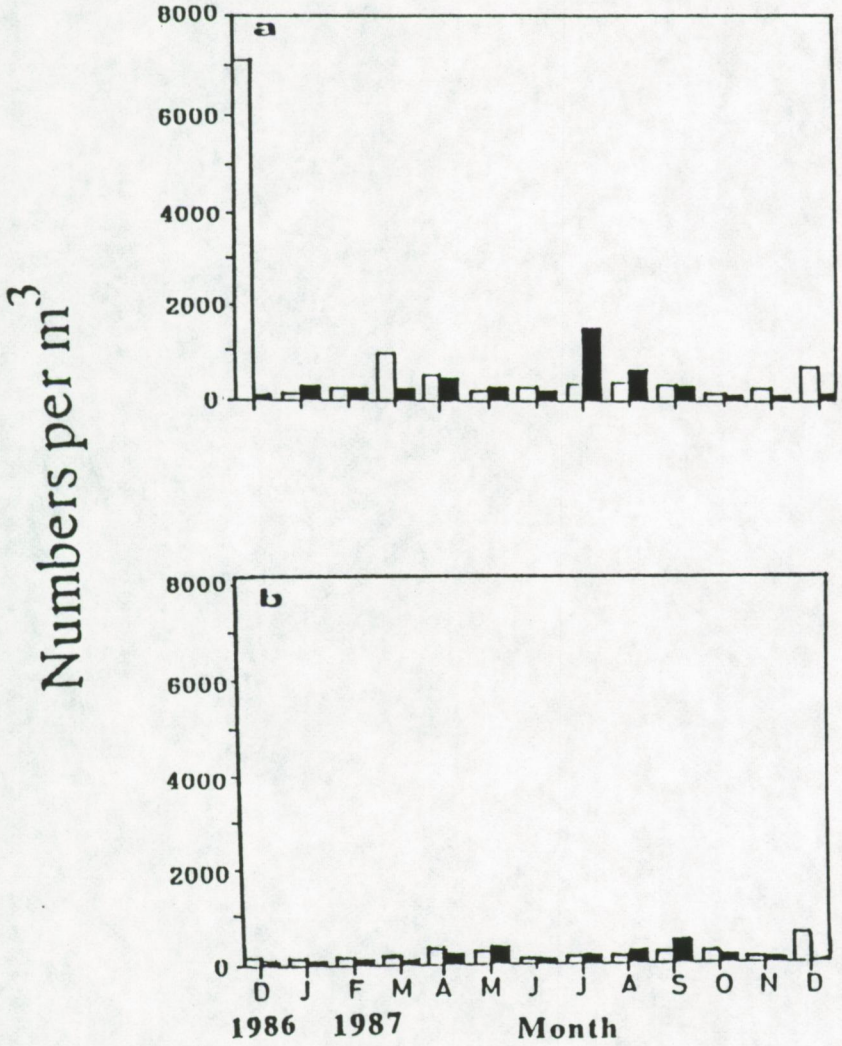


Fig.5.16. Annual variation of (a) Zooplankton and (b) Copepod numbers in station 4 Tudor Creek from December 1986 to December 1987 for one neap and one spring in each month. (▫ neap, ▪ spring).

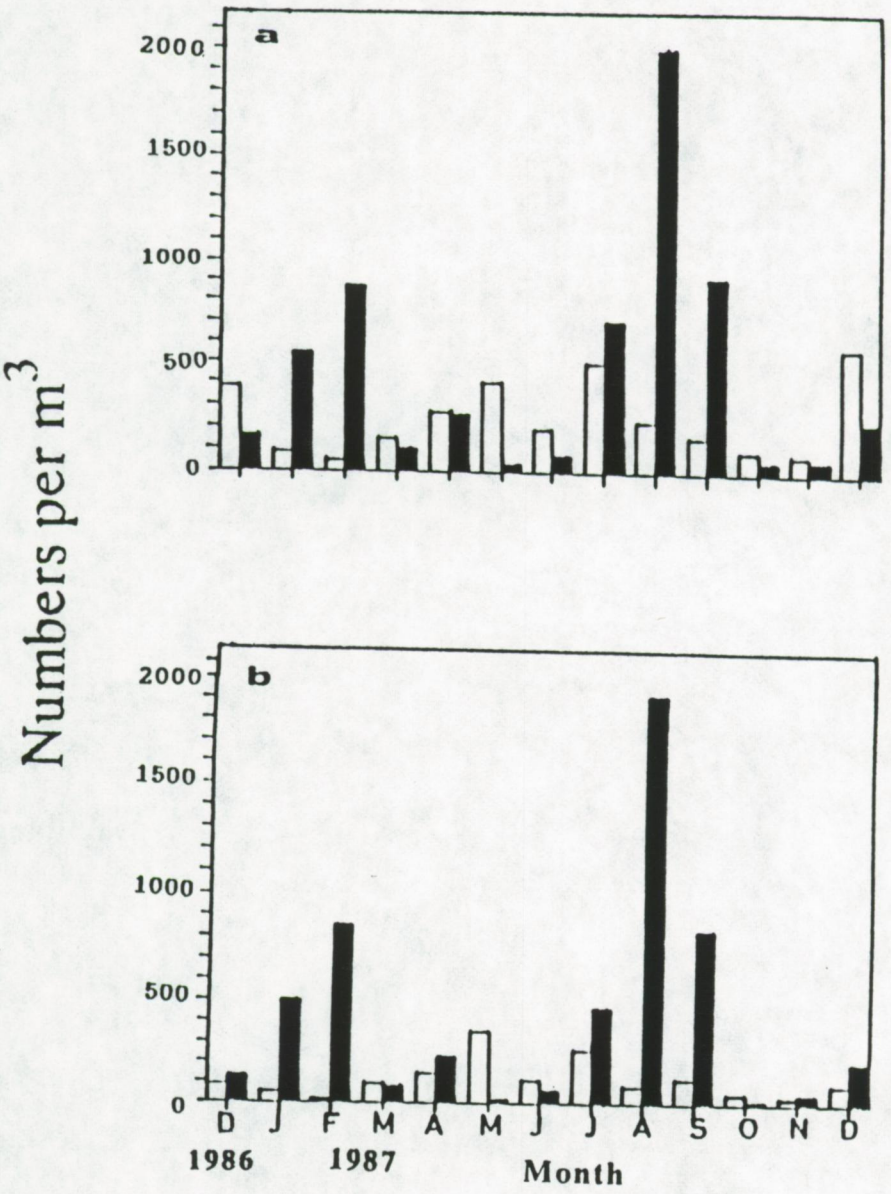


Fig.5.17. Annual variation of (a) Zooplankton and (b) Copepod numbers in station 5 in Tudor Creek from December 1986 to December 1987: for one neap and one spring in each month. (Stn = Station). (▫ neap, ▪ spring).

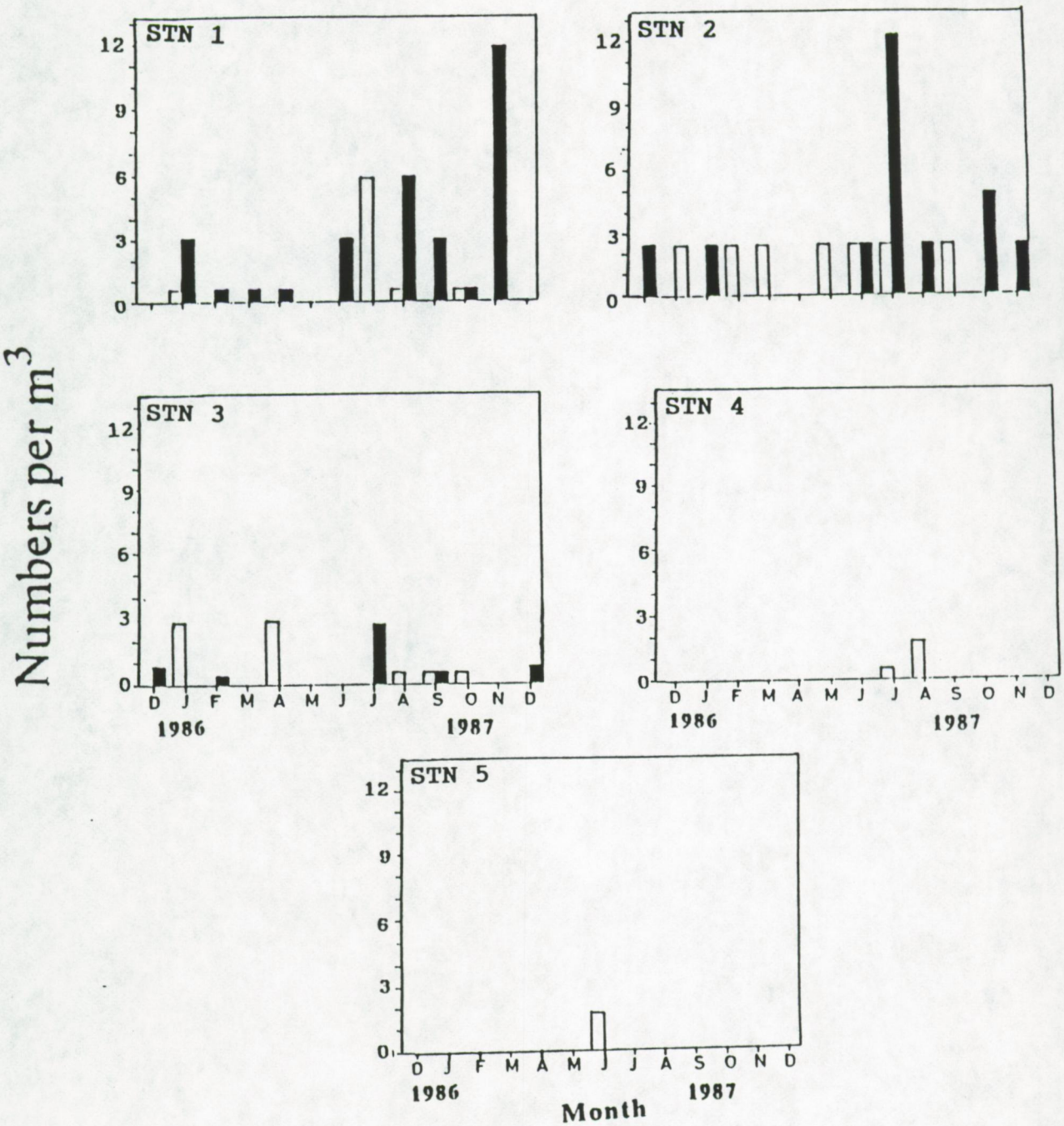


Fig.5.18. Temporal changes in abundance of Undinula vulgaris in five stations in Tudor Creek from December 1986 to December 1987: for one neap and one spring in each month. (▫ neap, ▪ spring).

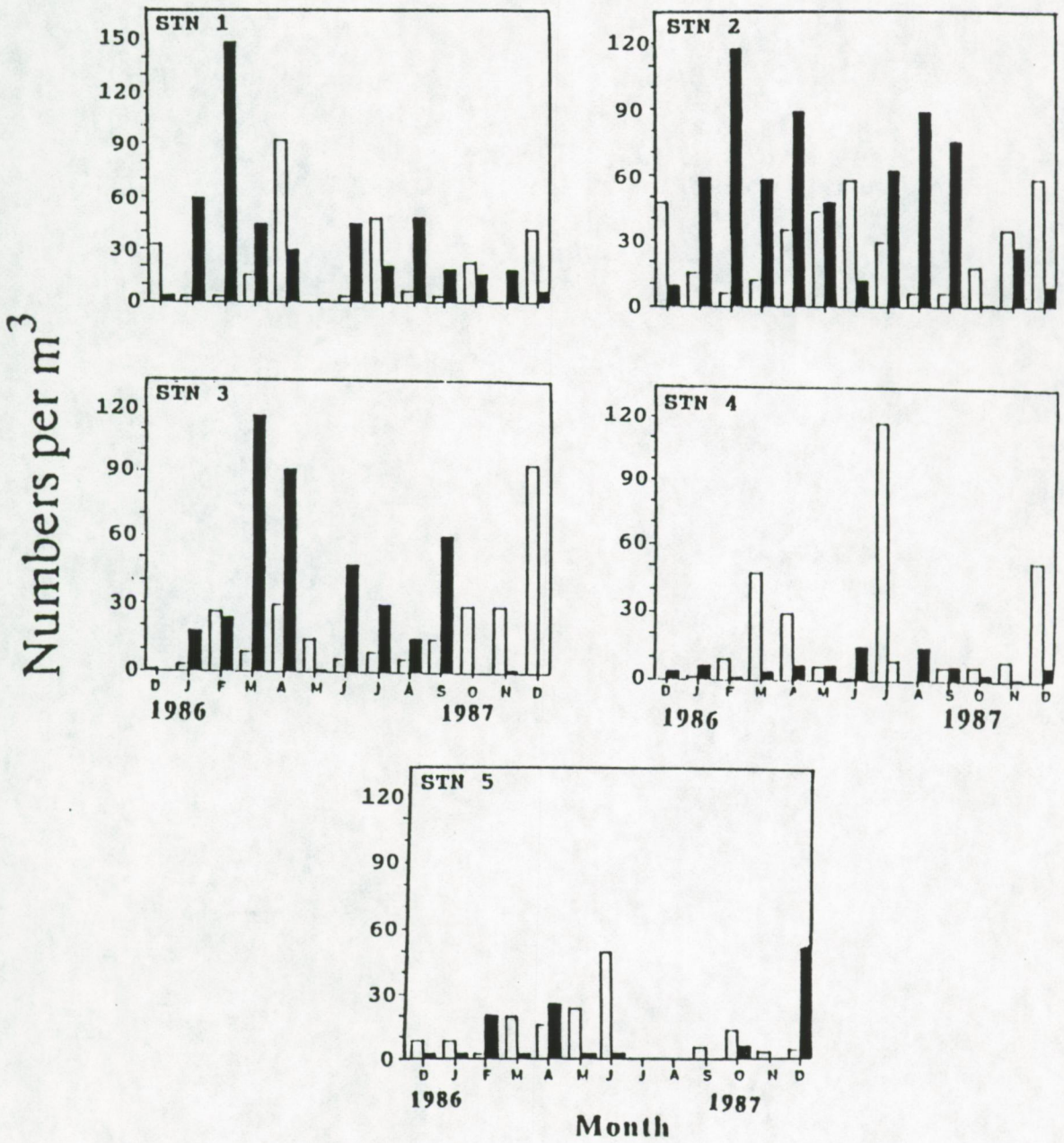


Fig.5.19. Temporal changes in abundance of Acrocalanus spp. in five stations in Tudor Creek from December 1986 to December 1987: for one neap and one spring in each month. (▫ neap, ▪ spring).

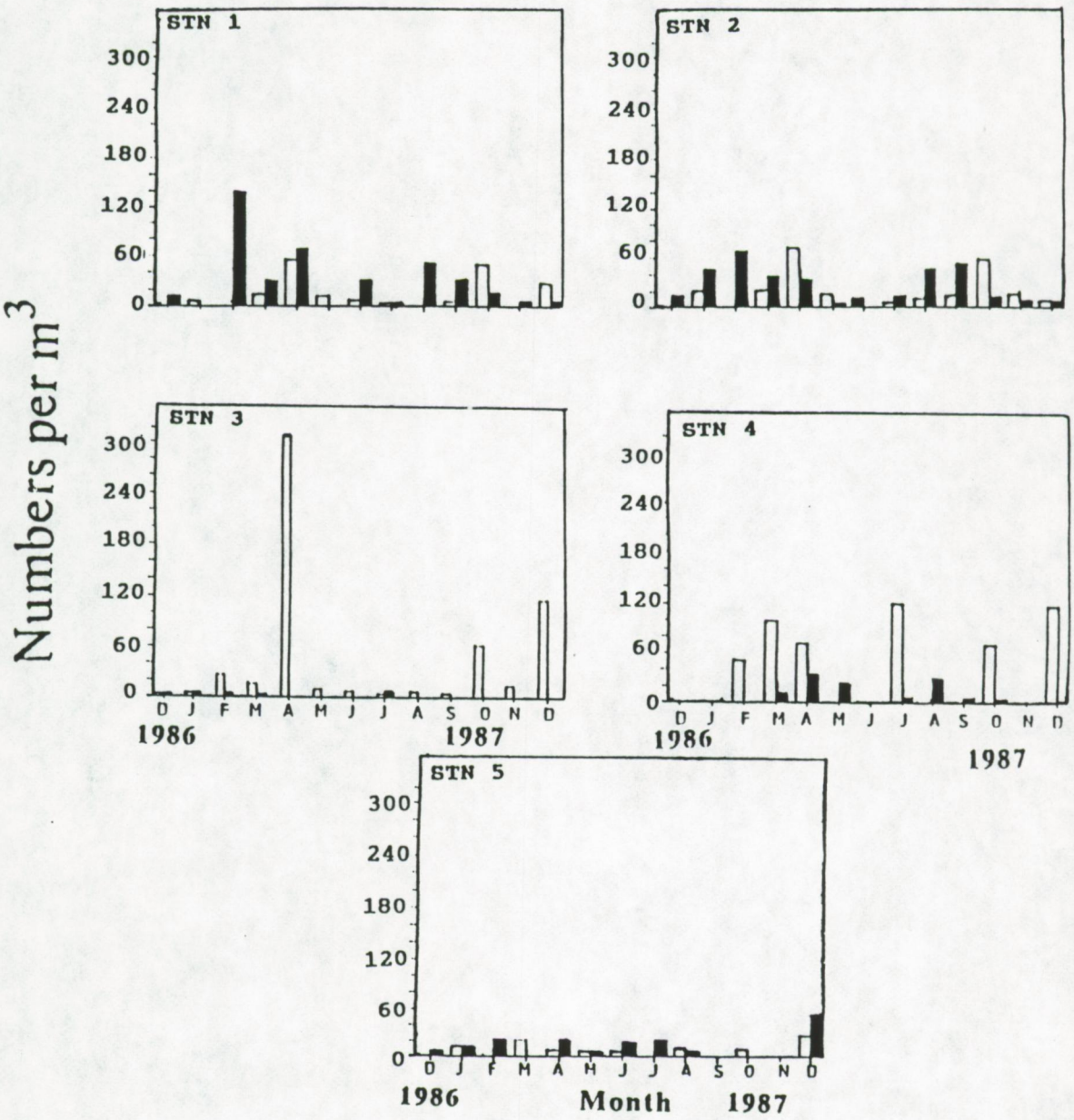


Fig.5.20. Temporal changes in abundance of Paracalanus spp. in five stations in Tudor Creek from December 1986 to December 1987; for one neap and one spring in each month. (▫ neap, ▪ spring).

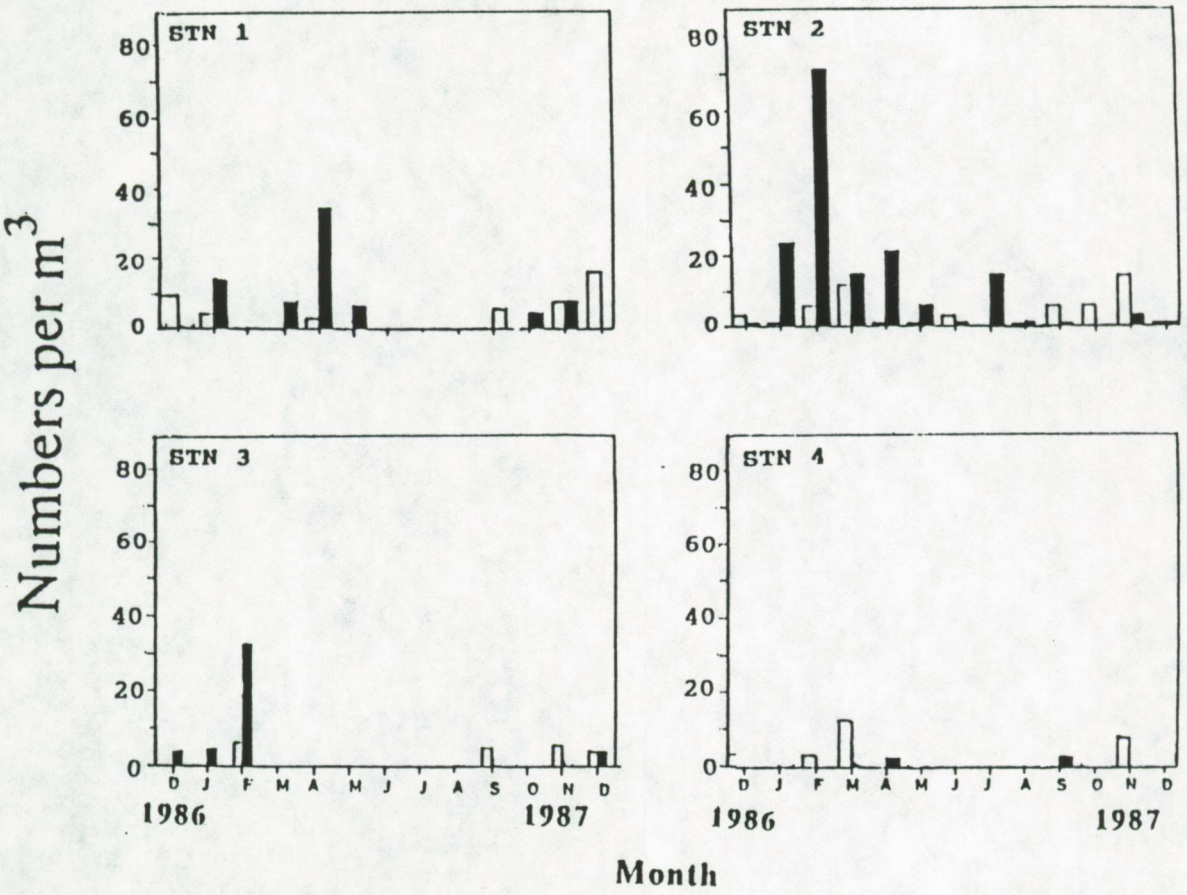


Fig.5.21. Temporal changes in abundance of Temora spp. in five stations in Tudor Creek from December 1986 to December 1987: for one neap and one spring in each month. (▫ neap, ▪ spring).

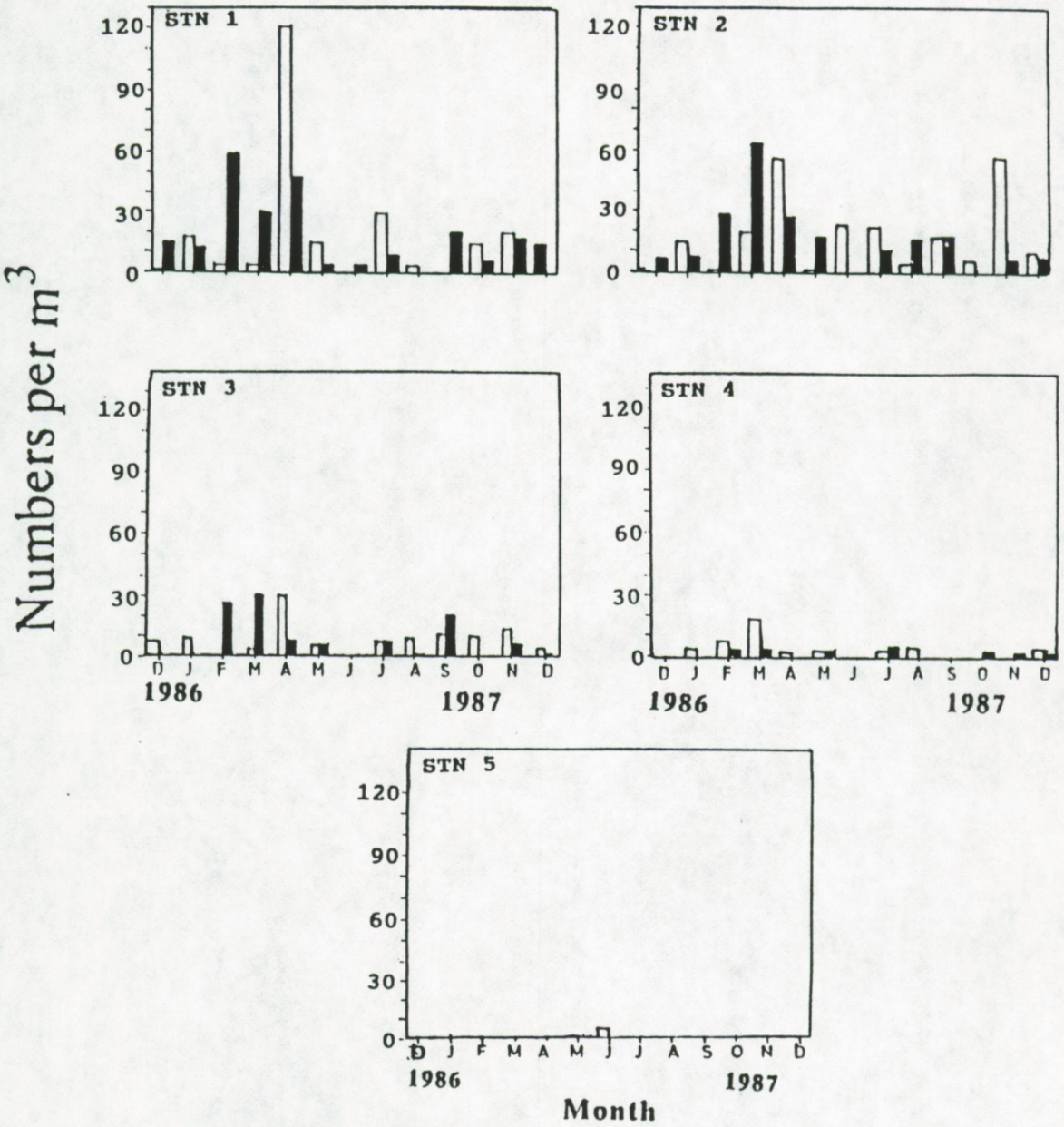


Fig.5.22. Temporal changes in abundance of Centropages spp. in five stations in Tudor Creek from December 1986 to December 1987; for one neap and one spring in each month. (▫ neap, ▪ spring).

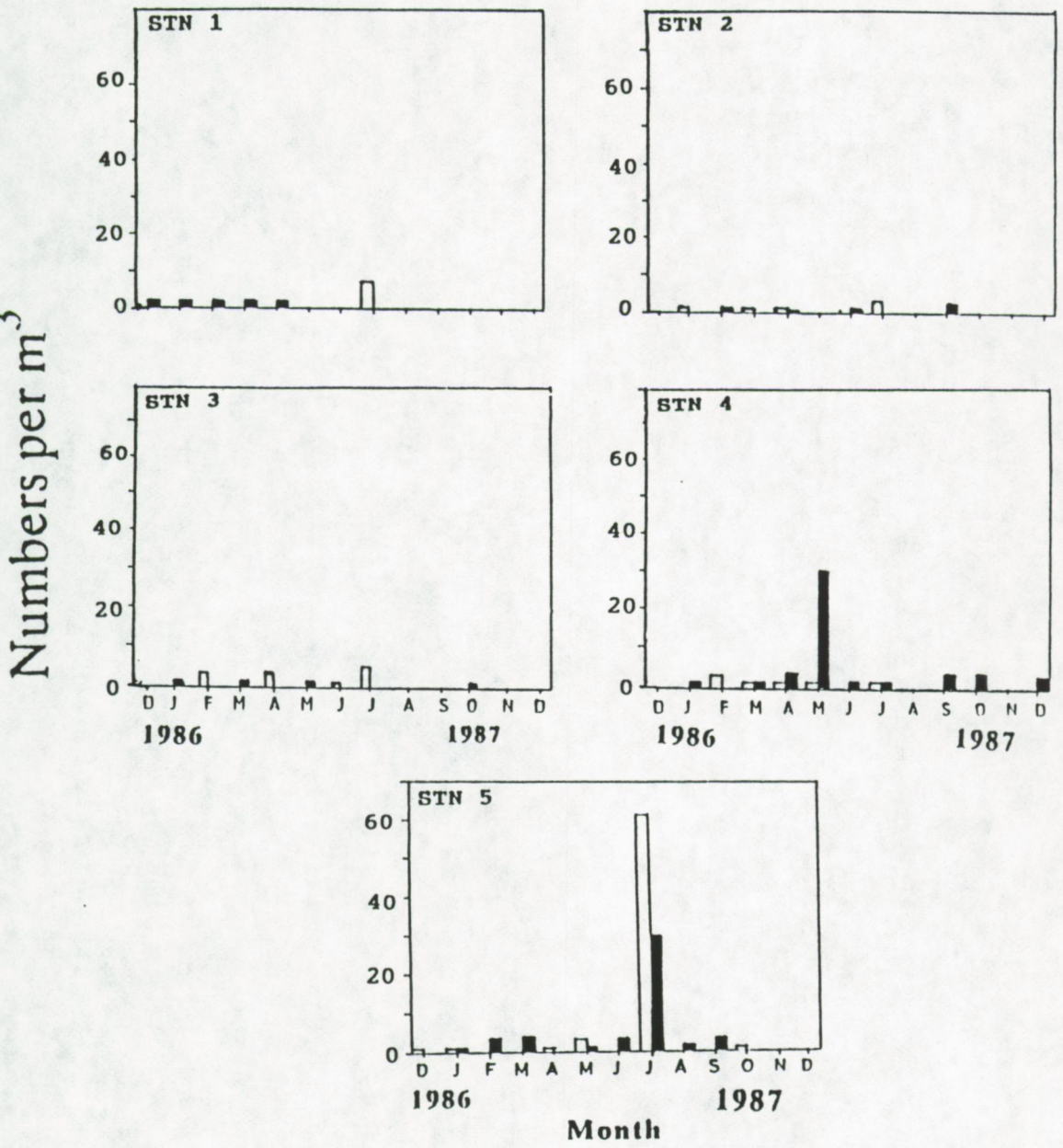


Fig.5.23. Temporal changes in abundance of Pseudodiaptomus spp. in five stations in Tudor Creek from December 1986 to December 1987; for one neap and one spring in each month. (▫ neap, ▪ spring).

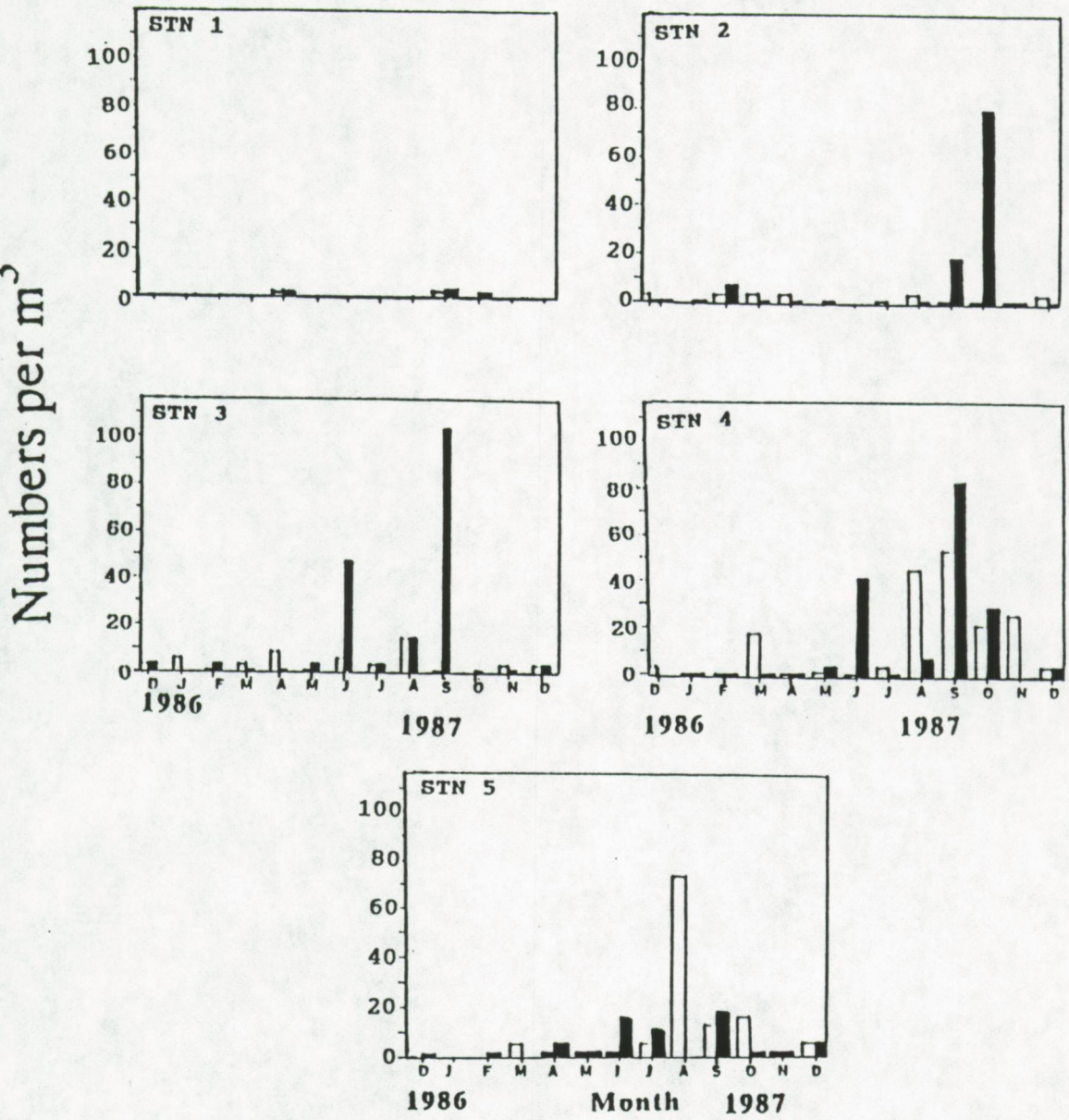


Fig.5.24. Temporal changes in abundance of Labidocera spp. in five stations in Tudor Creek from December 1986 to December 1987: for one neap and one spring in each month. (▫ neap, ▪ spring).

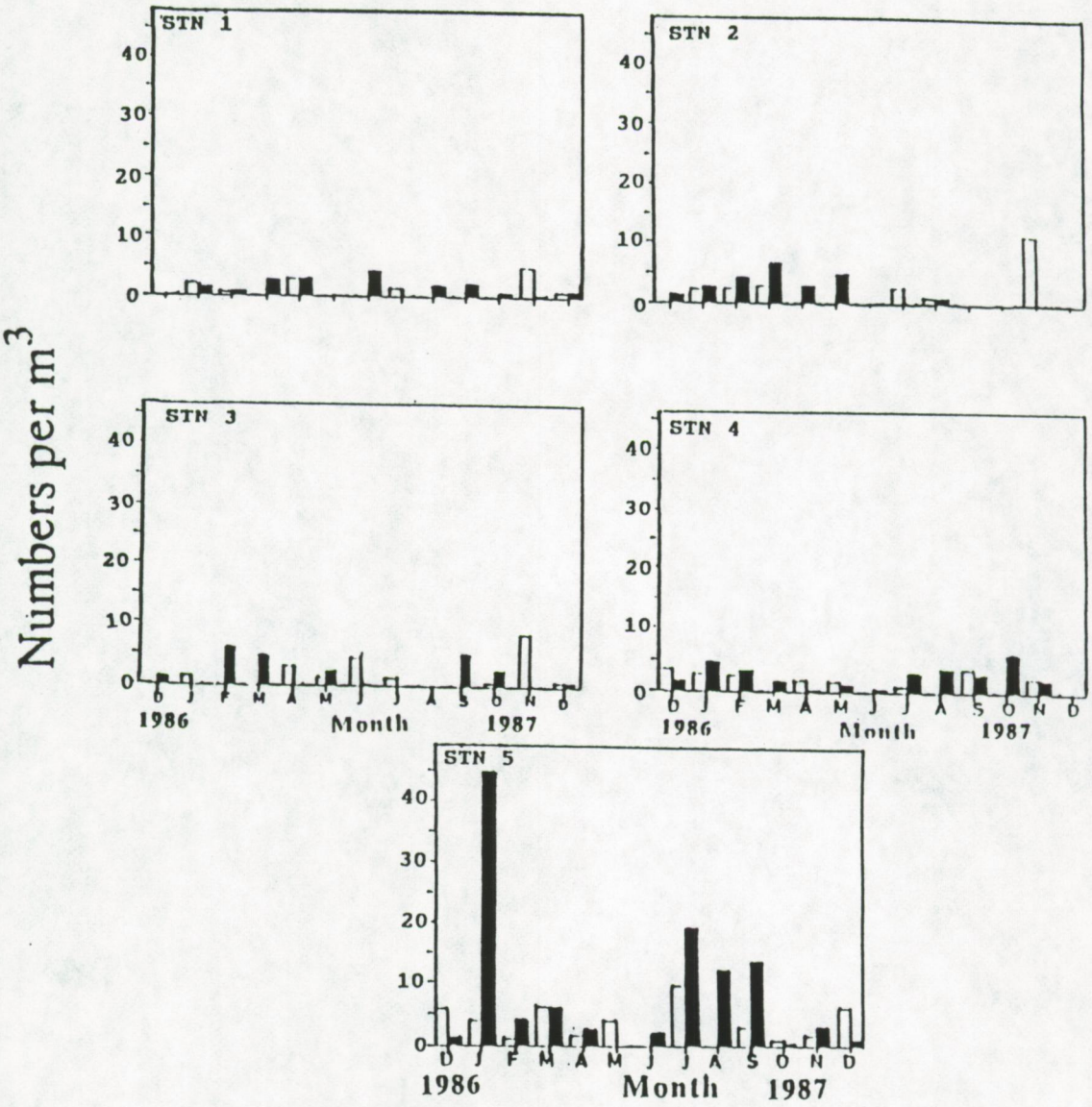


Fig.5.25. Temporal changes in abundance of Acartia spp. in five stations in Tudor Creek from December 1986 to December 1987: for one neap and one spring in each month. (▫ neap, ▪ spring).

Table 5.2. Average abundance of copepoda from the fives stations in the Tudor Creek for spring and neap tides for the period December 1986 to December 1987

STATION	TIDE	COPEPODA(No.10 m^{-3})	SD ±
1	Neap	4,896	299
	Spring	11,224	617
2	Neap	6,904	306
	Spring	13,744	893
3	Neap	8,733	384
	Spring	10,751	506
4	Neap	8,285	397
	Spring	12,814	723
5	Neap	9,329	483
	Spring	20,676	1,296

5.2. The diversity of copepod communities in the Tudor Creek

5.2.1. Introduction

Diversity is a function of two elements, one being the number of species (richness) and the other the "equitability" (evenness) with which individuals are distributed among species.

Diversity indicates the degree of complexity of community structure. Diversity decreases when a community becomes dominated by one or a few species, when individuals of rare species are replaced by individuals of a more common species, or when one or a few species rapidly reproduce.

The use of diversity and evenness indices is well established in recent ecological literature. Diversity is one of the most important parameters used in the description of a community. Several theories relating diversity to other phenomena as competition, predation and stability have been

proposed (Pianka, 1966). Coull (1972) studied the diversity of harpacticoid copepods. Very little studies on diversity of copepods have been done in the tropics. Therefore the aim of this study was to investigate the factors influencing copepod diversity in the Tudor Creek.

5.3. Diversity

The materials and methods have been explained in Chapter 2. The investigation covers the five stations in Tudor Creek, during the period December 1986 to December 1987. The diversity index used is as described by Margalef (1951). The function used is defined by:

$$D = \frac{S-1}{\ln N}$$

Where S is the number of species and N is the total number of individuals in the sample. The Simpson's index (1949) was also used. This index expresses the probability that two specimens taken at random belong to the same species. Such a probability (λ) is

$$\lambda = \sum_{i}^{S} \frac{n_i(n_i-1)}{N(N-1)} \qquad (1)$$

N is the total number of individuals, and n_i is the number of individuals of the species i.

5.4. Results

The five stations yielded 99 species of copepods as shown in table 4.3. Station 1 ,2 and 3 yield most species (83, 54 and 50 respectively); while the inner creek stations have a low number of species (15 at stn 4 and 8 at stn 5). This clearly shows that species richness is much higher in stations 1, 2 and 3.

The species composition is totally different for the species-rich stations 1, 2 and 3. On a total of 99 species, only 37 are specific in station 1 and 4 specific in station 2. In station 3, 3 species were specific, none was specific in stations 4 and 5 respectively.

The diversity of the copepod communities at five stations was calculated (table 5.3).

The data in table 5.3 show that the diversity is higher in station 1 than station 5. The probability that two specimens taken at random belong to the same species is higher in station 5 than in station 1 (table 5.2).

Table 5.3: Diversity of copepods in the Tudor Creek during the period December 1985 to December 1986, shown by both Margalef (M) and Simpson (S) indices

STATION	DIVERSITY	
	M	S
1	3.704	0.173
2	3.434	0.217
3	2.973	0.240
4	2.932	0.247
5	1.979	0.378

5.4.1. Comments

The diversity of the investigated copepod communities shows a clear pattern: diversity is lowest at station 5, it is probably influenced by the environmental conditions such as temperature and salinity which are most extreme in station 5 as opposed to station 1 in Tudor Creek. The shallowness in station 5 probably plays a role as well as turbidity. This accounts for a few species specially adapted to more extreme conditions.

The number of Pseudodiaptomus stuhlmani and Acartia natalensis in station 5 is found to be very much higher than the number of species of other taxa in the same biotope indicating a high dominance and high degree of specialization in the group.

Higher diversity is found in station 1 (table 5.3).This may be attributed to the environmental conditions in station 1 which are slightly different than those in station 5. These are: Salinity, temperature, water depth and turbidity.

Okera's (1974(a)) nearshore zooplankton study (20m deep, vertical tows at $0.3ms^{-1}$), indicates that zooplankton in Tanzania is most abundant during late NE and early SE monsoons and probably lags somewhat behind phytoplankton peaks (Fig. 5.12). The present study (Figs. 5.1 to 5.11) agrees with the results obtained by Okera (1974a).

This distinct seasonality in the tropical Indian Ocean is quite different from the known lack of seasonality of very small variations in phytoplankton production in the tropical Atlantic Ocean (Menzel & Ryther, 1960; Owen and Zeitschel, 1970). The numerous studies in the Atlantic Ocean have led various authors (Parsons and Takahashi, 1973; Boney, 1975) to generalize about the lack of seasonality in tropical zooplankton communities. However, it is apparent, based on the present study, that this generalization is not altogether valid for the tropical Indian Ocean.

Revis 1988 reported 12 copepod species in Tudor Creek which were the most numerically abundant and categorized them into 5 main groups (Table 5.1).

The present study is in agreement with the five grouping of copepods reported by Revis (1988). Except we found seventeen copepod species which were numerically abundant (Fig 5.2).

5.5 Effects of preservation on copepod dry weights

5.5.1. Introduction

We use the dry weight of non-preserved animal as a parameter for its biomass but this is not always possible and/or easy. The individual dry weights are easier to obtain from samples fixed in formalin. But the animals fixed in formalin have dry weights which differ from the fresh dry weights Omori (1978) and Daro and van Gijsegem (1984). So a series of biomass measurements was done, first on animals without being fixed in formalin, freshly collected sample, then on samples fixed on formalin for two months, and more than a year.

5.5.2. Results

Table 5.4 shows changes of dry weight through fixing the samples in formalin. Preservation method in formalin show a reduction in the dry weight. The average loss in weight in percentage for all copepods examined is 46.1.

A decrease in dry weight is still measured after two months of storage and was least after one year.

The dry weight was greatest in adult females (see Table 8.4). This great change is not so evident in the adult males and is probably associated with the reproductive capacity of the females.

Table 5.4.Change of dry weight of Copepods through fixing in formalin.

Species	1	2	3	4
Canthocalanus pauper	43.4	30.6	23.4	46.1
Undinula vulgaris	147.4	101.3	76.1	48.4
Rhincalanus cornutus	108.1	80.9	64.9	40.0
Acrocalanus spp.	10.9	6 9.3	8.3	24.3
Eucalanus spp.	74.7	56.1	36.86	50.7
Paracalanus spp.	20.1	15.6	10.59	47.3
Pseudodiaptomus sp.	22.4	17.0	11.9	46.9
Temora turbinata	56.6	40.7	25.4	55.1
Centropages orsinii	51.9	35.9	24.1	53.6
Labidocera orsinii	182.0	115.6	92.8	49.0
Acartia amboinensis	22.4	15.0	8.7	61.2
Oithona spp.	7.5	5.6	3.4	54.7
Macrosetella gracilis	26.1	18.6	13.2	49.4
C. parathompsoni	41.2	36.7	27.6	33.1
Temora discaudata	37.2	28.7	21.9	41.1
Scolecithrix danae	101.7	75.8	49.0	51.8
Pontellina spp.	105.0	63.8	56.8	45.9
Pontellopsis herdmani	99.0	85.0	72.4	26.9
Candacia catula	47.4	28.0	26.1	44.9
Calanopia elliptica	54.6	36.7	26.0	52.4
Average				46.1

Codes used are :

1 - Dry weight of copepods without formalin

2 - Dry weight of copepods in formalin for two months

3 - Dry weight of copepods in formalin for one year

4 - Percentage loss in body weight.

5.6. Discussion

Presumably when the copepods are fixed in formaldehyde, body fluids are either leaching from the copepods or being exchanged with the surrounding preservative fluid. The use of 4% formaldehyde solution more than doubles the osmotic pressure of sea-water (Steedman, 1976) and this hyper- osmotic pressure could cause loss of body fluid.

The effects of fixation and preservation of zooplankton on loss of weight, have been reviewed by Steedman (1976). Lasker (1966), Fudge (1968), Hopkins (1968), and Omori (1970, 1978) used formaldehyde as a preservative and all reported a loss of dry weight from crustacean zooplankton compared with the fresh weight. Daro and van Gijsegem (1984), working on five dominant copepods in the Southern Bight of the North Sea, showed values of dry weight of preserved animals are on average 43% lower than 'live' dry weight values. The results of the present study are in agreement with the results in the literature.

5.7. Trends in biomass and seasonal changes of plankton

The common copepod species which constituted about 90% of the total copepod biomass are: Undinula vulgaris, Acrocalanus spp., Paracalanus spp., Temora discaudata, Temora turbinata, Centropages orsinii, Pseudodiaptomus stuhlmani, Labidocera orsinii, and Acartia spp. Illustrations are given for only the common copepod species.

A detailed presentation of the seasonal changes in individual weights of the dominant adult (males and females) copepods is shown in Figs. 5.26 - 5.34. On figures 5.35 - 5.43 we averaged all data obtained per species and per station in order to show the differences along the creek.

Finally, combining numbers and individual weights we showed on Figures 5.44 - 5.51, the seasonal changes in biomass expressed (m^{-3}) for the same dominant copepods, at day and night.

The major observable pattern in changes of biomass on both spring and neap tides is a great increase in the numbers of copepods

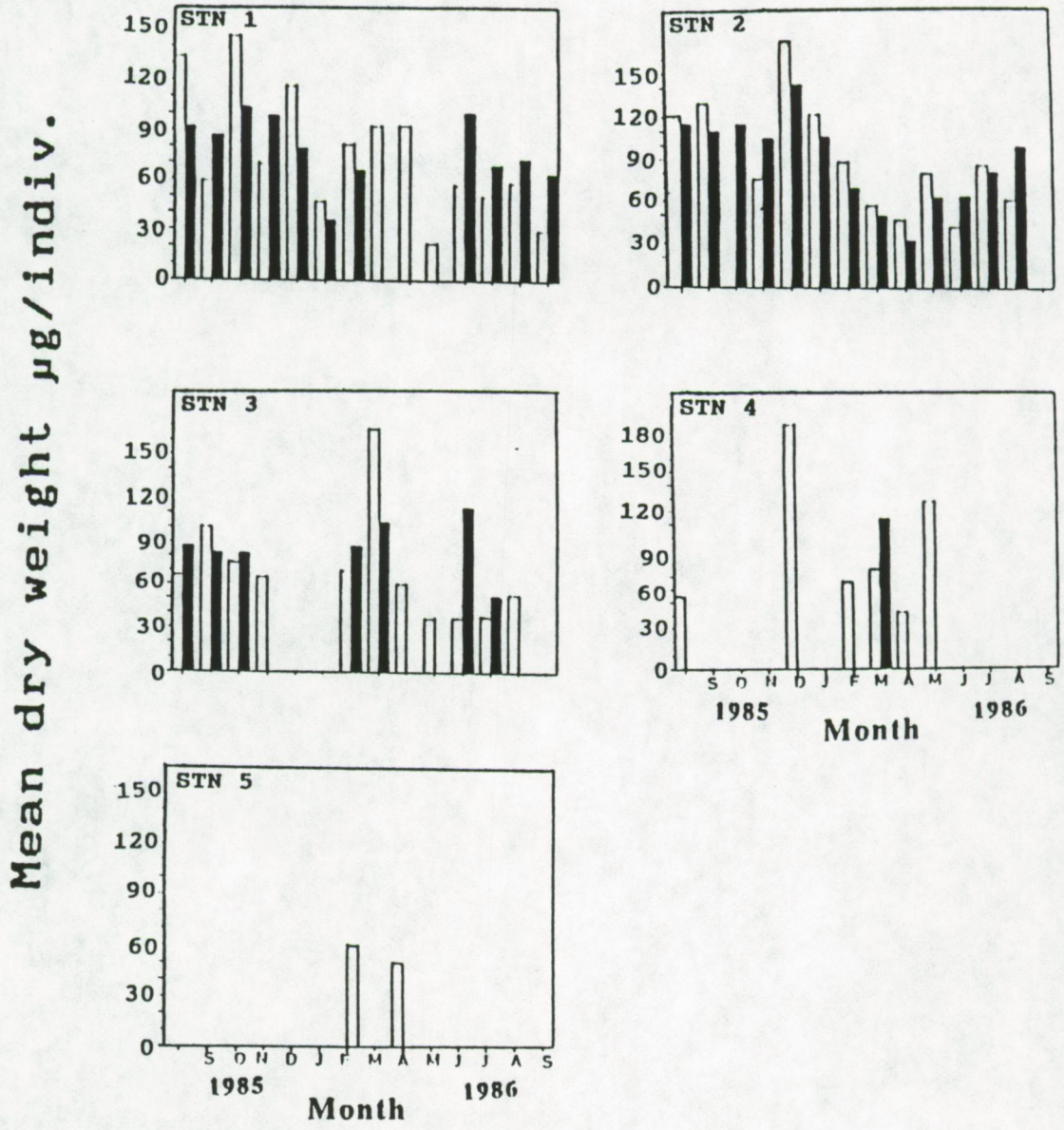


Fig.5.26.Seasonal changes in mean dry weight (μg) Undinula vulgaris in five stations in Tudor Creek from September 1985 to September 1986. (▫ ♀; ▪ ♂).

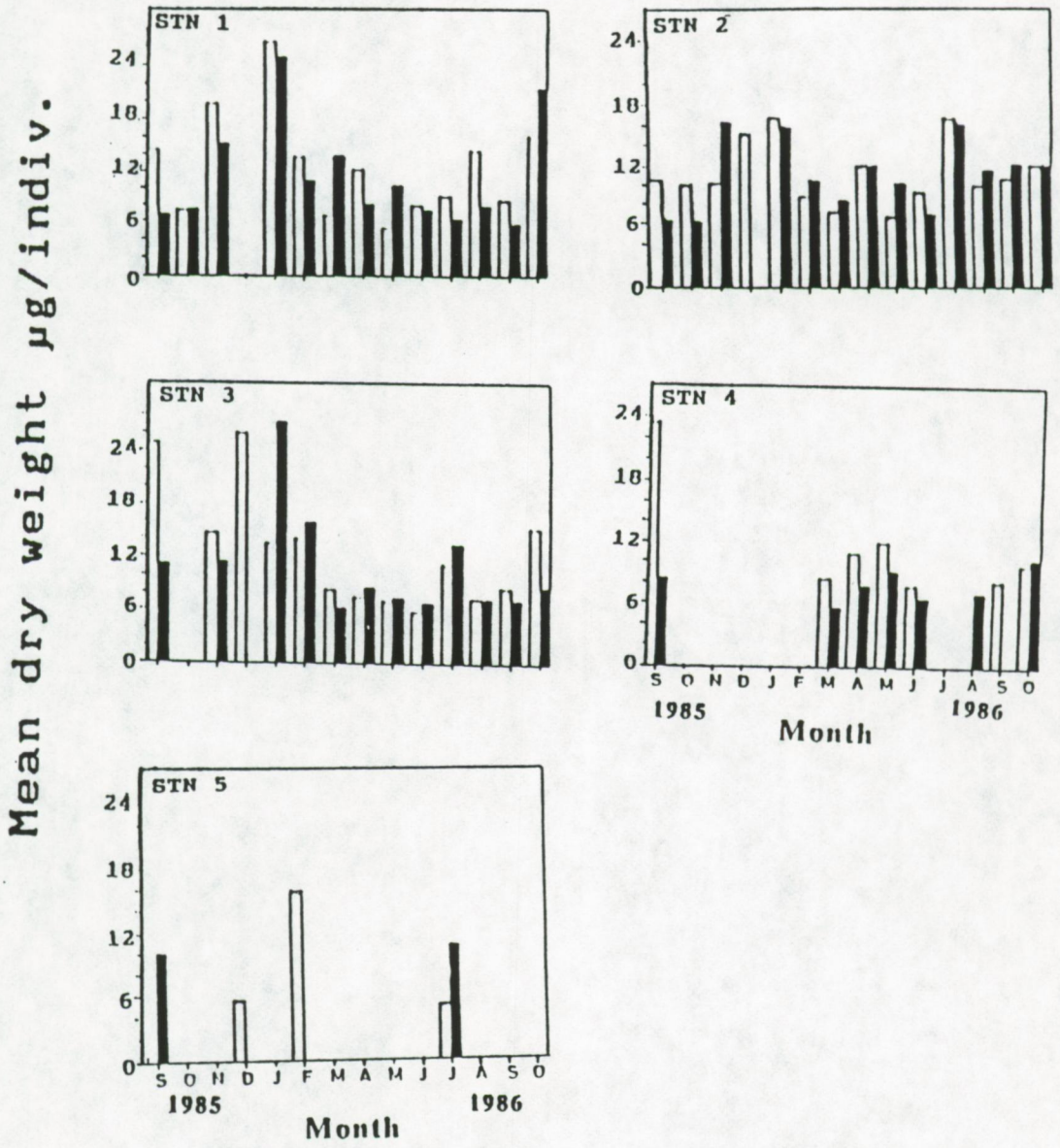


Fig.5.27.Seasonal changes in mean dry weight (μg) of Acrocalanus spp. in five stations in Tudor Creek from September 1985 to September 1986. (▫ ♀; ▪ ♂).

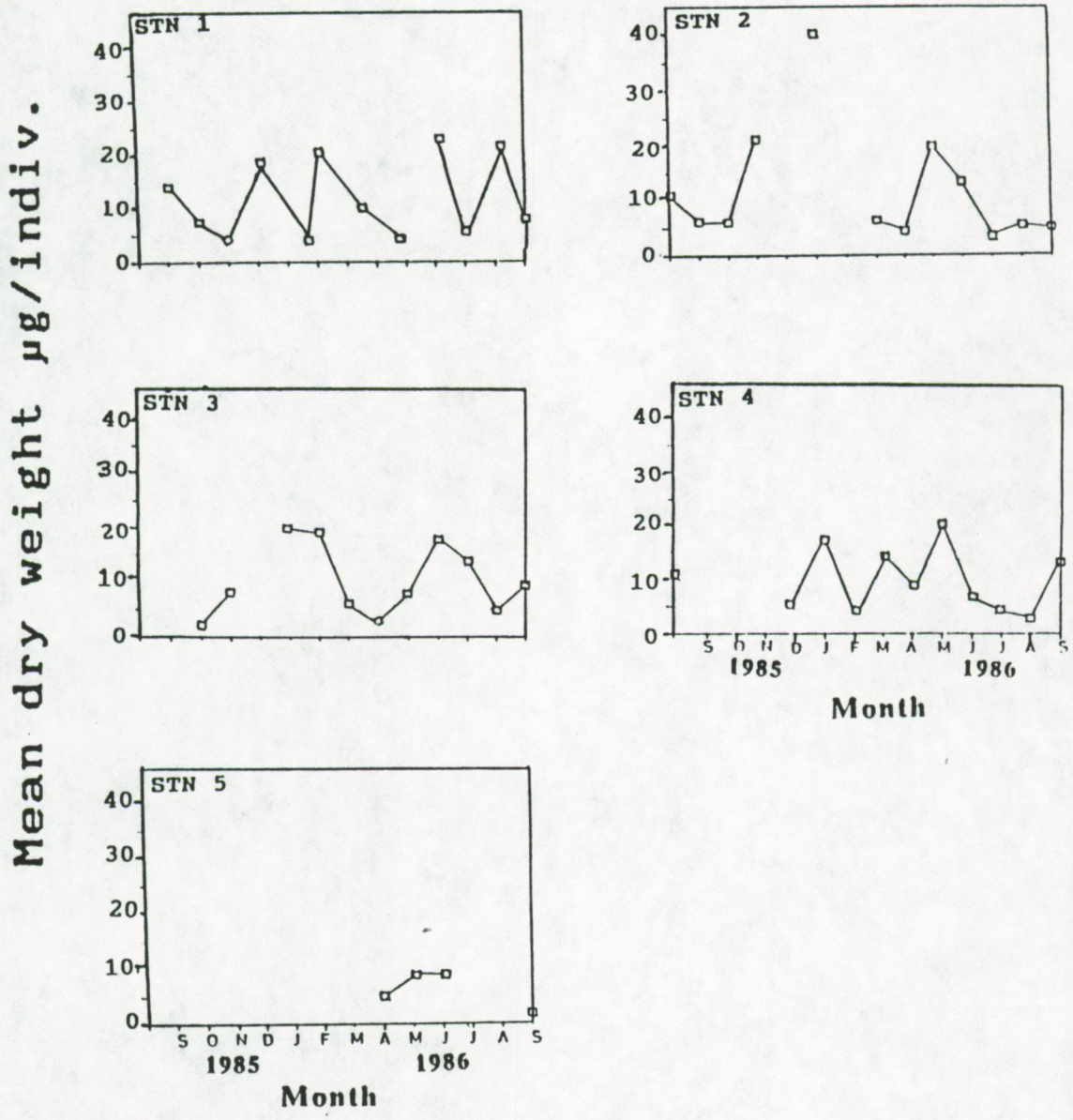


Fig.5.28.Seasonal changes in mean dry weight (μg) of Paracalanus spp. in five stations in Tudor Creek from September 1985 to September 1986.

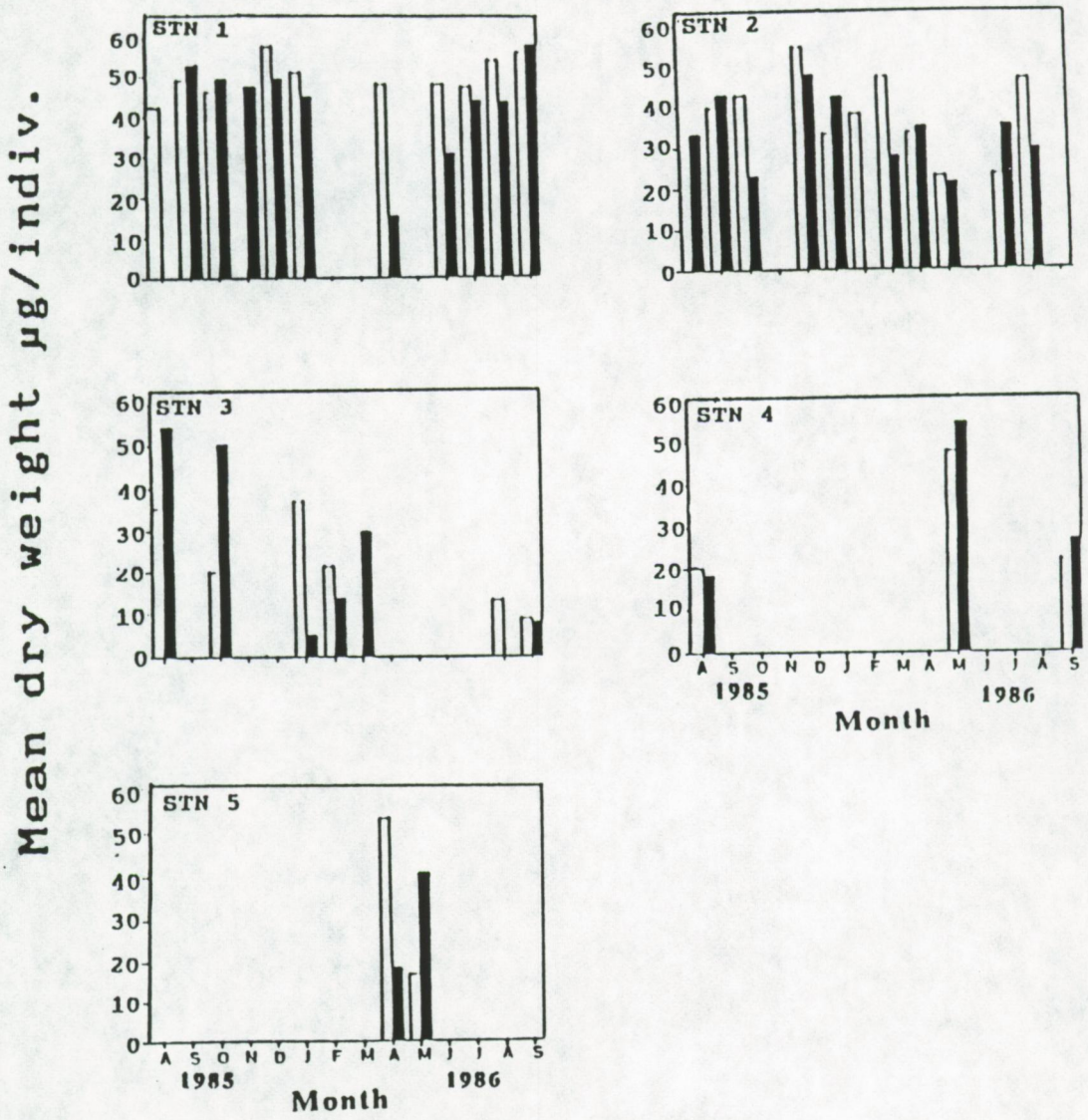


Fig.5.29 .Seasonal changes in mean dry weight (μg) of Temora discaudata in five stations in Tudor Creek from September 1985 to September 1986. (▫ ♀; ▪ ♂).

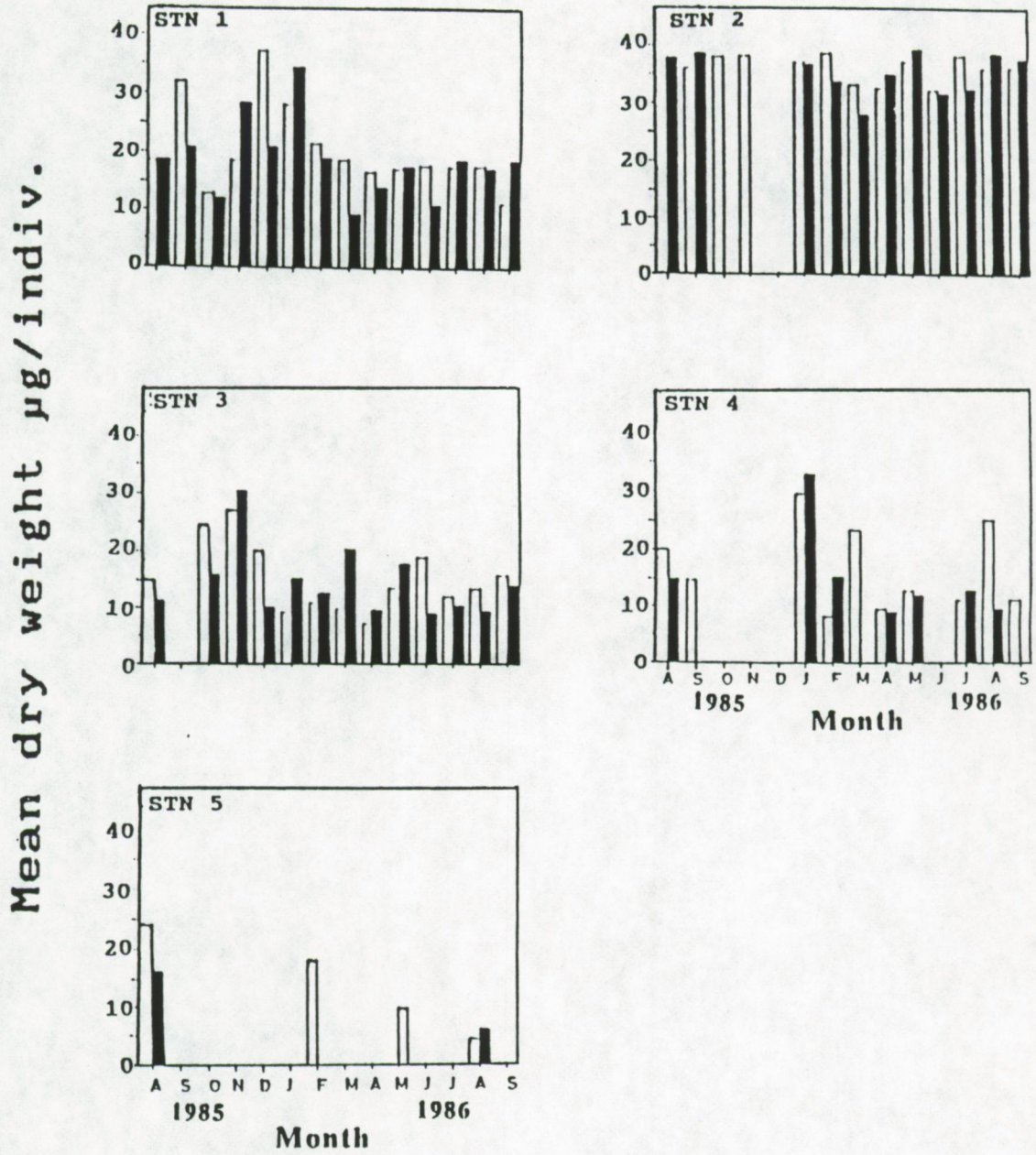


Fig.5.30.Seasonal changes in mean dry weight (μg) of Temora turbinata in five stations in Tudor Creek from September 1985 to September 1986. (▫ ♀; ■).

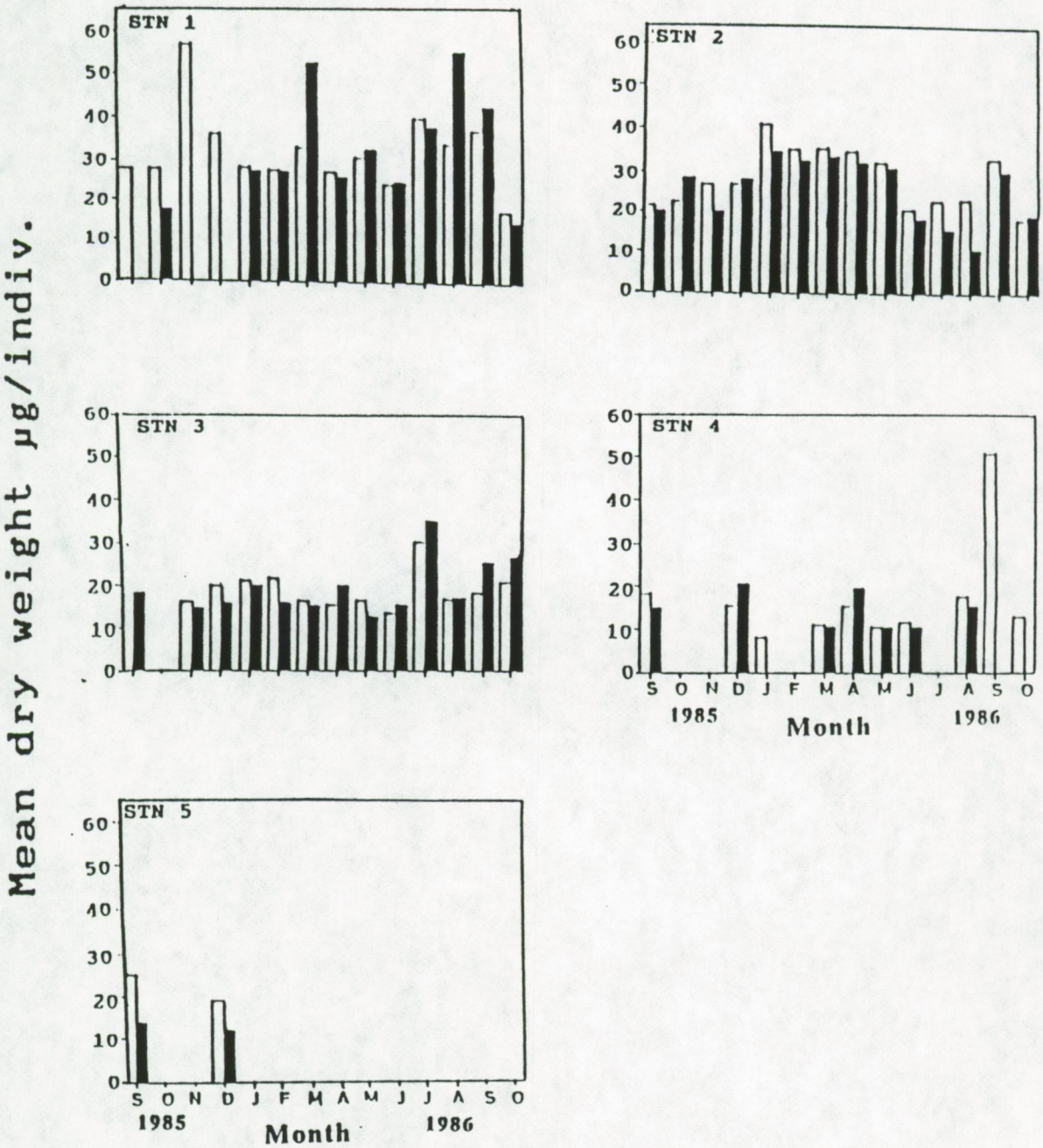


Fig.5.31.Seasonal changes in mean dry weight (μg) of Centropages orsinii in five stations in Tudor Creek from September 1985 to September 1986. (▫ ♀; ▪ ♂).

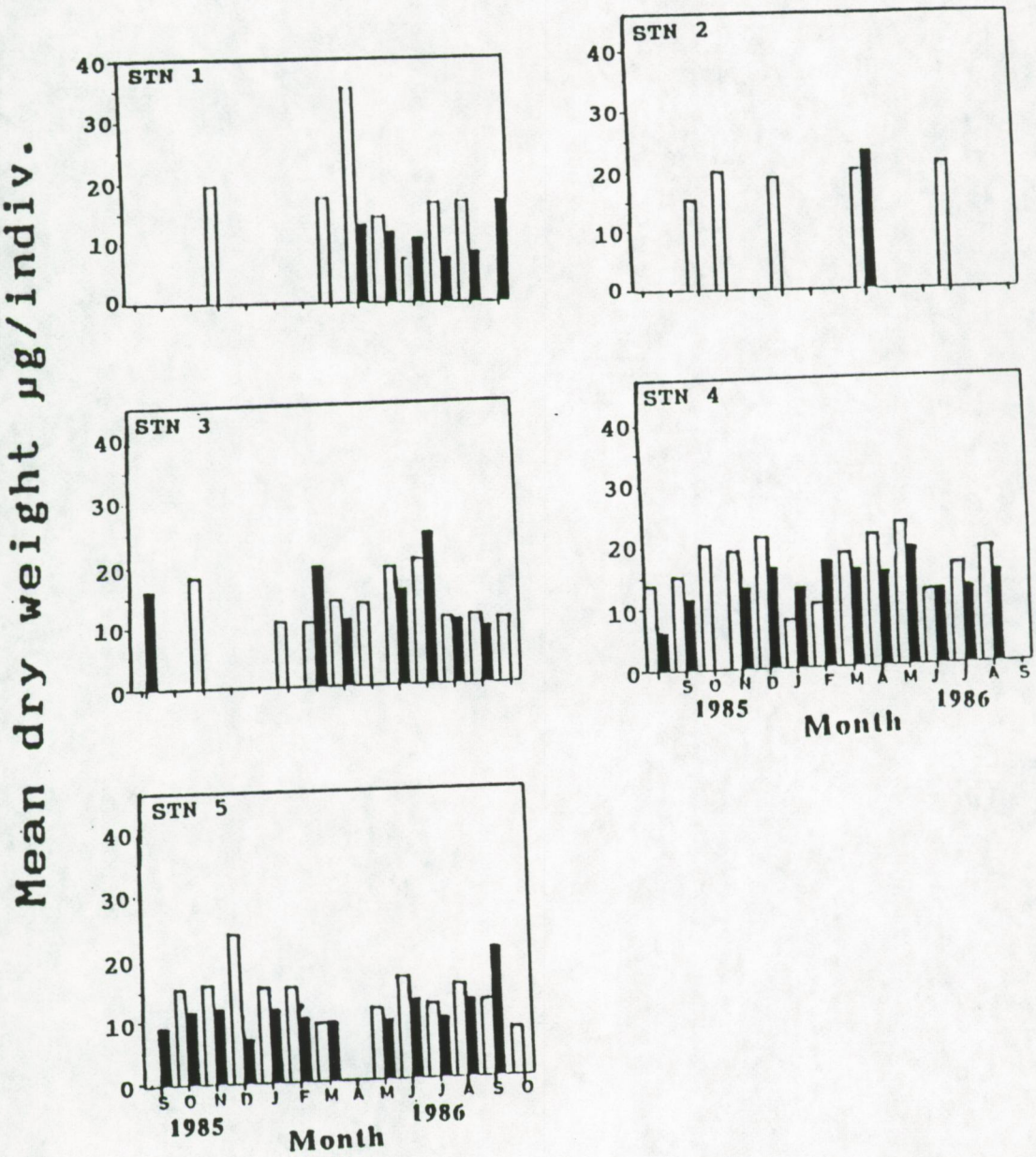


Fig.5.32.Seasonal changes in mean dry weight (μg) of Pseudodiaptomus stuhlmani in five stations in Tudor Creek from September 1985 to September 1986. (▫ ♀; ▪ ♂).

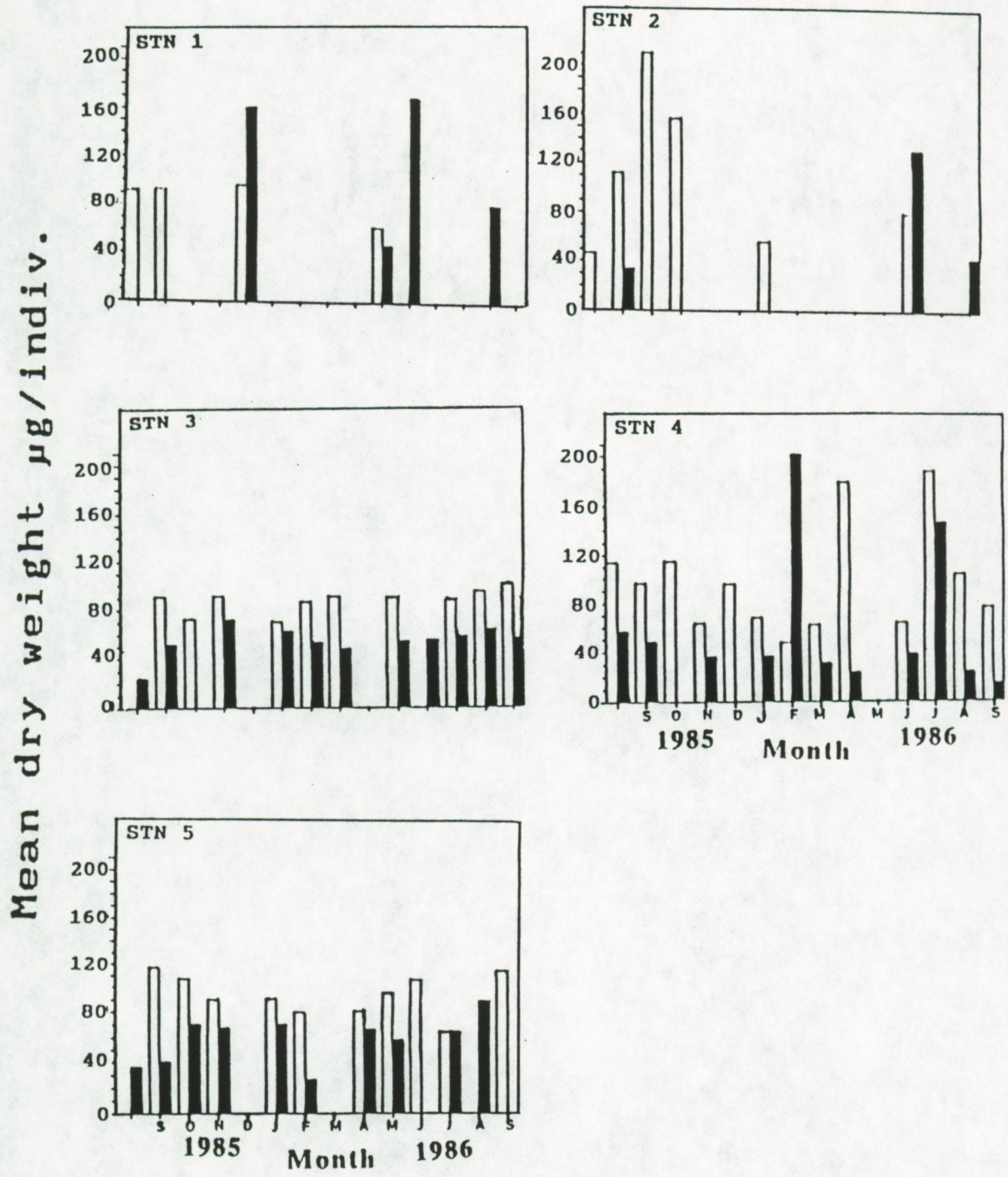


Fig.5.33. Seasonal changes in mean dry weight (μg) of Labidocera orsinii in five stations in Tudor Creek from September 1985 to September 1986. (□ ♀; ■ ♂).

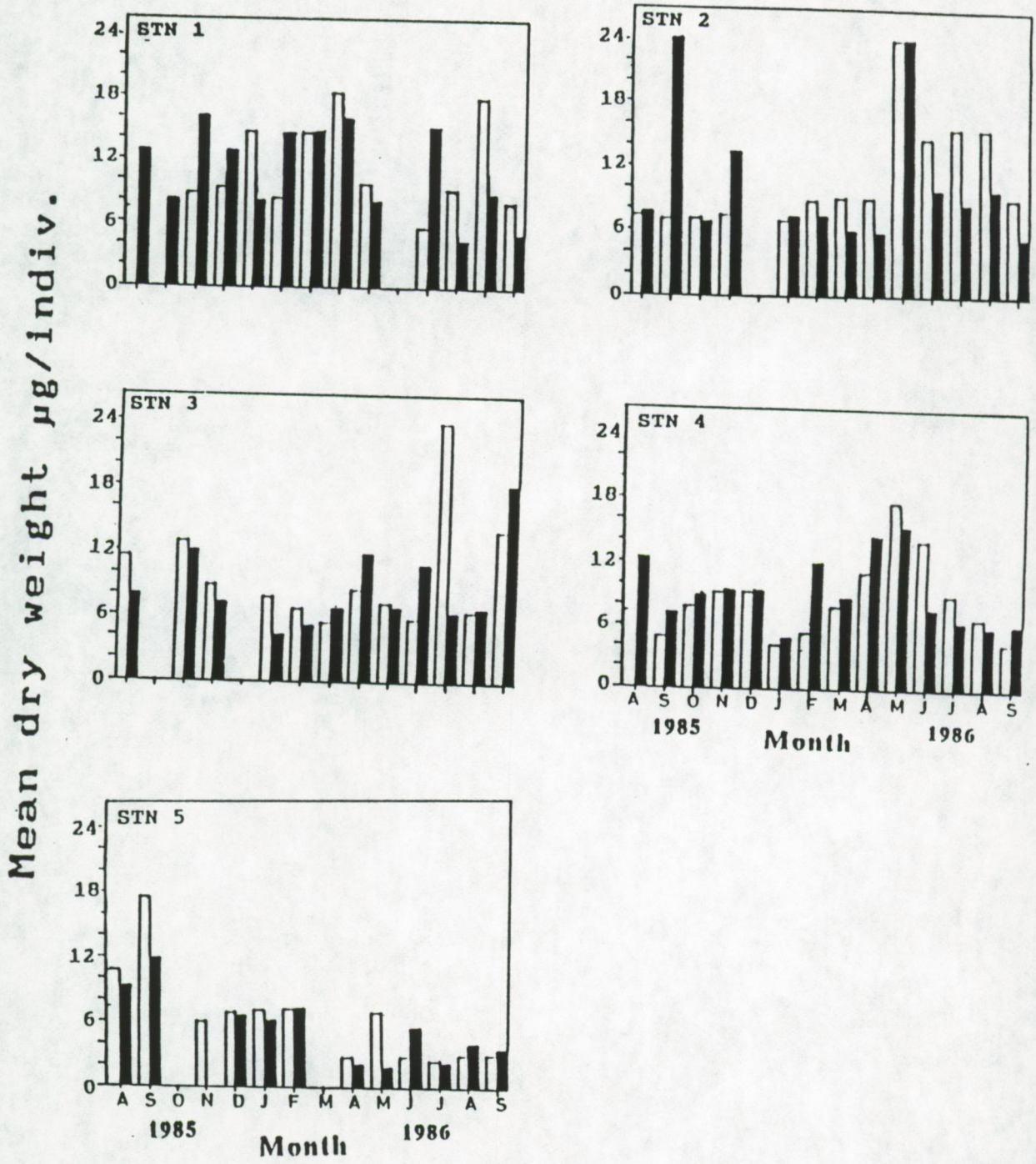


Fig.5.34. Seasonal changes in mean dry weight (μg) of Acartia spp. in five stations in Tudor Creek from September 1985 to September 1986. (▫ ♀; ▪ ♂).

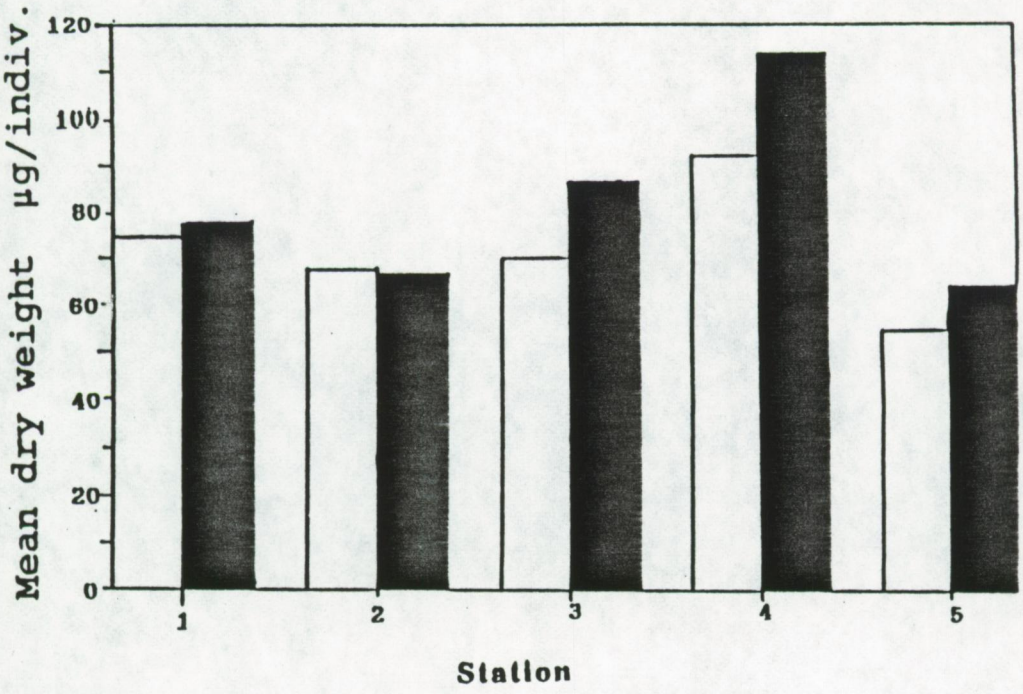


Fig.5.35. Mean dry weight (μg) of Undinula vulgaris in five stations of Tudor Creek from September 1985 to September 1986. (▫ ♀; ▪ ♂).

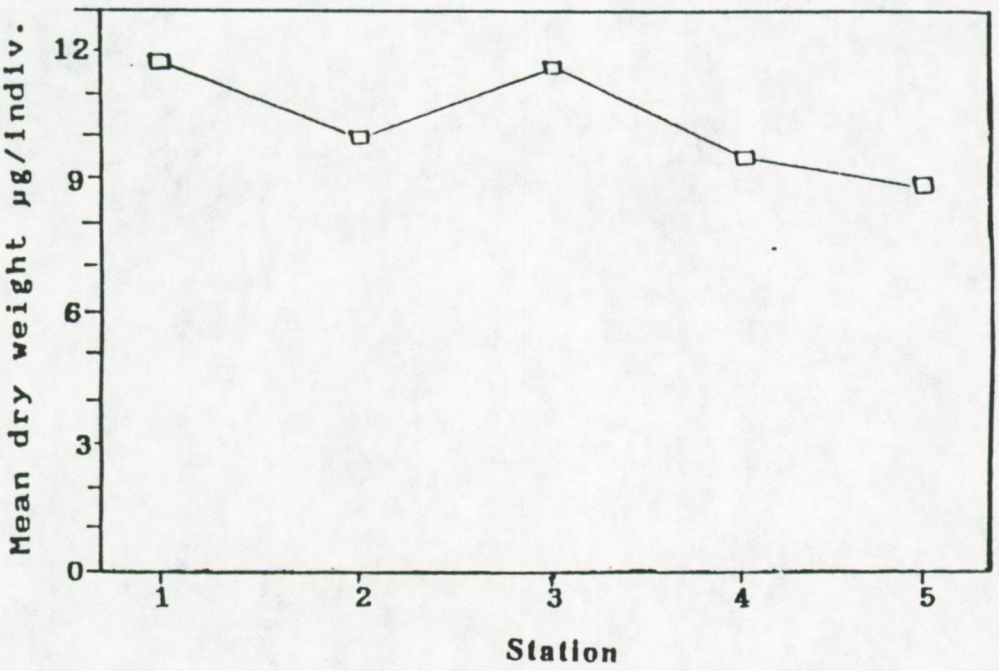


Fig.5.36. Mean dry weight (μg) of Acrocalanus spp. in five stations of Tudor Creek from September 1985 to September 1986. (▫ ♀ and ♂).

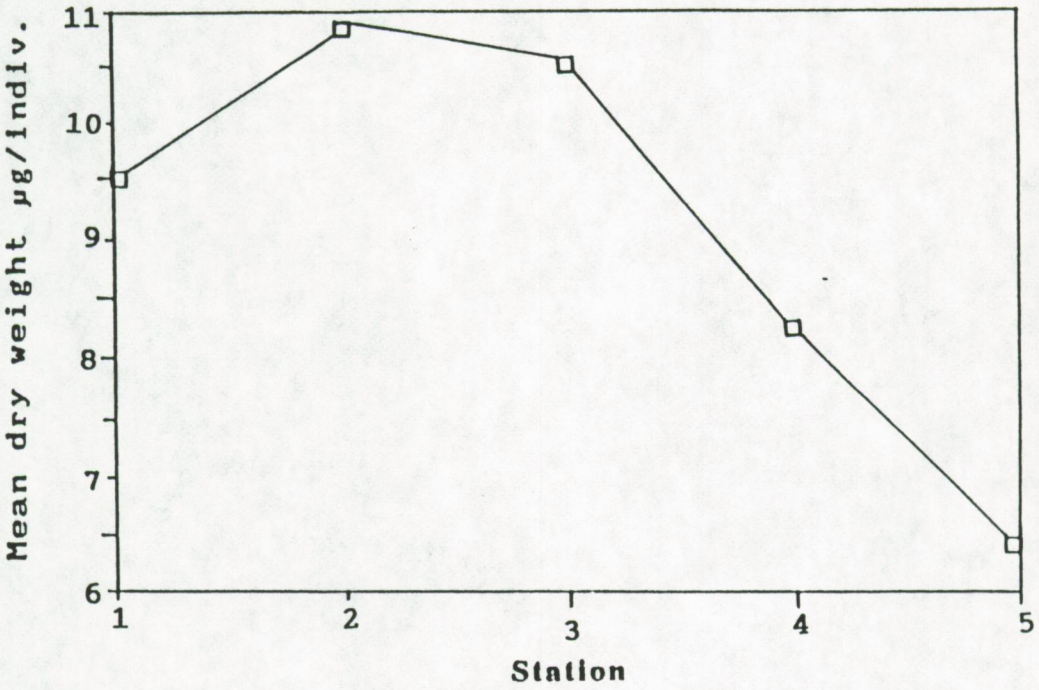


Fig.5.37.Mean dry weight (μg) of Paracalanus spp. in five stations of Tudor Creek from September 1985 to September 1986.

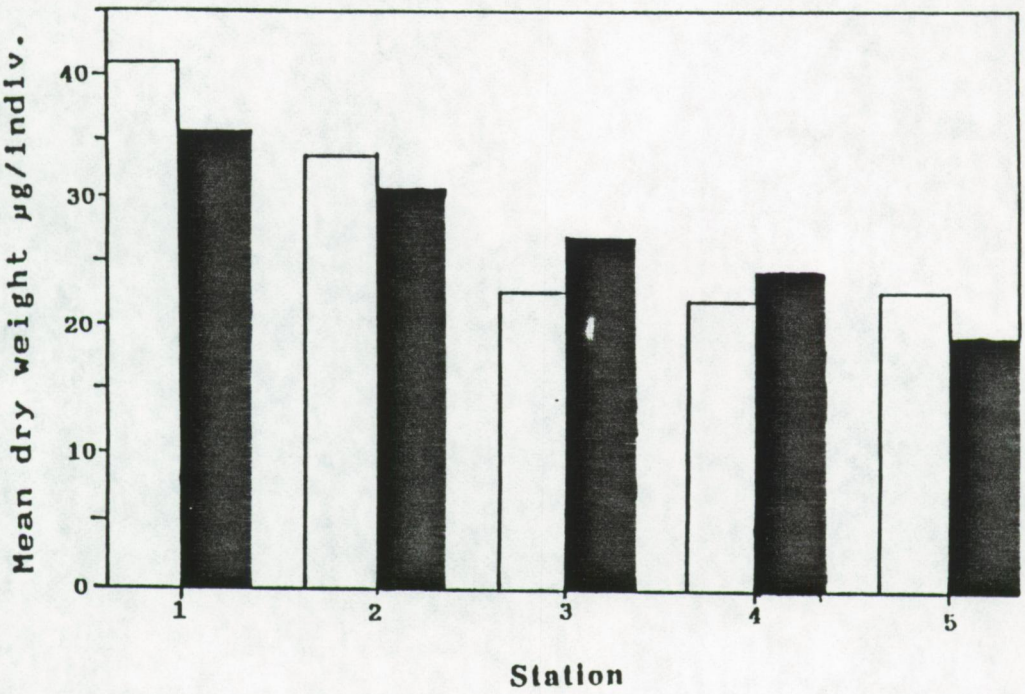


Fig.5.38. Mean dry weight (μg) of Temora discaudata in five stations of Tudor Creek from September 1985 to September 1986. (▫ ♀; ▪ ♂).

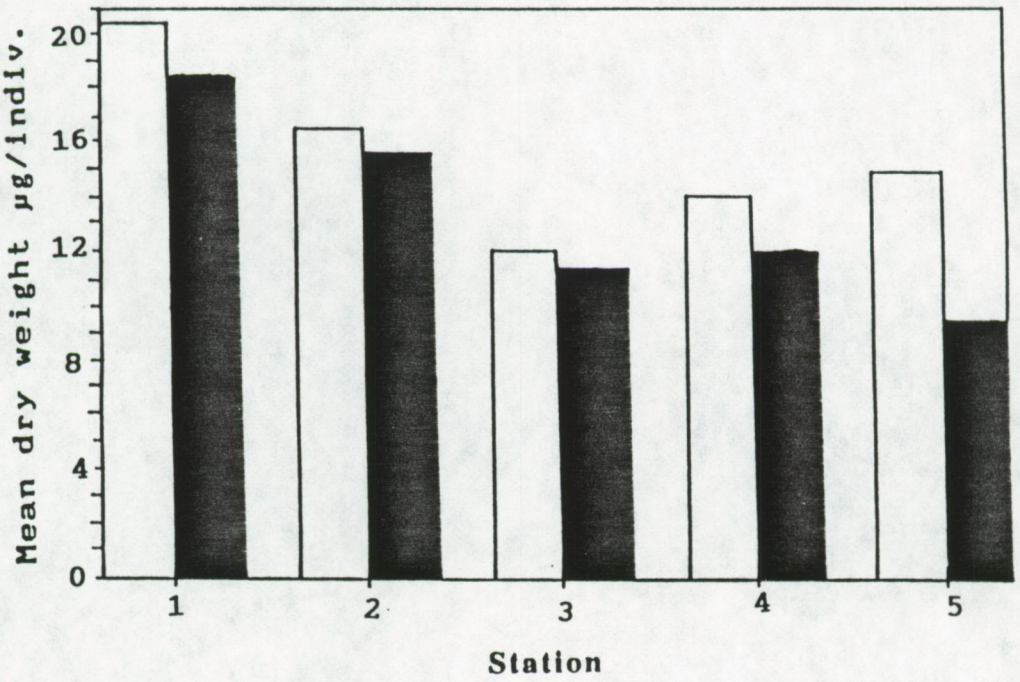


Fig.5.39.Mean dry weight (μg) of Temora turbinata in five stations of Tudor Creek from September 1985 to September 1986. (□ ♀; ■ ♂).

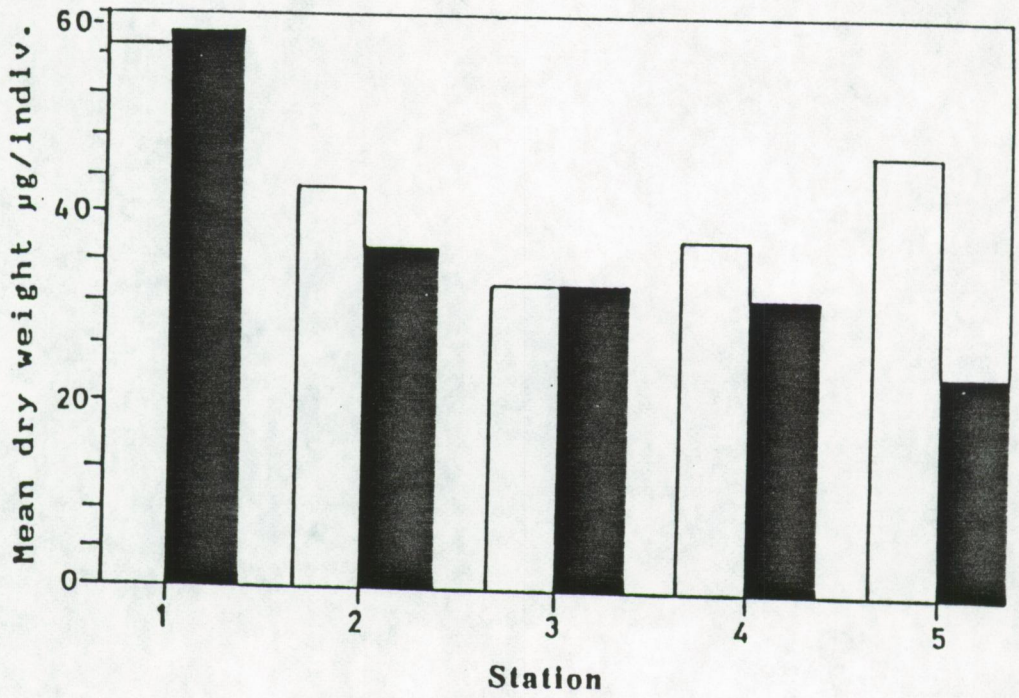


Fig.5.40.Mean dry weight (μg) of Centropages orsinii in five stations of Tudor Creek from September 1985 to September 1986. (□ ♀; ■ ♂).

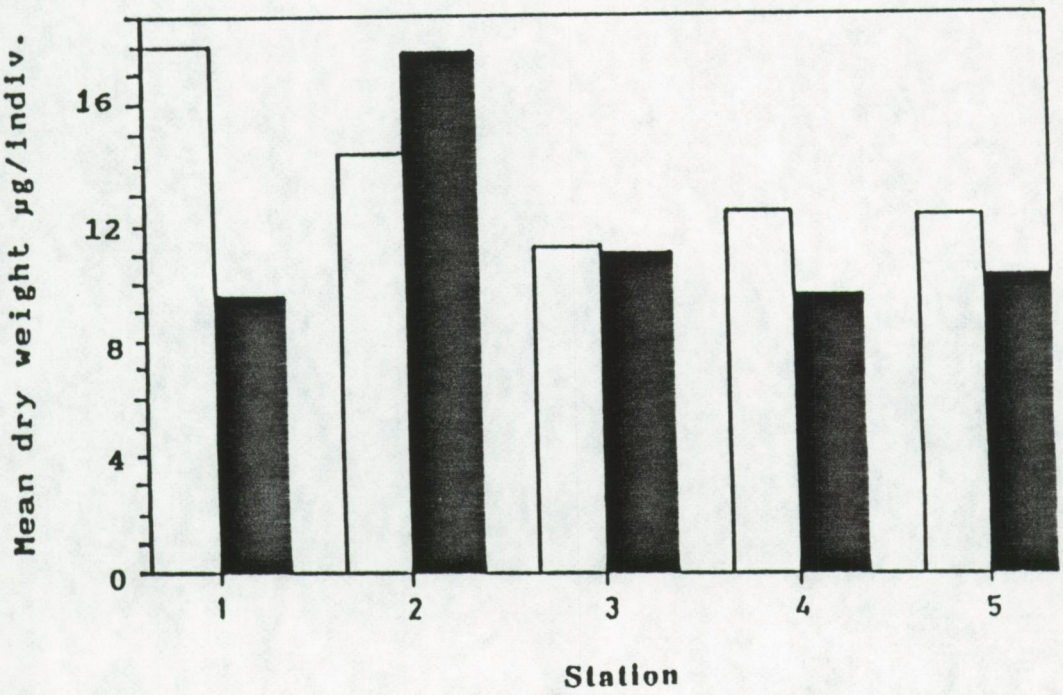


Fig. 5.41. Mean dry weight (μg) of Pseudodiaptomus stuhlmani in five stations of Tudor Creek from September 1985 to September 1986. (▫ ♀; ▪ ♂).

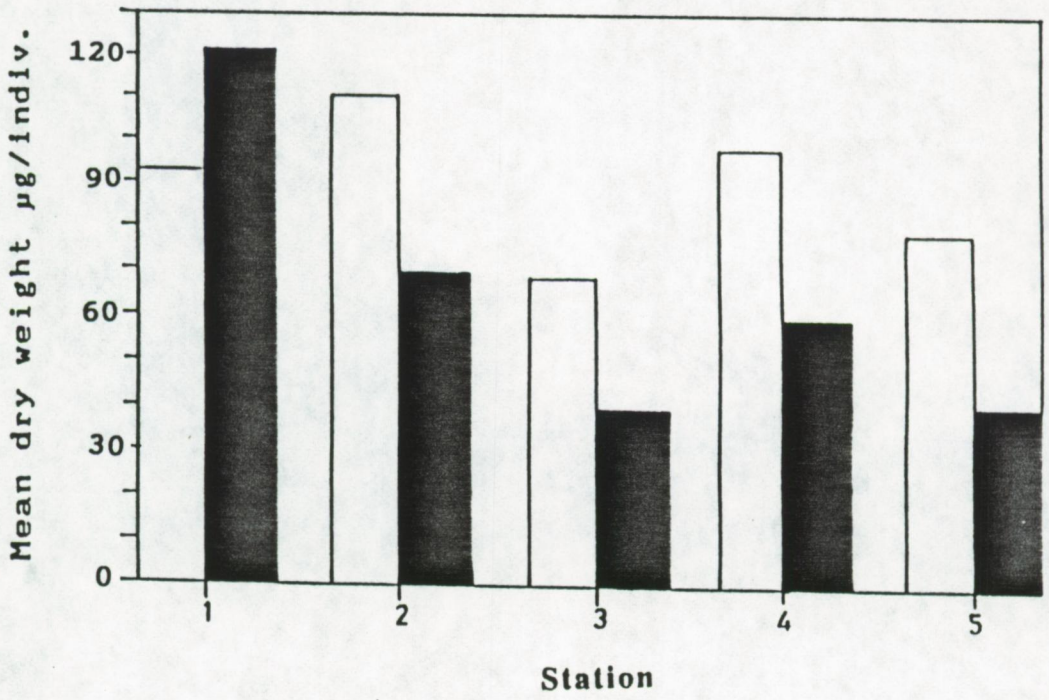


Fig.5.42. Mean dry weight (μg) of Labidocera orsinii in five stations of Tudor Creek from September 1985 to September 1986. (▫ ♀; ▪ ♂).

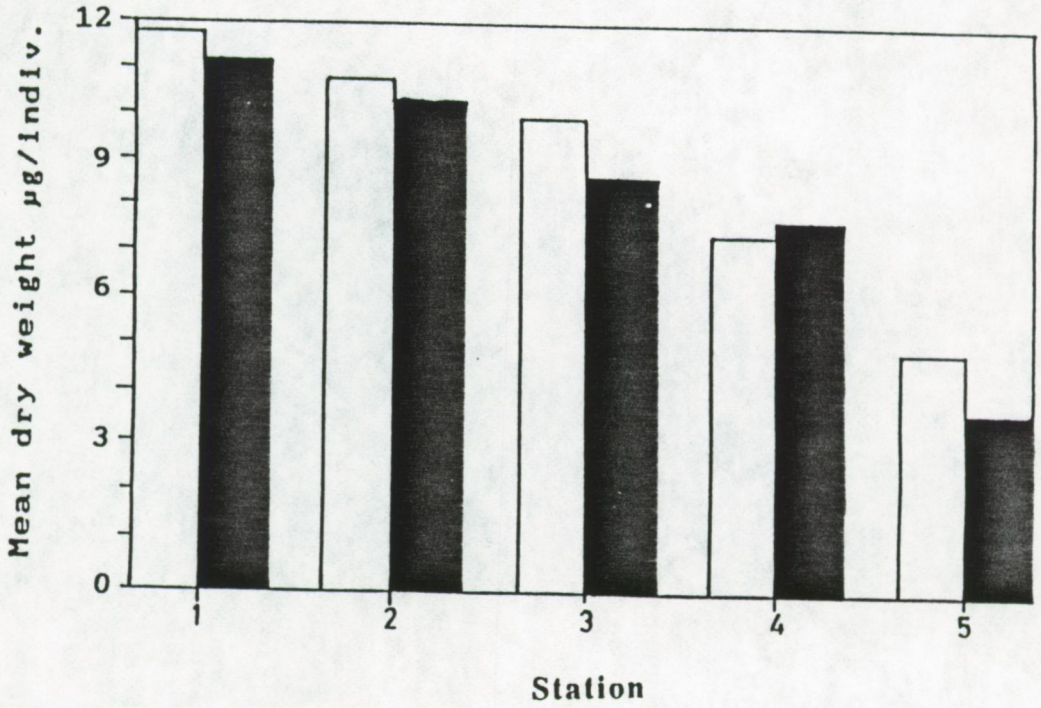


Fig.5.43.Mean dry weight (μg) of Acartia spp. in five stations of Tudor Creek from September 1985 to September 1986. (▫ ♀; ▪ ♂).

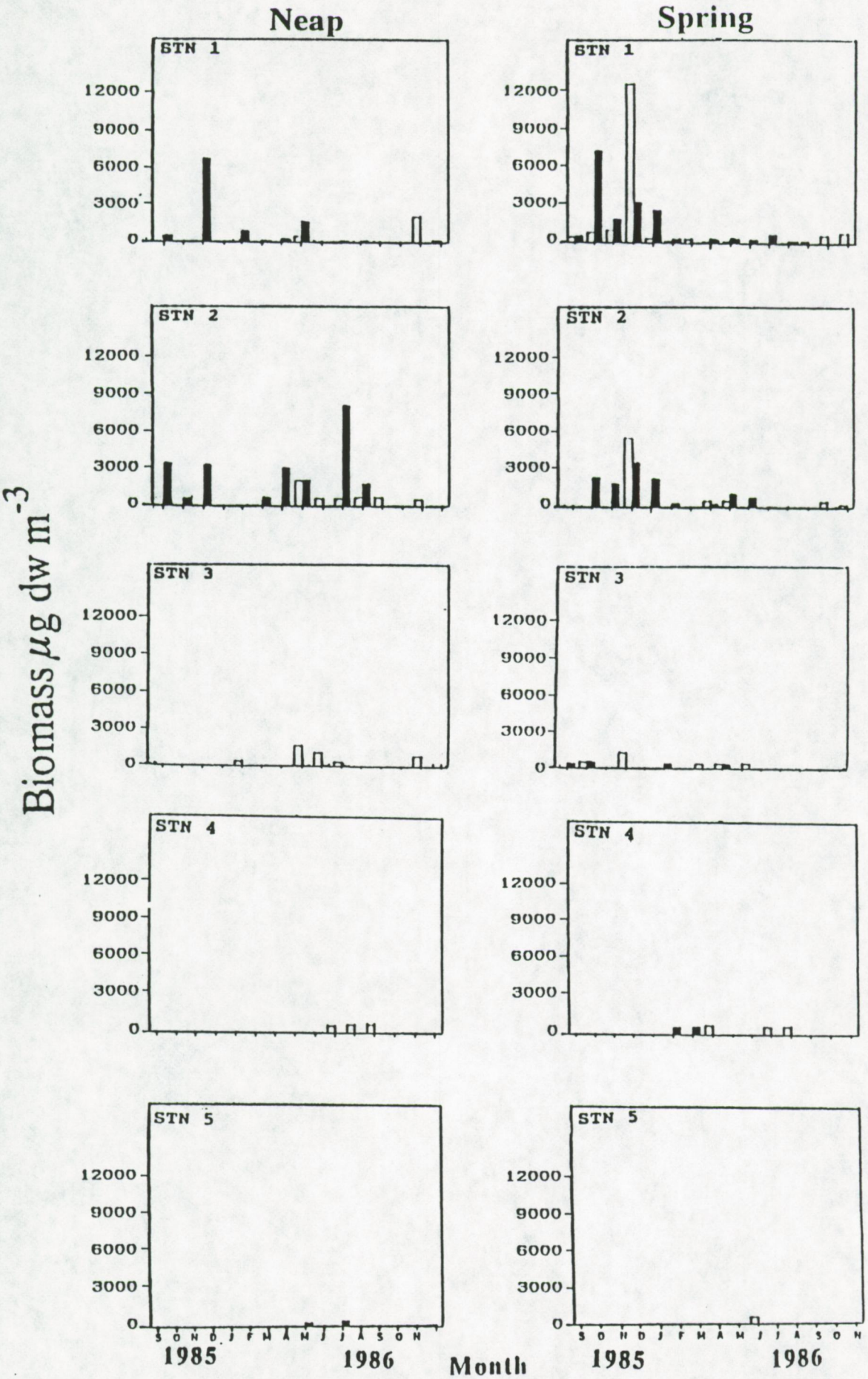


Fig.5.44.Seasonal changes in biomass of Undinula vulgaris in five stations in Tudor Creek from September 1985 to November 1986: for day and night in one neap and one spring in each month. (▫ day, ▪ night).

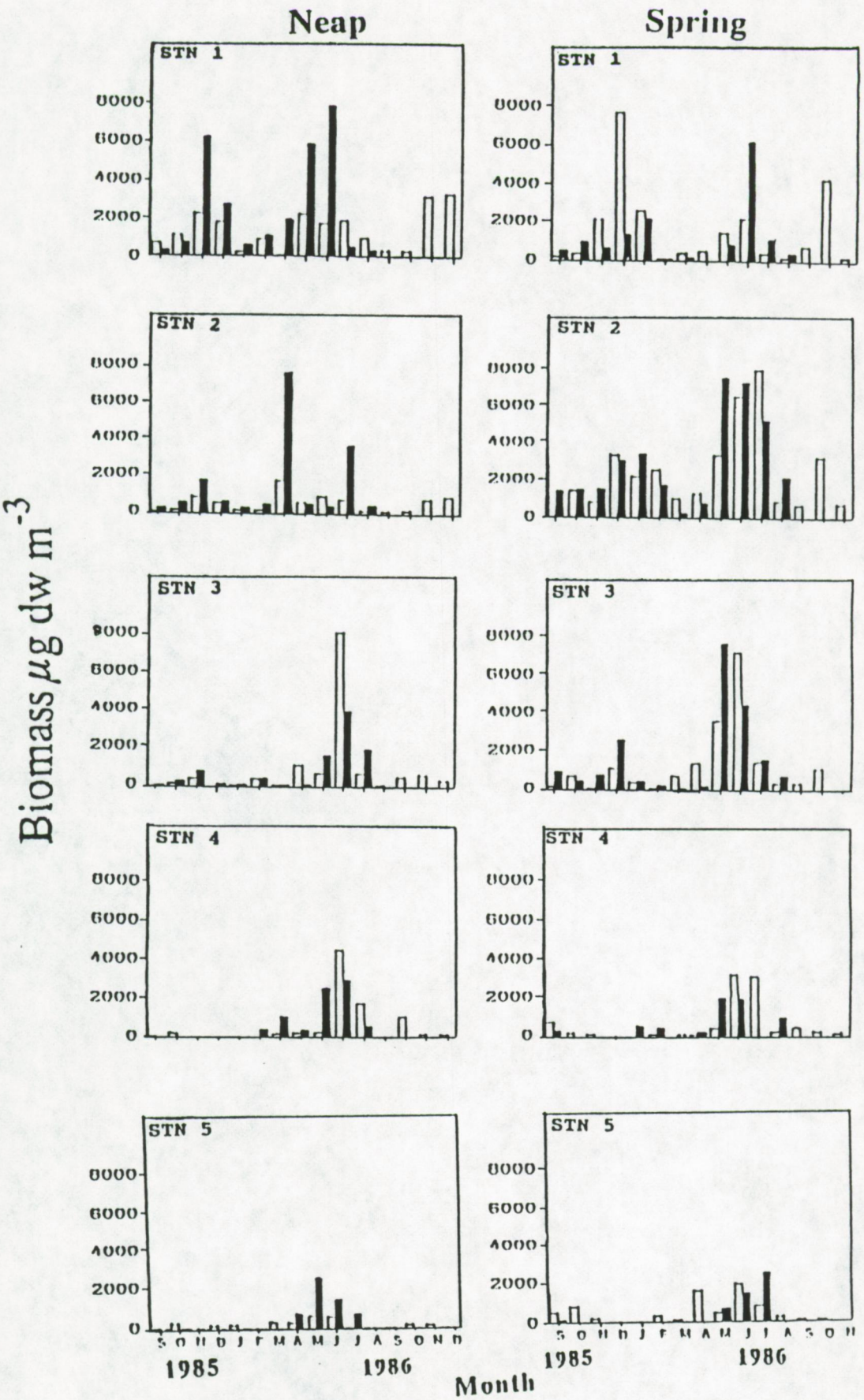


Fig.5.45.Seasonal changes in biomass of Acrocalanus spp. in five stations in Tudor Creek from September 1985 to November 1986: for day and night in one neap and one spring in each month. (▫ day, ▪ night).

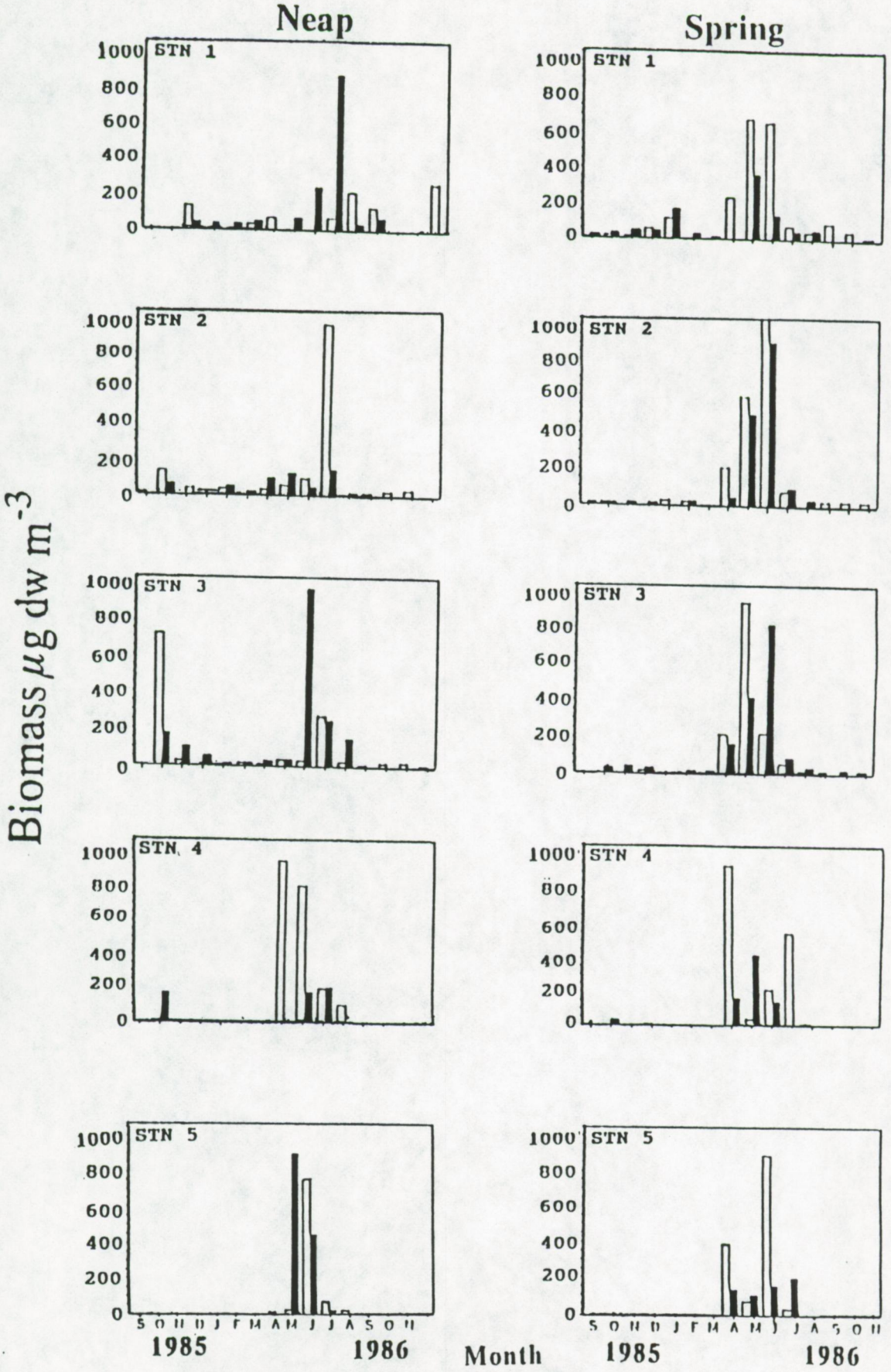


Fig:5.46.Seasonal changes in biomass of Paracalanus spp. in five stations in Tudor Creek from September 1985 to November 1986: for day and night in one neap and one spring in each month. (▫ day, ▪ night).

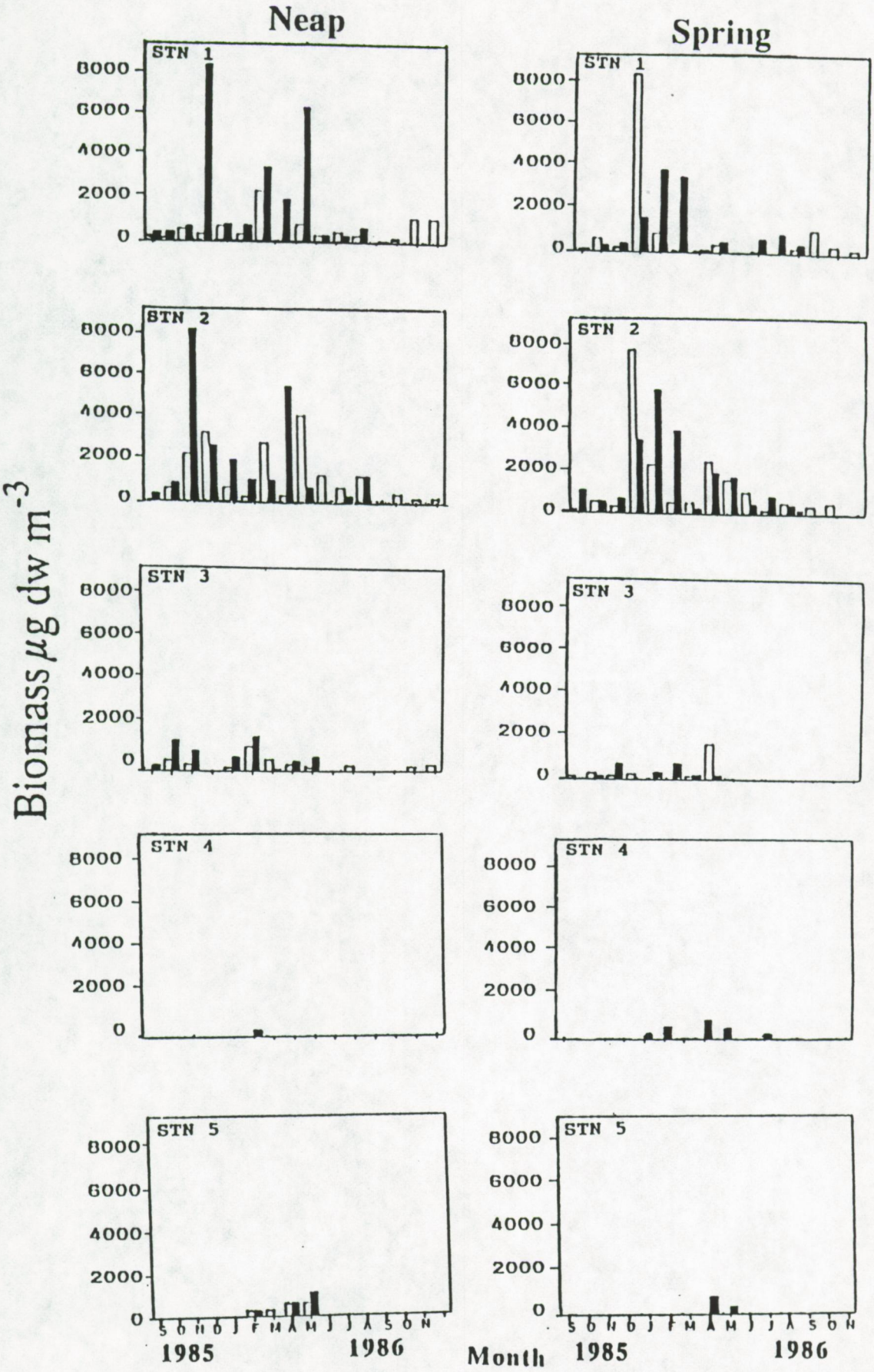


Fig.5.4 7.Seasonal changes in biomass of Temora spp. in in five stations in Tudor Creek from September 1985 to November 1986: for day and night in one neap and one spring in each month. (▫ day, ▪ night).

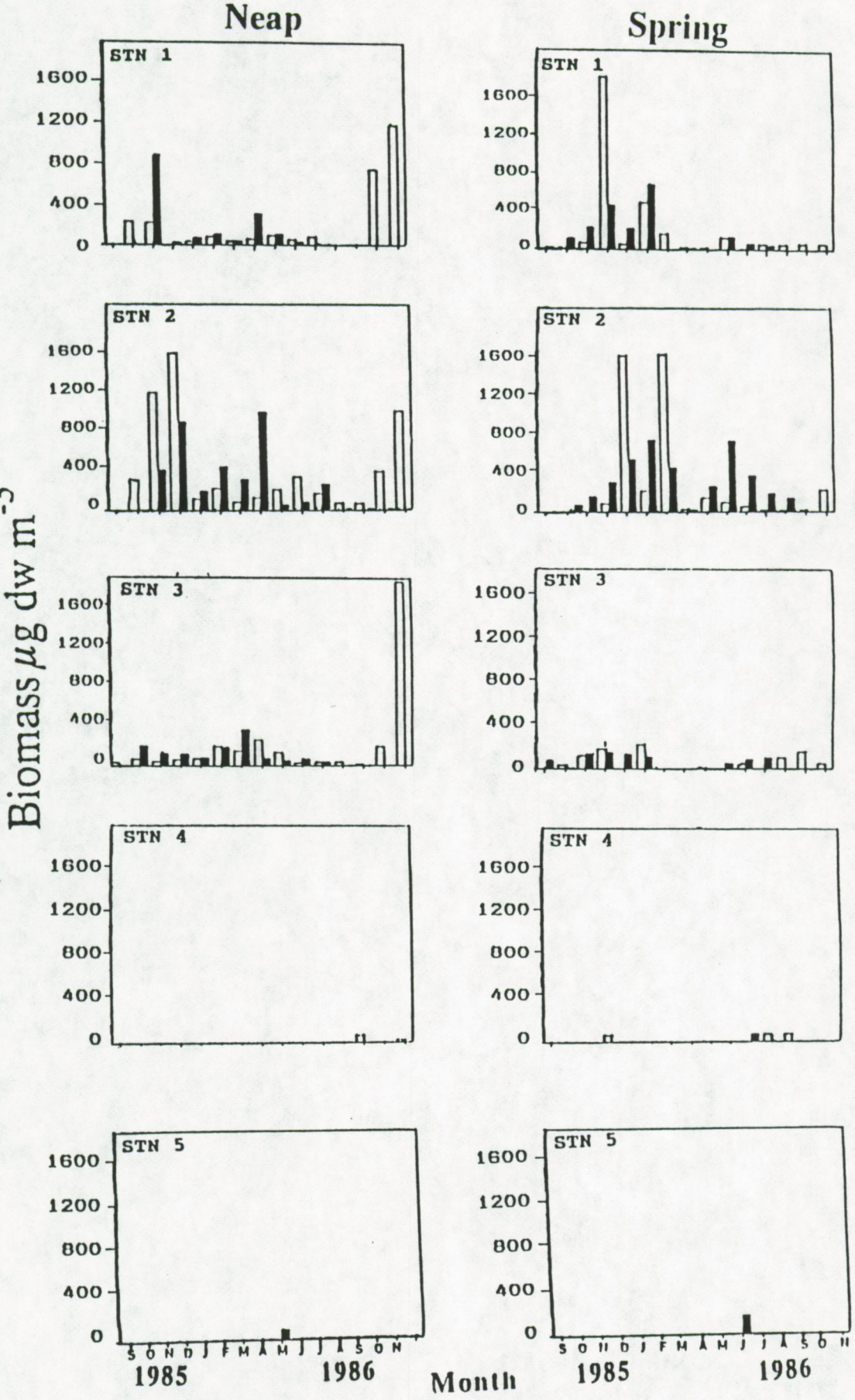


Fig.5.48.Seasonal changes in biomass of Centropages spp. in five stations in Tudor Creek from September 1985 to November 1986: for day and night in one neap and one spring in each month. (▫ day, ▪ night).

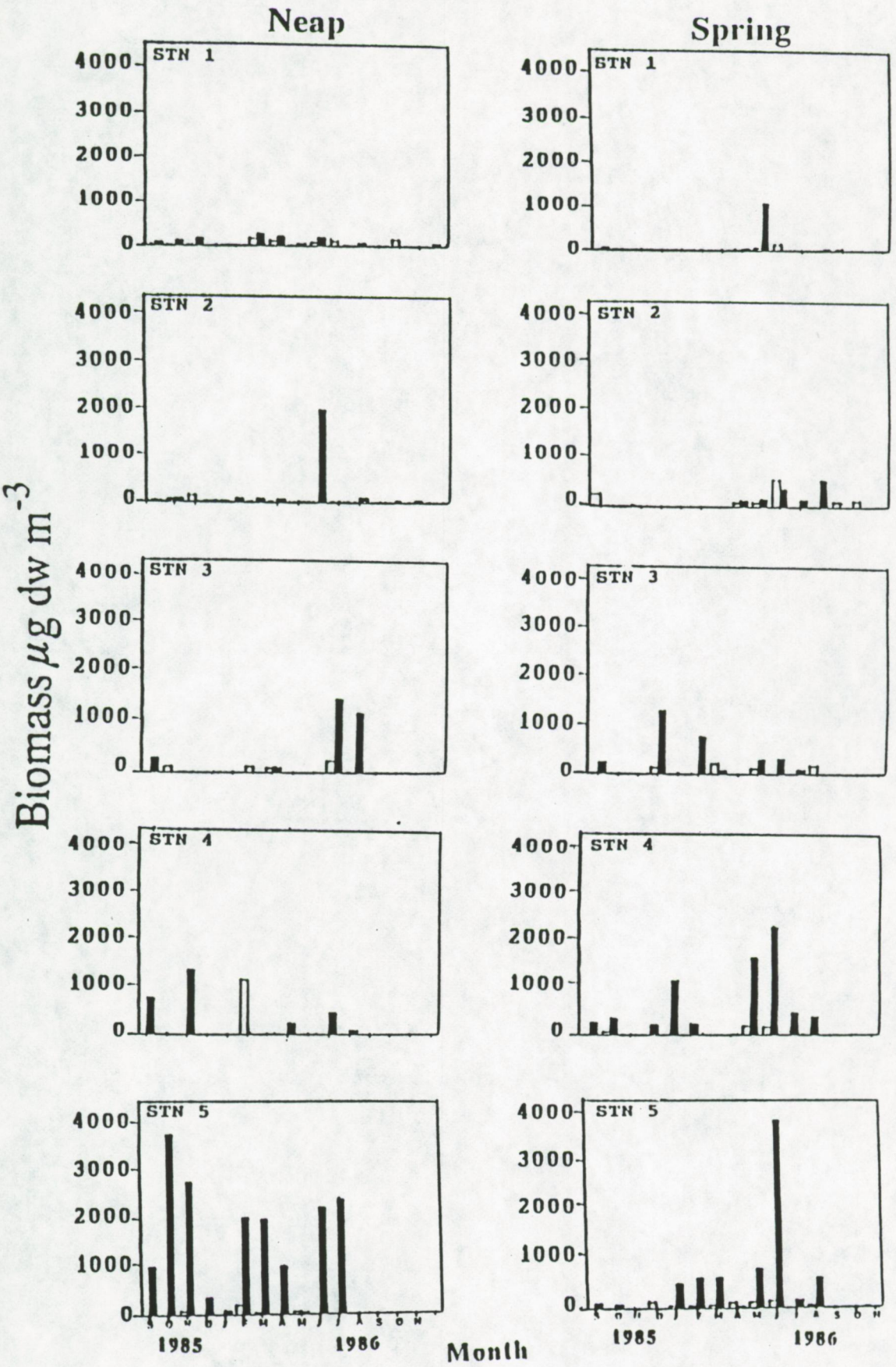


Fig.5.49.Seasonal changes in biomass of Pseudodiaptomus spp. in five stations in Tudor Creek from September 1985 to November 1986: for day and night in one neap and one spring in each month. (▫ day, ▪ night).

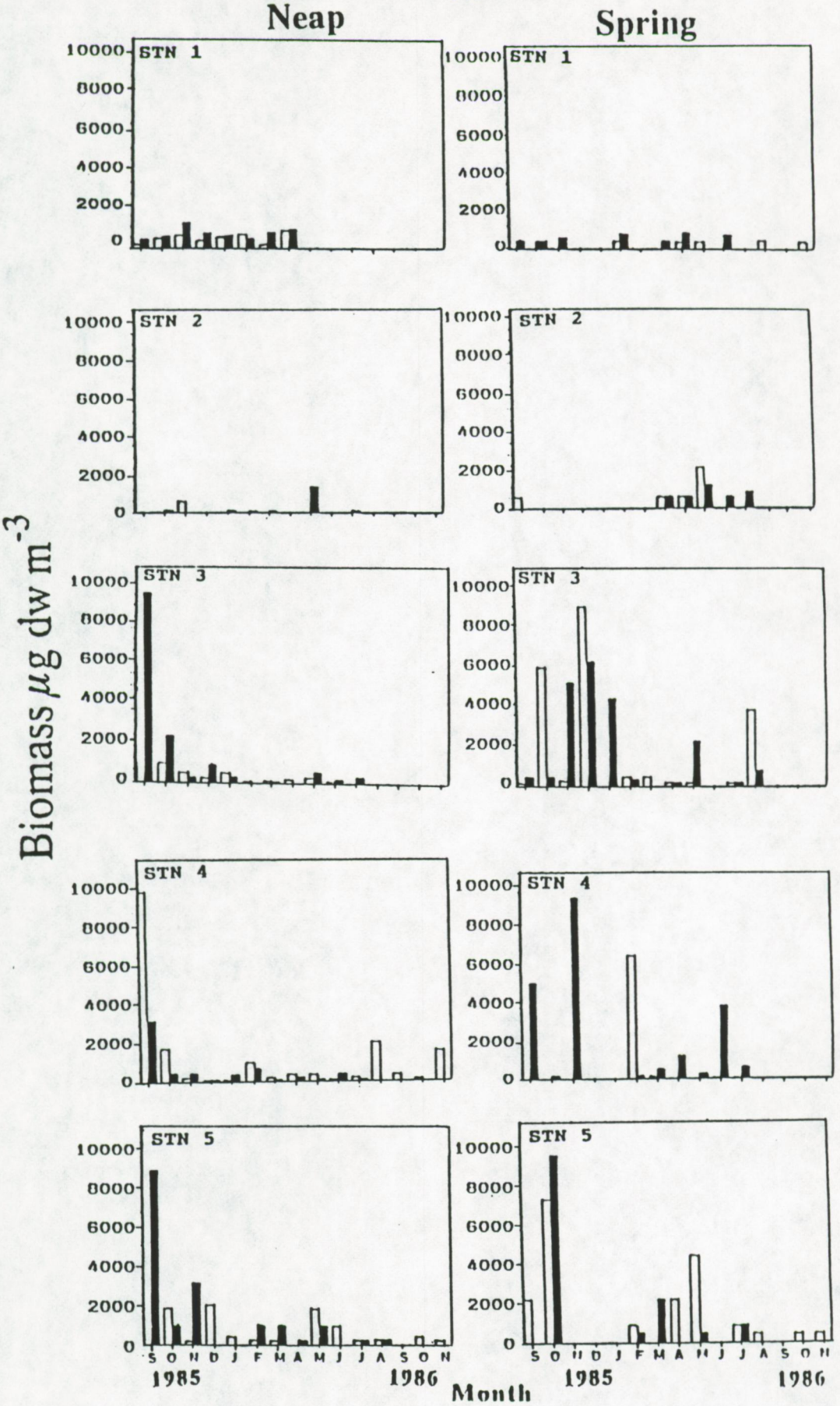


Fig.5.50. Seasonal changes in biomass of Labidocera spp. in five stations in Tudor Creek from September 1985 to November 1986: for day and night in one neap and one spring in each month. (▫ day, ▪ night).

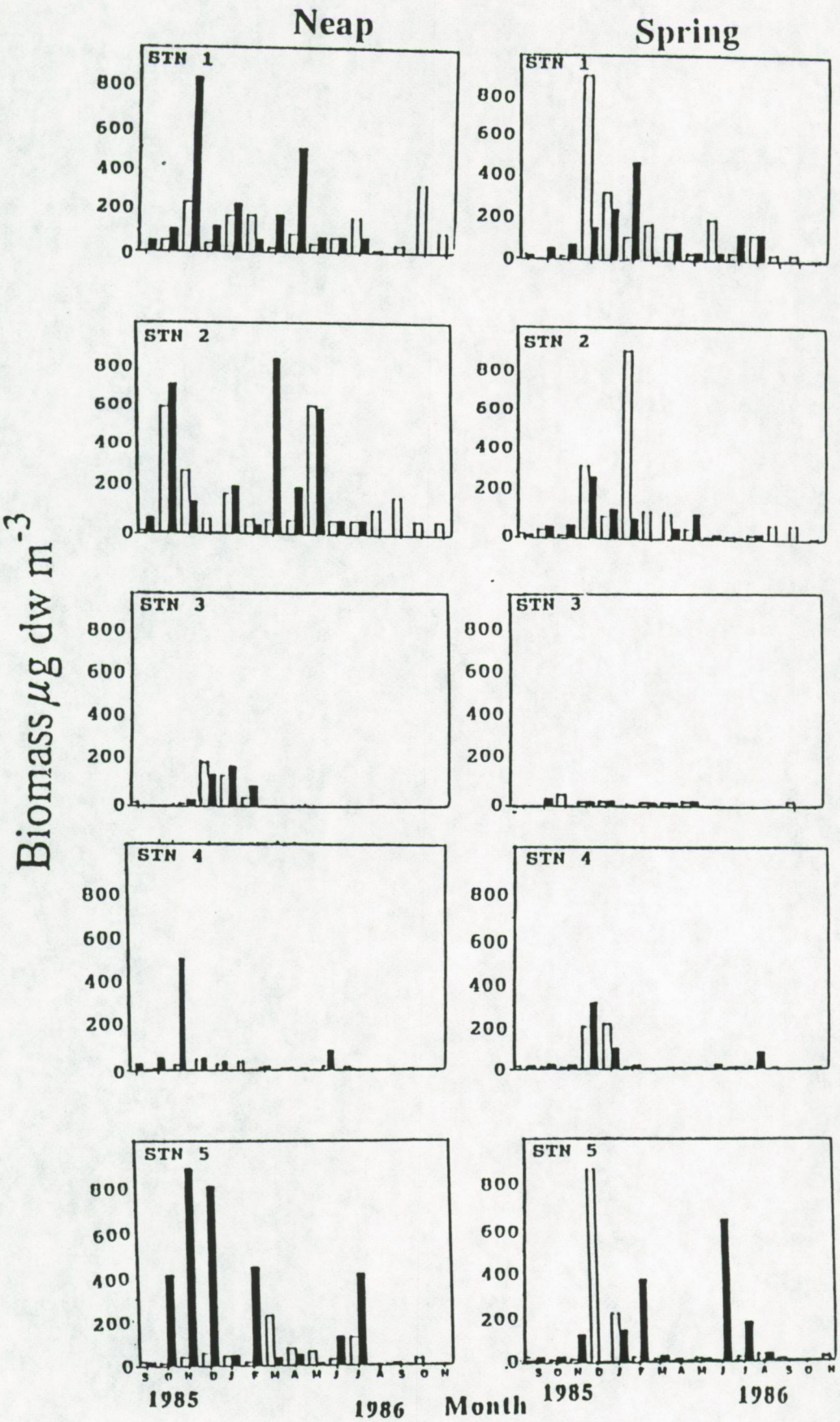


Fig.5.51.Seasonal changes in biomass of Acartia spp. in five stations in Tudor Creek from September 1985 to November 1986: for day and night in one neap and one spring in each month. (▫ day; ▪ night).

at night than day time. The general pattern of total biomass variation follows that of total numbers as seen in Fig.5.1. The first major peak that occurred in March, April and May and the second one in November, December during long rain and short rain respectively.

The annual contributions of biomass by the total copepod species during the three year study period is summarized in Table 5.5.

Biomass abundance decreased tremendously in all the copepod species in December 1985 to November 1986, and was not experienced in December 1984 (Table 5.5).

The annual mean total copepod standing stocks in biomass in Tudor Creek were estimated to be 308 mg dw $_{10}$ m^{-3} in the 1984/85 study period, and 90, 149 mg dw $_{10}$ m^{-3} in 1985/86 and 1986/87 study period respectively.

The average and maximum values of this biomass of copepods at 182 and 832 mg dw $_{10}$ m^{-3} respectively. The largest biomass of copepods, 832 mg dw $_{10}$ m^{-3}, was recorded on 29th December, 1984 at station 2, and mostly contributed by Canthocalanus pauper and Undinula vulgaris. The maximum biomass of calanoids, 790 mg dw $_{10}$ m^{-3}, was observed on 14th April 1985 at station 3, and the main species responsible for this were :
Paracalanus spp, Labidocera acuta and Tortanus barbatus.

The diversity of forms decreases from 3.704 in station 1 to 1.979 in station 5 as shown in the table 5.3; but the biomass in station 5 remains rather low, which reflects a low density.

In order to obtain a general idea of the course of the biological seasons we had to group the stations according to months, as only in this way were we able to trace the regular pattern of seasonal processes. High abundance was found during long rainy season (April to June) and during the short rainy season (November to December) and low numbers were found during the dry seasons in between the rainy seasons. The seasonal changes in total biomass of copepods in the three stations in Tudor creek from December 1984 to November 1985 is shown in figure 5.52. Figure 5.53

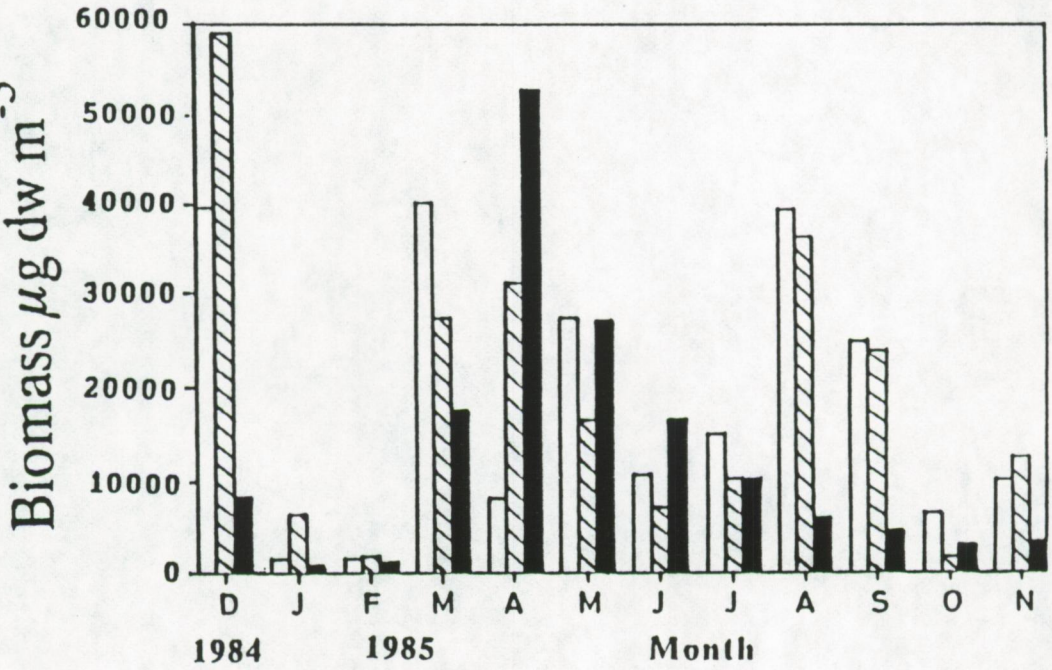


Fig.5.52. Seasonal changes in total biomass of copepods in three stations in Tudor Creek from December 1984 to November 1985. ▫ station 1; ▪ station 2; ■ station 3.

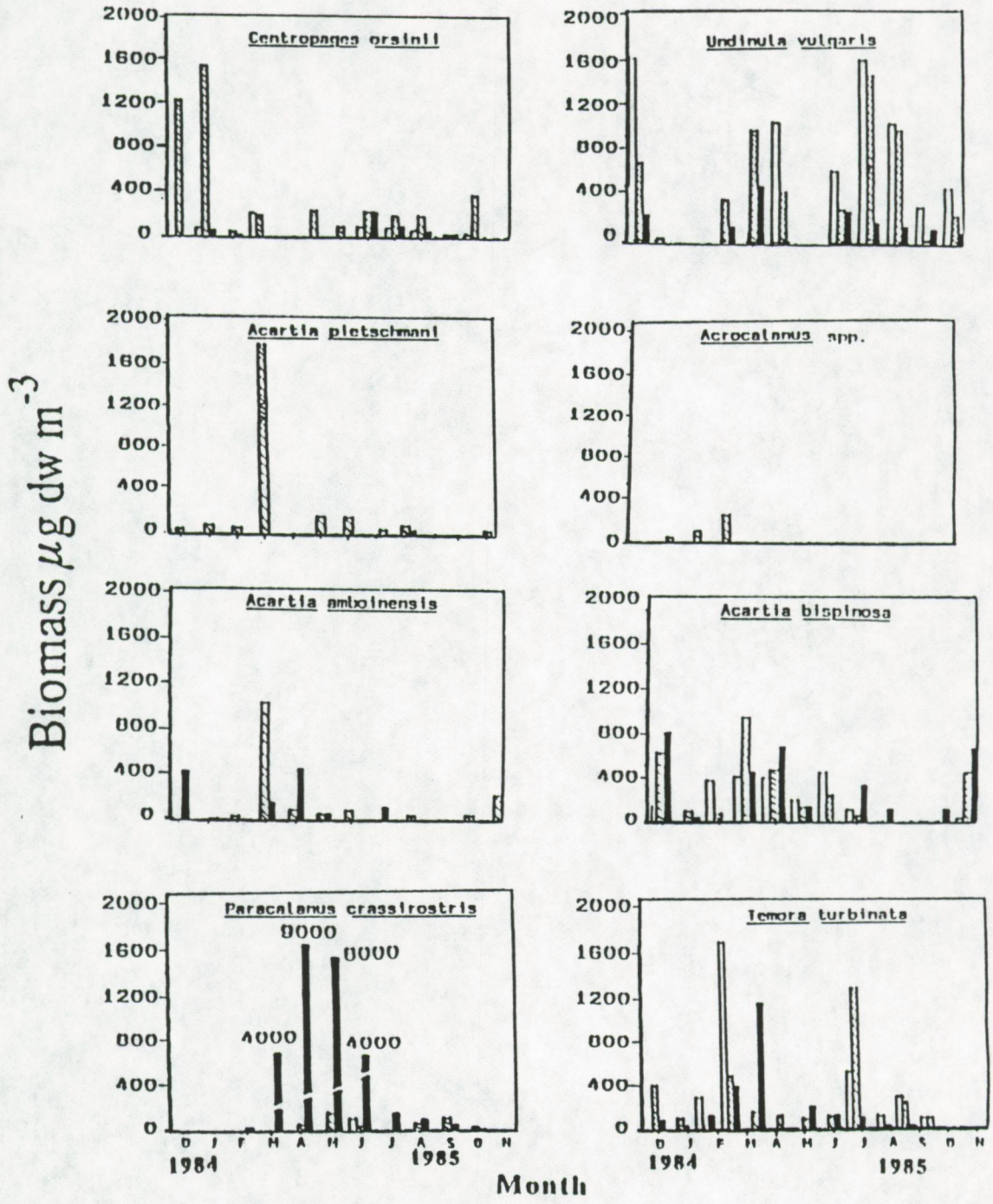


Fig:5.5 3.Seasonal changes in total biomass of copepods in three stations in Tudor creek from Dec 1984 to Nov 1985. (▫ station 1; ▪ station 2; ■ station 3).

shows temporal changes in biomass of the main common copepod species in three stations in Tudor Creek.

Table 5.5. Monthly means in dry weight (mg/10m^3) of total copepod standing crop Biomass in 1984-87 study period.

Month	Dec'84-Nov'85		Dec'85-Nov'86		Dec'86-Nov'87	
	$\overline{X}$	SE	$\overline{X}$	SE	$\overline{X}$	SE
Dec.	559.8	188.5	49.3	31.2	58.5	14.3
Jan.	89.1	49.4	126.2	12.0	129.6	44.0
Feb.	53.5	16.2	124.9	9.1	194.6	50.3
Mar.	832.1	308.8	136.4	17.7	164.2	41.2
Apr.	790.2	274.8	123.7	11.5	238.0	66.5
May	518.1	196.5	151.1	32.2	70.7	18.3
Jun.	350.3	106.9	172.7	34.3	143.1	70.6
Jul.	101.8	57.8	121.6	7.5	139.2	33.9
Aug.	185.7	137.0	19.3	2.9	178.7	95.4
Sep.	119.0	103.1	17.5	2.5	252.9	169.9
Oct.	25.0	108.5	17.1	2.8	128.3	78.6
Nov.	68.9	31.0	15.7	2.2	92.1	28.0
Mean	307.8		89.6		149.2	
Std Dev	282.8		20.1		8.1	

Between January and February 1985 the copepods were of the dry season type characterized by low biomass. Acrocalanus spp., Temora turbinata, Centropages orsinii, Acartia bispinosa and Tortanus barbatus accounted for more than 90%.

The long rain season in 1985 started in March. Its coming brought a fresh outburst of Eucalanus spp., Acrocalanus spp., Centropages furcatus, Acartia amboinensis and Acartia bispinosa. The total biomass of the copepods increased, and the number of forms rose somewhat above the February level.

In April, when the long rain season is at its peak, a new combination and more abundant copepods appear. These include the following: Undinula vulgaris, Paracalanus crassirostris, Temora turbinata, Labidocera acuta, Acartia bispinosa, Tortanus barbatus, Oncaea spp. and Oithona spp.

The samples taken between July and October, 1985 can be assigned to the dry season group based on the rain conditions. The common copepod species found are: Undinula vulgaris, Temora discaudata, Temora turbinata and Oncaea venusta. The numbers of copepods were much lower; the biomass of the copepods was hardly above the rain season level.

During the short rain season (November - January) the biomass of copepods increases but, do not attain the April-June level Undinula vulgaris, Centropages orsinii, Labidocera acuta, Acartia bispinosa, Tortanus barbatus and Oncaea venusta constitute 85% of the total copepod biomass during this period.

5.7.1. Discussion

A comparison of change in monthly mean density (Figs 5.1 & 5.12) and biomass (Fig 5.52) of the total copepod species for the three stations in Tudor Creek from December 1984 to November 1985 shows that the abundance of copepod followed similar trends throughout this period. All the seasonal abundance maxima coincided with the rain seasons during this period. Seasonal variation patterns in relative abundance were similar for all the seven copepod species independently, at least in the 1984/85 year of study.

The annual average standing crop biomass estimates of the pelagic copepods for 1984/85 were calculated as 12320 tons dry weight in 1984/85,

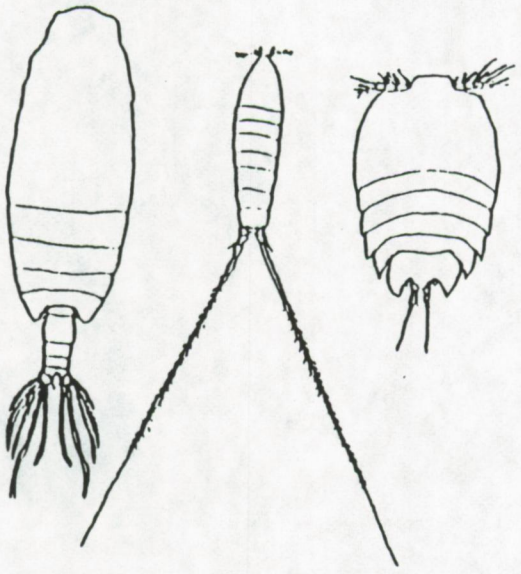
3600 and 59 60 tons dry weight in 1985/86 and 1986/87 respectively for Tudor Creek, based on an estimated volume of 40 $x10^{10}$ m^3 of water in during the mean tidal prism for the creek as given by (Norconsult, 1975).

A comparison of changes in monthly mean density and biomass of the total copepods for the three year study period shows that copepod density and biomass followed similar trends throughout this period but with the times of biomass maxima occurring somewhat later than the density maxima. All the seasonal abundance maxima were found to generally coincide with the rainy seasons during 1984/87. Seasonal variation patterns in density and biomass were similar for all the common copepod species. Generally, the copepod density peaks in November-December 1984 March-June, August-September 1985 appeared immediately after the rains.

These results contradict the assertion by Parsons and Takahashi (1973) and Boney, (1975) that seasonal fluctuations astride the Equator are essentially absent. There is evidence from the present data indicate that seasonal changes in abiotic factors influence and determine aquatic productivity and seasonality in the Tudor Creek.

The mean monthly biomass of individual copepod species for both sexes are presented in Figs. 5.35 - 5.43 for each of the 5 stations. The results show that female copepods were relatively heavier than males.

DIEL DISTRIBUTION OF COPEPOD SPECIES, HYDROGRAPHICAL FEATURES AT STATIONS 1 AND 5



CHAPTER 6

CHAPTER 6

6.0 DIEL DISTRIBUTION OF COPEPODA SPECIES AT STATIONS 1 AND 5 IN THE TUDOR CREEK

6.1 Spring and neap patterns in the plankton

On September 23 - 24 the neap tide data for station 1, showed a very clear difference between day and night samples with an indication of a peak three hours after sunset (Fig. 6.1). This peak occurred in the middle of the flooding and ebbing tide. The peak at 21 00 hr involved high numbers of copepoda. The lowest values were during ebb tide at 17 00 hr. The peak at 21 00 hr was caused by high numbers of Paracalanus spp, Temora spp. and Oncaea spp.

On the same day congruent data for station 5 demonstrated a clear difference between day and night samples mostly shared a higher density than those of September 23 - 25 Station 1 composition, calanoid numbers greatly influenced the rise in abundance. The lowest value was during ebb tide at 17 00 hr and 07 00 hr. The peak at midnight involved high numbers of Pseudodiaptomus stuhlmani and Acartia spp. Labidocera spp. appeared in large numbers at 1900 hr.

On the 1st and the 2nd of October the spring tide series station 1 showed a peak at 1300 hr and the other peak at 0100 hr, respectively (Fig. 6.2). At station 1, samples were not taken after 0100 hr due to technical problems. The lowest day value coincided with a low tide. The peaks at 2100 hr involved high numbers of Paracalanus spp, Temora spp and Corycaeus spp, while the one at 01 00 hr involved Paracalanus spp, Temora spp, Calanopia spp and Tortanus spp.

Data for station 5 on the same day showed a clear difference between day and night samples. These peaks coincided with the ebbing tide, and were caused by high numbers of calanoids. The peak at 21 00 hr appeared with maximum numbers 2 hr after high tide. The lowest values occurred during ebb tide at 13 00 hr. The peak at 21 00 hr was caused by high numbers of Pseudodiaptomus stuhlmani, Acartia spp. and Oithona spp.

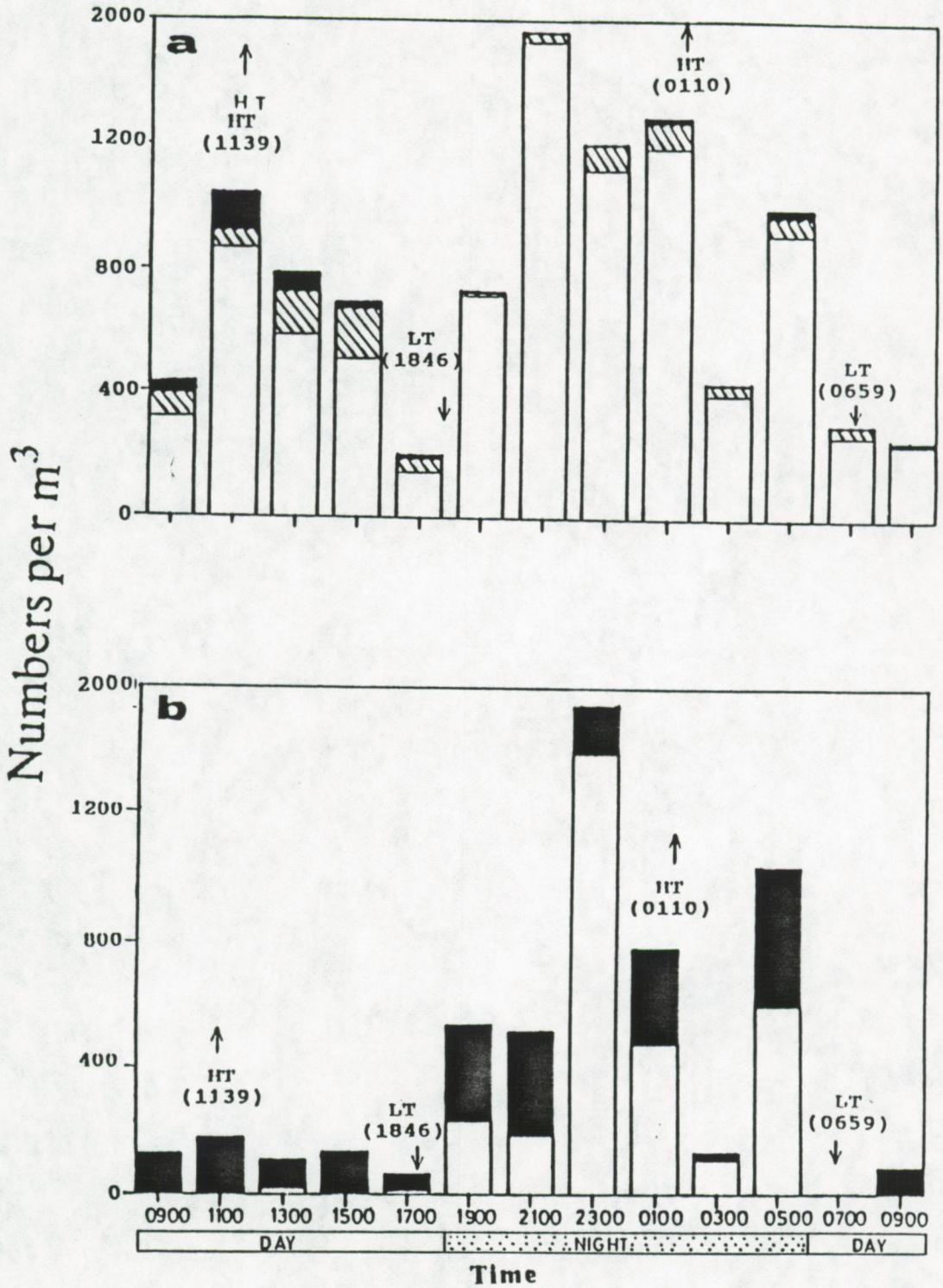


Fig.6.1. Temporal changes in abundance of copepods in Tudor Creek in (a) Station 1 and (b) Station 5 on 24-hr cycle experiment on 23-24 Sept 1985 in relation to the tidal cycle which were conducted simultaneously at station 1 (Top) and station 5 (bottom). Experiment was conducted during neap tide. ▫ Calanoida, ▪ Poecilostamatoida, ■ others.

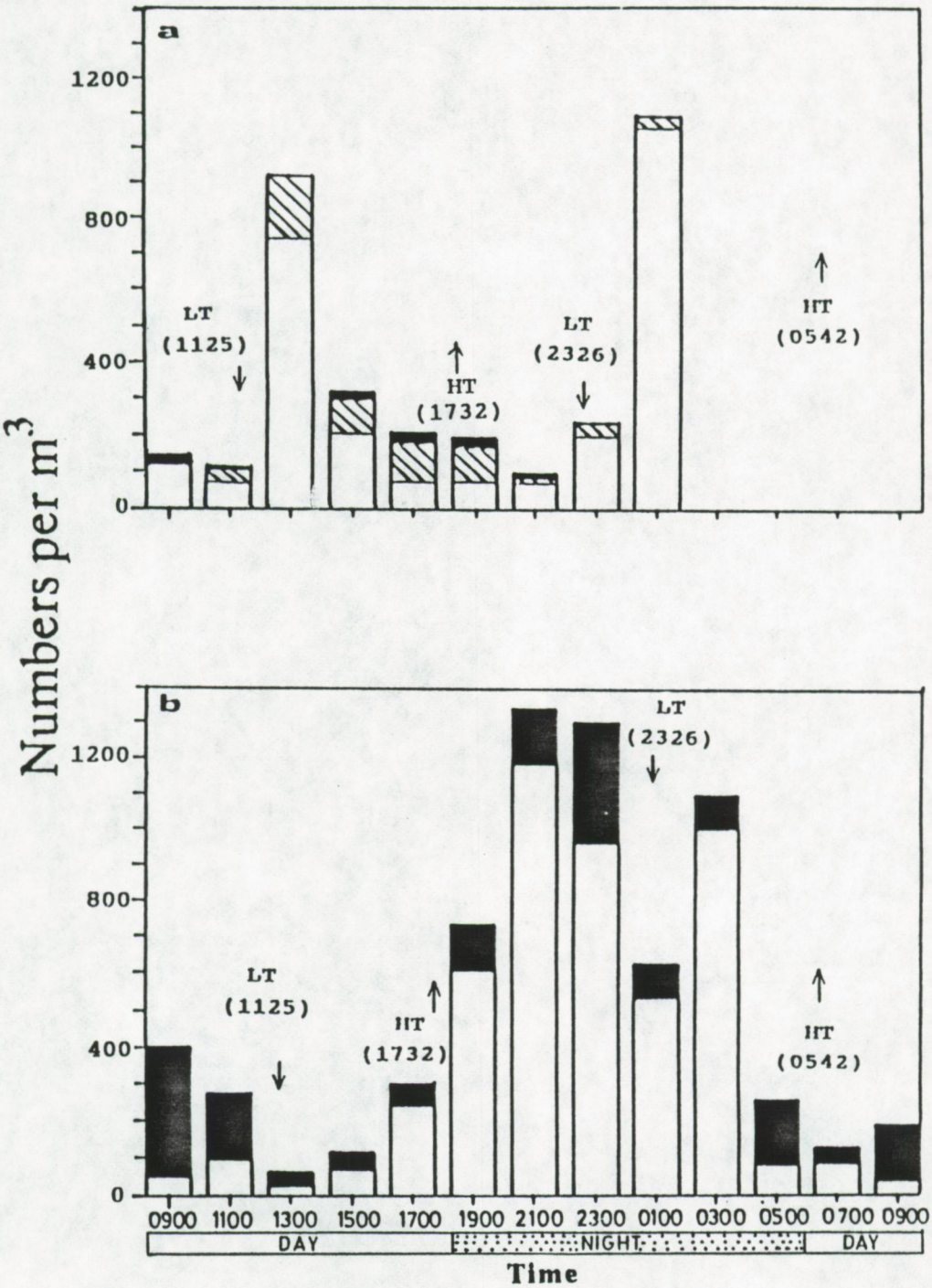


Fig.6.2. Temporal changes in abundance of copepods in Tudor Creek, in station 1 and 5 on 24-hr cycle experiment on 1st - 2nd October 1985 in relation to the tidal cycle. (HT = high tide, LT = low tide). ▫ Calanoida, ▪ Poecilostamatoida, ■ others .

6.2. Copepoda

Figures 6.3 and 6.4 show the comparison of abundance of the common copepoda during the 24-hr cycle experiment on 23/24-9-1985 (neap tide) and 1/2-10-1985 (Spring tide) between stations 1 and 5 which were carried out simultaneously in Tudor creek in relation to the tidal cycle. Fig 6.5 shows the comparison in biomass of copepods during the 24-hr cycle in spring and neap between stations 1 and 5.

Figures 6.6 - 6.11 give a comparison in biomass of the common copepods during the 24-hr cycle experiment on 23/24-9-1985 (neap tide) and 1/2-10-1985 (spring tide) between stations 1 and 5 which were carried out simultaneously in Tudor Creek, in relation to the tidal cycle and day/night rhythm.

This diel pattern is of considerable importance in interpreting the results of the 5-station series and any other studies like it, since on those occasions sampling was conducted at different times during the night according to whether the tide was spring or neap. It now appears likely that the observed differences in catch-rates between neaps and springs can be accounted for by these differences in tides and day/night.

6.2.1. Station 1

Total copepoda density showed during daytime a pattern similar to the tidal cycle, a little displaced in time, with a second peak at 2300 hr during spring of 1/2-10-1985, with a density increase of nearly all genera. Total density reached its highest value at 1300 hr in station 1 and at 2100 hr in station 5, formed by an increase of mainly calanoids and poecilostomatoids in both neap and spring at stations 1 and 5 respectively. The same overall pattern was reflected by the calanoids and poecilostomatoids grouped as others (Fig. 6.1 and 6.2). Canthocalanus pauper, Undinula vulgaris, Eucalanus spp, Acrocalanus spp, Paracalanus spp, Temora spp, Corycaeus spp, Oncaea spp, Euterpina acutifrons and Microsetella rosea occurred in every or nearly every sample in rather high numbers. Tortanus spp was found either only at night or in higher numbers during the night than during day time.

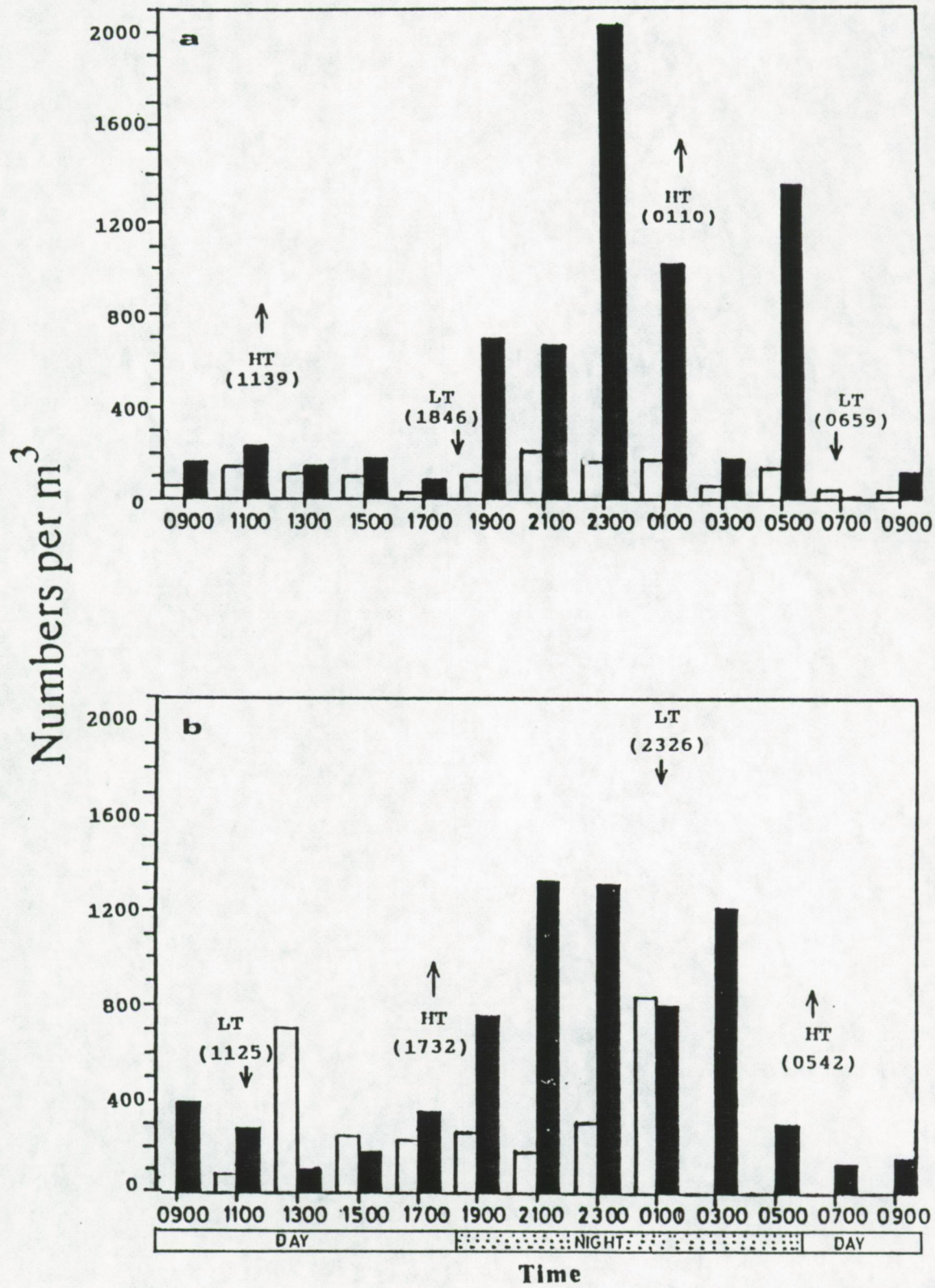


Fig.6.3.Comparison in abundance of copepods during the 24-hr cycle experiment on (a) 23rd-24th September 1985 and (b) 1st-2nd October 1985 between stations 1 and 5 which were sampled simultaneously in Tudor Creek. (HT= high tide; LT= low tide). ▫ station 1, ▪ station 5.

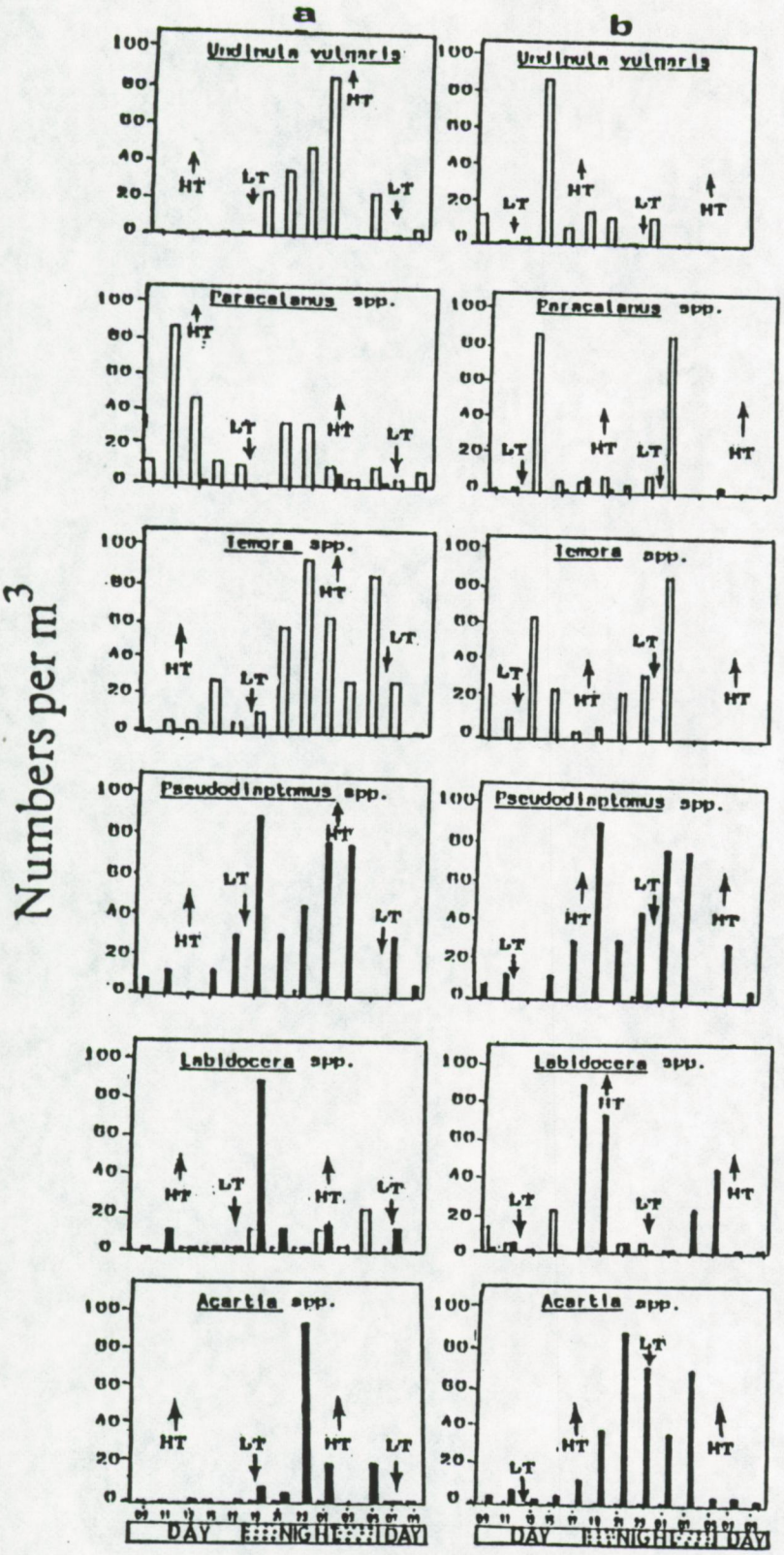


Fig.6.4. Comparison of abundance of the common copepods during the 24-hr cycle experiment on (a) 23rd-24th September 1985 (Neap tide) and (b) 1st-2nd October 1985 (Spring tide) between stations 1 and 5 which were carried out simultaneously in Tudor Creek, in relation to the tidal cycle and day/night rhythm. (HT = high tide; LT = low tide). (▫ station 1, ▪ station 5).

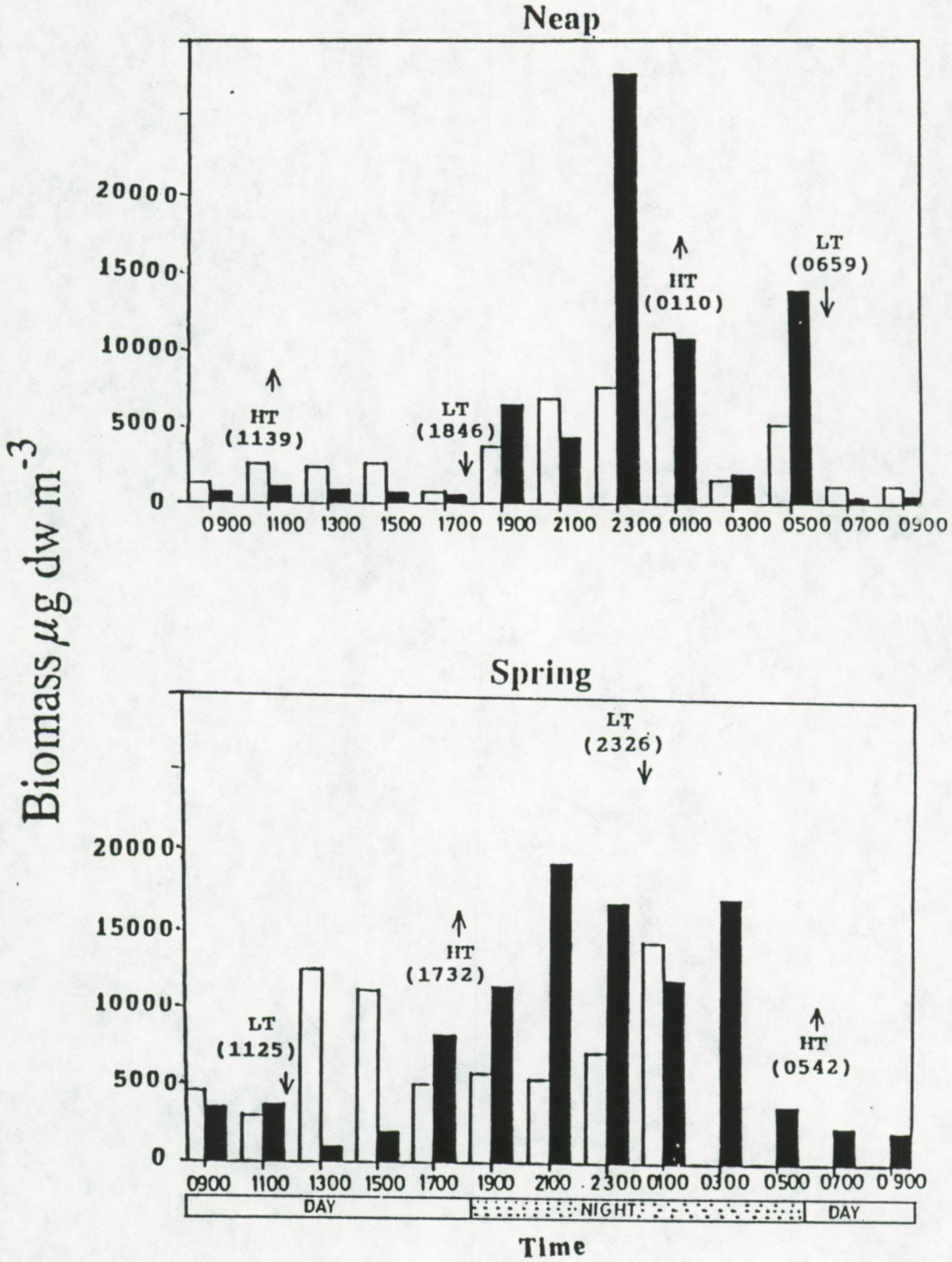


Fig.6.5. Comparison in biomass of copepods during the 24-hr cycle experiment on (a) 23rd-24th September 1985 (Neap tide) and (b) 1st-2nd October 1985 (Spring tide) between station 1 and 5 which were carried out simultaneously in Tudor Creek, in relation to the tidal cycle and day/night rhythm. (▫ station 1, ▪ station 5).

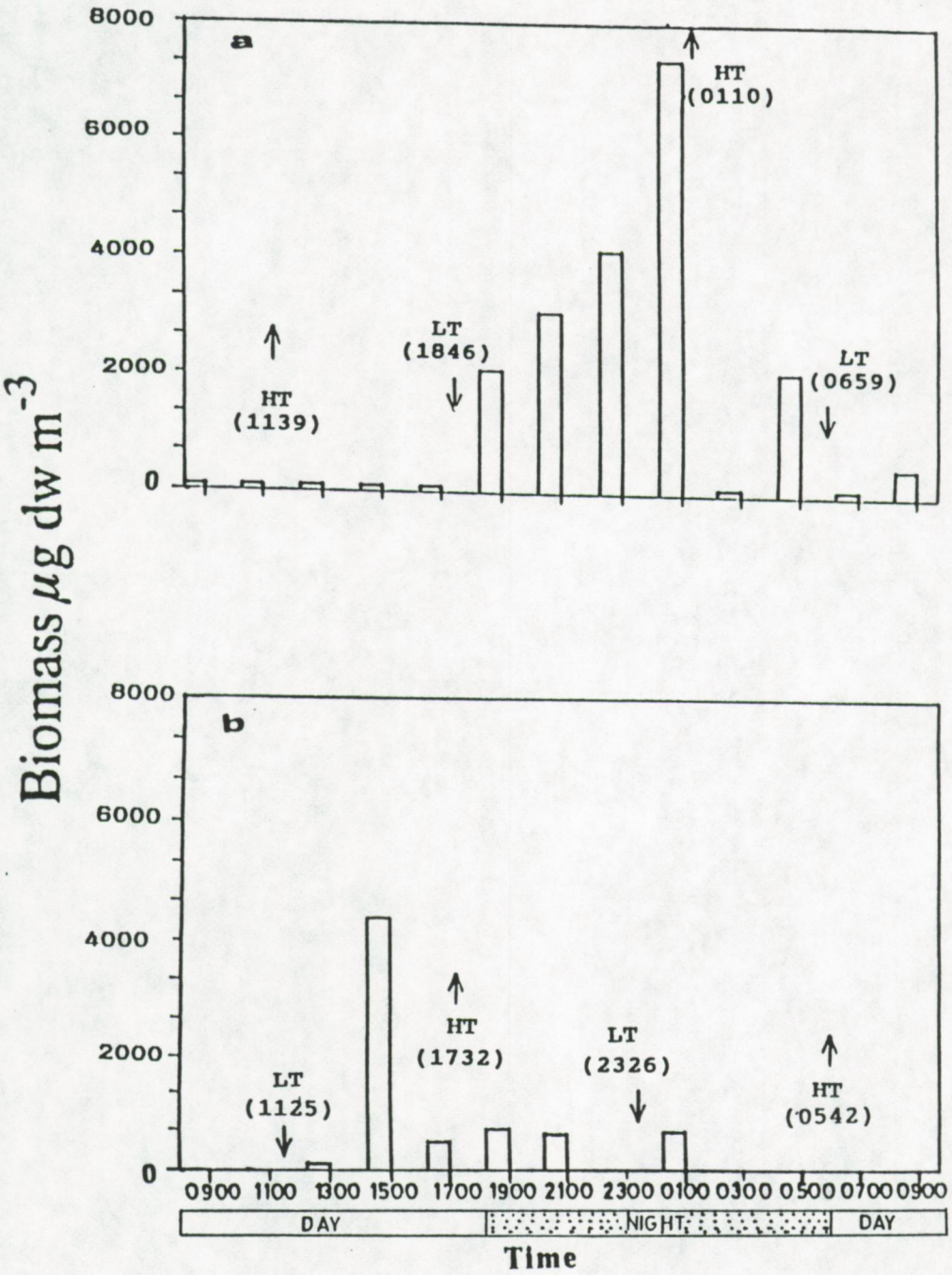


Fig.6.6. Comparison in biomass of Undinula vulgaris during the 24-hr cycle experiment on (a) 23rd-24th September 1985 (Neap tide) and (b) 1st-2nd October 1985 (Spring tide) between sations 1 and 5 which were carried out simultaneously in Tudor Creek, in relation to the tidal cycle and day/night rhythm. (▫ station 1, ▪ station 5).

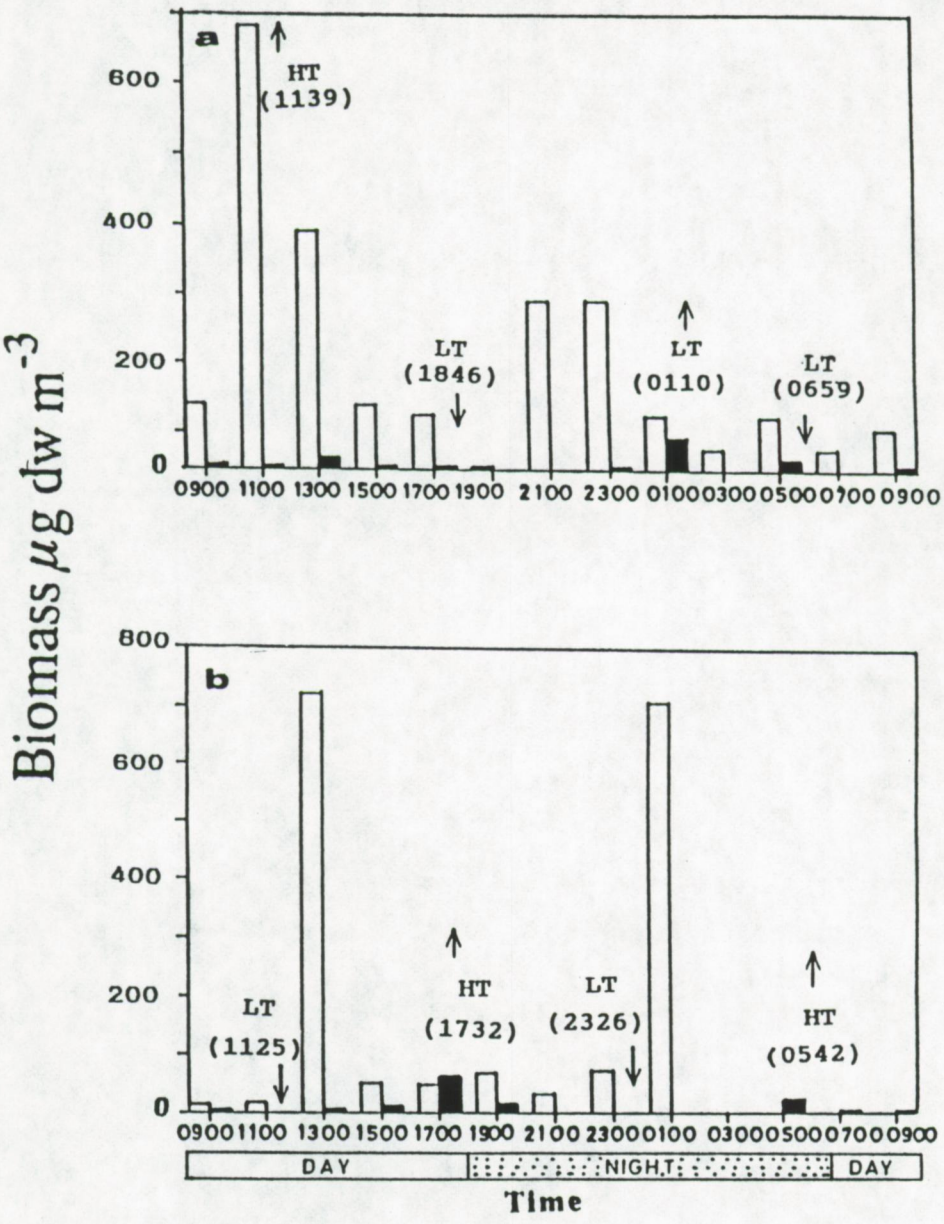


Fig.6.7. Comparison in biomass of Paracalanus spp. during the 24-hr cycle experiment on (a) 23rd-24th September 1985 (Neap tide) and (b) 1st-2nd October (Spring tide) between stations 1 and 5 which were carried out simultaneously in Tudor Creek, in relation to the tidal cycle and day/night rhythm. (▫ station 1, ▪ station 5).

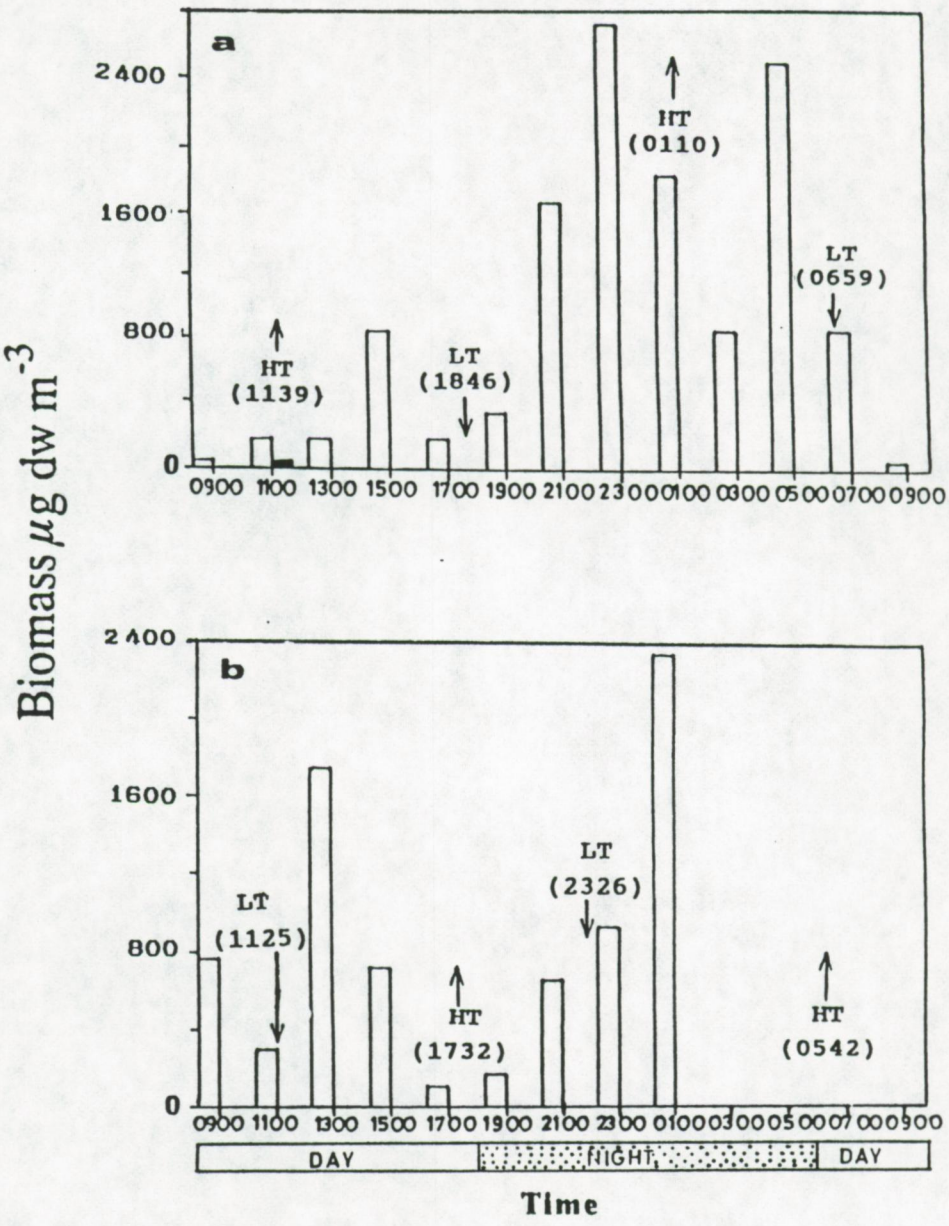


Fig.6.8. Comparison in biomass of Temora spp. during the 24-hr cycle experiment on (a) 23rd-24th September 1985 (Neap tide) and (b) 1st-2nd October (Spring tide) between stations 1 and 5 which were carried out simultaneously in Tudor Creek, in relation to the tidal cycle and day/night rhythm. (▫ station 1, ▪ station 5).

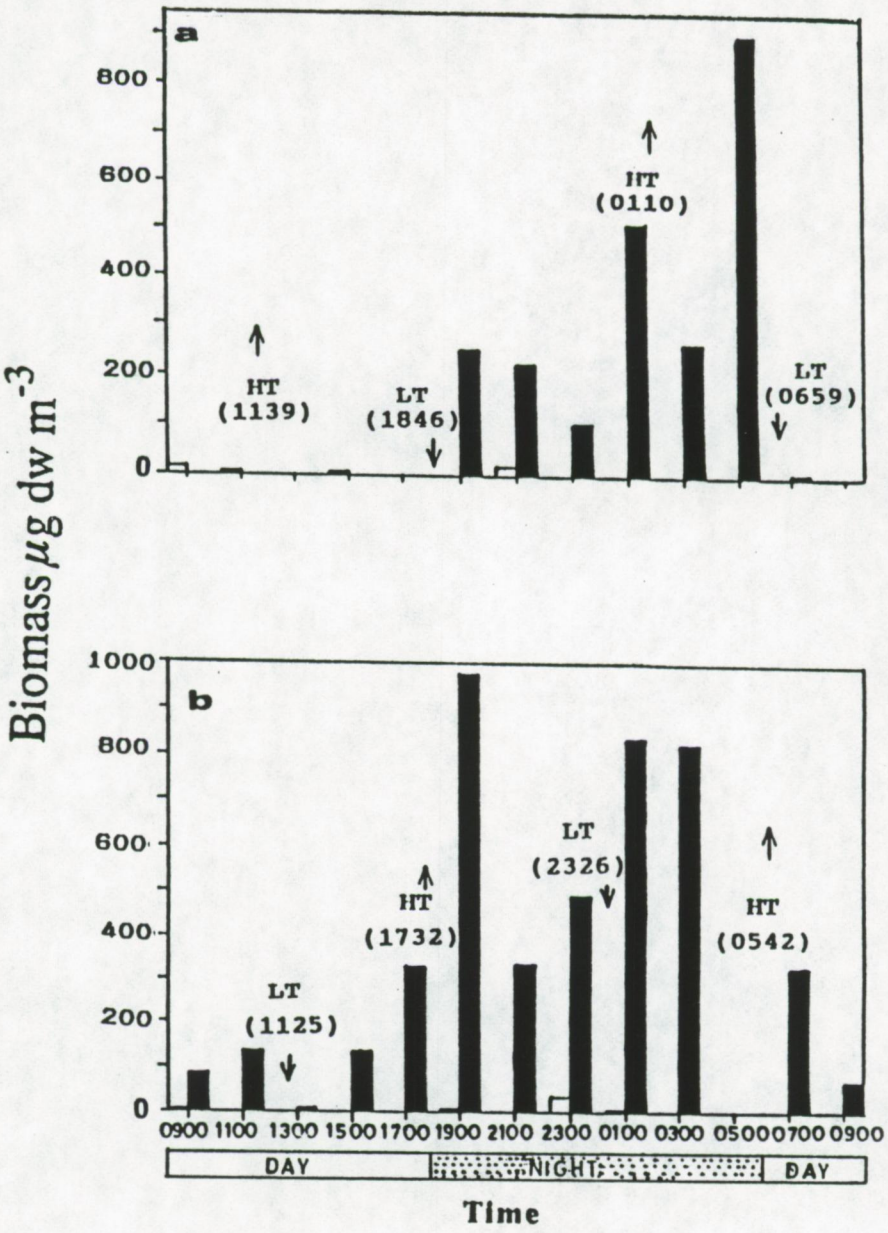


Fig.6.9. Comparison in biomass of Pseudodiaptomus stuhlmani during the 24-hr cycle experiment on (a) 23rd-24th September 1985 (Neap tide) and (b) 1st-2nd October (Spring tide) between stations 1 and 5 which were carried out simultaneously in Tudor Creek, in relation to the tidal cycle and day/night rhythm. (▫ station 1, ▪ station 5).

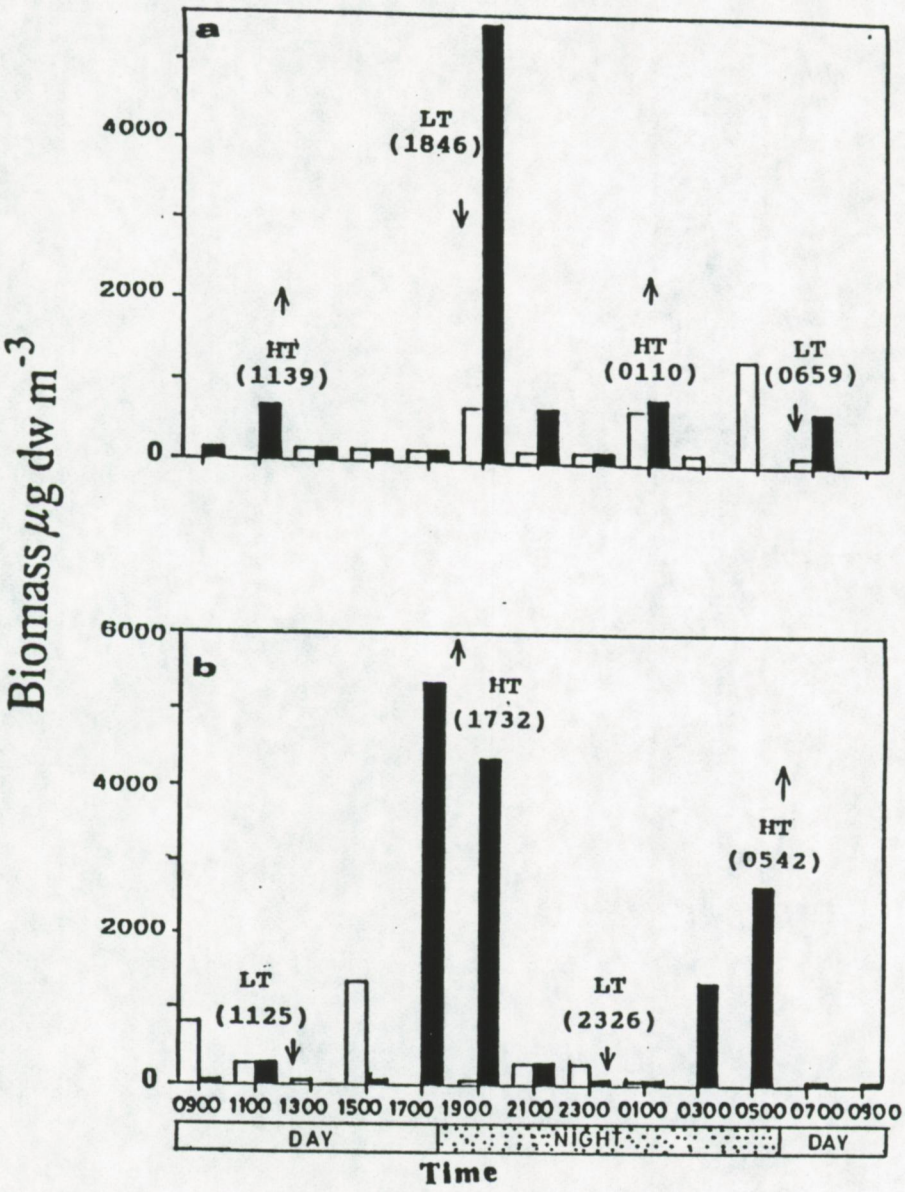


Fig.6.10. Comparison in biomass of Labidocera spp.during the 24-hr cycle experiment on (a) 23rd-24th September 1985 (Neap tide) and (b) 1st-2nd October (Spring tide) between stations 1 and 5 which were carried out simultaneously in Tudor Creek, in relation to the tidal cycle and day/night rhythm. (▫ station 1, ▪ station 5).

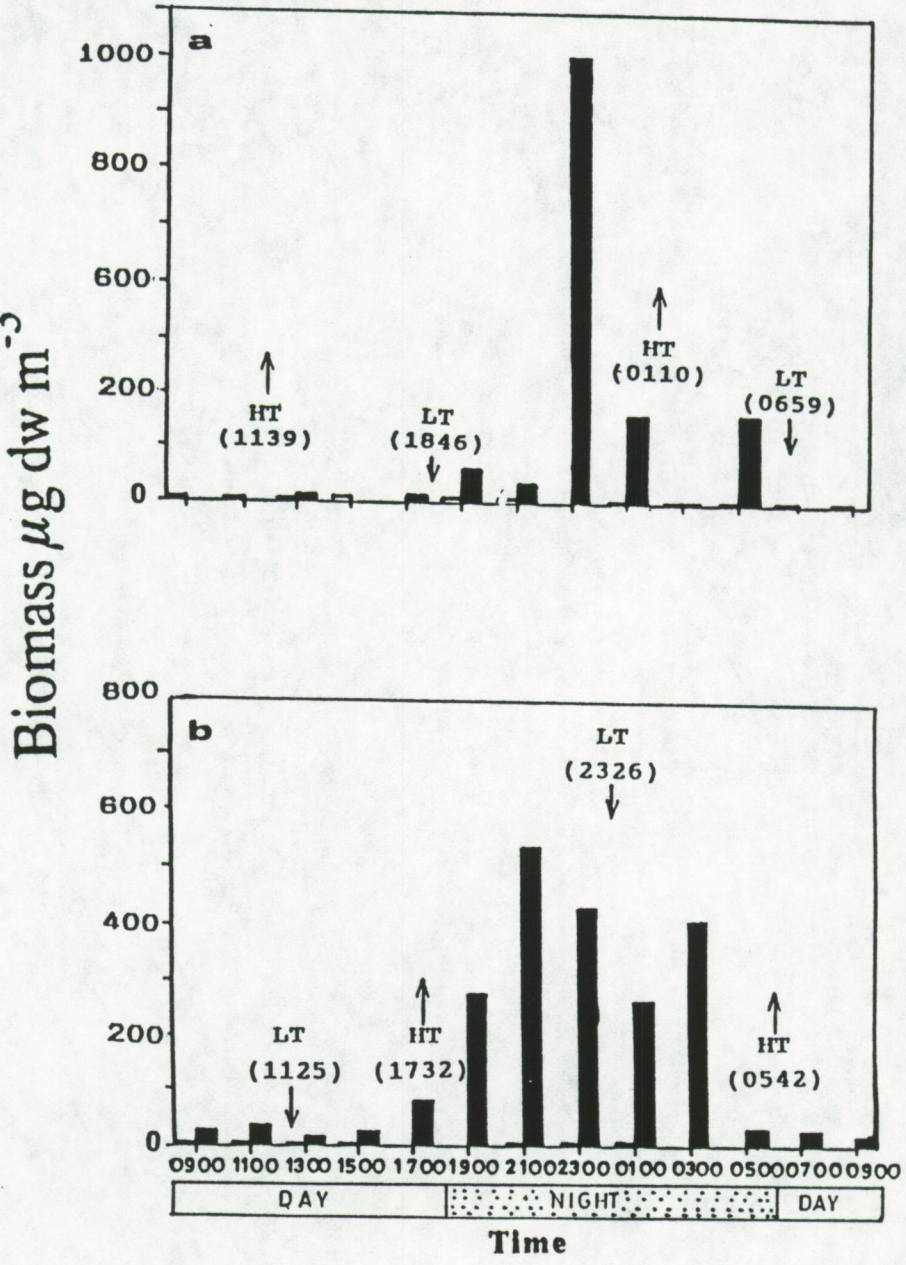


Fig.6.11. Comparison in biomass of Acartia spp. during the 24-hr cycle experiment on (a) 23rd-24th September 1985 (Neap tide) and (b) 1st-2nd October (Spring tide) between stations 1 and 5 which were carried out simultaneously in Tudor Creek, in relation to the tidal cycle and day/night rhythm. (▫ station 1, ▪ station 5).

6.2.2. Station 5

The total copepods showed a marked diurnal variation. The total density was clearly much higher during the night than during the day, mainly caused by an increase of the calanoids which comprised by far the major part of the copepods. some of these (Figs. 6.3 and 6.4) include: Acrocalanus spp., Paracalanus spp and Euterpina acutifrons occurred sporadically. Pseudodiaptomus stuhlmani, Labidocera spp. occurred mainly at night within this diurnal variation pattern. During daytime the total density showed a pattern more or less parallel with the tidal cycle with the highest peak at 2300 hr during the neap tide on 23/24-9-1985. A second very high peak is recorded at 0500 hr (low tide, one hour before sunrise). At 1900 hr a third very high peak was noted. A sudden drop of total copepod density was noted at 07 00 hr, one hour after sunrise while the tide was flowing.

6.2.3. Comparison between station 1 and 5.

For nearly all genera a diurnal variation occurred at both station 5 and at station 1.During daytime the total density was lower at station 1 and 5, while at night however the total density was much higher in both stations 1 and 5. This was due to a much higher calanoid density increase during the night in both stations. At both stations the highest density peak occurred at 2300 hr. Canthocalanus pauper, Undinula vulgaris, Eucalanus spp, Temora spp, Tortanus spp, Corycaeus spp, Oncaea spp. Euterpina acutifrons and Microsetella rosea occurred only at station 1. Pseudodiaptomus stuhlmani and Labidocera spp. occurred mainly in station 5.

The number of genera encountered during the 24 hours cycles at both stations during neap and spring is represented in Figs. 6.12 and 6.13. In total fifty two genera were encountered at Tudor Creek at both stations during the two 24 hours cycles. At both stations more copepod genera were encountered during the night than during the day. Diversity, expressed as the number of taxa encountered, was at any sampling moment lower at station 5 than at station 1.

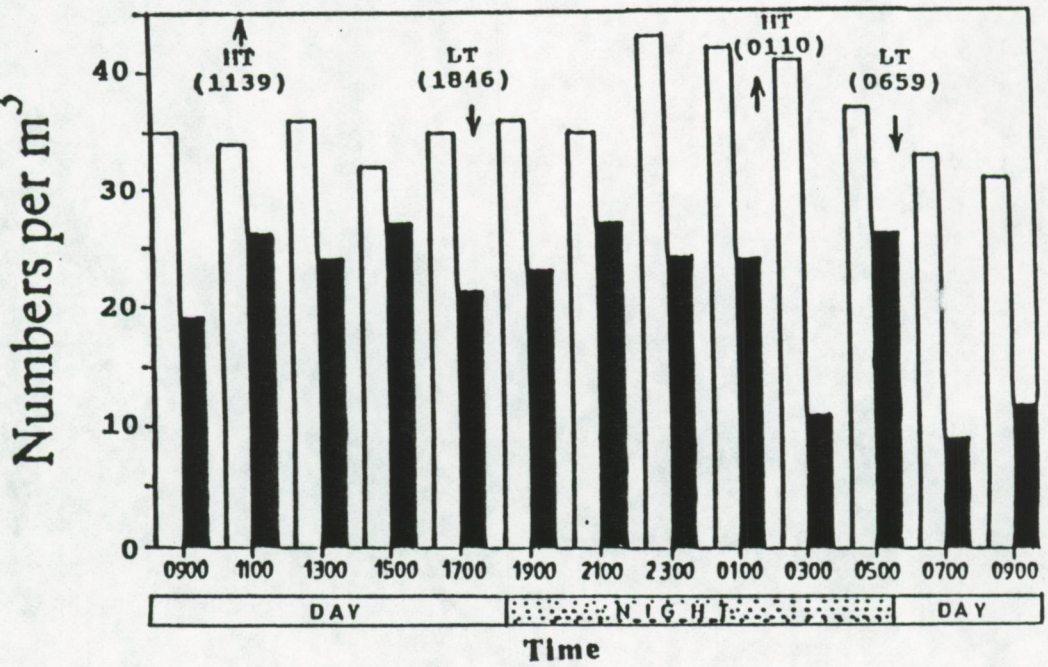


Fig.6.12. Comparison of the number of Copepod genera found during the 24-h cycle experiment on 23rd-24th September 1985 between stations 1 and 5 in Tudor Creek which were carried out simultaneously in relation to the tidal cycle and day/night rhythm. (HT = high tide; LT= low tide). (▫ station 1, ▪ station 5).

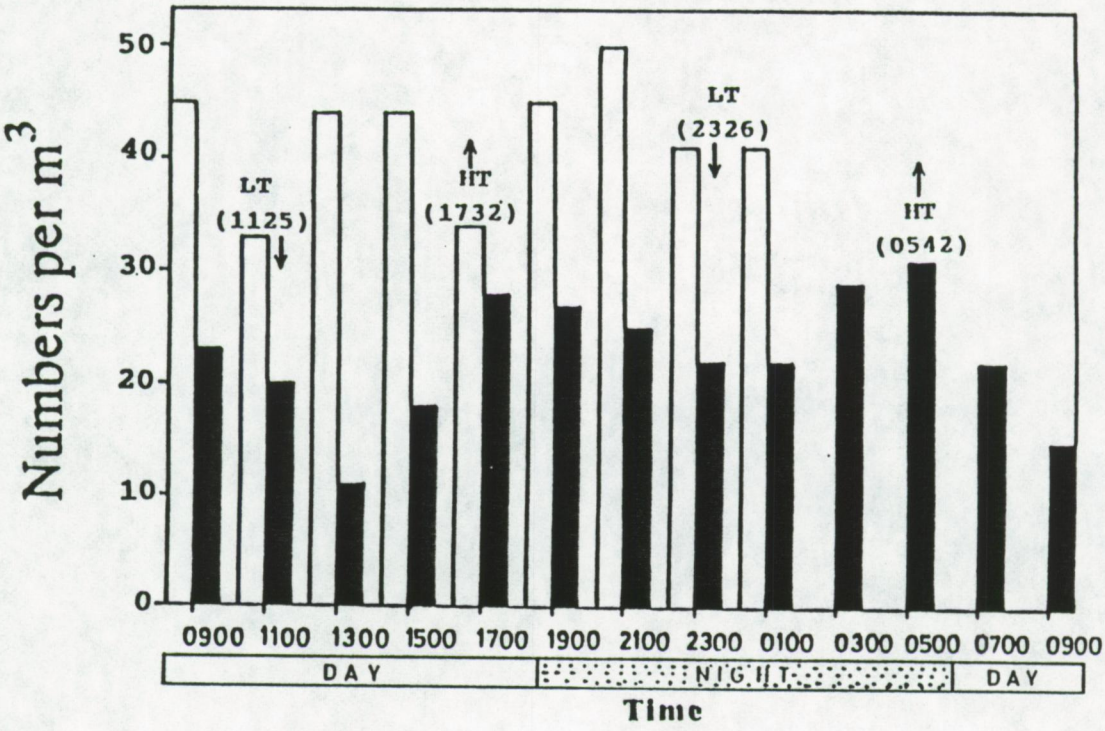


Fig.6.13. Comparison of the number of copepod genera found during the 24h cycle experiment on 1st-2nd October 1985 between stations 1 and 5 in Tudor Creek which were carried out simultaneously in relation to the tidal cycle and day/nigt rhythm. Experiment conducted during spring tide. (▫ station 1, ▪ station 5).

6.3. Discussion

Tudor creek support a diverse zooplankton community that is similar to that found in other inshore waters of Dar-es-Salaam, Tanzania (Okera 1974) and Transkei, South Africa (Wooldridge 1977).

The zooplankton population consisted of a large number of species dominated by copepods. Amongst the copepods, calanoids dominated the samples. Decapod larvae mainly brachyuran and caridean zoeae, were usually the most abundant crustaceans after the copepods. In comparison with the results of the 24-hr sampling series in February and March 1983 (Reay & Kimaro, 1984), those from the present study agree well and demonstrate, for example a clear difference between day and night catches of plankton. Catches were higher at night. In addition, copepods reflect fluctuations parallel to the tidal cycle. The day/night pattern is much more obvious at station 5 than station 1 during both neap and spring tides. This may be attributed probably to vertical migration and less mixing. Station 5 is shallower than station 1.

In South African estuaries the vertical migration pattern differed from the type-pattern usually described (Wooldridge 1977). Most species in shallow waters do not rise until after dark and remain in the surface water almost all night, descending again before dawn (Grindley, 1972). This pattern is also found at Tudor Creek, in the shallow area.

Vertical migration behavior occurs in almost all groups of animals represented in the plankton. This behavior is particularly well-marked in the plankton of estuaries (Grindley, 1972). In South African estuaries vertical migration appeared to occur for almost all the zooplankton observed. At Port Reitz (Okemwa, 1989) vertical migration was found for Polychaeta, Ostracoda, Cumacea, Prosobranchia and Amphioxus. Larvacea, Chaetognatha, Salpida and Euphausiacea fluctuated with the tidal cycle. As our samples were taken by horizontal tows no final conclusions can be made concerning vertical migration of zooplankton. Although vertical migration is most probably the explanation for the high copepod densities occurring at night at station 5, it is clear that depending

on the species of copepods considered, tidal and/or diel quantitative and/or qualitative changes can occur. However, it is difficult to judge on the degree of importance of tidal movement and vertical migration as parameters influencing the copepod abundance and distribution.

The tidal effect has probably a stronger influence on the creek mouth than River Kombeni which is entering Tudor Creek because of its little flow. Sameoto (1975) showed the relationship between tidal fluctuations and the compositions of zooplankton samples at St. Margaret's Bay and concluded that diurnally migrating species of zooplankton did not show a tidal correlation.

Salinity did not fluctuate very much. The present work has demonstrated small variation in temperature towards low tide which can be attributed to the out-going warmer estuarine water. Towards high tide the temperature declined due to the in-coming cooler coastal water.

It is well known that plankton collecting with only one type of net will not sample the total zooplankton community because of the varying size of the zooplankton organisms (UNESCO, 1968). However, the plankton net used here is well suited for obtaining information about the composition of the coastal copepod community including large copepodite and adult copepods. Quantitative comparisons between data from different zooplankton studies can only be made with great caution because of differences in sampling patterns and particularly the net mesh-size used. This is well demonstrated by Greenwood (1980).

Greenwood (1980), for example, using a Clarke-Bumpus net of 195um pore size recorded total zooplankton abundance of 1691 m^{-3} whereas comparisons between estimates of zooplankton numbers from similar studies elsewhere ranged between 1,350 and 45,900 m^{-3}. The distribution and the dynamics of plankton in Tudor Creek are, as in any estuary, complex.

Physical factors, as tides are very effective because the exportation and importation of plankton including economically important species which come from spawning grounds to nursery biotopes (the mangroves).

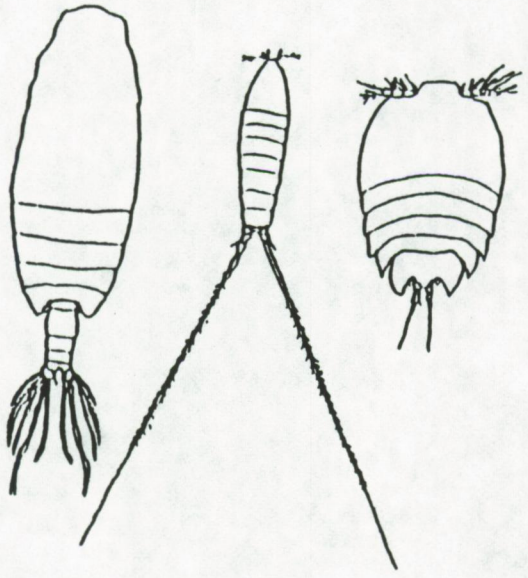
Together with the diurnal vertical migrations (to the surface at night time), we have seasonal fluctuations correlated with the rainy season and probably due to the input of nutrients and phytoplankton abundance.

Nutrient enrichment caused by land run off during the rain period leads to proliferation of phytoplankton and swarming of filter feeders in the coastal waters (Goswani, 1985). In this study several copepod species showed peaks in December and April, i.e. after the short November rains and during the long rains in April respectively.

Many of the common herbivores of East African inshore waters have extremely fine and highly specialized filtration mechanisms. These include Thaliacea and Appendicularia as well as several copepods, such as Undinula vulgaris. Omnivorous forms are well represented in the zooplankton of Tudor creek. These include the copepod genera Temora (Sars, 1902) and Centropages (Giesbrecht 1892) which have mouth parts with adaptations for the capture of small animals as well as filter feeding on unicellular algae (Gauld, 1966).

Carnivore forms were also represented and these include the genera Candacia (Giesbrecht, 1892), Sapphrina (Thorell, 1859), and Copilia (Dana, 1849). The carnivores succeeding the filter feeders and omnivores contribute to trophic and species diversity in this ecosystem.

PRIMARY PRODUCTIVITY



CHAPTER 7

CHAPTER 7

7.0. PRIMARY PRODUCTIVITY AND PHYTOPLANKTON BIOMASS.

7.1. Introduction

The behavior of light in the atmosphere and oceans is an important consideration for photosynthesis. However, photosynthesis is also affected by the physiological condition of the phytoplankton, available nutrients and physical mixing processes.

7.1.1. Photosynthetic process:

Briefly, the photosynthetic reaction may be presented as:

$$nCO_2 + 2nH_2O \xrightarrow{light} n(CH_2O) + nO_2 + nH_2O$$

This involves the capture of light energy (via chlorophyll a and accessory pigments), and transformation into chemical energy by the phosphorylation of ADP to ATP, and reduction of $NADP^+$ to NADPH. This energy may then be used to fix CO_2 and H_2O low energy inorganic compounds into carbohydrates, (high energy organic compounds). The light penetrating the ocean is a function of the turbidity of the water, (K, vertical extinction coefficient), and the wavelength, (shorter wavelengths penetrate deeper than long wavelengths). Although photosynthesis by marine algae is restricted between approximately 400 and 720 nm, (the PAR, or "Photosynthetically available radiation"), this description may be narrowed even further.

The "photosynthetically usable radiation," PUR, which is dependent on that part of the light energy actually absorbed, (according to the pigment composition of the specific algal group and the light spectra). Also, the "photosynthetically stored radiation," PSR, which is that fraction of PUR used in the photosynthetic reactions, (where light energy is transformed into chemical energy).

PSR < PUR < PAR

The light energy > 600 nm is mostly absorbed by chlorophyll a, while that < 600 nm is mainly absorbed by the accessory pigments. As most of the light penetrating into the ocean is between 400 to 600 nm, the accessory pigments are as important as the primary pigments, chl a. Primary production is the rate of synthesis of organic material, in a unit volume of water (or under a unit of area).

Respiration consumes the photosynthesized products, and may occur in the light or dark. This is the reverse reaction of photosynthesis, and has been thought to be around 10% of maximum gross photosynthesis, Parsons et al (1984).

7.1.2. Primary Production

Figure 7.1 shows the seasonal changes of the primary production of Tudor Creek. Figure 7.2 shows the results of primary production obtained for Tudor Creek at different times in the year. The peak of production is obtained in May-June during long rainy season and November-December during short rainy season; the lowest values are found in February during the dry season for the period under study. Figure 7.2 also shows the gross and the net production.

Figure 7.3. shows primary production as a function of depth in different months in Tudor Creek.

During the period of the present study phytoplankton primary production in Tudor Creek occurred between 3.0-5.0 m depth in the month February and July, but at the surface in May-June. Secchi disc transparency ranged between 1.0-8.1 m. This could most probably attribute to light inhibition which occurs during the dry season, when the weather is not cloudy and not during the rain season. Light inhibition occurs at the surface in April and July in Tudor Creek.

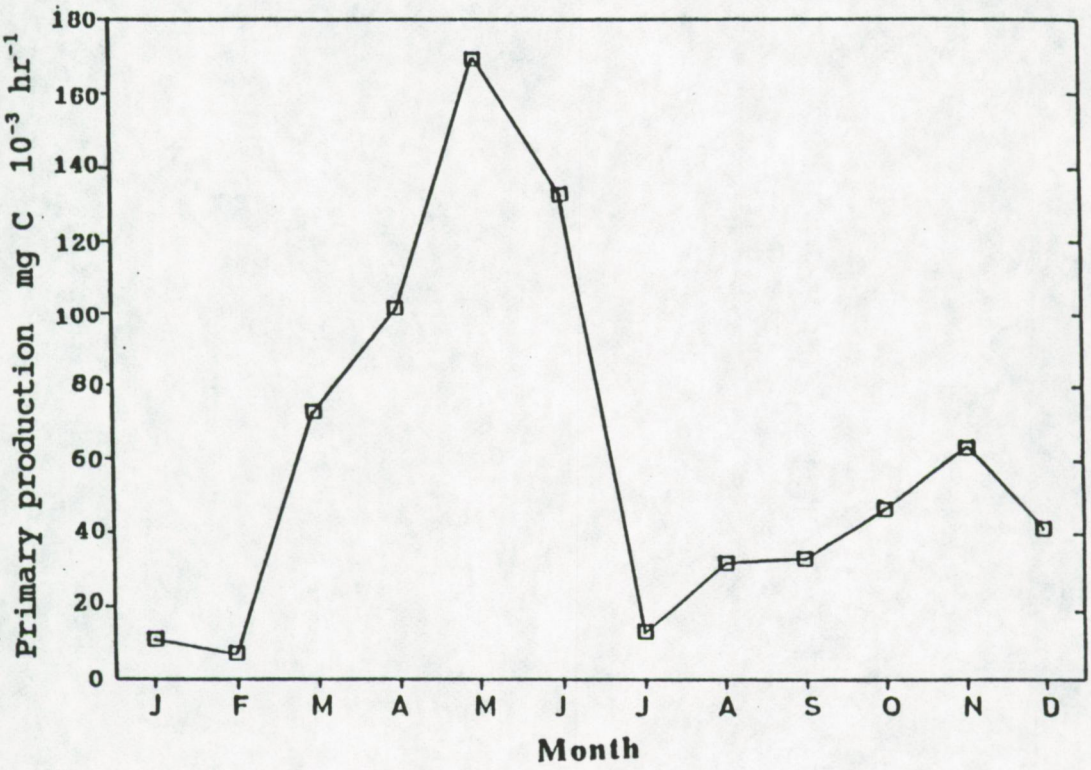


Fig.7.1.Seasonal changes in sea water (1985-1987; depth 0 - 7m) primary production at English Point near station 1 of Tudor creek.

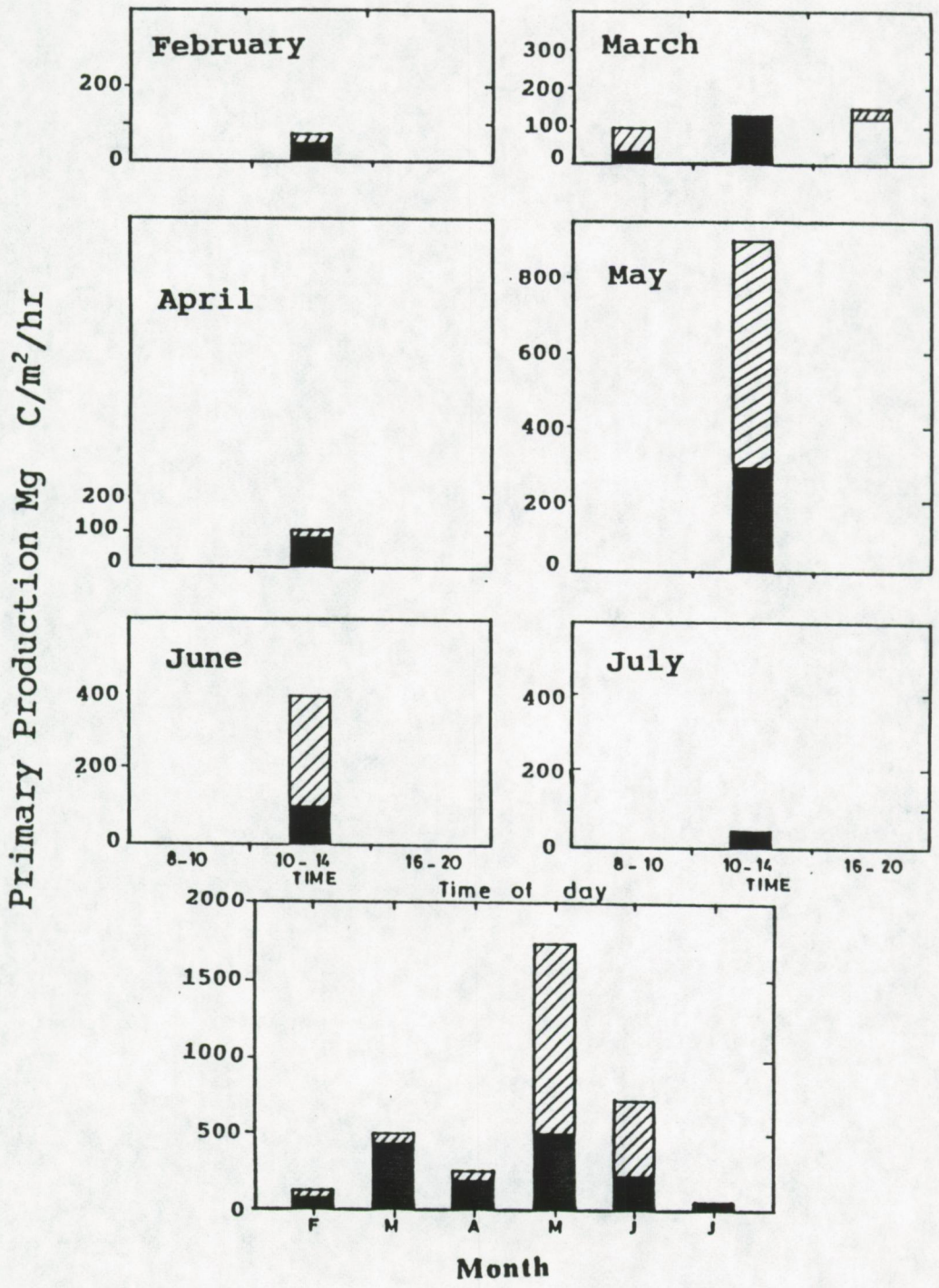


Fig.7.2. Seasonal changes in Sea water (1985-1987; depth 0-7m) primary production at station 2 in Tudor Creek. ▨ Respiration, ■ Netto production. (Data after Daro et al 1990) .

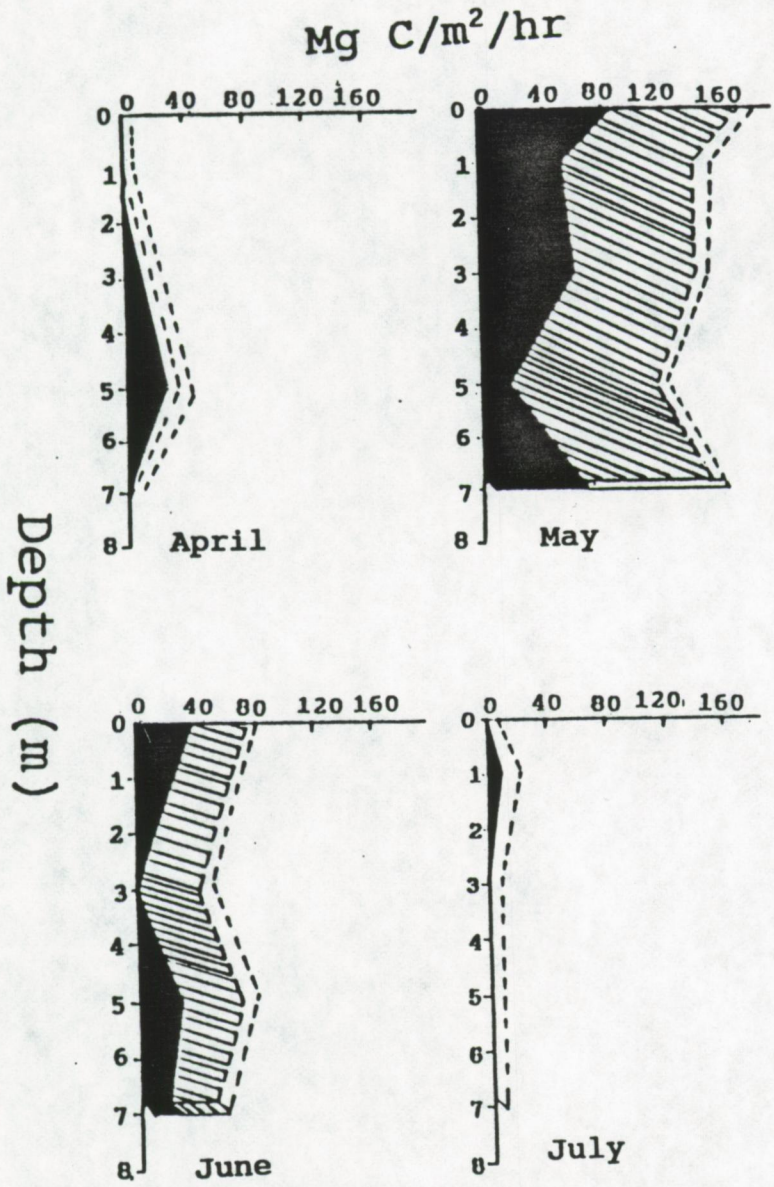


Fig.7.3.The seasonal changes of primary production with depth at station 2 in Tudor Creek. ▫ Respiration, ▪ Netto production.(Data from Daro et al (1990)).

7.1.3. Gross primary production

The results presented were obtained between 1000hr and 1400hr and in this case considered to represent about half of the total daily production. Table 7.1 shows the daily gross primary production of Tudor Creek in February and May, 1988.

Table.7.1: Daily gross primary production (mg Cm^2d^{-1}) of Tudor Creek in February and May, 1988.

Month	Net	Gross
February	200	300
May	2,000	4,000

7.2 Chlorophyll a

Figure 7.4 shows seasonal changes of chlorophyll a on different stations in Tudor Creek. The results show the same trend as the primary production results with maximal value in May-June. Figure 7.5 indicates chlorophyll a in different months in Tudor creek. The results of the different stations show that samples got from the most country side stations exhibit the highest values. The phytoplankton takes advantages of the abundance of nutrients flushed out from the small river on one hand (see fig. 3.9), but also of from the presence of the rich mangrove vegetation surrounding this area. From this data it is obvious that the source of nutrients stimulating growth of the vegetation is coming from the mangrove area. In June this influence is extending to more sea side stations.

7.3. The role of plankton in the total ecosystem

Table 7.2 shows a comparison of the oxygen concentration in the water with the primary production at station 2 in Tudor creek in March-April 1988. We could observe at day-time an increase in O_2 concentration of 880 mg O_2 m^{-3} and a net production of phytoplankton of 320 mg O_2 m^{-3} during

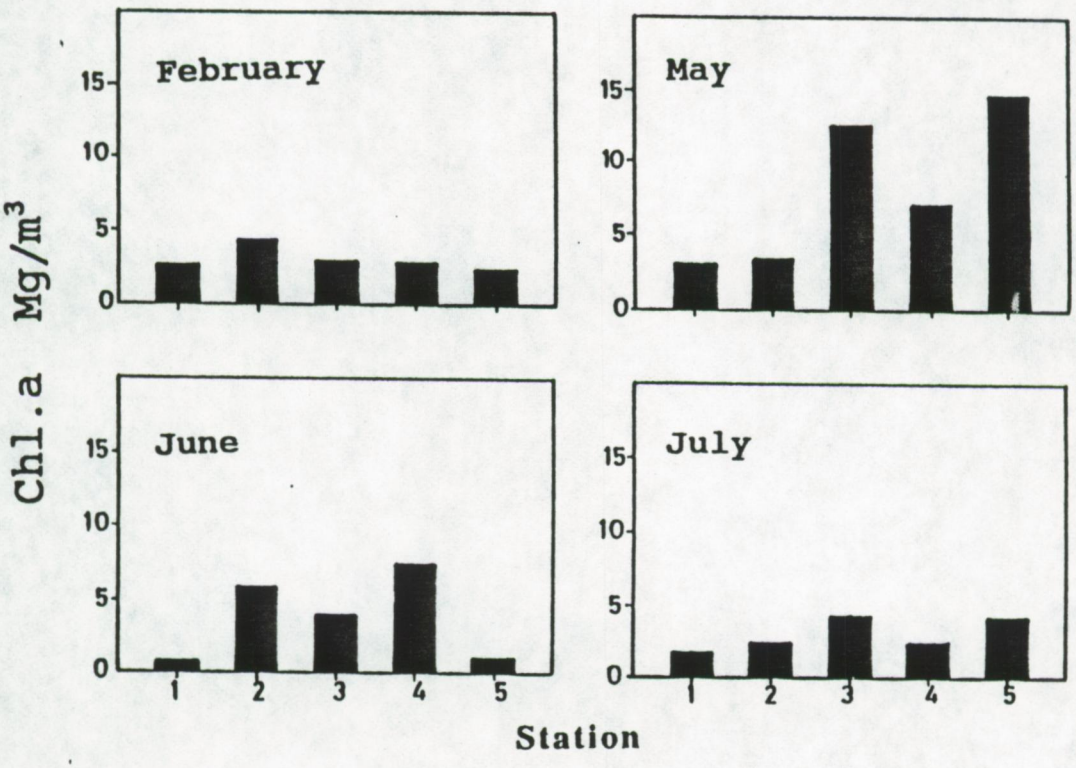


Fig.7.4. Spatio- temporal variation of Chlorophyll a in Tudor Creek. (Data after Daro et al. 1990) .

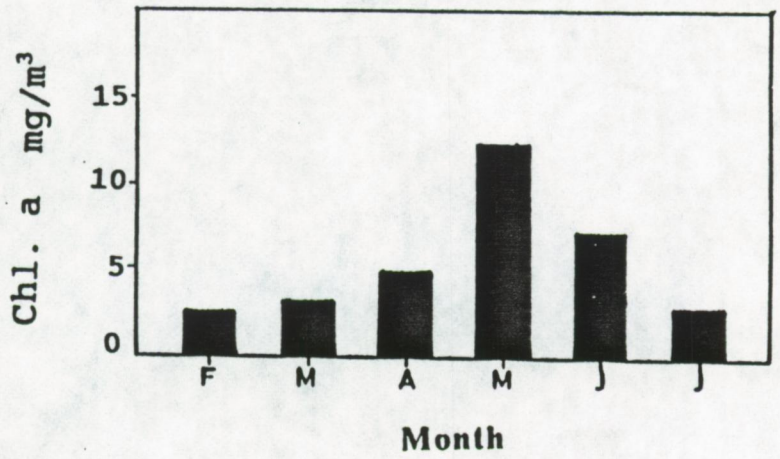


Fig.7.5.Chlorophyll a in different months in Tudor creek. (Data after Daro et al. 1990) .

the same time. Primary phytoplanktonic production from these data accounts only for 36% of the increase in oxygen, the remaining 64% probably being caused by the sea grasses and seaweeds field extending very broadly on the beach in front of the Tudor Creek. More data have to be obtained to ascertain this assumption. So in such environments, benthic primary production should represent the highest part of the total primary production, which is contrasting with the 10% contribution of the benthos in temperate environments (Daro pers.comm).

Table 7.2.Comparison of oxygen concentrated (mg O_2 l^{-1}) and saturation (%) levels in the water with the Primary Production.

Time	Concentration	Saturation
09.30	5.60	82.00
11.30	6.16	95.00
13.30	6.48	100.00
15.30	6.49	99.00
17.30	6.40	96.00
19.30	5.84	88.00
21.30	5.60	84.00
23.30	5.84	88.00
01.30	6.16	92.00
03.30	6.16	91.00
07.30	5.84	88.00

Depth (m)	Nett Production (mg O_2 l^{-1} day^{-1})	Gross Production (mg O_2 l^{-1} day^{-1})
0	0	0.18
3	0.29	0.38
5	0.44	0.54

7.4. Discussion

We have found out that gross primary production in Tudor Creek is estimated at 200 to 4000 mgC $m^{-2}d^{-1}$.

Such values are much higher than open ocean values for tropical latitudes, but are similar to values for the more productive oceanic environments (see f.i Koblentz-Mischke, 1970). They are significantly lower than North Sea values during spring bloom (10,000 - 1,500 mgC $m^{-2}d^{-1}$; Daro, pers. comm.). As yet it is difficult to assess the relative importance of this food supply in supporting the secondary and tertiary producers in the creeks.

Seasonal changes in primary production in Tudor Creek can be attributed to rainfall pattern throughout the year. At the end of the dry season all nutrients are consumed and during the rain season nutrients are flushed out by the river and the erosion of the mangrove bottom. Probably the strong winds occurring during this period also plays an important role in the mixing of the water column, bringing the nutrients to the upper layer. This influence of wind is still observed in March with an increase of production. However, additional information indicates phytoplankton activity to be relatively poor in Tudor Creek. Nutrients distributions during rain seasons (April-May and November) show important concentration gradients along the creeks (Kazungu et al., 1987; Kazungu, 1987). These nutrient concentrations are observed to be linearly related with salinity, indicating conservative dilution as the main process controlling nutrient distribution (Kazungu et al., 1987). This absence of a clear signal of nutrient uptake by local phytoplankton would suggest a poor phytoplankton activity, which can be understood in view of water-mass turn-over time. But the regeneration time and uptake of nutrient is unknown. We cannot exclude a very high turn-over of nutrients. Tidal currents in the Mombasa creeks are very efficient in exchanging the lagoonal water-mass and the two daily tidal prisms represent 50 to 100% of total creek volume, depending on the tidal range (Norconsult, 1975). This efficient exchange of lagoonal water with coastal water probably impedes pelagic phytoplankton stocks to build up to levels at which their activities

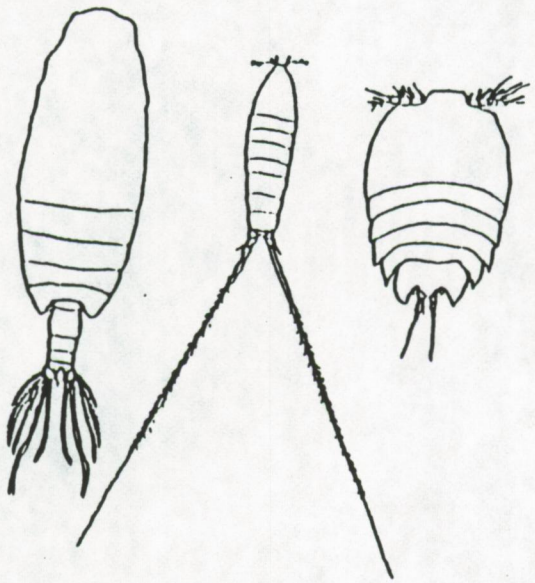
would start to deplete the enhanced nutrient stocks observed during rain seasons. A further factor that is likely to impede phytoplankton growth, is turbidity. Light penetration in the creeks is generally limited to a few meters (Secchi disc). Thus the general physico-chemical and hydrological conditions are not in favor of an important phytoplankton production in the creeks and this stands in contrast to the reported important stocks of secondary and tertiary producers. Therefore, other sources of nutrients to these secondary and tertiary producers must exist.

The results of respiration measured as a whole of the total sample in all seasons was very high. This could be due to the water samples contain always a lot of different particles: true phytoplankton but also pieces of leaves of mangroves and even seaweeds and seagrass which are probably strongly colonized by bacteria, these last playing an important role in the respiration. The high chlorophyll concentration of between 10 - 15 mg m^{-3} could probably be because of non-phytoplankton pieces of leaves of mangrove and sea grasses which were measured.

The density of zooplankton in Tudor Creek was higher during the study period of the North-East monsoon season than during the South-East monsoon. The seasonal cycle of zooplankton is probably due to differences in phytoplankton production between the two monsoon season.

Annual study of phytoplankton production in Tudor Creek show that there was higher primary production during the early South-East monsoon season than during the late North-East monsoon. Phytoplankton dynamics in Tudor Creek can be associated with zooplankton dynamics. Bryceson (1977) established the annual cycle of phytoplankton production at an offshore station in the coastal waters around Dar-es-Salaam, Tanzania. He recorded mean counts of 130 cells ml^{-1} of phytoplankton during the North-East and 62 cells ml^{-1} during the South-East monsoon. He could not establish a similar pattern of seasonality in a mangrove creek.Tudor creek is typical of other tropical coastal waters where plankton community dynamics are not controlled primarily by physical factors.

BIOMASS AND RESPIRATION



CHAPTER 8

CHAPTER 8

8.0. BIOMASS AND RESPIRATION

8.1. Length-weight relationship

Regression equations were established by working out the relationship between length and weight. Figure 8.1 shows the individual length (length of cephalothorax) weight relationship of the common copepod species occurring in the period February - March 1988 in Tudor Creek.

The data for each copepod have been plotted in Figure 8.1 which also show the regression equation for each set of data. The pairs of measurements for Oncaea spp have been combined with those for Corycaeus spp. The same was done for Oithona spp and small copepodites; Eucalanus spp and Rhincalanus cornutus. This was done because relatively few length-weight measurements were obtained for these six groups separately.

In each group separately these animals have similar body forms, more so than any of the other copepods studied, and so, presumably, similar length-weight relationships.For this reason, the increased precision in computing the joint regression equation is assumed to outweigh the error introduced by combining the measurements. This assumption is supported by figure 8.2 which show that the two sets of points are not separate. The points from each set lie on both sides of the regression line. The length-weight relationships obtained, some are satisfying and others are not. We put all different results together in order to try to find a more general relationship.

We could distinguish two groups, on one hand the long ellipsoidal shape with thin carapace (Acartia spp., Centropages spp., Acrocalanus spp., Oithona spp., Eucalanus spp., Undinula spp., Rhincalanus spp. and Labidocera spp.) we called this "Eucalanus shape", on the other hand more compact and spherical shape with a thick carapace (Temora spp., Tortanus spp., Oncaea spp., Pontella spp., Calanopia spp., Scolecithrix spp. and Pontellopsis spp.), and referred it to " Temora shape". We put the results

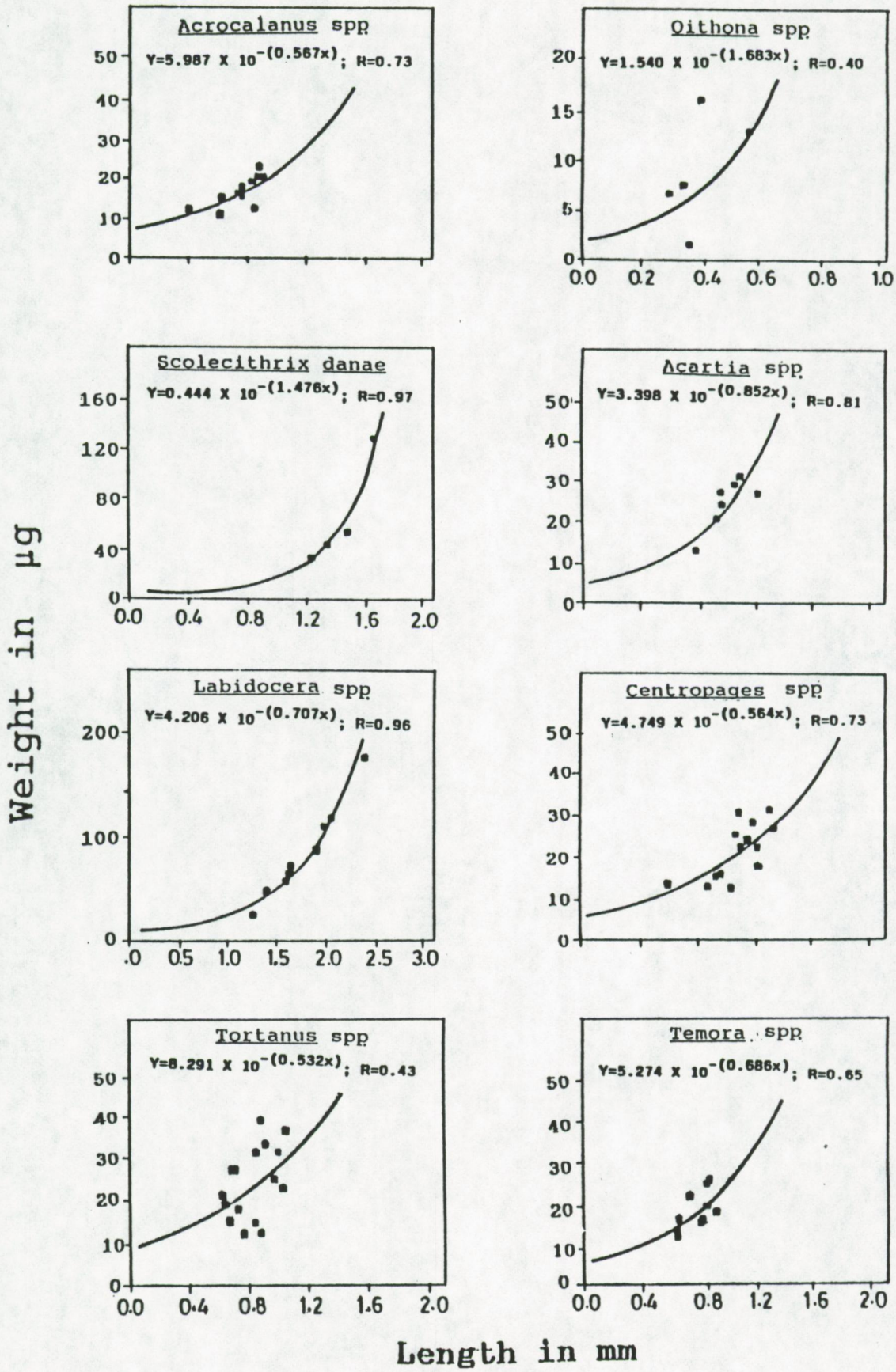
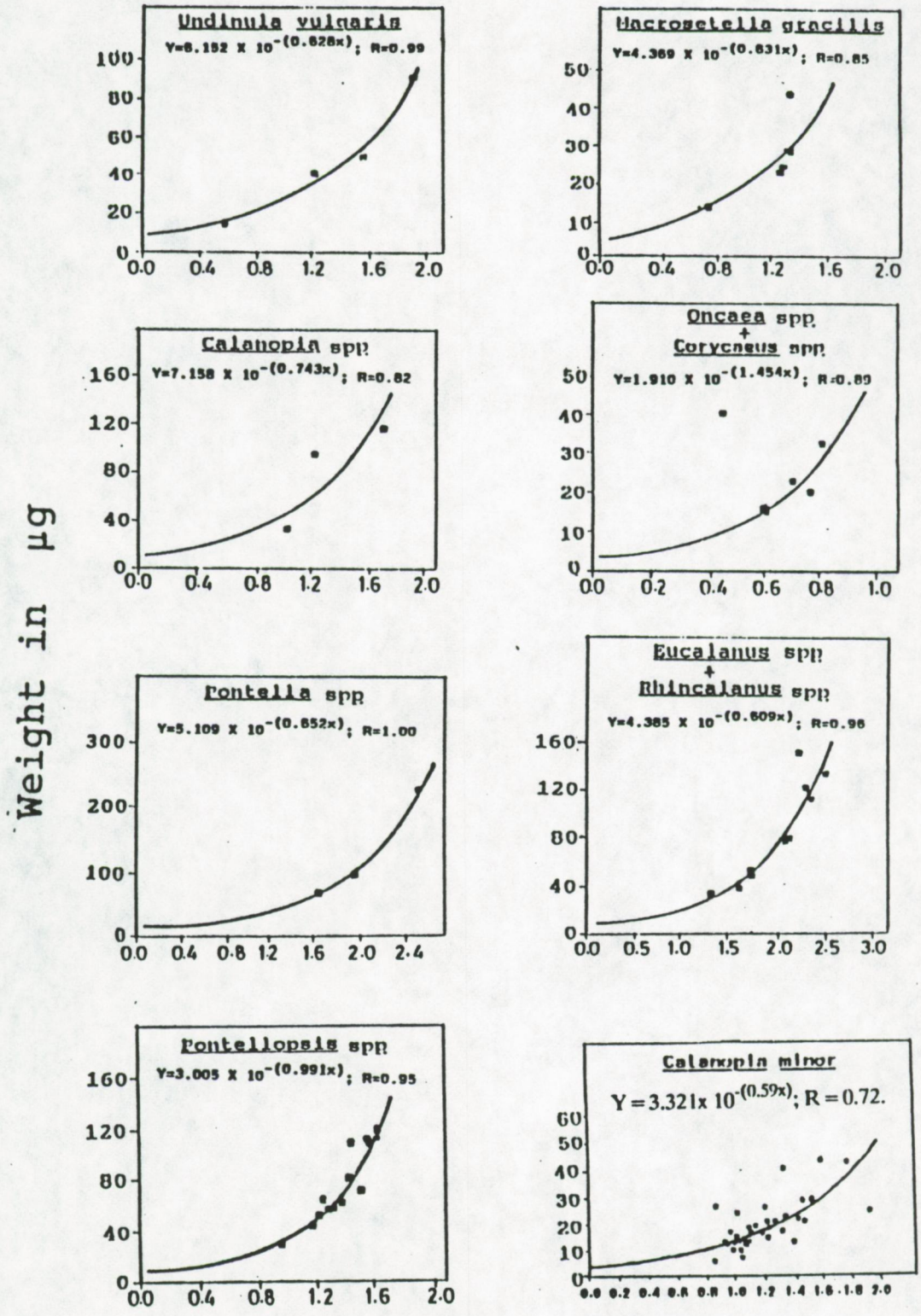


Fig.8.1. Regressions of length on weight for the copepods of the Tudor Creek.

Fig. 8.1 (continued)



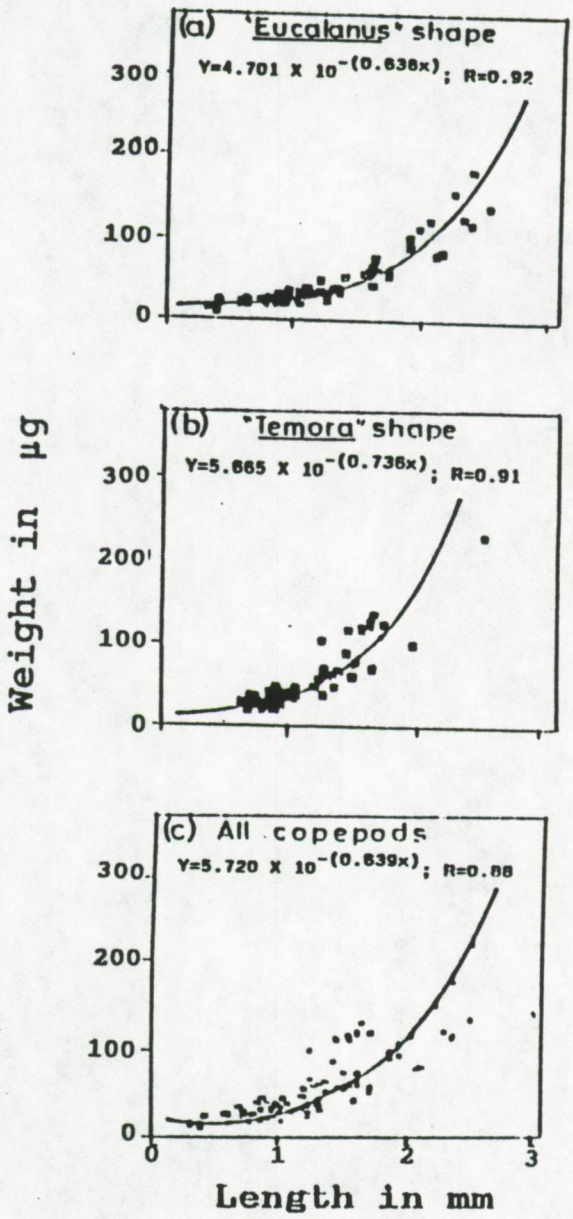


Fig 8.2. Length-weight relationship of the two groups of the common copepod species belonging to the two categories (a) "Eucalanus shape", (b) "Temora shape" and (c) all copepods.

of dry weights against length of cephalothorax for the two groups on fig 8.2. The relations were $Y = 4.701 \times 10^{-(0.636x)}$ for eucalanus shape, $Y = 5.665 \times 10^{-(0.736x)}$ for temora shape, and $Y = 5.720 \times 10^{-(0.639x)}$ for all copepods grouped together.

These kinds of length-weight relationship can be used to estimate weight of the total population of copepods.

The fig 8.3 shows the group of species belonging to the two categories. As we can observe, the Eucalanus group are long thin animals, with a cephalothorax more or less ellipsoidal, but also with a thing carapace. The animals belonging to the "Temora" group exhibit various shapes, much more compact and spherical, but the important distinction against the first group is that they have a thick carapace and they are in general much more colored (brownish, greenish). The presence of the thick carapace explains the very rapid increase of the weight versus length.

8.2. Size frequency distribution

Figure 8.4 shows the frequency of the body size distribution of the common copepod species in Tudor Creek. The five distinct modes correspond to copepodite 1-2, copepodite 3-4, copepodite 5, female and male.

As shown in Figure 8.4 a mixture of several developing stages is commonly observed in a given sample. The separation of each age class can be made easily when age groups differ morphologically, but this is not the case for animals which develop directly.

One can observe that for each stage of development there is a more or less broad range of sizes. It can be distinguished that even females and males are sometimes "big" and "small".

This kind of determination is very useful when we try to determine the growth curve of the different animals, a basis value in the production studies.

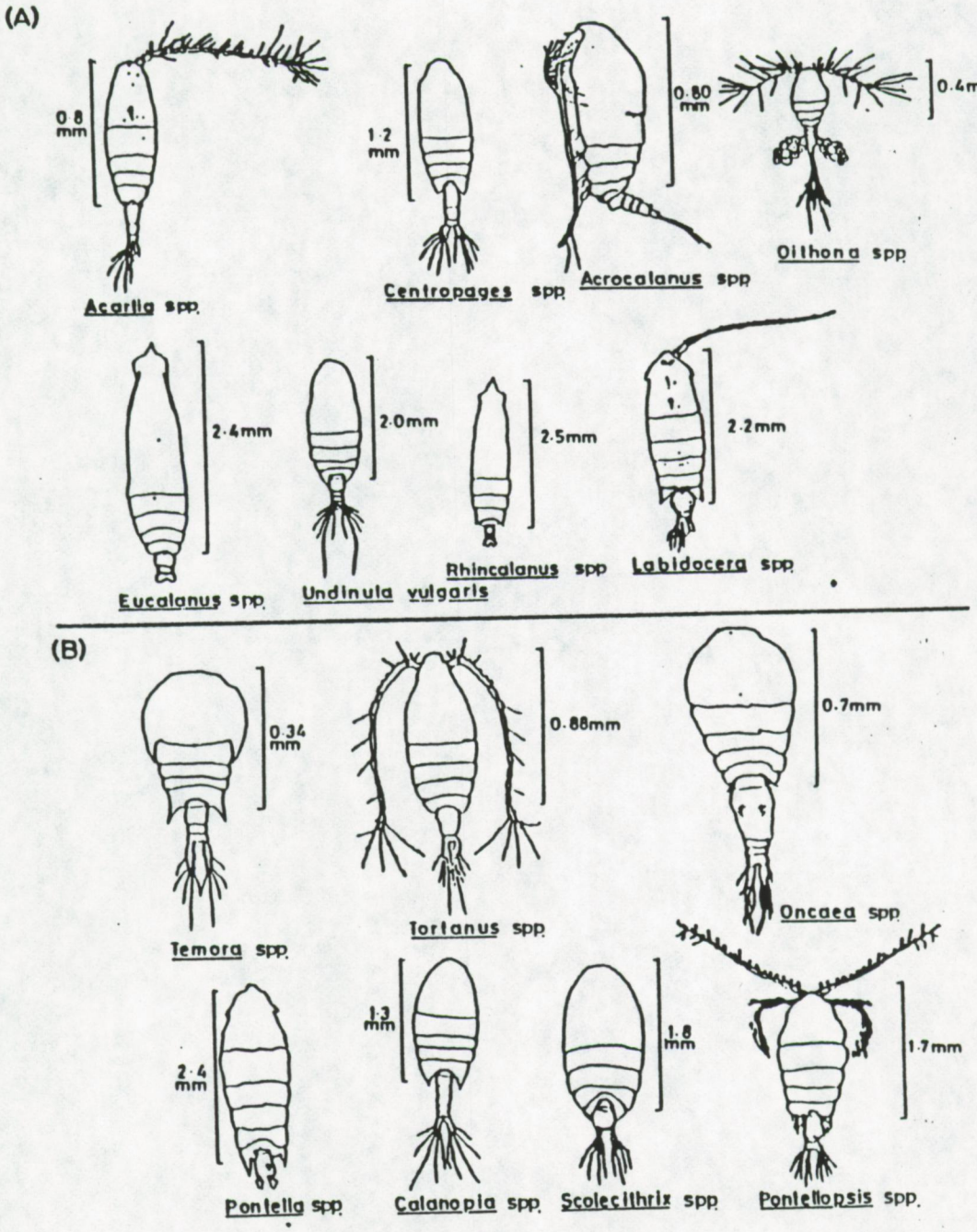


Fig.8.3. Groups of copepod species showing (a) "Eucalanus" shape (b) "Temora" shape.

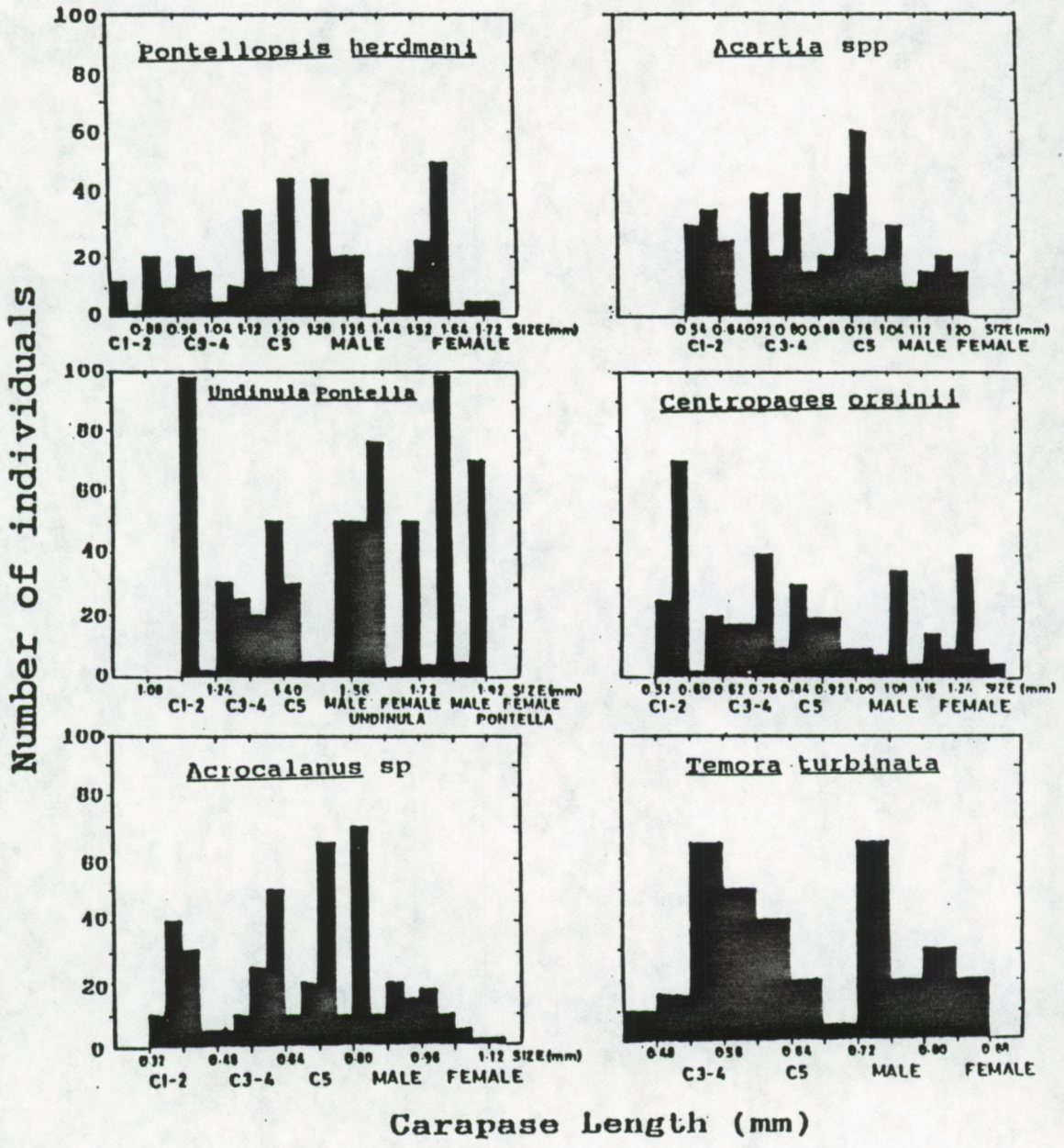


Fig.8.4.Size (Carapace length) distribution of the common calanoids collected from Tudor Creek between February and March 1988.

8.3. Weights and respiration of selected species.

Table 8.1 gives a detailed review of all results obtained during the different experiments at different times of the day. Figure 8.5 shows the daily evolution of weight and respiration of the common copepod species of Tudor creek expressed in $\mu g\, O_2$ per unit dry weight. Most species show very large differences in weight and respiration. In all cases the respiration per unit weight is the highest at night and does not correspond to the highest weight, but in many cases to the lowest weight observed.

These data are very difficult to interpret; I try to give some hypothetical explanations. The decrease of weight is often observed together with an increase of respiration. So these two features could be related: in tropical environments indeed metabolic expenditure is high due to high temperature. On the other hand the increase of weight could be due to feeding activity so that the two activities of the animals are separated in time. A phase of feeding activity with low metabolic losses and a phase of a rather high metabolism using the food ingested before. An explanation could be, that the animals we sampled at different times of the day in the Tudor Creek are totally different populations and that the differences we observed are simply due to environmental conditions. Table 8.2 shows day and night respiration of the common copepod species of Tudor Creek. In most of the cases the respiration/animal is much higher at night than at day, but sometimes the difference are smoothed due the variation of weight itself.

Table 8.3 lists the copepod species worked on respiration measurements, mean dry weights, respiratory rates in terms of $\mu g\, O_2\, An^{-1}\, 24hrs^{-1}$ and percentage of body carbon weight used by respiration. The numbers of copepods used varied from 10-100.

The total respiration per copepod and per 24 hrs ranged from 6.78 to41 $\mu g\, O_2\, An^{-1}\, 24hrs^{-1}$.

On the figure 8.6 we showed the different measurements performed in different seasons for having a comparison between dry and rainy season.

Table 8.1
Weights and respiration of selected species of zooplankton as function of time.

Species	Time	µg DW	Mean	Resp. (μgO_2/An/hr)	Resp. $\mu gO_2/\mu gDW/hr.$	Resp. $\mu gO_2/\mu gC/hr.$ (W in µgC)	Resp. µgC/µgC/24hrs.
Eucalanus	10.00	79.3					
			76.96				
		74.7					
	12.00	79.2	79.2	0.252	$3.18\ 10^{-3}$	$7.1\ 10^{-3}$ (35.64)	
	16.00	79.9	79.9				0.17
	18.00	79.9	79.0	0.507	$6.42\ 10^{-3}$	$14.3\ 10^{-3}$ (35.55)	
	22.00	71.05	71.05	1.44	$20.26\ 10^{-3}$	$45.0\ 10^{-3}$ (31.97)	
Acrocalanus	10.00	18.39	18.34	0.016	$0.87\ 10^{-3}$	$1.93\ 10^{-3}$ (8.27)	
	16.00	10.63	10.63	-			
	22.00	17.35	17.35	-			
Temora	12.00	25.26	25.26	0.117	$4.63\ 10^{-3}$	$10.3\ 10^{-3}$ (11.37)	
	16.00	24.54	24.54				
	22.00	20.65		0.73			
			24.17	0.626	$25.9\ 10^{-3}$	$57.6\ 10^{-3}$ (10.87)	
		27.7		0.522			
	24.00	28.9		0.94	$32.5\ 10^{-3}$		
Temora	10.00	25.3					
		45.01					
		31.4					
		16.5	30.44	0.255	$8.4\ 10^{-3}$	$18.6\ 10^{-3}$ (13.7)	
		29.4					0.27
		28.0					
		27.0					
		40.9					
Pseudo-dioptomus	12.00	7.21	7.21	0.617	$85.5\ 10^{-3}$	$190.4\ 10^{-3}$ (3.24)	
	18.00	21.94	21.94	0.142	$6.47\ 10^{-3}$	$14.4\ 10^{-3}$ (9.87)	0.86
	24.00	24.6	24.6	1.21	$49.2\ 10^{-3}$	$109.0\ 10^{-3}$ (11.1)	
	24.00	22.1	21.1				
Acartia	12.00	8.9	8.9	0.236	$26.5\ 10^{-3}$	$59.0\ 10^{-3}$ (4.00)	
	16.00	47.26	47.26	0.237	$5.0\ 10^{-3}$	$11.1\ 10^{-3}$ (21.27)	
	22.00	20.76					
		20.0					
		16.1					
		21.1	22.38				0.97
			29.3				
		22.5					
		26.9					
	24.00	8.0					
		13.5					
		12.5	10.46	1.885	$180.2\ 10^{-3}$	$400.2\ 10^{-3}$ (4.71)	
		8.8					
		9.5					
Acartia	22.00	30.0					
Tortanus	12.00	15.1	15.1	1.94	$128.47\ 10^{-3}$	$285.7\ 10^{-3}$ (6.79)	
Oncea	10.00	38.2	38.2	1.09	$28.5\ 10^{-3}$	$59.3\ 10^{-3}$ (17.19)	
							0.63
	22.00	17.76	17.76	0.74	$41.66\ 10^{-3}$	$92.6\ 10^{-3}$ (7.99)	
Macrosetella	10.00	19.23	19.23	0.0297	$1.54\ 10^{-3}$	$3.43\ 10^{-3}$ (8.65)	
	12.00	13.30					
	12.00	13.50	14.97				
	12.00	18.10		0.021	$1.40\ 10^{-3}$	$3.11\ 10^{-3}$ (6.74)	

Table 8.1(Continued)

Species	Time	µgDW	Mean	Resp. (μgO_2/An/hr)	Resp. μgO_2/µgDW/hr.	Resp. μgO_2/µgC/hr. (W in µgC)	Resp. µgC/µgC/24hrs.
	16.00	62.61					0.3
			52.94				
		43.27		0.044	$1.02\ 10^{-3}$	$2.26\ 10^{-3}$ (19.47)	
	18.00	47.10		0.176	$5.17\ 10^{-3}$	$11.43\ 10^{-3}$ (15.39)	
			34.2				
		21.30					
	22.00	10.44		0.22	$21.03\ 10^{-3}$	$46.7\ 10^{-3}$ (4.71)	
			10.46				
		10.48					
	24.00	13.20	13.2	0.73	$55.3\ 10^{-3}$	$122.9\ 10^{-3}$ (5.94)	

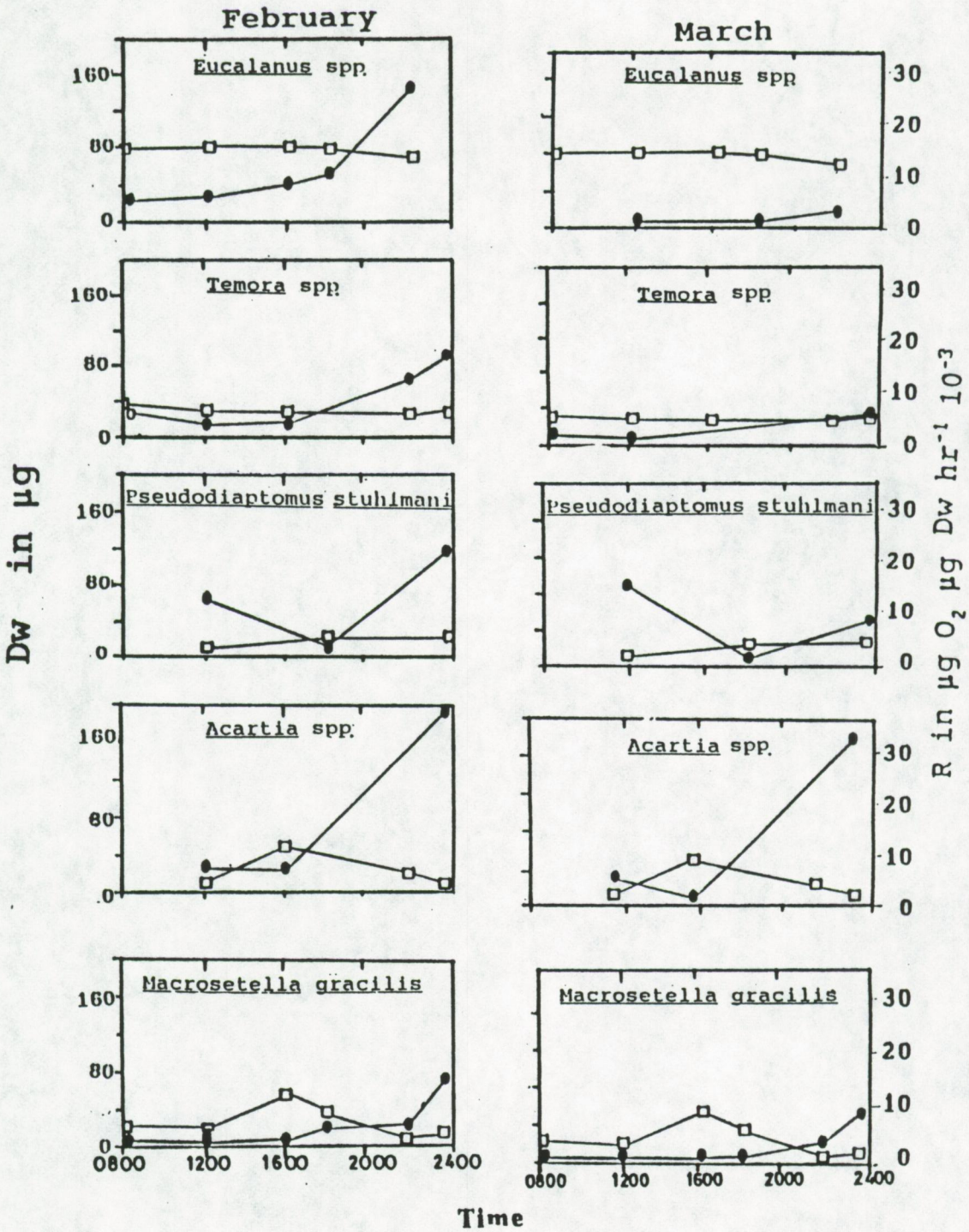


Fig.8.5. Dry weight and respiration of common copepod species of Tudor Creek found at different times of the day in February-March 1988. -□- Dw in μg; -●- R in μg O_2 μg Dw hr^{-1} 10^{-3}.

Table 8.2. Day and night respiration (μgO_2/An/12 hrs) of the common copepod species of Tudor Creek.

Species	DAY	NIGHT	TOTAL
Eucalanus spp	5.61	34.98	40.59
Acrocalanus spp	3.39	21.63	25.02
Temora discaudata	9.99	20.39	30.38
Centropages furcatus	3.15	8.07	11.22
Tortanus gracilis	20.76	22.24	43.00
Acartia amboinensis	5.97	7.83	13.8
Calanopia minor	10.14	13.32	23.46
Canthocalanus pauper	9.21	17.04	26.00
Centropages orsinii	5.58	7.98	13.56
Macrosetella gracilis	10.41	12.6	23.01
Pontellopsis herdmani	26.94	81.48	108.42
Temora turbinata	2.19	4.59	8.78
Oncaea venusta	2.0	9.81	11.85

NB: Day and night respiration cover 12 hrs each and the total respiration is given for 24 hrs.

Table 8.3

Dry wieght, respiration and percentage of body carbon weight used by respiration of the commo copepod species from Tudor Creek.

Species		Mean Dry weight (DW µg)		Respiration					
		Day	Night	Day µg O_2/ An/4hrs	Night µg O_2/ An/4hrs	Total Respiration/24 hrs µg O_2/An/ 24hrs	in carbon µg C/An/ 24hrs	Weight in µg C	% of Body carbon weigh used by respiration
Temora discaudata	Female	25.26	27.7	0.467	2.09	7.67	2.40	11.77	20.4
	Male	4.93	25.5						
Macrosetella gracilis		18.1	13.2	0.083	2.94	9.04	2.83	7.04	129
Pseudodiaptomus stuhlmani	Female	7.21	24.5						
	Female + Eggs		21.94	2.47	4.84	21.93	6.85	7.69	89
	Males		22.1						
Temora turbinata	Female	28.8		1.2				26.1	14
	Male	25.7		1.1				19.1	16
Centropages furcatus		22.7		0.82		41.77	5.34	7.82	15
Acartia bispinosa		8.9		0.20		19.69	8.86	30.5	3
Eucalanus spp		74.7		0.59		40.50	12.68	33.61	38
Acrocalanus spp		10.34		0.71		7.13	2.23	4.51	49
Calanopia minor		80.1		0.29		23.46	7.33	36.04	20
Candacia catula		44.7		0.38		17.01	5.32	20.12	26
Canthocalanus pauper		34.1		0.77		26.25	8.2	15.35	53
Centropages orsinii		17.1		0.74		12.66	3.96	7.7	51
Centropages orsinii		23.1		0.59		13.56	4.24	10.4	41
Oncaea venusta		26.1		0.45		11.85	3.7	11.79	31
Acartia amboinensis		24.5		0.56		13.8	4.31	11.03	39

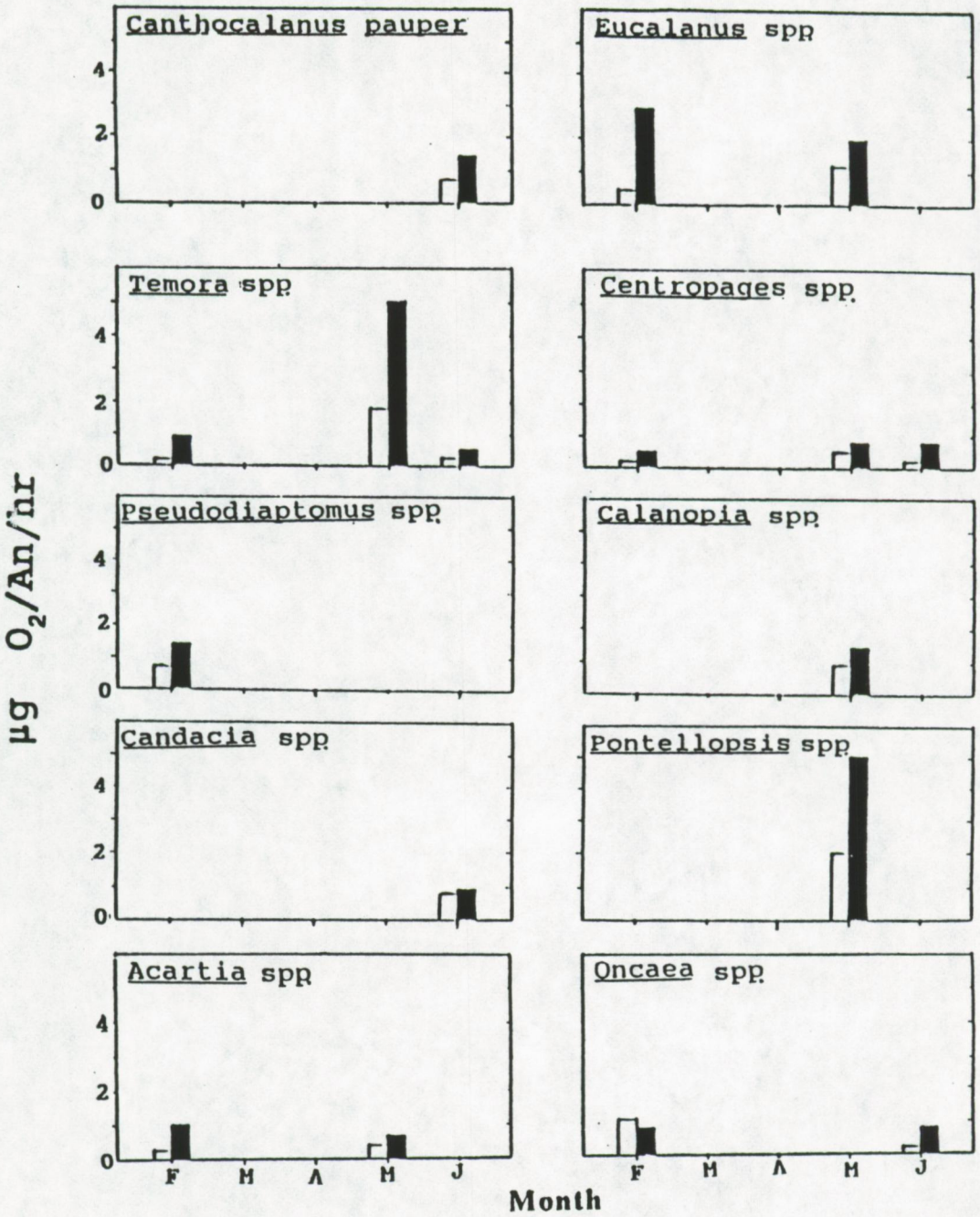


Fig.8.6. Seasonal comparison of respiration of different Copepod species between day and night time. (▫ day, ▪ night) .

For some species (Macrosetella gracilis, Centropages spp., Temora spp.) the total respiration is higher in May- June than in February, due probably to much better feeding conditions. But Eucalanus show in February a much higher respiration at night than at day, this difference being lower in May, although the total respiration (day + night) is the same in both seasons.

In order to compare much better the dry and the rainy season we calculate the respiration in carbon as a percentage of the body carbon of different species on figure 8.7 and the body weight on the same figure.

The percentage of body carbon respired is in general higher in the rainy season (around 40%) than in the dry season (around 20-30%) but in general the weights are also higher in May-June than in February (with the exception of Eucalanus spp.). From this data it is obvious that herbivorous zooplankton is in much better conditions in the rain season than in the dry season. Percentage of body carbon respired daily in the dry and in the rain season for different species of herbivorous copepods (above) and dry weights of the same species in both seasons (under).

8.4. Discussion

Individual weights of the studied copepods cover a large range. Variation in weight is not always due to a corresponding variation in size, however. In fact the variable weights of copepod species is one of the most impressive observations brought forward by weighing individual specimens. An illustration to the range of variation is given in Table 8.4. Weight range for copepods of all species are large with maximum values up to 3 times the minimum values.

Variation in weights can be due to differences in overall conditions. In this respect specimens from these populations can frequently be expected to suffer from nutritional deficiencies; some could be attributed to a starvation effect; on the other hand for large weight can be coupled to the

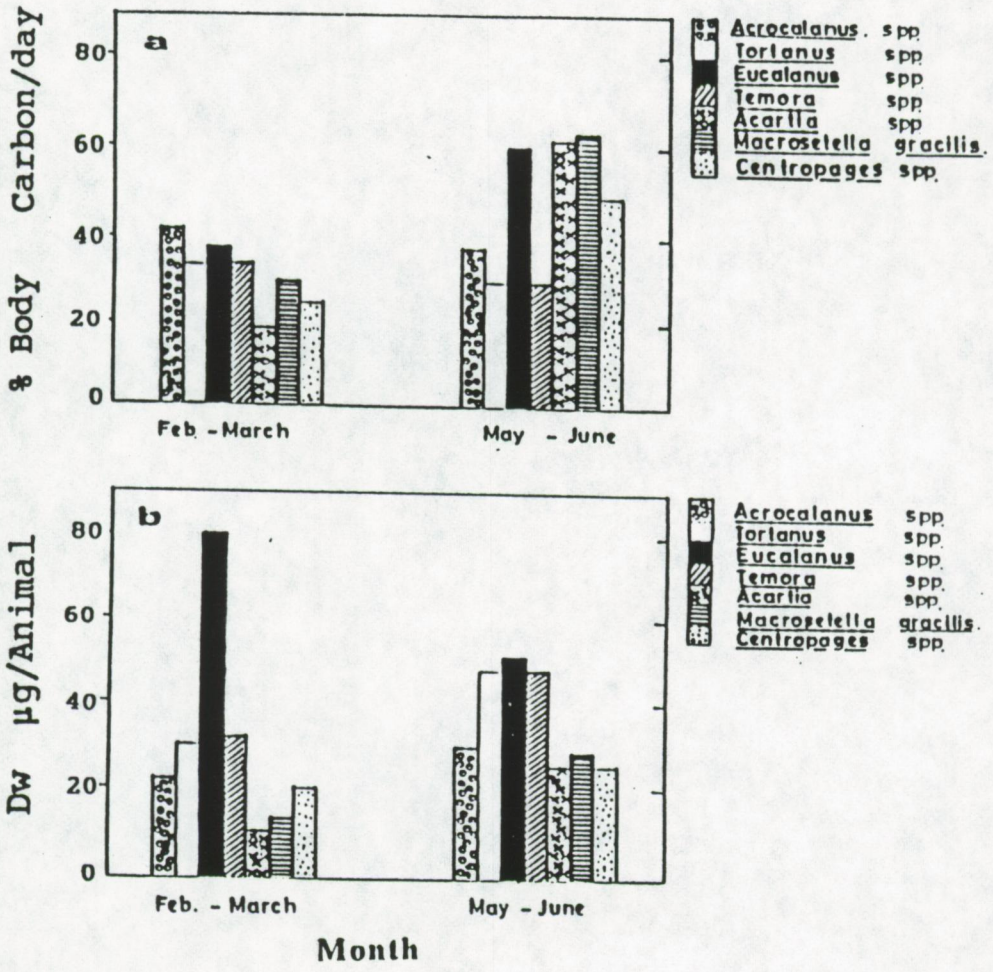


Fig.8.7. Seasonal changes in (a) Percentage of body Carbon respirated daily; (b) Dry weights for different herbivorous copepod species.

Table 8.4. Dry weight µg ranges for adult specimens of the planktonic Copepods of Tudor Creek.

SPECIES		WEIGHT (Lowest) µg (highest)	
Canthocalanus pauper	♂♂	23.4	60.4
Canthocalanus pauper	♀♀	24.8	50.5
Undinula vulgaris	♀♀	76.1	147.4
Undinula vulgaris	♂♂	50.0	140.0
Scolecithrix danae	♀♀	15.4	200.0
Temora discaudata	♀♀	31.9	37.2
Temora discaudata	♂♂	20.6	32.6
Temora turbinata	♀♀	15.4	56.6
Temora turbinata	♂♂	6.1	40.5
Centropages furcatus	♀♀	16.2	45.1
Centropages furcatus	♂♂	13.7	36.1
Centropages orsinii	♀♀	40.8	51.9
Centropages orsinii	♂♂	10.1	46.0
Pseudodiaptomus stuhlmani	♀♀	11.9	22.4
Pseudodiaptomus stuhlmani	♂♂	6.6	19.0
Calanopia elliptica	♀♀	35.4	41.6
Calanopia elliptica	♂♂	30.6	36.1
Calanopia minor	♀♀	11.3	40.9
Calanopia minor	♂♂	9.9	30.2
Calanopia parathompsoni	♀♀	23.0	95.5
Calanopia parathompsoni	♂♂	15.7	78.3
Labidocera orsinii	♀♀	92.8	182.0
Labidocera orsinii	♂♂	30.6	168.2
Pontellopsis herdmani	♀♀	80.6	99.0
Acartia amboinensis	♀♀	8.3	10.9
Acartia amboinensis	♂♂	4.8	10.6
Tortanus gracilis	♀♀	14.5	24.6
Tortanus gracilis	♂♂	10.7	17.8
Oncaea venusta		14.8	75.8
Oithona plumifera		2.2	7.5
Microsetella rosea		2.0	6.7
Macrosetella gracilis		10.2	26.1

well-nourished status visualized by accumulation of oil droplets within the body.

Kamshilov (1951) has established the regression of the cube root of weight on length for Calanus finmarchicus and several other copepods as well as for copepods collectively. He uses the cube root of weight because he assumes that weight varies proportionally as the third power of length. This is equivalent to assuming that K equals three in the present study. An examination of the values of K that were found in the present work reveals that they are sometimes quite different from three. Yet, Kamshilov (1951) finds high correlation coefficient between length and the cube root of weight; so his assumption seems valid for his data.

These apparent contradictory results are probably explained, at least partially, by the fact that Kamshilov's regressions include measurements from all copepodite stages and not just stages V and VI as in the present study. Stage VI are the adults, lose part of their mass in the form of eggs and spermatozoa. So regression in which a large proportion of the measurements are of stage VI individuals would be expected to have a different K, or slope, from regressions where only a small proportion of the measurements are from stage VI individuals.

In the Tudor Creek, small rapidly developing species are dominant. Therefore, as rightly noted by Cushing (1959) the delay period between the peak of phytoplankton and zooplankton in the oceanic zone of tropical waters is short and the phytoplankton is fully utilized by the zooplankton and the seasonal cycle of the plankton community is balanced. The yearly maximum of copepod biomass is reached soon after the maximum of phytoplankton biomass.

Copepods in Tudor creek have short life cycle and have a sequence in which they reach maximum peak and their generations follow one another. Because of different species and their life cycles, they are following each other in time. Enough copepods are present to graze on the phytoplankton intensively. The high degree of balance of the seasonal cycle in Tudor Creek is favored not only by the phases of life cycles of different planktonic copepods do not coincide with each other in time. Consequently, animals in the older developmental stages are always present which can graze the phytoplankton intensively.

Thus the course of the successive maxima of phyto - and zooplankton biomass and the peculiarities of trophic relationships in any pelagic community depend on the characteristics of the life histories of the dominant species.

In the tropics, the seasonal cycles of plankton communities are less well balanced in the neritic zone than in the oceanic. Thus great quantities of phytoplankton are frequently observed in the neritic zone (Sewell, 1957; Subrahmanyan, 1959) and their seasonal variations are far more marked than in the oceanic zone.

In the Tudor Creek, phytoplankton maximum occurs during the period of long rain (April - June), but there is corresponding copepod maximum. It could be possible that the zooplankton feed on phytoplanktons and sources other than endogenous phytoplankton. Abundant organic matter is supplied by the rivers particularly during rain season, and this is probably their main food. It is suggested that the copepod may play a useful role in cleaning the water of particulate matter from the mangroves in this way.

Tudor Creek supports rich plankton communities. More than one hundred copepod species are found at the mouth of Tudor Creek. This high diversity usually corresponds to a low biomass while further up to the inner creek, the characteristic estuarine plankton with a higher biomass but a low diversity occurs. These distribution patterns appear to be determined by the extent of tidal exchange and are apparently unrelated to the position of mangrove area. The composition of copepod does not appear to be any species restricted to Mangrove in Tudor Creek. The distribution boundaries are related to hydrological features such as the extent of tidal movement affecting residence time and salinity.

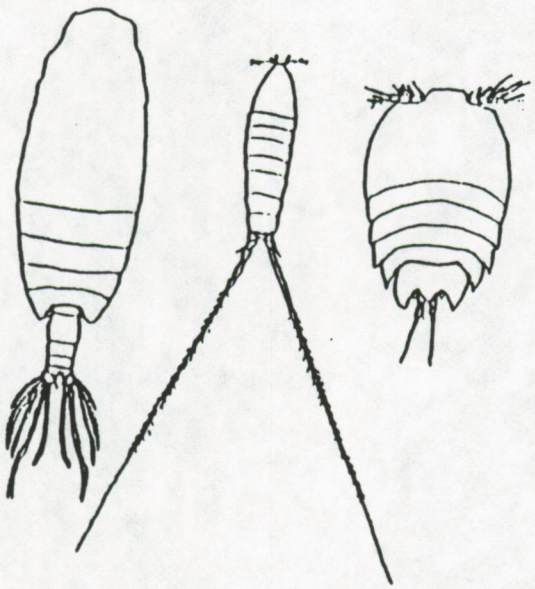
The most important biological process occurring in the water column is production; primary production by the phytoplankton and secondary production by the copepods and zooplankton in general. The secondary production depends on the primary production and the primary production is regulated by the availability of light and of nutrients from outside the compartment and on the recycling of nutrients within the compartment.

Rainfall is promoting biological productivity which is subsequently correlated to the increase in nutrients in aquatic ecosystems during the rainy seasons in the tropics.

Nutrient regenerate through circulation and input through decomposed mangrove leaves and river water.

Irradiation increases the phytoplankton production which is grazed by herbivorous copepods, and also fed on by carnivorous copepod and fish and other zooplankton. Data from the present study gives the bases of secondary productivity of Tudor Creek.

GENERAL DISCUSSION AND CONCLUSIONS



CHAPTER 9

CHAPTER 9

9.0 GENERAL DISCUSSION AND CONCLUSIONS.

In this section, an attempt is made at making a general model of the role and ultimate effect of rainfall on the production of inshore water plankton in Tudor creek.

Measurement of biomass in the marine pelagic ecosystem has traditionally been modelled on a food- chain production concept, where only a simple relationship between each trophic level was present. The structure of food webs and trophic levels vary for different regions, and may change within a region. Among the zooplankton, the two main types of feeding are (1) filter feeding (for smaller food items), where the animal induces a flow of water against a screen; and (2) raptorial feeding (for larger food items), where grasping/seizing responses with the use of appendages are the norm (Parsons et al., 1984). The zooplankton community includes herbivores, omnivores and carnivores, but a dynamic component of marine plankton may include the bacteria and the heterotrophic micro-flagellates which prey upon them.

Other workers have shown that relationships between rainfall and growth activity exist in several aquatic organisms. Kimaro (1986) showed that there was some degree of increase in zooplankton biomass during the rainy season in Tudor Creek. Ruwa (pers. comm.) has also related oyster breeding and growth to increases in primary production in Gazi Bay, Kenya during the rainy season. These findings show the important role played by rainfall in promoting biological productivity which is subsequently correlated to the increase in nutrients in aquatic ecosystems during the rainy seasons in the tropics.

Figure 9.1 shows a general model of the role and ultimate effect of rainfall on the production of inshore water plankton in Tudor Creek.

In the estuarine environment transport processes play an important role in determining the concentration of biotic and abiotic substances. In Tudor Creek, nutrients are regenerated through tides, currents and wind increase

during wet season (Fig. 9.1). Rainfall also contribute directly to the sea through leaching of local rocks and soils and river water in increasing nutrient concentration.

Tudor Creek is surrounded by mangroves on its upper reach. With the tides, a large area of the mangroves is submerged at flood and emerged at the ebb. Nutrients are also export from the mangroves to the ecosystem of Tudor Creek.

The seagrass, seaweed communities and corals contribute a lot to the nutrient budget to the system, although this has not been quantified.

During rainy season Tudor Creek show high productivity because it receives a high proportion of river water and runoff from the land which promotes mixing of the coastal waters and brings in nutrients such as nitrates and phosphates as well as organic detritus (Kazungu, et. al. (Press)).

The relationship between rainfall and total zooplankton abundance is obviously not a direct one but may be related as indicated in figure 9.1. Under these circumstances, delayed response by zooplankton to rainfall may be expected.

Copepod production in Tudor Creek was found to increase during rainy season. Grazing of phytoplankton is carried by zooplankton in Tudor Creek and fish feed upon zooplankton. The food chain in Tudor Creek is complex (Fig. 9.1).

Tudor Creek support a diverse zooplankton community that is similar to that found in other inshore waters of Dar-es-Salaam, Tanzania (Okera, 1974) and Transkei, South Africa (Wooldridge, 1977). The zooplankton population consisted of a large number of species dominated by copepods. Amongst the copepods, calanoids dominated the samples. Decapod larvae mainly brachyuran and caridean zoeae, were usually the most abundant crustaceans after the copepods.

In comparison with the results of the 24-hr sampling series in February and March 1983 (Reay & Kimaro 1984), those from the present study

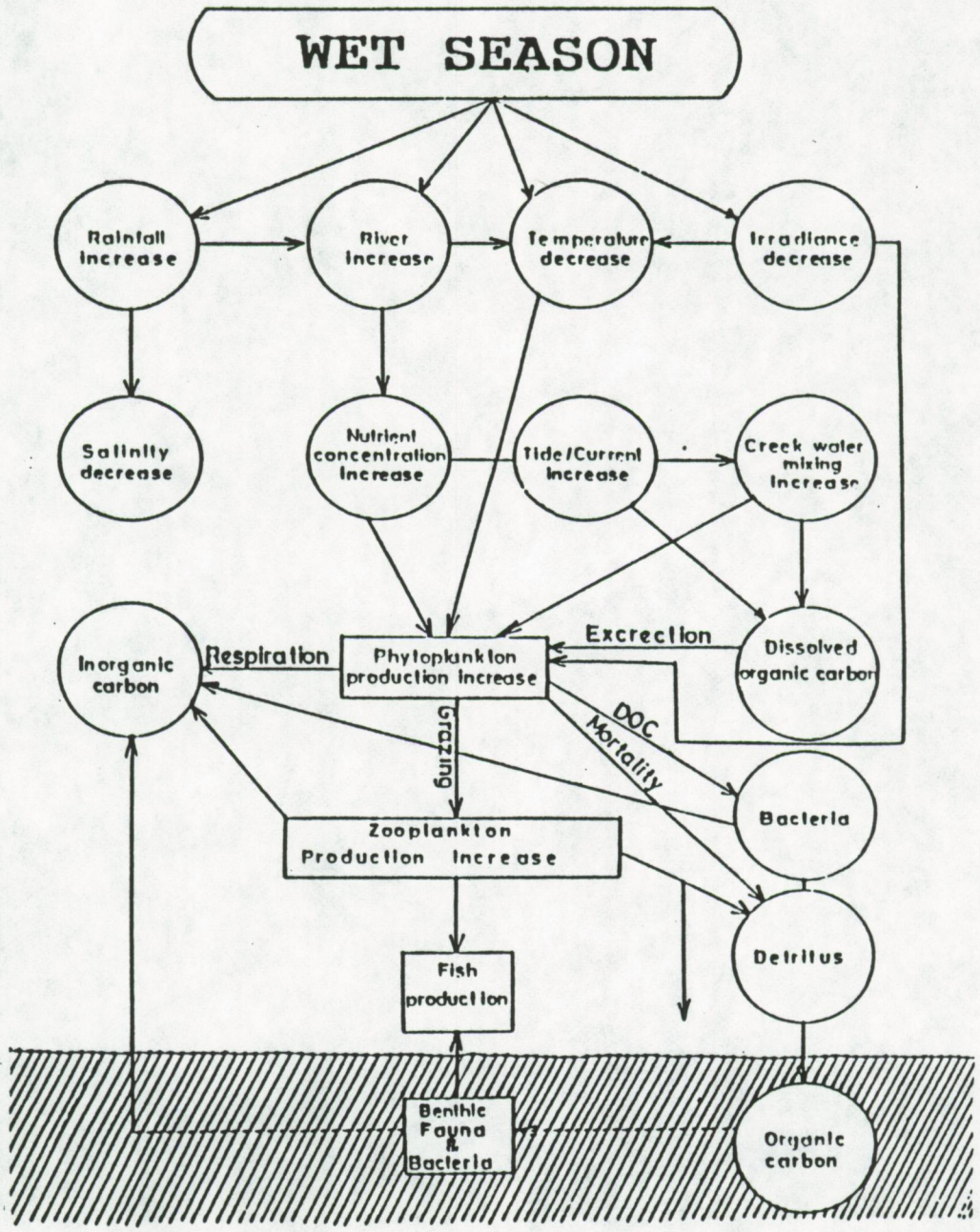


Fig.9.1A general model of the role and ultimate effect of rainfall on the production of inshore water plankton in Tudor creek.

agree well and demonstrate, for example a clear difference between day and night catches of plankton. Catches were higher at night.

The groups of zooplankton that occurred only in the night samples were mysids, cumaceans, ostracods, amphipods, isopods and the cephalochordate Amphioxus.

Although the copepod community composition varies little throughout the year, there exists apparently a gradient in diversity and each station has a more or less characteristic copepod fauna.

Surveys of zooplankton in the same Tudor Creek have reported communities which are similar in species composition to those found in this study (Reay & Kimaro, 1984; Kimaro, 1986; Okemwa & Revis, 1986 and Revis, 1988).

Several copepod species have peaks in December and in March, i.e. after the short November rains and after the beginning of the long rains in March, respectively. During the rain periods high concentrations of dissolved nutrients occur as a result of land drainage.

The tidal effect has probably a stronger influence on the creek mouth and river Kombeni has more influence in the upper reaches at station 5 in Tudor Creek. Sameoto (1975) showed that the composition of zooplankton did not follow tidal fluctuation.

Salinity did not fluctuate very much. The present work has demonstrated short term temperature fluctuations of about 3.9 °C associated with season and tide (Fig.9.1). There was an increase in temperature towards low tide which can be attributed to the out-going warmer estuarine water. Towards high tide the temperature declined due to the in-coming cooler coastal water.

The density of zooplankton was higher during the 24-hr series of the South-East monsoon season than during the North-East monsoon. The seasonal cycle of zooplankton is probably due to differences in phytoplankton production between the two monsoon seasons.

The distribution and the dynamics of plankton in Tudor Creek are, as in any estuary, complex. Physical factors, as tides, influences among others, the import and export of economically important species from spawning grounds to nursery biotopes (the mangroves).

Together with the diurnal vertical migrations (to the surface at night time), we have seasonal fluctuations correlated with the raining season and probably due to the input of nutrients and phytoplankton abundance.

Nutrient enrichment caused by land run off during the rain period leads to proliferation of phytoplankton and swarming of filter feeders in the coastal waters Goswami (1985).

This study has evidently shown that:

1. A wide range of copepod species occur in Tudor Creek.

2. Lower diversity of copepod communities is found in station 5 than in station 1 in Tudor Creek, probably because of environmental conditions such as temperature and salinity.

3. There exists a gradient in copepod species, which decreases from station 1 to 5 in Tudor Creek and each station has a more or less characteristic copepod fauna. The plankton distribution patterns appear to be determined by hydrological parameters such as residence time, salinity and topography.

4. Seasonal fluctuation of the zooplankton groups is due to rainfall. In April, when the long rain season is at its peak, a new combination and more abundant copepods appear, and decreases during the dry season. This is probably due to the input of nutrients and phytoplankton abundance.

5. A clear difference between day and night catches of plankton exists. Catches were higher at night than day.

6. Six copepod species have been recorded in Western Indian Ocean off the Kenyan coast for the first time. Three new species have been encountered and their descriptions are in preparation.

7. Tidal fluctuation has been suggested as the single most important factor controlling salinity, temperature and transparency in the Creek mouth and river Kombeni has more influence in the upper reaches at station 5 in Tudor Creek.

8. Preservation method of copepods in formalin show a reduction in the dry weight.

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