5. BENTHIC ECOLOGY

5. Benthic Ecology

5.1. Introduction

The benthic fauna forms an important component of the food web in an aquatic ecosystem. While they serve as a source of food for many bottom living fishes, their larvae contribute much to the bulk of zooplankton. The benthos, like their counterparts, the plankton and nekton, are involved in the recycling of materials, the flow of energy through food chain and the proliferation of their kind (Schweitzer, 1974).

5.2. Review of Literature

Several studies are available on the ecology of benthos at the global level. Peterson(1913) made a report on the animal communities of the sea bottom and their importance for marine zoogeography. Blegvad(1930) made a quantitative investigation of bottom invertebrates in Kattegal with special reference to plaice food. Jones(1950) reviewed the marine bottom communities. Holme(1953) studied the biomass of the bottom fauna in the English Channel of Plymouth. Stone and Reish(1965) studied the effect of freshwater run off on a population of estuarine polychaetous annelids. Thorsen (1966) investigated the factors influencing the recruitment and establishment of marine benthic communities. Boesch(1973) studied the classification and community structure of macrobenthos in the Hampton Roads Area. Day(1973) reported new Polychaeta from Beaufort with a key to all species recorded from North Carolina. Feder *et al.* (1977) investigated the distribution, abundance, diversity and biology of benthic organisms in the Gulf of Alaska and the Bering Sea. Platt (1979) studied sedimentation and the distribution of organic matter in sub - Antarctic marine. Maurer *et al.* (1979) studied benthic invertebrate assemblage of Delaware Bay and the seasonal fluctuations in coastal benthic invertebrate assemblage. Moore (1980 and 1981) investigated the factors influencing the composition, structure and density of a population of benthic invertebrates and the factors influencing the species composition, distribution and abundance of benthic invertebrates in the profundal zone of a eutrophic northern lake. Read *et al.* (1983) studied the benthic fauna in the Firth of Forth estuary, England. Maurer and Vargas (1984) reported the benthic fauna in the Gulf of Nicoya, Costa Rica. Roberto Sandulli and Marina de Nicola - Giudici (1990) studied the benthic fauna in relation to pollution effects in the Bay of Naples. Anvar Batcha (1997) carried out studies on intertidal and benthic macrofauna of Dammam corniche and half moon bay beaches of the Arabian Gulf. Bianchi and Argyrou (1997) reported the temporal and spatial dynamics of particulate organic carbon in the lake Pontchartrain estuary, south east Louisiana, U.S.A. Lou and Ridd(1997) studied modelling of suspended sediment transport in coastal areas under waves and currents. Matthiessen *et al.* (1998) made an assessment of sediment toxicity in the river Tyne estuary, UK by means of Bioassays. Smith and Schafer (1999) observed sedimentation, bioturbation and Hg uptake in the sediments of the estuary and Gulf of St. Lawrence.

In India the ecology of benthic fauna was initiated by Annandale (1907) in Gangetic delta. In the east coast the studies on benthic fauna were carried out by Panikkar and Aiyar (1937) in Adyar Backwater; Ramamoorthi (1954), Ajmal Khan *et al.* (1975), Thangaraj *et al.* (1979), Srikrishnadhas *et al.* (1981), Sivakumar (1982), Chandran *et al.* (1982), Fernando *et al.* (1983) and Rajathy (1985) studied the benthic fauna of Vellar estuary. Gnanamuthu (1954) studied two sand dwelling isopods from Madras sea-shore. Ganapati and Rao (1959) made preliminary observation on the bottom fauna of the continental shelf of the north east coast of India. Ganapati (1965) studied the benthic fauna in Godavari estuarine system. Bhavanarayana (1975) observed the benthic faunal distribution in the Kakinada Bay. Srikrishnadhas *et al.* (1981) studied the ecology of the population of polychaetes in the intertidal region of the Vellar estuary. Prabha Devi (1986) and Jegadeesan (1986) studied the benthic fauna of Coleroon estuary. Srikrishnadhas *et al.* (1987) studied the polychaetes in Porto Novo waters. Rajagopal *et al.* (1990) studied the ecology of fouling organisms in Edaiyur backwaters, Kalpakkam. Reddy and Reddeppa Reddi (1994) observed the seasonal distribution of Foraminifera in the Araniar river estuary of Pulicat,south east coast of India. Sarma and Wilsanand(1996) made a report on the meiofauna of the outer channel of Chilka lagoon, Bay of Bengal. Kannapiran *et al.*

(1999) isolated magneto bacteria from estuarine, mangrove and coral reef environs in Gulf of Mannar.

In the west coast of India, the studies on the Ecology of benthos were more. Kurian (1953, 1967, 1972 and 1975) studied the benthic fauna of south west coast and Vembanad lake. Seshappa (1953) observed the benthos of the inshore sea bottom along the Malabar coast. Pillai (1954) made a preliminary note of the Tanaidacea and Isopoda of Travancore. Desai and Krishnankutty (1967) made studies on the benthic fauna of Cochin backwaters. Govindankutty (1967) studied the nematodes of the south west coast of India. Rajan (1972) studied the interstitial fauna of the south west coast of India. Parulekar and Dwivedi (1973) studied the polychaetes from Maharashtra and Goa and the benthic fauna on the inner shelf of central west coast of India. Damodaran (1973) studied the benthos of the mud banks of the Kerala coast. Kasinathan *et al.* (1974) studied the distribution of benthic fauna in the Gulf of Kutch. Ansari (1974 and 1977) studied the macrobenthos of Vembanad lake and Cochin backwater. Harkantra (1975) studied the benthos of Kali estuary. Parulekar and Dwivedi (1975) carried out benthic studies in the estuary of Mandovi river. Parulekar *et al.* (1976 and 1980) studied the benthos of Bombay and Goa estuaries. Harkantra *et al.* (1980) studied the benthos of shelf region along the west coast of India. Murugan *et al.* (1980) observed the distribution and seasonal variation of the benthic fauna of the Veli lake. Divakaran *et al.* (1981) studied the distribution and seasonal variation of the benthic fauna of the Ashtamudi lake. Abdul Azis and Nair (1983) studied the meiofauna of the Edava Nadayara Paravur backwater system. Nair *et al.* (1984) made a study on the ecology of soft bottom benthic fauna in Kadinamkulam backwater. Reddy and Hariharan (1985) studied the meiofauna of Netravathi - Gurupur estuary (Mangalore). Varshney *et al.* (1988) studied the macrobenthos off Versova (Bombay). Bhat and Neelakantan (1988) studied the environmental impact on the macrobenthos distribution of Kali estuary, Karwar. Bijoy Nandan (1991) studied the benthos of Kadinamkulam estuary in relation to retting. Shibu (1991) studied the benthic fauna of Paravur lake. Ansari *et al.* (1994) studied macrobenthic assemblage in the soft sediment of Marmugao harbour, Goa. Sunil Kumar and Antony (1994) reported the impact of environmental parameters on polychaetous annelids in the mangrove swamps of Cochin. Sunil Kumar (1995) studied macrobenthos in the mangrove ecosystem of Cochin backwaters. Madhukumar and Anirudhan (1995) studied phosphorus distribution in the sediments of Edava Nadayara and Paravur lake systems. Sunil Kumar (1996) observed the distribution of organic carbon in the sediments of Cochin mangroves.Goldin *et al.* (1996) observed meiobenthos of mangrove mudflats from shallow region of Thane creek, central west coast of India.Nasnolkar *et al.* (1996) made studies on organic carbon, nitrogen and phosphorus in the sediments of Mandovi estuary, Goa. Bijoy Nandan and Abdul Azis (1996) investigated the organic matter of sediments from the retting and non-retting areas of Kadinamkulam estuary.

The present study deals with the distribution and abundance of sediment composition, organic carbon, benthic fauna and animal-sediment relationship of Manakkudy estuary.

5.3. Materials and Methods

Sediment samples were collected monthly from February 1990 to January 1992 in three stations using a PVC corer having 6.6 cm. internal diameter and 21 cm. long. Each sample covered a surface area of approximately 34 cm^2 and a sediment volume of 718 cm^3 (Abdul Azis, 1978).

To get a real situation of the fauna five similar samples were taken in each station from a radius of 3 m. The samples were preserved in 4% formalin mixed with Rose Bengal for identification and enumeration.

A portion of the sediment sample was transferred to a polythene bag, air dried and was used for analysing textural composition and total organic carbon. Sediment composition was determined by using the pipette method of Krumbein and Petti John (1938). Total organic carbon was estimated as described by Wakeel and Riley (1957).

Species diversity, species richness and species evenness were calculated by applying formula used for plankton studies.

5.4. Results

5.4.1. Sediment Composition

The percentage composition of sediment at station I, II and III during 1990-’91 and 1991-’92 is given in Fig. 5.1. The sediment texture is presented in Fig.5.2.

In the present study, during 1990-'91 the percentage composition of sand varied from 21.7% to 5.1%, of silt from 15.3% to 43.5% and of clay from 19.9% to 57.4% at station I; at station II the sand varied from 20.7% to 62.1%, the silt from 21.4% to 45.5% and the clay from 13.1% to 37.2% and at station III the sand varied from 34.8% to 72.9%, the silt from 16.2% to 40.3% and the clay from 6.2% to 33.2%.

During 1991-'92 at station I the percentage of sand varied from 17.2% to 35%, the silt from 21.2% to 53% and the clay from 12.1% to 57.3%; at station II the sand varied from 24.1% to 48.2%, the silt from 21.3% to 50.2% and the clay from 19.5% to 40.1% and at station III the sand varied from 29.7% to 68.2%, the silt from 14.3% to 53.8% and the clay from 7.9% to 29.3%.

The texture of the sediment showed that it was sand silt clay in station I and II and it was silty sand in station III during both the years.

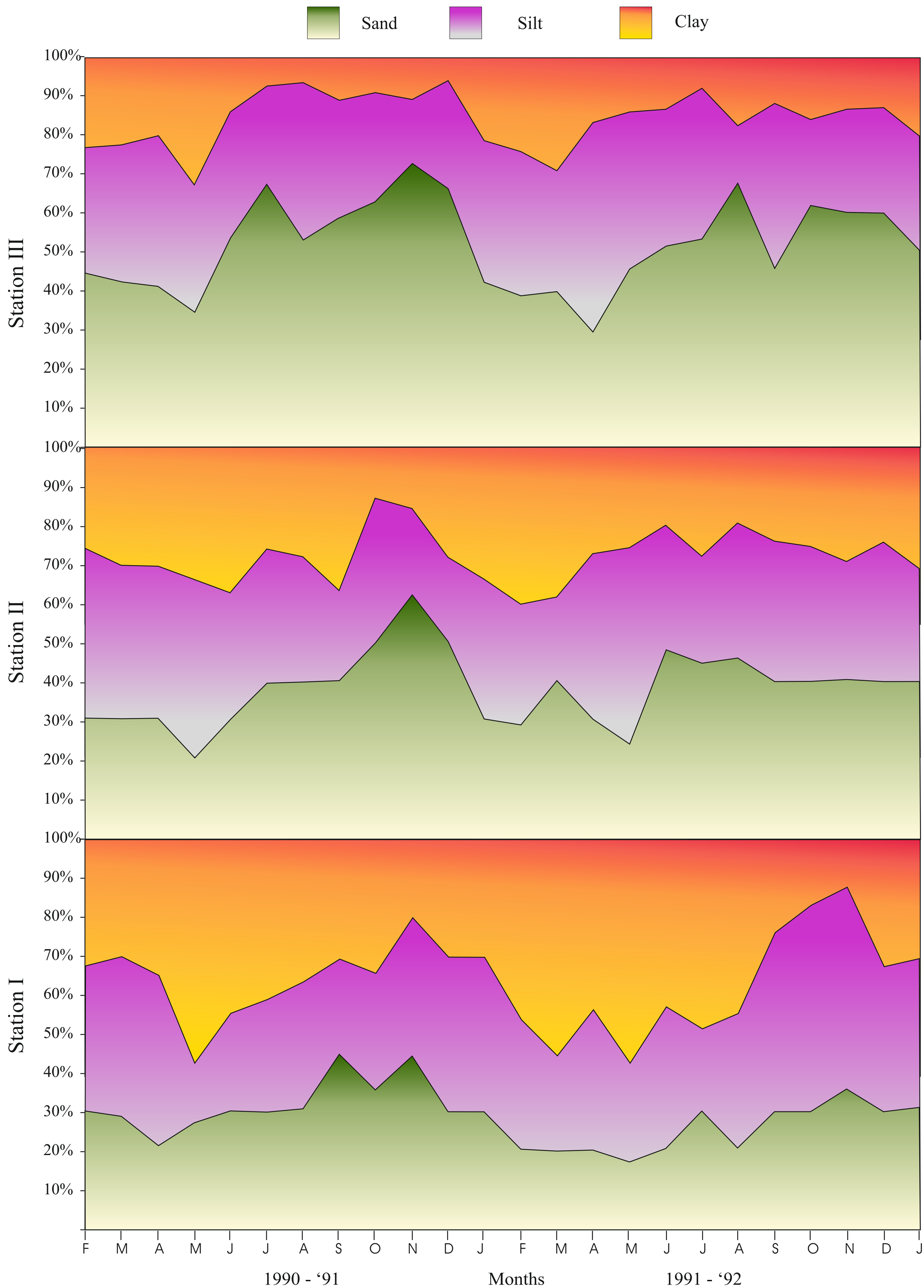

Fig. 5.1: Percentage composition of sediment collected from Manakkudy estuary, at station I, II and III during 1990 - '91 and 1991 - '92.

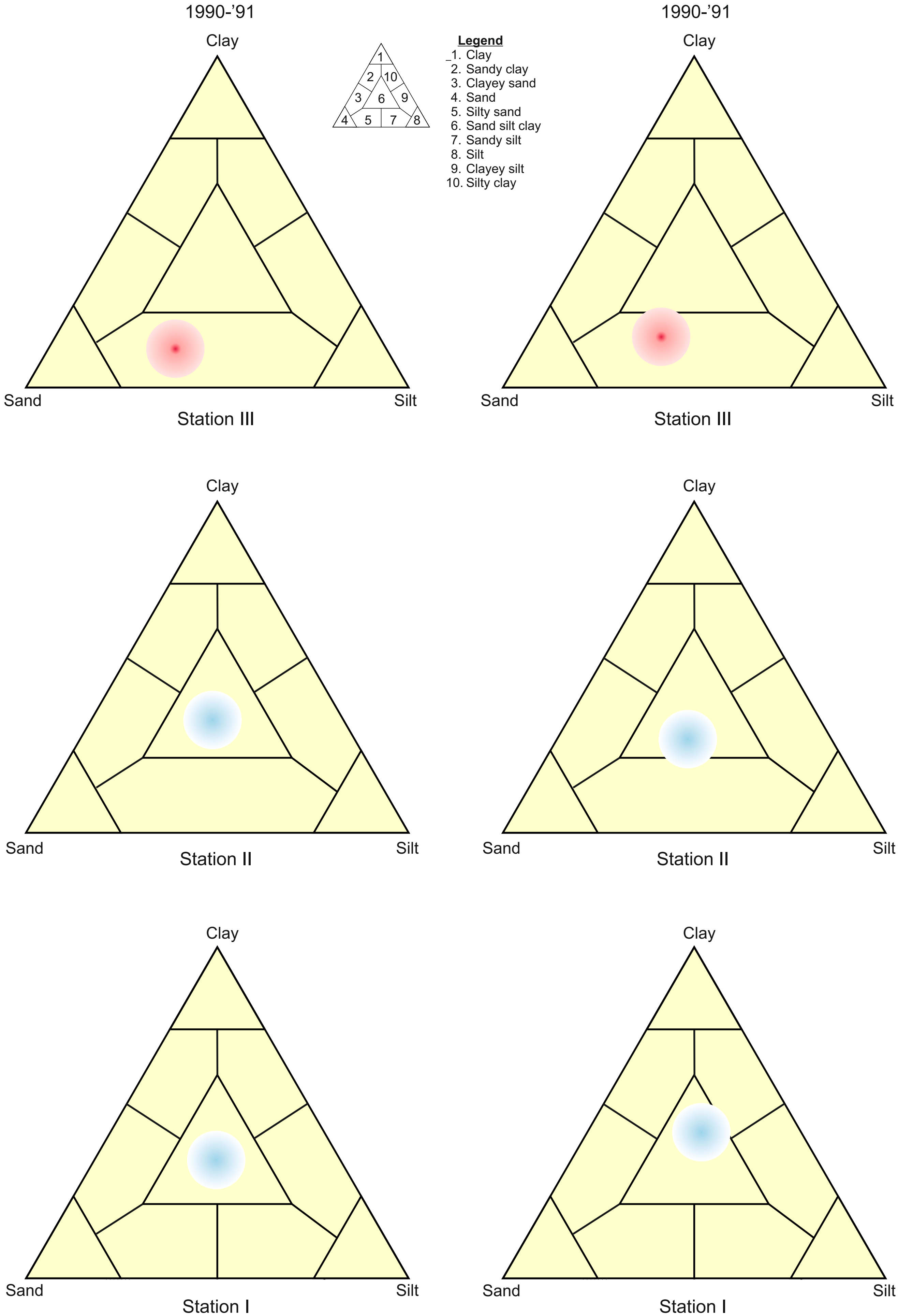

Fig. 5.2. Textural composition of sediment collected from station I, II and III in Manakkudy estuary during 1990-'91 and 1991-'92.

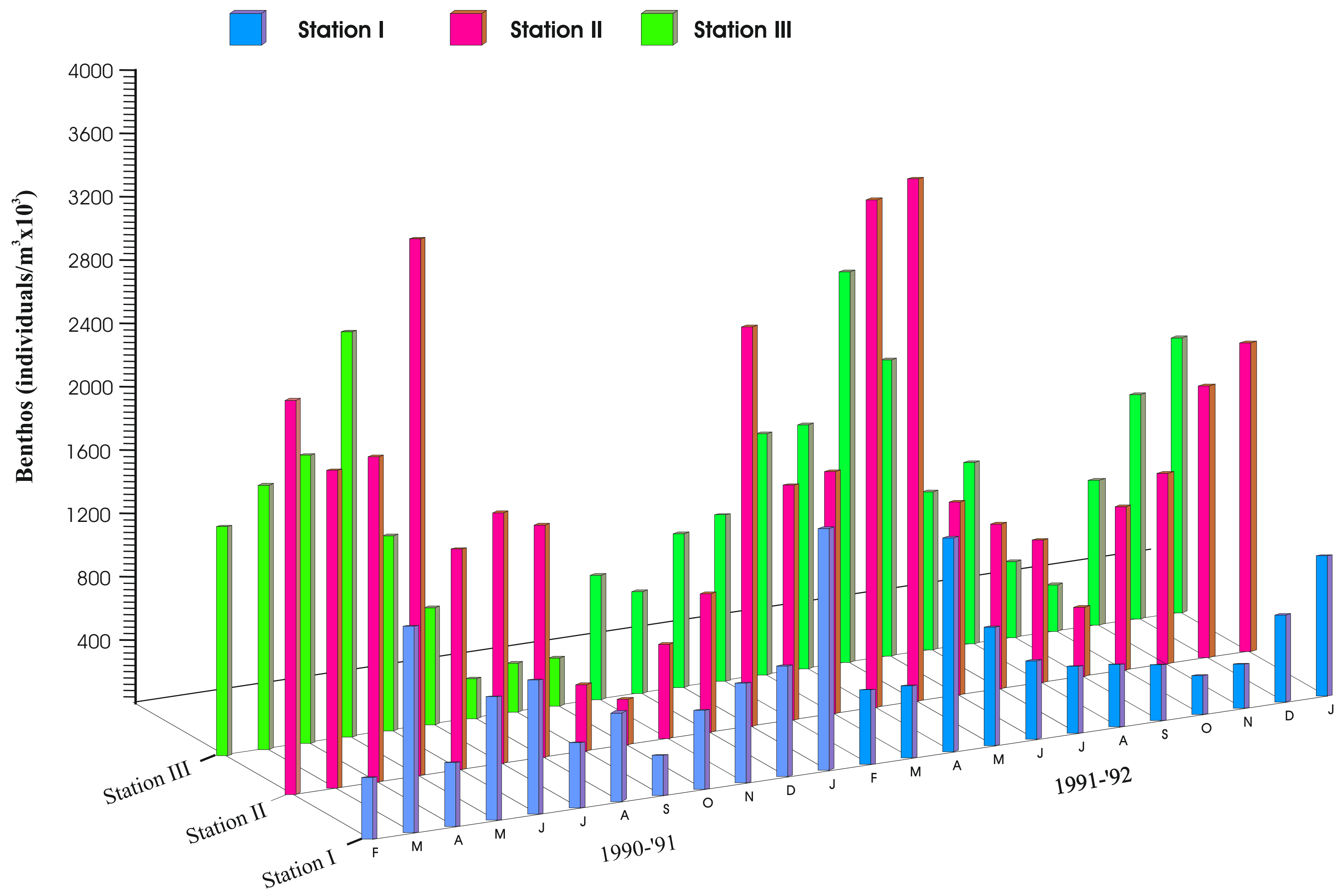

Fig. 5.4: The variations in populations density of benthos at station I, II and III during 1990-'91 and 1991-'92.

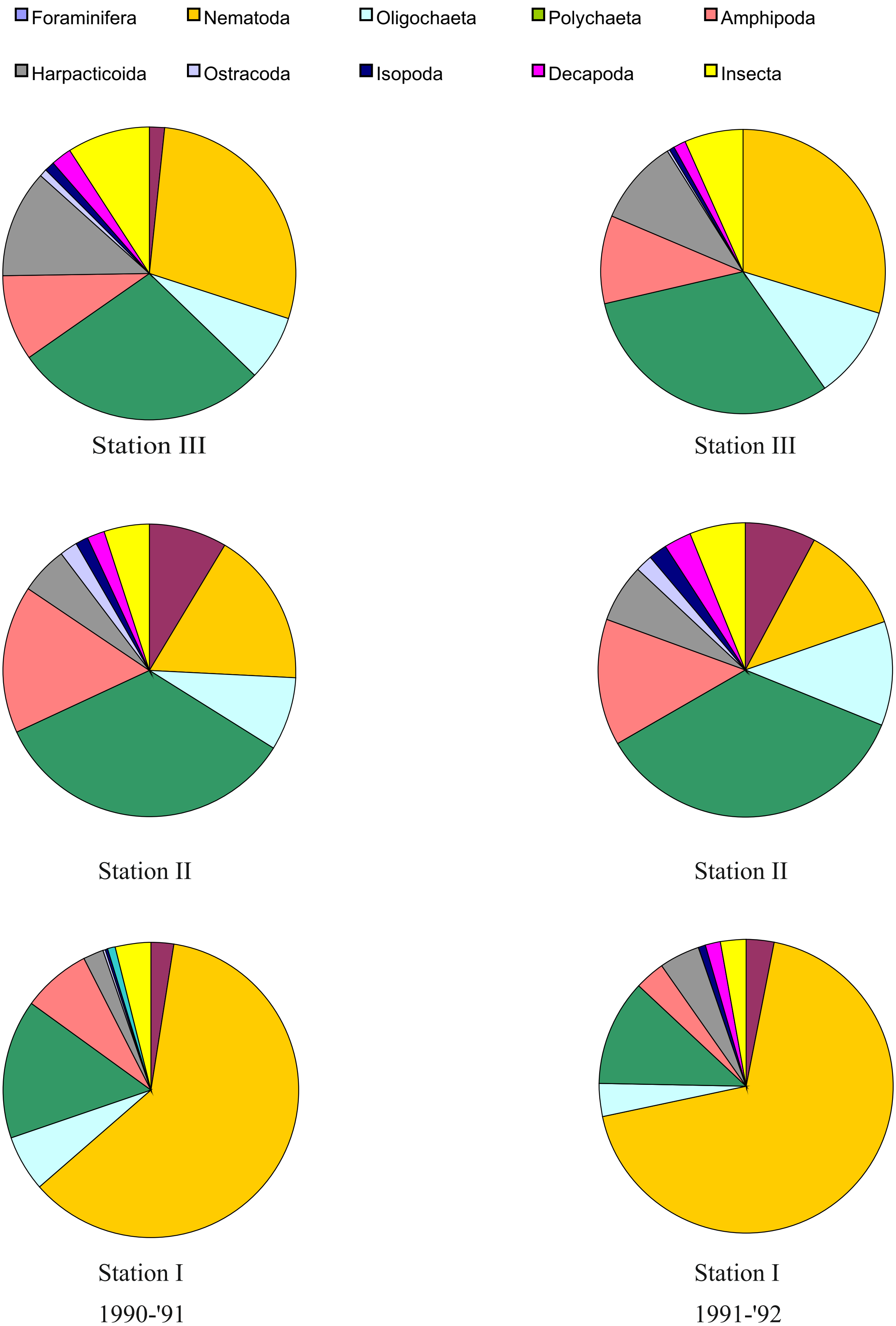

Fig 5.5: Relative abundance of the various groups of benthic fauna at stations I, II and III in Manakkudy estuary during 1990-'91 and 1991-'92

5.4.2. Organic Carbon

The percentage of organic carbon present in the sediment collected from Manakkudy estuary at station I, II and III during 1990-'91 and 1991-'92 is presented in Fig. 5.3.

In the present investigation organic carbon ranged from 0.55% in October to 5.01% in May at station I, from 0.82% in October to 2.51% in December at station II and from 0.45% in November to 1.92% in March at station III during 1990-'91. During 1991-'92 it varied between 0.85% in November and 5.02% in March at station I, between 0.54% in October and 2.62% in March at station II and between 0.38% in November and 1.99% in March at station III.

5.4.3. Benthic Fauna

5.4.3.1. Population Density

The population density of benthic fauna is shown in Fig. 5.4. During 1990-'91 the density of benthic population varied from 254 individuals/m^2 in September to 1526 individuals/m^2 in January at station I, from 300 individuals/m^2 in October to 3399 individuals /m^2 in May at station II and from 253 individuals/m^2 in August to 2560 individuals/m^2 in May at station III. During 1991-'92, the density of benthic population ranged between 246 individuals/m^2 in October and 1350 individuals/m^2 in April at station I; between 437 individuals/m^2 in September and 3300 individuals/m^2 in May at station II and between 293 individuals/m^2 in October and 2475 individuals/m^2 in May at station III.

The total benthic fauna of 1990-’91 comprised of 35.75% of nematodes, 25.78% of polychaetes, 20.92% of crustaceans, 7.32% of oligochaetes, 5.94% of insects and 4.29% of foraminiferans. During 1991-'92, the benthic fauna comprised of 36.71% of nematodes, 26.05% of polychaetes, 20.07% of crustaceans, 8.4% of oligochaetes, 5.17% of insects and 3.60% of foraminiferans.

5.4.3.2. Species Composition of Benthic Fauna

The relative abundance of the various groups of benthic fauna collected from Manakkudy estuary at station I, II and III during 1990-’91 and 1991-’92 is given in the pie diagram 5.5.

In the present study, the benthic population was composed of ten groups, namely Foraminifera, Nematoda, Polychaeta, Oligochaeta, Ostracoda, Harpacticoidea, Isopoda, Amphipoda, Decapoda and Insecta. All these groups occurred in all the three stations I, II and III during both the years except station I and II where Ostracoda and Foraminifera were not represented during 1991-'92.

Alive adult molluscan forms were completely absent from Manakkudy estuary, though the estuary contained enormous shells in the form of subfossil deposits.

In terms of number, benthic fauna was higher in station II and lower in station III. It was lowest at station I, the retting-influenced area. The density, abundance and occurrence of benthic fauna were low in the retting affected station I compared to the non-retting stations II and III.

During 1990-'91 at station I among the total benthic fauna, foraminiferans formed 2.47%, nematodes formed 61.23%, annelids formed 21.19%, crustaceans formed 11.16% and insects formed 3.96%. At station II foraminiferans constituted 8.67%, nematodes constituted 17.09%, annelids constituted 42.24%, crustaceans constituted 27.03% and insects constituted 4.92%. At station III the percentage of the different benthic groups was the following: foraminiferans - 1.74%, nematodes - 28.15%, annelids - 35.50%, crustaceans - 25.56% and insects - 8.87%.

During 1991-'92 at station I foraminiferans constituted 3.16%, nematodes constituted 67.94%, annelids constituted 15.15.%, crustaceans constituted 10.99% and insects constituted 2.76%. At station II foraminiferans formed of 7.78%, nematodes formed of 11.9%, annelids formed of 47.12%, crustaceans formed of 27.08% and insects formed of 6.12%. At station III the percentage of the different benthic groups was the following: nematodes - 29.66%, annelids - 41.67%, crustaceans - 21.9% and insects - 6.77%. At station I ostracods were not noticed during 1991-'92. Foraminiferans were not recorded at station III during 1991-'92.

At station I nematodes were the dominant taxon while at station II and III polychaetes were the dominant taxon.

A total number of 31 species of benthic fauna were recorded in the present study. The species composition included 2 species of foraminiferans, 3 species of nematodes, 4 species of polychaetes, 3 species of oligochaetes, 2 species each of ostracods and isopods, 3 species of harpacticoides, 7 species of amphipods, 3 species of decapods and 2 species of insects. A check list of benthic fauna recorded in Manakkudy estuary is given in the Table 5.1.

Table 5.1: Check list of benthic fauna

Foraminiferans	
Elphidium sp.	*Globigerina* sp.
Nematodes	
Desmodora sp.	*Eurystomina* sp.
Oncholaimus oxyuris	
Polychaetes	
Dendronereis aestuarina	*Prionospio cirrifera*
Dendronereis zululandica	*P.polybranchiata*
Oligochaetes	
Tubifex tubifex	*Branchiodrilus* sp.
Dero sp.	
Ostracods	
Cypris sp.	*Candocypria* sp.
Harpacticoides	
Paramesochra wilsoni	*O.bengalensis*
Onychocamptus mohammed	
Isopods	
Sphaeroma sp.	*Cyanthura* sp.
Amphipods	
Corophium triaenony	*P.digitata*
Eriopisa chilkensis	*Raradidierlla* sp.
Grandidierella sp.	*Amphelisea* sp.
Photis geniculata	
Decapods	
Macrobrachium sp.	*Metapenaeus* sp.
Penaeus indicus	

Insects

Chironomus sp. *Pentaneura* sp.

Elphidium sp. and *Globigerina* sp. were the foraminiferans included in the benthic fauna.

The nematodes were represented by *Desmodora* sp., *Eurystomina* sp. and *Oncholaimus oxyuris.*

Among polychaetes, *Dendronereis aestuarina* was the dominant species. This was followed by *Dendronereis zululandica, Prionospio polybranchiata* and *P. cirrifera.*

The oligochaetes encountered were *Tubifex tubifex, Dero* sp. and *Branchiodrilus* sp.

The ostracods included two species, namely *Cypris* sp. and *Candocypria* sp. and the isopods recorded were *Sphaeroma* sp. and *Cyanthura* sp.

Paramesochra wilsoni, Onychocamptus mohammed and O.bengalensis were the three harpacticoides recorded.

The 7 species of amphipods recorded were *Amphelisea* sp., *Corophium triaenony, Eriopisa chilkensis, Grandidierella* sp., *Photis geniculata, P. digitata* and *Raradidierlla* sp.

Among decapods, the three species were *Macrobrachium* sp., *Penaeus indicus* and *Metapenaeus* sp.

Among insects, two species, namely *Chironomus* sp. and *Pentaneura* sp. were recorded.

5.4.3.3. Species Diversity

The species diversity for benthos collected from Manakkudy estuary at station I, II and III during 1990-'91 and 1991-'92 is presented in Fig. 5.6.

The species diversity values at station I ranged from 0.35 bits/ individuals in April to 0.70 bits/individuals in March during 1990-'91 and from 0.33 bits/individuals in February to 0.71 bits/individuals in April during 1991-'92.

At station II the species diversity varied from 0.33 bits/ individuals in September to 1.21 bits/individuals in May during 1990-'91 and from 0.56 bits/individuals in February to 1.38 bits/individuals in May during 1991 -'92.

At station III it was ranging from 0.32 bits/individuals (July) to 1.11 bits/individuals (May) during 1990-'91 and from 0.52 bits/individuals (July & September) to 1.21 bits/individuals (May) during 1991-'92.

5.4.3.4. Species Richness

The species richness for benthic fauna collected from Manakkudy estuary at station I, II and III during 1990-'91 and 1991-'92 is given in Fig. 5.6.

The species richness for 1990-'91 at station I varied from 0.33 bits/individuals (April) to 0.56 bits/individuals (March) and for 1991-'92 it varied from 0.32 bits/individuals (February and June) to 0.69 bits/ individuals (April).

At station II species richness was fluctuating between 0.31 bits/individuals in September and 0.98 bits/individuals in May during 1990-'91 and between 0.44 bits/individuals in August and 1.15 bits/individuals in May during 1991-'92.

At station III it was ranging from 0.30 bits/individuals in July to 0.89 bits/individuals in May during 1990-'91 and from 0.43 bits/individuals in July to 1.02 bits/individuals in May during 1991-'92.

5.4.3.5. Species Evenness

Species evenness for benthos collected from Manakkudy estuary at station I, II and III during 1990-'91 and 1991-'92 is presented in Fig. 5.6.

The species evenness values at station I were varying from 0.32 bits/individuals in April to 0.45 bits/individuals in February and September during 1990-'91 and from 0.3 bits/individuals in February to 0.47 bits/individuals in March during 1991-'92.

At station II it was fluctuating from 0.30 bits/individuals (September) to 0.57 bits/individuals (April and May) during 1990-'91 and from 0.35 bits/individuals (February) to 0.63 bits/individuals (April) during 1991-'92.

At station III it was ranging from 0.29 bits/individuals in July to 0.54 bits/individuals in April during 1990-'91 and from 0.37 bits/individuals in July and September to 0.63 bits/individuals in March during 1991-'92.

5.5. Statistical Treatment

5.5.1. Sediment Composition

The mean and standard error of sediment composition are given in the Table 5.2. The seasonal mean values are given in Table 5.3. Simple correlation of sediment composition with rainfall is given in Table 5.4.

5.5.1.1. Sand

The mean level of sand was smallest in station I in both the years and greatest in station III. In both the years the mean in station III was significantly greater than that in the other two stations. In 1990-'91 the mean in station I and II were themselves on par with each other statistically, whereas in 1991-'92 they were statistically different from each other. The maximum recorded value was 68.2% in station III in 1991-'92 and the minimum was 17.20% in station I in 1991-'92.

The percentage composition of sand was high at station III and it decreased downstream in both the years. Again the percentage composition of sand was higher during postmonsoon period in both years. The annual average value of sand was high during 1990-'91 and low during 1991-'92. Sand showed positive correlation with rainfall at station I and negative correlation at all other stations.

5.5.1.2. Silt

The average of the silt content measured in both the years did not differ significantly over the stations. Only marginal difference was observed in the mean values. The maximum recorded value was 53.80% in station III in 1991-'92 and the minimum was 14.30% in the same station in the same year. Silt was high during premonsoon season and low during monsoon season. The annual average value of silt was low during 1990-'91 and high during 1991-'92. Silt had negative correlation with rainfall at station I and positive correlation at station II and III.

5.5.1.3. Clay

The average value of clay content was least in station III and highest in station I during both the years. In 1990-'91 the clay content in station III was significantly lower than that in the other two stations which were on par between them and in 1991-'92 all the three mean values were significantly different statistically. The maximum of 57.40% was recorded in station I in 1990-'91 and the minimum of 6.20% was recorded in station III in the same year.

The annual average of clay was high during 1991-'92 and low during 1990-'91. The seasonal mean value of clay was high during premonsoon season and low during monsoon season. Clay showed positive correlation with rainfall at station III only.

5.5.2. Organic Carbon

The mean and standard error of organic carbon are given in Table 5.2. The seasonal mean values are given in Table 5.3. Simple correlation of organic carbon with rainfall is given in Table 5.4. Simple correlation of organic carbon with sediment composition is given in Table 5.5.

In the case of organic carbon, in both the years the average was greatest for station I. However in both years the average for the other two stations were on par and the minimum average was in station III on both the years. In both the years average in station I was significantly greater than that of the other two stations. The maximum recorded value was 5.02% in station II in 1990-'91 and the minimum was 0.38% in station III in 1991-'92.

The annual average value of organic carbon did not show much variation between the two years of study. The seasonal average was high for premonsoon season and low for postmonsoon season. Organic carbon was negatively associated with rainfall at all the stations throughout the period of study.

Maximum values of organic carbon were recorded at all the stations during premonsoon season where as minimum values were recorded during postmonsoon season. The values of organic carbon decreased upstream from station I to III through station II. Organic carbon was maximum during 1990-'91.

Organic carbon showed negative correlation with sand and positive correlation with clay at station I during 1990-'91.

5.5.3. Benthos

The mean and standard error of benthic fauna (group wise) are given in Table 5.7. Simple correlation of benthos with physico-chemical parameters, nutrients, primary production and chlorophylls is given in Table 5.6. The inter correlation matrix of benthos, sediment composition, organic carbon and rainfall at station I, II and III during 1990-'91 and 1991-'92 is given in Table 5.8 to 5.13.

The maximum density of benthic fauna was found to occur during premonsoon season at station II and III in both years. In these stations the minimum density was found during the monsoon season. However, the retting-affected station I showed maximum density in the postmonsoon season and the minimum was recorded during premonsoon.

The benthic population density was comparatively higher in the non-retting station II and III and the minimum density was shown in the retting affected station I.

While the premonsoon season was favourable for benthic fauna at the non-retting station II and III, the rainy season was favourable at the retting affected station I. The premonsoon season was unfavourable for benthic fauna in the retting affected station I, because of the high concentrations of dissolved hydrogen sulphide and sharp depletion in the dissolved oxygen concentration.

The annual average benthic population density during 1990-'91 was lower than that of 1991-'92. Benthic fauna showed positive association with rainfall throughout the period of study except for station I and II during 1990-'91. The population density of benthic fauna was positively associated with salinity, pH (except station I), gross primary production (except station I) and negatively associated with oxygen, hydrogen sulphide, all nutrients and sand. There was no significant association between benthos and silt and clay.

In general higher diversity values were recorded during premonsoon periods. Station II recorded higher annual average followed by station III and I. The annual average was high during 1991-’92 and low during 1990-’91.

The annual average, seasonal average and station maximum of species richness followed the same pattern as that of species diversity.

The annual average species evenness was high during 1991-’92, and low during 1990-’91. The seasonal average was maximum during premonsoon season and minimum during monsoon season. Station II recorded maximum annual average values followed by station III and station I.

5.5.3.1. Foraminifera

Foraminifera in 1990-’91 had given the highest mean for station II. However, there was no significant difference in the mean values over the three stations. In 1991-’92 though the greatest average was for station II and 0 for station III, all the three mean values were significantly different from one another. The maximum recorded value was 615 individuals/m^2 in station II in 1990-’91 and the minimum was 0 in all the stations in both the years (Table 5.7).

Results of regression analysis with correlation for Foraminifera are presented in Tables 5.14, 5.15 and 5.16 for the three stations in both the years.

The results exhibited in the Table 5.14 reveal that in station I none of the variables showed any relationship with the foraminifera in 1990-'91. In the same station in 1991-'92 silicate had shown negative association and it's presence is optimum and any more increase in silicate would further decrease the presence of this group considerably.

In station II (Table 5.15) in 1990-'91 chlorophyll 'c' had shown positive association and its addition to the water any more would be productive and phosphorus seemed to be in excess and any more addition would further damage the growth of foraminifera. In 1991-'92 in the same station this group was absent throughout the year.

Regarding station III (Table 5.16) this group was not present in 1991-'92 throughout where as in 1990-'91 surface temperature and bottom temperature were in excess and their further increase would considerably reduce the growth of this group.

5.5.3.2. Nematoda

Though the greatest average for 1990-'91 in station I and in 1991-'92 it was for station III, there was no statistical significant difference among these stations in both the years. The maximum recorded value was 1369 individuals/m^2 in station I in 1990-'91 and the minimum was zero in both the years in all the stations (Table 5.7).

The relationships of Nematoda with the physico-chemical parameters are exhibited in Table 5.17, 5.18 and 5.19. It reveals that in station I in 1990-'91 no parameter had any relation with Nematoda where as in 1991-'92 salinity at the surface and bottom had shown positive association and more increase in this was more productive to Nematoda where as oxygen at the two levels, H_2S and phosphorus, phosphate and nitrate were in excess in such a way that any more increase in these were harmful to Nematoda growth.

Regarding station II (Table 5.18) in 1990-'91 again salinity at the two levels had positive association so that any addition would be more productive and depth and phosphorus were in excess so that any more increase would be harmful to Nematoda and in 1991-'92 also salinity at the two levels and pH at the surface were favourable where as depth, phosphorus, phosphate and nitrate were in excess and any more addition in these were harmful to Nematoda.

In station III (Table 5.19) in 1990-'91 salinity at the bottom and visibility were productive and depth, silicate, phosphorus and nitrate were harmful to Nematoda and in the same station in 1991-'92 temperature at the bottom, salinity at the surface, pH at the surface and bottom were in shortage so that increases in these were highly productive and the parameters surface oxygen, silicate, phosphorus, phosphate, nitrate and nitrite were in excess so that any more addition would diminish the Nematodes.

On the whole, there was exact similarity in the performance in station I and II in both the years and the performance in station III (Table 5.19) was completely different in both the years.

5.5.3.3. Polychaeta

The relative performance of Polychaeta was almost same in both the years over the three stations. In both the years the average value was highest in station II and least in station I. In 1990-'91 the average in station III was significantly greater than that in station I and significantly smaller than that in station II. In 1991-'92 the average in station I was significantly smaller than the other two and that in station III and station II were statistically on par with each other. The maximum value recorded was 1202 individuals/m^2 in station II in 1991-'92 and the minimum was 0 in 1991-'92 for station I and III (Table 5.7).

Table 5.20 gives the details of Polychaeta with the physico-chemical parameters. In station I in 1990-'91 oxygen at the two levels and nitrate were in shortage to Polychaeta and nothing was in excess and in 1991-'92 phosphate, nitrate, nitrite and chlorophyll 'b' were in shortage and salinity at the two levels were in excess.

In station II (Table 5.21) in 1990-'91 salinity at the two levels were in shortage and oxygen at the surface, silicate, phosphorus, phosphate, nitrate and nitrite were in excess. In 1991-'92 salinity at the surface was in shortage and depth, oxygen at surface, phosphorus and phosphate were in excess.

In station III (Table 5.22) in 1990-'91 visibility and salinity at the two levels were in shortage and oxygen at the two levels, silicate, phosphorus, phosphate, nitrate and nitrite were in excess already and in 1991-'92 no parameters showed any relationship with Polychaeta.

5.5.3.4. Oligochaeta

Oligochaeta recorded the greatest average value in both the years in station II. In 1990-'91 this value was significantly greater than the same in the other two stations, I and III which were on par with each other. In 1991-'92 both station II and station III were on par and station I had the significantly smaller value in the average than that in the other two stations. The maximum recorded value was 345 individuals/m^2 in station II in 1991-'92 and the minimum was 0 in all the stations except station I in 1990-'91 (Table 5.7).

Tables 5.23, 5.24 and 5.25 present the relationship of Oligochaeta with the physico-chemical parameters. It is seemed that in Station I (Table 5.23) in 1990-'91 oxygen at the two levels, silicate, phosphorus, phosphate and nitrate were in shortage to Oligochaeta in such a way that any more addition in these would make Oligochaeta to be more productive where as salinity and H_2S were in excess in both at the surface and at the bottom and were harmful to Oligochaeta. In 1991-'92 phosphate and nitrate were at the lower level so that any addition in these were favourable for Oligochaeta. At the same time surface temperature, salinity at surface and bottom and H_2S both at surface and bottom were in excess so that any more addition became harmful to Oligochaeta.

In station II (Table 5.24) in 1990-'91 visibility, salinity at the surface and bottom, net primary production and chlorophyll 'c' were in shortage and silicate, phosphorus and phosphate were in excess and in 1991-'92 no parameter showed any association with Oligochaeta.

In station III (Table 5.25) in 1990-'91 visibility, salinity at surface and bottom and pH at the surface were in shortage and oxygen at the two levels, silicate, phosphorus, phosphate, nitrate and nitrite were in excess. In 1991-'92 oxygen at the two levels, phosphorus, phosphate, nitrate and nitrite were in shortage and pH at the two levels, gross primary production, net primary production. chlorophyll 'a' and chlorophyll 'c' were in excess.

5.5.3.5. Ostracoda

In this case in both the years all the 3 stations had significantly different means. The greatest average was for station II in both the years and the smallest was for station I. The maximum recorded value was 221 individuals/m^2 in station II in 1990-'91 and the minimum was 0 in all the stations in both the years (Table 5.7).

As indicated in Table 5.26 in station I in 1990-'91 the data was unable to predict any relationship with any of the parameters in 1990-'91 and in 1991-'92 Ostracoda was not present throughout in station I.

In station II (Table 5.27) in 1990-'91 the data was unable to give any information on Ostracoda where as in 1991-'92 only silicate was in excess and harmful to Ostracoda.

In station III (Table 5.28) in 1990-'91 temperature at the atmosphere was in shortage and additional temperature was highly productive and oxygen at the bottom was in excess and harmful to Ostracoda and in 1991-’92 the data could not provide any information.

5.5.3.6. Harpacticoidea

As far as the average values were concerned, Harpacticoidea had identical behaviour in both the years. In both the years station I had recorded the smallest average and station III the greatest. The significance was also similar in both the years. In both the years the average for station II and station III were on par with each other and that in station I was significantly smaller than the other two. The maximum recorded value was 413 individuals/m^2 in station II in 1991-’92 and the minimum was 0 in all the stations in both the years (Table 5.7).

The results of the analysis for Harpacticoidea is presented in Tables 5.29, 5.30 and 5.31. In station I (Table 5.29) in 1990-’91 salinity at the two levels was in shortage to Harpacticoidea and oxygen at the two levels, silicate and nitrate were in excess to Harpacticoidea and in 1991-’92 also the salinity at the two levels were in shortage. Apart from this pH at the two levels and chlorophyll ‘a’ were in shortage in this year. At the same time only nitrate was in excess and harmful to Harpacticoidea.

In station II (Table 5.30) in 1990-’91 the salinity at the two levels and pH at the two levels were in shortage where as silicate, phosphate, nitrate and chlorophyll ‘b’ were in excess here. In 1991-’92 also salinity and pH at the two levels were in shortage and oxygen at the two levels, silicate, phosphorus, phosphate, nitrate and nitrite were already in excess and harmful to Harpacticoidea.

In station III (Table 5.31) in 1990-'91 as in the case of the other two stations, the salinity at the two levels were in shortage and more productive where as oxygen at the two levels, silicate, phosphorus, phosphate, and nitrate were already in excess and harmful. In 1991-'92 pH was in shortage and productive at the surface and none was in excess.

5.5.3.7. Isopoda

Isopoda recorded the smallest average in both the years in station I and the greatest in station II. However, there was difference in the significance levels in the two years. In 1990-'91 the averages in station II and III were on par statistically and significantly greater than that in station I. In 1991-'92 the mean for station II was significantly greater than that in the other two stations which were on par with each other. The maximum recorded value was 135 individuals/m^2 in station II in 1991-'92 and the minimum was 0 in all the stations in both the year (Table 5.7).

The details of Isopoda presented in Table 5.32 reveals that in station I in 1990-'91 salinity at the two levels were highly productive where as silicate was in excess and harmful to Isopoda. In 1991-'92 H_2S at the surface was in excess and less productive and depth, oxygen at the two levels and phosphate were already in excess and harmful to Isopoda.

In station II (Table 5.33) in 1990-'91 only phosphorus was in excess and harmful and in 1991-'92 salinity was less at the two levels and more productive. Similarly pH at the two levels was also more productive. The parameters depth, oxygen at the two levels, silicate, phosphorus, phosphate and nitrate were in excess and harmful.

In station III (Table 5.34) in 1990-'91 higher visibility could bring more Isopoda, increase in the salinity at the bottom was also favourable for Isopoda where as in 1991-'92 salinity at the two levels were highly favourable for Isopoda. Higher visibility was also favourable where as silicate, phosphorus and nitrate were already in excess and harmful and in 1991-'92 also salinity was highly favourable and silicate, phosphorus, phosphate, nitrite and nitrate were already in excess and harmful to Isopoda.

5.5.3.8. Amphipoda

Amphipoda recorded the smallest mean value in station I in both years. Next in the order was station III and the greatest was station II in both the years. Regarding the significance in 1990-'91 the averages in station I and III were statistically on par and that in station II was significantly greater than that in the other two stations. In 1991-'92 the averages in station III and II were statistically on par with each other where as that in station I was significantly smaller than the average in the other two. The maximum of 135 individuals/m^2 was recorded in station II in 1991-'92 and the minimum was 0 in all the stations in both the years (Table 5.7).

The details regarding Amphipoda with the physico-chemical parameters are as in Tables 5.35, 5.36 and 5.37. It is seen that in station I (Table 5.35) in 1990-'91 only the pH level was surplus in the surface level and hence it was unproductive and in 1991-'92 oxygen at the two levels and H_2S, phosphate, nitrate and chlorophyll were already in excess and harmful whereas salinity at the two levels was in shortage so that its addition would be productive.

In station II (Table 5.36) in 1990-'91 pH at the surface and chlorophyll 'c' were in shortage, so that any more addition in these two might be productive. In 1991-'92 addition in salinity at the bottom, pH at the surface could be more productive where as phosphate and nitrate were already in excess.

In station III (Table 5.37) in 1990-'91 salinity at the two levels were needed more to produce more of Amphipoda where as oxygen at the bottom, phosphorus, nitrate and nitrite were already in excess and harmful to Amphipoda. In 1991-'92 salinity at the two levels pH at the two levels were in deficit and oxygen at the two levels and phosphate were already in excess in this station.

5.5.3.9. Decapoda

In both the years decapoda had recorded the smallest mean values in station I and the greatest in station II. The mean in station III was inbetween the two. In 1990-'91 the means of station II and III were on par with each other and both of them were significantly greater than that in station I. In 1991-'92 the mean in station II was significantly greater than that in the other two and the mean in these two were statistically on par. The maximum of 230 individuals/m^2 was recorded in station II in 1991-'92 and the minimum was 0 in both the years except station III in 1990-'91 (Table 5.7).

The details pertaining to Decapoda presented in Table 5.38 reveals that in station I in 1990-'91 increase in the atmospheric temperature would be favourable to Decapoda where as increase in depth, H_2S, silicate and phosphorus would be harmful. In 1991-'92 increase of salinity at the surface and bottom, H_2S at the surface and chlorophyll 'a' were favourable where as decrease in oxygen at the surface and bottom, phosphate, nitrate and chlorophyll 'b' were favourable to Decapoda.

In station II (Table 5.39) in 1990-'91 increase in chlorophyll 'c' was favourable and decrease in silicate and phosphorus were favourable and in 1991-'92 increase in salinity at the surface and bottom, pH at the surface and bottom and chlorophyll 'c' were favourable where as decrease in depth, oxygen at the surface and bottom, silicate, phosphorus, phosphate, nitrate and nitrite were favourable to Decapoda.

In station III (Table 5.40) in 1990-'91 increase in visibility and salinity were favourable and decrease in oxygen at the bottom, silicate, phosphorus, phosphate, nitrate and nitrite were favourable.

5.5.3.10. Insecta

The pattern of performance on the mean values was different for insecta for both the years. The lowest mean was in station I on both the years. In 1990-'91 the greatest was in station III where as it was in station II in 1991-'92. In both the years the mean in station I was significantly lower than that in the other two stations. In both the years the averages were statistically on par with each other in station II and III. The maximum recorded value was 380 individuals/m^2 in station III in 1991-'92 and the minimum was 0 on both the years in all the stations except station III in 1991-'92 (Table 5.7).

Details of insecta as seen in Table 5.41 show that in station I in 1990-'91 increase in surface oxygen alone would add more Insecta. In 1991-'92 increase in oxygen at the bottom alone could increase the Insecta where as the same could be achieved by decreasing the visibility level and H_2S.

In station II (Table 5.42) in 1990-'91 increasing the level of nitrite would add Insecta. In 1991-'92 increase in surface oxygen level would favour Insecta and the decrease in the levels of visibility, bottom salinity and bottom pH level will give the same benefit.

In station III (Table 5.43) in 1990-'91 increase in silicate and nitrite were productive where as decrease in visibility alone would favour Insecta and in 1991-'92 increase in chlorophyll 'b' would act favourably where as the same can be achieved by decreasing the levels of bottom temperature.

5.6. Discussion

The substratum acts as an important abiotic factor in the benthic environment. Following the method of Shepard (1954), the textural composition in the present study was classified as silty sand and sand silt clay. On comparing the soil texture and benthic fauna, it was concluded that higher benthic production was associated with silty sand and lower benthic production was associated with sand silt clay. This observation was in agreement with the findings of Varshney *et al.* (1981) in the Narmada estuary, Chandran *et al.* (1982) in the Vellar estuary, Jegadeesan (1986) in the Coleroon estuary and Shibu (1991) in the Paravur lake.

In the present investigation, the composition of organic carbon was found to be high during premonsoon season and low during postmonsoon season. The very low rain fall, reduced fresh water influx and the closure of the mouth of the estuary during premonsoon season resulted in the development of a stagnant condition in the estuary leading to the sharp rise in the organic content of the estuary. The postmonsoon season was marked by heavy rainfall and the subsequent floods lead to the fall in carbon values. The same type of result was obtained by Remani (1979) and Remani *et al.* (1981) in Cochin backwaters, Nair *et al.* (1984) in Ashtamudi estuary and Bijoy Nandan (1991) in Kadinamkulam estuary.

In the estuaries of west coast of India, retting of coconut husk is one of the main sources of organic carbon (Abdul Azis, 1978, Remani, 1979, Nair *et al.,* 1984, Shibu, 1991 and Bijoy Nandan, 1991). Retting of coconut husk is basically a biological process. It is brought about by the action of bacteria and fungi (Bhat and Nambudiri, 1971) and also yeast (Bhat *et al.,* 1972). The process of retting liberates large quantities of organic matter like pectin, phenol, tannin and lignin into the water (Prabhu, 1957). These organic materials released during the retting process got deposited at the bottom of the kayal and this accounted for the high percentage of organic carbon at station I. The low percentage of organic carbon at station II and III was due to the absence of retting in these areas.

Organic carbon was higher in sediments rich in clay particles and lower in sediments consisting of sand and silt. In the present investigation also the organic carbon content was found to be lower with high percentage of sand-composed sediment and higher with high percentage of clay composed sediment. The percentage of organic carbon increased during premonsoon and decreased during postmonsoon. This was in conformity with earlier studies (Divakaran *et al.,* 1981, Chandran *et al.,* 1982, Sivakumar, 1982, Thangaraj, 1984, Jegadeesan, 1986, Harkantra *et al.,* 1980, Bijoy Nandan, 1991 and Shibu, 1991).

In Manakkudy estuary, the values of organic carbon ranged between 0.38% to 5.02%. In Cochin backwater Remani (1979) recorded

0.5% to 5.0%; in the retting zones of cochin backwater, Remani (1979) recorded 3.0% to 14%; in Ashtamudi estuary Nair *et al.* (1984) recorded 0.48% to 1.84%; in Paravur lake, Shibu (1991) recorded 0.09% to 13.94% and in Kadinamkulam estuary, Bijoy Nandan (1991) recorded 0.31% to 13.79% of organic carbon.

The values of organic carbon showed positive correlation with salinity and hydrogen sulphide and negative correlation with oxygen. This was in conformity with the findings of Bijoy Nandan (1991) in Kadinamkulam estuary and Shibu (1991) in Paravur lake.

The percentage of organic carbon and benthic faunal density showed a negative relationship in the present study. Harkantra *et al.* (1980) observed a decrease in benthic animals when organic carbon was high. Similar observations were also made by Bijoy Nandan (1991). An increasing faunal composition with increasing organic carbon was reported by Parulaker *et al.* (1973) in Mandovi and Zuari estuary, Chandran *et al.* (1982), Sivakumar (1982) and Thangaraj (1984) in Vellar estuary and by Jegadeesan (1986) in Coleroon estuary. Shibu (1991) did not find any significant relationship between organic carbon and faunal density in Paravur lake.

The estuarine fauna are chiefly constituted by marine, brackish-water, freshwater and migratory components (Day, 1951). The present study indicated the influence of the substratum and the salinity on the distribution of fauna. A similar trend of benthic distribution was reported by Desai and Krishnankutty (1967) from the nearshore regions of the Arabian Sea, Parulekar and Dwivedi (1973 and 1974) and Parulekar *et al.* (1973) from Mandovi - Zuari estuarine complex of Goa.

The population density values indicated variations in relation to the prevailing monsoon. A higher numerical abundance was noticed during premonsoon season. A reduction in the mean population density was observed during monsoon and postmonsoon periods. The reduction in the numerical abundance of the benthic fauna noticed during monsoon and postmonsoon periods may be attributed to the flooding of the river system and low salinity. Similar type of observations were also made by Seshappa, 1953; Sanders, 1958; Desai and Krishnankutty, 1967; Kinne, 1972; Kurian, 1972; Damodaran, 1973; Parulekar and Dwivedi, 1974; Kurian *et al.,* 1975; Redding and Cory, 1975; Murugan *et al.,* 1980; Varshney *et al.,* 1981; Chandran *et al.,* 1982; Gopinathan, 1985; Jegadeesan, 1986 and Shibu, 1991.

The great variations in the density of benthic fauna observed during premonsoon and monsoon seasons were mainly due to the unstable nature of the bottom sediment, the salinity and the fresh water flow. During monsoon period, the density of benthos decreased mainly because of the fresh water inflow and the flushing of the soft bottom sediment along with the animals of the upper layers (Seshappa, 1953; Sanders, 1958; Desai and Krishnankutty, 1967; Kurian, 1972; Redding and Cory, 1975; Chandran *et al.,* 1982; Shibu, 1991). By the end of postmonsoon the freshwater flow decreased step by step and this resulted in the settling of the suspended materials. The settled materials formed a suitable substratum for the recolonization of the benthic community in the forth coming premonsoon season. A similar view was expressed by Parulekar *et al.* (1980).

Redding and Cory (1975) stressed that the distribution of any given species in nature is the result of the complex interaction of various environmental factors. The environmental factors, which influence the distribution and abundance of benthic fauna, may include temperature, salinity, dissolved oxygen, hydrogen sulphide, sediment texture, etc. In tropical estuaries, the effect of temperature as a limiting factor is only of secondary importance (Kurian *et al.* 1975) because of very low temperature variation. As Manakkudy estuary is also a tropical estuary, the present study also showed very low variation of temperature and it was not sufficient enough to affect the distribution of benthic fauna. Similar observations were also made in the Cochin backwaters by Kurian (1972), in Vellar estuary by Ajmal Khan *et al.* (1975) and Chandran *et al.* (1982), in the Veli lake by Murugan *et al.* (1980), in the Narmada estuary by Varshney *et al.* (1981), in the Ashtamudi estuary by Nair *et al.* (1984), in the Coleroon estuary by Jegadeesan (1986) and in the Paravur lake by Shibu (1991). However, Bijoy Nandan (1991) observed a negative relationship between temperature and benthos in Kadinamkulam estuary.

The dissolved oxygen, though a limiting factor in the distribution of benthic fauna, had no significant correlation with the benthic fauna in shallow estuaries where the flow of water is continuous. In the present study also dissolved oxygen had no impact on the abundance and distribution of benthic fauna except station I. This is in conformity with the previous observations (Parulekar and Dwivedi, 1975; Parulekar *et al.,* 1976; Chandran *et al.,* 1982; Jegadeesan, 1986 and Shibu 1991). However, Bijoy Nandan (1991) observed a positive relationship between benthos and dissolved oxygen.

Salinity plays the key role in the dynamics of an estuarine ecosystem. A slight change in salinity will reflect on other physical, chemical and biological factors (Dehadrai, 1970; Goswami and Singbal, 1974). In the present study salinity had a positive correlation with benthic fauna at all stations except station I where no significant correlation was observed. The salinity was low during monsoon and postmonsoon seasons. It went up during premonsoon season due to the ceasation of fresh water flow and intensive evaporation. Hence during this season a relatively stable environment was produced. This stable environment provided a congenial situation for the growth of the benthic fauna during this period. The reduction in the density of benthic fauna during monsoon season was due to low salinity caused by the flooding of the river system. This observation was in agreement with the previous observations made by Varshney *et al.*, 1981; Chandran, 1982; Nair *et al.,* 1984; Jegadeesan, 1986; and Shibu, 1991. The contrasting observation where the salinity had a negative correlation with the peak incidence and abundance of the benthic fauna was made by Parulekar and Dwivedi (1973) from the estuaries of Goa, Prabha Devi (1986) from the Coleroon estuary, Divakaran *et al.* (1981) from the Ashtamudi lake and Bijoy Nandan (1991) from Kadinamkulam estuary.

In the present investigation polychaetes were found to be the dominant taxon at all stations except the retting-affected station I. This observation is in agreement with the previous observations along the east and west coasts of India (Kurian, *et al.* 1975; Thangaraj *et al.* 1979; Divakaran *et al.* 1981; Ansari *et al.* 1982; Chandran *et al.* 1982; Fernando *et al.* 1983; Nair *et al.* 1984 and Jegadeesan 1986). However, this observation is in contrast to the observations of Abdul Azis and Nair (1983) and Shibu (1991) in Paravur lake, and Murugan *et al.* (1980) and Gopinathan (1985) in Veli lake, where they recorded crustaceans as the dominant taxon.

The general composition, incidence and abundance of the benthic fauna in the retting zones were qualitatively and quantitatively depleted and were remarkably low. Similar observations were made by Remani (1979) in the retting zones of Cochin backwater, Abdul Azis and Nair (1986) in the retting zones of Edava Nadayara backwater system, Bijoy Nandan (1991) in the Kadinamkulam estuary and Shibu (1991) in

Paravur lake.

In the present investigation a negative relationship existed between hydrogen sulphide and benthos. This was in conformity with the previous results (Remani, 1979, Abdul Azis and Nair, 1986, Bijoy Nandan, 1991 and Shibu, 1991).

In the retting-influenced station I nematodes were found to be the dominant group. This observation was in close agreement with the observations on the retting zones of Edava Nadayara backwater system by Abdul Azis and Nair (1983) and on the Paravur lake by Shibu (1991).

Macrobenthos of Indian estuaries are usually polychaetes, crustaceans and molluscs (Kurian *et al.* 1975, Parulekar and Dwivedi 1975, Parulekar *et al.* 1973, Ajmal Khan *et al.* 1975 and Chandran *et al.* 1982). A reasonable percentage of benthic fauna in Indian estuaries is contributed by Mollusca as evidenced by Kurian *et al.* (1975) in Vembanad lake, Parulekar *et al.* (1973) in Mandovi, Cambarzua canal and Zuari estuarine system, Chandran *et al.* (1982) and Sivakumar (1982) in Vellar estuary, Jegadeesan (1986) in Coleroon estuary, Shibu (1991) in Paravur lake and Bijoy Nandan (1991) in Kadinamkulam estuary. However, as an oddity, the alive molluscan fauna of Manakkudy estuary is completely depleted, though it contains heavy deposits of sub fossil molluscs. The depletion of molluscan fauna may be attributed to comparatively low and changing salinity and the constantly changing substratum due to human activity.