Studies on the macrobenthic community of Cochin backwaters with special reference to culture of *Eriopisa chilkensis*

(Gammaridae-Amphipoda)

Thesis submitted to the
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In Partial fulfillment of the degree of

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Under the
Faculty of Marine Sciences

By

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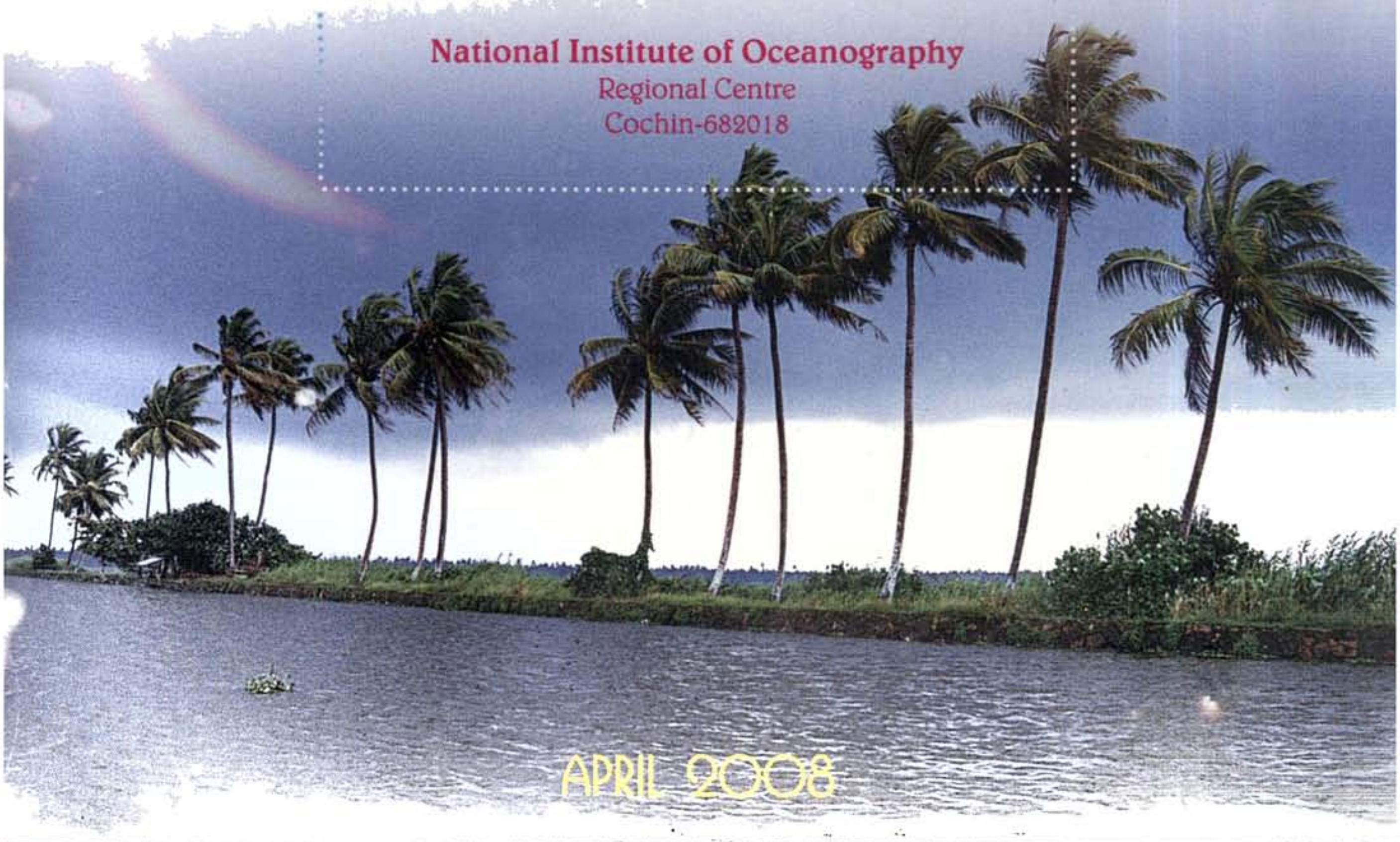

APRIL 2008

DECLARATION

I hereby declare that the thesis entitled "**Studies on the macrobenthic community of Cochin backwaters with special reference to culture of *Eriopisa chilkensis* (Gammaridae-Amphipoda)**" is an authentic record of the research work carried out by me, under the joint guidance and supervision of Dr. (Mrs.) Saramma. U. Panampunnayil, Scientist-F, National Institute of Oceanography, Regional Centre, Kochi-18 and Dr. K.K.C. Nair, Scientist-in-Charge (Rtd.) National Institute of Oceanography, Regional Centre, Kochi-18 in partial fulfillment of the requirement for the award of Ph.D degree of the Cochin University of Science and Technology in the faculty of Marine Sciences and that no part of this has been presented before for any degree, diploma or associateship in any university.

Kochi-18
April 2008

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April, 2008

CERTIFICATE

This is to certify that the thesis entitled "**Studies on the macrobenthic community of Cochin backwaters with special reference to culture of *Eriopisa chilkensis* (Gammaridae-Amphipoda)**" is an authentic record of the research work carried out by Smt. Nisha. P. Aravind, under our supervision and guidance in the Regional Centre of National Institute of Oceanography (Council of Scientific and Industrial Research), Kochi-18 in partial fulfillment of the requirements for Ph.D degree of the Cochin University of Science and Technology in the faculty of Marine Sciences and no part thereof has previously formed the basis for the award of any degree, diploma or associateship in any university.

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Dedicated to my beloved family and my friends

Acronyms and Abbreviations

BOD	Biological Oxygen Demand
C.E	Central Estuary
Chl 'a'	Chlorophyll 'a'
d'	Margalef's richness
DIC	Dissolved Inorganic Carbon
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
eg.	Exempli gratia (Latin word meaning 'for the sake of example')
et al.,	et alii (Latin word meaning 'and others')
etc.	et centera (Latin word meaning 'and other similar things and so on')
H'	Shannon weaver diversity
I.R	Industrial Region
J'	Pielou's index
K'	Attenuation coefficient
M	Monsoon
N.E	Northern Estuary
Post-M	Post summer monsoon
Pre-M	Pre-monsoon
psu	Practical Salinity Unit
S.E	Southern Estuary
SPM	Suspended Particulate Matter
T_{Alk}	Total Alkalinity
TN	Total Nitrogen
TOC	Total Organic Carbon
λ'	Simpson's index

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1.1 Estuarine environment

Estuaries are home to a variety of animals and plants. Pritchard (1967) defined estuary as "a semi-enclosed coastal body of water which has a free connection with the open sea and within which, sea water is measurably diluted with fresh water derived from land drainage". Estuaries have been the focal point of inshore activities and related studies. As they are semi-enclosed often they provide natural harbours for trade and commerce. They are also effective nutrient traps and provide a vital source of natural resources to man and are used for commercial, industrial and recreational purposes. Estuaries also function as important sinks and transformers of nutrients, thus altering the quantity and quality of nutrients transported from land to the sea. Thus, by virtue of their natural location and easy accessibility, estuaries are more amenable to anthropogenic influences. They also act as nursery ground for a variety of shrimps and finfishes. It has been estimated that 60 to 80 % of the commercial marine fishery resources depend on estuaries for part of or entire life cycles.

1.1.1 Cochin backwaters

Cochin backwater is one of the largest wetlands along the west coast of India (Lat. 09°30'& 10°12'N and Long. 76°10' & 76°30'E) with its northern boundary at Azhikode and southern boundary at Thannirmukham bund. The total area of the estuary is around 250 km^2. The depth varies from 1.5 m to 7 m with an average tidal range of 1 m and the shipping channels are maintained at a depth of 10-13m. The area is about 80 km long and 0.5-4 km wide on an average (Menon et al., 2000). It forms a complex system of shallow estuarine network running parallel to the coastline of Kerala. The backwater system has two permanent opening to the Arabian Sea- one at Cochin and the other at Azhikode. The Cochin barmouth is much wider and forms the main entrance to the Arabian Sea. The estuarine system around the city of Cochin and neighbouring areas is known as Cochin backwaters. Six rivers (Pamba, Achancoil, Manimala, Meenachil, Periyar and Muvattupuzha) with their tributaries and several canals bring large volumes of freshwaters into this backwater system predominantly during the South West monsoon (May-September) and relatively less during the North East monsoon (October-February). Among these rivers, Periyar and Muvattupuzha discharge into the northern part of the backwater system and hence have an active influence on the distribution of salinity in the estuary. Tides from the Arabian Sea contribute a regular flow of salt water, which diminish considerably towards the head of the estuary (Madhupratap 1987).

The annual rainfall at Cochin is around 3200mm, of which nearly 75% occurs during summer monsoon that vary from year to year. Normally, it occurs from June to September. During the peak of summer monsoon period (July/ August) heavy rain occurs in the region (40-50cm rain fall in a few hours) (Qasim 2003). Salinity remains at near zero values over a large portion of the estuary during this period. The seasonal effect of freshwater and salinity, play an important role in the ecobiology of the system (Madhupratap 1987). During post monsoon period (Oct to January), the river discharge gradually diminishes and tidal influences gains momentum as the estuarine conditions change to a partially mixed type (Menon et al., 2000). During pre summer monsoon period (Mar- May), fresh water input to Cochin backwaters is minimum due to low rainfall over the region when the lower reaches of the estuary behave as a section of the Arabian Sea (Madhupratap 1987; Menon et al., 2000). Since the backwater system is geographically located in the tropical region, the surface temperature is about 28°C in summer monsoon period (June –Sept) and 30°C in pre summer monsoon period (March – May) (Madhupratap 1987).

In Cochin backwaters, phytoplankton biomass and primary production remains largely constant all through the year, although marked salinity variations arise seasonally as a result of heavy freshwater influx (Menon et al., 2000). Low saline water has insignificant effect on the growth and production of phytoplankton in this system (Qasim et al., 1974). However, a qualitative shift in phytoplankton composition is reported during extremely low saline conditions where small forms contribute to the majority of the standing stock (Menon et al., 2000; Qasim 2003). Interestingly, mesozooplankton standing stock and production varies seasonally with a minimum during summer monsoon, which increases up to eight times during pre summer monsoon (Madhupratap 1987). The reduction is attributed to limitation in osmotic adaptation in low saline waters.

Estuarine and coastal waters are rich in nutrients, and hence productivity is high when turbidity is low. On the other hand, in turbid estuaries, even though there are sufficient nutrients, lack of sufficient amount of light restricts primary production. In the Cochin backwaters, the estimated annual consumption by the zooplankton herbivores is approximately 25 per cent of the total primary production. Benthos play a vital role in the food chain and recycling of essential elements like, Carbon, Nitrogen and Phosphorus in the ecosystem. Because of the shallow depth of estuaries, suspended food particles are readily available for benthic animals through sinking as well as downward transport by turbulent water movements (Wolff et al, 1976).

Assuming that tertiary production is about 1% of primary production and 10% of secondary production (Cushing, 1971 & 1973), and estimating their carbon values by a factor (7.41) to obtain wet weight (Vinagradov, 1953) the fish production in the Cochin estuary is approximately 2400 tonnes. Accordingly, the catches of herbivorous fishes were about 1470 to 2640 tonnes (Madhupratap et al., 1977). Most of the estuarine fishes are omnivorous and the common estuarine fishes like *Mugil* sp. can feed at different trophic levels (Odum, 1971).

1.2 Benthos

1.2.1 Definition and factors affecting benthos

Benthos are identified as organisms living in or on the bottom of any body of water (Bostwick, 1983). In estuarine systems, the benthic community is primarily dominated by species that burrow into the sediments (infauna), either living within tubes or burrow systems. Taxa dominating the infauna in most estuaries include small worms (polychaetes and oligochaetes), amphipods, crustaceans, clams, and insect larvae, depending on prevailing salinities. In addition to infauna there are also a number of epibenthic organisms that reside on the sediment surface at least for part of their lives. Epibenthic species include mysid shrimp, some amphipods and isopods. Benthic animals generally consume detrital or planktonic food, and are in turn prey for larger fish, shrimp and crabs. In many estuarine systems there is a link between timing of predator recruitment (e.g. larval fish) and their benthic prey.

Benthic animals are classified according to their size: microfauna - <100 μm; meiofauna - 100-500 μm; and macrofauna - >500 μm (Mare 1942), and according to where they live (epifauna, on the sediment, or infauna, within the sediment).

The following environmental factors determine the community structure of benthic organisms: -

- Physico-chemical factors such as temperature, salinity, water currents, tidal exposure, depth, substratum, sediment grain size, oxidation-reduction state, dissolved oxygen, organic content, nutrients and light
- Biological factors like food availability, feeding activities, prey-predator relationship, breeding, spawning, dispersal and settlement and behavioural effects (movement, aggregation, growth and mortality)

1.2.2 Role in estuaries

Benthos play a critical role in the functioning of estuaries. The diverse benthic groups form a major link in the food chain. Filter feeders in the benthic community pump large amount of water through their bodies, and as they do so, they remove sediments and organic matter, cleaning the water. Organic matter that is not used within the water-column is deposited on the bottom. It is then remineralized by benthic organisms into nutrients which are given back into the water column. This remineralization of organic matter is an important source of nutrients and is critical in maintaining the high primary production rates of estuaries.

1.2.3 Food and feeding

Infaunal organisms either move through the sediment, to capture their prey or to swallow large quantities of organic deposits, or tend to stay still and capture their food either from the seston (suspension feeders) or from within the sediment while inside their burrows (e.g. lugworm, *Arenicola marina*). Organisms that move within the sediment or disturb the sediment (i.e. cause it to move, resuspend, erode or redeposit) during their feeding are called bioturbators (or sediment destabilisers). These include both sessile (organisms that do not move) or motile organisms like bivalves (e.g. *Macoma*), crustaceans (the mud shrimp, *Corophium volutator*), polychaete (e.g. lugworm, *Arenicola*), echinoderms (e.g. the deposit-feeder sea cucumber, *Molpadia*).

Other organisms, like tube-building Polychaete (e.g. *Diopatra neapolitana*) tend to consolidate the sedimentary habitat and are therefore called sediment stabilisers. Assemblages are studied by classifying organisms into functional groups which include all the species of different animal taxa that use and affect the environment in similar ways. Organisms can also be classified as sediment-stabilisers or sediment-destabilisers, and both categories include deposit-feeders, suspension-feeders and carnivores. Burrowing deposit-feeders tend to be more abundant in fine-grained organic rich sediments. The activity of these organisms create resuspension of fine particles and clog the fine filtering structures of some of the suspension-feeders, making their feeding very difficult.

1.2.4 Benthic productivity

Distribution and abundance of benthic animals of a region is directly related to the fisheries of that region. Benthos that form an important source of food for demersal fishes can be good indicators of fish stocks. Since, the demersal fishery contributes about 30 to 50% of the total fishery potential of any area, the benthic production plays a major role in deciding the demersal fishery potential. Benthic production in estuaries is quite high when compared to other aquatic habitats because of the abundance of food and shallow depth. In such situations, food becomes readily available to the bottom living animals through sinking and vertical transport. Another reason is the presence of opportunistic species, which produce more generations per year compared to the other slower reproducing fauna.

1.2.5 Ecological importance

Benthos is an important part of the food chain, especially for fish. Many invertebrates feed on algae and bacteria, which are on the lower end of the food chain. Because of their abundance and role as "middlemen" in aquatic food chain, benthos plays a critical role in the natural flow of energy and nutrients. As benthic invertebrates die, they decay, releasing nutrients that are reused by aquatic plants and other animals in the food chain. Benthic communities can be used to monitor stream quality conditions over a broad area or they can be used to determine the effects of point source discharges such as sewage treatment plants and factories.

Unlike fish, benthos cannot move around much so they are less able to escape the effects of sediment and other pollutants that diminish water quality. Therefore, benthos can give reliable information on stream and lake water quality. Due to their differential tolerance, they have been considered the best indicators of anthropogenic perturbation. Their long life cycles allow studies conducted by aquatic ecologists to determine any decline in environmental quality. Benthos represents an extremely diverse group of aquatic animals, and the large number of species possess a wide range of responses to stressors such as organic pollutants, sediments, and toxicants. Many benthic macroinvertebrates are long lived, allowing detection of past pollution events such as pesticide spills and illegal dumping.

Ecologists who evaluate environmental quality using the benthos often consider the following characteristics of a benthic sample to be important indicators of stream, river or lake quality: -

taxa richness: a measure of the number of different types of animals; greater taxa richness generally indicates better water quality.

pollution tolerance: many types of benthos are sensitive to pollutants such as metals and organic wastes. Mayflies, stoneflies, and caddisflies are generally intolerant of pollution. If a large number of these insect types are collected in a sample, the water quality in the stream is likely to be good. If only pollution tolerant organisms such as non-biting midges and worms are found, the water is likely to be polluted.

functional groups: the presence or absences of certain feeding groups (such as scrapers and filterers) may indicate a disturbance in the food supply of the benthic animals in the stream and the possible effects of toxic chemicals.

1.2.6 Economic importance

Benthos, the bottom dwelling organisms at the water sediment interface of lakes and rivers are the main food for many fish, besides supporting the carbon cycling to circulate nutrients from the ocean floor to the overlying water column. The macrobenthos is an important component of the estuarine environment, as a large proportion of the estuarine habitat's biodiversity is found in the benthic community. Many of the worms, shrimps, snails and bivalves are important food for fish and birds. For these reasons alone, the benthos are an integral part of an ecosystem.

1.2.7 Benthos and estuarine pollution

Knowing the spatial distribution of benthos their relative high and low levels in distribution is the first step in understanding the human impacts on the benthic community. Global climate change, for example, may be adversely affecting the benthos in the region. This cannot be proven unless there is an understanding of the current distribution of benthos in this region, which can, in the future, be compared with spatial distributions of different time periods to investigate temporal changes. Chemical changes associated with the change from freshwater to saltwater result in the flocculation of dissolved materials that have been transported in the water down the river into the estuary. Because of the flow restrictions, suspended particles can settle out of the water into the sediments. These processes allow pollutants to reach greater concentrations in the sediments than in the water. Because of their close association in the sediment, benthic organisms will respond to these pollutants before the animals in the water column. Thus, benthic community may be the first component of the estuarine fauna to show weakening environmental health. The changes brought about by the deposition of pollutants on the bottom greatly affect the bottom fauna and flora by reducing species diversity. The elimination of non-tolerant species is often accompanied by an increase in benthic invertebrates due to lack of predation and competition by changes and simplification of food chain or by the surplus supply of allocthonous source of food for the remaining tolerant species. A reduction in the macrofaunal species due to pollution will have a direct impact on demersal fishes.

There has been an estimated reduction in the area of Cochin backwaters by about 35% as a result of construction of bunds and reclamation for agriculture, harbour and urban development. Since 1970, an area covering 176 hectares has been reclaimed for harbour and urban development. Effluents from industrial, agricultural, domestic and retting sources have lead to its deterioration. The decreased volume of backwaters with limited exchange with the sea reduces the diluting capacity of the backwaters. The physical alteration also play a major role in changing the abundance of flora and fauna (Gopalan et al., 1983).

The discharges from industrial, domestic and agricultural wastes have increased the pollutant levels in the estuary (SCMC, 2004). In the past two decades, estuary and feeders were affected by anthropogenic, industrial and domestic loading (CPCB, 1996; Balachandran et al., 2005). Enhanced nutrient discharges to the coastal waters have lead to toxic algal blooms in this region (Naqvi et al., 1998).

1.3 Literature review

Studies on bottom fauna in India was first made by Annandale (1907), Peterson (1913) and Annandale and Kemp (1915). The benthos of Malabar and Trivandrum coasts were studied by Seshappa (1953) and Kurian (1953) respectively. Kurian (1967) has given an account of benthos of south west coast of India. Work on benthos of the mud banks of Kerala coast was done by Damodaran (1973). Macrobenthic polychaetes along the shelfwaters of the west coast of India was studied by Joydas and Damodaran (2001). Macrobenthos of the shelf waters of the west coast of India was studied by Joydas (2002). Kumar et al., (2004) has studied the macrobenthos in relation to sediment characteristics of nearshore waters, west coast of India receiving industrial effluents.

The bottom fauna of Cochin backwaters was studied by Desai and Krishnan Kutty (1967). Kurian (1972) has worked on the ecology of benthos in Cochin backwaters. Ansari (1974) has investigated the macrobenthic production in the Vembanad Lake. Bottom fauna of the Vembanad Lake was studied by Kurian et al., (1975). The biochemical constituents of some faunal components of the Cochin backwaters were studied by Gopalakrishnan et al., (1977). Incidence of fish mortality due to industrial pollution from the upper reaches of Cochin backwater was reported by Unnithan et al., (1977). Ansari (1977) and Pillai (1978) have studied the distribution of macrobenthos of the Cochin backwaters. The effect of pollution on benthos was made by Remani (1979). Fish mortality due to ammonia poisoning in Chitrapuzha was reported by Venugopal et.al. (1980). Nair et al., (1983) have studied the population dynamics of estuarine amphipods in Cochin backwaters. Remani et al., (1983) have reported on the indicator species of organic pollution in the Cochin backwaters. Bottom fauna of north Vembanad Lake was studied by Batcha (1984). Effect of pollution on the benthic communities in Cochin backwaters was studied by Saraladevi (1986). The spatial and temporal distribution of benthos in northern limbs of Cochin backwaters was made by Saraladevi and Venugopal (1989). Saraladevi et al., (1991) have given an account of the benthic communities and co-existence of species in the Cochin backwaters. Benthic ecology of the prawn culture fields in the northern and adjoining areas of Cochin backwaters was studied by Aravindakshan et al., (1992). Fauna of the mangrove swamps of Cochin was studied by Sunilkumar (1993). Impact of environmental parameters on polychaetous annelids in the mangrove area was investigated by Sunilkumar and Antony (1994). The comparative study on the community structure and distributional ecology of benthos in the mangrove swamps of Cochin estuary was made by Sunil Kumar (1995). The effect of dredging on benthic fauna in and around Cochin harbour was studied by Rasheed (1997). A new record of five species of polychaetes from the mangrove ecosystem of Cochin backwaters was reported by Sunilkumar (1999). Sheeba (2000) studied the benthic infauna in the Cochin backwaters in relation to environmental parameters. Menon et al., (2000) has reviewed the hydrobiology of Cochin backwaters. Pillai (2001) has studied the spatial and temporal distribution of polychaetes in the Cochin estuary. Arun (2002) has studied the biology, experimental culture and toxicity studies of *Villorita cyprinoides* in the Cochin estuary. Arun (2004) has studied the impact of artificial structures on biodiversity of Cochin estuary.

1.4 Purpose of the study

Benthic organisms are usually studied for environmental impact assessment, pollution control and resource conservation.

The benthic monitoring component has three major objectives: 1) characterize the benthic communities to assess the estuarine health, 2) determine seasonal and spatial variability in benthic communities, and 3) detect changes in the estuarine community through examination of changes in abundances of specific indicator taxa and other standard benthic indices.

Unlike fish and plankton, which move in the water column, the benthos live in a two dimensional environment. Because of their reduced mobility, benthic communities will not change greatly with the tide or weather. Also, where there is intermittent pollution or the concentration changes with the tides, fish and plankton will rapidly recolonise in an area. Many benthic animals can only recolonise an area by larvae settling thus cannot recolonise till the next breeding season. Also many of the mobile animals will only move slowly into the area. Thus short-term pollution events will be detectable in the benthic community for a considerable time. The macrobenthos also live in an environment where concentration of pollutants is likely to occur. Benthic fauna are considered as important indicators of water quality and are used in a variety of monitoring programs to assess overall estuarine health and to follow long-term trends in estuarine communities related to anthropogenic impacts (Boesch et al., 1976, Aschan and Skullerod 1990, Simboura et al., 1995, Hyland et al., 1999).

From a monitoring perspective, benthos offer 3 positive attributes: 1) they are relatively sedentary and long-lived, 2) they occupy an important intermediate trophic position, and 3) they respond differentially to varying environmental conditions. After settlement, most benthos remain within a relatively constrained area, often less than 5 m^2, for their entire adult lives. Therefore, unlike many other biotic or chemical measures, benthos reflect conditions at a specific location.

Many benthos are also relatively long-lived, with life spans generally ranging from weeks for some opportunistic worms to months or years for many larger taxa, leading to a community structure that reflects average conditions integrated over a time period of months. However, benthos vary in their responses to changes in water quality. Some taxa are relatively tolerant to organic enrichment and low dissolved oxygen (D.O) while others are quickly eliminated under low D.O conditions (Boesch et al., 1976, Simboura et al., 1995). Increased nutrient inputs can strongly affect abundances of some species, while some are not affected. Similarly, there is a wide variation in tolerance to pesticides and some metal contaminants such as mercury or cadmium. By examining shifts in the benthic community over time, one can gain an understanding of the major environmental processes affecting the local biota (Hyland et al., 1999).

Hence, keeping an account of all these factors, an attempt has been made to study the composition, distribution and diversity of macrobenthos in relation to the environmental parameters in the Cochin backwaters. Until now, there has been no complete study of the Cochin backwaters covering the entire area. Earlier studies are fragmented and restricted mainly to small areas. The present data is examined against the backdrops of the available information and an attempt is made to evaluate changes on the benthic community over 25 years. Along with this an attempt has been made to study the life cycle of a benthic fodder organism (*Eriopisa chilkensis*- Gammaridae, Amphipoda) under laboratory conditions and its population dynamics at the mangrove area of Puduvypin.

CHAPTER 2

MATERIALS AND METHODS

2.1 Sampling location

2.2 Sampling Methodology

2.3 Analytical methods

2.4 Statistical methods

2.1 Sampling location

2.1.1 Cochin backwaters

To study the spatial distribution of benthic fauna, sampling was carried out in 2005 during Early pre-monsoon (February), Pre-monsoon (April) and Monsoon (September) seasons from 56 stations at 2km intervals covering the Cochin backwaters extending from Azhikode in north to Thannirmukham in south.

Sampling was also carried out from 9 stations during the three seasons namely pre-monsoon (April), monsoon (July) and post monsoon (October) during 2003.

To study the population dynamics of *Eriopisa chilkensis*, one-year (2003-2004) sampling was carried out from the mangrove rich environment of Puduvypin.

2.2 Sampling Methodology

The sample collection was carried out under the multi-disciplinary program of Ecosystem Modeling of Cochin Backwaters. Along with the present data samples were also collected (water and sediment) in association with Integrated Coastal Marine Area Management-Project Directorate (ICMAM-PD), Chennai for the analysis of (Dissolved Inorganic Carbon) DIC, (Dissolved Organic Carbon (DOC), Total Alkalinity (T_{Alk}), Total Organic Carbon (TOC) and Total Nitrogen (TN). Details regarding the sampling and analytical techniques are explained in Gupta et al., (2008).

2.2.1 Water quality

Water samples were collected from the surface and bottom. Surface water was collected using a clean plastic bucket and bottom water was collected using a Niskin sampler.

Water samples for the analyses of salinity and nutrients were collected in pre-cleaned polyethylene bottles. Nutrient samples were transported to the laboratory keeping in ice and analysed immediately.

Samples for dissolved oxygen were collected in 125 ml stoppered glass bottles taking care that no air bubbles are getting trapped in the sample. The samples were fixed immediately with manganous chloride solution (Winkler A) followed by alkaline potassium iodide (Winkler B) solution.

Samples for BOD were collected in 300 ml stoppered glass bottles without any air bubble getting trapped in the bottle and incubated.

Secchi disc of the standard size of 30 cm diameter was used to measure light penetration in water.

2.2.2 Benthos and Sediment

Duplicate grab samples were collected from all stations using a van Veen grab (mouth area $0.048m^2$) and sieved through a strainer of 0.5mm pore size and stained using Rose Bengal. Samples for grain size and organic carbon content were collected separately.

van Veen grab

2.3 Analytical methods

2.3.1 Water quality

Temperature was recorded using Brannan thermometer (1-51°C range within ±1°C) and salinity using Digi Auto Salinometer (Accuracy ±0.001).

pH was measured using a ROSS combination glass electrode (ORION 8102U) and pH meter (ORION 555A) calibrated on the NBS scale as described by Frankignoulle and Borges (2001). The pH values on NBS scale were first converted to the pH in situ and then to total scale.

Dissolved Oxygen (DO) was estimated by Winkler's method and were fixed by adding 0.5 ml of Winkler A and 0.5 ml of Winkler B solution and mixed well for precipitation (Grasshoff et al., 1983). Dissolved Oxygen was analysed after acidification by titration against standard sodium thiosulphate using starch as indicator.

Biochemical Oxygen Demand (BOD). The sample was incubated for 5 days at 20°C in the dark. The reduction in dissolved oxygen concentration from initial to final during the incubation period yields the biochemical oxygen demand.

Nutrient analysis was carried out on filtered water following standard procedures (Grasshoff et al., 1983) using Spectrophotometer (1650 Shimadzu).

Nitrite-N

Nitrite-N was measured by the method of Bendschneider and Robinson (1952). In this method, nitrite in the water sample when treated with sulphanilamide in acid solution results in diazo compound which reacts with N-1-naphthyl ethylene diamine dihydrochloride to form an azo dye. The absorbance of the colour complex is measured at 543 nm.

Nitrate-N

Nitrate-N in the water sample was quantitatively reduced to nitrite by passing the sample through a reduction column filled with copper coated cadmium granules and measured as nitrite. During the reduction stage, ammonium chloride buffer is added to the sample to maintain a stable pH (Grasshoff et al., 1983). The estuarine samples containing high concentration of nitrate-N were diluted before passing them through the column.

Ammonia-N

Ammonia-N was determined according to the indophenol blue method of Koroleff (1983). In a moderately alkaline medium, ammonia reacts with hypochlorite to form monochloramine which in the presence of phenol, catalytic amount of nitroprusside ions and excess hypochlorite forms indophenol blue. The formation of monochloramine requires a pH between 8 and 11.5. At higher pH, ammonia is incompletely oxidised to nitrite. Both calcium and magnesium ions in seawater precipitate as hydroxide and carbonate at pH higher than 9.6, however their precipitation can be prevented by complexing them with citrate buffer. The samples were fixed by addition of reagents and the absorbance measured at 630 nm after colour development (about 6 hours). The measured ammonia include both free dissolved ammonia gas and the ammonium ions.

Inorganic Phosphate

Determination of inorganic phosphate involves the measurement of the concentration of orthophosphate ions by the formation of a reduced phosphomolebdenum blue complex in an acid solution containing molybdic acid, ascorbic acid and trivalent antimony. The most accepted method based on this reaction, which was developed by Murphy and Riley (1962) is that given by Strickland and Parsons (1972). A variation of this method described by

Grashoff et al., (1983) is adopted in the present work. Instead of single solution reagent as in the Murphy and Riley procedure, two stable reagent solutions are used here. 0.5 ml of the mixed reagent containing molybdic acid and antimony tartrate were added to 25 ml aliquots of the samples followed by 0.5 ml of ascorbic acid reagent. The absorbance was measured at 882 nm within 30 minutes to reduce any possible interference from arsenate. Turbidity corrections were made wherever found necessary.

Silicate

Silicate was measured following the standard procedures of Grasshoff et al., (1983). Determination of silicate was based on the formation of molybdenum blue complex when the acid sample is treated with molybdic solution. The absorbance was read at 810 nm.

Suspended particulate matter (SPM)

SPM was measured by filtering a known volume of water through 0.45μm cellulose acetate membrane filters (Millipore), rinsed with copious Milli-Q water and by taking the difference of initial and final weights of filter paper.

Attenuation coefficient ('K' value)

Attenuation coefficient ('K' value) was calculated using the formula K = 1.5/D (Qasim et al., 1968), where D is the depth of visibility in meters as determined by secchi disc.

Chlorophyll 'a'

Chlorophyll 'a' was measured using spectrophotometer (Strickland and Parson, 1972). A known volume of water sample was filtered through 47 mm Whatman GF/F filter paper with $MgCO_3$ suspension. The chlorophyll retained in the filter was extracted in 10 ml of 90% acetone for about 10-20 hrs in dark and was centrifuged for 10 minutes at 3000-4000 rpm. The extinction of the supernatant solution was measured spectrophotometrically against a cell containing 90% acetone at 750, 665, 645, 630, 510 and 480 nm and the concentration of pigment was calculated using standard equations.

2.3.2 Sediment samples - grain size analysis and estimation of organic matter

The samples were dried in a hot air oven at 60°C. Sediment granulometry (sand, silt and clay) was analysed using pipette analysis (Krumbein and Pettijohn, 1966). TOC (total organic carbon) and TN (Total Nitrogen) was analysed using CHN analyser (Freeze-dried and homogenised sediment samples were acidified for 24 hr with 1 M HCl and rinsed three times with deionised water to remove carbonate. Carbon and nitrogen contents in the carbonate free samples were determined in duplicate using Flash EA 1112 CHNS analyser. The combustion temperature was set at 960° C. Relative precision for the entire experimental procedure was estimated at ± 2% for TOC and ± 3% for TN (using reference material NIST 1941B). Organic matter was calculated by multiplying organic carbon values by a factor of 1.724 (Trask, 1955).

2.3.4 Benthos

Samples were collected using van-Veen grab (0.048 m^2) and sieved through a 500 μm seive (Birkett and McIntyre, 1971) to separate specimens from the substrate and preserved in 5% neutral formalin mixed with rose bengal stain for subsequent identification. The actual number of organisms counted were converted to ind./m^2. The fauna were identified to the lowest taxonomic level (species) wherever possible following standard references (Day, 1967; Fauval, 1953; Gosner, 1971). The biomass values were expressed as wet weight in g/m^2 (shell on weight wherever applicable).

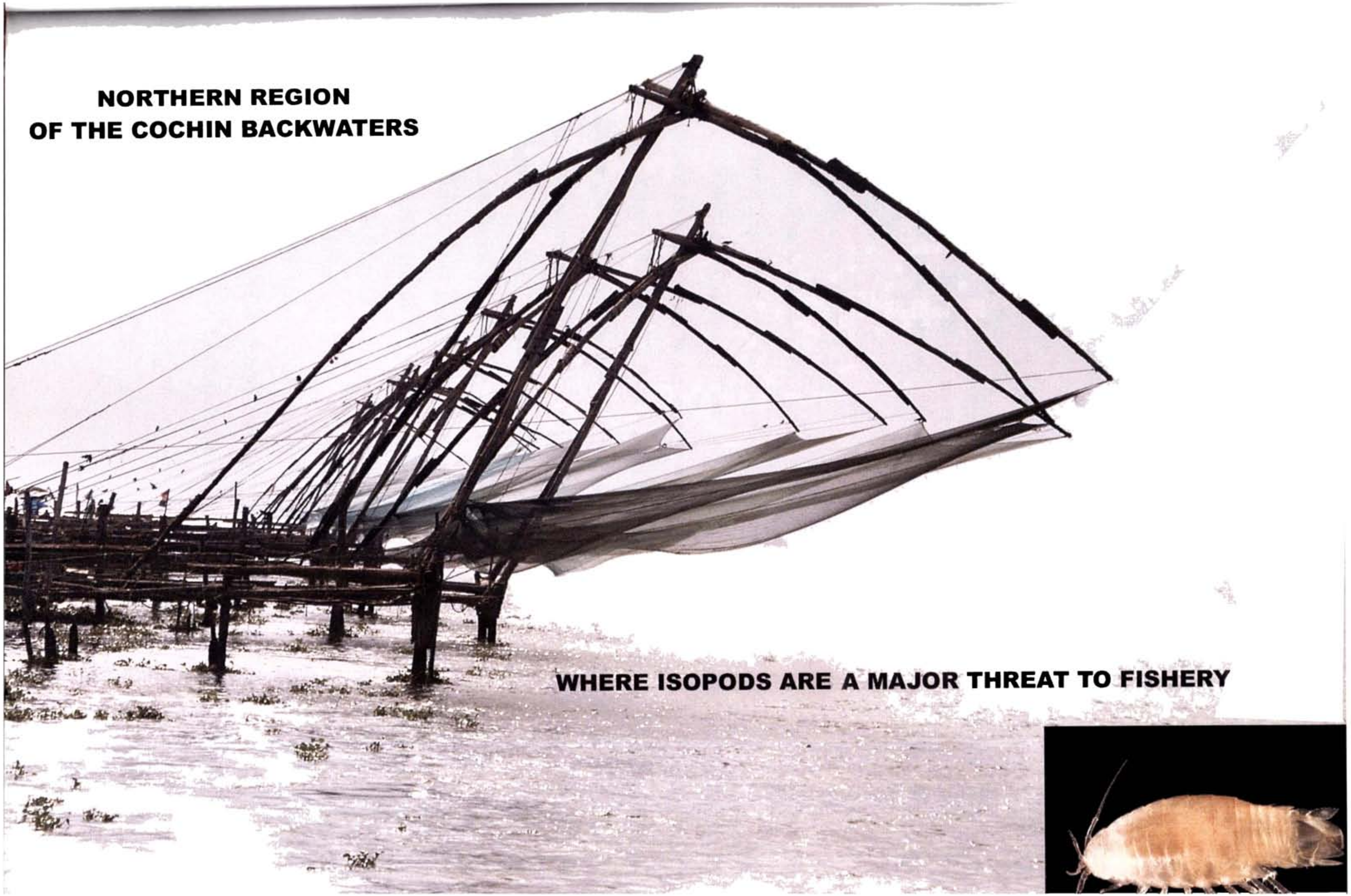
2.4 Statistical Methods

Community indices

Diversity is a concise expression on how individuals of a community are distributed in subsets of groups. Diversity decreases when one or a few groups dominate in a community. Species diversity is used as a tool to mathematically analyse and compare changes in aquatic communities due to environmental influence. Margalef's species richness index (d'), Shannon Weaver's species diversity index (H'), Simpson's index (λ') and Pielou's index (J') was tested using univariate methods (implemented in PRIMER).

Cluster Analysis

Differences between sites were examined based on species abundance data using Bray-Curtis similarity ie. hierarchical clustering through group average linking, a microprocessor based classification implemented in PRIMER v. 5 (Plymouth Routines in Multivariate Ecological Research) developed by Clarke and Gorley (2001). At each site the number of individuals of each species was used for measuring Bray–Curtis similarity after root transformation. Based on resulting dendrogram it was possible to distinguish the benthic assemblages in the study area. MDS (Multi-dimensional Scaling) analysis was also carried out using the multivariate techniques implemented in PRIMER v. 5.


NORTHERN REGION
OF THE COCHIN BACKWATERS
WHERE ISOPODS ARE A MAJOR THREAT TO FISHERY

CHAPTER 3

Spatial variation and abundance of macrobenthic fauna in the Cochin estuary

3.1 Sampling location
3.2 Sampling period
3.3 Results
    3.3.1 Hydrography
    3.3.2 Sediment characteristics
    3.3.3 Benthic density and biomass
    3.3.4 Faunal composition and community structure
3.4 Discussion

3.1 Sampling location

The sampling stations were categorized into 4 regions (Fig.3.1)

Northern Estuary (N.E-8 stations) is the northern region, which has an opening to Arabian Sea at Azhikode.

Central Estuary (C.E-19 stations) located at the central region of the Cochin backwaters. This region also has a permanent opening to the Arabian Sea at Cochin bar mouth. This region is heavily influenced by anthropogenic impacts.

Industrial Region (I.R-4 stations) This region is influenced by fresh water influx from river Periyar. Some of the major industries located at this region include Binani Zinc Edayar, Merchem Ltd Eloor, Cochin Minerals and Rutiles Ltd. Edayar, Travancore Rayons Ltd, Periyar chemicals, FACT Ltd, FACT Petrochemical Division Eloor, Indian Aluminium Company Ltd, United Catalysts Ltd, Hindustan insecticides Ltd, Indian Rare Earths Ltd, Travancore Cochin Chemical Ltd Eloor, Cochin Fertilizers Edayar, Cochin Chemical Industries Edayar, Sud Chemie India Pvt. Ltd, Sree Sakthi Paper mills Edayar etc.

Southern Estuary (S.E-25 stations) extends towards the southern region of Cochin backwaters. This region is relatively unpolluted and covers the retting yards of the estuary.

3.2 Sampling period

Samples were collected during three seasons, early pre-monsoon (February), pre-monsoon (Heavy summer shower was received during the period 1st April to 14th April) and monsoon (September) -2005. The survey was carried out as a part of the project "Ecosystem Modelling of Cochin backwaters. Pinkster and Goris (1984) recommended that two sampling periods (April-June and Sept/Oct) would give the best representation (up to 60%) of the species that occur throughout the year.

3.3 Results

3.3.1 Hydrography

Water temperature

At the northern region (N.E) the temperature ranged from 27.5 to 31.8 °C during the sampling period. High temperature was recorded during pre-monsoon and the values ranged from 32.0 to 34.5°C. In early pre-monsoon, the temperature ranged from 27.5 to 28.0°C and during the monsoon period (September), the values ranged from 29.0 to 31.8°C. In the Central estuary (C.E) the values ranged from 27.0 to 33.5°C and the temperature recorded during pre-monsoon ranged from 31.5 to 33.5°C. Comparatively low temperature was recorded during the monsoon period (September) wherein the temperature ranged from 27.0 to 30.9°C. In early pre-monsoon the value ranged from 27.5 to 32.0°C. In the Industrial region (I.R) again high temperature was recorded during pre-monsoon and ranged from 32.3 to 33.0°C, while low temperature was recorded during the monsoon period (range 26.5 to 27.0°C). In early pre-monsoon, the value was 31.0°C in all the four stations. In the southern region (S.E), the values ranged from 28.5 to 35.2°C, high temperature was recorded during pre-monsoon in all the stations and it ranged from 32.5 to 35.2. Low water temperature was recorded during monsoon and it ranged from 28.5 to 31.1°C. During early pre-monsoon the values ranged from 30.1 to 32.6°C (Table 3.3.1).

Salinity

In the northern region (N.E) with the influence of Azhikode bar mouth the values ranged from, 0.54 to 33.53 psu during the sampling period. High salinity was recorded during the early pre-monsoon period and the values ranged from 20.09 to 25.52 psu. In pre-monsoon the values ranged from 15.57 to 33.53 psu. During monsoon low salinity was recorded and it ranged from 0.54 to 8.88 psu. In the central estuary (C.E) with an influx of saline waters from Cochin bar mouth high salinity was recorded and it ranged from 0 to 29.03 psu. High salinity was recorded during early pre-monsoon and ranging from 7.33 to 27.13 psu. During pre-monsoon the salinity values ranged from 5.63 to 22.35 psu and during the monsoon period fresh water condition dominated the estuary and it ranged from 0 to 2.82 psu. In the Industrial region extremely low salinity was recorded through out the sampling period and it ranged from 0 to 15.28 psu. This region was influenced by fresh water influx from the river Periyar during all the seasons. Comparatively high salinity was recorded during the early pre-monsoon period and it ranged from 1.09 to 15.28 psu, in pre-monsoon the values ranged from 0.29 to 3.19 whereas during the monsoon period strictly fresh water condition dominated the region. At the southern region (S.E), the values ranged from 0 to 20.20 psu. High salinity was recorded during the early pre-monsoon period and it ranged from 2.61 to 20.20 psu and during pre-monsoon the values ranged from 8.92 to 18.22 psu. In monsoon low salinity (range 0 to 0.98 psu) was recorded due to the influx of fresh water from Thaneermukam bund. In all these regions high average was recorded during the early pre-monsoon period and low average was observed during monsoon, extremely low values (< 1 psu) were recorded from the Industrial and S.E region (Table 3.3.1).

pH

In the northern region (N.E) pH values ranged from 7.08 to 8.57. During the early pre-monsoon period the values ranged from 7.53 to 8.02 and the average ± standard deviation was 7.69 ± 0.15. In pre-monsoon the values ranged from 7.33 to 8.11 (avg. 7.76 ± 0.35) whereas during monsoon the values ranged from 7.08 to 8.57 and the mean was 7.54 ± 0.54. In the central estuary, the values ranged from 6.38 to 8.60. Minimum average of 7.11 ± 0.45 was recorded during monsoon (range: 6.38 to 7.80) and a maximum of 8.06 ± 0.26 (range: 7.23 to 8.60) was recorded during early pre-monsoon. In pre-monsoon the values ranged from 7.06 to 8.09 with an average of 7.15 ± 1.81. In the I.R region low pH was recorded and the values ranged from 6.18 to 7.91. Comparatively high pH was recorded during early pre-monsoon period and it ranged from 6.92 to 7.91 (avg. 7.33 ± 0.43) and low pH was recorded during monsoon (range 6.18 to 6.57 and avg. 6.46 ± 0.18). The corresponding value during Pre-monsoon was 6.70 ± 0.14 (range: 6.53 to 6.84). In the southern region the values ranged from 6.38 to 8.32. High average was recorded during early pre-monsoon and it ranged from 6.62 to 8.15 (7.48 ± 0.52) and low average was recorded during monsoon and it ranged from 6.62 to 7.25 (6.69 ± 0.16). The corresponding values during the pre-monsoon were 6.38 to 8.32 (7.19 ± 0.57). Comparison between regions showed high average at the central estuarine region and low average at the Industrial region (Table 3.3.1).

Dissolved Oxygen (DO)

In the Northern region (N.E) the values ranged from 2.67 to 8.24 mg/l, high values were recorded during the monsoon period and it ranged form 4.69

to 7.24 mg/l (avg. 6.22 ± 0.92 mg/l). Early pre-monsoon values ranged from 5.33 to 7.14 mg/l and the average was 5.87 ± 0.66 mg/l whereas during early-monsoon the values ranged from 2.67 to 8.24 mg/l and the average was 4.83 ± 1.81 mg/l. In the central estuary the values ranged from 2.89 to 11.60 mg/l, minimum average was recorded during pre-monsoon (4.50 ± 1.15 mg/l) and the values ranged from 2.89 to 7.23 mg/l. The maximum average (7.18 ±1.67 mg/l) was recorded during early pre-monsoon and the values ranged from 5.26 to 11.60 mg/l. During monsoon the values ranged from 5.03 to 7.60 mg/l (6.67 ± 0.61 mg/l). In the I.R region, the values ranged from 4.77 to 7.99 mg/l during the sampling period. High average was recorded during the early pre-monsoon period (7.05 ± 0.83 mg/l) and the values ranged from 6.04 to 7.99 mg/l. Low average (5.78 ± 1.27 mg/l) was recorded during the pre-monsoon and the values ranged from 4.77 to 7.63 mg/l. During monsoon the values ranged from 5.79 to 7.00 mg/l and the average was 6.39 ± 0.57 mg/l. In the southern region (S.E) during the sampling period the values ranged from 3.45 to 10.87 mg/l. Minimum average was recorded during monsoon (6.37 ± 0.83 mg/l) and it ranged from 4.74 to 7.47 mg/l. High average (6.98 ± 1.56 mg/l) was recorded during the pre-monsoon and it ranged from 3.45 to 10.87 mg/l. During the early pre-monsoon period the values ranged from 4.09 to 9.63 mg/l and the average was 6.76 ± 1.27 mg/l. Most of the regions showed well-oxygenated condition. The minimum values in general were recorded from the central estuarine region due to the influence of domestic sewage (Table 3.3.1).

Biological Oxygen Demand (BOD)

Samples were collected only during pre-monsoon and monsoon period. The values ranged from 0.01-5.87 mg/l, minimum values were recorded from the northern region and maximum from the southern region both during pre-monsoon. In the N.E region high average was recorded during pre-monsoon (2.66 ± 1.79 mg/l) and the values ranged from 0.01 to 3.77 mg/l. The corresponding values during monsoon were 0.55 to 3.18 mg/l (2.12 ± 1.13 mg/l). In the central estuary the values ranged from 2.92 to 4.29 mg/l (avg. 3.72 ± 0.48 mg/l) during the pre-monsoon and it ranged from 0.66 to 3.13 mg/l (avg. 2.03 ± 0.71 mg/l) during monsoon. In the Industrial region maximum average (3.44 ± 0.27 mg/l) was recorded during the pre-monsoon and that during the monsoon period was 0.50 ± 0.48 mg/l. In the southern region (S.E) high average (3.79 ± 1.32 mg/l) was again recorded during the pre-monsoon and the values ranged from 2.29 to 5.87 mg/l and the corresponding values during monsoon was 0.36 to 5.08 mg/l (avg. 1.96 ± 1.65 mg/l). Comparatively high average was recorded in the central and southern region (Table 3.3.1).

Suspended Particulate Matter (SPM)

SPM values generally ranged from 0.4-80.6 mg/l within the estuary. In the northern region the values ranged from 18.13 to 76.8 mg/l, high average (40.15 ± 17.89 mg/l) was recorded during pre-monsoon. Low average (27.37 ± 7.25 mg/l) was recorded during monsoon and the corresponding values during early pre-monsoon were 39.47 ± 4.81 mg/l. In the central estuarine region the values ranged from 0.4 to 62.6 mg/l and high average (37.69 ± 11.90 mg/l) was recorded during early pre-monsoon period and low average (17.64 ±6.53 mg/l) was recorded during monsoon, the corresponding values during pre-monsoon was 31.56 ± 15.37 mg/l. In the I.R region the values ranged from 0.8 to 41.16 mg/l. Early pre-monsoon values was high and average for the season was 37.11 ± 3.66 mg/l. Low average (5.4 ± 3.66 mg/l) was recorded during the pre-monsoon and the corresponding values during monsoon was 8.7 ± 4.39 mg/l. In the southern region (S.E) the values ranged from 5.73 to 80.6 mg/l. Comparatively high average was recorded during pre-monsoon (23.43 ± 17.63 mg/l) and the early pre-monsoon (22.51 ± 4.84 mg/l) period. Spatial variation was observed within the estuary with generally high values recorded from the northern region through out the sampling seasons (Figure 3.3.1).

Nitrite (NO_2)

For the entire area NO_2 values ranged from 0.08 to 1.53μM. The minimum and maximum values were obtained during early pre-monsoon. Early pre-monsoon average was high in the northern region (0.52 ± 0.18μM) and comparatively low average (0.35 ± 0.26μM) was recorded during pre-monsoon. The corresponding values during monsoon were 0.40 ± 0.18μM. In the central estuarine region the values ranged from 0.11 to 1.29μM, high average was recorded during early pre-monsoon (0.56 ± 0.27μM) and the pre-monsoon (0.55 ± 0.60μM) period. The corresponding values during monsoon were 0.43 ± 0.13μM. In the I.R region the value ranged from 0.18 to 1.53μM and high average (1.03 ± 0.44μM) was recorded during early pre-monsoon period. The corresponding values during pre-monsoon and monsoon was 0.34 ± 0.17μM and 0.29 ± 0.09μM respectively. In the southern region the values ranged from 0.08 to 0.62μM. High average (0.36 ± 0.11μM) was recorded during monsoon and low average (0.13 ± 0.04μM) was recorded during the early pre-monsoon period. The corresponding values during pre-monsoon was 0.21 ± 0.07μM. Spatial variation was observed, wherein high average was recorded from the Industrial region during early pre-monsoon and from the central estuarine region during the pre-monsoon and monsoon period (Figure 3.3.1).

Nitrate (NO_3)

During the study period nitrate values ranged from 0.64 to 72μM. In the northern region the values ranged from 0.86 to 36.43μM, high average (21.76 ± 11.65μM) was recorded during monsoon and low average (5.71 ± 4.39μM) was recorded during early pre-monsoon. The corresponding values during pre-monsoon were 7.43 ± 8.17μM. In the central estuary the value ranged from 1.20 to 50.48μM, minimum average (8.12 ± 4.04μM) was observed during the pre-monsoon and maximum average (29.69 ± 10.53μM) was observed during monsoon. The corresponding values during early pre-monsoon period were

10.23 ± 5.65µM. In the Industrial region, values ranged from 8.55 to 42.30µM. Low average (11.50 ± 3.62µM) was recorded during the pre-monsoon and high average (37.44 ± 3.78µM) was recorded during monsoon. The corresponding values during early pre-monsoon period was 20.39 ± 12.31µM. In the southern region (S.E) the values ranged from 0.64 to 72.00µM. High average (13.71 ± 15.58µM) was recorded during monsoon and generally low average was observed during early pre-monsoon (5.81 ± 3.12µM) and pre-monsoon (6.69 ± 5.12µM). Spatial variation was apparent in the estuary and generally high values were observed in the Industrial region and the central estuarine region (Figure 3.3.1).

Ammonia (NH_4)

Ammonia values ranged from 0-162.83µM, minimum being observed at the southern region and maximum at the central estuary. In the northern region values ranged from 1.19 to 99.89µM, high average (28.91 ± 30.59µM) was observed during the pre-monsoon and low average (7.02 ± 3.91µM) was recorded during the monsoon period. During early pre-monsoon an average of 13.38 ± 9.21µM was recorded. Central estuary showed high average (22.29 ± 14.96µM) during the pre-monsoon and the values ranged from 0.06 to 162.83µM. Low average (7.68 ± 2.84µM) was recorded during monsoon and the corresponding values during the pre- monsoon period was 18.88 ± 36.28µM. In the Industrial region the values ranged from 1.19 to 99.89µM, high average (28.91 ± 30.59µM) being recorded during the pre-monsoon and low average (7.02 ± 3.92µM) during the monsoon period. The corresponding values during the early pre-monsoon period was 13.38 ± 9.22µM. Southern estuary also showed high values during the pre-monsoon period and the values ranged from 0 to 51.01µM. High average (11.35 ± 12.30µM) was observed during the pre-monsoon and low average was observed during the early pre-monsoon (5.42 ± 3.87µM) and monsoon (5.62 ± 5.05µM) period. Spatial variation was apparent in the estuary with high average observed from the Industrial region (Figure 3.3.2).

Phosphate (PO_4)

For the entire region the values ranged from 0.21 to 6.87µM. In the N.E region the values ranged from 0.79 to 4.43µM and high average (2.36 ± 0.72µM) was recorded during monsoon and low average (1.96 ± 0.43µM) was recorded during early pre-monsoon period. The corresponding values during the pre-monsoon were 2.30 ± 1.48µM. In the central estuary the values ranged from 0.49 to 6.87µM, with high average (2.79 ± 0.86µM) observed during pre-monsoon and low average (2.00 ± 1.35µM) during early pre-monsoon. The corresponding values during monsoon were 2.28 ± 0.87µM. In the I.R region the values ranged from 0.96 to 5.70 and the minimum average (0.80 ± 0.62µM) was observed during early pre-monsoon period whereas the maximum average (3.46 ± 2.18µM) was observed during the monsoon. During the pre-monsoon period an average of 1.79 ± 1.04 µM was observed. In the southern region the values ranged from 0.21 to 4.84µM. High average (1.67 ± 0.99µM) was observed during monsoon and low average (0.87 ± 0.91µM) was observed during the early pre-monsoon period. During pre-monsoon the average values recorded was 1.09 ± 0.93µM. In general high average was observed from the central estuary during the early pre-monsoon and pre-monsoon period, whereas during the monsoon period high average was observed from the Industrial region (Figure 3.3.2).

Silicate (SiO_4)

The values ranged from 14.80 to 140.44µM, minimum recorded at the central estuary and maximum at the northern region. In the northern region the values ranged from 14.23 to 140.44µM and high average (126.63 ± 10.01µM) was observed during the monsoon period and low average (37.19 ± 16.33µM) during pre-monsoon. The corresponding values observed during the early pre-monsoon period were 71.10 ± 19.68µM. In the central estuary the values ranged from 14.80 to 131.53µM. Minimum average was observed during the early pre-monsoon (42.20 ± 16.83µM) and pre-monsoon (47.85 ± 19.86µM) period whereas maximum average was observed during the monsoon (68.81 ± 49.78µM). In the Industrial region the values ranged from 24.37 to 110.53µM. High average was observed during the pre-monsoon (80.69 ± 7.17µM) and early pre-monsoon (73.33 ± 39.13µM) period and low average (27.72 ± 3.98µM) was observed during monsoon. Southern region showed a variation in values ranging from 4.93 to 129.90µM. High average (95.41 ± 15.57µM) was observed during monsoon and low average (26.68 ± 16.48µM) was observed during the pre-monsoon. The corresponding values during early pre-monsoon was 78.79 ± 15.41µM (Figure 3.3.2).

Dissolved Inorganic Carbon (DIC)

During the study period DIC values ranged from 162.08-1888.8µM. Northern region showed high average (1592.54 ± 313.13µM and 1276.88 ± 75.66µM respectively) during the pre-monsoon and early pre-monsoon period and the values ranged from 449.13 to 1965.9µM. In monsoon the average value observed for the region was 571.60 ± 117.45µM. In the central estuary the values ranged from 269.15 to 1888.8µM. High average was observed during early pre-monsoon (1309.91 ± 366.44µM) and pre-monsoon (1177.84 ± 401.56µM) and low average (376.84 ± 110.64µM) was observed during the monsoon period. In the Industrial region the values ranged from 260.96 to 913.9µM. High average (597.28 ± 241.67µM) was observed during the early pre-monsoon period and low average (288.11 ± 42.75µM) was observed during the monsoon. The corresponding value during the pre-monsoon was 485.13 ± 163.84µM. In the southern region the values ranged from 79.7 to 1147.8µM. High average (691.65 ± 252.48µM) was observed during the early pre-monsoon period and low average (249.85 ± 73.63μM) was observed during monsoon. The corresponding value during pre-monsoon was 524.28 ± 316.38μM. Spatial variation in DIC was observed in the study area with high values observed from the northern and central estuary (Figure 3.3.3).

Dissolved Organic Carbon (DOC)

Within the estuary the value of DOC ranged from 0.77 to 16.78. Minimum average (3.17 ± 1.80μM) was recorded during monsoon in the northern estuary and maximum average (5.04 ± 0.89μM) was recorded during early pre-monsoon period. The corresponding value during the pre-monsoon was 3.20 ± 1.27μM. In the central estuary the values ranged from 0.79 to 6.32μM. High average (3.92 ± 1.04μM) was observed during the early pre-monsoon period and low average (1.67 ± 0.96μM) was observed during monsoon, the corresponding value during the pre-monsoon was 2.88 ± 0.99μM. In the Industrial region the values ranged from 0.77 to 4.50μM and high average (3.25 ± 0.91μM) was observed during the early pre-monsoon period and low average (0.99 ± 0.31μM) was observed during the monsoon. During the pre-monsoon an average of 2.14 ± 0.34μM was observed. Whereas in the southern region the values ranged from 1.53 to 16.78μM and high average of 7.39 ± 5.12μM was observed during the early pre-monsoon period. Low average of 2.75 ± 0.89μM was observed during monsoon and the corresponding value observed during the pre-monsoon was 3.77 ± 1.00μM. In general high average was observed in the southern and northern part of the estuary (Figure 3.3.3).

N/P

N/P ratio ranged between 1.49 and 256.42 within the estuary. In the northern part of the estuary the values ranged from 2.84 to 48.01. Minimum average (10.18 ± 5.17) was recorded during the early pre-monsoon season and maximum average (16.26 ± 10.58) was recorded during the pre-monsoon and the corresponding value during monsoon was 15.76 ± 14.61. In the central estuary it ranged from 2.73 to 64.64 and high average (18.94 ± 8.45) was recorded during monsoon and the corresponding value during early pre-monsoon and pre-monsoon was 17.06 ± 18.50 and 12.68 ± 11.87 respectively. In the Industrial region the values ranged from 10.04 to 256.42. High average was observed during early pre-monsoon (122.31 ± 100.98) and low average (20.22 ± 10.66) was recorded during monsoon. During pre-monsoon an average of 48.03 ± 52.15 was recorded. In the southern region it ranged from 1.49 to 99.08 and high average was recorded during early pre-monsoon (22.21 ± 19.18) and pre-monsoon (22.43 ± 14.29) the corresponding value during monsoon was 18.11 ± 21.37. Generally high values were recorded from the Industrial region mostly during the early pre-monsoon period (Figure 3.3.3).

Total Alkalinity (T_{Alk})

T_{Alk} values ranged from 389.1 to 2285.71µM in the northern region of the estuary. High average was recorded during the early pre-monsoon (1281.78 ± 83.84µM) and pre-monsoon (1708.95 ± 454.09µM) and low average was recorded during monsoon (517.03 ± 125.03µM). In the central estuarine region it ranged from 123.5 to 2077.29µM and high average was observed during pre-monsoon (1215.08 ± 441.66µM) and early pre-monsoon period (1461.43 ± 423.81µM). The corresponding value during monsoon was 309.56 ± 138.53µM. Industrial region showed a range from 75.70 to 960.87µM and early pre-monsoon average (556.68 ± 302.51µM) was higher than pre-monsoon (390.23 ± 141.01µM) and monsoon average (130.48 ± 51.29µM). In the southern region the values ranged from 60.51 to 1243.90µM and high average was observed during the early pre-monsoon (683.94 ± 306.14µM) and pre-monsoon (516.03 ± 357.26µM) period compared to monsoon (176.16 ± 69.25µM). Spatial variation was apparent in the estuary with high values being observed from the northern and central estuarine regions (Figure 3.3.4).

Attenuation coefficient (K')

In the northern estuary the values ranged from 1.03 to 4.29 and comparatively high average was observed during early pre-monsoon (2.50 ± 0.65) and pre-monsoon (2.45 ± 0.93) than monsoon (2.08 ± 0.69). The values ranged from 1.07 to 5.00 in the central estuary and comparatively high average was observed during the pre-monsoon (2.38 ± 0.86) and early pre-monsoon (2.24 ± 0.68) period. The corresponding value during monsoon was 2.05 ± 0.89. In the industrial region the values ranged from 0.97 to 2.73 and comparatively high average was recorded during early pre-monsoon (1.72 ± 0.72) than pre-monsoon (1.26 ± 0.19) and monsoon (1.18 ± 0.13) period. Southern estuarine values ranged from 0.83 to 6.00 and high average (2.14 ± 1.02) was recorded during the pre-monsoon. The corresponding value during early pre-monsoon and monsoon was 1.53 ± 0.28 and 1.89 ± 1.16 respectively. Comparatively high values were recorded from the northern and central estuarine regions (Figure 3.3.4).

Chlorophyll *a*

Chl *a* ranged from 0.21-49.13 $mg.m^{-3}$within the estuary, with minimum at the northern region and maximum in the southern region. The values ranged from 0.21-27.77 $mg.m^{-3}$ in the northern region and high average (15.35 ± 8.03 $mg.m^{-3}$) was recorded during the pre-monsoon, whereas low average (1.29 ± 0.95$mg.m^{-3}$) was recorded during early pre-monsoon period. During monsoon an average of 4.51 ± 2.97 $mg.m^{-3}$ was recorded. In the central estuary it ranged from 0.96 to 48.27 $mg.m^{-3}$ and high values were generally recorded during pre-monsoon (avg. 16.84 ± 9.65 $mg.m^{-3}$). Low average was observed during the early pre-monsoon and monsoon period (8.11 ± 7.16 $mg.m^{-3}$ and 9.31 ± 9.76

$mg.m^{-3}$ respectively). In the Industrial region it ranged from 2.56 to 19.54 $mg.m^{-3}$ and comparatively high values were recorded during the early pre-monsoon (10.78 ± 6.85 $mg.m^{-3}$) and pre-monsoon (10.68 ± 3.59 $mg.m^{-3}$) than the monsoon season (7.12 ± 8.28 $mg.m^{-3}$). Southern estuary showed a range from 0.64 to 49.13 $mg.m^{-3}$and high values were generally observed during the pre-monsoon (16.92 ± 11.39 $mg.m^{-3}$). The corresponding average during early pre-monsoon and monsoon was 5.59 ± 4.87 $mg.m^{-3}$ and 3.71 ± 3.35 $mg.m^{-3}$ respectively (Figure 3.3.4).

3.3.2 Sediment Characteristics

Sediment properties like grain size (sand, silt, clay) and sediment TOC and TN were also studied for all the 4 regions during the three sampling periods (Figure 3.3.5 a, b, c and Figure 3.3.6).

Grain size (%)

In the northern region, clay was found to be dominant through out the sampling period (68.71 ± 19.86 in early pre-monsoon, 63.08 ± 25.32 during pre-monsoon and 67.43 ± 21.83 in monsoon). The substratum in general was silty clay during early pre-monsoon (20.5 ± 13.17% silt), whereas during pre-monsoon there was almost equal proportion of sand (19.37 ± 23.27) and silt (20.65 ± 18.95) and it was sandy clay during monsoon with 22.36 ± 26.17% sand.

Central estuary was also dominated by clay in most of the stations during the sampling period with maximum clay% observed during monsoon (56.68 ± 19.12) the corresponding value during early pre-monsoon was 41.39 ± 17.89 and that during the pre-monsoon was 52.63 ± 21.98. The substratum was sandy clay (35.76 ± 30.84% sand) in early pre-monsoon and monsoon (27.78 ± 28.16% sand). The contribution of sand during the pre-monsoon was 28.10 ±

26.04. The stations towards the barmouth region were dominated by sand during the early pre-monsoon and monsoon period.

In the Industrial region the substratum was clayey sand during early pre-monsoon (42.57 ± 31.63% sand; 35.38 ± 16.67% clay) and pre-monsoon (69.92 ± 9.66% sand; 27.50 ± 10.03% clay). During monsoon the substratum was sandy clay with 47.50 ± 14.58 % clay and 36.70 ± 30.94 % sand.

The southern region was dominated by sand and the substratum was clayey sand with sand% of 58.29 ± 32.46 during early pre-monsoon and the corresponding value for clay% was 29.38 ± 18.45. During the pre-monsoon the substratum was again clayey sand (47.84 ± 32.88% sand and 38.10 ± 25.51% clay). During monsoon the substratum was sandy clay with 41.74 ± 26.89 % sand and 48.27 ± 19.52% clay.

Total Organic Carbon (TOC)

The values ranged from 0.08 to 7.01%, the highest value was recorded from the central estuarine region (station 30, outlet of market canal) during monsoon. At northern region, the values ranged from 0.52 to 4.28%, minimum average was recorded during pre-monsoon (2.56 ± 1.06%). High average was recorded during the monsoon (2.97 ± 1.05%) and early pre-monsoon (2.89 ± 1.17%) period. In the central estuary it ranged from 0.08 to 7.01%, high average (3.09 ± 1.72%) was observed during the monsoon period and low average (2.26 ± 1.14%) was observed during early pre-monsoon. The corresponding value during pre-monsoon was 2.43 ± 1.03%. The values ranged from 0.76 to 4.77% in the Industrial region and high average (3.27 ± 1.55%) was recorded during early pre-monsoon. Low average was recorded during the pre-monsoon (1.57 ± 1.17%) and the corresponding value during monsoon was 2.82 ± 2.09%. In the southern region it varied from 0.28 to 4.93% and high average (2.00 ±1.24%) was observed during monsoon and low average was observed during the pre-monsoon (1.58 ± 0.89%) and early pre-monsoon (1.51 ± 1.03%) period.

Total Nitrogen (TN)

TN values ranged from 0-0.78 %within the estuary. In the northern region it ranged from 0.04 to 0.68 %and high average (0.41 ± 0.17%) was recorded during pre- monsoon. The corresponding value during monsoon and pre-monsoon was 0.32 ± 0.11% and 0.29 ± 0.19% respectively. Central estuary showed a range from 0 to 0.78 %with minimum average (0.18 ± 0.13%) during pre-monsoon and maximum average (0.27 ± 0.16%) during early pre-monsoon. The corresponding value during monsoon was 0.24 ± 0.17%. In the Industrial region the values ranged from 0 to 0.48 %and high average (0.31 ± 0.13%) was recorded during the early pre-monsoon period. Low average was recorded during the pre-monsoon (0.05 ± 0.07%) and the corresponding value during monsoon was 0.29 ± 0.18%. In the southern region it ranged from 0 to 0.69%. Minimum average (0.05 ± 0.07%) was recorded during the pre-monsoon and maximum average (0.20 ± 0.10%) was recorded during monsoon. The corresponding value during early pre-monsoon was 0.14 ± 0.18%. Spatial variation was observed within the estuary and generally high values were observed from the northern region of the estuary.

3.3.3 **Benthic density** and **biomass**

Density values ranged from 0-65527 No./m^2 within the estuarine region, highest value was recorded from the northern estuary during early pre-monsoon. On an average high density was recorded at the northern region and it ranged from 0-65527 No./m^2 and the average was 10327 ± 22465 No./m^2 during early pre-monsoon, 9517 ± 19139 No./m^2 during pre-monsoon and 8722 ± 9684 No./m^2 in monsoon. In the central estuary the density ranged from 0-3313 No./m^2 and high average was recorded during the pre-monsoon (2033 ± 1913 No./m^2) and the corresponding value during early pre-monsoon was 579 ± 770 No./m^2 and that during monsoon was 740 ± 761 No./m^2. Industrial region recorded low average during monsoon 172 ± 277 No./m^2 and high average during pre-monsoon (2293 ± 2997 No./m^2). Average during early pre-monsoon was 439 ± 371 No./m^2 and the values in the Industrial region ranged from 21 to 6690 No./m^2. Southern region recorded high density during monsoon (3217 ± 11418 No./m^2) and low density (950 ± 911 No./m^2) during the pre-monsoon, and that during early pre-monsoon was 1515 ± 3221 No./m^2 (Figure 3.3.7).

Biomass (including shell weight) ranged from 0-4874.18 g/m^2 within the estuarine region. Comparatively high average was recorded from the southern estuary. In the northern region the values ranged from 0-654.83 g/m^2, high biomass being recorded at station 9 during early pre-monsoon. Average values observed during the study period were 65.18± 88.89 g/m^2 during early pre-monsoon and 85.73 ± 111.47 g/m^2 during monsoon. High average observed during the pre-monsoon was 105.57 ± 223.88 g/m^2. In the central estuary biomass ranged from 0-201.32 g/m^2 and monsoon average (20.27 ± 44.59 g/m^2) was higher. The corresponding biomass during early pre-monsoon and pre-monsoon was 10.13 ± 11.32 g/m^2 and 13.47 ± 14.19 g/m^2 respectively. High average (10.08 ± 8.58 g/m^2) was observed in the Industrial region during early pre-monsoon and the values ranged from 0-20.75 g/m^2 during the sampling period. The corresponding value during the pre-monsoon and monsoon was 7.29 ± 5.88 g/m^2 and 3.75 ± 2.92 g/m^2 respectively. Southern region recorded the maximum average during early pre-monsoon (302.02 ± 966.32 g/m^2) and the minimum during pre-monsoon (37.60 ± 68.95 g/m^2). The corresponding value during monsoon was 221.31 ± 555.61 g/m^2 (Figure 3.3.7).

3.3.4 Faunal composition and community structure

(Figure 3.3.8 – a, b, c, d and Table 3.3.2 a, b, c)

In the northern region the major groups recorded were isopods and amphipods. During early pre-monsoon, the dominant group was isopods (93.52%). Altogether 21 species were recorded and the dominant species was *Cirolana fluviatilis* (93.36%). 41 species were recorded during pre-monsoon and the community was dominated by isopods (44.93%) and amphipods (40.61%), *Cirolana fluviatilis* (44.41%) and *Corophium triaenonyx* (35.93%) were the dominant species respectively. In monsoon the community was again dominated by isopods (41.44%) followed by amphipods (23.35%) and tanaidaceans (23.25%). Altogether 28 species were recorded and the dominant species were *Cirolana fluviatilis* (39.83%), *Apseudes chilkensis* (20.06%) and *Corophium triaenonyx* (19.67%).

Central estuary showed the dominance of polychaetes followed by amphipods and tanaidaceans. During early pre-monsoon period polychaetes dominated the community (59.21%) followed by tanaidaceans (24.07%) and amphipods (11.00%). Thirty seven species were recorded and the dominant species was *Capitella capitata* (11.95%) among polychaetes and *Apseudes chilkensis* (21.60%) among tanaidaceans. Pre-monsoon showed the dominance of polychaetes (75.32%) followed by amphipods (17.43%). Altogether 50 species were recorded during the season and the dominant species recorded was *Capitella capitata* (21.05%). Monsoon season also showed the dominance of polycheates (58.48%) followed by amphipods (30.39%). 41 species were recorded and the dominant species were *Heteromastus similes*, *Prionospio cirrobranchiata* among polychaetes and *Grandidierella gilesi* among amphipods.

Polychaetes, amphipods and molluscs were the major groups recorded from the Industrial region. Polychaetes (48.88%) and amphipods (33.31%) dominated the community and altogether 19 species were recorded during early pre-monsoon and the dominant species recorded was *Lycastis indica* (21.44%), *Capitella capitata* (5.93%), *Grandidierella gilesi* (11.86%), *Eriopisa chilkensis* (10.72%), *Grandidierella bonnieri* (7.13%) and *Littorena littorea* (9.47%). Twenty four species were recorded during pre-monsoon and the major groups were amphipods and bivalves and the dominant species recorded were *Grandidierella gilesi*, *Grandidierella bonnieri*, *Pendora flexosa*, and caprellids.

Polychaetes (51.52%) and amphipods (39.33%) dominated the community during monsoon period, and was mainly represented by species like *Paraheteromastus tenius*, *Heteromastus similes* and caprellids and only nine species were recorded during this period.

Molluscs and polychaetes dominated southern estuary. Total number of species recorded were 41 in early pre-monsoon, 45 during pre-monsoon and 40 during monsoon. During early pre-monsoon the dominant community recorded was polychaetes (44.45%) followed by molluscs (33.50%) which was dominated by species such as *Villorita cyprinoides* (26.27%). Pre-monsoon recorded the dominance of polychaetes (60.73%) and molluscs (25.53%) and *Villorita cyprinoides* (20.44%), *Capitella capitata*, *Heteromastus similes* and *Paraheteromastus tenius* werethe most abundant species. Molluscs (43.19 %) followed by polychaetes (24.56%) and tanaidaceans (15.99%) were dominant during monsoon period. Dominant species recorded during the period were *Villorita cyprinoides* (40.45%) and *Apseudes chilkensis* (14.81%).

Northern Estuary

Isopods and amphipods were abundant in the northern region. In early pre-monsoon, polychaete abundance was low and the highest ($521/m^2$) value was observed at station 15. In Pre-monsoon comparatively high abundance was observed, highest ($1355/m^2$) from station 9. Twenty-four species of polychaetes were recorded and the dominant species were *Heteromastus similes* and *Paraheteromastus tenius.* Average abundance recorded during monsoon was $772/m^2$ and the dominant species recorded were *Prionospio cirrobranchiata* and *Heteromastus similes*. Seven species of amphipods were recorded from the study region and high abundance was reported during Pre-monsoon (avg. $3865/m^2$) and low value (avg. $320/m^2$) was recorded during early pre-monsoon. During monsoon an average abundance of $2037/m^2$ was recorded and the dominant species recorded from the study region in the order of dominance was

Corophium triaenonyx, *Melita zeylanica*, *Eriopisa chilkensis*, *Grandidierella gilesi* and caprellids. High isopod abundance was observed during early pre-monsoon (avg. 9657/m^2) and was highest density was recorded from station 9 (65214/m^2) contributed by *Cirolana fluviatilis*. In pre-monsoon, the average abundance observed was 4276/m^2 and that during monsoon was 3615/m^2. Low abundance of molluscs was observed from the study region maximum (1604/m^2) being recorded from station 12 during monsoon dominated by *Pendora flexosa*. Different species recorded from the region in the order of dominance were *Pendora flexosa*, *Modiolus striatulus*, *Assiminea breviculata*, *Littorina littorea* and *Meritrix* sp. Tanaidaceans like *Apseudes chilkensis* and *A. gymnophobia* were also recorded from the study region. Maximum abundance (avg.2029/m^2) was observed during monsoon and the corresponding values during early pre-monsoon and pre-monsoon were 237/m^2 and 336/m^2 respectively.

Central Estuary

High abundance of polychaetes were recorded from the central estuarine region during pre-monsoon (avg. 1628/m^2). Altogether 33 species of polychaetes were recorded from the study area. The percentage contribution of capitellids was 36.38% and that of *Capitella capitata* was 21.05% in pre-monsoon whereas in early pre-monsoon it was 35.28% and that of *C. capitata* was 11.95%. In monsoon the percentage contribution of capitellids was comparatively low (27.61%) and that of spionids was 13.50%. In capitellids the dominant species was *Heteromastus similes* (12.30%) and *Paraheteromastus tenius* (6.83%), among spionids the dominant species was *Prionospio cirrobranchiata* (10.82%) and *Prionospio cirriferra* (2.37%). This shows that pollution tolerant polychaete species dominated the central estuarine region. Among amphipods the dominant species recorded was *Eriopisa chikensis* (7.01%) and *Melita zeylanica* (3.04%) during early pre-monsoon whereas during pre-monsoon the dominant species recorded was caprellids (8.88%), *Eriopisa chilkensis* (2.91%) and *Grandidierella bonnieri* (2.62%). During Monsoon the community was dominated by *Grandidierella gilesi* (10.52%), caprellids (8.75%), *Corophium triaenonyx* (6.22%) and *Grandidierella bonnieri* (4.00%). Isopod abundance was very low in the central estuary with a maximum of 146/m^2 recorded from a single station. The dominant species of mollusc recorded from the central estuarine region was *Pendora flexosa* (3.42% in early pre-monsoon and 3.13% in pre-monsoon). *Villorita cyprionides* (416/m^2) was recorded only from a single station (station no. 31) in the central estuary and that too during monsoon. Among tanaidaceans high abundance of *Apseudes chilkensis* (2042/m^2) was recorded from station 24 during Early pre-monsoon and this was responsible for the high percentage contribution (21.60%) recorded during this month. *Apseudes gymnophobia* was the other species observed during the sampling period. Other organisms recorded during the study were *Metapenaeus dobsoni*, *Portunus* sp. and the river fauna *Anatopynia*. The macroinvertebrate assemblage in the central estuarine region was characterized by high abundance of deposit feeders (44.01% in early pre-monsoon, 37.88% in pre-monsoon and 40.66% in monsoon).

Industrial Region

In the industrial region polychaete abundance was comparatively high during pre-monsoon (avg.302/m^2) and that during early pre-monsoon and monsoon was 214/m^2 and 118/m^2 respectively. The dominant species recorded from the study region during early pre-monsoon in their order of dominance were *Lycastis indica*, *Capitella capitata*, *Notomastus fauveli*, *Dendronereis aestuarine*, *Branchiocapitella singularis* and *Paraheteromastus tenius*. In Pre-monsoon the community was dominated by *Prionospio cirrobranchiata*, *Heteromastus similes*, *Dendronereis aestuarina* and *Paraheteromastus tenius*. Different species recorded during monsoon in the order of dominance was

Paraheteromastus tenius, *Heteromastus similes*, *Dendronereis aestuarina* and *Mediomastus capensis*. Next abundant group was amphipods represented by seven species. Maximum abundance was recorded during Pre-monsoon (avg. 1188/m^2) and the species in their order of dominance was *Grandidierella gilesi*, *Grandidierella bonnieri*, caprellids, *Melita zylanica*, *Eriopisa chilkensis*, *Quadrivisio bengalensis* and *Corophium triaenonyx*. Early pre-monsoon period (avg. 146/m^2) was again dominated by *G. gilesi* followed by *E. chilkensis* and *G. bonnieri*. Monsoon average was 90.33/m^2 represented by caprellids and *E. chilkensis*. *E. chilkensis* was the only species present during all the seasons. Isopod abundance was low in this study region and was present only during monsoon period represented by a single species belonging to the family Anthuridae. Mollusc was present only during early pre-monsoon (avg. 68/m^2) and pre-monsoon (avg.730/m^2) showing high abundance represented by a single species (*Pendora flexosa*). Different species of mollusks recorded during early pre-monsoon was *Littorina littorea*, *Pendora flexosa* and *Villorita cyprinoides*. Tanaidaceans though in low densities were present during early pre-monsoon and pre-monsoon represented by *Apseudes chilkensis* and *Apseudes gymnophobia*. Other organisms present were chironomids (21/m^2).

Southern Estuary

Polychaetes dominated the community during pre-monsoon (avg.577/m^2) represented by species such as *Heteromastus similes* (12.39%), *Capitella capitata*, *Paraheteromastus tenius*, *Prionospio cirrobranchiata*, *Nepthys dibranchus* and *Branchiocapitella singularis* in their order of dominance. An average of 386/m^2 was recorded during the early pre-monsoon period (February) and was dominated by species such as *Prionospio cirrobranchiata* (8.11%) followed by *Capitella capitata*, *Paraheteromastus tenius*, *Heteromastus similes* and *Dendronereis aestuarina*. Average abundance of 327/m^2 was recorded during monsoon dominated by species like

Paraheteromastus tenius, *Heteromastus similes*, *Dendronereis aestuarina*, *Capitella capitata* and *Lycastis indica*.

Amphipod abundance was high during monsoon (avg. 166/m^2) and was dominated by caprellids (5.87%) followed by *G. gilesi*, *Melita zeylanica*, *G. bonneri*, *C. triaenonyx* and *E. chilkensis* in their order of abundance. Average abundance recorded during early pre-monsoon was 57.8/m^2 and the community was dominated by *E. chilkensis* (2.99%) followed by *Melita zeylanica*, caprellids, *G. gilesi*, *Quadrivisio bengalensis* and *G. bonnieri*. During pre-monsoon it was 49/m^2 and was dominated by *E. chilkensis* (3.77%). Isopod abundance was low in the study region and was restricted to few stations. Comparatively high density was recorded during monsoon from station 52 (250/m^2 Anthuridae, 333/m^2 *Cirolana fluviatilis*) and station 44 (104/m^2 Anthuridae). The density was 21/m^2 reported from station 38 during early pre-monsoon and from station 46 during pre-monsoon. Percentage contribution of mollusc was high in the study region and dominated the community during monsoon (avg. 574/m^2) maximum contributed by *Villorita cyprinoides* from station 52 (7501/m^2). Other species present during the study in their order of abundance was *Pendora flexosa*, *Littorina littorea*, *Cardium* sp., *Tellina pulcherrima* and *Assiminea breviculata*. In early pre-monsoon, an average of 291/m^2 was recorded and maximum abundance (2333/m^2) was recorded from station 38. The community was dominated by *Villorita cyprinoids* (26.27%) followed by *Pendora flexosa* (3.87%) and *Littorina littorea* (3.07%). During the pre-monsoon an average of 243/m^2 was recorded and was again dominated by *Villorita cyprinoids* (20.44%) followed by *Pendora flexosa* (4.39%). Average density of tanaidaceans recorded from the study region was high during monsoon (avg. 212/m^2) and was contributed by *Apseudes chilkensis* (14.81%) and *Apseudes gymnophobia* (1.18%). In early pre-monsoon the average density recorded was 113.8/m^2 dominated by *Apseudes chilkensis* (11.71%) followed by *Apseudes gymnophobia* and *Tanais filitarous*. Average abundance during pre-monsoon was 58/m^2 and was dominated by *Apseudes gymnophobia* (3.51%). Other organisms recorded from the study region were *Metapenaeus dobsoni*, *Portunus* sp. and Diamesa.

3.3.5 Statistical Analysis

Diversity indices

Number of species recorded from each station in the northern region varied from 1-28 during the sampling period and those from the central estuary varied from 1-22. In the Industrial region a maximum of 21 species were recorded and in the southern estuary a maximum of 17 species were recorded from individual stations.

Species richness (Margalef's index, d')

Species richness within northern estuary varied from 0.27-1.20 during early pre-monsoon with an average value of 0.56 ± 0.37. It ranged from 0.33 to 3.08 during the pre-monsoon (avg. 1.09 ± 1.09) and from 0.39 to 2.10 during monsoon (avg. 1.12 ± 0.56). In the central estuary it ranged from 0.27-2.18 and the average was 0.96 ± 0.49 during early pre-monsoon and it ranged from 0.27-2.38 (avg. 1.46 ± 0.54) during pre-monsoon. In monsoon the values ranged from 0.24-2.34 and the average was 0.94 ± 0.58. In the Industrial region the values ranged from 0.61-1.43 (avg. 1.13 ± 0.45) in early pre-monsoon and 0.96-1.45 (1.56 ± 0.66) during pre-monsoon and the average during monsoon was 0.54 ± 0.49. Comparatively high value (1.19 ± 0.58) was recorded during the pre-monsoon and it ranged from 0.43-2.21 in the southern region. It ranged from 0.21-1.99 (avg. 0.84 ± 0.55) during early pre-monsoon and 0.15-1.59 (avg. 0.88 ± 0.44) during monsoon (Table 3.3.3).

Evenness (Pielou's index, J')

Pielou's evenness (Table 3.3.3) ranged from 0.03-1.00 for the northern region and the average was 0.44 ± 0.32 during early pre-monsoon and it ranged from 0.33-3.08 (avg. 0.75 ± 0.22) during pre-monsoon and 0.19-0.74 (avg. 0.54 ± 0.19) in monsoon. In central estuary the evenness values varied from 0.57-1.00 and the average for this area was 0.84 ± 0.13 in early pre-monsoon and it ranged from 0.41-1.00 (avg. 0.76 ± 0.16). In monsoon the values ranged from 0.64-1.00 (avg. 0.84 ± 0.11). Industrial region showed a ranged from 0.65 to 1. High average (0.90 ± 0.15) was recorded during monsoon and low average (0.76 ± 0.10) was observed during pre-monsoon, the corresponding value during early pre-monsoon period was 0.88 ± 0.07. In the southern region it ranged from 0.03-0.96 (avg. 0.69 ± 0.23) during early pre-monsoon and 0.23-0.96 (avg. 0.79 ± 0.16) during pre-monsoon and the corresponding values during monsoon was 0.23-1.00 (avg. 0.73 ± 0.24).

Diversity (Shannon index, H')

In the northern region diversity values (Table 3.3.3) ranged from 0.04-1.29 (avg. 0.56 ± 0.47) during early pre-monsoon and 0.92-2.71 (avg. 1.34 ± 0.92) during pre-monsoon and the corresponding values during monsoon were 0.42-2.07 (avg. 1.23 ± 0.59). Diversity index at the central estuary varied from 0.69 to 2.32 (avg. 1.34 ± 0.65) during early pre-monsoon. High average (1.77 ± 0.47) was recorded during the pre-monsoon and it ranged from 0.69-2.32 and the corresponding values during monsoon was 0.64 to 2.32 (avg. 1.42 ± 0.59). In the industrial region the values ranged from 0 to 2.13 and high average (1.87 ± 0.24) was recorded during the pre-monsoon and low average (0.98 ± 0.85) during monsoon the corresponding value during early pre-monsoon was 1.36 ± 0.98. In the southern estuary it ranged from 0-2.29 (avg. 1.13 ± 0.67) in early pre-monsoon. High average (1.61 ± 0.59) was recorded during the pre-monsoon and it ranged from 0-2.08. The corresponding value during pre-monsoon was 1.29 ± 0.65.

Dominance (Simpson's index, λ')

For northern estuary the values (Table 3.3.3) ranged from 0.01-0.54 and the average was 0.31 ± 0.21 during early pre-monsoon and 0.60 ± 0.30 during pre-monsoon (range: 0.51-0.90). The corresponding values during monsoon were 0.16-0.82 (avg.0.55 ± 0.22). λ' at central estuary ranged from 0.40-0.88 and the average was 0.71 ± 0.13 during early pre-monsoon, 0.73 ± 0.15 in pre-monsoon and 0.67 ± 0.20 during monsoon. In the industrial region values ranged from 0-0.86 (avg.0.79 during early pre-monsoon and pre-monsoon) and the average was 0.50 ± 0.43 during monsoon. In southern estuary it ranged from 0.01-0.87 (avg.0.54 ± 0.27) in early pre-monsoon and 0.14-0.91 (avg.0.70 ± 0.21) during pre-monsoon and the corresponding values during monsoon was 0.17-0.87 (avg. 0.59 ± 0.28).

Correlation between benthic density and the environmental variables

Northern estuary

Significant positive correlation (Table 3.3.4, a) between benthic density and total nitrogen in the sediment was observed during the early pre-monsoon period ($n=8$, $r=0.69$, $p>0.05$) and pre-monsoon ($r=0.79$, $p>0.05$). Positive correlation was also observed during monsoon ($r=0.48$, p not significant). Negative correlation (p not significant) between benthic density and salinity was observed during all the three sampling periods in the northern region. Significant negative correlation between Clay% and benthic density was observed during Pre-monsoon ($r=-0.64$, $p<0.05$). Positive correlation between density and phosphate was observed during the early pre-monsoon period ($r=0.74$, $p>0.05$).

Central estuary

Significant negative correlation (n=20, r=0.43, p>0.05) between salinity and benthic density was observed during pre-monsoon (Table 3.3.4, a). Negative correlation between the variables was also observed during the other seasons (early pre-monsoon and monsoon; r=0.2[illegible] and r=0.33 respectively) though it was not significant. Significant negative correlation (r=0.39, p>0.10) with pH was also observed during the same season. Benthic density was again negatively correlated with SPM (r=0.45, p>0.05 during early pre-monsoon), TA (r=0.43, p >0.05 in pre-monsoon) and DIC (r=0.43, p>0.05 in pre-monsoon) during all the three sampling seasons. Benthic abundance was positively correlated with clay during early pre-monsoon (r=0.20) and pre-monsoon (r=0.30).

Industrial region

Benthic density was positively correlated with (Table 3.3.4, b) TA (n=4, r=0.81, p>0.10 during monsoon; r=0.73 during early pre-monsoon) and DIC (r=0.98, p>0.01 during monsoon; r=0.72 in early pre-monsoon). Negative correlation with silicate was observed during early pre-monsoon (r=0.96, p>0.01) and monsoon (r=0.52) period. Benthic density was negatively correlated with nitrate during early pre-monsoon (r=0.97, p>0.01) and pre-monsoon (r=0.55).

Southern estuary

In the southern estuary significant positive correlation between the benthic density and SPM (Table 3.3.4, b) was observed (n=25, r=0.38, p>0.05 during pre-monsoon and r=0.44, p>0.05 during monsoon). Significant positive correlation with DOC (r=0.33. p>0.10), DIC (r=0.38, p>0.05) and Total Alkalinity (r=0.38, p>0.05) was also observed during early pre-monsoon period. The benthic density was negatively correlated with sand during early pre-monsoon ($r=0.36$, $p>0.05$) and positively correlated ($r=0.06$, p not significant) during monsoon.

3.4 Discussion

Hydrography

The hydrography of an estuary mainly depends upon the intrusion of sea water and the influx of fresh water from the rivers. The concentration of nutrients was high in the northern and central estuarine region. Towards the southern region the concentration of these were comparatively less. Variation in temperature, salinity and dissolved oxygen were similar to the observations made in other estuaries and backwaters along the southwest coast of India. Industrial effluents contain large quantities of nutrients like nitrite, nitrate, ammonia, phosphate and related compounds. Large quantities of sewage disposed into the estuary through the outlets leads to increased organic carbon in the sediments. Variation in these parameters in an aquatic ecosystem can affect the water quality and in turn affect the biota. Sampling was carried out during Early pre-monsoon (February), Pre-monsoon (April) and Monsoon (September) 2005. Heavy summer shower received during April 1st to April 14th had affected the hydrographic parameters and was responsible for the low salinity observed during the pre-monsoon period. The changes in the hydrology controlled by the seasons play an important role in regulating the migrant fauna in the estuary.

Distribution of temperature in an estuarine region depends on the flow of freshwater from rivers (Sankaranarayanan and Qasim, 1969) and the mixing of seawater (Ramamirtham and Jayaraman, 1963). High temperature was recorded during Pre-monsoon (April) and low during Monsoon (September). Joseph (1988), Sivadasan (1996) and Sheeba (2000) have also reported high water temperature during pre-monsoon in the Cochin estuary. Spatial variation in temperature was not apparent in the estuary in the present study.

The major hydrological variable in the Cochin backwaters is salinity, similar to the situation observed earlier (Nair and Tranter, 1971; Menon et al., 2000). Comparatively high salinity was recorded in the northern region and central estuarine region due to the incursion of Arabian Sea water through the Azhikode barmouth and Cochin barmouth. Due to the intrusion of fresh water from the river Periyar comparatively low salinity was recorded through out the sampling period in the industrial region. In early pre-monsoon, high saline waters prevailed in the estuary due to the incursion of Arabian Sea waters through the barmouth when the lower reaches of the estuary behaved as a section of the Arabian Sea (Menon et al., 2000). Jyothibabu et al., (2006) has also reported marked salinity gradient with high values towards the lower reaches of the estuary. According to the observations made during the study, almost freshwater conditions prevailed in the entire estuary during peak monsoon period as reported early (Nair and Tranter, 1971).

Most estuarine organisms prefer conditions with pH values ranging from about 6.5 to 8.5. Wide range in pH (6.18- 8.6) was observed within the estuary. Low pH was recorded at the industrial region and high pH was recorded at station 30, a sewage outlet at the central estuarine region. Acid precipitation in the upper reaches of an estuary can diminish the survival rate of eggs released by spawning fish. Saraladevi et al., (1979) noted erratic fluctuations in pH during non-monsoon months in industrial zone. Silas and Pillai (1976) reported large-scale fish mortality in the region of river Periyar due to high acidity of water. Variation in pH due to chemical and other industrial discharge makes the stream unsuitable for rearing of fish and other aquatic life (Webb, 1982). Human activities that cause, short-term fluctuations in pH or long-term acidification of a waterbody are exceedingly harmful. Estuarine pH levels generally averaged from 7.0 to 7.5 in the freshwater sections and between 8.0 and 8.6 in the more saline areas. Bacterial activity, water turbulence, chemical constituents of water, sewage overflows determine the pH of the water.

D.O values ranged from 2.67 to 11.60 mg/l in the estuarine region. It is considered that in healthy ecosystem, dissolved oxygen level in coastal water should not fall below 2.8 mg/l for prolonged periods. The decomposition of organic waste and oxidation of inorganic waste reduce the dissolved oxygen, and may be harmful to the aquatic organisms. Johannessen and Dahl (1996) reported decline in dissolved oxygen level as a result of increased nutrient load. When oxygen is low, nutrients bound to bottom sediments can be released into the water column, thereby permitting more plankton growth and eventually more oxygen depletion (VEM, 2006). Low average D.O was recorded during pre-monsoon from the central estuarine region due to high anthropogenic influence. Remani et al., 1983 had reported a range of 0.05-4.4 mg/l for the sewage discharge site of the central estuarine region. Generally, D.O levels of greater than 5 mg/l indicate an adequate supply of D.O while organisms become stressed at levels 3-5 mg/l. Levels below 3 mg/l indicate hypoxic conditions. The variation in dissolved oxygen is attributed to the seasonal and tidal fluctuation (Vijayan et al., 1976). Low average D.O might be due to increased microbial activity (Nair et al., 1988). The observations made during the present study are comparable with that of Saraladevi (1986) and Sheeba (2000) in the Cochin estuary.

BOD measures the amount of oxygen that organisms would require in decomposing the organic material in the water column and is indicative of pollution levels. Unpolluted water has a BOD of less than 5mg/l, while raw sewage has a BOD of 150 to 300 mg/l. Waste water effluent might have a BOD from 8 to 150 mg/l (VEM, 2006). In general BOD values were low in the estuary (< 5 mg/l) except for high value (> 5.6) at retting yards of the southern estuary (stations 33 and 47). Remani et al., 1983 reported a range of 77-478 mg/l for the bottom waters of retting yards in the estuarine region. Sheeba (2000) also observed low BOD values in the Cochin estuarine regions.

SPM values ranged from 0.4 to 80.6 mg/l and were generally high during early pre-monsoon and pre-monsoon and comparatively high average was recorded from the northern and central estuarine regions. High value observed during the study is due to heavy resuspension, discharge of sewage and industrial effluents. Concentration of suspended solids in Cochin backwater vary considerably with tides and seasons and the total material transported from sea into the backwater amounts to approximately 900 tonnes/day during the pre-monsoon and post-monsoon months (Gopinathan and Qasim, 1971). Total sewage disposed into the estuary in the form of dissolved solids is as high as 53750 mg/l during summer, but lowering drastically to 160 mg/l during the rainy season (CHISCB, 2002).

Nitrite within the entire estuary ranged from 0.08-1.53 µM. High value of 1.53 µM was recorded at the industrial region. Nitrite concentration in the estuary was low compared to the observations made by Sheeba (2000). Monsoon values were high in the southern limb whereas early pre-monsoon average was high in the northern region and the central estuary. Segar and Hariharan (1989) attributed the increase in nitrite concentration to bacterial decomposition of planktonic detritus, and its variation to the quantum of effluent discharged. The concentration of nitrite exhibited seasonal variation and also indicated large inputs from industrial units, sewage waste and agricultural run offs. High values recorded during monsoon suggest the presence of external source.

High nitrate values were recorded during monsoon, this shows its input from terrestrial origin induced by land runoff. Nitrate values generally ranged between 0.64 and 72.0 µM and high average was recorded at the central estuarine region and the industrial region. High nitrate concentration generally indicates the eutrophic nature of the estuary. High values of nitrate in the estuary indicate addition of effluents rich in nitrogenous compounds into the estuary, by agricultural run off and municipal sewage (Sheeba, 2000).

Jyothibabu et al., 2006 reported that high nitrate in the estuary during monsoon is not exclusively brought in by the river influx. Industrial and domestic sewage that reach directly into the estuary, may also contribute significantly to the prevailing concentrations. Extensive human settlements in the region produce large quantities of domestic sewage as well as agricultural wastes (Qasim, 2003). During 1980-81, the study region had nitrate levels up to 40 µM with its upstream peaks of 108 µM (Saraladevi, 1986). During 1990, the nutrient maximum reported from this estuarine region was 98.48 for nitrate (Kunjikrishna Pillai, 1991). Sheeba (2000), reported nutrient enrichment in the system and recorded nitrate up to 451µM at the bar mouth region. Many investigators reported gradual rise in nitrate concentration in Cochin backwaters (Sankaranarayanan and Qasim, 1969; Devassy and Bhattathiri, 1974; Remani,et al., 1980; Lakshmanan et al., 1987).

NH_4 value ranged from 0-162.83 µM and high average was recorded from the industrial region. Joseph et al., (1984) observed considerably higher concentration of free ammonia in polluted area of Periyar River, especially in pre-monsoon period. High ammonia (162.83 µM) was recorded from the central estuarine region (station 16) during early pre-monsoon. In estuarine sediments due to the reducing conditions, NH_4^+ is the major product (Mathews et al., 2006). According to KSPCB (2000) the range of free ammonia at sewage disposal point was 0.005 to 0.023 mg/l. High concentration of NH_4^+ is due to the influence of liquid waste discharge that contains industrial/domestic sewage (Tait, 1981). Higher concentration might be due to death and decomposition of phytoplankton and terrigeneous input. Generally low values were recorded from the southern limb. Seasonal comparison showed that monsoon average was low compared to early pre-monsoon (February) and pre-monsoon (April). The values reported were comparable with those reported by Sheeba 2000.

High average in PO_4 was recorded from the industrial region during monsoon. Higher phosphate values were recorded in polluted region of Periyar river by Paul and Pillai (1976). Central estuarine region and northern region also recorded high values during the sampling period and comparatively low values were recorded from the southern limb. Rivers are the minor source of phosphorus input to the estuaries. The external sources such as domestic sewage and industrial effluents particularly from fertilizer plants producing phosphate fertilizer in addition to sediment resuspension contribute significantly to the phosphorus concentrations. Phosphate values were generally high during monsoon in the estuary and ranged from 0.21 to 6.87μM, which is lower compared to those reported by earlier workers. During 1980-81, the study region had phosphate levels up to 12 μM with its upstream peaks of 186μM (Saraladevi, 1986). Sankaranarayan et al., (1986) have reported phosphate levels up to 88μM during 1982-83, in the northern upstream stations. Balachandran et al., (2002) recorded phosphate levels from 5 to 40μM for the same region. During 1990, the nutrient maximum reported from this estuarine region was 15.11 μM for phosphate (Kunjikrisha Pillai, 1991).

Highest average of silicates were recorded from the northern estuary during monsoon. The silicon content of the backwater is generally high because of considerable freshwater discharge and land drainage. High silicate values are associated with low salinity of water indicating an inverse relation between the two (Sankaranarayanan and Qasim, 1969). High values of silicates reported during monsoon are due to influence of terrestrial runoff (Propp, 1977) or to a high degree of turbulence releasing silica from sediments into the bottom waters (Sverdrup et al., 1961). The major changes in the silicate content of estuarine waters are due to the difference in dilution and the highest concentration is observed during the SW monsoon season when the fresh water discharge is maximum. During pre-monsoon season when the river discharge is minimum the longitudinal variation in the silicate content was minimum (0.03-2.66mg.l^{-1}) (Sankaranarayanan et al., 1986).

Dissolved inorganic carbon (DIC) consists of dissolved species of carbon as carbonate, bicarbonate and dissolved carbon dioxide. High values were recorded from the northern and central estuarine region during the early pre-monsoon and pre-monsoon period. Comparatively low values were recorded from the industrial region and the southern limb. DIC values recorded in the northern region towards Azhikode bar mouth (stations 13, 14 and 15) during pre-monsoon (range; 1930-1975µM) were comparable with the DIC values (~1950µmol) reported for shelf waters of Arabian Sea (Sarma et al., 1998). Decomposition of soil organic matter is an important source of DIC apart from this DIC also comes from human settlements, organic wastes and as runoff from the soil (Subramanian and Anuradha, 2000).

DOC (Dissolved Organic Carbon) may be divided into allochthonous carbon, which is produced on land and autochthonous carbon, which is produced in the estuary. DOC is categorised as carbon in carbohydrates, amino acids, hydrocarbons, fatty acids and phenolic compounds (Subramanian and Anuradha, 2000). Comparatively high values were recorded from the southern limb of the estuary and were generally recorded during the early pre-monsoon period. The stations situated in the Vayalar lake of the estuary (Stations 50 to 56) showed a range from 10.54 to 16.78µM during the early pre-monsoon period. High DOC recorded from this region might be due to the effluents discharged from the fish processing plants situated in this region.

Generally high N/P ratio was recorded in the industrial region. The ratio recorded from the central estuarine region (2.73-64.64) was high compared to the value recorded in 1974-75 (range 1.2-4.07) by Sankaranarayanan and Panampunnayil (1979). High ratio indicates significant contribution of Nitrogen from effluents. Madhu et al., 2007 has also reported high N:P ratio in the Cochin estuary during monsoon and post-monsoon season indicating the excess loading of nitrogen into the estuary. According to Madhu et al., 2007 during pre-monsoon when the tidal activities dominate, the system reverts to normalcy and the primary nutrients reach the Redfield ratio (N:P 15.9 ± 10.1). Grasshoff (1975) has reported N/P ratio in plankton as 13.3:1 and Sen Gupta et al., (1976) has reported 13.8:1 for natural plankton.

Total Alkalinity ("buffer capacity") is a measure of the capacity of water to neutralize acids and is influenced by the presence of alkaline compounds in the water such as bicarbonates, carbonates, and hydroxides. This test is important in determining the estuary's ability to neutralize acidic pollution from rainfall or wastewater. The value ranged from 60.15 to 2285.71µM within the estuary. Generally high values were recorded from the northern and central estuarine regions especially during the pre-monsoon period. Total alkalinity of seawater averages 116 mg/l and is greater than fresh water (30 to 90 mg/l), and it depends on the watershed. The brackish water of an estuary will have total alkalinity between these values (VEM, 2006).

Comparatively high attenuation coefficient (K') was recorded from the northern and central estuarine region. These high values are consistent with high SPM recorded from the same region. Generally high values were recorded during April. Heavy summer shower received during this period has had its impact on the hydrography and has increased the turbidity of the water column. Sheeba (2000) reported higher attenuation coefficient during monsoon compared to pre-monsoon season. Higher attenuation coefficient is expected in monsoon months due to turbidity of the water and low intensity of solar radiation (Saraladevi, 1989). Soil erosion, waste discharge, urban runoff, stirred up bottom sediments from dredging, boating and bottom feeding animals and excessive algal growth are the main sources of turbidity in the estuary. High turbidity may also be caused by high amount of dead organic mater known as detritus. Turbidity and total solids often increase sharply during and immediately following a rainfall (VEM, 2006).

In general, high chlorophyll *a* has been recorded from the industrial and central estuarine region during the sampling period. Indiscriminate disposal of sewage and industrial wastes have been a major cause for the nutrient enrichment resulting in domination of opportunistic algal species (Kimor, 1992). The causative factors for enhanced phytoplankton crop in Edayar-Eloor stretch of the River Periyar may be partly attributed to the effluents discharged from the factories nearby (Joy et al., 1990). Primary productivity varies considerably in proportion to environmental parameters such as light intensity, turbidity, water temperature and inorganic nutrients available in the water (Raymont 1980). High primary production can be related to high inorganic nutrients from the sediment/water. High average was also recorded from the northern and southern region during April. Heavy summer shower received during this period has lowered the salinity. Low saline water has an insignificant effect on the growth and production of phytoplankton in this system (Qasim et al., 1974). Summer shower received during this period might have promoted the growth of phytoplankton. Primary production in the water column has major bearing on many characteristics of estuaries including benthic metabolism and flux and the ecology and life histories of benthic organisms (Schlacher and Wooldridge, 1996; Zimmerman and Canuel, 2001)

High concentrations of nutrients were recorded from the Industrial region. The source of nitrogen in most of the aquatic environments is discharges from the land, where fertilizers and detergents are major contributors. The inorganic species nitrite, nitrate and ammonium ions are considered as the major sources of bio-available-N. Ammonia, in its unionized form in the effluent it is injurious to organisms and often results in mass mortality (Nair et al., 1988). A major portion of the recycled nitrogen released to the water from the sediments is in the form of NH_4^+. Green Peace Reports (1999, 2003) describe Eloor industrial area as one of the most vulnerable industrially polluted "hot spots" in the world. Elevated levels of nutrients indicate eutrophication and its consequences like blooming of obnoxious algae, depletion of dissolved oxygen, deterioration of water quality leads to dystrophic condition and total destruction of biocoenosis. Inspite of receiving 42.4×10^3 $mol.d^{-1}$ of inorganic phosphate and 37.6×10^3 $mol.d^{-1}$ of inorganic nitrate from the Periyar region, the export to the coastal waters is only 28.2×10^3 $mol.d^{-1}$ of inorganic phosphate and 24×10^3 $mol.d^{-1}$ of inorganic nitrate. (Hema Naik, 2000). This shows that the estuary acts as a sink for the nutrients, flushing out only a portion of the pollutants that it receives. The nutrient inputs are received (i) mainly through the effluent discharge from the fertiliser factory and (ii) from the nonpoint sources in the system itself (Saraladevi et al., 1991). Sixteen major industries discharge nearly 0.104 M m^3 d^{-1} of wastes containing organic wastes (260 td^{-1}) into the Cochin backwaters. The river discharge of 19,000 M m^3y^{-1} carries a substantial portion of the fertilizer load (20,000 t y^{-1}) (Balachandran et al., 2002). The booming city of Cochin has a population of nearly 1.5 million (Anon, 1998) and 60% of the chemical industries of Kerala are situated in this area. The 16 major and ~220 minor industries situated in the upstream region of the backwaters discharge nearly 0.105 Mm^3d^{-1} of effluents (Anon, 1996). The industrial typology includes fertilizers, pesticides, radio active mineral processing, chemical and allied industries, petroleum refining and heavy metal processing and fish processing. The fertilizer consumption in Kuttanad region (the main agricultural fields draining to Cochin backwaters) alone is reported to be 20,239 t y^{-1} (Anon, 1998).

Sediment Characteristics

The proportion of sand, silt and clay is of importance for the distribution of many organisms since the porosity and interstitial space are directly influencing the relative abundance and these parameters are critical for organisms within the sediment. The distribution of sediments in an estuary depends on several factors such as sediment sources, the texture of the sedimentary material supplied, the topography of the basin and general hydrographical factors (Veerayya and Murthy, 1974).

Northern region was dominated by high clay fraction throughout the sampling period. Central estuarine region was dominated by an equal proportion of sand and clay fraction during early pre-monsoon whereas it was dominated by clay during the other two seasons. Dominance of sand was recorded from most of the stations in the southern region. Run-offs from the local streams and minor rivers connected to the estuarine region are the main sources of sediments in the backwater region. Connection to the open sea through the Azhikode and Cochin bar mouth permit saltwater influx into the estuary. Circulation of water in the estuarine environment controls the deposition of sediments in this region (Murty and Muni, 1987). According to Kirby and Parker, (1977) fine sediments are generally carried in suspension as flocks and during slack periods they settle to the bottom. Deposits of sand noticed in the backwater could be attributed to strong bottom currents prevailing. It is probable that these are relict sands belonging to a preglacial period subsequently left uncovered by recent sediments (Murty and Muni, 1987). Vasudevan Nayar (1992) also reported that the main constituent fraction in the sediment in southern region was sand (>80%) with negligible amount of silt and that the central estuary was dominated by clay. Sand, clay and silt were found to be relatively important factors controlling the benthic biomass (Aravindakshan et al., 1992).

TOC values in the estuary ranged from 0.08 to 7.01% and high values were recorded from the northern and central estuarine regions. High average was recorded from the industrial region during early pre-monsoon. Owing to almost regular discharge of a variety of wastes, the Periyar river bottom in the vicinity of the industrial belt is completely covered with decaying organic matter (Azis and Nair, 1981). High TOC in the sediment can be related with the luxuriant organic productivity in the overlying water and terrestrial run off. In general high values were recorded during monsoon and this indicates the input from terrestrial origin. High TOC recorded during premonsoon in the industrial region might be due to the high primary production recorded during this month. The total organic detritus settling in Cochin backwaters is reported to be higher during pre-summer monsoon compared to summer monsoon (Qasim and Sankaranarayanan, 1972) and could be a result of high residence time of the estuary and the high abundance of micro- and mesozoooplankton. Organic matter in the sediment is mainly due to plant and animal matter brought in from land through runoff and deposited from the overlying water (Sankaranarayanan and Panampunnayil, 1979). The in situ production and land runoff brings in comparatively high organic content into the sedimentary compartment (Mathews et al., 2006). According to Seralathan et al., (1993) the organic carbon content varied from 0.24 to 6.15% and a comparative evaluation of the organic carbon contents showed a substantial increase during the last two decades. Positive correlation between TOC and clay was observed during the study.

High TN values were observed in the northern and central estuarine regions. Industrial region also showed high values during early pre-monsoon and monsoon period. Sankaranarayanan and Panampunnayil (1979) had reported an average of 0.32 from the central estuarine region. High TN is reported from fine grained sediments. Rittenberg et al., (1955) opinioned that the particle size of the sediment is an important factor that controls the TN content of the sediment and that finer sediment contains more N than coarser sand. Positive correlation between TN and fine-grained sediment was observed in the present study. Low TN was recorded during the pre-monsoon period; this might be due to leaching of sediment nitrogen to the overlying water column (Vasudevan Nayar, 1992). High primary production was reported during pre-monsoon. Nutrients get depleted from the water column during high rate of production (Vasudevan Nayar, 1992). This leads to release of sedimentary nitrogen in an enhanced rate to the overlying water column through diffusion and/or desorption. As a result simultaneous decrease in the concentration of sediment nitrogen was observed.

Macrobenthos

The macrobenthic resource of the estuary, though abundant has not been systematically surveyed. Most of the studies were restricted to certain areas of the estuary. In the present study an attempt was made to study the macrobenthic fauna of the estuary extending from Azhikode to Thaneermukam bund.

Isopods dominated the northern estuarine region due to the dominance of *Cirolana fluviatilis*, followed by the amphipod *Corophium triaenonyx* and the tanaidacean *Apseudes chilkensis*. In the northern region high abundance was recorded during early pre-monsoon period. The substratum was silty clay during this period. Silty sediment is understood to accommodate denser fauna by virtue of the rich nutrient contents in contrast to the sandy bottom which can hold lesser bottom fauna due to reduced retention of nutrients. According to Remani et al., (1983) *Cirolana fluviatilis* are sensitive organisms, which are absent in polluted sites. The presence of this particular species in the present study might indicate that this environment is comparatively less polluted. Mathew et al., (1994) reported the proliferation of this isopod in Kumbalangi-Perumpadapppu area of the Cochin backwaters causing threat to the aquatic living resources. These isopods tolerated wide variations in salinity (freshwater to 33 psu) and pH (5.92-9.04) Cherian (1977). These isopods are voracious carnivores and were found to feed on weak or dead prawns and fishes, fish baits, fish and crustaceans trapped in nets. The fish catch in isopod infested area was reduced by more than 80% (Mathew et al., 1994). It is found that the northern region of estuary extending from the Azhikode bar mouth to the Cochin bar mouth is highly productive based on the fishery potential (personal observation) but the abundance of *Cirolana fluviatilis* might reduce the fish catch from this area in future. *Corophium triaenonyx* was found abundantly during pre-monsoon and monsoon period. According to Nair et al., (1983) *Corophium triaenonyx* can tolerate lower salinity. According to Remani et al., (1983) *Apseudes chilkensis* was the only species recorded from polluted as well as non-polluted areas.

Polycheates followed by amphipods and tanaidaceans dominated the central estuary. Polychaetes belonging to the family Capitellidae and Spionidae were abundant during the study period. Dominant species were *Capitella capitata*, *Heteromastus similes*, *Paraheteromastus tenius*, *Prionospio cirrobranchiata* and *Prionospio cirriferra*. Among amphipods the dominant species recorded was *Eriopisa chilkensis*, *Grandidierella gilesi*, caprellids, *Corophium triaenonyx* and that among tanaidacean was *Apseudes chilkensis*. In the central estuary high abundance of indicator species like *Capitella capitata* and other tolerant species were recorded which indicates increased pollution in this region (Remani et al., 1983). The proliferation of opportunistic species in early phases of secondary succession is a well-known phenomenon (Pearson and Rosenberg, 1978). Opportunists are usually small-sized surface deposit feeders, which exhibit continuous or semi-continuous reproduction. They are adapted to rapidly colonize in open environments and are successful competitors when the availability of organic matter is high. As far as polychaetes are concerned, typical examples of opportunists are the Capitellidae and the Spionidae (Oug, 1998; Bailey Brock et al., 2002; Diaz-Castaneda and Harris, 2004). During the present study capitellids reached high abundance. Polychaetes from families Spionidae, Capitellidae and Eunicidae recorded more in number were identified as indicator species of pollution (Pearson and Rosenberg, 1978). Macrobenthic assemblages in the central estuary were numerically dominated by deposit feeders (maximum recorded during early pre-monsoon 44% of the total benthic community). The dominance of deposit feeding species indicates the great importance of detritus as an energy source for the macrobenthic community, because deposit feeders assemblages vary according to the availability of food in sediments in the estuary (Whitlatch, 1981; Rossi, 2003). Dominance of deposit feeders also indicates organic pollution (Pearson and Rosenberg, 1978).

The industrial region supported low benthic abundance and biomass. Polychaetes and amphipods dominated the industrial region and the major species recorded were *Lycastis indica*, *Capitella capitata*, *Paraheteromastus tenius*, *Heteromastus similes*, *Grandidierella gilesi*, *Eriopisa chilkensis*, *Grandidierella bonnieri* and *Pendora flexosa*. Ansari (1977), Saraladevi and Venugopal (1989) and Saraladevi et al., (1991) have observed the changes in the quality of benthos due to the influence of industrial effluents in Cochin backwaters. According to Saraladevi and Venugopal (1989) polychaetes were the most common group comprising mainly of *Capitella capitata* in the effluent discharge region at Eloor. High density of *Villorita cyprinoides* was also reported from the downstream stations (Saraladevi and Venugopal, 1989). In the present study *Capitella capitata* was not recorded during monsoon. *C. capitata*, though euryhaline in habit, is incapable of living in totally freshwater conditions, which prevailed in this region during monsoon (Menon et al., 2000). Low density ($21/m^2$) of *Villorita cyprinoides* was recorded in the present study from the industrial region.

In the central estuarine region and industrial region comparatively high density was recorded during pre-monsoon. According to Kurian (1972) maximum number of fauna occurs immediately after the onset of monsoon and a second maximum in pre-monsoon period. Indicator species like *Capitella capitata* were not present in the polluted stations (Industrial region) throughout the sampling period. This clearly indicates that the presence of benthic organisms depend on a number of environmental parameters (Saraladevi and Venugopal, 1989).

Bivalves and polychaetes dominated the southern estuary. In the southern region high abundance was observed during monsoon due to the abundance of *Villorita cyprinoides* followed by *Heteromastus similes*, *Paraheteromastus tenius* and *Capitella capitata*. Molluscan fishery of the Vembanad lake is exclusively sustained by the black clam *Villorita cyprinoides* and the peak clam landing is registered during the months of May and October (Kurup et al., 1990; Menon et al., 2000). Variation in salinity has been indicated as a major factor in limiting the distribution of benthic fauna in coastal water. Aravindakshan et al., (1992) has observed that at Cochin backwaters 79% of the variability of the benthic fauna is based on bottom composition (sand, silt, and clay), organic matter and salinity. Analysis of the sediment characteristics showed that the substratum in the southern region was dominated by sand. More sandy substrates supported more healthy populations dominated by *Villorita cyprinoides*. The nature of substrate also influenced the variation in quality and quantity of benthos in the study area (Saraladevi and venugopal, 1989). The nature of substratum is an important factor in the distribution of macrofauna where clay bottom (organic matter 1.5-6%) supports poor fauna, whereas areas with sand, silt and clay in equal proportions support dense and diverse benthic populations (Batcha, 1984). High biomass was recorded from the southern estuary due to the abundance of *Villorita cyprinoides*. Devassy and Gopinathan (1970) have noted an increase in benthic biomass from marine to fresh water region during monsoon in Cochin backwaters. Desai (1971) has also observed more number of molluscan individuals when the sediment was dominated by sand particles. According to Saila (1976) highest biomass in a benthic environment was associated with coarse grained sediment which favours more number of suspension feeders such as molluscan organisms. Salinity and substratum influenced the macrobenthic community (Desai, 1971; Kurian, 1972; Ansari, 1974). Kurian et al., (1975) reported that bivalves formed the major component and dominated freshwater end of the estuary. *Villorita* sp. can tolerate very low salinities (Kurian et al., 1975). According to Kurup et al.,

(1990) perennial abundance of *Villorita cyprinoids* was encounterd only from those areas where bottom salinity values varied from 0 to 13.

Richness and diversity values observed in the present study are lower than those reported by Sheeba (2000). Comparatively high richness values were observed from the central estuarine region due to the abundance of pollution tolerant species. A similar observation was made by Sheeba (2000) from the sewage-polluted region of the estuary. Particle size of the substratum can also influence the diversity of benthic fauna (Sanders, 1958). High diversity was observed during pre-monsoon period. Negative correlation between salinity and benthic density observed during the study might be due to wider fluctuation in salinity values. Wade (1972) stated that the benthic communities may result in lower densities if there is a physiological stress due to fluctuation in salinity values.

According to Desai (1971) mollusc dominated the estuarine region with sandy substratum contributing 90-95% to total biomass. The presence of rich beds of *Meretrix ovum* and *M. striatus* contributed 30 to 60% of the total biomass. According to Kurian et al., (1975) samples collected from 124 stations were mainly composed of bivalves especially *Villorita* sp. Batcha (1984) studied in detail the macrobenthos distribution and composition, numerical abundance, species diversity, biomass and its relation to hydrography. He identified a total of 92 species, of which 33 were polychaetes, 28 crustaceans and 15 molluscs, but 85% of the total fauna was dominated by mollusk. Among these, gastropods were dominated by *Babylonia spirata.* All these studies reported the dominance of mollusc in the estuarine region whereas in the present study a total of 73 species were identified of which 41 were polychaetes, 18 crustaceans and 11 mollusc and polychaetes dominated the community. The present study reports a decline in the total number of species and an increase in the number of polychaete species. Kurian (1972) and Ansari (1977) indicated that the density of bivalves, gastropods and isopods in the backwaters have been considerably reduced with time due to increased pollution. The present study showed that over the years, some of the species recorded abundantly earlier such as tube dwelling polychaete *Diopatra neopolitana* and molluscan species such as *Meretrix* sp., have been considerably reduced and species such as *Modiolus undulates*, *Nuculana mauritiana* and *Babylonia spirata*, were totally absent in the present study, a trend indicating anthropogenic impact. The presence of gastropods like *Nassarius* sp., *Nerita* sp., *Cerethidia fluviatilis*, and *Telescopium* sp. observed by Preetha (1994) from Cochin backwaters were again not observed in the present study. The benthic study revealed that the central estuarine and industrial region is comparatively more polluted and is under stress, where indicator organisms (*C. capitata*) and pollution tolerant species were found to inhabit.

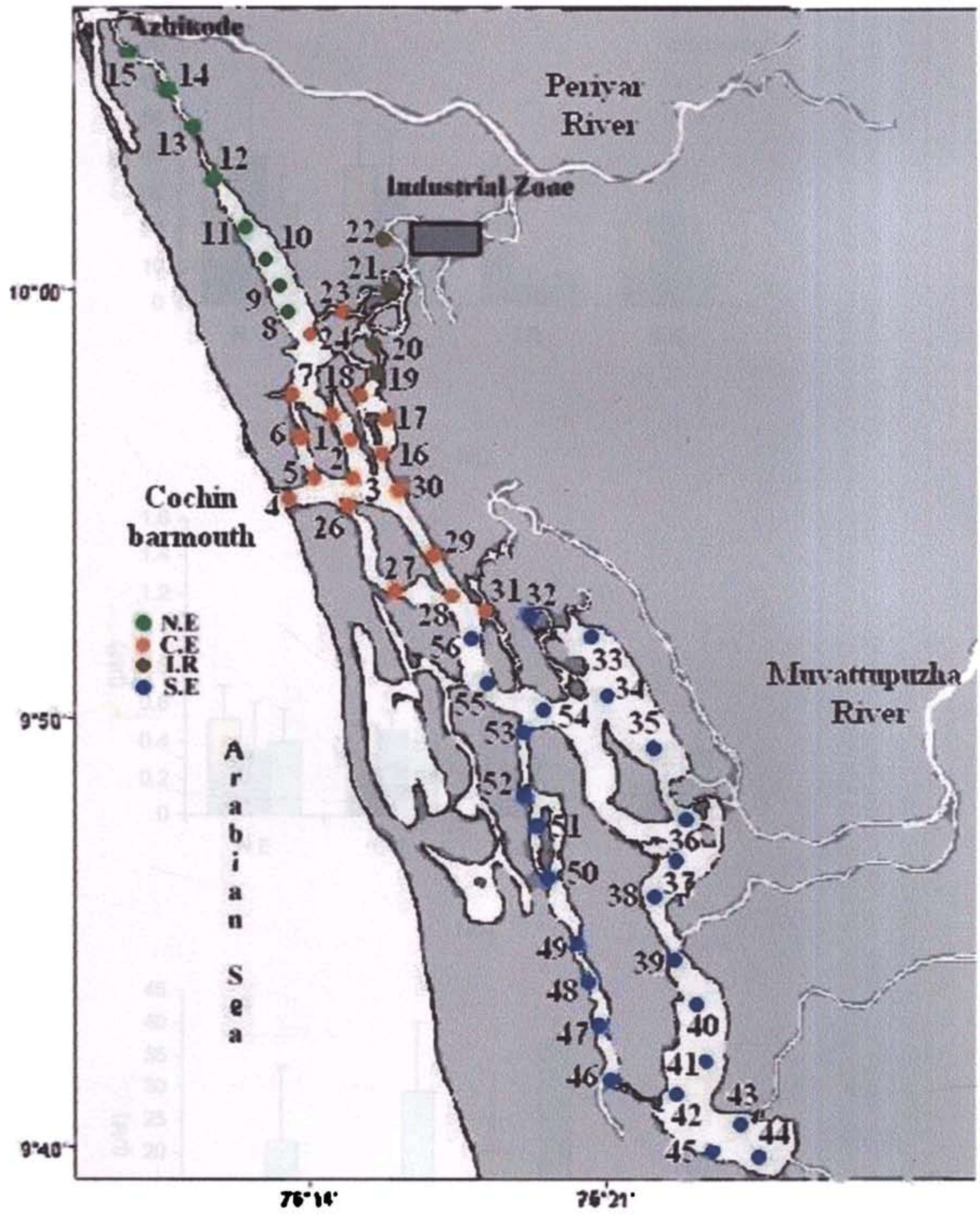


Figure 3.1 Map showing the study region

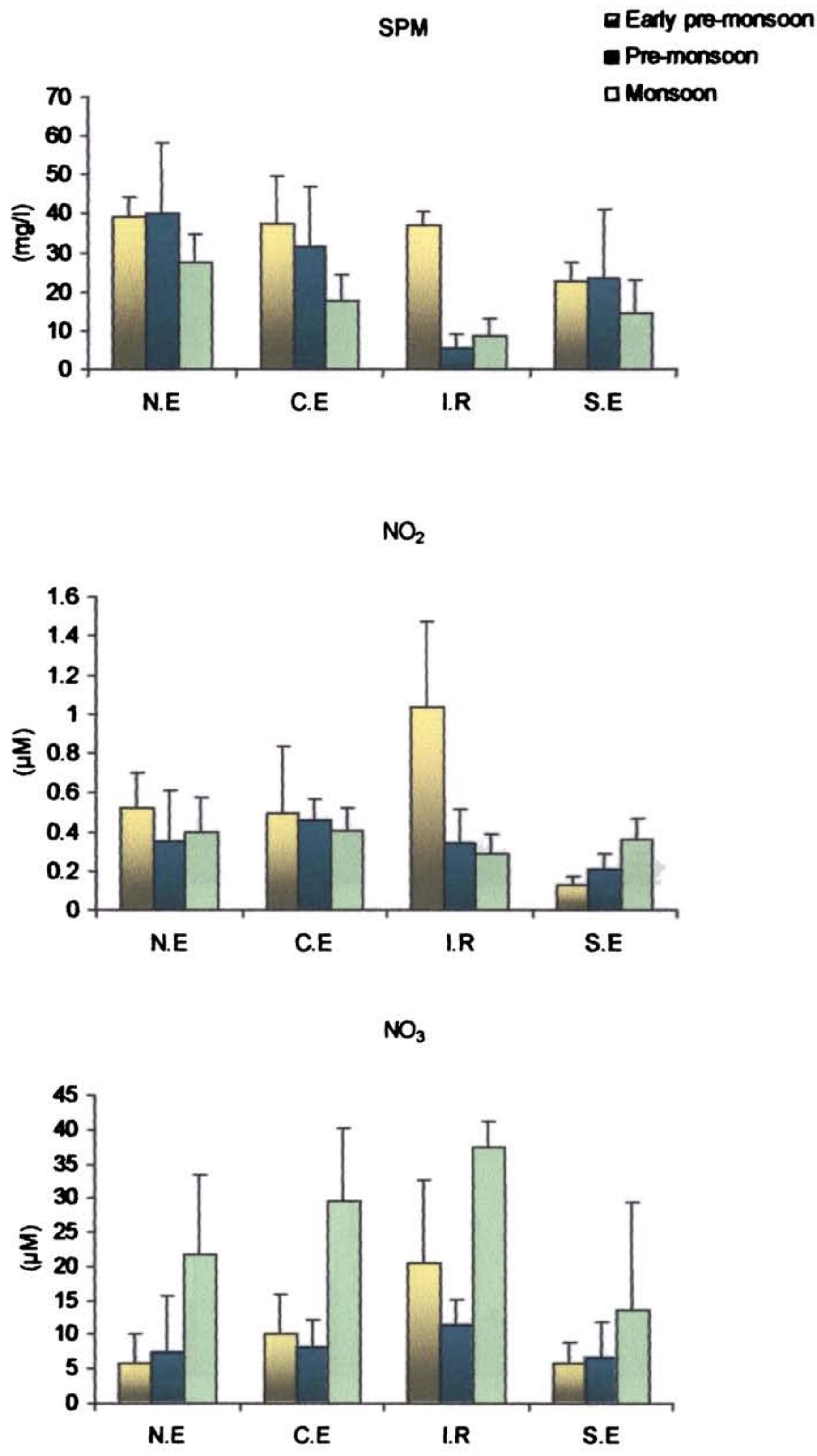


Figure 3.3.1 Variation of SPM, NO_2 and NO_3 in the study region (Average±S.D)

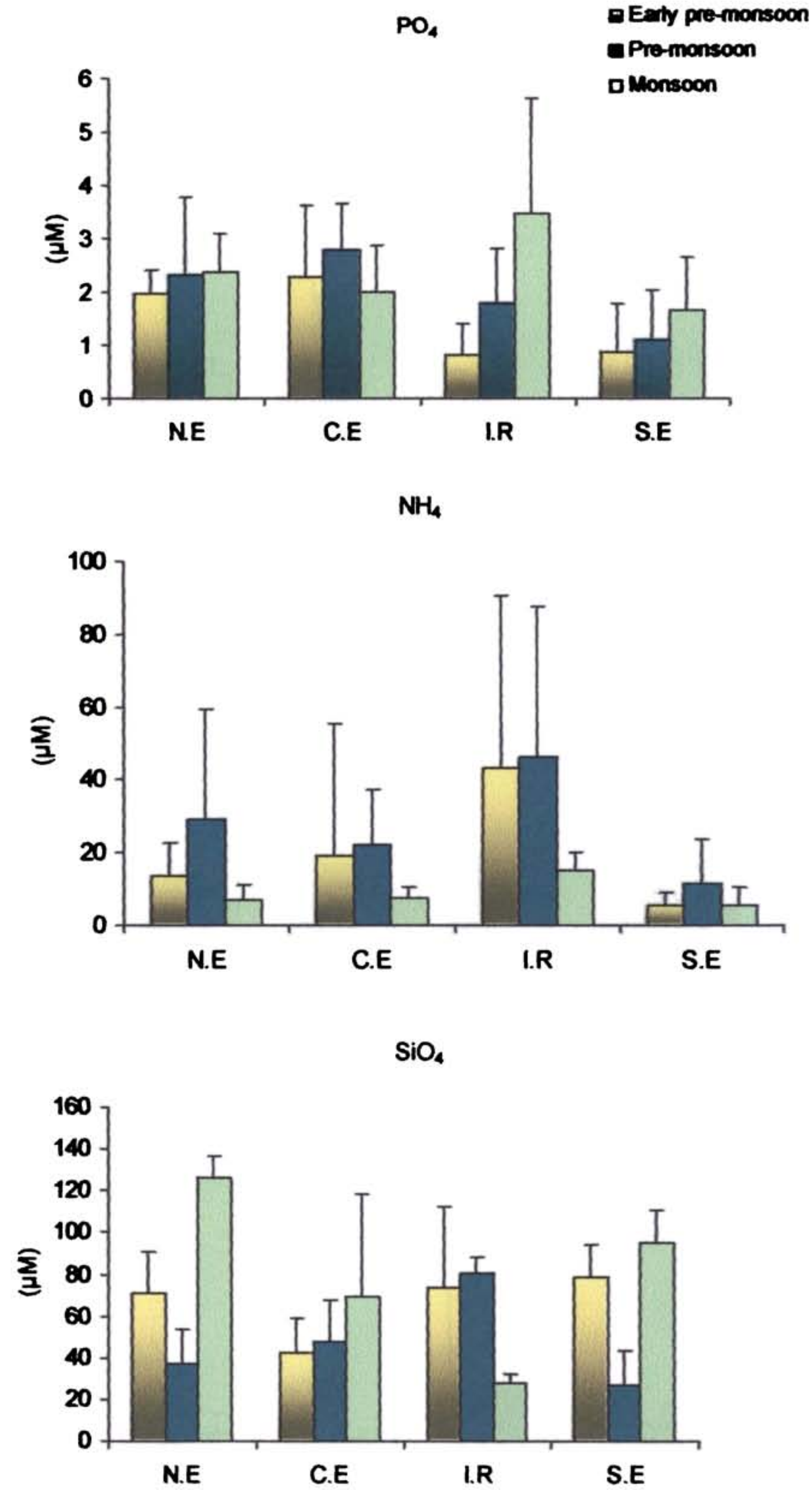


Figure 3.3.2 Variation of PO4, NH4 and SiO4 in the study region (Average±S.D)

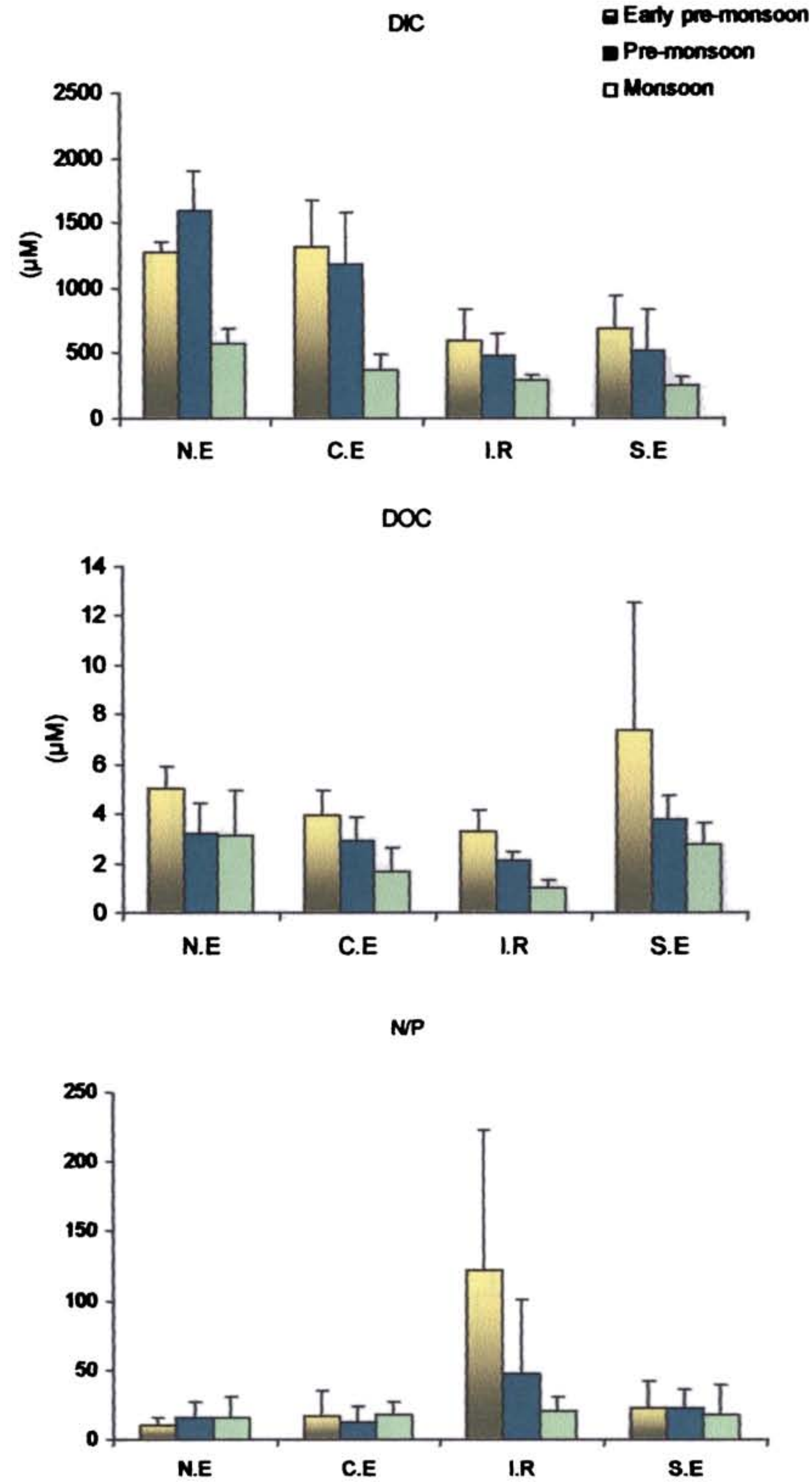


Figure 3.3.3 Variation of DIC, DOC and N/P in the study region (Average±S.D)

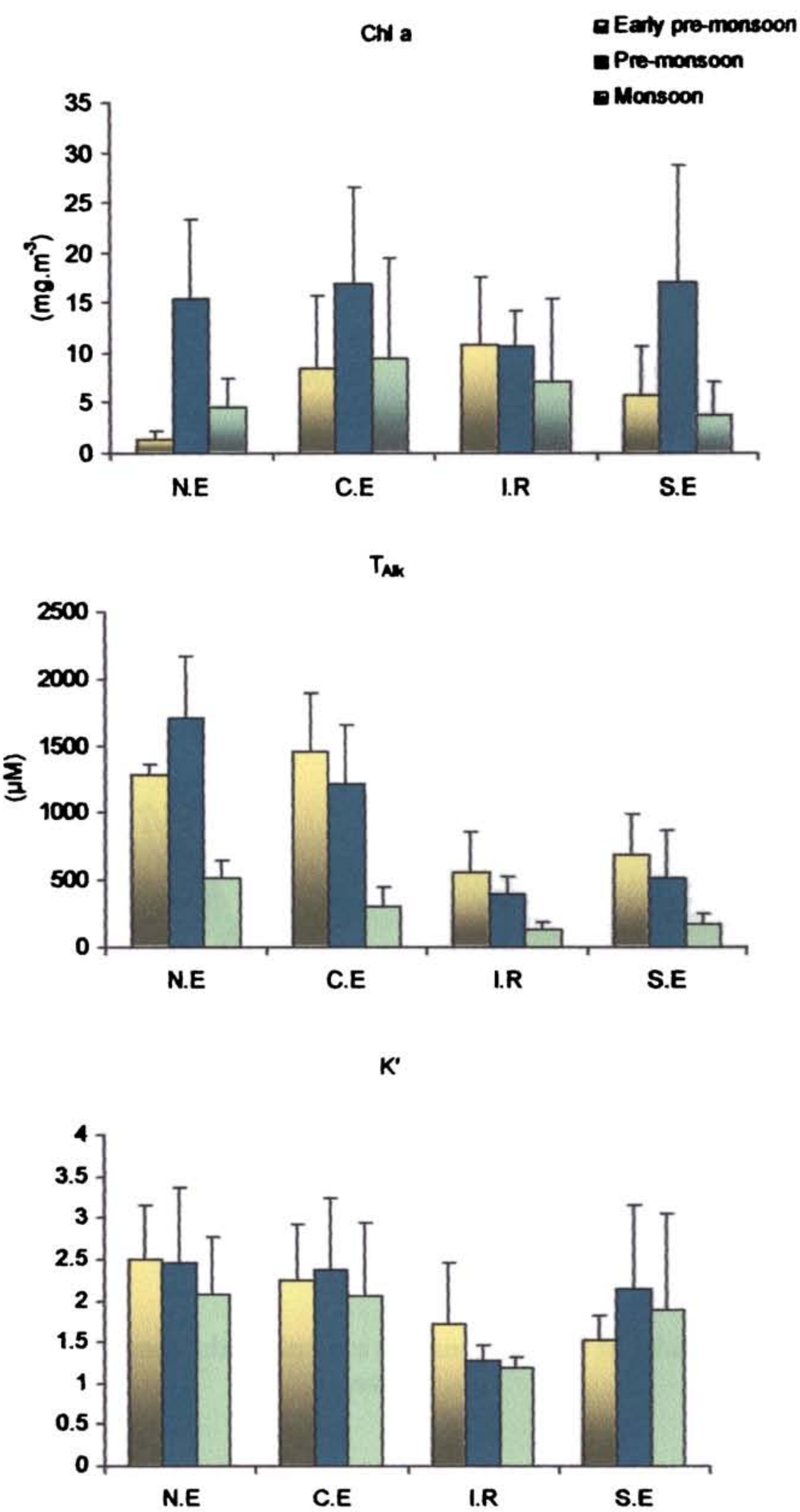


Figure 3.3.4 Variation of Chl *a*, TA and Attenuation coefficient (K') in the study region (Average±S.D)

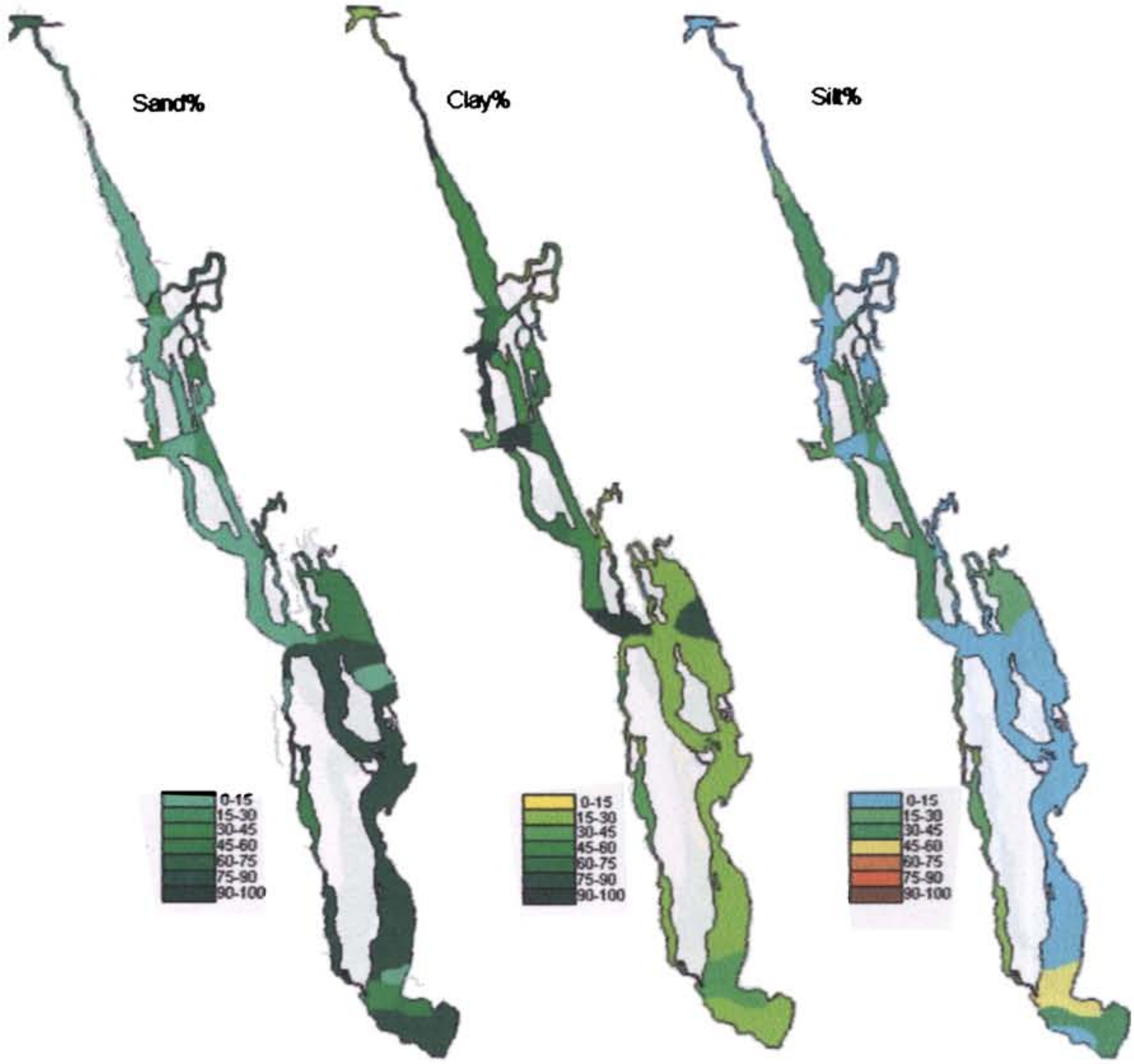


Figure 3.3.5 (a) Sediment characteristics (% sand, clay and silt) during Early pre-monsoon.

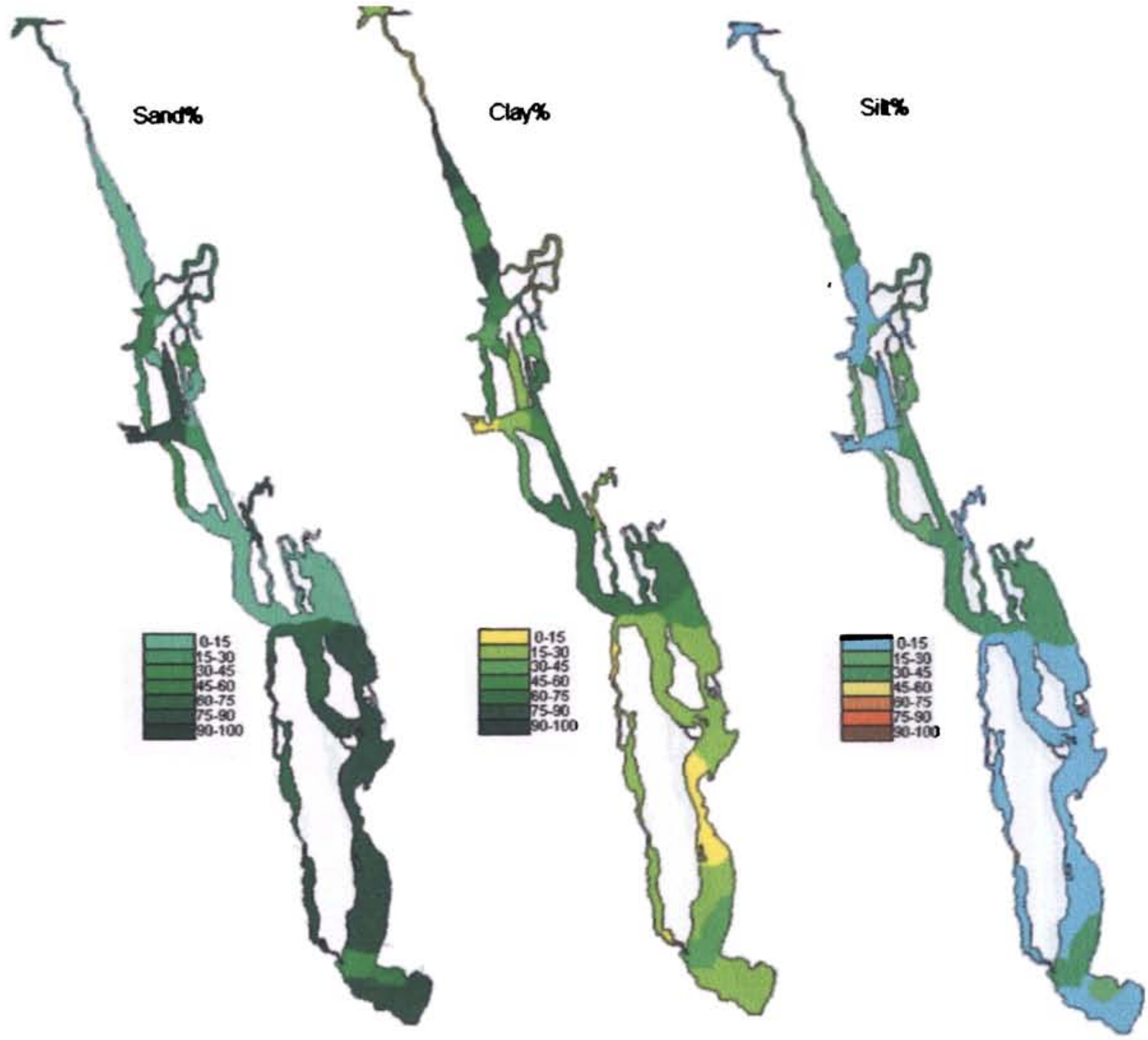


Figure 3.3.5 (b) Sediment characteristics (% sand, clay and silt) during Pre-monsoon

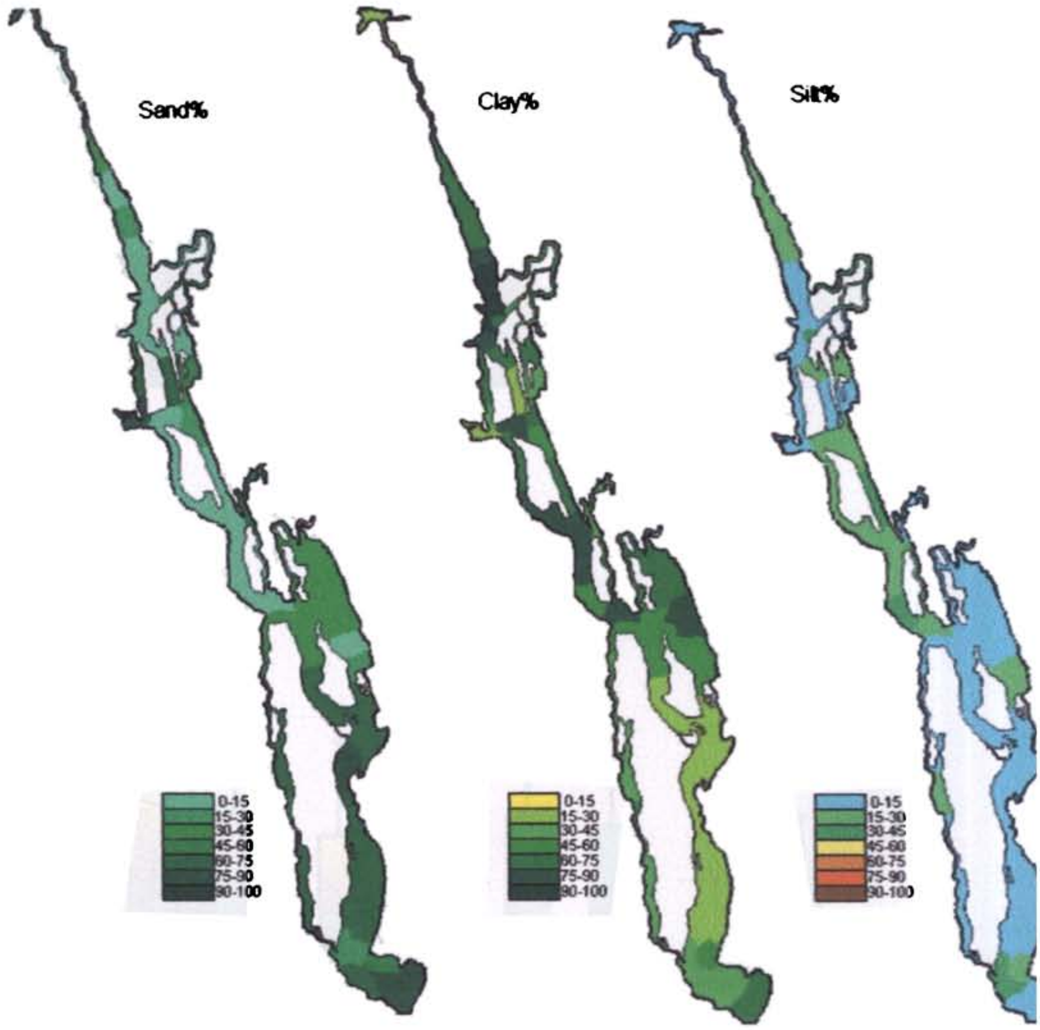


Figure 3.3.5 (c) Sediment characteristics (% sand, clay and silt) during monsoon

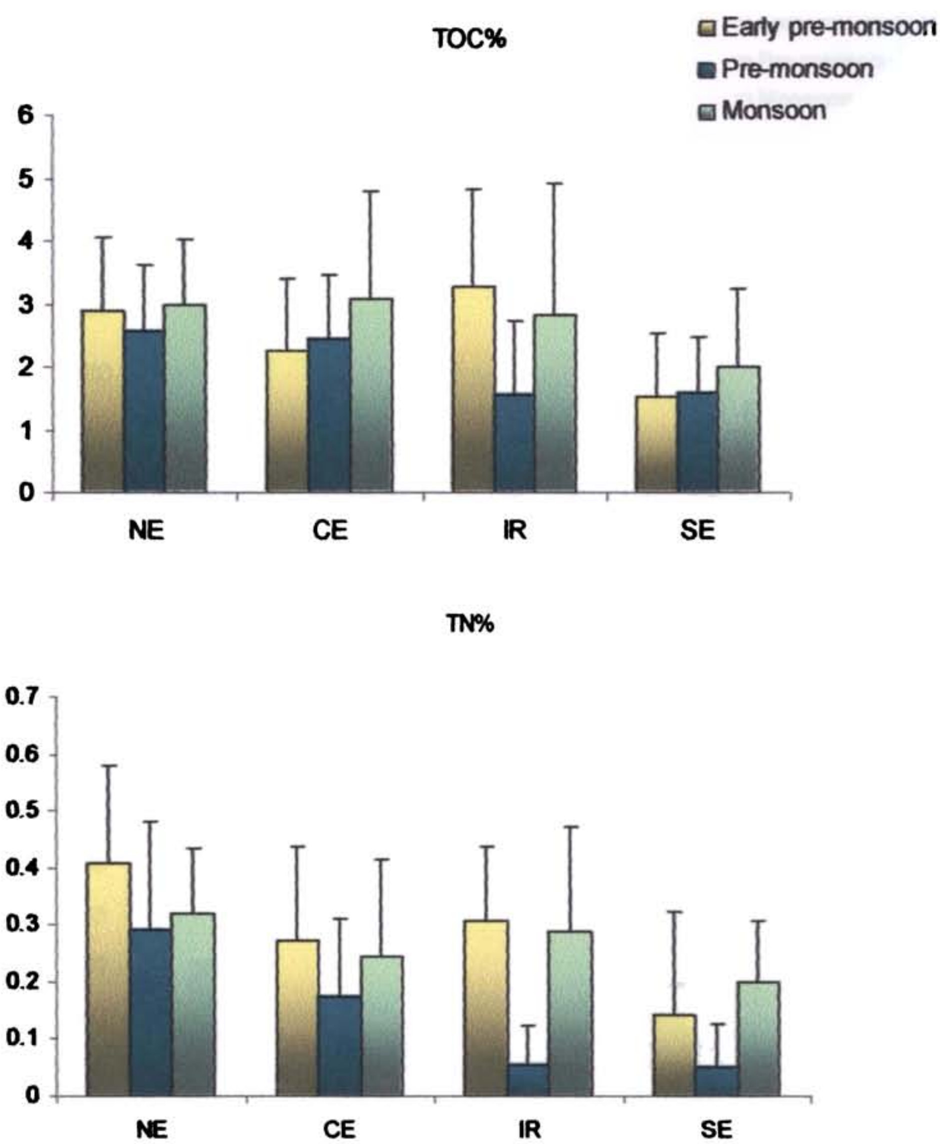


Figure 3.3.6 Variation of TOC and TN% in the sediment (Average±S.D)

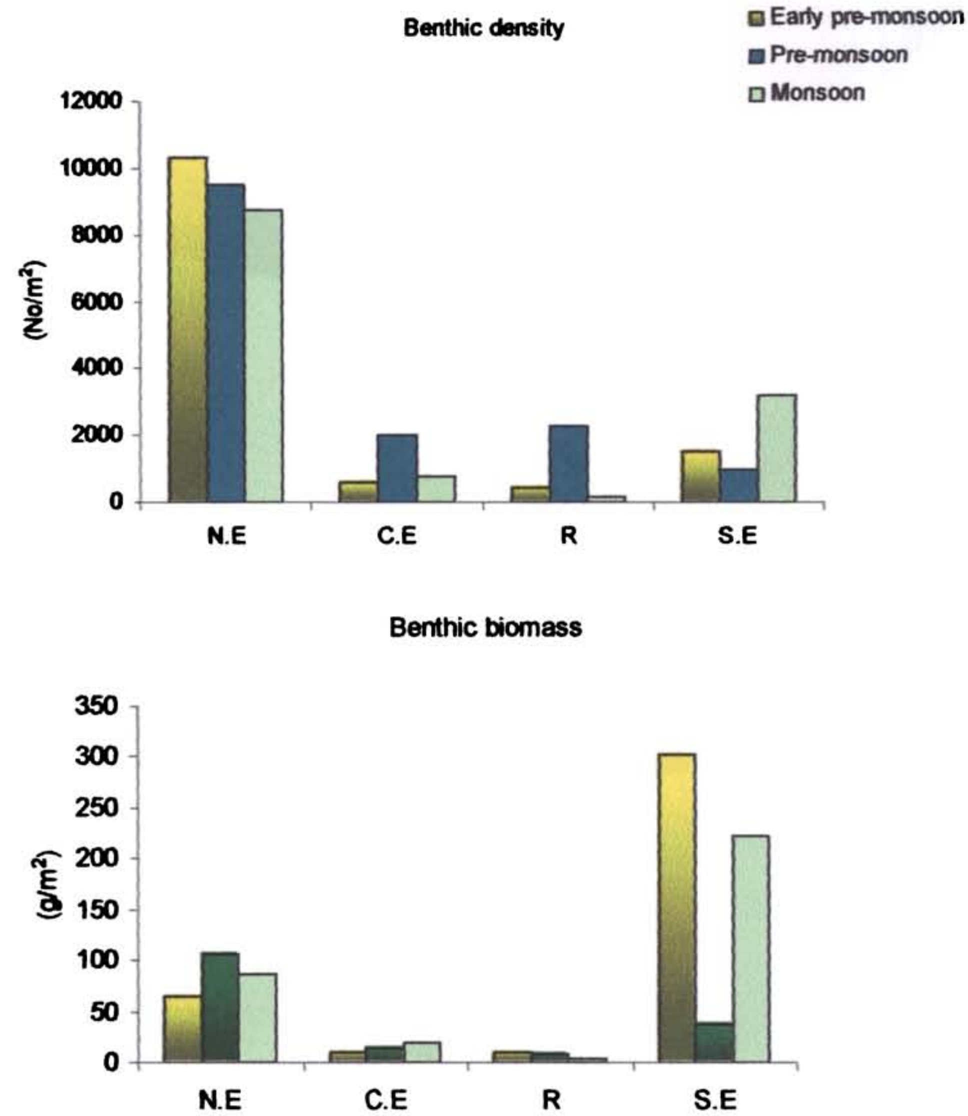


Figure 3.3.7 Benthic density and biomass of the study region

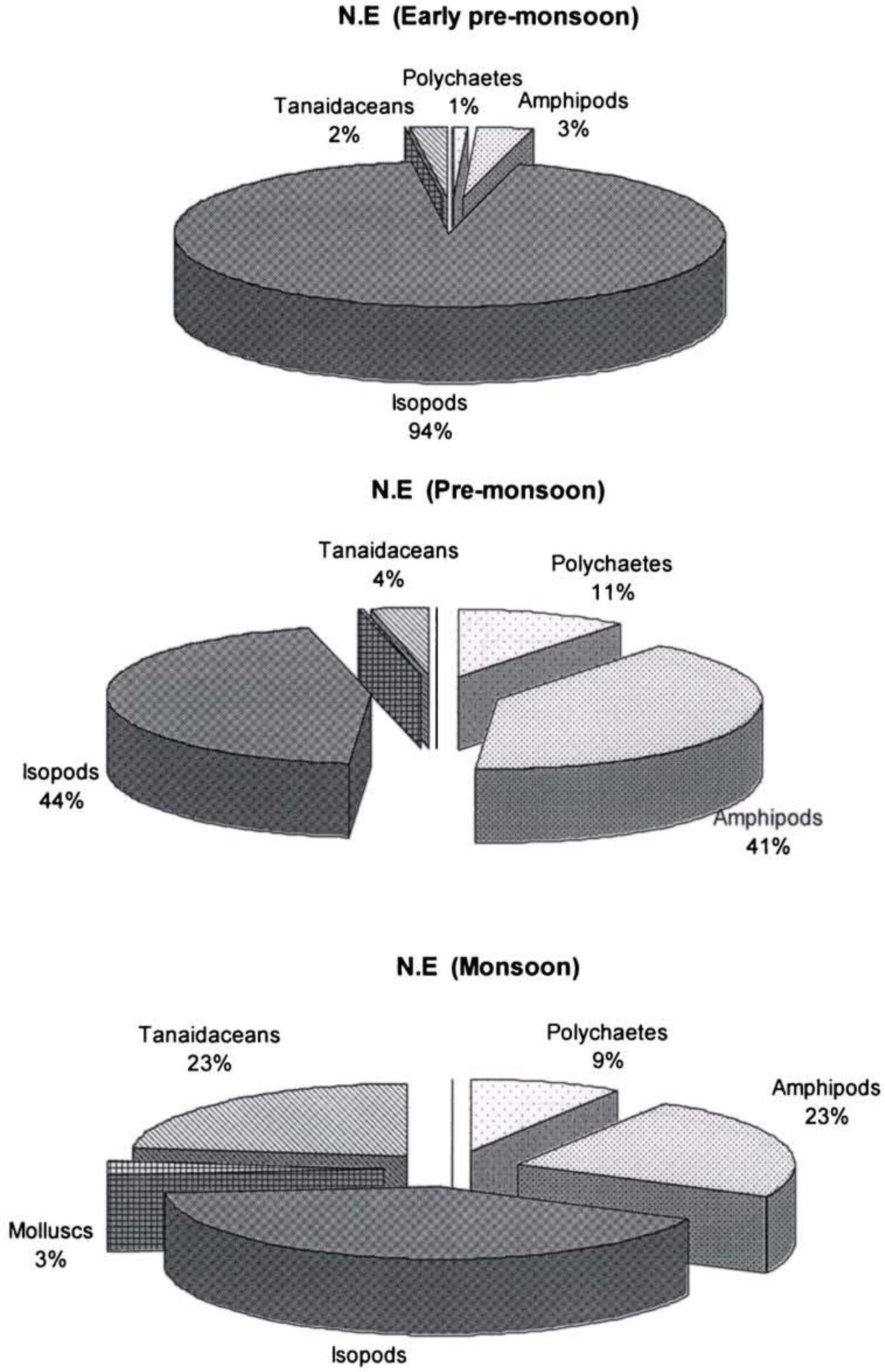


Figure 3.3.8 (a) Percentage contribution of major groups in N.E (Northern Estuary)

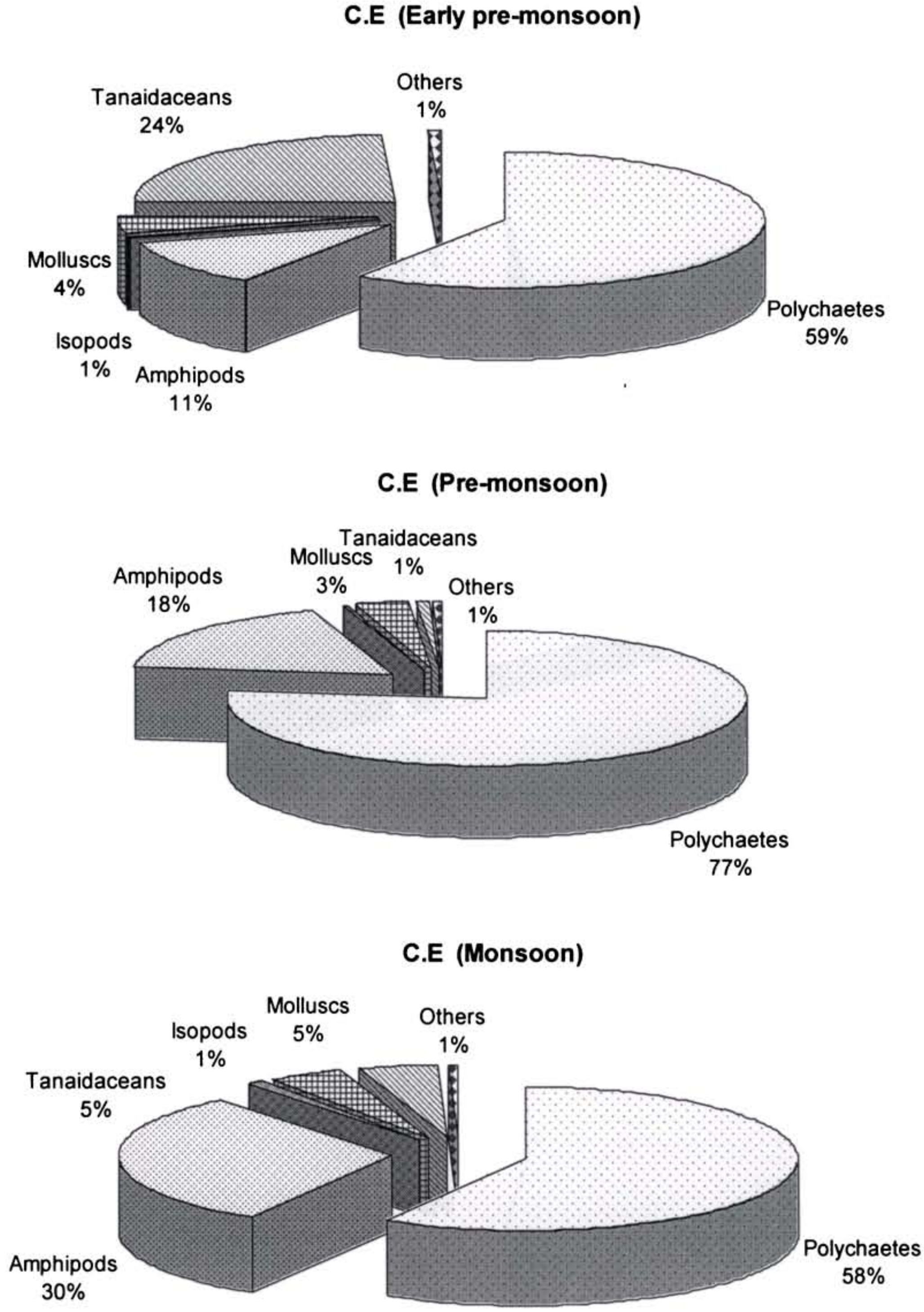


Figure 3.3.8 (b) Percentage contribution of major groups in C.E (Central Estuary)

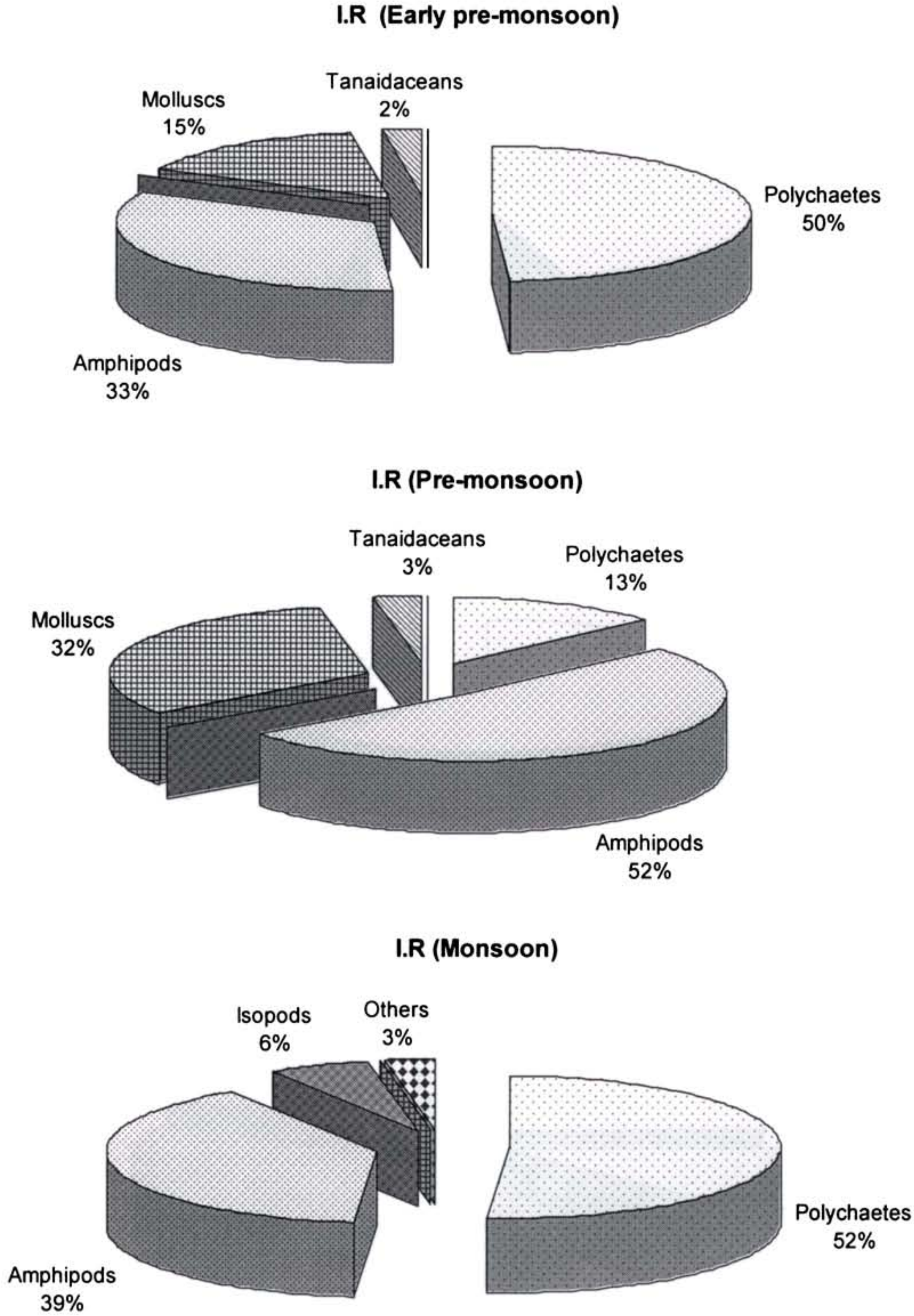


Figure 3.3.8 (c) Percentage contribution of major groups in I.R (Industrial Region)

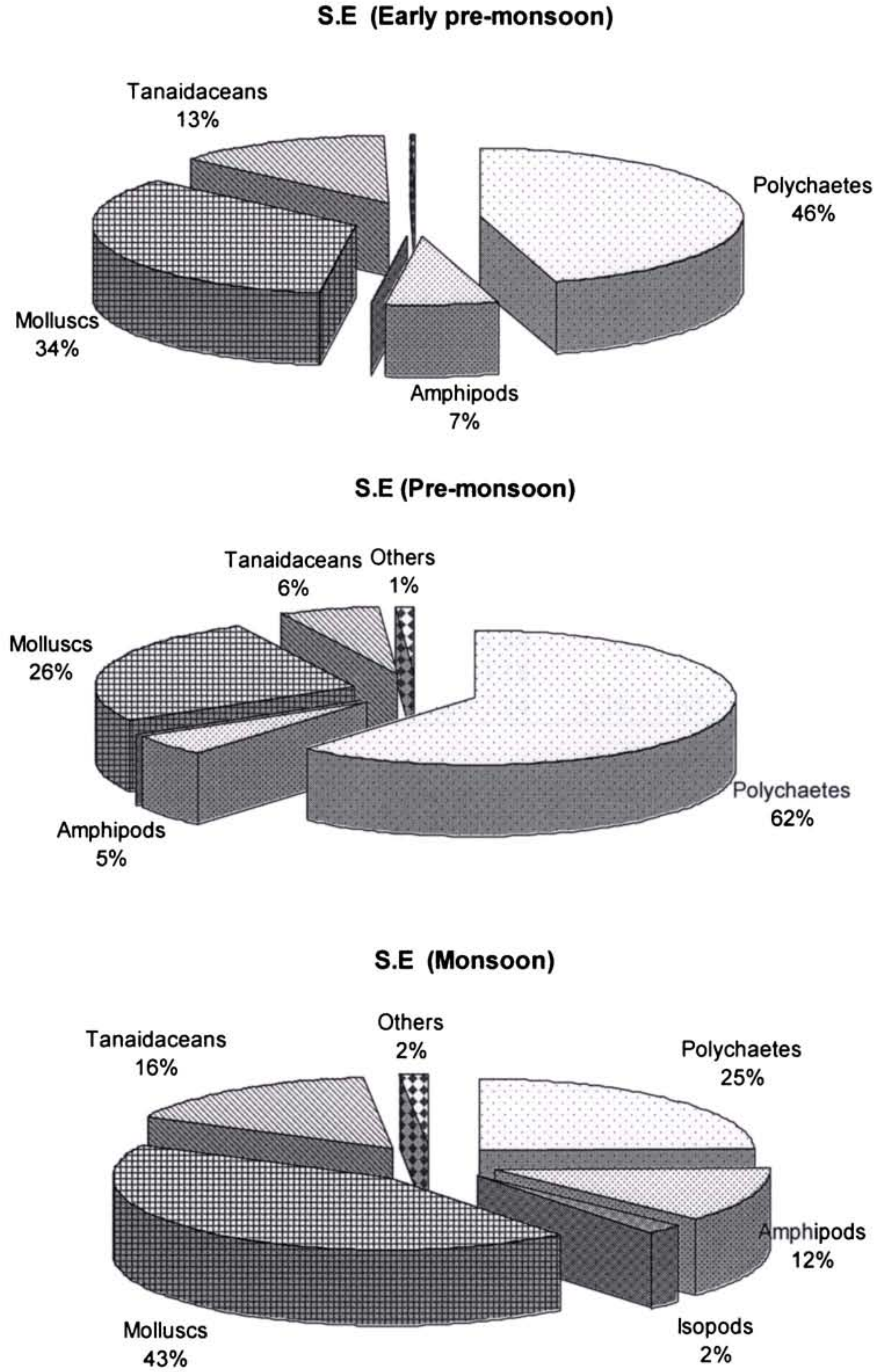


Figure 3.3.8 (d) Percentage contribution of major groups in S.E (Southern Estuary)

Table 3.3.1. Water quality parameters (range) during the sampling period February (Early pre-monsoon), April (Pre-monsoon) and September (Monsoon)

	Northern Estuary (N.E)			**Central Estuary (C.E)**		
	February	April	September	February	April	September
Water temperature	27.5-28.00	32.00-34.50	29.00-31.80	27.5-32.0	31.5-33.5	27.0-30.9
pH	7.53-8.02	7.33-8.11	7.08-8.57	7.23-8.60	7.06-8.09	6.38-7.80
Salinity	20.09-25.52	15.57-33.53	0.54-8.88	7.33-27.13	5.63-22.35	0-2.82
B.O.D	-	0.01-3.77	0.55-3.18	-	2.92-4.29	0.66-3.13
D.O	5.33-7.14	2.67-8.24	4.69-7.24	5.26-11.60	2.89-7.23	5.03-7.60

	Industrial Region (I.R)			**Southern Estuary (S.E)**		
	February	April	September	February	April	September
Water temperature	31.00	32.3-33.0	26.5-27.0	30.1-32.6	32.5-35.2	28.5-31.1
pH	6.92-7.91	6.53-6.84	6.18-6.57	6.62-8.15	6.38-8.32	6.62-7.25
Salinity	1.09-15.28	0.29-3.19	0.00	2.61-20.20	8.92-18.22	0-0.98
B.O.D	-	3.25-3.63	0.16-0.84	-	2.29-5.87	0.36-5.08
D.O	6.04-7.99	4.77-7.63	5.79-7.00	4.09-9.63	3.45-10.87	4.74-7.47

Table 3.3.2 (a) Percentage contribution of different species during February (Early pre-monsoon) N.E-Northern Estuary, C.E-Central Estuary, I.R-Industrial Region, S.E-Southern Estuary

	N.E	C.E	I.R	S.E
Polychaetes				
Amphinomae rostrata	0.00	0.00	0.00	0.00
Ancystrosyllis constricta	0.00	0.57	0.00	0.39
Aphrodita alta	0.00	0.00	0.00	0.00
Branchiocapitella singularis	0.08	3.23	3.59	0.48
Capitella capitata	0.15	11.95	5.93	7.97
Cirratulus cirratus	0.00	3.42	0.00	0.00
Cirratulus filiformis	0.00	0.19	0.00	0.00
Cossura coasta	0.00	4.55	0.00	0.19
Dasybranchus sp	0.00	0.19	0.00	0.00
Dendronereis aestuarina	0.00	3.78	3.59	3.29
Diopatra neapolitana	0.10	0.00	1.20	0.10
Glycera alba	0.00	0.00	0.00	0.10
Glycera convoluta	0.00	0.38	0.00	0.00
Glycera longipinnis	0.00	0.19	0.00	0.12
Goniada emerita	0.00	0.00	0.00	0.00
Goniada incerta	0.00	0.00	0.00	0.00
Heteromastidus bifidus	0.00	0.00	0.00	0.00
Heteromastus filiformis	0.00	0.00	0.00	0.00
Heteromastus similis	0.03	6.83	2.40	3.96
Lumbriconereis latreilli	0.00	0.00	0.00	0.19
Lumbriconereis notocirrata	0.00	0.00	0.00	0.00
Lumbriconereis simplex	0.25	0.57	1.20	0.77
Lycastis indica	0.03	2.85	21.45	0.67
Mediomastus capensis	0.00	0.38	0.00	0.29
Nephthys dibranchus	0.05	2.67	0.00	1.46
Notomastus aberans	0.00	3.23	0.00	1.88
Notomastus fauveli	0.03	1.90	4.73	1.06
Notomastus latericeus	0.00	0.00	0.00	0.24
Orbinidae	0.00	0.00	0.00	0.00
Owenia fusiformis	0.00	3.41	1.20	1.37
Paraheteromastus tenius	0.13	7.57	3.59	7.03
Perinereis cavifrons	0.00	0.38	0.00	0.00
Platynereis sp.	0.00	0.00	0.00	0.10
Prionospio cirrifera	0.00	0.19	0.00	2.76
Prionospio cirrobranchiata	0.13	0.38	0.00	8.11
Prionospio pinnata	0.00	0.00	0.00	0.00
Prionospio polybranchiata	0.00	0.38	0.00	1.82
Prionospio sexoculata	0.00	0.00	0.00	0.00
Pulleila armata	0.00	0.00	0.00	0.00
Scyphoproctus djiboutiensis	0.00	0.00	0.00	0.10
Unidentified	0.08	0.38	0.00	1.97
Total	**0.96**	**59.21**	**48.89**	**44.45**
Oligochaetae	0.00	0.00	0.00	0.00

Contd.

	N.E	C.E	I.R	S.E
Amphipods				
Corophium trinoenyx	1.21	0.00	0.00	0.00
Cprellidae	1.46	0.38	0.00	0.96
Eriopisa chilkensis	0.30	7.01	10.72	3.00
Grandidierella bonnerii	0.00	0.00	7.13	0.19
Grandidierella gilesi	0.00	0.57	11.87	0.67
Melita zylanica	0.13	3.04	3.59	1.54
Quadrivisio bengalensis	0.00	0.00	0.00	0.29
Total	**3.10**	**11.00**	**33.31**	**6.66**
Isopods				
Anthuridae	0.16	0.38	0.00	0.10
Cirrolana fluvitilis	93.36	0.19	0.00	0.00
Total	**93.52**	**0.57**	**0.00**	**0.10**
Mollusc				
Assiminea breviculata	0.00	0.00	0.00	0.00
Pendora flexosa	0.00	3.42	4.73	3.87
Cardium sp.	0.00	0.00	0.00	0.00
Gastropod sp.	0.00	0.38	0.00	0.00
Littorena littorea	0.00	0.00	9.47	3.07
Meritrix	0.00	0.00	0.00	0.00
Modiolus striatulus	0.05	0.00	0.00	0.19
Solariella lacunella	0.00	0.19	0.00	0.10
Tellina pulcherrima	0.00	0.00	0.00	0.00
Villorita cyprinoides	0.00	0.00	1.20	26.28
Total	**0.05**	**3.99**	**15.40**	**33.51**
Tanaidaceans				
Apseudes chilkensis	2.02	21.60	1.20	11.71
Apseudes gymnophobia	0.28	2.47	1.20	0.91
Tanais filitarous	0.00	0.00	0.00	0.48
Total	**2.30**	**24.07**	**2.40**	**13.10**
Others				
Cumacea	0.00	0.00	0.00	0.00
Anatopynia	0.00	0.00	0.00	0.00
Chironomids (insect larvae)	0.00	0.00	0.00	0.00
Diamesa	0.00	0.00	0.00	0.00
Portunus sp.	0.00	0.38	0.00	0.10
Metapenaeus dobsoni	0.00	0.00	0.00	0.12
Barnacle	0.00	0.00	0.00	0.00
Sea anemone	0.00	0.19	0.00	0.00
Juvenile fish	0.00	0.19	0.00	0.00
Total	**0.00**	**0.76**	**0.00**	**0.22**

Table 3.3.2 (b) Percentage contribution of different species during April (Pre-monsoon) N.E-Northern Estuary, C.E-Central Estuary, I.R-Industrial Region, S.E-Southern Estuary

	N.E	C.E	I.R	S.E
Polychaetes				
Amphinomae rostrata	0.11	4.04	2.14	1.41
Ancystrosyllis constricta	0.00	0.52	0.00	0.00
Aphrodita alta	0.00	0.00	0.00	0.18
Branchiocapitella singularis	0.08	4.01	6.43	3.17
Capitella capitata	0.16	21.05	0.00	11.58
Cirratulus cirratus	0.00	0.00	0.00	0.27
Cirratulus filiformis	0.00	0.00	0.00	0.00
Cossura coasta	0.00	0.61	0.00	0.00
Dasybranchus sp	0.00	0.00	0.00	0.00
Dendronereis aestuarina	0.77	0.09	12.76	0.88
Diopatra neapolitana	0.25	8.06	0.00	0.18
Glycera alba	0.00	0.09	0.00	0.09
Glycera convoluta	0.08	0.28	0.00	0.09
Glycera longipinnis	0.00	0.09	0.00	0.09
Goniada emerita	0.06	0.79	0.00	0.53
Goniada incerta	0.00	0.05	0.00	0.00
Heteromastidus bifidus	0.11	0.23	0.00	0.27
Heteromastus filiformis	0.00	0.00	0.00	0.18
Heteromastus similis	2.16	3.59	19.08	12.39
Lumbriconereis latreilli	0.11	0.75	0.00	0.00
Lumbriconereis notocirrata	0.00	0.42	0.00	0.00
Lumbriconereis simplex	0.16	4.52	0.00	0.61
Lycastis indica	0.03	0.09	4.29	0.09
Mediomastus capensis	0.06	0.19	4.29	0.44
Nephthys dibranchus	0.19	3.17	0.00	3.34
Notomastus aberans	0.88	1.31	6.43	2.38
Notomastus fauveli	0.77	1.68	10.61	2.65
Notomastus latericeus	0.79	1.26	10.61	3.08
Orbinidae	0.00	0.05	0.00	0.00
Owenia fusiformis	0.11	0.98	0.00	1.14
Paraheteromastus tenius	1.34	2.75	17.04	8.60
Perinereis cavifrons	0.03	0.23	2.14	0.35
Platynereis sp.	0.08	0.05	2.14	0.70
Prionospio cirrifera	1.89	0.47	4.29	0.27
Prionospio cirrobranchiata	0.44	0.56	19.18	4.66
Prionospio pinnata	0.00	0.00	0.00	0.09
Prionospio polybranchiata	0.00	0.05	0.00	0.70
Prionospio sexoculata	0.00	0.00	0.00	0.09
Pulleila armata	0.00	0.00	0.00	0.00
Scyphoproctus djiboutiensis	0.03	0.33	2.14	0.27
Unidentified	0.00	0.00	0.00	0.00
Total	**10.68**	**75.32**	**13.20**	**60.74**
Oligochaetae	0.00	0.00	0.00	0.18

Contd.

	N.E	C.E	I.R	S.E
Amphipods				
Corophium trinoenyx	35.93	0.23	0.23	0.00
Cprellidae	0.19	8.88	12.27	0.44
Eriopisa chilkensis	0.74	2.91	2.95	3.77
Grandidierella bonnerii	0.38	2.62	13.17	0.09
Grandidierella gilesi	1.42	1.31	18.63	0.09
Melita zylanica	1.89	1.31	3.41	0.82
Quadrivisio bengalensis	0.06	0.17	1.13	0.00
Total	**40.61**	**17.44**	**51.80**	**5.21**
Isopods				
Anthuridae	0.52	0.40	0.00	0.09
Cirrolana fluvitilis	44.41	0.00	0.00	0.00
Total	**44.93**	**0.40**	**0.00**	**0.09**
Molluscs				
Assiminea breviculata	0.00	0.00	0.00	0.00
Pendora flexosa	0.19	3.13	31.81	4.39
Cardium sp.	0.00	0.06	0.00	0.00
Gastropod sp.	0.00	0.06	0.00	0.00
Littorena littorea	0.03	0.00	0.00	0.27
Meritrix	0.03	0.06	0.00	0.00
Modiolus striatulus	0.00	0.00	0.00	0.00
Solariella lacunella	0.00	0.00	0.00	0.44
Tellina pulcherrima	0.00	0.00	0.00	0.00
Villorita cyprinoides	0.00	0.00	0.00	20.44
Total	**0.25**	**3.31**	**31.81**	**25.53**
Tanaidaceans				
Apseudes chilkensis	0.41	0.57	2.95	2.63
Apseudes gymnophobia	3.12	2.11	0.00	3.51
Tanais filitarous	0.00	0.00	0.00	0.00
Total	3.53	2.68	2.95	6.15
Others				
Cumacea	0.00	0.00	0.06	0.00
Anatopynia	0.00	0.00	0.00	0.00
Chironomids (insect larvae)	0.00	0.00	0.00	0.00
Diamesa	0.00	0.00	0.00	0.00
Portunus sp.	0.00	0.00	0.00	1.14
Metapenaeus dobsoni	0.00	0.57	0.00	0.09
Barnacle	0.00	0.00	0.00	0.00
Sea anemone	0.00	0.00	0.00	0.00
Juvenile fish	0.00	0.06	0.00	0.00
Total	**0.00**	**0.63**	**0.06**	**1.23**

Table 3.3.2 (c) Percentage contribution of different species during September (Monsoon) N.E-Northern Estuary, C.E-Central Estuary, I.R-Industrial Region, S.E-Southern Estuary

	N.E	C.E	I.R	S.E
Polychaetes				
Amphinomae rostrata	0.00	8.30	0.00	0.00
Ancystrosyllis constricta	0.00	0.00	0.00	0.00
Aphrodita alta	0.00	0.00	0.00	0.00
Branchiocapitella singularis	0.30	1.64	0.00	1.24
Capitella capitata	0.39	4.61	0.00	2.55
Cirratulus cirratus	0.00	0.00	0.00	0.00
Cirratulus filiformis	0.00	0.00	0.00	0.00
Cossura coasta	0.00	0.15	0.00	0.00
Dasybranchus sp	0.00	0.00	0.00	0.00
Dendronereis aestuarina	0.45	2.08	3.05	2.94
Diopatra neapolitana	0.00	0.15	0.00	0.00
Glycera alba	0.00	0.00	0.00	0.00
Glycera convoluta	0.00	0.00	0.00	0.00
Glycera longipinnis	0.00	0.45	0.00	0.00
Goniada emerita	0.00	0.00	0.00	0.00
Goniada incerta	0.00	0.00	0.00	0.00
Heteromastidus bifidus	0.00	0.00	0.00	0.46
Heteromastus filiformis	0.12	0.45	0.00	0.13
Heteromastus similis	3.31	12.30	9.14	3.59
Lumbriconereis latreilli	0.00	0.00	0.00	0.00
Lumbriconereis notocirrata	0.00	0.00	0.00	0.00
Lumbriconereis simplex	0.00	0.30	0.00	0.00
Lycastis indica	0.00	0.45	0.00	1.37
Mediomastus capensis	0.00	0.30	3.05	0.07
Nephthys dibranchus	0.21	4.16	0.00	0.59
Notomastus aberans	0.03	0.00	0.00	0.00
Notomastus fauveli	0.03	0.15	0.00	0.39
Notomastus latericeus	0.09	0.90	3.05	1.25
Orbinidae	0.00	0.00	0.00	0.00
Owenia fusiformis	0.00	0.00	0.00	0.33
Paraheteromastus tenius	0.45	6.83	33.24	4.44
Perinereis cavifrons	0.00	0.00	0.00	0.13
Platynereis sp.	0.12	0.45	0.00	0.00
Prionospio cirrifera	0.30	2.37	0.00	0.39
Prionospio cirrobranchiata	3.02	10.82	0.00	3.46
Prionospio pinnata	0.00	0.00	0.00	0.00
Prionospio polybranchiata	0.00	0.00	0.00	0.00
Prionospio sexoculata	0.00	0.15	0.00	0.00
Pulleila armata	0.00	0.15	0.00	0.13
Scyphoproctus djiboutiensis	0.03	0.75	0.00	0.65
Unidentified	0.00	0.60	0.00	0.46
Total	**8.85**	**58.48**	**51.52**	**24.56**
Oligochaetae	0.00	0.30	0.00	0.00

Contd.

	N.E	C.E	I.R	S.E
Amphipods				
Corophium trinoenyx	19.67	6.22	0.00	0.33
Cprellidae	0.24	8.75	33.24	5.87
Eriopisa chilkensis	1.67	0.75	6.10	0.13
Grandidierella bonnerii	0.00	4.00	0.00	0.98
Grandidierella gilesi	0.84	10.52	0.00	3.99
Melita zylanica	0.81	0.15	0.00	1.18
Quadrivisio bengalensis	0.12	0.00	0.00	0.00
Total	**23.35**	**30.39**	**39.33**	**12.47**
Isopods				
Anthuridae	1.61	0.00	6.10	1.11
Cirrolana fluvitilis	39.83	1.04	0.00	1.04
Total	**41.44**	**1.04**	**6.10**	**2.15**
Molluscs				
Assiminea breviculata	0.03	0.89	0.00	0.07
Pendora flexosa	3.02	0.15	0.00	0.98
Cardium sp.	0.00	0.30	0.00	0.39
Gastropod sp.	0.00	0.00	0.00	0.00
Littorena littorea	0.00	0.00	0.00	0.91
Meritrix	0.00	0.00	0.00	0.00
Modiolus striatulus	0.00	0.00	0.00	0.00
Solariella lacunella	0.00	0.00	0.00	0.00
Tellina pulcherrima	0.00	0.30	0.00	0.39
Villorita cyprinoides	0.00	2.96	0.00	40.45
Total	**3.05**	**4.59**	**0.00**	**43.19**
Tanaidaceans				
Apseudes chilkensis	20.06	3.71	0.00	14.81
Apseudes gymnophobia	3.19	0.90	0.00	1.18
Tanais filitarous	0.00	0.00	0.00	0.00
Total	**23.26**	**4.61**	**0.00**	**15.99**
Others				
Cumacea	0.00	0.00	0.00	0.07
Anatopynia	0.00	0.30	0.00	0.00
Chironomids (insect larvae)	0.00	0.00	3.05	0.00
Diamesa	0.00	0.00	0.00	0.39
Portunus sp.	0.00	0.00	0.00	0.33
Metapenaeus dobsoni	0.03	0.00	0.00	0.00
Barnacle	0.00	0.00	0.00	0.78
Sea anemone	0.00	0.00	0.00	0.00
Juvenile fish	0.03	0.30	0.00	0.07
Total	**0.06**	**0.60**	**3.05**	**1.63**

Table 3.3.3 Seasonal variability showing the species richness (d'), evenness (J'), diversity (H') and dominance (λ') of macrobenthos during February (Early pre-monsoon), April (Pre-monsoon) and September (Monsoon)

	February	April	September	February	April	September
	Northern Estuary (N.E)			**Central Estuary (C.E)**		
d	0.56	1.09	1.12	0.96	1.46	0.94
J'	0.44	0.75	0.54	0.84	0.76	0.84
H'(loge)	0.56	1.34	1.23	1.34	1.77	1.42
λ'	0.31	0.60	0.55	0.71	0.73	0.67
	Industrial Region (I.R)			**Southern Estuary (S.E)**		
d	1.13	1.56	0.54	0.84	1.19	0.88
J'	0.88	0.76	0.90	0.69	0.79	0.73
H'(loge)	1.36	1.87	0.98	1.13	1.61	1.29
λ'	0.79	0.79	0.50	0.54	0.70	0.59

Table 3.3.4.(a) Pearson's correlation coefficient between benthic density and environmental variables in northern and central estuarine region (Significant correlations are indicated with bold letters) during February (Early pre-monsoon), April (Pre-monsoon) and September (Monsoon)

	Northern Estuary (N.E)			**Central Estuary (C.E)**		
	February	April	September	February	April	September
At	0.02	-0.16	0.18	0.135417	-0.20672	-0.14453
Wt	0.12	-0.24	-0.06	0.26	-0.34	-0.13
K'	0.09	-0.38	-0.03	0.07	0.18	**-0.39**
Salinity	-0.46	-0.38	-0.17	-0.26	**-0.43**	-0.33
pH	0.00	-0.50	-0.36	-0.11	**-0.39**	-0.09
SPM	-0.01	0.05	-0.30	**-0.45**	-0.36	-0.01
DO	-0.09	-0.56	0.43	0.17	-0.11	0.12
NO_2	0.46	0.58	0.33	0.18	-0.03	**0.59**
NO_3	0.20	0.51	0.13	0.34	0.20	-0.15
NH_4	-0.44	0.03	-0.26	0.16	-0.17	0.18
PO_4	**0.74**	0.45	0.46	-0.36	-0.04	0.36
SiO_4	-0.34	0.33	0.29	-0.10	**0.47**	**0.41**
N/P	-0.45	-0.12	-0.22	0.36	-0.14	-0.21
Chl 'a'	-0.26	-0.23	-0.02	**0.38**	0.30	-0.10
DOC	-0.29	0.18	-0.27	-0.05	-0.24	-0.04
T_{Alk}	-0.23	-0.39	-0.25	-0.25	**-0.43**	-0.31
DIC	-0.22	-0.35	-0.21	-0.22	**-0.43**	-0.35
Sand %	-0.18	-0.34	-0.17	-0.27	0.08	0.18
Clay %	0.46	**-0.64**	0.17	0.20	0.30	-0.33
Silt %	-0.33	-0.41	0.07	0.31	-0.17	0.10
TN %	**0.69**	**0.79**	0.48	0.20	0.08	**-0.46**
TOC %	-0.57	0.51	0.28	0.31	0.00	**-0.46**

Table. 3.3.4 (b) Pearson's correlation coefficient between benthic density and environmental variables in industrial and southern estuarine region (Significant correlations are indicated with bold letters)

	Industrial Region (I.R)			Southern Estuary (S.E)		
	February	April	September	February	April	September
At	0.30	**0.86**	**-0.88**	0.09	0.12	**0.33**
Wt	-	-0.37	0.67	**-0.39**	0.04	-0.23
K'	**-0.82**	-0.51	-0.26	-0.13	-0.14	-0.31
Salinity	0.68	0.36	-	0.30	0.19	0.09
pH	0.75	0.56	0.07	0.27	0.27	0.05
SPM	0.31	0.18	-0.40	0.19	**0.38**	**0.44**
DO	**0.99**	-0.50	0.33	0.05	0.11	-0.15
NO_2	0.09	0.17	**0.82**	-0.11	0.00	0.22
NO_3	**-0.97**	-0.55	0.08	-0.06	-0.11	-0.10
NH_4	0.60	-0.40	0.46	-0.09	0.08	-0.10
PO_4	0.41	0.18	0.42	0.05	0.22	**0.33**
SiO_4	**-0.96**	0.44	-0.52	-0.26	0.15	0.04
N/P	0.26	-0.50	-0.49	-0.11	-0.08	-0.13
Chl 'a'	**0.94**	0.39	-0.40	-0.08	-0.03	-0.10
DOC	0.51	0.34	-0.23	**0.33**	-0.11	0.05
T_{Alk}	0.73	0.25	**0.81**	**0.38**	0.19	0.24
DIC	0.72	0.27	**0.98**	**0.38**	0.14	0.19
Sand %	0.31	0.58	0.52	**-0.36**	-0.31	0.06
Clay %	-0.06	-0.45	-0.50	**0.42**	-0.16	-0.04
Silt %	-0.55	-0.28	-0.53	0.26	0.26	0.05
TN %	-0.49	-0.38	-0.55	0.26	0.01	-0.08
TOC %	-0.66	-0.43	-0.57	0.29	0.04	-0.04

CHAPTER 4

Impact of organic enrichment on macrobenthic community in the Cochin Estuary

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4.1 Introduction

4.2 Study area and sampling period

4.3 Results

- 4.3.1 General hydrography
- 4.3.2 TOC, TN distribution and sediment texture
- 4.3.3 Macrobenthic community

4.4 Discussion

4.1. Introduction

The rapidly growing population and industries in the vicinity of Cochin city (Southwest coast of India) have lead to substantial discharge and consequent accumulation of organic wastes in the Cochin estuary, causing a significant environmental impact on the water body and the dependent flora and fauna. In estuarine ecosystems, sedimentation or settling is a major cause for concern because sediments act both as a pollutant sink and a carrier and hence has a direct impact on the benthic organisms. Many authors (Schlacher and Wooldridge, 1996, Zimmerman and Canuel, 2001, Kathleen et al., 2004) have studied the impact of organic matter enrichment on benthic organisms. However, the sources and composition of sediment organic matter and their impact on macrobenthic fauna have not been explored in the Cochin estuary. Benthic infauna are particularly useful in assessing the environmental quality, as they are relatively sedentary and are exposed to the potential toxicants

(Pocklington and Wells, 1992). Knowledge of the toxicity of common pollutants, which influences shifting of benthic community structure, would be of great help in ecological risk assessments (Ho et al., 1997; Burgess et al., 2000; Stronkhorst et al., 2003). Sediment organic matter is derived from plant and animal detritus, bacteria or plankton formed in situ, or derived from natural and anthropogenic sources. Sewage and effluents from food- processing plants, pulp and paper mills and municipal wastes are examples of such organic-rich wastes of anthropogenic origin.

Organic matter is a source of food and energy to benthic organisms, and its nutritional balance, Total organic carbon (TOC): Total Nitrogen (TN) ratio plays an important role in material flow through ecosystems. Decomposition rate of organic matter increases as TOC:TN ratio decreases (Enriquez et al., 1993). Labile organic matter with low TOC:TN ratios (e.g. Phytoplankton) breaks down easily, whereas refractory organic compounds (wood debris made of lignin and cellulose) have very high TOC: TN ratios.

Cochin estuary, widely regarded as one of the polluted estuaries in India, has been facing increased anthropogenic pressures during the last five decades (Menon et al., 2000). The Cochin city (the second largest city along the west coast) is located along this estuarine system. There are many potential pollutant sources and effluents that are brought into this estuary, including petroleum hydrocarbons due to intense maritime activities, domestic and industrial sewages etc. The sewage effluents are largely discharged into the lower reaches of the estuary through two outlets, namely Mullassery canal and Market canal. The extent of pollution in these areas is well above the tolerance level of the estuarine fauna. Cochin estuary receives an average daily sewage of 260 tonnes from the township (Nair, 2002). Continued discharge of effluents in the present rate may adversely affect the ecosystem and the dependent life. The population density in Cochin metropolitan area which was 3281 persons/sq. km in 1991 has gone up to ~6250 persons/sq. km according to 2001 census. The population explosion in and around Cochin contributes to the outflow of enormous amount of sewage effluents to the estuary. Total dissolved solids in the estuary are as high as 53750 mg/l during summer (CHISCB, 2002). Retting of coconut husk was another source of organic pollution in the estuary as, the pectinolytic activity of microorganisms liberates large amounts of organic matter into the medium. Studies on the macrobenthic fauna in an organically enriched environment of sewage and retting yards in Cochin estuary (Remani et al.1983) form the base of the present study. The present study evaluates the distribution and characteristics of the sediments and benthic organisms obtained from a seasonal survey conducted in 2005.

In this chapter, the available data on organic pollution in sediments and its impact on macrobenthic population within the Cochin estuary are compiled and compared with the present results. This will serve as an assessment of the status, severity, and environmental consequence of organic contamination in sediments. It is expected to provide an insight as well as a future perspective for an environmental management strategy for the Cochin estuary. The present study, is aimed to examine the long-term changes in species composition and distribution of benthic organisms at selected sites (ecologically comparable) in the Cochin estuary, since the studies of Remani et al (1983) from the same study area.

4.2 Study area and sampling period

A survey of 56 stations covering almost the entire Cochin estuary was carried out as a part of the project "Ecosystem Modelling of Cochin backwaters". Out of these, 14 stations were selected for this study based on their significance and classified into two different zones (Figure 4.1). Sewage zone (S-zone: stations 25, 26, 28, 29 and 30) covers the sewage-polluted region in the lower estuary, which receives the composite sewage from the city. Retting zone (R-zone: stations 19, 23 and 24 at vaduthala) covers the former traditional retting yards, which is also influenced by industrial discharge and stations 46, 47, 48, 50, 51 and 53 towards the southern estuary (comprises the regions of the Vayalar lake which is also influenced by organic enrichment due to discharge from fish processing plants, domestic waste and retting factories). In the present study sampling was carried out during February (Early pre-monsoon), April (Pre-monsoon) and September (Monsoon) 2005.

4.3. Results

4.3.1 General Hydrography

Variations in salinity, pH, Suspended Particulate Matter (SPM), Dissolved Organic Carbon (DOC), Dissolved Inorganic Carbon (DIC) and Chlorophyll *a* between the two zones are given in Table 4.1.

Water temperature

High temperature was recorded during pre-monsoon and the values ranged from 32.5 to 33.5°C in the S-zone and 32.3 to 35.2°C in R-zone. In early pre-monsoon the values ranged from 31.0 to 31.5°C in S-zone and 30.5 to 32.5°C in R-zone. Low values were recorded during monsoon and the values ranged from 29.0 to 30.5°C in S-zone and 27.0 to 31.1°C in R-zone.

Salinity

During all the 3 periods of sampling, S-zone showed relatively high salinity. Salinity varied from 1.00 to 27.13 psu in S-zone and zero to 18.95 psu in R-zone. In early pre-monsoon the value ranged from 17.30 to 27.13 psu (21.32 ± 4.29 psu) in S-zone whereas at R-zone the value ranged from 7.33 to 18.95 psu (13.99 ± 3.48 psu). During monsoon the value ranged from 1.00 to 7.83 psu (2.93 ± 2.78 psu) in S-zone and 0.00 to 0.23 psu (0.11 ± 0.09 psu) in R-zone. The low salinity obtained during Monsoon was attributable to land runoff induced by heavy rainfall. The corresponding value during pre-monsoon was 19.51-25.57 psu in S-zone and 3.19-15.8 psu in R-zone. High saline conditions prevailed in S-zone due to its proximity to the Arabian Sea. Low saline conditions prevailing in R-zone may be due to the influence of fresh water influx from the River Periyar at Vaduthala and the River Muvattupuzha in the southern region.

pH

pH was also generally high in the S-zone and ranged from 7.92-8.35 (8.07 ± 0.17) in S-zone and 6.44-7.85 (7.18 ± 0.56) in R-zone during early pre-monsoon. It ranged from 7.64 to 7.83 (7.73 ± 0.08) in the S-zone and 6.46-8.19 (7.15 ±0.57) in R-zone during pre-monsoon and from 6.71 to 7.46 (7.15 ± 0.28) in S-zone and 6.02-6.72 (6.43 ± 0.23) in R-zone during monsoon.

Dissolved Oxygen (DO)

DO values ranged from 8.24 to 11.60 $mg.l^{-1}$ in the S-zone and 5.24 to 8.97 $mg.l^{-1}$ in R-zone during early pre-monsoon. Pre-monsoon values ranged from 3.95 to 6.10 $mg.l^{-1}$ in S-zone and 4.73 to 9.13 $mg.l^{-1}$ in R-zone. During monsoon the values ranged from 6.37 to 7.56 $mg.l^{-1}$ in S-zone and 4.84 to 7.21 $mg.l^{-1}$ in R-zone.

Suspended Particulate Matter (SPM)

SPM was generally high in S-zone (32.79 ± 11.1 $mg.l^{-1}$) ranging from 12.33-49.6 $mg.l^{-1}$ and 7.6-41.16 $mg.l^{-1}$in R-zone. Early pre-monsoon average was comparatively higher and the value ranged from 34.32-49.60 $mg.l^{-1}$ (41.5 ± 7.45 $mg.l^{-1}$) in S-zone and 9.85-41.16 $mg.l^{-1}$ (22.85 ± 8.94 $mg.l^{-1}$) in R-zone. In pre-monsoon the value ranged from 28.00-47.12 $mg.l^{-1}$ (36.61 ± 7.16 $mg.l^{-1}$) in S-zone and 0.40-80.60 $mg.l^{-1}$ (21.97 ± 22.27 $mg.l^{-1}$) in R-zone and in monsoon the value ranged from 12.33-26.00 $mg.l^{-1}$ (20.27 ± 5.51 $mg.l^{-1}$) in S-zone and 6.27-30.20 $mg.l^{-1}$ (16.03 ± 9.46 $mg.l^{-1}$) in R-zone.

Dissolved organic carbon (DOC)

DOC values were comparatively higher in R-zone and the value ranged from 0.93 to 15.45µM and in the S-zone it ranged from 1.28 to 6.32µM during the study. Early pre-monsoon average was high and it was 7.96 ± 4.41µM in R-zone and 4.28 ± 1.42µM in S-zone. The corresponding value during pre-monsoon was 4.3 ± 1.09µM and 3.0 ± 0.57µM respectively. The mean values recorded during monsoon was 2.7 ± 1.17µM and 2.4 ± 1.64µM respectively for R and S-zone.

Dissolved Inorganic Carbon (DIC)

DIC values were high in S-zone and high values were recorded during pre-monsoon and early pre-monsoon period. The value ranged from 958.9 to 1454.4µM (1152.42 ± 259.78µM) in S-zone and 368.5 to 991.3µM (716.52 ± 222.75µM) in R-zone during early pre-monsoon. In pre-monsoon it ranged from 1255.4 to 1570.7µM (1444.1 ± 124.18µM) and 388.7 to 1253.2µM (690.0 ± 246.90µM) respectively for S-zone and R-zone. In monsoon the values recorded were comparatively low and it ranged from 285.50 to 667.92µM (392.1 ± 159.77µM) in S-zone and 269.15 to 386.84µM (320.6 ± 44.66µM) in R-zone.

Chlorophyll 'a'

Chlorophyll 'a' values generally ranged from 6.4 to 22.4 $mg.m^{-3}$ in the S-zone and 4.3 to 49.1 $mg.m^{-3}$ in R-zone. High chlorophyll 'a' (R-zone 24.4 ± 12.71 $mg.m^{-3}$; S-zone 11.5 ± 6.56 $mg.m^{-3}$) was recorded during pre-monsoon and low values were recorded during monsoon (S-zone, 5.9 ± 3.36 $mg.m^{-3}$; R-zone, 9.1 ± 11.34 $mg.m^{-3}$). The corresponding value during early pre-monsoon was 10.35 ± 6.69 $mg.m^{-3}$ in S-zone and 12.00 ± 6.96 $mg.m^{-3}$ in R-zone. In general R-zone showed higher concentration of chlorophyll 'a' than S-zone.

High primary production is usually related with low SPM, and hence the sewage discharge site (S-zone) having high SPM (avg. 32.79 $mg.l^{-1}$) showed low chlorophyll 'a' values (Table 4.1).

4.3.2 TOC, TN distribution and sediment texture

TOC content in the sediment of the two zones showed considerable difference. It ranged from 1.4 to 7.0% (2.8 ± 1.5%) at S-zone and 0.4 to 4.2% (avg. 1.7 ± 1.0%) in R-zone. Seasonal variation was also observed in sediment organic matter parameters. The highest mean value of TOC (3.68 ± 2.57%) was found in S-zone during monsoon and the lowest (1.47 ± 0.74%) in R-zone during pre-monsoon. The corresponding value for TOC at S- zone during early pre-monsoon and pre-monsoon was 2.71 ± 0.92% and 2.02 ± 1.09% respectively. In R-zone the mean value reported during early pre-monsoon and monsoon period was 1.94 ± 1.28% and 1.80 ± 1.08% respectively. Comparison with earlier works revealed an increase in TOC content of the sediment during the past few decades in S-zone and a reduction of the same in R-zone (Table 4.3).

TN values ranged from 0.1-0.48% in S-zone and 0.1-0.41% in R-zone. TN contents also showed the highest mean value at S-zone (0.26 ± 0.09%) during monsoon and the lowest at R-zone (0.04 ± 0.06%) during pre-monsoon. The corresponding value of TN in S-zone during early pre-monsoon and pre-monsoon was 0.26 ± 0.09% and 0.08 ± 0.08% respectively. In R-zone the mean value recorded during early pre-monsoon and monsoon was 0.15 ±0.17% and 0.18 ± 0.10% respectively. In general, TOC and TN were high in S-zone and low in R-zone (Table 4.1).

TOC/TN ratio ranged from 8.8-42.0 (Mean 18.20 ± 11.6) in S-zone and 7.9-77 (Mean 21.62 ± 12.85) in R-zone (Table 4.1). In general, low TOC/TN values (<10) were obtained during monsoon in both the zones, except for a high value at station 30 (outlet of market canal in S-zone). Monsoon average (24.71

± 30.26) was high in S-zone and the corresponding value during early pre-monsoon and pre-monsoon was 11.12 ± 2.42 and 18.78 ± 2.25 respectively. In R-zone high value was recorded during pre-monsoon (mean 34.38 ±25.26) and the corresponding value during early pre-monsoon and monsoon was 20.46 ± 11.38 and 10.04 ± 1.90 respectively. Both the zones showed a combination of refractory and labile organic matter, but the source of refractory organic matter was different (sewage effluent in S-zone and coconut husk in R-zone).

In S-zone, the sediment texture (Table 4.1) was silty-clay (56.73 ± 10.75% clay: 29.73 ± 11.04% silt) whilst in R-zone, it was clayey-sand (56.65 ± 25.39% sand: 30.54 ± 14.49% clay). Dominance of clay was reported from the S-zone throughout the sampling period (49.8 ± 10.7%, 53.6 ± 10.8% and 66.8 ± 10.7% clay during early pre-monsoon, pre-monsoon and monsoon respectively). In R-zone the substratum was dominated by sand (58.1 ± 32.4, 65.2 ± 30.4 and 46.7 ± 27.0% sand during early pre-monsoon, pre-monsoon and monsoon respectively). TOC, TN distribution in sediments along with clay, have been compared to assess the relationship between soil OM and texture. It was found that TOC and TN preservation in sediments were strongly related to particle size. A significant positive correlation was obtained between clay, TOC and TN (Figure 4.2 and Table 4.2). Strong correlation suggests that similar processes affected the movement of each within the estuary. The correlation was, however weak in April (Table 4.2).

4.3.3 Macrobenthic community

A total of 35 species of macrobenthos were identified from S-zone (sewage discharge site), and 42 species from R-zone (retting yards) during the present study as compared to 45 and 19 species respectively recognised in 1983 (Table 4.3). The faunal density at S-zone ranged from 21 to 1961 No.m^{-2} and the average density and biomass was 672 No.m^{-2} and 11.1 mg g^{-1} respectively. Polychaetes (27 species) were the most abundant faunal group (90%) and were the main contributor to species richness. Table 4.4 shows the mean numerical abundance and composition (%) of the macrobenthic fauna in the two zones. S-zone was dominated by capitellids (57%) and spionids contributed only 3% of the population. The dominant species was *Capitella capitata* (31%) followed by *Branchiocapitella singularis*, *Nepthys dibranchus* (9% each), *Heteromastus similes* (6%), *Paraheteromastus tenius* (5%), *Cosura coasta* and *Cirratulus cirratus* (4% each). Maximum percentage contribution of capitellids was recorded during pre-monsoon (62%) and early pre-monsoon (47%) and that of *C. capitata* in specific was 36% during pre-monsoon (Table 4.6). S-zone was dominated by polychaetes in all the three seasons (94% in early pre-monsoon, 92% in pre-monsoon and 86% during monsoon). The next dominant group was tanaidaceans, maximum was recorded during monsoon (9%) followed by 4% in pre-monsoon and 3% in early pre-monsoon. Other groups recorded during the study period comprised of amphipods and molluscs. (Figure 4.6)

Average faunal density (958 $No.m^{-2}$), biomass (26 $mg.g^{-1}$) and total number of species (42) were comparatively higher at R-zone. Polychaetes (61%), tanaidaceans, bivalves and amphipods [*P. tenius* (16%) and *H. similes* (14%), *Apseudes chilkensis* (12%), *Pendora flexosa* (7%), *Prionospio cirrifera* (6%), *Eriopisa chilkensis*, *Dendronereis aestuarina* and caprellids (4% each)] were the major contributors to the population density. R-zone was also dominated by polychaetes during the different seasons (52% in early pre-monsoon, 69% in pre-monsoon and 67% during monsoon). Other groups recorded in their order of dominance were taniadaceans (28%), amphipods (15%) and mollusc (5%) during early pre-monsoon, mollusc (16%), amphipods (12%) and tanaidaceans (3%) in pre-monsoon and amphipods (22%), tanaidaceans (5%), mollusc (4%) and isopods (1%) during monsoon (Figure 4.6).

Both the zones supported macroinvertebrate assemblages characterized by high abundance of deposit feeders (68% in S-zone and 49% in R-zone)

(Tables 4.4 and 4.5). This indicates the fact that quality of sediment organic matter is an important factor in defining the benthic community structure in addition to the sediment grain size (Rhoads, 1974; Aravindakshan et al., 1992).

4.3.4 Statistical Analysis

Cluster analysis

In order to relate the spatial distribution of benthic fauna to the presumed pollution gradient, Bray-Curtis similarities were calculated on (root transformed) species abundance data for the 14 sites and the resulting dendrogram is shown in Figure 4.3. Multi Dimensional Scaling (MDS) analysis (stress 0.12) of the same is given in Figure 4.4. Two major macrobenthic assemblages (at 40% similarity) were identified based on cluster analysis (Figure 4.3). The species composition and abundance of each assemblage primarily reflected responses to the nature and extent of organic pollution. Increased number of pollution tolerant and opportunistic taxa inhabited S-zone, which contained higher organic carbon compared to R-zone. The dominant community in the sewage-polluted zone was *C. capitata*, whereas in the retting yard it was *P. tenius*. Comparison with the earlier study (Remani et al., 1983) indicated a shift in the community structure from spionids in the early 80's to capitellids in 2005 in the sewage polluted zone, but no such variation was observed in the retting yards where the dominant community remained the same over the years (Table 4.5).

Species richness and diversity

Species richness and diversity (d, H') was tested using univariate methods (implemented in PRIMER). Margalef, d and Shannon-Wiener, H' ($\log_e$) indices indicated low species richness and diversity (d 0.94 ± 0.63 and H' 1.38 ± 0.71) and reduced number of species (35) at S-zone -Table 4.1. The community diversity was negatively correlated to sediment organic carbon

($n=13$, $r= 0.5596$, $p< 0.05$) at S-zone (Figure 4.5). At R-zone, the species diversity (avg. d 1.11 ± 0.40 and H' 1.64 ± 0.32), species abundance and density were high compared to S-zone in the present study.

Study of long-term variation in this region indicates a change in the species composition compared to the last few decades. In this site, high organic carbon content in the sediments owing to increased anthropogenic input was observed in the present study compared to earlier works. There was a clear-cut reduction both in qualitative and quantitative distribution of benthos (Table 4.3). *P. polybranchiata* (68-80%) dominated the sewage discharge area and *P. tenius* dominated the retting ground during 1983 (Remani et al., 1983). Fourty five species belonging to Coelentrata, Sipunculida, Crustacea, Mollusca and Polychaeta were reported from the sewage discharge site in 1983 but in the present study only 35 species were encountered and most importantly, the community was dominated by polychaetes. Sipunculids were found to be totally absent. In the retting yards, only 19 species belonging to polychaetes, molluscs and crustaceans were reported in 1983 by Remani et al., while in the present study, 41 species were recorded. It is mainly due to the reduction in retting activities since last two decades, resulting in the reduction of organic carbon input as reflected in the present study (Table 4.3). In both sites, polycheates dominated the benthic fauna (S-zone; 18% in 1983 and 90 % in 2005, R-zone; 48 % in 1983 and 61 % in 2005). Low benthic density is recorded in the present study in S-zone when compared with earlier work (Table 4.3).

4.4. Discussion

In general, S-zone sustained comparatively high saline conditions due to the incursion of marine waters. Low saline conditions prevailed in R-zone due to the influence of fresh water from River Periyar at Vaduthala and River Muvattupuzha in the South. Increased fresh water flow during monsoon reduced the salinity of the entire study area during Monsoon. Low D.O value of

3.95 mg/l was recorded during pre-monsoon from S-zone. Generally, DO levels of greater than 5 mg/l indicate an adequate supply of DO while organisms become stressed at levels 3-5 mg/l (VEM, 2006). pH and SPM were also high in S-zone. Industrial and domestic sewage that reach directly into the estuary significantly increased the SPM concentration. Extensive human settlements along the coast produce large quantities of domestic sewage as well as agricultural wastes (Qasim, 2003). High value of Chlorophyll a was recorded at R-zone relative to S-zone. High primary production is generally related with low SPM, hence the sewage discharge site (S-zone) with high SPM (avg. 32.79) showed low chlorophyll a values. In general, high chlorophyll a and high primary production implies that eutrophication was apparent in the estuary. High DOC values were reported from the R-zone and high values were recorded during the early pre-monsoon period. High DOC input might be autochthonous (transported from land) or allochthonous (produced in the estuary itself). High DIC values were reported from the S-zone. DIC comes from human settlements, organic wastes and by the decomposition of soil organic matter (Subramanian and Anuradha, 2000). Large amount of sewage disposed into the estuary at this region is the main source of DIC.

High TOC and TN recorded in sediments of S-zone were due to the impact from sewage discharge site. Both TOC and TN were high during monsoon due to increased terrestrial inputs, resulting from the prevailing monsoon. In R- zone comparatively high TOC was reported during the early pre-monsoon period. Remani et al., (1981) had also reported high organic carbon content during pre-monsoon (January-May) from the retting zones at Vaduthala. Whereas TOC:TN ratio was high at R-zone, high TOC/TN ratio signifies the presence of refractory organic carbon in this zone. High C/N ratios in the retting ground show the limitation of sediments and detritus as a food source for bottom fauna (Remani et al., 1981). But studies indicate that some of the refractory organic compounds may decompose easily in the presence of labile or some specific organic compounds (Graf, 1992; Lovely et al., 1994; Hee et al., 2001). Seasonal variation in the C/N ratio of the sediments of the Cochin backwaters may be attributed to the changes in the physico-chemical characteristics caused by the freshwater discharge bringing in lot of organic matter, considerably high in humic materials, from land during the monsoon months and also to the more stable conditions during the premonoon season, which are favourable for a good plankton population (Sankaranarayanan and Panampunnayil, 1979). Sediment texture was dominated by clay in S-zone which might have supported the high abundance of deposit feeders reported from this region. In R-zone the texture was dominated by sand during all the three seasons. Preetha (1994) sampled the regions of retting yards at Vaduthala during the period 1989-1990. The study showed that the substratum was silty sand (more than 60% sand) during all the seasons.

In general S-zone and R-zone showed a combination of labile and refractory organic matter. The study finds that apart from primary production, terrestrially derived OM from sewage effluents is the main source in S-zone and the coconut husk at the retting yards contributed to the OM at R-zone. TOC:TN ratio in sediments vary with quality of the organic matter and is a frequently used index to identify the source of organic matter. High TOC/TN ratio at R-zone was due to the contribution of refractory OM from coconut husk at the retting yards. The quality of OM depends on the supply from different pathways, including marine algae or terrestrial plants (Volkman et al., 2000). Values in the of range 6-9 are typically reported for marine derived organic matter, whereas values greater than 12 are usually found in terrestrially derived organic matter (REMP 2003). Marine algae, due to richness in protein and absence of cellulose, typically have TOC/TN ratios between 4 and 10, whereas vascular land plants, due to abundance of cellulose, have TOC/TN ratios of 20 and greater (Meyers, 1997). Considering the different sources of organic matter in the two zones, it is inferred that terrestrially derived organic matter contributed significantly along with production within the aquatic system.

Comparatively high primary production was recorded at R-zone, but sediment organic carbon was high at S-zone this clearly indicates the major input of O.M from other artificial sources (Anthropogenic input) than natural process (primary production). In most natural sedimentary systems, labile and refractory O.M occurs concomitantly. Sedimenting plankton blooms and food materials (consisting of animal or plant debris; Gage and Tyler, 1991) are sources of labile OM in the sediments. In estuarine environments large amounts of refractory OM of terrestrial origin are introduced into sedimentary systems.

Long-term organic carbon retention is commonly related to clay concentration, and the pattern is strong in this study. TOC and TN storage was strongly related to fine particle concentration. The correlation was comparatively weak in April; this might be due to highly intensified pollution. Correlation between TOC and TN was weak during September, probably due to the large input of terrestrially derived O.M containing low TN during monsoon. Sediment carbon and nutrient concentrations increase with decreasing grain size because organic matter adsorbs to mineral surfaces and has a high affinity for fine-grained sediment. The adsorption process helps to preserve the organic matter and gives rise to a generally positive correlation between TN, TOC and % mud (Hedges and Keil, 1995).

The species diversity in the selected zones during the three sampling periods appears to respond to environment quality. In general, both zones showed low species diversity. The classic model proposed by Pearson and Rosenberg (1978) predicts an increase in species diversity as levels of organic matter fall, which is evident at R-zone. Comparatively higher species diversity, abundance and density at the retting yards is due to the reduced coconut husk retting activities in the recent years and subsequent reduction in the organic carbon accumulation in the sediment. This indicates that this zone is less impacted, while lower species diversity at S-zone signifies the increased environmental stress. The significant negative correlation between the diversity indices and sediment carbon levels confirmed that benthic community structure has deteriorated at S-zone. The dominant community in the sewage-polluted zone was *C. capitata*, whereas the retting yard was dominated by *P. tenius*, *H. similes*, *A. chilkensis* and the bivalve *P. flexosa*. According to Preetha (1994) the dominant species reported from the retting yards were *D. aestuarina*, *P. polybranchiata*, *P. tenius*, *Apseudes chilkensis A. gymnophobia*, *C. trinoenyx* and bivalves like *Nuculana mauritiana*.

Comparison of the present data with the earlier work (1983) revealed that sewage effluent zone showed a shift in the community structure from spionids to capitellids. Replacement of spionids like *Prionospio pinnata* and *P. polybranchiata* with more tolerant species of capitellids such as *C. capitata* and *B. singularis* in S-zone may be an indication of the progressive deterioration of the region. *C. capitata*, a classical indicator of organic pollution, was most abundant (36% in April) in the sewage-polluted zone. This shows a change in environmental condition at the sewage-polluted zone, due to the increased anthropogenic activity. Organic enrichment intensified during the last two decades has resulted in the dominance of most tolerant group/species. Community responses to contaminants generally involve reduction in taxa richness, diversity or number of individuals. The retting yards with low species abundance reported in 1983 has however, become more diverse due to reduced retting activities in this region. There was not much variation in the community structure in the retting yards, where the dominant community remained the same over the years. Polychaetes (capitellids and spionids) when recorded more in number at polluted regions were identified as indicator species of pollution. In particular, species belonging to genera *Capitella* and *Prionospio* are recorded at places were organic load is extremely high (Pearson and Rosenberg, 1978, Glemarec and Hily, 1981 and Levin, 2000). Polychaetes like *P. cirrifera*, *B.*

singularis, *Dendronereis* sp. and crustaceans namely *A. chilkensis* were reported as pollution tolerant species, even though they were less abundant (Saraladevi et al., 1991). The continuous discharge of effluents, which got settled at the bottom, has led to the decimation of many species and dominance of opportunistic polychaete species. Increased anthropogenic activity at the sewage-polluted site has changed the benthic community structure. As a consequence, spionids dominated community during early 80's was replaced by more tolerant capitellids in 2005. Dominant deposit feeders reported in the present study (68% at S-zone) could reduce the density of other benthos (Kurihara, 1988), which is reflected in the low species abundance in the region when compared with earlier works (Remani et al., 1983). Sediment reworking by deposit feeders increases resuspension of sediment and thus, excludes suspension feeders by either inhibiting their feeding activities or burying their larvae (Shelgrove and Butman, 1994). Changes in benthic species composition and abundances often co-occur with changes in sediment contamination (Swartz et al., 1986). At moderate contaminant concentrations, sensitive organisms may be excluded by toxic response, providing a competitive release of space and food to more tolerant taxa, allowing them to increase (Millward and Klerks, 2002). Capitellid polychaetes are particularly tolerant and well-known pollution indicators and these dominated our samples at S-zone (64% in April) indicating a severely stressed environment.

Tolerant species may increase in abundance at moderate to relatively high concentrations until their toxic thresholds are exceeded. The polychaete *C. capitata* is the best-known benthic indicator taxon (Reish 1957). They are opportunistic and not only specifically keyed to organic enrichment, but also tolerant to a wide variety of contaminants. (Bridges et al., 1994). Effects of organic additions to sediment on *Capitella* sp. and a spionid *Streblospio benedicti* showed opportunistic response in *Capitella* sp., wherein the juveniles grew 2 times larger than the Spionid (Bridges, 1996). In contaminated areas, natural selection can result in populations that have enhanced tolerance that acts as a selective force in the environment. Tolerant genotypes may appear in other species and this might be the reason for the replacement of spionids in early 80's by the more tolerant capitellids in 2005. The assemblages and distribution of the benthic macroinvertebrates frequently change in response to pollution stress in predictable ways. This is the basis for the development of biological criteria to evaluate anthropogenic influences (Boyle and Fraleigh, 2003). Gray (1989) summarized the responses into three distinct categories: reduced diversity, increased domination by a single or group of opportunistic species, and reduced individual size. The first two were characteristic of S-zone, where a single opportunistic species (*C. capitata*) dominated, reducing the species diversity. Spatio-temporal changes in soft bottom macrobenthic communities along gradients of organic enrichment follow the typical secondary succession model initially described by Pearson and Rosenberg (1978) and then subsequently adopted by many others (e.g., Zmarzly et al., 1994; Trueblood et al., 1994; Nilsson and Rosenberg, 2000; Bolam et al., 2004). According to this model, macrobenthic species richness and abundance tend to decrease with increasing organic enrichment. However, abundance and biomass may also show marked peaks in early stages of succession due to the proliferation of opportunistic species. From a qualitative standpoint, the whole sequence of succession is characterized by the transition in the dominance from sensitive to tolerant species (Pearson and Rosenberg, 1978; Grall and Glemarec, 1997; Karlson et al., 2002).

The benthic infaunal communites recorded in the sewage polluted zone of Cochin estuary were characteristic of those generally seen in organically enriched sediments. As sediment organic matter increases above a critical level, changes in physicochemical properties of the sediment, caused by excessive organic matter leads to decreasing faunal densities (Pearson and Rosenberg, 1978). Regions receiving such high inputs of sewage have been reported to undergo drastic changes in the composition of benthic fauna, as observed in the present study. This has resulted in the dominance of more tolerant and opportunistic species of polychaete worms, especially deposit feeders belonging to the family Capitellidae, which are reported to be the biological indicators of organic pollution (Ansari et al., 1986). The long-term changes in the Cochin estuary gives an indication to how anthropogenic influences have dominated the natural process and affected the benthic organisms. The former retting yards in the estuary showed ecological recovery, as an increase in species abundance due to reduced activities of retting in the recent years and subsequent reduction in levels of organic carbon in the sediments.

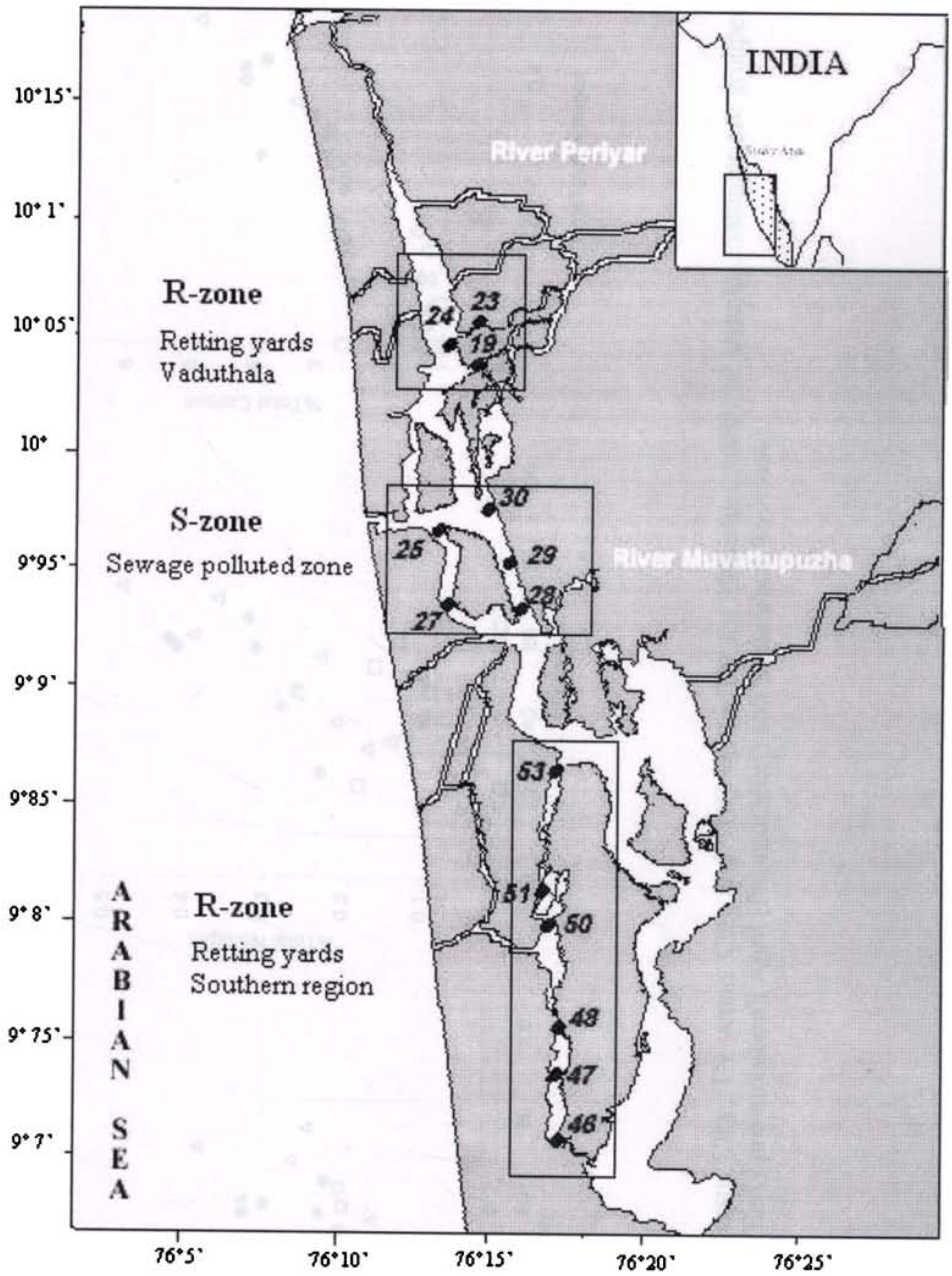


Figure 4.1. Study region (Cochin estuary) showing the sampling locations

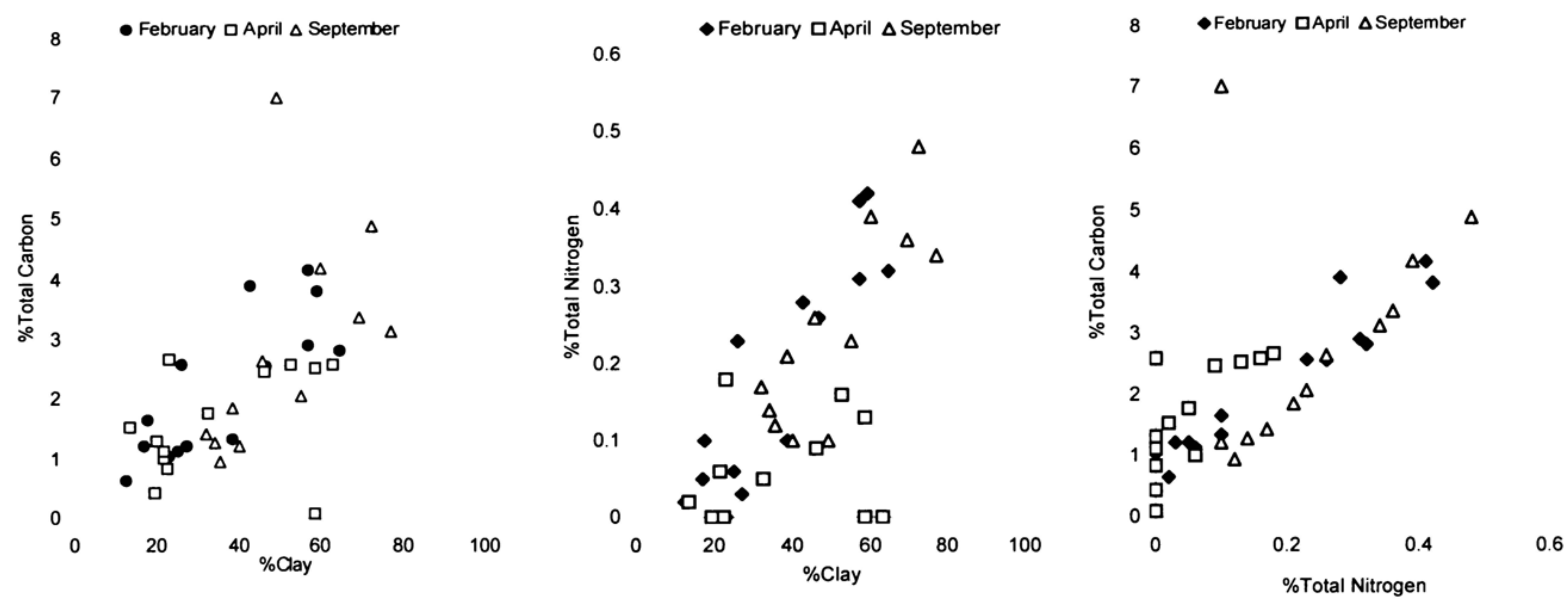


Figure 4.2. Plot for TOC versus Clay, TN versus Clay and TOC versus TN for 39 surface sediment samples. Samples are grouped based on different months February (Early pre-monsoon), April (Pre-monsoon) and September (Monsoon).

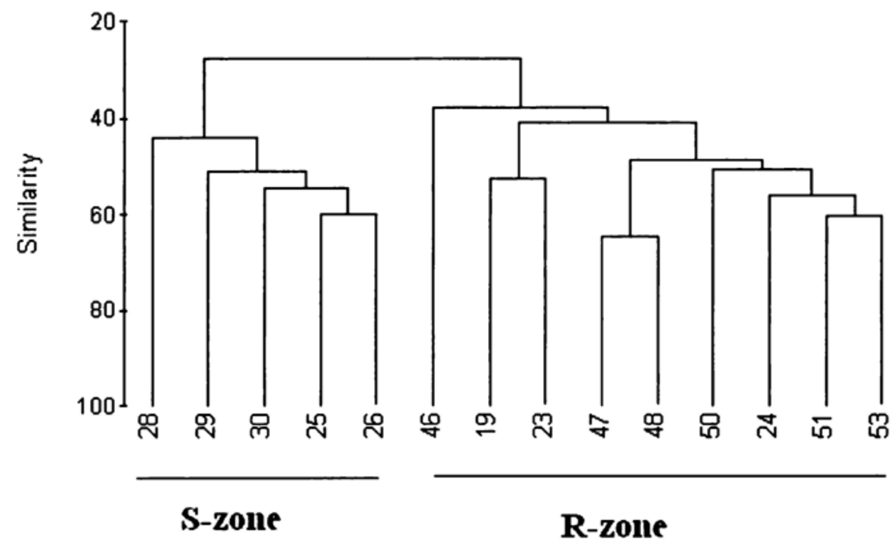


Figure 4.3. Macrobenthic fauna of Cochin estuary: hierarchical clustering of 14 sites using Bray – Curtis similarities (zone 1– sewage polluted zone, zone 2 – retting yards)

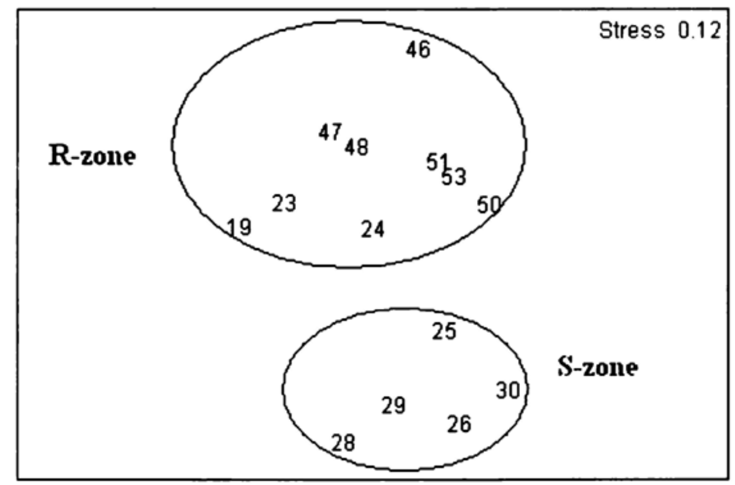


Figure 4.4. MDS analysis showing the two zones

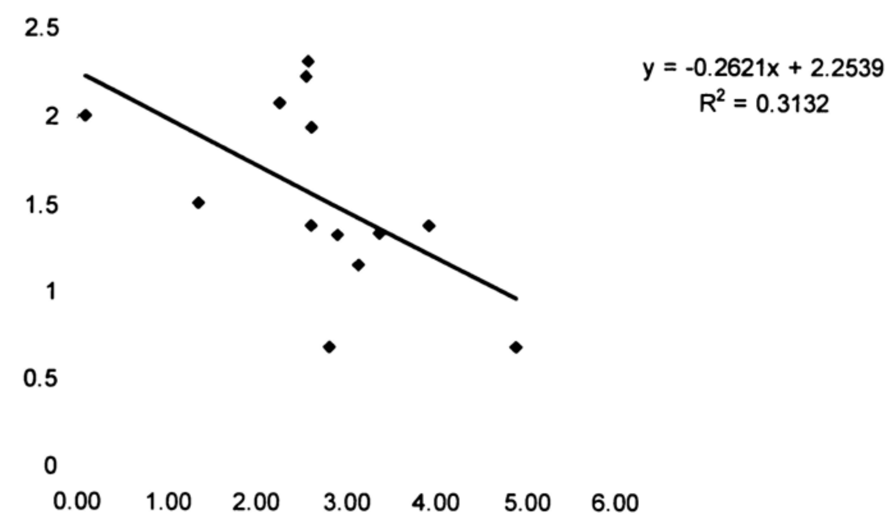


Figure 4.5. Correlation between community diversity (H' $\log_e$) and Sediment TOC at S-zone during the sampling period

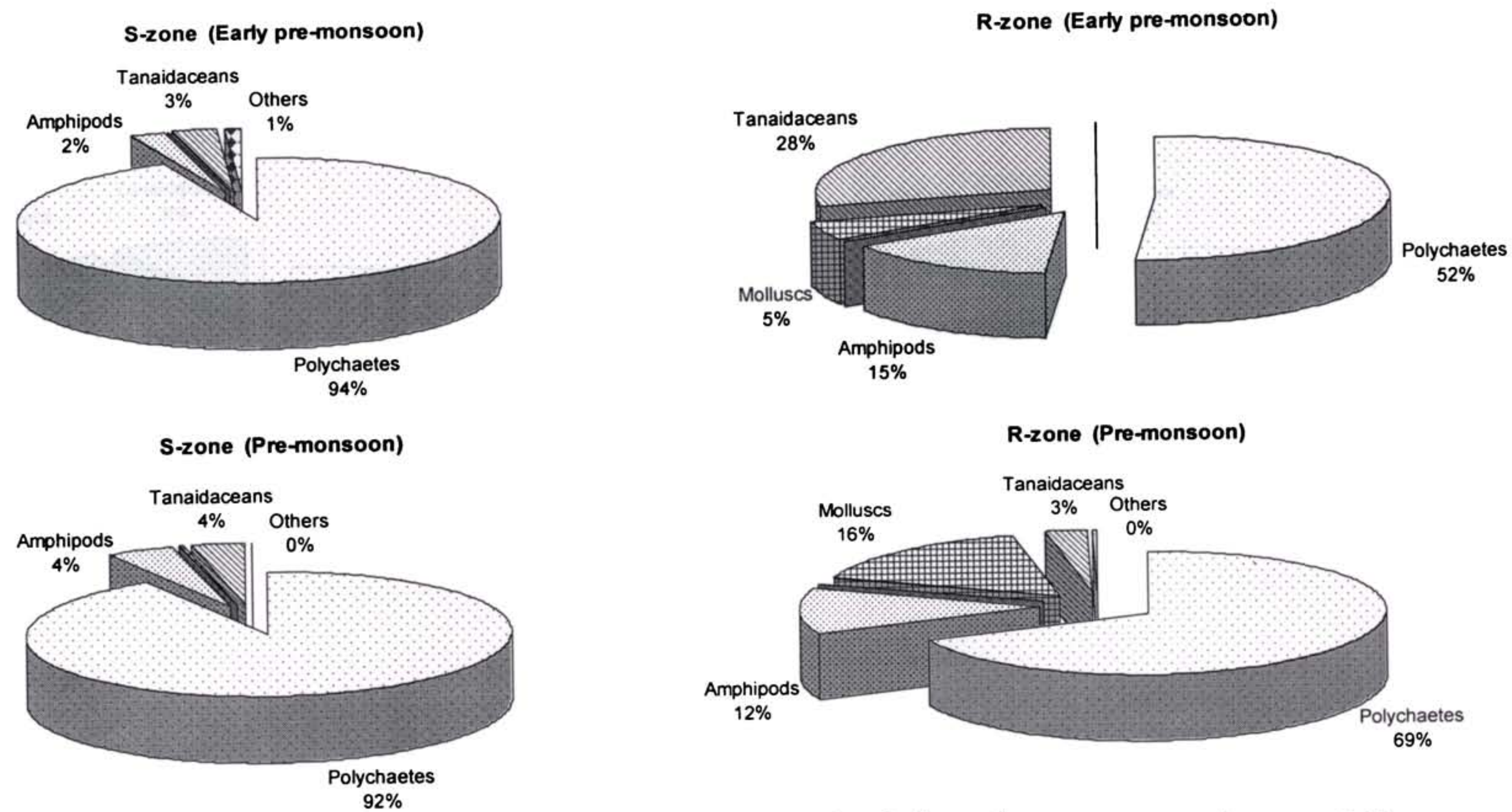


Figure 4.6 (a) Percentage contribution of major groups from the study region during early pre-monsoon and pre-monsoon

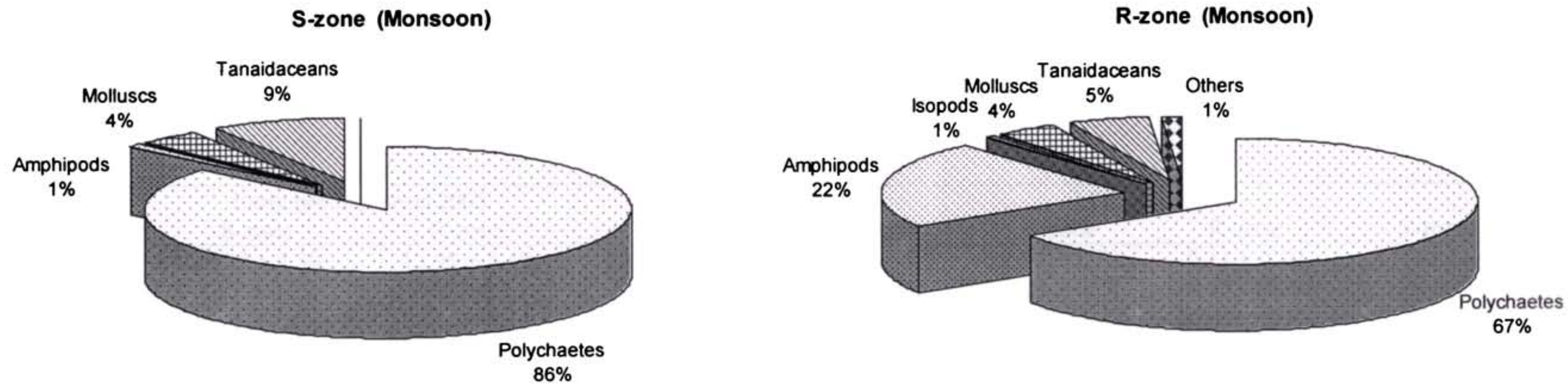


Figure 4.6 (b) Percentage contribution of major groups from the study region during monsoon

Table 4.1. Seasonal changes in the physico-chemical, biological and ecological parameters (average ± S.D) in the two zones of the study region

Parameters (avg ± S.D)	Early pre-monsoon 2005		Pre-monsoon 2005		Monsoon 2005		Average	
	S-zone	R-zone	S-zone	R-zone	S-zone	R-zone	S-zone	R-zone
Salinity (p.s.u)	21.32 ± 4.30	13.99 ± 3.48	22.81 ± 2.40	10.82 ± 4.00	2.93 ± 2.78	0.11 ± 0.10	15.7 ± 11.0	8.3 ±11.1
pH	8.07 ± 0.17	7.18 ± 0.56	7.73 ± 0.08	7.15 ±0.57	7.15 ± 0.28	6.43 ± 0.23	7.9 ±0.4	7.1 ±0.4
SPM ($mg.l^{-1}$)	41.5 ± 7.45	22.85 ± 8.94	36.61 ± 7.16	21.97 ± 22.27	20.27 ± 5.51	16.03 ±9.46	32.79 ± 11.1	20.29 ± 3.71
DOC	4.28 ± 1.42	7.96 ±4.41	3.0 ± 0.57	4.3 ± 1.09	2.4 ± 1.65	2.7 ± 1.17	3.21 ± 1.46	5.00 ±3.44
DIC	1152.42 ±259.78	716.52 ± 222.75	1444.1 ± 124.18	690.0 ± 246.90	392.1 ± 159.77	320.6 ± 44.66	996.19 ± 491.69	575.69 ± 266.4
Chl *a* ($mg.m^{-3}$)	10.35 ± 6.69	12.00 ± 6.96	11.5 ± 6.56	24.4 ± 12.71	5.9 ± 3.36	9.1 ± 11.34	9.25 ± 2.96	15.2 ± 8.13
TOC %	2.71 ± 0.92	1.94 ±1.28	2.02 ± 1.09	1.47 ±0.74	3.68 ± 2.57	1.80 ±1.08	2.80 ± 1.53	1.74 ± 1.04
TN %	0.26 ± 0.09	0.15 ±0.17	0.08 ± 0.08	0.04 ±0.06	0.26 ± 0.19	0.18 ± 0.10	0.20 ± 0.12	0.13 ± 0.11
TOC/TN	11.12 ± 2.42	20.46 ± 11.38	18.78 ± 2.25	34.38 ±25.26	24.71 ± 30.26	10.04 ± 1.90	18.20 ± 11.64	21.62 ± 12.85
Sand %	15.9 ± 17.4	58.1 ±32.4	15.7 ±14.4	65.2 ±30.4	9.0 ±10.3	46.7 ±27.0	13.54 ± 14.01	56.65 ± 25.39
Silt %	34.3 ±10.7	12.5 ±16.0	30.7 ±17.3	10.4 ±15.9	24.2 ±5.1	4.4 ±12.6	29.73 ± 11.04	9.11 ± 11.99
Clay %	49.8 ±10.7	29.3 ±18.1	53.6 ±10.8	24.4 ±17.9	66.8 ±10.7	37.8 ±21.9	56.73 ± 10.75	30.54 ± 14.49
Texture class	Silty clay	Clayey sand	Silty clay	Clayey sand	Silty clay	Clayey sand	Silty clay	Clayey sand
Benthic Biomass ($mg.g^{-1}$)	12.22 ± 17.63	44.79 ± 57.25	11.7 ± 8.11	17.1 ± 18.60	9.49 ± 11.27	16.12 ± 13.26	11.1 ±1.4	26.0 ±1.4
Benthic density ($No.m^{-2}$)	397 ± 364	967 ± 967	1106 ± 549	1224 ± 658	513 ± 652	721 ± 605	672 ±522	958 ±726
Sp. Diversity (H')	1.39 ± 0.57	1.55 ± 0.43	1.93 ± 0.32	1.76 ± 0.28	0.82 ±0.76	1.62 ± 0.19	1.38 ± 0.71	1.64±0.32
Diversity (d')	0.86 ± 0.68	1.00 ± 0.43	1.45 ± 0.36	1.36 ± 0.43	0.54 ± 0.53	0.96 ± 0.22	0.94±0.63	1.11 ± 0.40

Table 4.2. Pearson's correlation of coefficients between TOC, TN and clay in sediments during different sampling periods

Parameters	n	r	p
Clay & TOC Feb	14	0.804	< 0.001
Clay & TOC April	13	0.389	-
Clay & TOC Sept	12	0.555	< 0.05
Clay & TN Feb	14	0.885	< 0.001
Clay & TN April	13	0.24	-
Clay & TN Sept	12	0.830	< 0.001
TOC & TN Feb	14	0.9562	< 0.001
TOC & TN April	13	0.719	< 0.01
TOC & TN Sept	12	0.376	-

Table 4.3. Comparison with earlier records, - indicates no data

Year	TOC%		No. of species	Avg. density (No m^{-2})	Dominant faunal group	Reference
	Max.	Avg.				
					S-zone	
1975-76	3.84	1.62	-	-	-	Sankaranarayanan and Panampunnayil (1979)
1980	-	-	45	-	Polychaetes (18%)	Remani 1983
	2.68	-	-	-	-	Saraladevi et al., 1991
1996	5.9	2.10	44	1104	Polychaetes (75.7%)	Sheeba 2001
2005	7.0	2.8	35	593	Polychaetes (90%)	Present study
					R-zone	
1974-75	-	4.68	-	-	-	Remani et al., 1981
1980	-	-	19	-	Polychaetes (48%)	Remani et al., 1983
1989-90	4.9	-	-	-	Polychaetes	Preetha 1994
2005	4.2	1.74	42	922	Polychaetes (61%)	Present study

Table 4.4 Mean numerical abundance and % composition of the macrobenthic fauna in the two zones, "-" indicates no species (absence), "*" indicates the species belonging to the family Capitellidae and "•" indicates Spionidae.

Species	S-zone							R-zone										
Stations	25	26	28	29	30	Total	%	19	23	24	46	47	48	50	51	53	Total	%
Amphinomae rostrata	7	28	26	31	-	92	3	-	7	7	-	-	-	-	-	-	14	-
Ancistrosyllis constricta	28	7	21	14	-	70	2	-	-	-	-	-	-	-	-	-	-	-
*Branchiocapitella singularis**	132	28	7	69	28	264	9	28	7	21	-	-	7	-	-	-	63	1
*Capitella capitata**	445	83	28	250	104	911	31	35	-	63	-	-	-	-	-	21	118	1
Cirratulus cirratus	-	-	97	7	-	104	4	-	-	-	-	-	-	-	-	-	-	-
Cosura coasta	7	83	7	7	7	111	4	-	-	-	-	-	-	-	-	-	-	-
Dasybranchus	-	-	7	-	-	7	-	-	-	-	-	-	-	-	-	-	-	-
Dendronereis aestuarina	-	-	-	-	-	-	-	-	7	76	-	160	35	43	7	7	335	4
Diopatra neapolitana	-	-	-	-	14	14	-	-	-	-	-	-	-	-	-	-	-	-
Glycera alba	-	-	-	-	7	7	-	-	-	-	-	-	-	-	-	-	-	-
Glycera convoluta	-	7	-	-	-	7	-	-	-	-	-	-	-	-	-	7	7	-
Glycera longipinnis	-	-	-	-	-	-	-	-	-	-	-	-	-	9	-	-	9	-
Goniada emerita	-	-	7	-	-	7	-	-	-	-	-	-	-	-	-	28	28	-
*Heteromastidus bifidus**	7	-	-	-	-	7	-	-	-	28	11	-	-	-	-	-	38	-
*Heteromastus filiformis**	-	-	-	-	-	-	-	-	-	-	-	-	-	7	7	-	14	-
*Heteromastus similes**	118	21	28	7	-	174	6	14	7	347	11	63	104	97	201	285	1129	14
Lumbriconereis polydesma	-	7	56	-	-	63	2	-	-	-	-	-	-	-	-	-	-	-
Lumbriconereis simplex	7	-	28	-	-	35	1	-	-	-	-	-	-	-	7	-	7	-
Lycastis indica	-	-	-	-	-	-	-	111	7	7	11	104	7	-	-	-	247	3
*Mediomastus capensis**	-	-	-	-	-	-	-	7	-	14	-	-	7	14	-	-	42	1
Nepthys dibranchus	111	-	42	90	21	265	9	-	-	76	-	-	-	85	-	-	162	2
*Notomastus aberans**	69	21	-	-	14	104	4	-	-	28	21	-	14	45	7	70	184	2
*Notomastus fauveli**	35	7	-	-	7	49	2	-	-	167	32	14	7	-	28	35	282	3
*Notomastus latericius**	7	-	-	-	-	7	-	7	-	90	-	7	28	52	7	14	206	2
Owenia fusiformis	14	-	28	-	-	42	1	-	-	21	-	-	-	23	28	-	72	1
*Paraheteromastus tenius**	56	14	49	14	14	146	5	69	21	403	11	35	7	166	271	312	1295	16

Contd.

Species / Stations	S-zone 25	26	28	29	30	Total	%	R-zone 19	23	24	46	47	48	50	51	53	Total	%
Perinereis cavifrons	14	-	35	-	-	49	2	-	-	-	21	7	-	-	-	-	28	-
Platynereis sp.	-	-	-	-	-	-	-	-	7	-	42	-	-	-	-	-	49	1
Prionospio cirrifera•	7	-	-	63	11	80	3	-	42	7	219	21	21	92	14	118	534	6
Prionospio cirrobranchiata•	7	-	-	-	-	7	-	-	-	7	11	-	7	95	7	7	134	2
Prionospio pinnata•	-	-	-	-	-	-	-	-	-	-	-	-	-	7	-	-	7	-
Prionospio polybranchiata•	-	-	-	-	7	7	-	-	-	-	-	7	-	35	-	-	42	1
Pulella armata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	7	-
*Scyphoproctus djiboutiensis**	-	-	14	14	-	28	1	-	-	-	-	-	-	-	-	21	21	-
Oligochaetae	-	-	-	-	-	-	-	-	-	-	11	-	-	7	-	-	18	-
Corophium trinoenyx	-	-	-	7	-	7	-	-	-	-	-	-	-	-	-	-	-	-
Caprellidae	-	-	-	-	-	-	-	146	14	125	11	7	21	-	14	21	358	4
Eriopisa chilkensis	14	-	14	-	49	77	3	139	77	111	-	-	-	24	7	-	358	4
Grandidierella bonnerii	-	-	-	-	-	-	-	83	-	-	11	-	7	-	-	-	101	1
Grandidierella gilesi	-	-	-	7	-	7	-	14	-	28	11	28	-	76	63	21	241	3
Melita zylanica	7	-	-	-	-	7	-	21	-	90	-	63	21	7	-	-	202	2
Anthuridae	-	-	-	-	-	-	-	14	-	-	11	-	-	-	-	-	25	-
Asemenia brevicualris	-	-	-	35	-	35	1	-	-	-	-	-	-	-	-	-	-	-
Cardium sp.	-	-	-	-	7	7	-	-	-	-	-	-	-	-	-	-	-	-
Littorena littorea	-	-	-	-	-	-	-	-	-	-	11	-	-	-	35	-	45	1
Pendora flexuosa	-	-	-	-	-	-	-	222	28	14	11	97	125	57	-	7	562	7
Solariella lacunella	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	7	-
Villorita cyprinoides	-	-	-	-	-	-	-	-	-	7	52	14	63	-	14	-	150	2
Apseudes chilkensis	14	-	7	63	-	84	3	7	77	688	-	70	42	-	97	7	987	12
Apseudes gymnophobia	21	-	35	-	21	77	3	-	-	21	-	-	-	17	-	-	38	-
Portunes sp.	7	-	-	-	-	7	-	-	-	-	-	-	-	-	-	28	28	-
Metapenaeus dobsoni	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7	7	-
Total	1134	306	534	678	310	2963		918	300	2446	512	696	522	961	814	1029	8198	

Table 4.5. Ecologically important species during 1983 and 2005 (zone 1 and zone 2) *contributing more than 3% in 2005, •dominant species (P-polychaetes, M-mollusc, C-crustaceans

Species	Zone 1			Zone 2			
	Feeding Type	1983	2005	Species	Feeding Type	1983	2005
*Branchiocapitella singularis**	Deposit feeder	+	+	*Branchiocapitella singularis*	Deposit feeder	-	+
*Capitella capitata**•P	Deposit feeder	-	+	*Capitella capitata*	Deposit feeder	-	+
*Cirratulus cirratus**	Deposit feeder	-	+	*Dendronereis aestuarina**	Detritus feeder	+	+
*Cosura coasta**	Deposit feeder	-	+	*Heteromastus similes**	Deposit feeder	-	+
Dendronereis aestuarina	Detritus feeder	+	+	*Lycastis indica**	Carnivore	-	+
*Heteromastus similis**	Deposit feeder	-	+	*Nepthys dibranchus*	Omnivorous	-	+
Lumbriconereis polydesma	Carnivore	+	+	*Notomastus fauveli*	Deposit feeder	-	+
Lumbriconereis simplex	Carnivore	+	+	*Paraheteromastus tenius**•P	Deposit feeder	+	+
Diopatra neopolitana	Carnivore	+	+	*Prionospio cirrobranchiata*	Deposit feeder		
Lycastis indica	Carnivore	+	-	*Prionospio cirrifera**	Deposit feeder	-	+
*Nepthys dibranchus**	Omnivorous	-	+	*Caprellidae**	Omnivorous	-	+
*Paraheteromastus tenius**	Deposit feeder	+	+	*Eriopisa chilkensis**	Omnivorous	-	+
Prionospio cirrifera	Deposit feeder	-	+	*Grandidierella gilesi**	-	+	+
Prionospio pinnata	Deposit feeder	+	-	*Melita zeylanica*	-	-	+
Prionospio polybranchiata	Deposit feeder	+	-	*Apseudes chilkensis**•C	Omnivorous	+	+
*Eriopisa chilkensis**•C	Omnivorous	-	+	*Pendora flexuosa**•M	-	+	+
*Apseudes chilkensis**•C	Omnivorous	-	+	*Villorita cyprinoides*	Filter feeder	-	+

Table 4.6. Numerical abundance and % composition of the macrobenthic fauna in the two zones during Pre-monsoon 2005, "-" indicates no species (absence), "*" indicates the species belonging to the family Capitellidae and "•" indicates Spionidae.

	S-zone							R-zone										
Species / Stations	25	26	28	29	30	Total	%	19	23	24	46	47	48	50	51	53	Total	%
Amphinomae rostrata	21	83	0	83	0	187	4	0	21	21	0	0	0	0	0	0	42	0
Ancistrosyllis constricta	21	21	63	42	0	147	3	0	0	0	0	0	0	0	0	0	0	0
*Branchiocapitella singularis**	167	42	21	208	83	521	10	42	0	63	0	0	21	0	0	0	126	1
*Capitella capitata**	729	125	42	688	313	1897	36	0	0	146	0	0	0	0	0	0	146	2
Cosura coasta	21	83	21	21	21	167	3	0	0	0	0	0	0	0	0	0	0	0
Dendronereis aestuarina	0	0	0	0	0	0	0	0	21	0	0	0	83	0	0	0	104	1
Diopatra neapolitana	0	0	0	0	42	42	1	0	0	0	0	0	0	0	0	0	0	0
Glycera alba	0	0	0	0	21	21	0	0	0	0	0	0	0	0	0	0	0	0
Glycera convoluta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21	21	0
Goniada emerita	0	0	21	0	0	21	0	0	0	0	0	0	0	0	0	83	83	1
*Heteromastidus bifidus**	21	0	0	0	0	21	0	0	0	83	21	0	0	0	0	0	104	1
*Heteromastus filiformis**	0	0	0	0	0	0	0	0	0	0	0	0	0	21	21	0	42	0
*Heteromastus similes**	250	42	63	0	0	355	7	0	0	271	21	125	208	63	354	458	1500	16
Lumbriconereis notocirrata	0	21	167	0	0	188	4	0	0	0	0	0	0	0	0	0	0	0
Lumbriconereis simplex	0	0	83	0	0	83	2	0	0	0	0	0	0	0	0	0	0	0
Lycastis indica	0	0	0	0	0	0	0	21	0	0	21	0	0	0	0	0	42	0
*Mediomastus capensis**	0	0	0	0	0	0	0	0	0	42	0	0	0	42	0	0	84	1
Nepthys dibranchus	208	0	0	146	63	417	8	0	0	229	0	0	0	42	0	0	271	3
*Notomastus aberans**	125	0	0	0	42	167	3	0	0	83	42	0	42	83	0	21	271	3
*Notomastus fauveli**	63	21	0	0	21	105	2	0	0	479	63	21	21	0	21	0	605	7
*Notomastus latericius**	21	0	0	0	0	21	0	0	0	208	0	21	21	42	21	42	355	4
Owenia fusiformis	42	0	0	0	0	42	1	0	0	63	0	0	0	42	21	0	126	1
*Paraheteromastus tenius**	146	42	146	0	0	334	6	0	21	542	21	63	0	208	208	354	1417	15
Perinereis cavifrons	0	0	104	0	0	104	2	0	0	0	42	21	0	0	0	0	63	1
Platynereis sp.	0	0	0	0	0	0	0	0	0	0	83	0	0	0	0	0	83	1
Prionospio cirrifera•	21	0	0	0	0	21	0	0	0	21	21	0	0	0	0	0	42	0
Prionospio cirrobranchiata•	0	0	0	0	0	0	0	0	125	21	438	63	63	0	21	0	731	8

Contd.

Species		S-zone							R-zone										
Species	Station	25	26	28	29	30	Total	%	19	23	24	46	47	48	50	51	53	Total	%
Prionospio pinnata•		0	0	0	0	0	0	0	0	0	0	0	0	0	21	0	0	21	0
*Scyphoproctus djiboutiensis**		0	0	0	21	0	21	0	0	0	0	0	0	0	0	0	0	0	0
Oligochaetae		0	0	0	0	0	0	0	0	0	0	21	0	0	21	0	0	42	0
Corophium trinoenyx		0	0	0	21	0	21	0	0	0	0	0	0	0	0	0	0	0	0
Caprellidae		0	0	0	0	0	0	0	229	0	0	0	21	21	0	0	63	334	4
Eriopisa chilkensis		21	0	42	0	146	209	4	188	167	0	0	0	0	0	0	0	355	4
Grandidierella bonnerii		0	0	0	0	0	0	0	250	0	0	21	0	0	0	0	0	271	3
Grandidierella gilesi		0	0	0	0	0	0	0	42	0	0	21	0	0	0	0	0	63	1
Melita zylanica		0	0	0	0	0	0	0	63	0	0	0	0	0	0	0	0	63	1
Anthuridae		0	0	0	0	0	0	0	0	0	0	21	0	0	0	0	0	21	0
Cardium sp.		0	0	0	0	21	21	0	0	0	0	0	0	0	0	0	0	0	0
Littorena littorea		0	0	0	0	0	0	0	0	0	0	0	0	0	0	21	0	21	0
Pendora flexuosa		0	0	0	0	0	0	0	667	42	0	21	292	375	0	0	0	1397	15
Villorita cyprinoides		0	0	0	0	0	0	0	0	0	21	0	0	21	0	42	0	84	1
Apseudes chilkensis		0	0	0	0	0	0	0	0	167	21	0	21	0	0	0	0	209	2
Apseudes gymnophobia		42	0	104	0	42	188	4	0	0	63	0	0	0	0	0	0	63	1
Metapenaeus dobsoni		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21	21	0
Total		1919	480	877	1230	815	5321		1502	564	2377	878	648	876	585	730	1063	9223	

CHAPTER 5

Seasonal variability of macrobenthic species abundance in a tropical estuary (Cochin backwaters-India)

5.1 Introduction
5.2 Sampling period
5.3 Results
5.3.1 Hydrography
5.3.2 Sediment characteristics
5.3.3 Benthic density and biomass
5.3.4 Faunal composition and community structure
5.4 Discussion

5.1 Introduction

Estuaries of the Indian subcontinent mostly come under the profound influence of monsoon and on occasions of heavy rains they effectively flush out contaminants accumulated over the dry period. Because of this efficient natural cleansing, the degradation in their quality is cyclic. The annual rainfall at Cochin is around 3200mm, of which nearly 75% occurs during summer monsoon and its duration may vary from year to year. Normally, it occurs from June to September. During the peak of summer monsoon period (July/August) heavy rain occurs in the region (40-50cm rain fall in few hours) (Qasim 2003). Salinity remains at near zero values over a large portion of the Cochin backwaters during this period. In this bar-built tidal estuary, seasonal effect of freshwater is readily visible in the prevailing salinities, which play an important role in the ecobiology of the system (Madhupratap 1987). During post Summer monsoon period (Oct to January), the river discharge gradually diminishes depending on the intensity of North East monsoon and tidal influences gains momentum as the estuarine conditions change to a partially mixed type, weakening stratification (Menon et al. 2000). During pre monsoon period (Mar-

May), fresh water input to Cochin backwaters is minimum due to low rainfall over the region. Due to wide difference in temporal freshwater inflow in most estuaries over the annual cycle, the environmental status of those receiving wastes vary from season to season with no detectable degradation during monsoon and high deterioration in summer particularly towards inner segments where flushing rate decreases substantially due to meagre freshwater inflow and weak tidal influence.

5.2 Sampling Period

Sampling was carried out at 9 stations in Cochin backwaters during Pre-monsoon (April), Monsoon (July) and post summer monsoon (October) 2003

Location of the sampling stations (Figure-5.1)

Details of the 9 stations are given below.

Stations	Location	Lat.	Long	Depth
1	Barmouth	76.2392	9.9707	12.5-17
2	Ayyaampilly	76.2200	10.0108	2-4
3	Varapuzha	76.2800	10.0600	3.5-5
4	Pathalam	76.3072	10.0760	2.75-5
5	Opp. Taj	76.2717	9.9700	1.75-3
6	Chitrapuzha	76.3433	9.9367	3-6
7	Perumbalam	76.3433	9.8500	3-5
8	Murinjapuzha	76.3850	9.8267	3.2-4.5
9	Thannermukkom	76.4020	9.6733	3.75-8.5

5.3 Results

5.3.1 Hydrography

The parameters studied included temperature, salinity, pH, dissolved oxygen, B.O.D, nutrients (NO_2, NO_3, NH_4, PO_4, SiO_4) and Chlorophyll 'a'.

Water temperature – Figure 5.3.1

Surface water temperature varied from 27.7-33.5°C within the study period. Maximum temperature gradient was observed at station 1 (5.2 during monsoon and 3.5 during post summer monsoon). Minimum bottom temperature of 24.3°C was recorded at station 1 during post summer monsoon and a maximum of 33.7°C was recorded at station 8 during pre-monsoon. High temperature was recorded during pre-monsoon and it ranged from 31.60 to 33.50°C (surface) and bottom water temperature ranged from 31.3 to 33.7°C. Minimum temperature recorded during monsoon ranged from 27.7 to 30.9°C (surface) and 27.2 to 30.2°C (bottom). The corresponding values during post summer monsoon were 27.8 to 31.5°C and 24.3 to 31.40°C respectively.

Salinity -Figure 5.3.2

In all the stations, high salinity was recorded during pre-monsoon and low salinity during monsoon. Surface water salinity ranged from 0.09 to 27.87 psu during pre-monsoon, 0 to 2.60 psu during monsoon and 0 to 14.54 psu during post summer monsoon. Bottom water salinity values ranged from 0.02 to 32.75 psu in pre-monsoon, 0 to 34.06 psu during monsoon and 0 to 35.06 psu during post summer monsoon, highest salinity of 35.06 psu was recorded at station 1. Stations 1 and 5 which were nearer to the bar mouth showed a similar trend in salinity. At station 1 though surface salinity values underwent considerable fluctuation during the seasons, bottom salinity always remained high (>32 psu). At station 2 surface and bottom salinity values were similar though they showed seasonal variation (~ 20 psu during pre-monsoon; ranged between 2.32 and 2.89 psu during monsoon and post summer monsoon period). Stations 3 and 4 were influenced by the fresh water conditions due to discharge from the river Periyar and low salinity was recorded throughout the sampling period. On an average maximum salinity was observed during pre-monsoon (16.84 ± 10.71 psu; surface and 19.94 ± 11.38 psu; bottom). During this period high surface salinity was recorded at station 5 and 6 (27.74 and 27.87 psu respectively) whereas bottom water salinity reached up to 32.75 psu (station 1) and 32.77 psu (station 5). Minimum average was recorded during monsoon (0.55 ± 0.92 psu; surface and 6.54 ± 12.32 psu; bottom). Absolute fresh water conditions were recorded at station 3, 4, 6, 7 and 8. Corresponding values observed during post summer monsoon was 4.92 ± 5.46 psu at surface and 8.11 ± 11.32 psu at bottom. Stratification was more prominent during monsoon and post summer monsoon periods with high saline waters at the bottom and low saline waters at the top.

pH – Figure 5.3.3

pH values ranged from 6.50 to 7.56 (surface) and 6.41 to 7.52 (bottom) during pre-monsoon, 6.27 to 7.51 (surface) and 6.25 to 7.70 (bottom) during monsoon and the corresponding values during post summer monsoon were 6.09 to 7.24 and 6.40 to 7.47 respectively. Bottom values always remained high during all the seasons at stations 1 and 5 as compared to the surface values. In general high average was recorded during pre-monsoon (7.07 ± 0.38; surface and 7.11 ± 0.42; bottom) and low average was recorded during monsoon (6.65 ± 0.43; surface and 6.77 ± 0.57; bottom). The corresponding average recorded during post summer monsoon was 6.84 ± 0.34 and 6.89 ± 0.31 respectively.

Dissolved Oxygen (D.O)– Figure 5.3.4

Dissolved Oxygen values ranged from 3.90 to 6.88 mg/l (surface) and 3.53 to 7.07 mg/l (bottom) during pre-monsoon, 4.66 to 7.08 mg/l (surface) and 0.24 to 7.27 mg/l (bottom) during monsoon and the corresponding values during post summer monsoon were 4.65 to 8.71 mg/l and 0.82 to 9.13 mg/l respectively. Generally low values (<1 mg/l) were reported at the bottom waters of station 1 during monsoon and post summer monsoon seasons and high values (>8 mg/l) were reported at stations 3, 4 and 8 during post summer monsoon. In general high average was recorded during post summer monsoon season (7.01 ± 1.34 mg/l; surface and 5.72 ± 2.58 mg/l; bottom) and low average was recorded during pre-monsoon (5.77 ± 0.93 mg/l; surface and 5.31 ± 0.98 mg/l; bottom). The corresponding average during post summer monsoon was 6.44 ± 0.79 mg/l and 5.02 ± 2.41 mg/l respectively.

Biological Oxygen Demand (BOD) – Figure 5.3.5

During pre-monsoon the values ranged from 1.95 to 5.70 mg/l (surface) and 1.34 to 5.51 mg/l (bottom) and from 0 to 3.31 mg/l (surface) and 0 to 1.82 mg/l (bottom) during monsoon. The corresponding values during post summer monsoon were 0 to 6.66 mg/l and 0 to 4.60 mg/l respectively. During pre-monsoon high B.O.D (>5 mg/l) was recorded in the surface waters at station 5 (5.70 mg/l) and 9 (5.37 mg/l). High values were recorded in the bottom waters at station 6 (5.30 mg/l) and 8 (5.51 mg/l). Monsoon values were comparatively low (<3.3 mg/l). Again during post summer monsoon high values were recorded in the surface waters at station 2 (6.66 mg/l) and 5 (5.81 mg/l). Comparatively higher values (> 4.5 mg/l) were recorded at station 6 during pre-monsoon and post summer monsoon periods. In general high average was recorded during pre-monsoon and post summer monsoon periods (4.05 ± 1.20 mg/l; surface, 3.54 ± 1.55 mg/l; bottom and 4.17 ± 1.87 mg/l; surface, 2.75 ± 1.50 mg/l; bottom respectively. The corresponding values during monsoon were 1.89 ± 1.24 mg/l and 1.12 ± 0.89 mg/l.

NO_2 –Figure 5.3.6

In pre-monsoon the nitrite values ranged from 0.22 to 0.89µM (surface) and 0.18 to 0.79µM (bottom) and during monsoon the values ranged from 0.20 to 1.04µM (surface) and 0.30 to 2.68µM (bottom). The corresponding values during post summer monsoon were 0.04 to 0.98µM and 0.00 to 1.24µM respectively. In general high values were recorded during monsoon and were reported at station 1, 2.44µM (bottom) and at station 6 (2.62µM; surface and 2.68µM; bottom). Low value was reported at station 4. On an average high value (0.83 ± 0.78µM; surface and 1.07 ± 0.97µM; bottom) was recorded during monsoon and low average (0.20 ± 0.29µM; surface and 0.22 ± 0.39µM; bottom) was recorded during post summer monsoon. The corresponding average during pre-monsoon was 0.48 ± 0.23µM and 0.43 ± 0.22µM respectively.

NO_3 – Figure 5.3.7

Nitrate values ranged from 3.33 to 22.48 µM (surface); 2.28 to 17.75µM (bottom) during pre-monsoon and from 5.86 to 12.69µM (surface); 5.98 to 14.52µM (bottom) during monsoon. The corresponding values during post summer monsoon were 2.63 to 16.88µM and 0.13 to 16.50µM respectively. High average was reported during pre-monsoon and monsoon periods. During pre-monsoon high values were reported from station 1, 22.48 µM (surface) and 17.75µM (bottom) and during monsoon high values were reported from station 4, 12.69µM (surface) and 14.52µM (bottom). During post summer monsoon, high values were reported from station 3 (16.88µM; surface and 16.50µM; bottom) and 4 (16.50µM; surface and 15.88µM; bottom). At station 6 comparatively high values were recorded during monsoon (8.05µM; surface and 9.27µM; bottom) and the corresponding values during pre-monsoon were 6.95µM; surface and 5.00µM; bottom. Post summer monsoon value was low and it was 4.12µM and 4.62µM respectively. Low values were recorded at station 7 and 9 and it ranged from 1.75 to 9.76µM. At station 8 high values were recorded during the pre-monsoon (11.33 and 13.70µM) and monsoon (12.08 and 13.05µM) period compared to post summer monsoon (6.63 and 9.380µM). High average was recorded during pre-monsoon (10.86 ± 5.55µM; surface and 9.34 ± 5.08µM; bottom) and monsoon (8.95 ± 2.44µM; surface and

10.16 ± 2.84μM; bottom). Corresponding value during post summer monsoon was 7.03 ± 5.63μM; surface and 7.00 ± 5.92μM; bottom) respectively.

NH_4 – Figure 5.3.8

Pre-monsoon values ranged from 2.21 to 14.24μM (surface) and from 3.39 to 11.54μM (bottom) and during monsoon the values ranged from 19.00 to 99.50μM (surface) and from 6.00 to 75.50μM (bottom). Post summer monsoon values ranged from 13.00 to 117.00μM (surface) and 11.00 to 61.50μM (bottom). High values were reported during monsoon and post summer monsoon seasons. During monsoon high values were reported from surface waters at station 1 (99.50μM) and station 6 (73.00μM), high value was also reported from the bottom waters at station 8 (75.50μM). In post summer monsoon high value was reported from station 1 (117.00μM) and station 2 (164.50μM). Comparison between seasons showed that post summer monsoon average (55.17 ± 51.78μM; surface and 36.17 ± 20.91μM; bottom) was the highest and pre-monsoon average (9.57 ± 4.22μM; surface and 6.74 ± 2.73μM; bottom) was the lowest. The corresponding average during monsoon was 47.75 ± 26.53μM and 33.19 ± 24.06μM respectively.

PO_4 – Figure 5.3.9

In pre-monsoon the values ranged from 0.49 to 3.27μM (surface) and from 0.34 to 5.08μM (bottom), during monsoon the values ranged from 0.55 to 22.1μM (surface) and from 0.60 to 17.25μM (bottom). The corresponding range during post summer monsoon was 0.40 to 3.10μM and 0.30 to 3.85μM. High values were reported at station 6 (22.1μM; surface and 17.25μM; bottom) during monsoon. High average (4.44 ± 7.22μM; surface and 3.62 ± 5.58μM; bottom) was reported during monsoon. The corresponding values during pre-monsoon and post summer monsoon were 1.61 ±1.07μM; surface, 1.49 ±

1.60µM; bottom and 1.30 ± 0.88µM; surface, 1.71 ± 1.21µM; bottom respectively.

SiO_4 – Figure 5.3.10

High values were reported during monsoon and post summer monsoon seasons and the values ranged between 62.00 and 136.50µM (surface); 24.50 to 120.00µM (bottom) and 54.50 to 120.00µM (surface); 52.50 to 126.00µM (bottom) respectively. During pre-monsoon the values ranged from 12.15 to 96.96µM (surface) and 17.33 to 96.11µM (bottom). High values were reported at station 1 (136.00µM; surface) and 3 (136.50µM; surface) during monsoon. Monsoon and post summer monsoon average was high during the sampling period and these were 94.63 ± 32.95µM; surface, 73.50 ± 32.15µM; bottom and 90.72 ± 22.13µM; surface, 90.06 ± 26.47µM; bottom respectively. Corresponding value during pre-monsoon was 44.14 ± 31.26 µM and 39.63 ± 30.51µM respectively.

Chlorophyll 'a' – Figure 5.3.11

Chlorophyll 'a' was relatively high during monsoon (18.23±10.06 $mg.m^{-3}$; surface and 15.08 ± 10.46 $mg.m^{-3}$; bottom) as compared to the pre-monsoon (11.63 ± 9.26 $mg.m^{-3}$; surface and 13.38 ± 10.16 $mg.m^{-3}$; bottom) and post summer monsoon (8.61 ± 4.04 $mg.m^{-3}$; surface and 7.14 ± 3.33 $mg.m^{-3}$; bottom). The values ranged from 2.5 to 34.6 $mg.m^{-3}$ (surface) and 3.9 to 37.7 $mg.m^{-3}$ (bottom) during pre-monsoon. In monsoon the values ranged from 8.3 to 34.7 $mg.m^{-3}$ (surface) and 2.8 to 27.4 $mg.m^{-3}$ (bottom). Post summer monsoon values ranged from 3 to 15.25 $mg.m^{-3}$ (surface) and 2.5 to 10 $mg.m^{-3}$ (bottom). Maximum concentration was recorded at station 3 (34.6 $mg.m^{-3}$; surface and 37.7 $mg.m^{-3}$; bottom) during pre-monsoon. During monsoon and post summer monsoon seasons high production was reported in the surface waters when compared with bottom waters.

5.3.2 Sediment Characteristics

Sediment properties like grain size (sand, silt, clay) and sediment organic carbon were also studied for all the 9 stations during the three sampling months.

Grain size (%) –Figure 5.3.12

During pre-monsoon the substratum was clayey sand (>50% sand) in all the stations except at station 2 and 5 wherein the substratum was clayey silt (>80% silt). In monsoon the substratum was dominated by clay (>45%) and was silty clay at stations 1, 2 and 3, whereas substratum at station 4 was sandy clay and station 5 was clayey silt (55% silt). Stations 6, 7 and 8 were dominated by sand (>65%) and the substratum was silty sand. Post summer monsoon season showed the dominance of sand (>65%) in all the stations except station 1 and 2 wherein the substratum was dominated by clay (>40%). The substratum was clayey sand in stations 4, 5, 6, 7, 8 and 9 whereas it was silty sand at station 3. Substratum at station 1 was sandy clay and that at station 2 was silty clay. On an average pre-monsoon season showed the dominance of sand (58.97 ± 33.53%) and the substratum was silty sand. Percentage contribution of silt was 22.32 ± 36.66% and that of clay was 18.72 ± 10.23%. Monsoon season again showed the dominance of sand (36.77 ± 32.25%) and the corresponding percentage contribution of clay and silt was 31.55 ± 20.69% and 31.69 ± 13.35% respectively. Post summer monsoon season also showed the average dominance of sand (65.84 ± 22.26%) and the substratum was clayey sand and the relative contribution of clay and silt was 22.22 ± 12.66% and 11.93 ± 12.76% respectively.

Organic Carbon– Figure 5.3.13

Pre-monsoon values ranged from 1.04 to 30.36 mg g^{-1} and the highest value was reported at station 2 and lowest at station 1. During monsoon the values ranged from 5.17 to 50.37 mg g^{-1}, highest being reported at station 4 and lowest at station 7. Post summer monsoon values ranged from 4.83 to 24.15 mg g^{-1}, highest at station 1 and lowest at station 7. High average (29.24 ± 15.64 mg g^{-1}) was recorded during monsoon and low average (14.95 ± 6.63 mg g^{-1}) was recorded during post summer monsoon. The corresponding value during pre-monsoon was 16.41 ± 12.25 mg g^{-1}. High values were reported from stations 3 and 4 during monsoon period.

5.3.3 Benthic density and biomass (Figure 5.3.14 & 5.3.15)

During pre-monsoon benthic density ranged from 313-3729 No.m^{-2} and the average density recorded was 1391 ± 1118 No.m^{-2}. Highest density was recorded from station 2 and low density was recorded at station 7. Benthic density during monsoon ranged from 125-3958 No.m^{-2} and the average was 1034 ± 1188 No.m^{-2}. High density was again recorded from station 2 and low density was recorded at station 4 &5. Post summer monsoon values ranged from 0-2458 No.m^{-2} and the average was 819 ± 791 No.m^{-2}. During post summer monsoon season high density was recorded at station 8 and no fauna was recorded at the stations 4&5. Comparatively high density was recorded during pre-monsoon and monsoon period.

Biomass values ranged from 7.19 to 580.04 g.m^{-2} during the pre-monsoon period. Low biomass was reported from station 4 and high biomass was reported from station 9. High average (79.92 ± 188.31 g.m^{-2}) was recorded during the pre-monsoon period. In monsoon the values ranged from 1.14 to 133 g.m^{-2}, low value was reported at station 5 and high biomass was again reported from station 9. Post summer monsoon values ranged from 0 to 325.5 g.m^{-2}. Fauna was absent at stations 4and 5 and high value was recorded from station 9. Generally low values were reported from stations 3, 4 and 5 during the sampling period and high value was reported from station 9.

5.3.4 Faunal composition and community structure (Figure 5.3.16 Table 5.1)

47 species belonging to 9 taxa were encountered during the study period from the 9 stations.

During pre-monsoon both polychaetes and mollusc dominated the region (38% respectively) followed by tanaidaceans (17%) and amphipods (7%). All together 35 species were reported during this season. Among polychaetes (total 22 species) the dominant species reported during the study period was *Capitella capitata* (13.11%) with a total density of 1958/m^2 followed by *Paraheteromastus tenius* (6.8%), *Heteromastus similes*, *Prionospio cirrobranchiata* and *Dendronereis aestuarina.* Among mollusc the dominant species reported was *Villorita cyprinoides* (16.74%) high abundance recorded at station 6 followed by *Pendora flexosa* (10.04%), an indicator of organic pollution, high abundance was reported at station 2. Among tanaidaceans high abundance of *Apseudes chilkensis* (16.04%) was also reported from station 2. Among amphipods high abundance of *E. chilkensis* (3.91%) was reported from station 2. At station 1, (Barmouth region) the community was constituted by mollusc (*Cardium* sp. and *Asseminea breviculata*) with a total density of 1583/m^2 and a single species of polychaete (*Capitella capitata* 42/m^2). Station 2 showed the dominance of *Apseudes chilkensis* (2396/m^2) and the bivalve *Pendora flexosa* (1458/m^2) followed by *Eriopisa chilkensis* (479/m^2), *Capitella capitata* (458/m^2), *Prionospio cirrobranchiata* (396/m^2) and *Dendronereis aestuarina* (229/m^2). Low density was recorded at stations 3 and 4 and were dominated by polychaetes (>85%) and the dominant species recorded was *Capitella capitata* (375/m^2 and 313/m^2 respectively). Other species reported from these stations were *Dendronereis aestuarina*, *Grandidierella bonerri*, *G. gilesi*, *E. chilkensis*, *Branchiocapitella singularis* and *Paraheteromastus tenius.* Station 5 was also dominated by polychaetes (91%) and the dominant species reported was *C. capitata* (667/m^2) followed by *B. singularis* (104/m^2), *Prinospio cirrifera* (104/m^2), and *E. chilkensis* (83/m^2). Station 6 was dominated by the bivalve *Villorita cyprinoides* (1875/m^2) followed by *Paraheteromastus tenius* and *Heteromastus similes*. Stations 7 and 8 were dominated by polychaetes (73% and 92% respectively) and the dominant species reported during the period were *Paraheteromastus tenius* and *Heteromastus similes*. Dominant community recorded at station 9 was *Villorita cyprinoides* (604/m^2) followed by *Lycastis indica, Dendronereis aestuarina* and *Prionospio cirrobranchiata*.

During monsoon average dominance of tanaidaceans (38.16%) and polychaetes (35.87%) followed by molluscs (16.49%) and amphipods (8.18%). All together 31 species were reported and the dominant species was *Apseudes chilkensis* (33.43%) followed by *P. flexuosa* (15.78%) and the polychaete *Capitella capitata* (10.90%). Low density (167/m^2) was recorded at station 1 and was represented by 2 species of polychaetes (*Capitella capitata* and *Sternaspis scutata*) and a single species of mollusc (*Assemenia breviculata*). High abundance (3958/m^2) was recorded at station 2 and the dominant species recorded were *Apseudes chilkensis* (4646/m^2) followed by *Pendora flexosa* (2188/m^2), *Apseudes gymnophobia* (563/m^2), *Eriopisa chilkensis* (417/m^2) and *Capitella capitata* (313/m^2). At station 3 the community was represented by only 2 species of polychaetes namely *Capitella capitata* (958/m^2) and *Dendronereis aestuarina*. The only species present at station 4 was *Anatopynia* and *Plectronemia conspersa*. Polychaetes (100%) were the only fauna present at station 5 represented by two species namely *Ancistrosyllis constricta* (104/m^2) and *Prionospio cirrobranchiata* (21/m^2). Station 6 and 7 were also dominated by polychaetes (>90%) and the dominant species recorded at station 6 was *C. capitata* (208/m^2). Other species were *Prionospio cirrobarnchiata*, and *Paraheteromastus tenius* and that at station 7 were *Prionospio cirrobarnchiata*, *Paraheteromastus tenius*, *Prionospio cirrifera* and *Heteromastus similes*. Dominance of polychaetes (67%) {*Dendronereis aestuarina* (188/m^2) followed by *Prioonospio cirrobranchiata* (167/m^2) and

Paraheteromastus tenius}, followed by tanidaceans (22%) {*Apseudes chilkensis* (167/m^2)} were reported at station 8. Polychaetes (52%) followed by amphipods (33%) dominated at station 9. *Dendronereis aestuarina* (125/m^2), *Paraheteromastus tenius* (104/m^2), Caprellids (83/m^2), *Grandidierella giles* (83/m^2), *G. bonerri* and *Villorita cyprinoids* were the dominant species.

In post summer monsoon period the dominant group was polychaetes (78%) followed by tanaidaceans (10%), amphipods (8%) and molluscs (4%). During this season 30 species were recorded and the dominant ones were *Paraheteromastus tenius* (22.32%), *Capitella capitata* (20.34%) and *Heteromastus similes* (14.12%). Station 1 was dominated by polychaetes (100%) represented by *C. capitata* (833/m^2) and *P. tenius* (104/m^2). High abundance of tanaidaceans {*Apseudes chilkensis* (354/m^2)} followed by amphipods {*Grandidierella bonerri* (167/m^2) and *G. gilesi* (125/m^2)} was recorded at station 2 Low density (125/m^2) was recorded at station 3 and no fauna was recorded from station 4 and 5. Station 3 was represented by two species of polychaetes (*Capitella capitata* and *Heteromastus similes*) and the *Anatopynia*. Stations 6 and 7 were entirely dominated by polychaetes (100%) and the dominant species recorded were *Capitella capitata* (167/m^2) at station 6 and *Paraheteromastus tenius* (292/m^2) followed by *Heteromastus similes* and *Capitella capitata* at station 7. Stations 8 and 9 were also dominated by polychaetes (>70%) and the dominant species were *Paraheteromastus tenius* followed by *Heteromastus similes* and *C. capitata*.

5.3.5 Statistical Analysis

Cluster Analysis

Cluster Analysis carried out after square root transformation of the species abundance data showed that few stations behaved in a similar manner during the different seasons. (Figure-5.3.17) At 60% similarity level 3 clusters were formed. Cluster I comprised of station 3 (during pre-monsoon &

monsoon), 4 (pre-monsoon) and 1(post summer monsoon). In these stations more than 85% of the benthic fauna were polychaetes dominated by *Capitella capitata*, other species reported from these stations were *Dendronereis aestuarina*, *Branchiocapitella singularis* and *Paraheteromastus tenuis*. At station 3 amphipods such as *Eriopisa chilkensis*, *Grandidierella bonneri* and *G. gilesi* were also reported during pre-monsoon. Cluster II comprised of station 2 during the different seasons. Irrespective of the different seasons the species composition remained unique. The dominant group reported was tanaidaceans (> 38%) that included the species *Apseudes chilkensis* and *A. gymnophobium*. Other species reported were the amphipods *Eriopisa chilkensis*, *Grandidierella bonneri* and *G. gilesi* and the polychaetes *Capitella capitata*, *Paraheteromastus tenuis*, *Prionospio cirrobranchiata* and *Dendronereis aestuarina*. Cluster III was composed of station 8 (pre-monsoon and post summer monsoon) and station 9 (post summer monsoon). In these stations the community was dominated by polychaetes (>70%) and the dominant species were *Paraheteromastus tenius* (>30%) followed by *Heteromastus similes* and *Capitella capitata*. At 40% similarity level two clusters were formed, cluster I comprised of station 3, 4 and 5 (pre-monsoon), station 3 (monsoon) and station 1, 3 and 6 during post summer monsoon. In these stations more than 80% of the benthic fauna was composed of polychaetes and the dominant species was *C. capitata*. Cluster II comprised of station 8 (pre-monsoon), station 6, 7 and 8 during monsoon and station 7, 8 and 9 during post summer monsoon. In these stations more than 65% of the community was composed of polychaetes and the common species present were *Paraheteromastus tenius*, *Heteromastus similes* and *Prionospio cirrobranchiata*.

Diversity indices (Table 5.2)

Number of species at each station varied from 2-18 during pre-monsoon, 2-15 during monsoon and 3-16 during post summer monsoon.

Species richness (Margalef's index, d')

During pre-monsoon the richness values ranged from 0.17-1.95 and the average was 1.01 ± 0.64. Low richness was reported at station 4 with only 2 species and high richness was reported at station 2. During monsoon the value ranged from 0.21-1.81, low values were reported from stations 4&5 and high value was reported at station 7. Average for this season was 0.94 ± 0.69. Post summer monsoon values ranged from 0.41-1.92, low value was reported at station 3 and high value was reported at station 8. Average for this season was 1.23 ± 0.57.

Evenness (Pielou's index, J')

Evenness during pre-monsoon ranged from 0.50-0.87 and the average was 0.69 ± 0.12. In monsoon the values ranged from 0.25-1.00 and the average was 0.77 ± 0.24. Post summer monsoon values ranged from 0.55-0.86 and the average was 0.79 ± 0.11. High values were reported from station 7 during pre-monsoon and post summer monsoon season and at station 4 during monsoon.

Diversity (Shannon weaver index, H')

During pre-monsoon the values ranged from 0.51-2.08 and the average was 1.33 ± 0.57. High diversity was reported at station 8 and low diversity was reported from station 4. In monsoon the values ranged from 0.17-2.34, low diversity being reported at station 3 and high diversity again from station 8. Comparatively high diversity (>2) was reported at station 7, 8 and 9. The average for this season was 1.38 ± 0.82. In post summer monsoon the value ranged from 0.87-2.22, low value was reported at station 3 and high diversity was reported at station 8. The average during this season was 1.70 ± 0.57.

Dominance (Simpson's index, λ')

Pre-monsoon values ranged from 0.33-0.81 and the average was 0.59 ± 0.19. During monsoon the values ranged from 0.08-0.90 and the average was 0.62 ± 0.29. In post summer monsoon season the value ranged from 0.45-0.85 and the average was 0.72 ± 0.17. Low dominance was reported at station 4, 3 and 1 during pre-monsoon, monsoon and post summer monsoon respectively. High dominance was reported at station during pre-monsoon and monsoon. During post summer monsoon high dominance was reported at station 7.

5.4. Discussion

Cochin backwaters, a tropical micro-tidal estuary with high biological production, provides an ideal breeding ground for many economically important fin fishes and shell fishes (Qasim, 2003). As a result of massive reclamation for the rapid urbanization and industrialization, the Cochin backwaters are facing severe ecological problems including eutrophication (Gopalan et al., 1983). Sixteen major and several minor industries situated on the banks of the River Periyar discharge untreated or partially treated wastes (acids, nutrients, heavy metals, pesticides etc.) into the estuary (Balachandran et al., 2003). The domestic waste from the Cochin metropolitan city also creates organic pollution. All these activities leads to the changes in the population and structure of trophic webs and even affect the overall functioning of the ecosystem (Unnithan et al., 1975; Menon et al., 2000).

Hydrography

Hydrography of an estuary is mainly influenced by the intrusion of seawater and the influx of freshwater from the rivers. The concentration of nutrients in the estuarine region is controlled by fresh water inflow and land drainage. Onset of summer monsoon leads to substantial increase in river discharge and this performs a clean up of the estuary, thereby completing the seasonal cycle (Shyanamma and Balakrishnan, 1973; Menon et al., 2000). Large input of nutrients into the estuary irrespective of seasons, originating from domestic sewage and industrial effluents has been reported (Unnithan et al., 1975). Variation in these parameters in an aquatic ecosystem can affect the water quality and in turn affect the biota.

High water temperature was recorded during pre-monsoon and low during monsoon for the entire study area. During pre-monsoon dry weather prevails over the region and with a considerably reduced fresh water flow (1.69%, Srinivas et al., 2003), the estuary becomes warmer due to high solar radiation (500-580 g cal cm^{-2} d^{-1}, Qasim et al., 1968). Thermal stratification (>5) was observed at barmouth (station 1), which is adjacent to sea during monsoon and post summer monsoon period. According to Sankaranarayanan and Qasim (1969) during pre-monsoon the temperature remains uniform through out the water column and with the onset of monsoon the changes in water temperature become apparent. This is accompanied by a gradual fall at the surface and a very rapid fall at deeper layers and a maximum thermal gradient of more than 5°C was often observed. Nair and Tranter (1972), Joseph (1988), Sivadasan (1996) and Sheeba (2000) have also reported high water temperature during pre-monsoon in the Cochin estuary. Similar observation was made in other estuaries (Talikhedkar et al., (1976), Beninger and Lucas (1984) Modassir (1990).

In the estuary high salinity was recorded during the pre-monsoon period. High saline waters prevailed in the estuary due to the incursion of Arabian Sea waters through the barmouth and the lower reaches of the estuary behave as a section of the Arabian Sea (Menon et al., 2000). Low salinity was recorded during all the seasons at stations 3 and 4 due to the intrusion of fresh water from the River Periyar and at station 8 due to the intrusion of fresh water from the River Muvattupuzha. In all the other areas a distinct seasonal pattern was evident. According to the observations made during the study almost freshwater conditions prevailed in the entire estuary during monsoon. The results are comparable with the observations made by Sivenkutty (1977), Gopakumar (1991) and Qasim, 2003. In pre-monsoon the estuary becomes well mixed and homogenous conditions prevail whereas during the monsoon and post-monsoon months a clear stratification occurs in the water column with low saline water at the top and high saline water at the bottom (Qasim and Madhupratap, 1981). Low salinity with near fresh water conditions observed during monsoon is due to the dilution by large amount of freshwater influx. Nair and Tranter (1972); Madhupratap, (1987) also reported that surface salinity reaches near zero values over most of the region during monsoon. With the commencement of monsoon the surface water is considerably diluted and a clearly defined halocline develops, with brackish water or nearly fresh water at the top and seawater at the bottom, both remaining more or less undisturbed (Sankaranarayanan and Qasim, 1969). The annual rainfall at Cochin is around 3200mm, of which nearly 75% occurs during summer monsoon period; June-September (Qasim, 2003). Premonsoon period exhibits least stratification with highest salinity at the bottom. Sudden changes are brought in the environment with the onset of the monsoons. During July (SW monsoon) a saline wedge is present and the surface waters show nearly freshwater conditions. Salinity shows an increase during November (NE monsoon) and January (winter) due to reduced monsoonal influence (Joseph and Kurup 1990).

pH of the medium depends on the different factors like photosynthetic activity, discharge of industrial effluents, nature of dissolved materials and rainfall. Industrial effluents discharged into the aquatic system may lower or elevate the pH depending on the nature of effluents. Wide range in pH (6.09-7.70) was observed within the estuary. Low pH was recorded at station 3 downstream of industrial region at Eloor and high pH recorded at a station 1, bar mouth region. According to Sankaranarayanan and Qasim (1969) during the period of fresh water discharge the values decreased and reached minimum during July and August. Nair et al. (1988) has also observed low pH values from the estuarine regions during monsoon months and stated that these low values are due to the effluents discharged from the fertilizer factories.

Low DO values were recorded in the bottom waters at station 1 during monsoon and post summer monsoon. This might be due to high anthropogenic influence at the central estuarine region. Generally high values were reported during monsoon and post summer monsoon season in the surface waters. According to Sankaranayanan and Qasim (1969), D.O shows a pronounced seasonal change though at surface the values are subjected to little fluctuations, at deeper layer values as low as 1 to 2 were commonly observed (in the present study at station 1). Monsoon showers influenced seasonal variation in D.O and the maximum was reported during July (Arun, 2004). Modassir (1990) reported similar observations in Zuari estuary at Goa. The variation in dissolved oxygen is attributed to the seasonal and tidal fluctuation and lowest oxygen contents were usually found during pre-monsoon periods (Vijayan et al., 1976). The observations made during the present study are comparable with that of Saraladevi (1986) and Sheeba (2000) in the Cochin estuary. Jyothibabu et al., (2006) has also reported high dissolved oxygen concentration during peak summer monsoon. High D.O reported during monsoon is due to greater solubility of oxygen in freshwater and high turbulence (Vasudevan Nayar, 1992).

Biological oxygen demand is dependent on the amount of suspended or dissolved organic matter in the water. According to Martin (1970), BOD of 8.0 mg/l indicates moderately polluted condition. In general, BOD values were low in the estuary (< 5 mg/l) except for high values recorded in the surface waters of station 2 (> 6 mg/l) during post summer monsoon and at station 5 (> 5.7 mg/l) during pre-monsoon and post summer monsoon season These stations are situated in the central estuarine region (station 5) nearer to the sewage outfall. Such high values might be due to the increased bacterial activity. High temperature regime accelerates the bacterial activity resulting in the uptake of dissolved oxygen and marked decreasing trend of BOD values were observed during monsoon. Bacterial oxygen consumption is significantly higher in sewage outfall stations (Vijayan et al., 1976).

Nitrite reaches the aquatic system through effluents from industry and through river run off from agricultural waste. Nitrite within the entire estuary ranged from 0.18-2.68 μM. High value of 2.68μM was recorded at station 6 and in the bottom waters at station 1 (2.44μM) during monsoon. Nitrite concentration in the estuary was low compared to the observations made by Sheeba (2000). Monsoon average was high in the estuarine region. Seasonal variation may be attributed to the variation in oxidation of ammonia and reduction of nitrate (Rajendran and Venugopalan, 1975).

High nitrate values were recorded in the estuary during monsoon, and pre-monsoon season which shows its input from terrestrial origin induced by land runoff and industrial discharge. Nitrate values generally ranged between 2.28 and 17.75 μM and high average was recorded at station 1, the central estuarine region during pre-monsoon period and at stations 3 and 4, the industrial region at Eloor during post summer monsoon period. High nitrate concentration generally indicates the eutrophic nature of the estuary. These values were low compared to the observations made by Sheeba (2000). Industrial discharge site at Eloor showed high values during all the seasons. The onset of south west monsoon was accompanied by a general rise in the nitrate level and the concentration of the nutrients was high during the monsoon months in Cochin estuary (Lakshmanan et al., 1987). Sankaranarayanan and Qasim (1969) also reported high values during the monsoon and post-monsoon period. Generally high values were reported from the bottom waters probably due to its release from the bottom waters. Nixon (1980) has also reported high values of nitrate in bottom waters.

Ammonia increases in the estuarine waters by the death and decay of organisms and is the most preferred form of nitrogen for phytoplankton assimilation. High concentration of ammonia was recorded during monsoon and post summer monsoon seasons. High value of ammonia observed during the monsoon months might be due to the high effluent discharge and heavy fresh water influx (Nair et al., 1988). High value was recorded from the surface waters of station 1 (Barmouth) and station 2. High value of 164.50µM was recorded at station 2, during post summer monsoon. The effect of effluents discharged from the fertilizer factories might be responsible for high ammonia concentration. Generally low values were reported during pre-monsoon season. Seasonal comparison showed that monsoon and post summer monsoon averages were high. Madhu et al., (2007) also reported a sharp increase in ammonia concentration during monsoon and post summer monsoon period.

Comparatively high phosphate values were recorded from the bottom waters in most of the stations. Estuarine sediments are rich in phosphorous and may be liberated to the overlying waters under favourable conditions. Abundant phosphate availability in water stimulates undesirable plankton bloom, a phenomenon known as eutrophication, which has been reported in the Cochin estuary. Phosphate values were high during monsoon in the estuary and generally ranged from 0.30 to 22.1µM. High value was reported at station 6, central estuarine region. High value of phosphate might be due to the larger amount of effluents containing phosphate (Nair et al., 1988). According to Sankaranarayanan and Qasim (1969) phosphorus values attain their first peak during monsoon showers. Jyothibabu et al., (2006) also reported high phosphate concentrations during the onset of summer monsoon. Such high values reported during the monsoon might be due to high river influx.

High silicate concentration was reported during monsoon and post summer monsoon seasons. In the estuary the values ranged from 12.15 to 136.50µM and high values were generally reported in the surface samples.

Increase in silicate concentration was around two-fold during monsoon and post summer monsoon compared to pre-monsoon; such high concentration might be due to the influx of river water. The silicate values remain low during the pre-monsoon and high during July-August and the cycle is entirely dependent upon the freshwater discharge which is evident by a decrease in value as observed from surface to bottom. The values at stations nearer to sea decreased after August but those away from the sea attained a secondary peak during October and November (Sankaranarayanan and Qasim, 1969). Sankaranarayanan et al., (1984) have also reported maximum silicate concentration in Cochin backwaters during south west monsoon. High silicate concentration during monsoon months may be due to monsoon showers and resultant land run off and lower during pre-monsoon may be due to the adsorbance of silicate by the suspended particles and co-precipitation with humic acid (Gouda and Panigrahy, 1992). Jyothibabu et al., (2006) has also reported high silicate concentrations during the onset of summer monsoon.

Generally high chlorophyll 'a' concentration was recorded and this implies that eutrophication was apparent in the estuary. Such high concentrations reported might be due to higher concentration of nutrients in the Cochin backwaters throughout the sampling period. The values generally ranged from 2.5 to 37.7 $mg.m^{-3}$. High values reported at station 3 during pre-monsoon season might be due to the availability of nutrients in this region, downstream of industrial discharge site. Joy et al., (1990) also observed high standing stock of phytoplankton during pre-monsoon in the industrial region of the river Periyar. Average seasonal distribution showed high values during monsoon. Jyothibabu et al., (2006) have reported low concentration of chlorophyll 'a' during pre-summer monsoon compared with onset of summer monsoon. In Cochin backwaters, phytoplankton biomass and production remain largely constant all through the year although marked salinity variations arise seasonally as a result of heavy freshwater influx (Menon et al., 2000). Low saline water has an insignificant effect on the growth and production of phytoplankton in this system (Qasim 1974). Being eutrophic, primary production in the estuary is always high and is mainly constituted by nano plankton (<20 μm) community (Qasim et al., 1974). Increased grazing of phytoplankton by microzooplankton could be one of the reasons for a relatively low level of chlorophyll 'a' during pre-monsoon season, even though the environmental conditions remained conducive for maximum phytoplankton growth (Madhu et al., 2007). High primary production was reported from the surface waters during monsoon and post summer monsoon period. High oxygen content in the surface found during monsoon due to high turbidity results in high primary production at the surface (Qasim et al., 1969).

Concurrent with the freshwater discharge from the Cochin backwaters during the monsoon months, there is an incursion of cold saline water from the Arabian sea into the backwaters. This is particularly noticed at the bottom and has been recognized as upwelled water from the Arabian sea which finds its way into the system through the main channel (Sankaranarayanan and Qasim, 1969). This is evident from the observations (Figure 3.3.2) made at station 1 which revealed that during monsoon the bottom layers suddenly become cold, saline, oxygen-deficient and rich in nutrients. During monsoon, heavy rainfall results in high river discharge that eventually reaches the estuary. Stratification often develops and results in conditions with less dense river water at surface and high dense seawater at the bottom layers. In post-monsoon, river discharge gradually diminishes and tidal influence gains momentum as the estuarine conditions change to a partially mixed type, weakening stratification. In pre-monsoon the river discharge is minimum and seawater influence is maximum upstream, the estuary is well mixed and homogeneity exists in the water column. (Menon et al 2000). The concentrations of nitrite, nitrate, phosphate and silicate exhibited pronounced seasonal variation and also indicated large inputs from industrial units, sewage works and agricultural runoffs (Anirudhan et al., 1987; Lakshmanan et al., 1987). Bottom water indicated higher value of inorganic nutrients than surface especially during the post-monsoon period probably because of through mixing enabling the release of nutrients from the sediment.

Sediment Characteristics

The substratum was dominated by sand during pre-monsoon at stations 1, 3, 4, 6, 7, 8 and 9 except stations 2 and 5 where silt was dominant. The substratum showed the dominance of fine-grained sediments during monsoon except at stations 6, 7 and 8 which showed the dominance of sand. During post summer monsoon the substratum was again dominated by sand at stations 3, 4, 5, 6, 7, 8 and 9 except stations 1 and 2 which showed the dominance of fine grained sediments. The admixture of freshwater and saline water reduces the velocity of the transporting agent, leading to the deposition of coarser particles such as sand at the head of the estuary (Mohan, 2000). According to Vereyya and Murthy (1974) in the Cochin estuary the dominant sediment texture was sandy silt with high sand and low clay levels. Station 2 (irrespective of the different seasons) was always dominated by fine-grained sediments (Clay and Silt). The absence of seasonal variations suggests that direct effects of river discharge and land runoff are not influencing the texture of this region. The upper estuary was mainly composed of sand particles whereas the lower estuarine regions indicated seasonal abundance of sand during monsoons pointing out to bedload movement. Otherwise, this area was predominantly covered by clay, silt and size fractions. Surficial sediments also indicated variations in texture resulting from detritus settlement influenced by mixing conditions in the estuary (Nair et al., 1993).

In the estuary organic carbon values generally ranged from 1.04 to 50.37 mg g^{-1}, the highest value being reported at station 4. High average was reported during monsoon and high values during this season were reported from stations

1, 2, 3, 4 and 5. High average reported during monsoon indicates the input of terrestrially derived organic matter through river run off. Remani, et al., (1980) have also reported high organic carbon in the sediments during monsoon. The study with reference to the indicator bacteria revealed that the principal source of faecal pollution is of the non-human type originating from land drainage, sewage and organic discharge (Gore et al., 1979). Studies have further shown that there is appreciable degree of organic pollution in the harbour area (Unnithan et al., 1975). High values reported during monsoon at the riverine stations 3 and 4 indicate terrestrial input (Vasudevan Nayar, 1992). In general high values were reported during monsoon followed by pre-monsoon and post summer monsoon which is due to high productivity, settling of detritus, decay of vegetation and sewage disposal. Sediment composition, productivity rate, land run-off and discharge from industries and sewage markedly influence the organic carbon content in the estuarine region (Vasudevan Nayar, 1992).

Macrobenthos

High density was recorded during pre-monsoon and monsoon months. Kurien et al (1975) reported a decline in benthic fauna during the monsoon months. Only few species (three species each during pre-monsoon and monsoon) were recorded from station 1 (Barmouth region) of the estuary. According to Saraladevi et al., (1991) maximum number of species (42 species) and high abundance (most abundant-*Corophium triaenonyx*) was recorded from the barmouth region. Sheeba (2000) also reported high abundance of macrobenthic fauna at the barmouth region. Low abundance reported in the present study might be an indication of increased pollution in the recent years. Low D.O (<1mg/l) reported from the bottom waters at station 1 during the present study might be the reason for low benthic abundance. Hypoxia is a common estuarine phenomenon defined as dissolved oxygen concentrations below 2 mg/l (Dauer et al., 1992). Direct effects of hypoxia include reduced benthic abundance and biomass (Dauer et al., 1992). High BOD and low D.O were reported from many parts of the estuary.

Distribution of benthic fauna is reported to have direct relationship with the type of the bottom and physical nature, and extraneous inputs may drastically alter the number and type of species (Saraladevi et al., 1991). High species abundance and density was recorded from station 2 further downstream of the effluent discharge site. Due to moderate contamination in the downstream stations sensitive taxa may be excluded by toxic response, providing a competitive release of space and food to more tolerant taxa, allowing them to increase (Thompson and Lowe, 2004). The dominant species reported from this station were *Apseudes chilkensis* and the bivalve *Pendora flexosa* followed by *Eriopisa chilkensis, Capitella capitata, Prionospio cirrobranchiata* and *Dendronereis aestuarina*. Pollution indicator and tolerant species dominated this station. *A. chilkensis, P. flexosa* and *D. aestuarina* had earlier been reported from the polluted environments of cochin backwaters (Remani et al., 1983; Saraladevi and Venugopal, 1989). *C. capitata* is the best-known benthic pollution indicator taxon. They are opportunistic and keyed to organic enrichment, but also are tolerant of a wide variety of contaminants (Reish, 1957; Bridges et al., 1994; Thompson and Lowe, 2004). *Prionospio cirrobranchiata* is an indicator species of industrial pollution (Khan et al., 2004). Through the present study, the amphipod *Eriopisa chilkensis* appears to be pollution tolerant as evidenced by its fair representation in organic rich enrichment and industrially polluted areas.

Low density and lower number of species were recorded from stations 3 and 4, which are nearer to the industrial region at Eloor. Sarala Devi et al., (1979) have shown the absence of benthic life at the effluent discharge area of Udyogmandal. Saraladevi and Venugopal (1989) observed a remarkable reduction both in biomass and population density in stations near Eloor. Station 5 (located in the central estuary) showed high abundance during pre-monsoon period and low values during monsoon and post-monsoon period. Polychaetes dominated these stations (3, 4 and 5) and the species present were either indicator organisms (eg. *Capitella capitata*) or pollution tolerant species (eg. *Dendronereis aestuarina).* Tolerant species may increase in abundance at moderate to relatively high concentrations until their toxic thresholds are exceeded. With high population and related human impacts to coastal systems, potential responses of coastal communities to increased nutrient loading or removal of top predators through fishery activities is becoming an increasingly acute management issue (Michelli, 1999; Jackson et al., 2001).

When extreme, eutrophication in coastal systems can have dramatic impacts through developing hypoxic conditions and possible blooms of undesirable taxa. The benthic macrofaunal community can similarly exhibit dramatic changes under such severe stress, with domination by capitelid polychaetes and other opportunistic species (Hyland et al., 2004). In pre-monsoon, bivalves (*Villorita cyprinoides*) were dominant at stations 6 and 9 whereas polychaetes dominated at stations 7 and 8. Dominance of polychaetes were reported from stations 6, 7, 8 and 9 during monsoon and post summer monsoon period. Abundance of *Villorita cyprinoides* was reported from the stations (6, 8 and 9) towards the southern region in pre-monsoon. According to Menon et al., (2000) fifty three percent of the clams exploited from the lake is from the southern region (Cochin to Thannirmukham) when the substratum was dominated by sand. In Cochin backwaters sandy bottom supported high bivalve population mainly of *Villorita cyprinoides* (Saraladevi et al., 1991). High biomass was reported from station 9. According to Saraladevi et al., (1999) high biomass was associated with sandy substratum where shelled forms dominated. It is well established that the type of substratum is the main criterion in the distribution of benthos. In general, polychaetes dominated the community in most of the stations. Comparatively high richness was recorded during pre-monsoon and post summer monsoon periods in the present study. Season-wise analysis of the macrobenthic fauna carried out by Sunil Kumar and Antony (1994) also revealed high species richness during pre and post-monsoon periods than during monsoon. In general low diversity was reported at the stations situated to the downstream of industrial region and high diversity was reported from the stations situated in the southern region of the estuary.

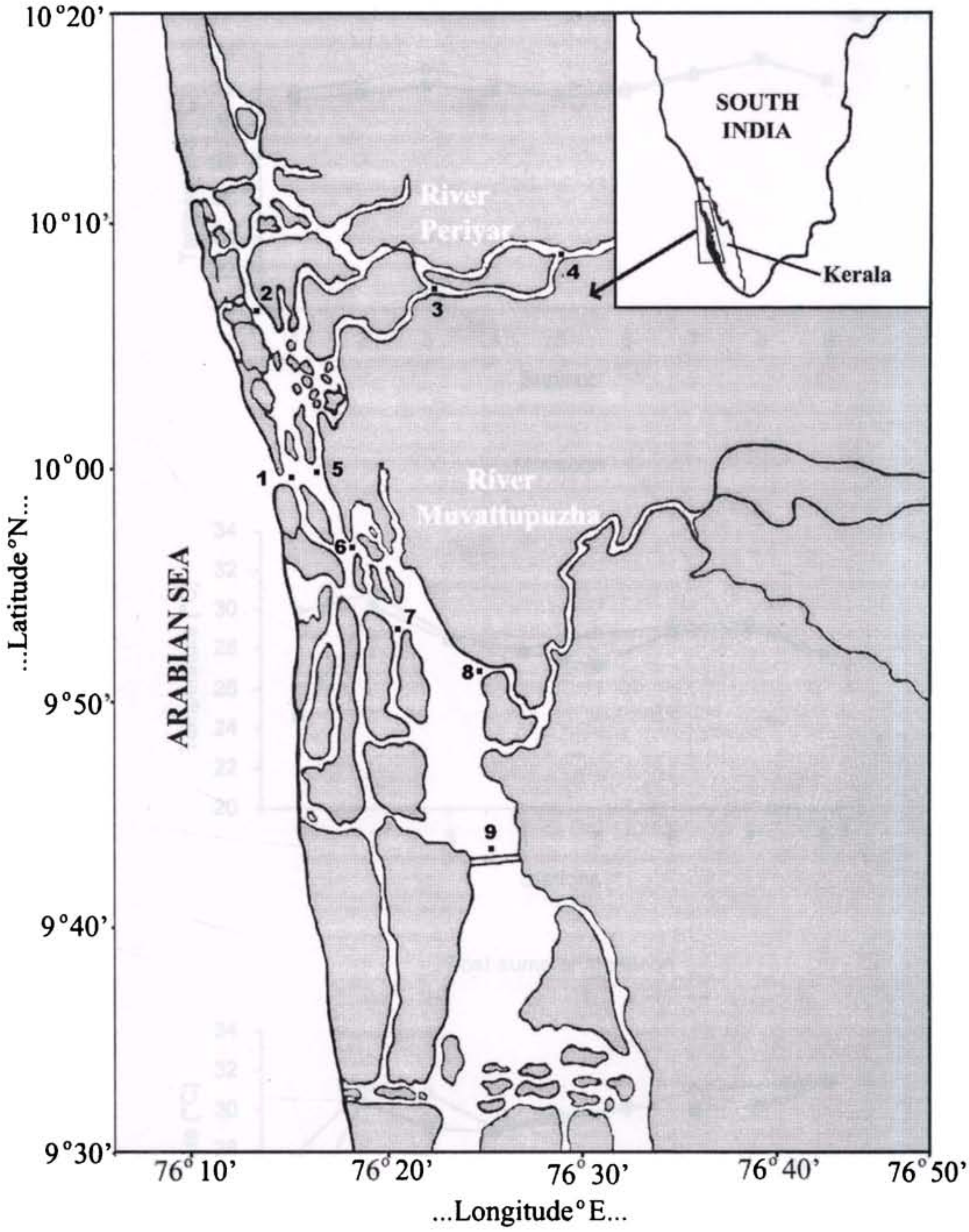


Figure-5.1 Study region (Cochin estuary) showing the sampling stations

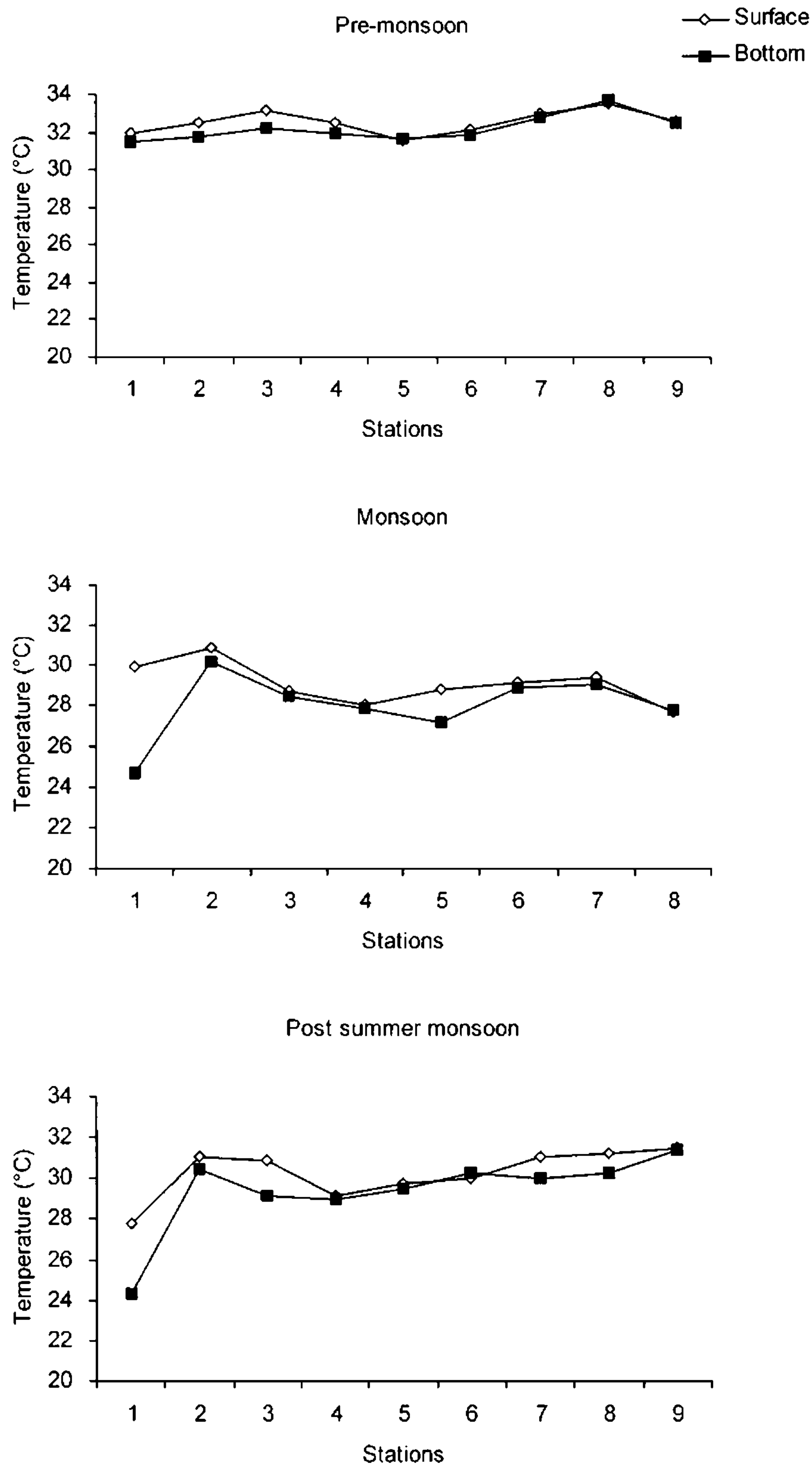


Figure 5.3.1 Water temperature (°C) during the sampling period

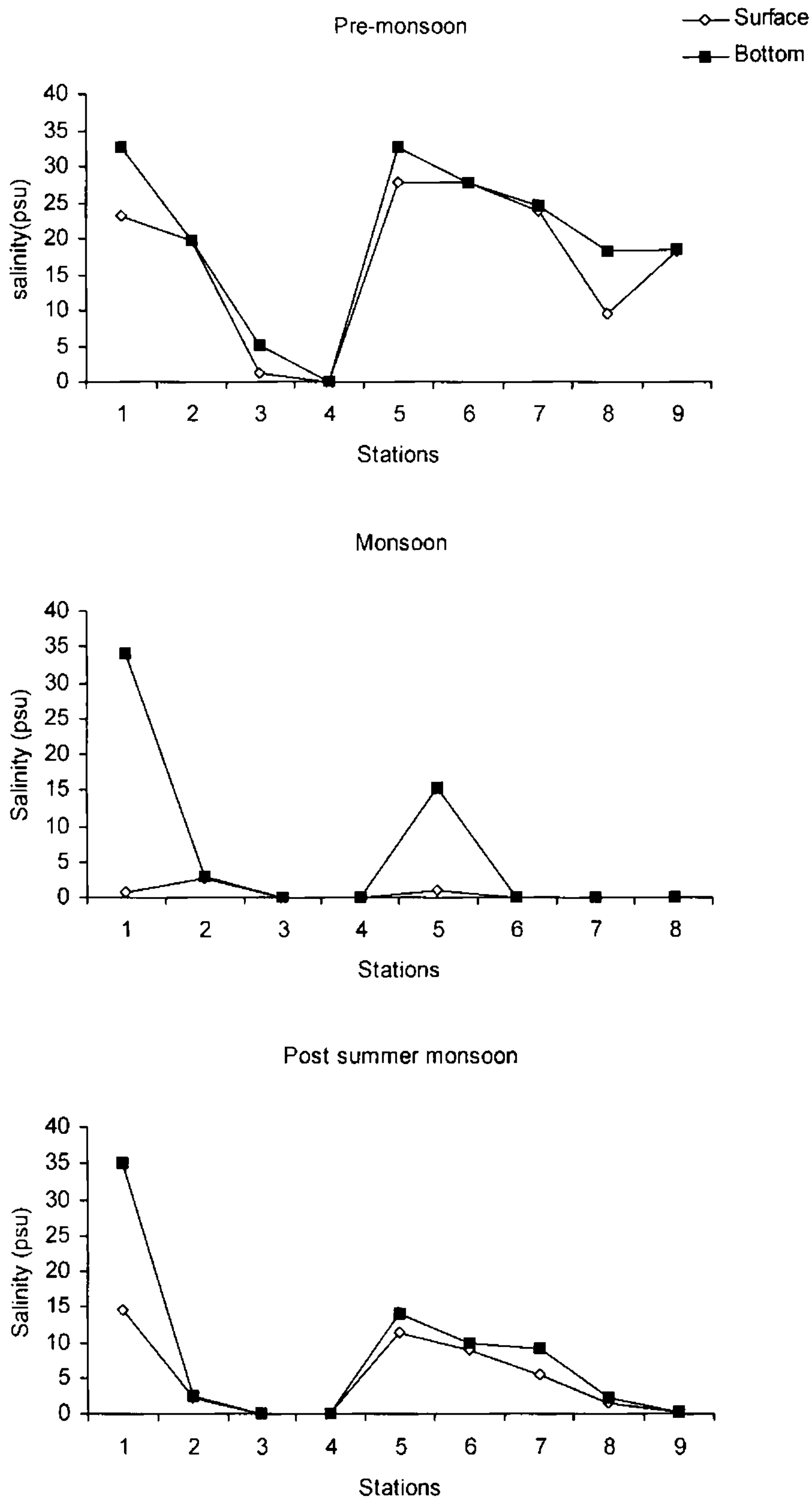


Figure 5.3.2 Salinity (psu) variation during the different seasons

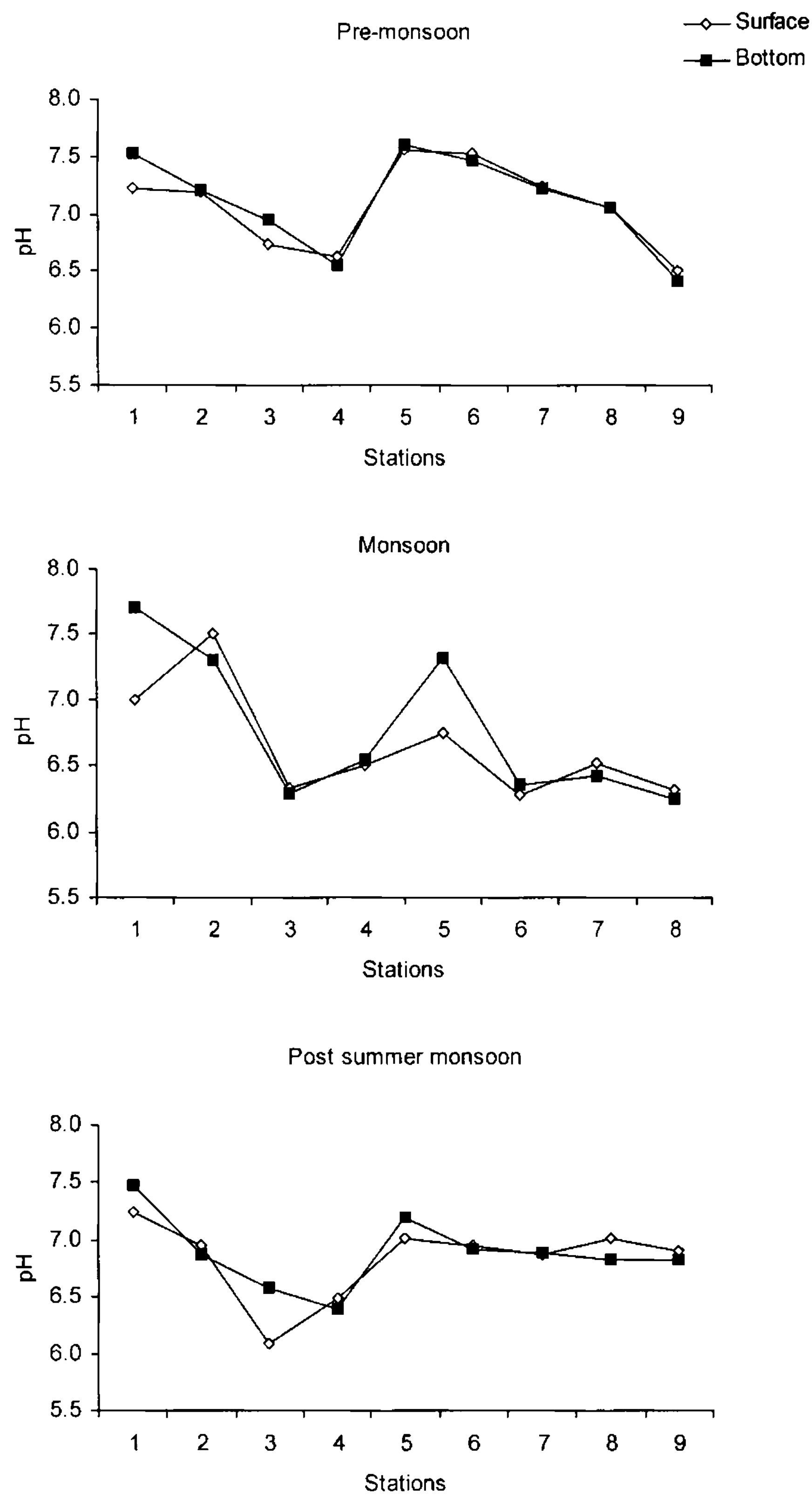


Figure 5.3.3 pH variation during the sampling period

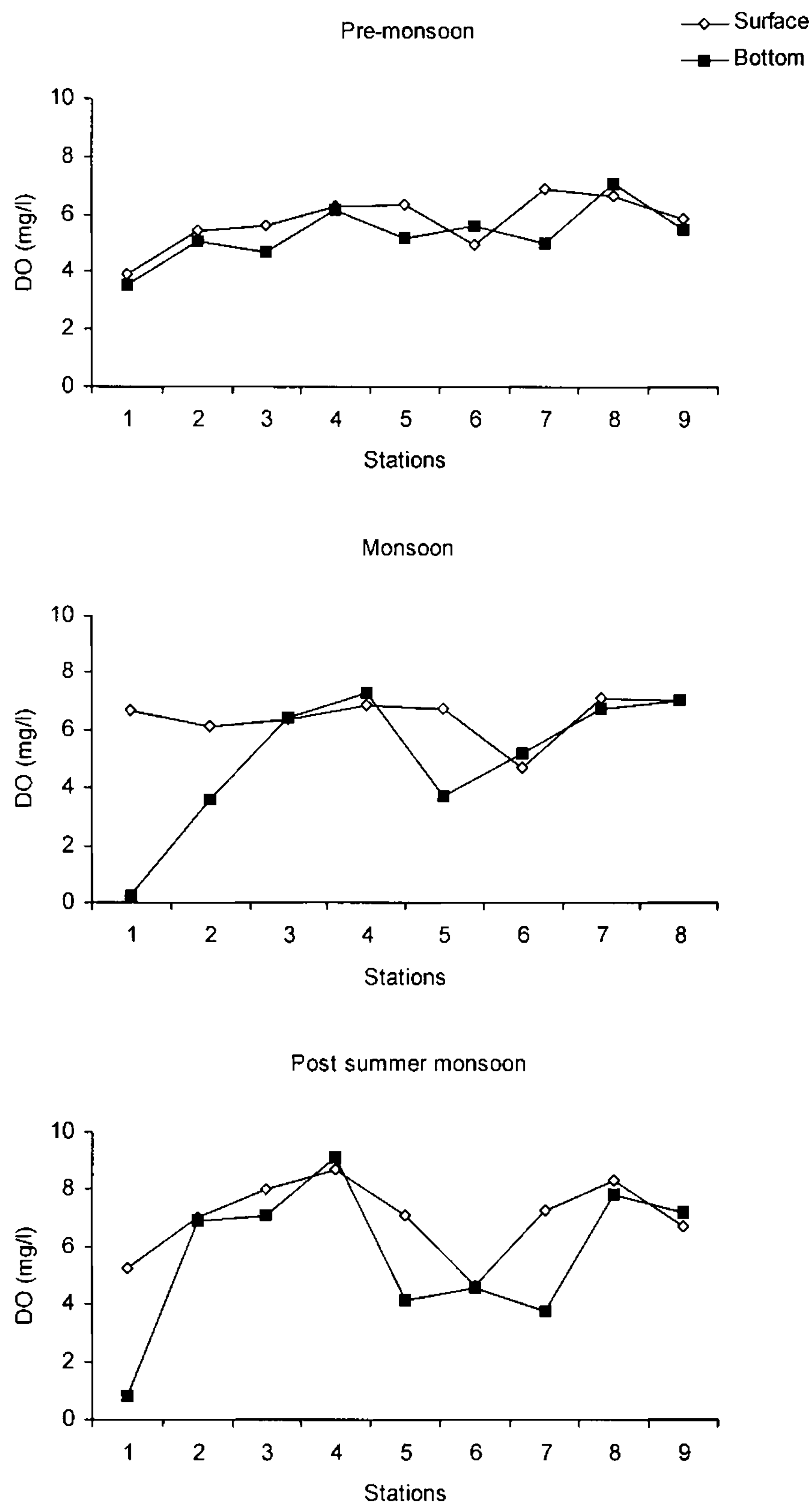


Figure 5.3.4 Variation in Dissolved Oxygen (DO) content during the sampling period

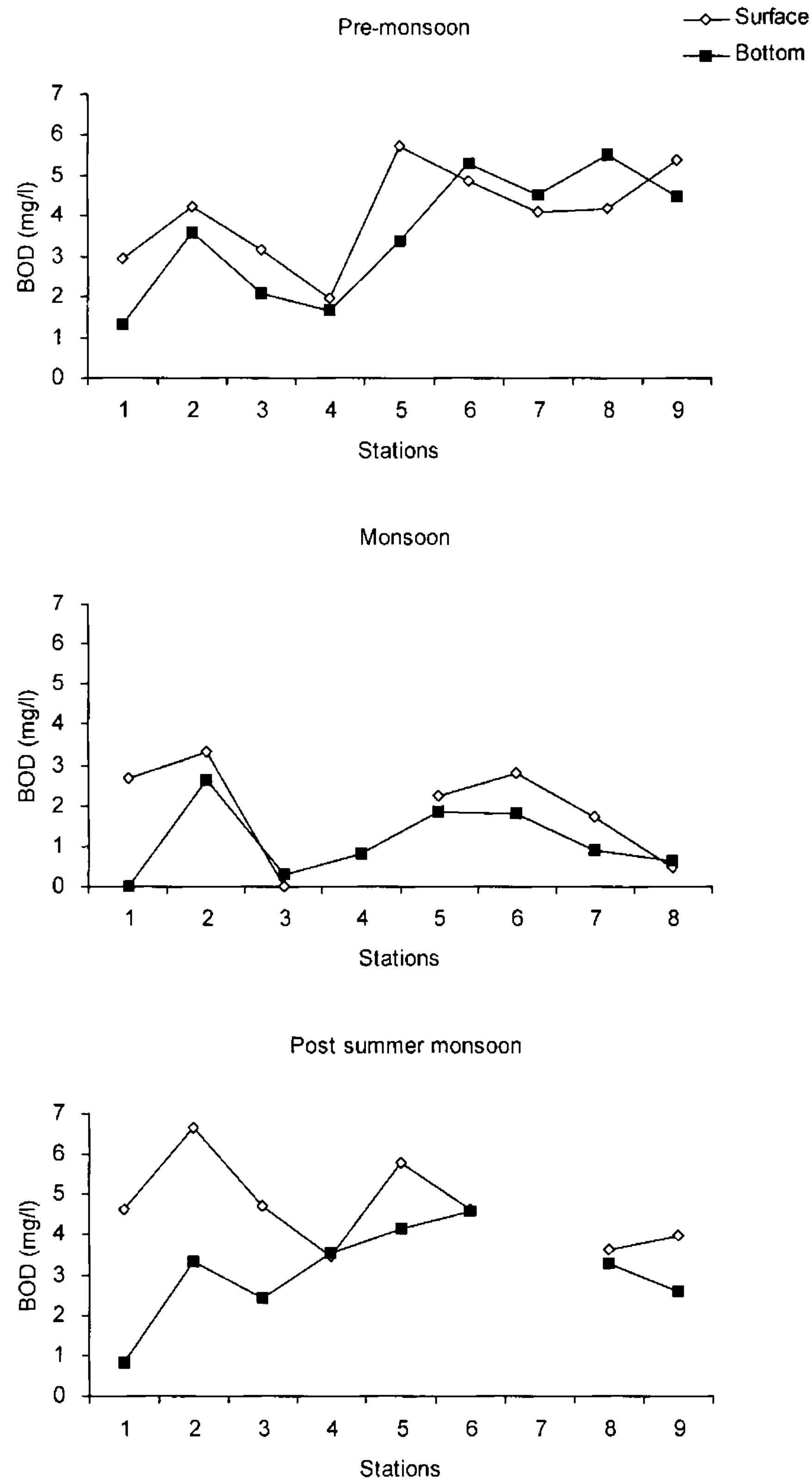


Figure 5.3.5 Biological Oxygen demand (BOD) variation during the sampling period

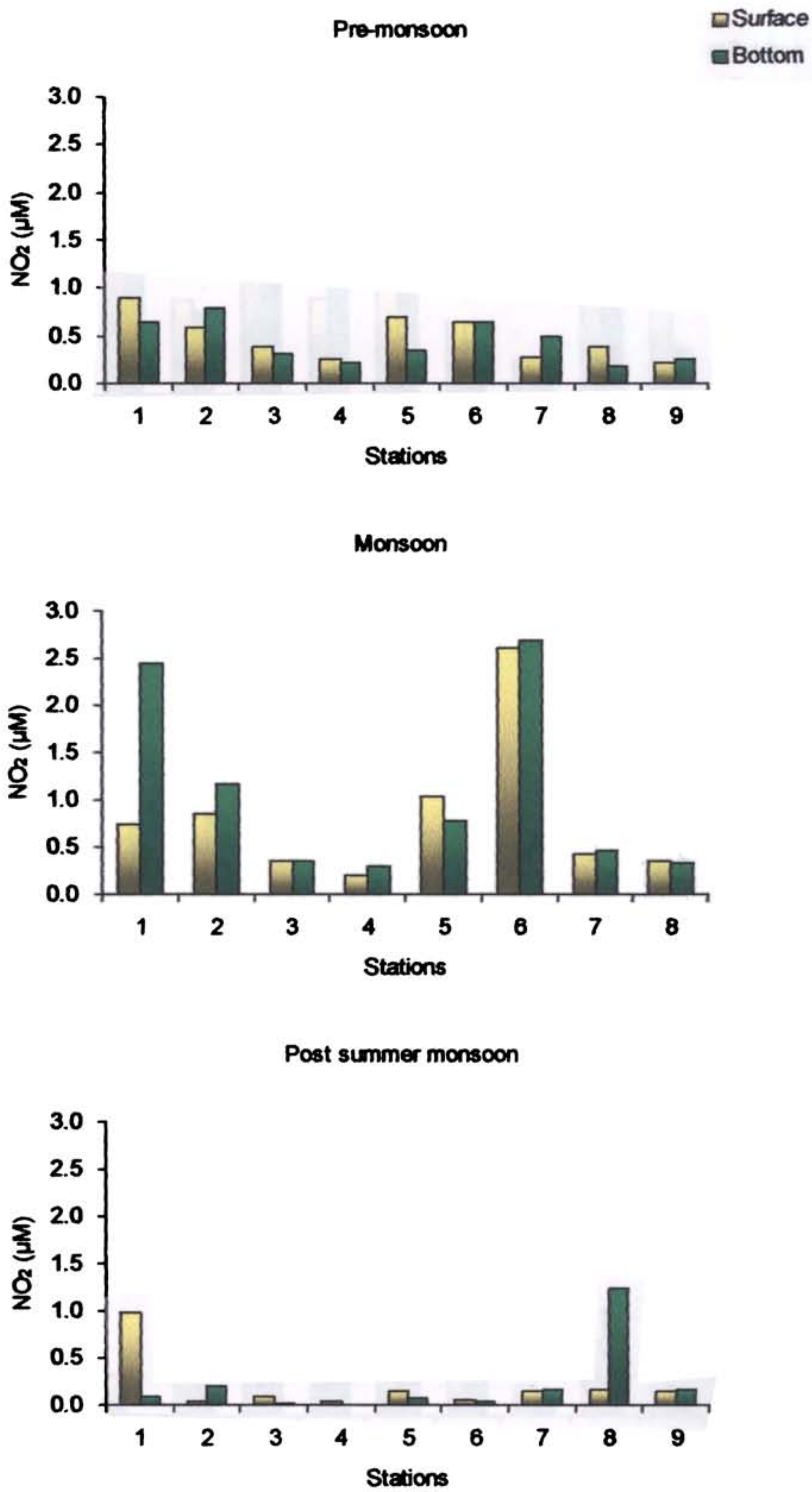


Figure 5.3.6 Seasonal variation of Nitrite (NO_2) during the sampling period

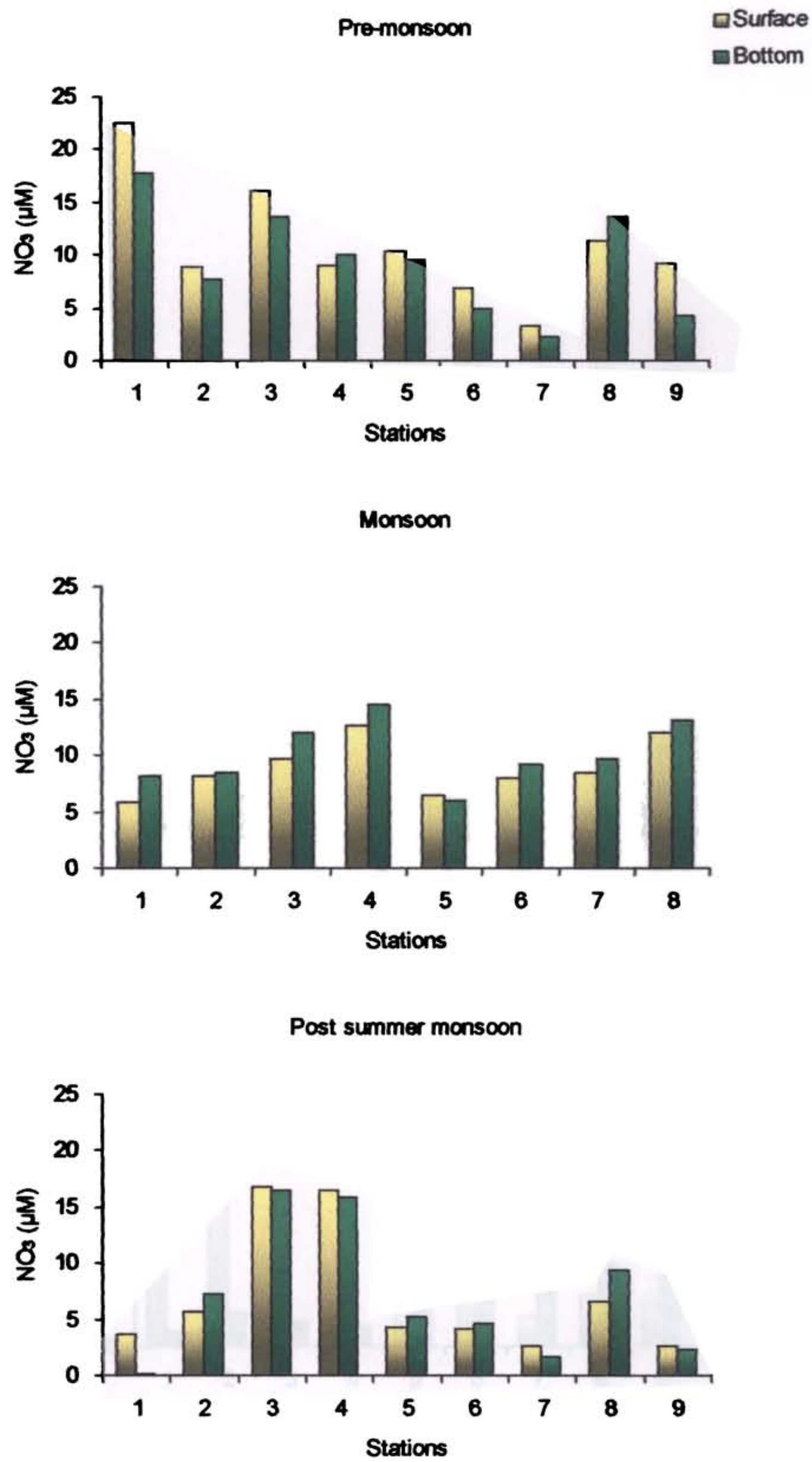


Figure 5.3.7 Seasonal variation in Nitrate (NO_3)

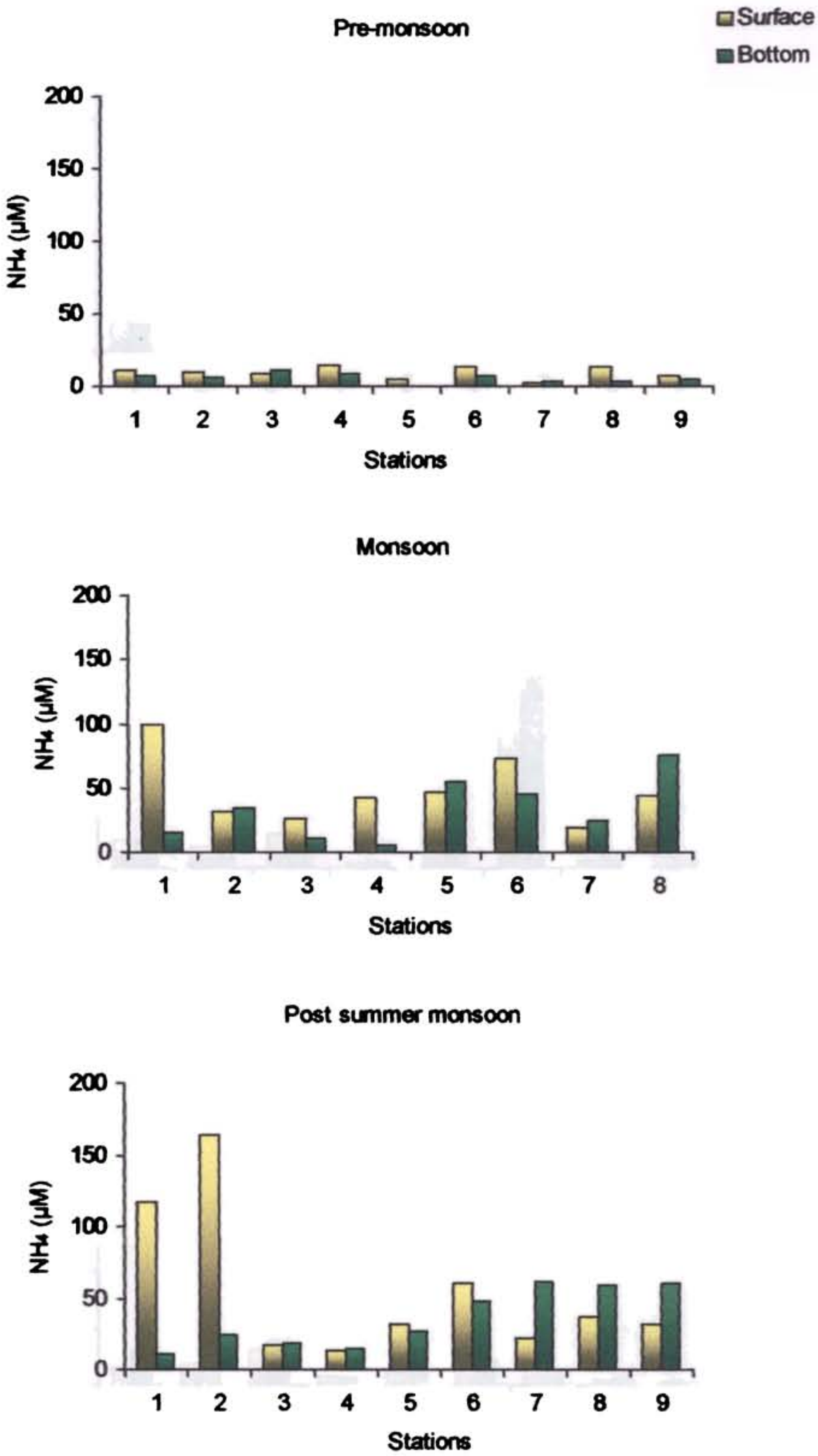


Figure 5.3.8 Seasonal variation in Ammonia (NH_4)

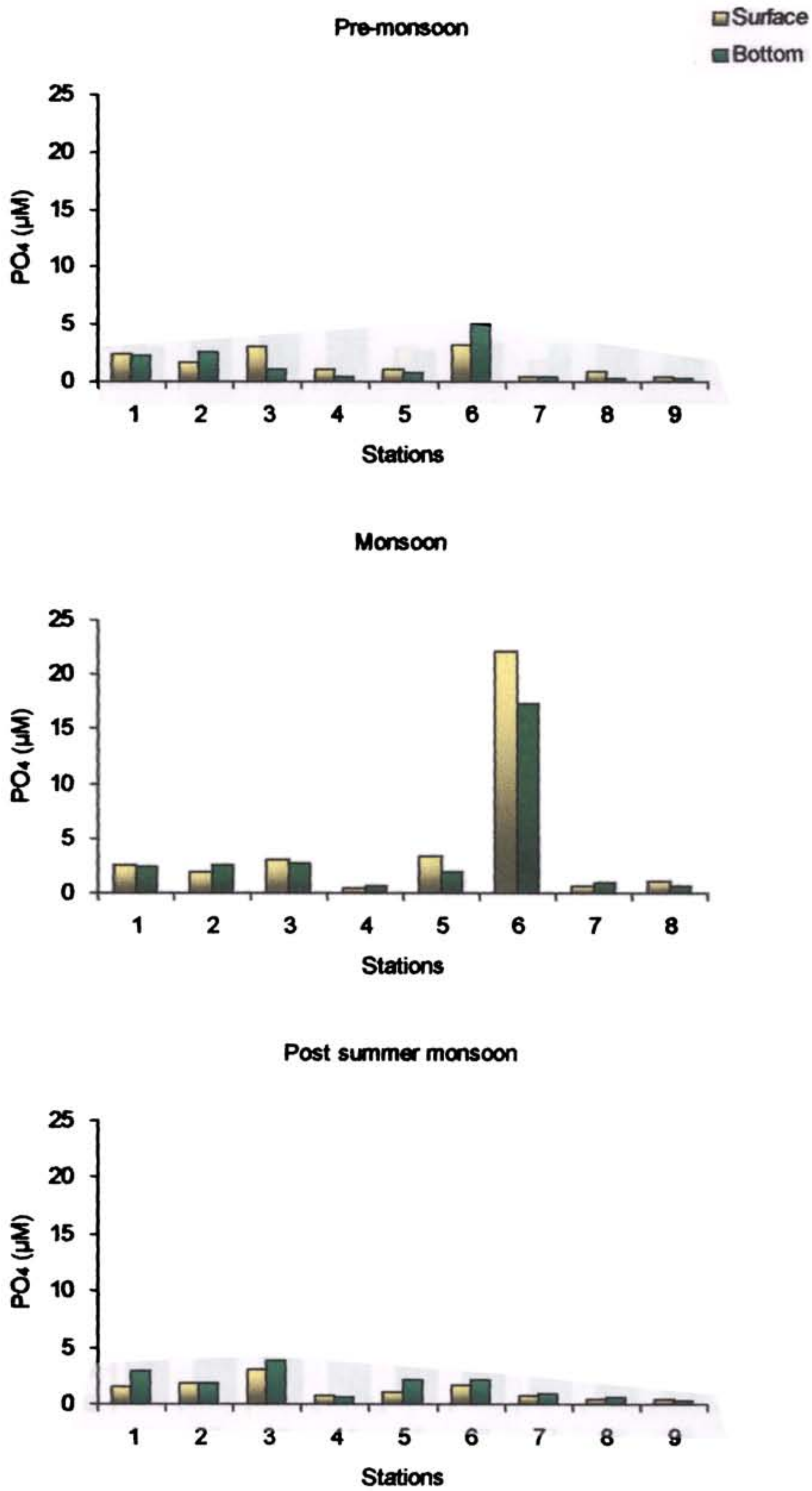


Figure 5.3.9 Seasonal variation in Phosphate (PO_4)

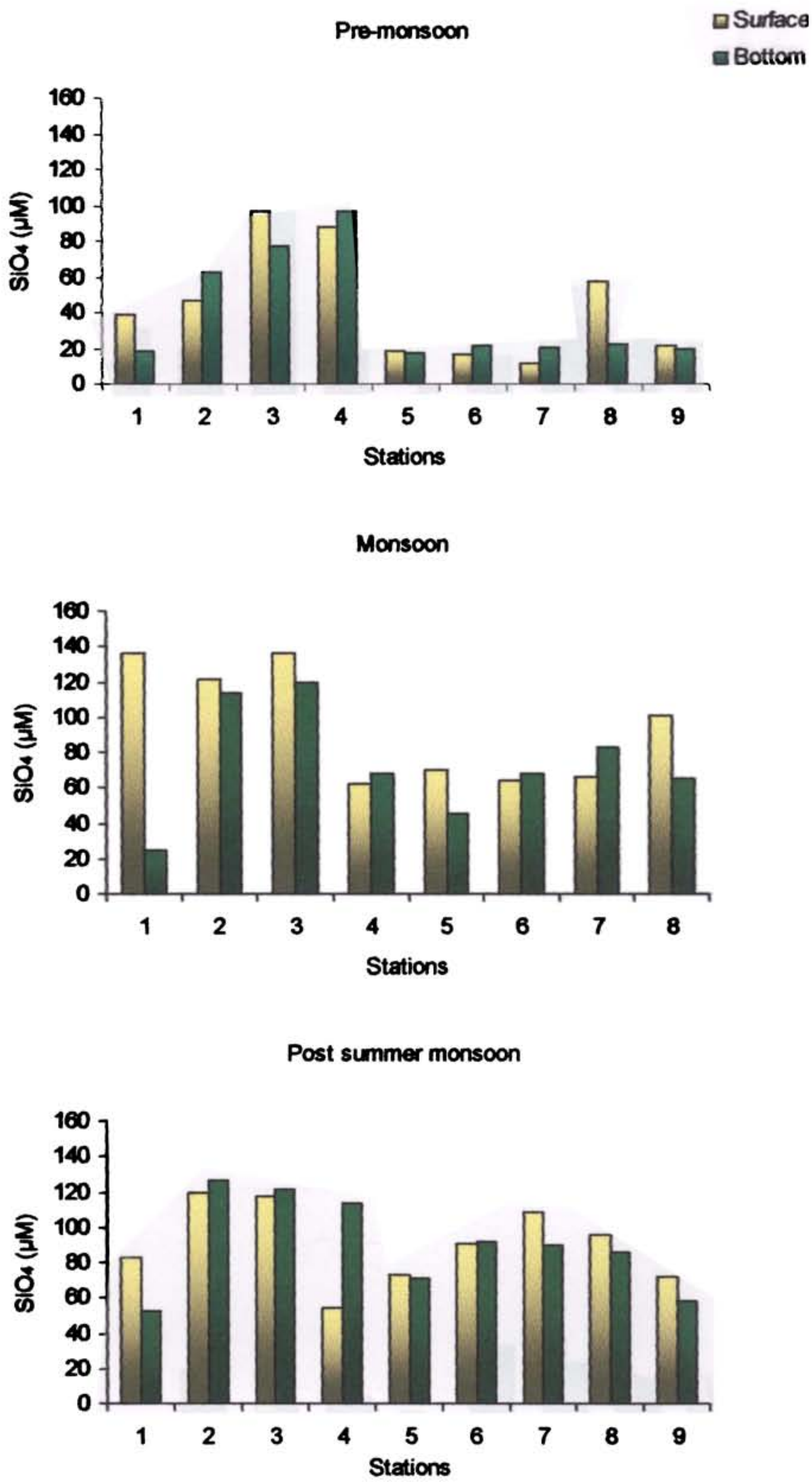


Figure 5.3.10 Seasonal variation in Silicate (SiO_4) content

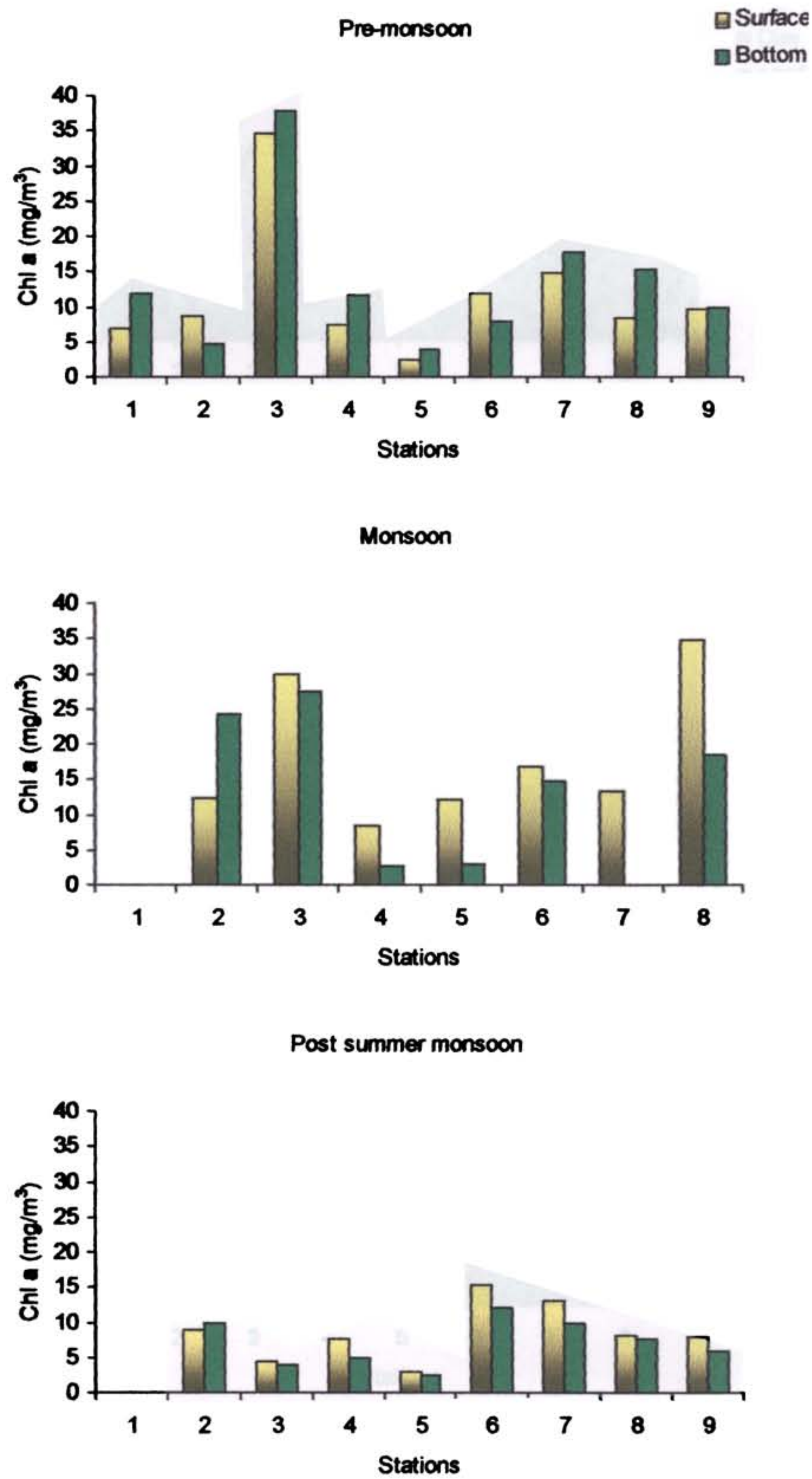


Figure 5.3.11 Seasonal variation in Chlorophyll 'a' (Chl a)

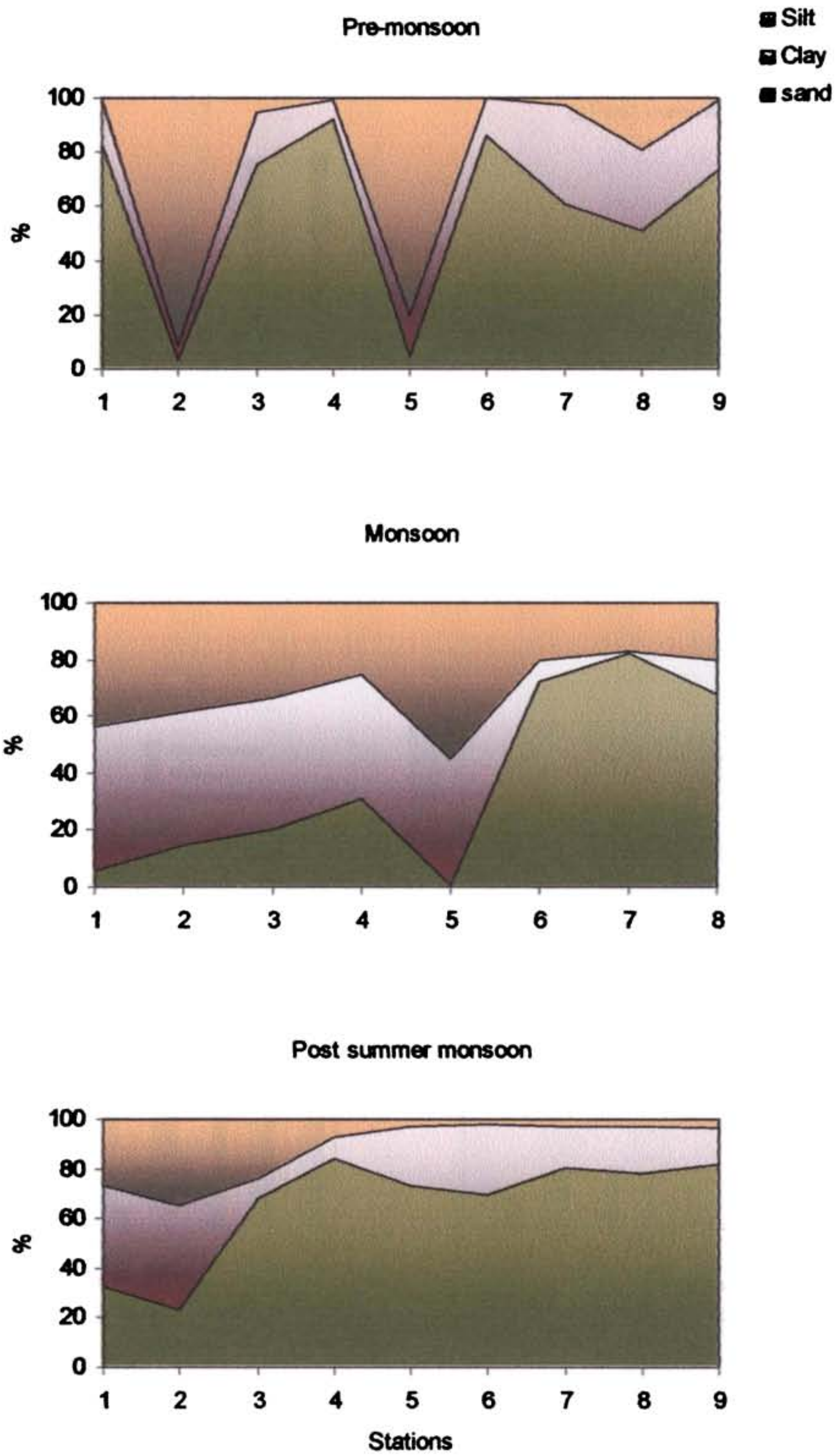


Figure 5.3.12 Substratum characteristics during the sampling period

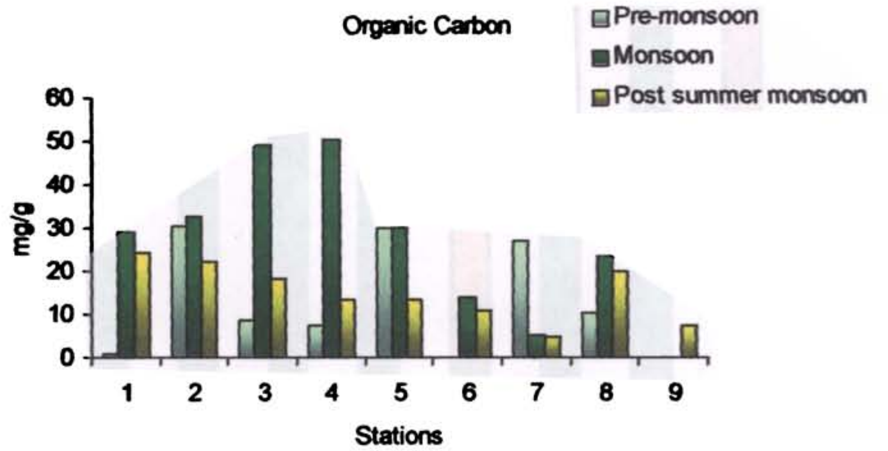


Figure 5.3.13 Sediment Organic carbon content (mg/g) during the sampling period

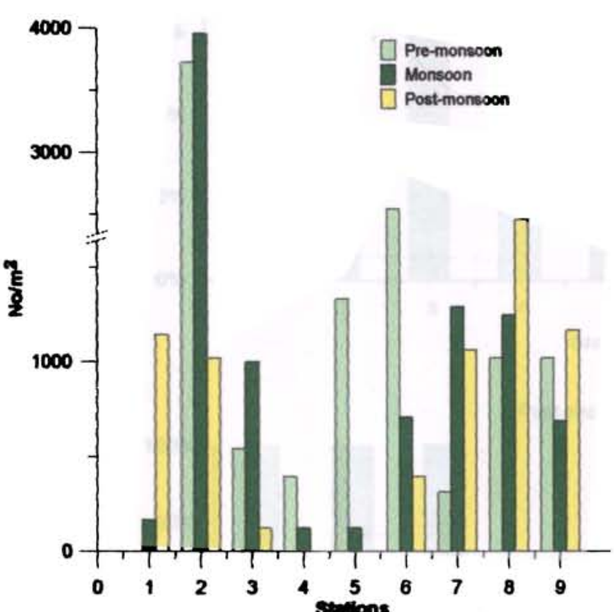


Figure 5.3.14 Benthic density (No/m^2)

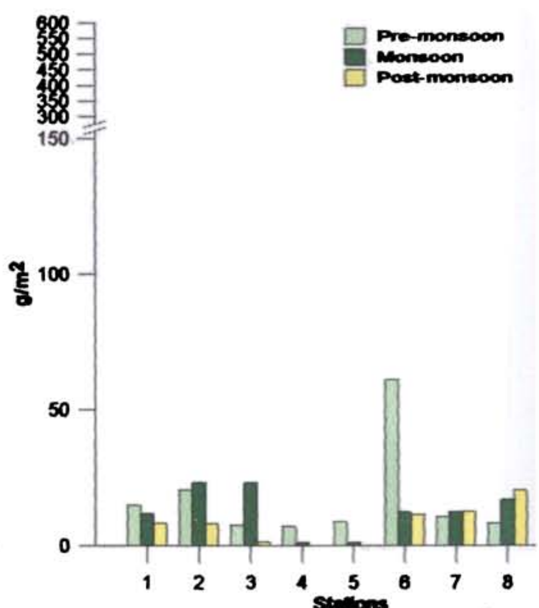


Figure 5.3.15 Benthic biomass (g/m^2)

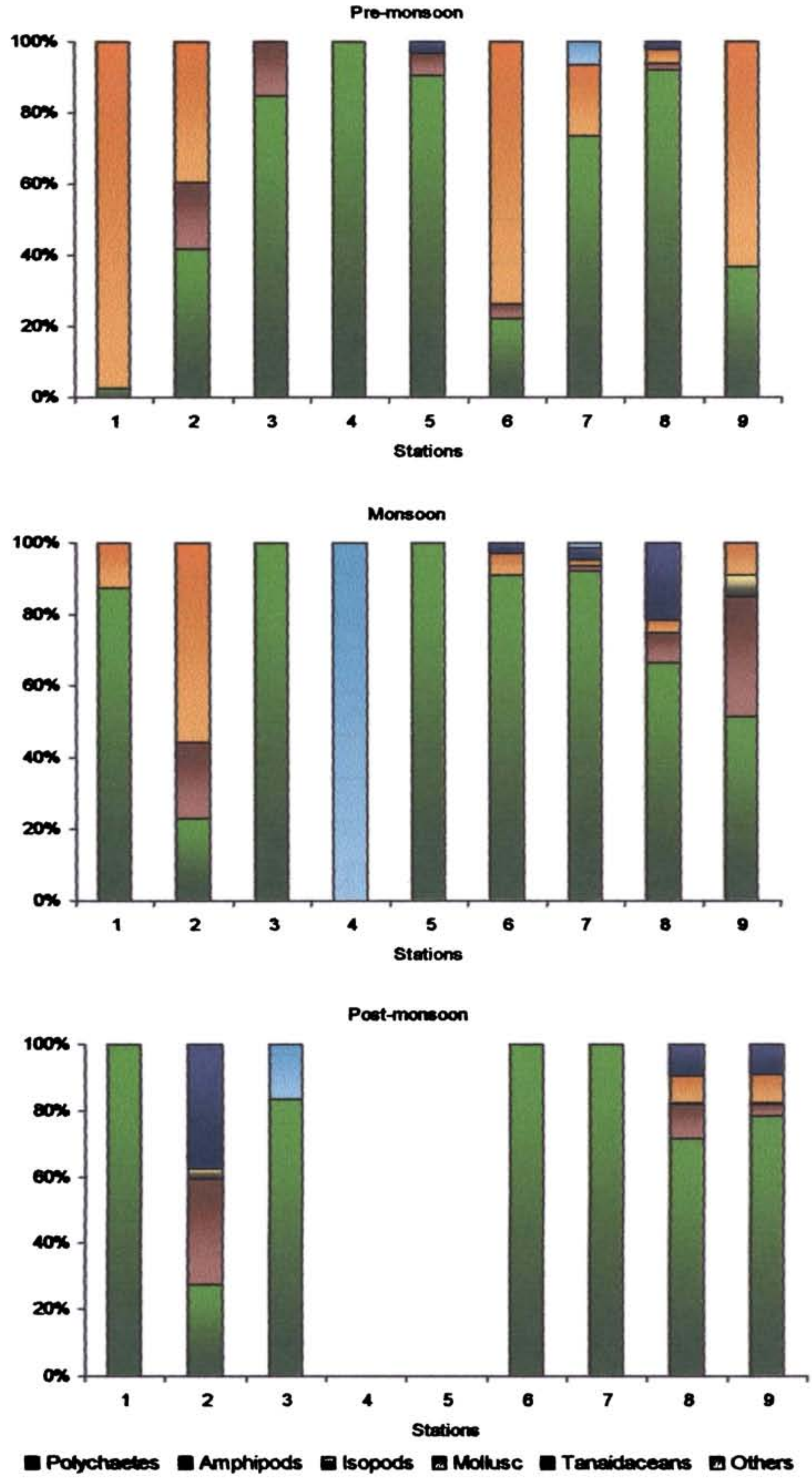


Figure 5.3.16 Percentage contribution of different faunal groups from the 9 stations

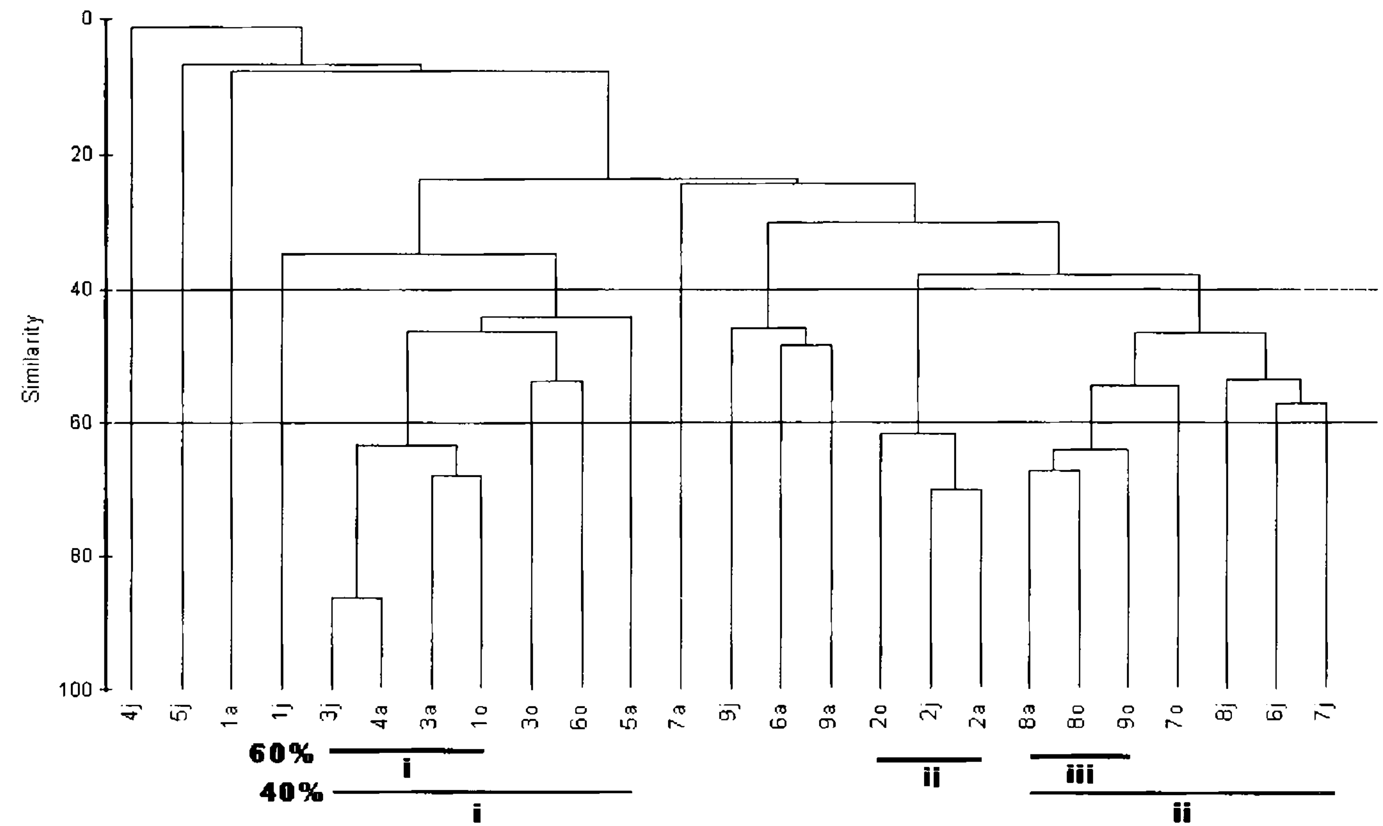


Figure 5.3.17. Cluster analysis carried out using species abundance data showing similarity between stations during the sampling period

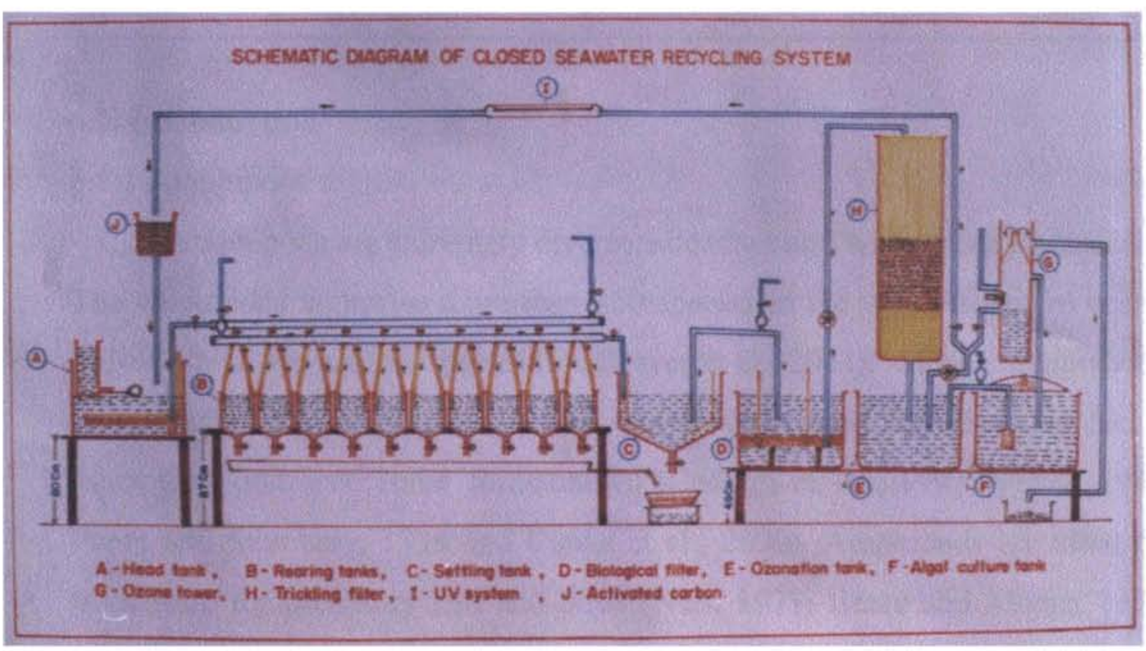
Table 5.1 Percentage contributions of the major groups from the study region during the sampling period
Abbreviations: Pre-monsoon (Pre-M); Monsoon (M); Post summer monsoon (Post-M)

		Polychaetes	Amphipods	Isopods	Mollusc	Tanaidaceans	Others
1	Pre-M	3	0	0	97	0	0
	M	88	0	0	13	0	0
	Post-M	100	0	0	0	0	0
2	Pre-M	25	11	0	24	39	0
	M	10	9	0	24	57	0
	Post-M	29	33	3	0	39	0
3	Pre-M	85	15	0	0	0	0
	M	100	0	0	0	0	0
	Post-M	83	0	0	0	0	17
4	Pre-M	100	0	0	0	0	0
	M	0	0	0	0	0	100
	Post-M	0	0	0	0	0	0
5	Pre-M	91	6	0	0	3	0
	M	100	0	0	0	0	0
	Post-M	0	0	0	0	0	0
6	Pre-M	22	4	0	74	0	0
	M	91	0	0	6	3	0
	Post-M	100	0	0	0	0	0
7	Pre-M	73	0	0	20	0	7
	M	92	2	0	2	3	2
	Post-M	100	0	0	0	0	0
8	Pre-M	92	2	0	4	2	0
	M	67	8	0	3	22	0
	Post-M	72	10	0	8	9	0
9	Pre-M	37	0	0	63	0	0
	M	52	33	6	9	0	0
	Post-M	79	4	0	9	9	0

Table 5.2 Community structure: Diversity indices – Margalef's richness (d'), Pielou's index (J'), Shannon weaver diversity (H'), Simpson's index (λ')

		Stations								
		1	2	3	4	5	6	7	8	9
Pre-monsoon	d'	0.27	1.95	0.95	0.17	1.67	0.64	0.87	1.73	0.87
	J'	0.56	0.66	0.59	0.74	0.73	0.50	0.87	0.81	0.71
	H'	0.62	1.92	1.15	0.51	1.86	0.90	1.55	2.08	1.38
	λ'	0.37	0.77	0.50	0.33	0.72	0.43	0.75	0.81	0.62
Monsoon	d'	0.39	1.53	0.14	0.21	0.21	1.22	1.81	1.54	1.38
	J'	0.89	0.59	0.25	1.00	0.65	0.88	0.77	0.94	0.97
	H'	0.97	1.59	0.17	0.69	0.45	1.93	2.02	2.34	2.22
	λ'	0.60	0.68	0.08	0.50	0.28	0.83	0.82	0.90	0.88
Post summer monsoon	d'	0.71	1.73	0.41	0.00	0.00	0.84	1.58	1.92	1.42
	J'	0.55	0.82	0.79	0.00	0.00	0.85	0.86	0.80	0.85
	H'	0.99	2.10	0.87	0.00	0.00	1.53	2.13	2.22	2.03
	λ'	0.45	0.82	0.50	0.00	0.00	0.74	0.85	0.83	0.82

RECIRCULATING SYSTEM



CHAPTER 6

Population characteristics and life history of *Eriopisa chilkensis* Chilton (Gammaridae-Amphipoda)

6.1 Introduction

6.1.1 Amphipods

6.1.2 Food and feeding

6.1.3 Literature review

6.2 Life history and reproductive biology

6.2.1 Materials and Methods

6.2.2 Results

6.2.3 Discussion

6.3 Population dynamics

6.3.1 Materials and Methods

6.3.2 Results

6.3.3 Discussion

6.1. Introduction

6.1.1 Amphipods

Amphipods are extremely diverse, abundant and widespread crustaceans. The amphipods comprise more than 850 species in the whole southern ocean, 741 of which are benthic species (De Broyer et al., 2003). Most amphipods are free-living benthic gammaridians that can occur in such high densities that at times they dominate some communities (Conradi et. al., 1997; Vetter, 1998; Poore and Steinberg, 1999 and Cunha et al., 2000). Amphipods are often the main food for predatory fish and birds (Nair, 1971; Beare and Moore, 1997; Bocher et. al. 2001 and Dauby et. al., 2001) and there is considerable potential for metal accumulated by amphipods to be transferred along marine food chains (Wang, 2002). Internationally, amphipods are used widely for sediment testing (Mearns et. al., 1986; Schlekat et. al., 1992 and Fairey et al., 2001), because they are ecologically relevant, have a short life cycle and are suitable for laboratory experiments. They are also known as biomonitors for trace metals, some species are ecologically sensitive and therefore are potential bioindicators of disturbed communities (Conradi et al., 1997 and Warwick, 2001). Amphipods are selected as biomonitors of trace metal because they are net accumulators of particular metals, relatively sedentary, abundant, easy to identify and resistant to handling stress (Rainbow, 1993a and Rainbow, 1993b). The benthic amphipods, especially Gammaridea, are an invaluable food source for many economically important fishes (Mason, 1974; Hobson and Chess 1976). Their limited mobility and their sensitivity to environmental changes suggest that their distribution and abundance can be used as an indicator of environmental quality (Albright 1982).

E. chilkensis, the species selected for the present study is an estuarine gammarid amphipod which was first recorded from Chilka Lake by Chilton (1921) and Asari (1983) studied the biology of *E. chilkensis* and reported that they are suspension feeders feeding on organic-rich detritus. Work done on the gammarid amphipods of Cochin backwaters by Nair et al. (1983) gave an account of the ecology and population dynamics of this group. *E. chilkensis* occur in large numbers in the organically enriched sediments of the Cochin estuary and it can be regarded as a tolerant species of organic pollution. *E. chilkensis* was encountered in varying densities in the benthic epifaunal communities in the mangrove swamps of Puduvypin (an area adjacent to Cochin backwater) in the present study. It also has an important trophic role in these areas in shredding leaf litter. In spite of its ecological importance, no detailed work on this species has been carried out in the Cochin estuary and adjoining areas. In this chapter, an attempt has been made to study the different traits of its life cycle, such as age at maturity, life-span, number of broods per female, duration of embryonic development, life time fecundity (based on number of juveniles released), growth rate and biochemical components in the laboratory. Along with this, the population dynamics of this species in the Cochin estuary was also studied for comparative assessment. This investigation was designed to find whether this species could be cultured in large numbers economically to be used as a feed for fish culture owing to its nutritive value.

6.1.2 Food and feeding

Amphipods exhibit different types of feeding behaviour namely deposit feeding, suspension feeding, deposit feeding coupled with predation, opportunistic predation, micropredatory browsing, macropredation coupled with scavenging, opportunistic necrophagy and true necrophagy. They have a wide dietary spectrum.

6.1.3 Literature review

Our knowledge of the Amphipoda is based on the work of number of authors and dates back to 1816. Studies on the amphipods of the Indian and the neighbouring waters received the attention of zoologists when Giles (1885) published a paper on the occurrence of two species of amphipods from Bengal. Bernard (1935) had worked on the amphipods from the waters of Travancore, Cochin and Bengal coasts from the collections of Zoological Survey of India. Life history of amphipods are known to us from the accounts given by Sexton and Mathews (1913) and Sexton (1924). Amphipoda of the Madras coast was studied by Nagappan Nayar (1959). Shyamasundari (1973) studied the effect of salinity and temperature on the tube-building amphipod (Corophium triaenonyx Stebbing). Breeding biology of a brackish-water amphipod *Melita zeylanica* in India was studied by Krishnan and John (1974). Morino (1978) classified breeding activity and life history of amphipods into four categories and concluded that low latitude species tend to breed throughout the year and have short life spans. Nair and Anger (1979 a,b) studied the life cycle of *Corophium insidiosum* and *Jassa falcata*) using laboratory culture. Seasonal variation in population structure and biochemical composition of *Jassa falcate* was studied by Nair and Anger (1980). Nelson (1980) reviewed the reproductive pattern of 65 species of gammaridean amphipods. Laboratory studies on the reproduction and growth of the amphipod (*Gammarus pulex*) was carried out by Welton and Clarke (1980). Life histories of the amphipods *Lembos websteri* Bate and *Corophium bonnelli* Milne Edwards was studied by Moore (1981). Asari (1983) has studied the biology of *Eriopisa chilkensis* and *Idunella chilkensis* from mangroves of Pitchavaram, India. Work done on the gammarid amphipods of Cochin backwaters by K.K.C Nair et al. (1983) gives an account of the ecology and population dynamics of this group. Breeding periodicity and sex ratio of *Orchestia gammarellus* (Pallas) was studied by Moore and Francis. Sainte-Marie (1991) reviewed the reproductive bionomics of aquatic gammaridean amphipods. Steele and Steele (1991) pointed out that tropical species are characterized by small size, low fecundity, short brood intervals and multivoltine life cycle. Life-history traits of 214 amphipod species were reviewed by Sainte- Marie (1991) and stated that life-history patterns of gammarid amphipods are influenced by latitude, depth and salinity. Life history of the amphipod *Gammarus locusta* in the Sado estuary was studied by Costa and Costa (1999). Cunha et al., (2000) studied the life history and reproductive biology of *Corophium multisetosum* and stated that low-latitude, warm-water amphipods show iteroparous, multivoltine life history patterns. Chandani and Alan (2004) studied the reproductive bionomics and life history traits of three gammaridean amphipods *Cymadusa filosa*, *Ampithoe laxipodus* and *Mallacoota schellenbergi* from the tropical Indian Ocean and reported multivoltinism and continuous reproduction.

6.2 Life history and reproductive biology

6.2.1 Materials and Methods

Amphipod Collection and maintenance

Live epibenthic samples were collected from Puduvypin, Cochin estuary (Figure 6.1) using van-Veen grab (0.048 m^2 mouth area) and brought to the laboratory along with the sediments. In the laboratory, the individuals of *E. chilkensis* were sorted out and kept in the tanks of the recirculating system designed and patented by Nair et al., (2006) where the environmental conditions were maintained as near to the insitu conditions for one month, to acclimatize the individuals for experimental studies. Mass culture of *E. chilkensis* was maintained in the tanks of the recirculating system (Plate 1). Later, pairs of this species (males and females) were isolated and transferred to separate finger bowls, each containing 125 ml of unaerated brackish water (Plate 2, 3). The temperature was maintained at 26 ± 1 ° C, salinity 19 ± 1 and pH 7.4-8.6. Few strands of dried algal matter (*Chara* sp.) were added to each bowl as food for the animal. These bowls were labeled for later identification. Individuals were studied under 3 different categories: - juveniles, males and females.

Feeding rates

These were tested with different types of feeds like decaying mangrove leaves, natural detritus available at the sampling site, flesh of young mussel (*Villorita cyprinoids*), algae (*Chara* sp. Plate 4) and *Navicula* sp. scraped from the sides of the culture tanks. For further experiments *Chara* sp. was selected as feed based on its abundance and local availability, and considering the fact that the farmers in the field can culture these amphipods with ease.

Feeding experiments were conducted in 125 ml finger bowls with filtered brackish water. Algae *Chara sp.* (muskgrass) was soaked in water, dried using blotting paper and weighed before introducing into the culture bowls. The quantity of feed used in each bowl ranged from 0.2 to 0.5 g w/wt (wet weight). Experiments were run using 10 amphipods each in 2 sets of culture bowls (adults and ovigerous females) and the experiment lasted for 24 hrs. Bowls containing algae and without experimental animals were used as controls. On termination of the experiment, the excess feed was netted (mesh size 10 μm) and re-weighed as before. Feeding rate was calculated as amount of feed consumed per day per individual.

Life span and mortality

Total life span was measured by rearing all the individuals released from a single brood in finger bowls until all of them died. Water was changed every day and fresh feed was added on every alternate day. The time of liberation of juveniles from the brood pouch until its death was recorded to measure the total life span. Experiments were run using five culture sets. Mortality in juveniles, females with brood and males after copulation were also assessed during this process.

Moulting and Growth rates

Individuals released from a single brood were reared together in a finger bowl and the moulting rate was assessed separately for males and females. Growth rates were assessed as the average length increment in body size. Live animals were removed from the culture bowls soon after their release from the brood pouch and measured for total length at regular intervals. An ocular micrometer was used for the body length measurements. Body size (length) was measured as distance from tip of the cephalon to the tip of the telson.

Sexual maturity and sex ratio

Newly hatched juveniles from a single brood was separated into finger bowls and reared. The reared animals when reached almost to maturity, a mature female was added to assess the time required for male maturity. The day at which the female was found to be ovigerous was recorded and this was the time for male maturity. Experiments were run using 5 sets of culture bowls to have a mosaic picture. Similarly a matured male was added to the female which have almost reached maturity. The appearance of the brood was taken as the time for female maturity. Number of males and females from various broods were counted to find out the sex ratio. Males were identified based on the structure of antennae and subsequently by the presence of an enlarged second gnathopod (Plate 5) and females based on the presence of brood / lamella (Plate 6).

Fecundity, embryonic development

After one month of acclimatization in the laboratory, pairs of amphipods (males and females) were removed from the main culture tank and placed in separate finger bowls. They were observed daily until the female was found to be ovigerous. The fecundity of *E. chilkensis* was estimated based on the total number of juveniles released by a female. The time for the embryonic development was recorded as the period from oviposition to the hatching of juveniles from the brood pouch.

Biochemical analysis

Live samples maintained during the culture were sorted out into three groups viz. juveniles, adults and ovigerous females for biochemical analysis. The specimens were rinsed with distilled water to remove salt, lyophilized and stored in a desiccator. Before analysis, the samples were thoroughly homogenized using a standard homogenizer. Protein was estimated according to the Faulin- Phenol method described by Lowry et al., (1951) using bovine albumin as standard. Total carbohydrate was estimated according to the colorimetric method using phenol and sulphuric acid, described by Dubois et al., (1956) using glucose as standard. Lipid extraction was carried out according to Bligh and Dyer (1959) by direct elution with chloroform and methanole (1:2). The extracted lipid was dried at 80^0 C (20min.) and determined spectrophotometrically after carbonization at 18^0 C in concentrated sulphuric acid according to Marsh and Weinstein (1966), tripalmitine solution were used as standard. Energy equivalents were calculated using the conversion factors given by Winberg (1971) and the values were corrected for biologically unavailable nitrogen oxidation energy according to Kersting (1972). Energy equivalents are expressed in Kcal g^{-1}.

6.2.2 Results

Food and feeding

Experiments with different feeds showed that the *E. chilkensis* fed on a variety of feeds like decaying mangrove leaves, natural detritus available at the sampling site, flesh of young mussel (*Villorita cyprinoids*), algae (*Chara* sp.) and *Navicula* sp. scraped from the sides of the culture tanks. Juveniles were found to survive only on the diatom (*Navicula* sp.) scraped from the sides of culture tanks and natural detritus. Based on the observation made during the study, *E. chilkensis* can be categorized as an omnivorous feeder showing a preference for natural detritus and decaying mangrove litter collected from the sampling site. At times they showed cannibalistic behaviour by feeding on their own juveniles and would also feed on moulted exoskeleton.

Feeding rates of adults on dried algal matter (*Chara* sp.) were calculated, after subjecting them to 24hr starvation. Average feeding rate was 615 μg day^{-1} $individual^{-1}$. Adults showed an average feeding rate of 1095 μg day^{-1} $individual^{-1}$ whereas females with broods showed lower rate of 205 μg day^{-1} $individual^{-1}$.

Life span and mortality

Females lived on average 1.4 times longer than males (average for females: 189 days and for males 132 days) Table 6.1. Mortality was high towards the latter half of the life span. Mortality in juveniles was relatively less, ranging from 8-33%. Mortality in females was also observed during the reproductive phase (usually towards the end of embryonic development –7^{th} to 9^{th} day). Mortality in males was related to copulatory behaviour, was evident as it was found that 10-20% of males died after copulation (Table 6.2).

Moulting and Growth rate

Moulting rate was found to be higher in females, as the female always moulted after the release of juveniles from the brood pouch. Total number of moults in females ranged between 6-9 as against 5-7 in males (Table 6.1). A higher size increment per moult was observed in males as compared to females as the males attained larger size in a shorter duration.

Newly-born juveniles were in the size range of 1.63-1.92 mm and the number of antennal segments were 6. Initially growth of the body was exponential for around 20 days after hatching with a growth rate of 0.12 mm day^{-1}. Individuals from the same brood exhibited different growth rates, even the number of antennal segments varied from one to another, as some 15-days old individuals had 9 segments for females while males had 11 segments in their antennae. Size of individual or number of antennal segments cannot be often taken as an exact measure of their age. Growth rate was generally higher in early developmental stages. The maximum length observed during the laboratory experiment was 15.2 mm in males and 14 mm in females, whereas in the natural population males attained a size up to 17.76 mm and females attained a size up to 16.42 mm.

Attainment of sexual maturity and sex ratio

Females of *E. chilkensis* attained sexual maturity within 30-49 days (39.25 ± 5.99) at sizes ranging from 5.48 to 5.76 mm. Males attained sexual maturity much earlier than females, within an average of 26.5 ± 5.55 days with a size range of 5.08 to 5.81 mm. According to this observation females attained a size of 5 mm within 39 days whereas males attained the same size within 27 days. This clearly indicates that the length increment per moult was higher in males compared with females and males grew faster than females. The sex ratio remained more or less the same at the time of maturity (Table 6.2). The number of males decreased as they died at an early age, and as a consequence, the number of males was relatively lower than females towards the end of the total life span. This might be a reason for relatively lower number of males than females in the natural benthic amphipod populations (Nair and Anger 1979; Kemp et al. 1985; Moore and Francis 1986). Age of the female at the time of brooding significantly affected the time required for the attainment of maturity in the next generation. Increase in the age of the female delayed the attainment of maturity of the offspring (Figure 6.2).

Mating behaviour

Sexually mature males were observed to grasp mature females and mount on them. Precopulatory riding behaviour, a condition known as amplexus was not observed in this case. A mature female amphipod is available for fertilization only for a short time immediately after moulting when the cuticle is sufficiently flexible to allow release of the eggs into the brood pouch through the genital pores. The copulatory process continued several times even after the release of eggs, may be to ensure complete fertilization. It was found that females kept separately in culture bowls had no eggs in their brood pouch, but with the introduction of the male it was found that they become gravid.

Therefore it can be inferred that egg bearing and release of eggs into the brood pouch takes place only in the presence of a male.

Brood

Amphipods, are peracarid crustaceans and thus are characterized by the presence of a brood pouch, or marsupium, in females during the breeding period. The brood pouches are formed by four pairs of brood plates (lamellae), projecting medially and the plates are fringed with long and thin hairs on their margin (Plate 7). These interlace to form a continuous brood pouch which is efficient in retaining the brood, whilst allowing the free exchange of water. The eggs are laid into this pouch, where they are fertilized owing to repeated copulation by the male. The developing embryos within the brood pouch are continuously exposed to the external medium. These brood plates or lamellae were found to be lost soon after the release of the juveniles.

Embryonic development and hatching

The brood pouch, which was initially yellowish in colour, turns to white as the embryo develops. The time for the embryonic development was recorded as the period from oviposition to hatching of juveniles from the brood pouch. Time between oviposition and hatching of juveniles (incubation period) varied from 8 to 14 days. There was no significant relation between the status of the brood (early or late) and incubation period. Mature eggs hatch directly into juveniles that resemble adults. Different stages of embryonic development were identified which were similar to those observed for other amphipods (Dick et. al. 2002). 1^{st} and 2^{nd} day: -formation of morulla and blastula. 4^{th} day: -eggs were black, homogeneous ovals with a clear zone beneath the egg membrane (chorion). 5^{th} day: - movement of the early embryo towards the periphery of the membrane. 8^{th} day: - curled very early embryos, eyespots and appendages were not yet visible and the embryo was tightly expanded within the egg membrane.

10th day: - Eggs were larger and more elongated at the head region of the embryo and appendages were well developed (Plate 8). The juveniles were released one at a time by the female and the whole process took hours, depending upon the number of juveniles.

Fecundity

The fecundity of *E. chilkensis* was estimated as the mean number of juveniles released by a female in each replicate. Newborn juveniles were removed soon after their release from the brood pouch to avoid cannibalism. The number of eggs produced from a single brood increased with the age of the female. The number of broods produced during the life span of *E. chilkensis* ranged from 4 to 7 (Figure 6.3). It was observed that a female could produce at least four broods consecutively. Females are able to carry eggs at a size of 5 –6 mm. During the study, only one set was observed with a maximum of 7 broods. Total number of juveniles produced in a brood ranged from 4 to 29 and the total number of juveniles from a single female varied from 35 to 139. Significant positive correlation was obtained between age of the female and number of juveniles from a single brood (Table 6.3). In amphipod population, two kinds of variation of fecundity are usually recognized: one related to size (size-specific fecundity) and the other to individual differences among females with the same size (scatter) (Cunha et. al. 2000).

Biochemical composition

Protein, carbohydrate, lipid and energy equivalents for all the three categories studied are given in table 6.4. Carbohydrate content was higher in all the three categories studied compared to protein content, the highest being in ovigerous females (87.95 mg. g^{-1}) and the lowest in juveniles (51.04 mg. g^{-1}). Protein showed a decreasing trend during individual growth- higher in juveniles (27.12 mg. g^{-1}) and lower in adults (20.74 mg. g^{-1}). Lipid content was higher in ovigerous females (89.75 $mg.g^{-1}$) compared to adults and juveniles. Protein content presently recorded was less compared to observations on other amphipods (Nair and Anger, 1980). It has been observed by Nair and Anger (1980) that variation in carbohydrate did not follow any regular pattern with the availability of food.

6.2.3 Discussion

E. Chilkensis can be cultured on different types of feeds like dead and decaying animals, algal matter and detritus. They also exhibited cannibalistic behaviour in the laboratory, by feeding on their own young ones. They even ingested moulted exoskeleton, which indicates that this species requires a high nitrogen food source at times. A similar observation was made by Agnew and Moore, (1986) while studying the feeding ecology of two littoral amphipods. According to our observation, average ingestion rate of adults feeding on dried algal matter was found to be lower in females with brood compared to other adults. Body distension caused by cramed stomach or swollen ovaries might constrict the gut and impair feeding mechanically (Thruston, 1979).

Females lived longer than males and mortality was high towards the last weeks of the life span. Nair and Anger (1979*a*) found that female *Jassa falcate* (Leach) lived up to 3.6% longer, but grew slower, than males in the laboratory. Mortality was low in juveniles, but increased with age. Death of males after copulation was observed, which might be due to energy used up during the behavioural activities associated with breeding. Mortality occurred even during brooding in females, due to the energy used up during incubation, and was usually towards the end of the developmental stages of the embryo (7^{th} to 9^{th} day). The energy allocated for reproduction is divided between the reproductive output (brood size, egg volume) and behavioural activities associated with breeding (mating amplexus, brooding of embryos and juveniles). The above activities can be substantial in amphipods and may vary with environmental conditions (Clarke, 1987).

Moulting rate was higher in females with less increment per moult compared to males. Males attained sexual maturity earlier than females. Nair and Anger (1979) reported that males and females of *Corophium insidiosum* moulted approximately at the same time until they reached sexual maturity after which the females moulted more frequently at regular intervals. Higher length increment per moult in males was also observed in this species. In *Ampithoe valida* females reached sexual maturity before males but males lived slightly longer than females (Pardal et al., 2001). Cunha et al., 2000(a) also reported that length increment per moult was higher in males of *Corophium multisetosum*.

There was a shift from an equal number of males and females at the time of attainment of sexual maturity to a female domination towards the end of the life cycle. Sexual differences in growth rate, longevity and rate of maturation may affect the apparent sex ratio (Moore, 1981). According to Moore (1981) sex ratios in populations can be either 1:1, skewed towards females or males, or may show seasonal variations. Female biased sex ratio towards the end of life cycle indicates an increased female longevity. When conditions are stable, any population would maintain an unbiased (1:1) sex ratio (Wildish, 1977).

Incubation period varied from 8 to 14 days and after hatching, the juveniles stay in the brood pouch for few hours before being released and were not allowed to re-enter the brood pouch. Nair and Anger (1979a) also reported similar type of brood protection in *Corophium insidiosum*.

The number of offsprings produced from a single brood varied with the age of the female. Significant positive correlation was found between the number of juveniles released and the age of the female. The number of eggs carried by a female amphipod generally increased at each successive moult (Fincham, 1974). Brood size in gammarideans is often found as being proportional to body length of females (e.g. Beare and Moore 1996; Costa and Costa, 1999; Persson, 1999; Cunha et al, 2000a). Age of the mother at the time of breeding influenced life cycle characteristics of its offspring namely attainment of sexual maturity in the next generation. In *E. chilkensis*, individuals from early brood attained sexual maturity earlier than those from late brood, but in *Corophium insidiosum* (Nair and Anger, 1979, a) individuals from late broods attained sexual maturity earlier. In *E. chilkensis,* there was no significant relation between age of the mother and duration of incubation. Again, this observation contradicted the observation in *C. insidiosum* wherein; early brood females incubated their offsprings for longer duration. Such contradictory observations may be due to phylogenetic and physiological constraints (Sainte- Marie, 1991).

Males and females of *E. chilkensis* attain different sizes at the same age, the males being larger. Based to our observations made, on attainment of sexual maturity, we found that females of *E. chilkensis* needs an average of 39 days to attain a size of 5mm whereas males attain a similar size within an average of 27 days. According to Sainte-Marie (1991), about 97% of gammarids show larger males compared to females. Growth rates were higher in the early phases, where it is commonly accepted that individuals grow exponentially (Welton and Clark, 1980). The maximum body size attained by individuals under laboratory conditions was smaller (15.2mm) compared to organisms in the field (17.76mm). Growth variations could also be associated with poor food quality. In addition to the quality of the food supplied, the small body size of individuals under laboratory conditions might be due to a decrease in the scope for growth in response to stress. For example, Chen et al. (1990) recorded lower growth rates of penaeid shrimps in culture due to deterioration of water quality caused by ammonia. Even in the present case, it may be possible that water quality suffered problems caused by ammonia since the excess food supplied was removed only once every week. Maximal body length attained in culture experiments was about 30% smaller than observed in the field for both sexes and the difference in maximal number of eggs is up to 60% in *Jassa falcata* (Nair and Anger 1980).

The average protein content was less compared to other amphipods, whereas the carbohydrate content compare favorably with other species of amphipods (Nair and Anger, 1980). This might be due to the difference in the type of feed used during the experimental set up. Lipid content was comparatively higher in ovigerous females than adults and juveniles.

6.3 Population Dynamics

Population dynamics of *E. chilkensis* was studied from the monthly samples collected over a period of one year from mangrove rich area of Puduvypin. The mangrove ecosystem is mostly self-balanced and is mainly detritus based unlike the coastal system that is mainly based on multi variables. Since these detritus rich mangrove areas are used by fishes, crabs and oysters for their reproduction or growth, such swamps are considered of great economic importance for capture as well as captive fisheries. Mangroves of Puduvypin are dense and dominated by *Avicennia officianalis*, *Exoecaria agallocha*, *Rhizophora mucronata*, *R. apiculata*, *Acanthens ilicifolius* and *Brugueira* sp.

6.3.1 Materials and Methods

Amphipod Collection

Population density and dynamics of *E. chilkensis* was studied from the monthly samples collected over a period of one year (October 2003-September 2004) during the low tide from Puduvypin (9° 59’ N and 76° 13’ E), adjacent to mangrove vegetation (Figure 6.1). The selected area had a depth of 3-4 m and was influenced by tides. Population density of *E. chilkensis* was also estimated at the polluted regions of Cochin Estuary (9° 59’ N 76° 16’ E). The mud samples were collected using van Veen grab (mouth area 0.048 m^2), sieved using 500-µm screen and preserved in 4% formaldehyde coloured with Rose Bengal. From these samples *E. chilkensis* was separated, identified and counted in the laboratory as juveniles (< 5 mm) and adults (> 5 mm). Sediment grain size was analysed by pipette method (Krumbein and Pettijohn, 1966) and organic carbon was estimated by wet oxidation method (El. Wakeel and Riley, 1957). Organic matter was calculated as 1.724 times the carbon (Trask, 1955).

6.3.2 Results

Hydrography

Temperature, salinity, pH, dissolved oxygen, nitrate, nitrite, silicate, phosphate and ammonia, measured during different months are given in Figure 6.4 (a, b and c) and Figure 6.7. All the environmental parameters measured were subjected to considerable variations throughout the period of observation. Water temperature ranged from 27.5-34.0°C. High temperature was observed during the pre-monsoon period (February-May) and ranged from 27.5-34.0°C. In monsoon (June-September) the values were comparatively lower and ranged from 29.0-32.0°C and during post-monsoon (October-January) the temperature varied from 29.0-33.0°C. The salinity values ranged from 5.11 (June 2004) to 33.61 psu (February 2004). Comparatively low salinity was recorded during the period May-September and the value fluctuated between 5.11 and 13.23 psu. From December to April high salinity was recorded and it ranged from 21.37-33.61 psu, highest was recorded during February. In the post monsoon months October and November moderate salinity was recorded 18.71 and 16.68 psu respectively. pH ranged from 7.42 to 8.21 and D.O ranged from 2.43 ml/l (May) to 6.34 ml/l (March). Seasonal comparison showed that monsoon average in D.O was higher. Nitrate values ranged from 2.37µM (December) to 60.91µM (June) and nitrite ranged from 0.16-1.80µM, highest value recorded during July. Phosphate ranged from 3.33 to 19.75µM high value was recorded during July. Seasonal comparison showed that monsoon average was higher for nitrite, nitrate and phosphate values. Silicate ranged from 5.15 to 109.40µM high value was recorded during June 2004. Ammonia ranged from 4.90 to 35.32µM and high value was recorded during March.

Sediment texture (Figure 6.5) was characterized by a high sand and clay fraction (mean: 43% and 38% respectively). The organic matter (Figure 6.6) in the sediment was generally high ranging from 16.6 (October 2003) to 72.74 mg g^{-1} (February 2004).

Annual Cycle

The distribution and population dynamics of *E. chilkensis* are concordant with previous records of the amphipods in Cochin estuary (Nair et al. 1983). *E. chilkensis* was encountered in varying densities in the epifaunal community in the mangrove rich regions of Puduvypin (21-1583 ind. m^{-2}). Changes observed in the proportion of adults and juveniles over a period of 12 months are shown as densities per m^2 (Table 6.5 and figure 6.8). These data were compared with the total gammarid population, contributed by *Eriopisa chilkensis, Corophium triaenonyx, Melita zeylanica, Quadrivisio bengalensis, Grandidierella gilesi* and *G. bonneri*. High densities of *E. chilkensis* have been attributed to its short life-span (4-8 months) and continuous possible gonad maturation. It attained large standing stock in these areas due to high fecundity and survival. *E. chilkensis* population underwent considerable fluctuation during the annual cycle. Laboratory culture of *E. chilkensis* showed that it breeds throughout the year, but in the field they were absent during February. The maximum population density of 1583 m^{-2} was observed during November. A similar peak in density (20,416 ind. m^{-2}) of total gammarid amphipods was also observed during the same month. Population density of gravid females ranged from 21 to 250 ind. m^{-2} and high abundance was recorded during the month of November. Population density of juveniles ranged from 42-333 ind. m^{-2} and high abundance was recorded during December. High abundance of gravid females were followed by the peak in juvenile abundance in the very next month showing high recruitment. Juveniles were also not recorded during February and March. High population density coincided with a salinity of 16.68 p.s.u (November 03) and moderate organic enrichment, 35.34 mg g^{-1} (November 03).

E. chilkensis is found to tolerate a wide range of salinity (5.11-35.35 p.s.u) and temperature (27.5-34 °C). Gravid females were observed in high numbers during November and December (250 m^{-2}; 229 m^{-2} respectively) when the salinity was around 16.68 and 28.85 p.s.u respectively indicating their preference for medium saline conditions during the breeding period, and were absent during February, March and June (Table 6.5, Figure 6.8). Highest number of juveniles (333 m^{-2}) was also recorded during the same period (November-December). It may be also possible that ovigerous females are under recorded due to egg spillages during fixation. Females with broods accounted for 13% of the total *E. chilkensis* population. A maximum of 46 eggs/brood was recorded during the field study. Juveniles were absent during February and March but were present during the low saline period (May-October), indicating their ability to tolerate low to moderate (5.11-18.71 psu) salinity conditions. Generally, there was lower number of males than females throughout the study period. Total number of males recorded during the study ranged from 21-458 ind. m^{-2}.

E. chilkensis could tolerate wide salinity fluctuations whereas other gammarid amphipods were absent during this (March-May) period. (Figure 6.7, 6.9 and Table 6.5). In the laboratory *E. chilkensis* within the finger bowls were subjected to natural evaporation and experiments confirmed they could survive a change in salinity from 18.39 (initial) to 35.35 p.s.u (final) over four days and with no mortality. This implies that *E. chilkensis* could tolerate short duration salinity fluctuations in the field whereas the other gammarid amphipods moved out to locations of preferred salinity. The percentage contribution of *E.*

chilkensis to the total gammarid amphipods on an average was 45.91% (Table 6.5). Population dynamics in the organic-rich environment of Cochin estuary, adjacent to the sewage discharge site followed a similar trend with the high abundance in November (42-667 ind. m^{-2}).

6.3.3 Discussion

The distribution of *E. chilkensis* is concordant with previous records of the amphipods in Cochin backwaters (Nair et. al, 1983). It was encountered in varying density in the epifaunal community of this estuary. *E. chilkensis* generally tolerates a wide range of salinity (5.22-32.64 p.s.u) and temperature (27.5-34°C), but preferred a range between 16 and 28 psu. The presence of ovigerous females throughout the year appears to be a widespread feature of amphipods (Mark and Alan, 1989). Asari (1983) also reported that *E. chilkensis* were found in bottom samples throughout the year. *E. chilkensis* could survive in water with D.O levels ranging from 2.43 to 6.34ml l^{-1} and ammonia ranging from 4.9 to 35.32 µM l^{-1}. Maximum density of *E. chilkensis* including the gravid females and juveniles were obtained during November and December, when the salinity values ranged between 16 and 28 psu, organic matter ranged between 35-37mg $g^{-1}$and the sediment was a perfect mixture of sand and clay in almost equal proportion. According to Asari (1983) *E. chilkensis* was absent in sandy areas. Experimental studies carried out with *Corophium multisetosum* showed that temperature, salinity and sediment type affect survival, sexual maturation and number of offsprings (Cunha et. al. 2000b). Relative importance of physico-chemical parameters revealed that salinity was the prominent factor controlling the abundance of gammarid amphipods followed by temperature and dissolved oxygen (Nair et al., 1983).

E. chilkensis could tolerate wide range (euryhaline) and wide fluctuation in salinity when compared with other amphipods. Salinity is often considered less important for reproductive activities, but some studies have suggested that salinity influences the brood sizes. Vlasblom and Bolier (1971) found that although eggs of *Echinogammarus marinus* could develop in salinities ranging between 4 and 7 psu, the number of juveniles produced was less. Cunha et al., (2000a) also reported the significance of salinity on the brood size in wild populations of *Corophium multisetosum*. When salinities do not vary significantly, other factors may determine amphipod distribution such as algal cover, shelter or interspecific relationships (Nicolaidou and Karakiri, 1989). Tanks used for mass culture contained *Corophium triaenonyx* and *E. chilkensis* and it was observed that in the presence of *Corophium triaenonyx*, the number of *E. chilkensis* decreased drastically, which may be due to competition for food and space. According to the observations made during the present study, *E. chilkensis* seek shelter under the algal covers, leafs and detritus which were added into the culture tanks. Our observations indicate that the population of *E. chilkensis* produces several generations per year.

Laboratory culture of *E. chilkensis* showed that it breeds throughout the year, but in the field during February they were completely absent. During this month high salinity (33.61p.s.u) and organic matter (72.74 mg g^{-1}) was observed. Salinity was found to be the prominent factor controlling the abundance of the gammarid amphipods, followed by temperature and dissolved oxygen (Nair et al., 1983). Our observation cannot be related with the high salinity (33.61psu), because experiments have shown that they could tolerate salinity up to 35.35 psu. Hence, such an observation may be attributed mostly to the high organic matter present during that month. This is in accordance with the classic model of Pearson and Rosenberg (1978), under which, increase in organic matter above a critical level causes hypoxia, smothering and change in physiochemical properties of the sediment and further leads to decreasing faunal density. The total benthic macrofauna was also less during this month. Nair et al., 1983 also reported high organic carbon and nitrogen content in sediments during the period of occurrence of gammarid populations. Remani et al. (1980) observed that high organic carbon and C/N ratios in sediments seem to have no influence on the gammarid populations. A distinct density peak in *E. chilkensis* and total gammarid amphipods was observed in November. During this month the salinity was 16 p.s.u and organic matter was 35.34 $mg.g^{-1}$. Steele and Steele (1975) observed a correlation between the abundance of organic matter in the sediment and the seasonal release of young in Gammarids of the North- Western Atlantic. The authors suggested that the release of young must coincide with the optimum conditions for their survival.

In Cochin estuary, *E. chilkensis* reproduce throughout the year showing continuous recruitment. Since *E. chilkensis* females produce broods consecutively (iteroparity) under laboratory conditions, based on the present study (duration of embryonic development, maturation and life span), one should expect six or seven generations annually, thereby exhibiting a multivoltine life cycle. Morino (1978) in his review stated that tropical species such as *M. zeylanica* in India breeds throughout the year. Steele and Steele (1991) pointed out that in tropics where there is a continuous supply of food, young ones could be produced continuously. Fenwick (1984) emphasized the importance of phylogenetic constrains and concluded that there is no simple optimum life history, but instead, a combination of different life-history traits may be equally successful in a given environment. This opinion was confirmed by Sainte- Marie (1991), who suggested that phylogenetic and physiological constraints should be best considered for the interpretation of gammaridean life history patterns.

Analysis of the gut contents of *Daysciaena albida* collected from the Cochin backwaters showed that amphipods and isopods formed the major part of their diet (Kurup and Samuel, 1988). Gammarids like *Anisogammarus pugettensis, Gammarus lacustrus* and *Gammarus tigrinis* have already been examined for their potential in fish culture. *Anisogammarus pugettensis* was proposed as an alternative to brine shrimp as food for young salmon (Chang and Parsons, 1975). *Gammarus lacustrus* in Hudson Bay meets dietary requirements for rainbow trout (Mathias et al., 1982). *Gammarus tigrinis*, a shoreline amphipod has been introduced into brackish streams as food for fishes (Reish and Barnard, 1979). Similarly *E. chilkensis* can be used as an alternative fish feed, as this gammaridean can tolerate wide range of temperature and salinity and consumes a wide variety of plant and animal material, in addition to scavenging dead and decaying organisms. They being resistant to handling stress can be easily mass cultured in the laboratory and used as natural feed.

E. chilkensis has been encountered in two different environments, moderately polluted regions (Harbour) and organic rich environments (Puduvypin). This shows that this organism can tolerate a wide range of environment in the estuary. In the Cochin backwaters, moderate enrichment of Zn, Cd, Pb, Fe and Cu have been reported and metal enrichment is high especially in case of Zn (x 25 – fold) and Cd (x 10 – fold) (Balachandran et al. 2005 and according to their study, the pollution in this region places the estuary as one among the impacted estuaries in the world. Sediment heavy metal contamination is a cause for concern as these metals undergo bioaccumulation and adversely affect the benthic organisms. Gammarid amphipods are used as biomonitors not only because they are net accumulators of trace metals, but they are relatively pollution tolerant, sedentary, abundant and easy to identify (Rainbow 1998). Here there is considerable scope for in-situ experimental studies and laboratory studies. Any impact on the reproductive and fecundity of these invertebrates may have significant ramifications on estuarine food chains and secondary production. The present study gives a basic knowledge about the life history and ecological aspects for evaluating the potential role of this amphipod as a test species in estuarine areas and to further develop assays for pollution monitoring at sub-lethal levels.

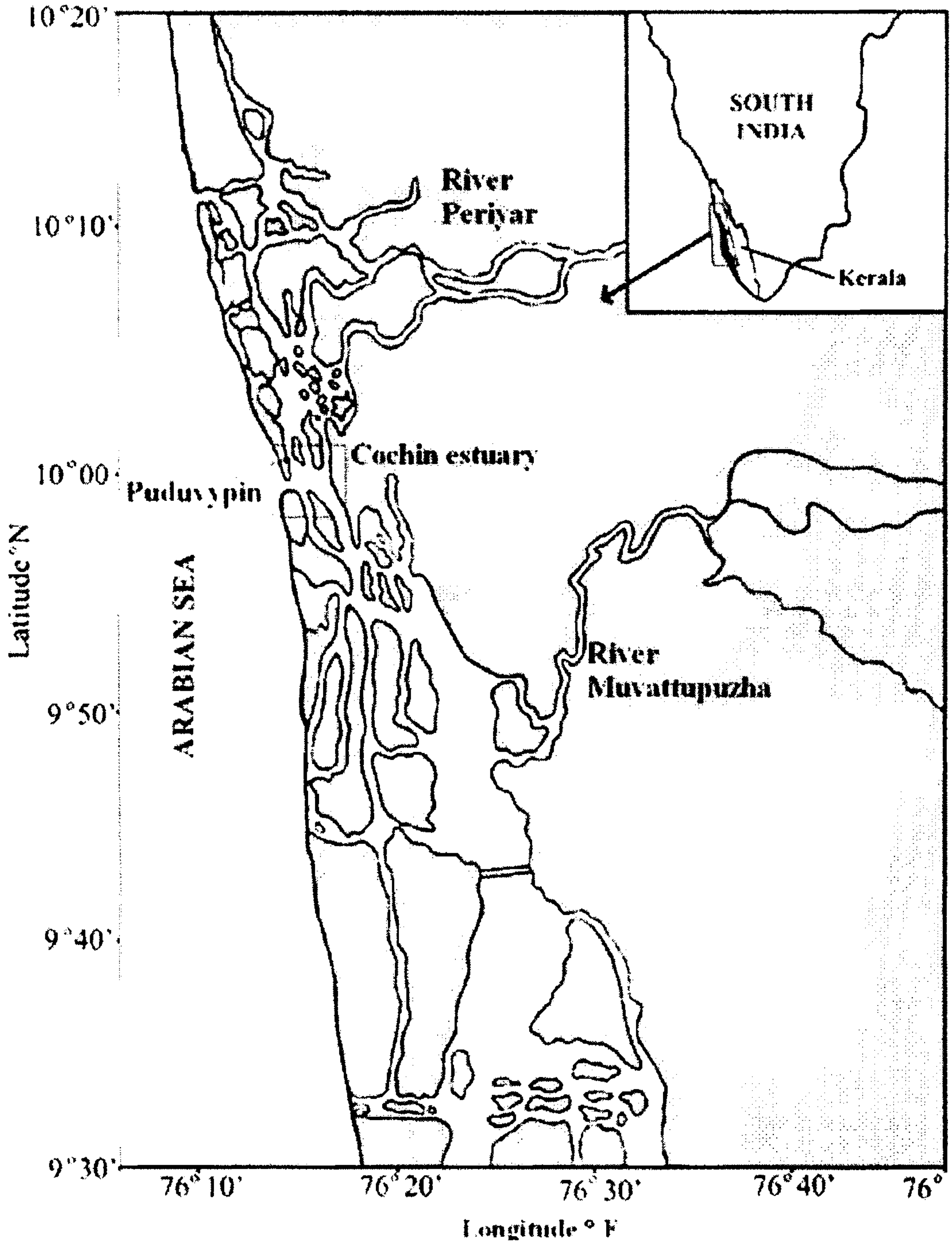


Fig. 6.1. Study region (Cochin backwaters) showing the sampling sites

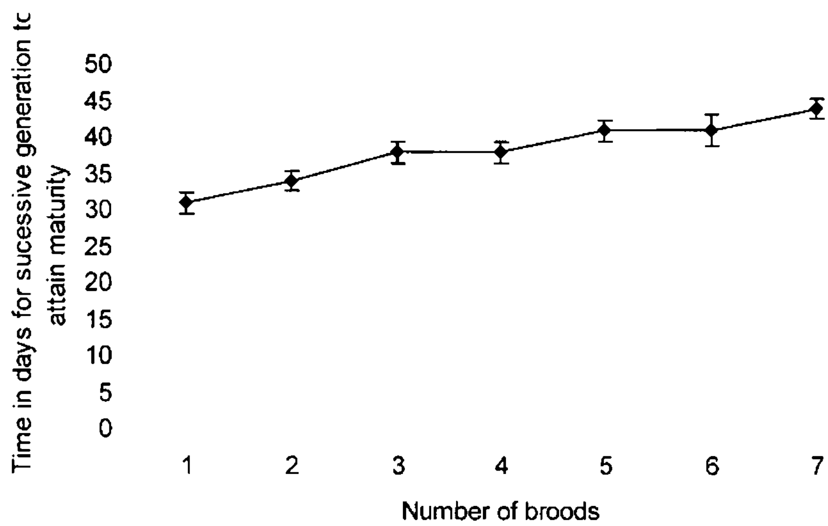


Figure.6.2 *E. chilkensis* - Attainment of sexual maturity in the F1 (First) generation

Figure 6.3 *E. chilkensis* fecundity pattern mean ± S.D

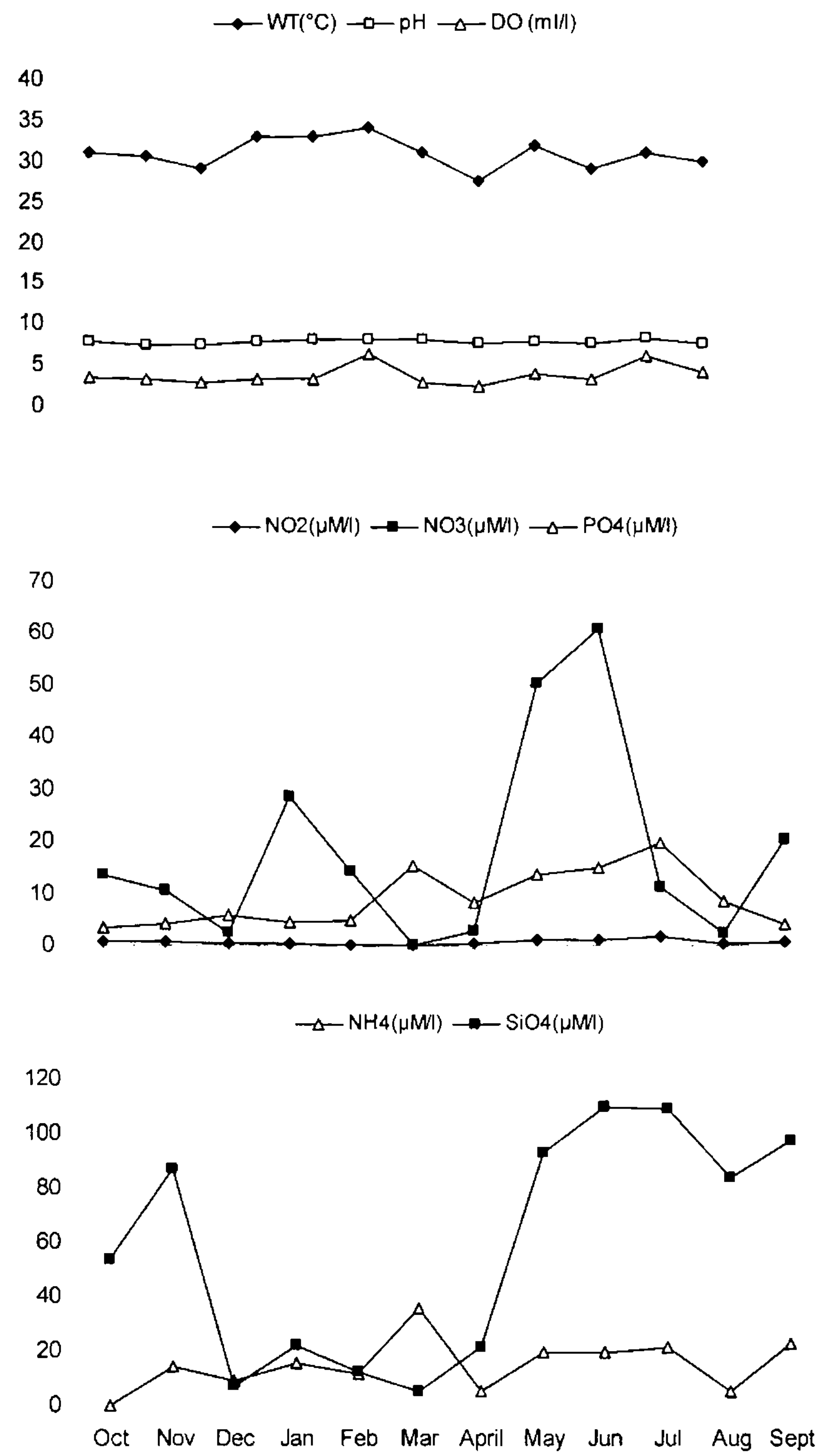


Figure 6.4 Environmental conditions at Puduvypin

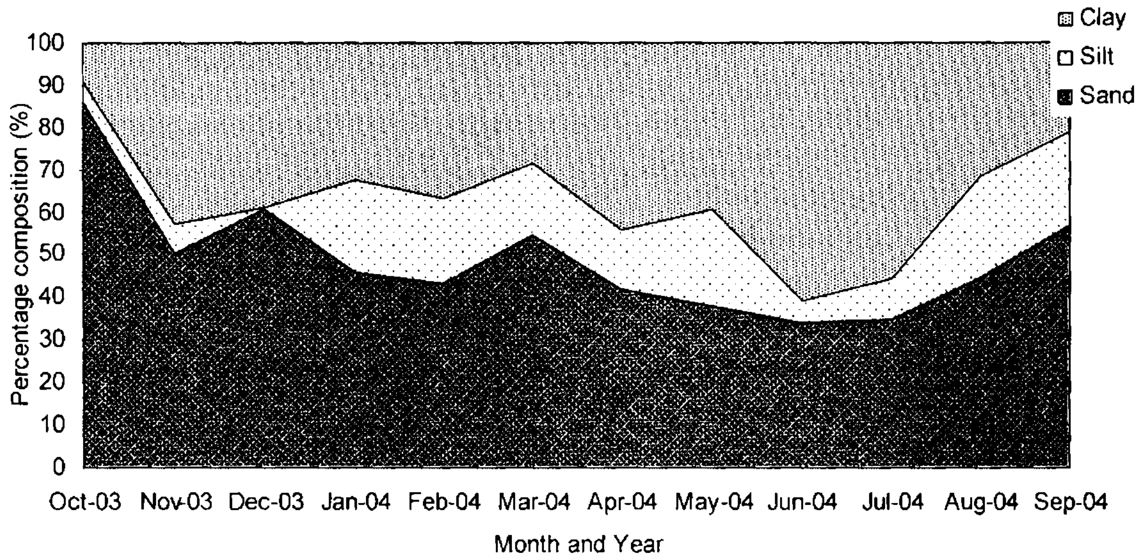


Figure 6.5 Variations in sediment texture at Puduvypin

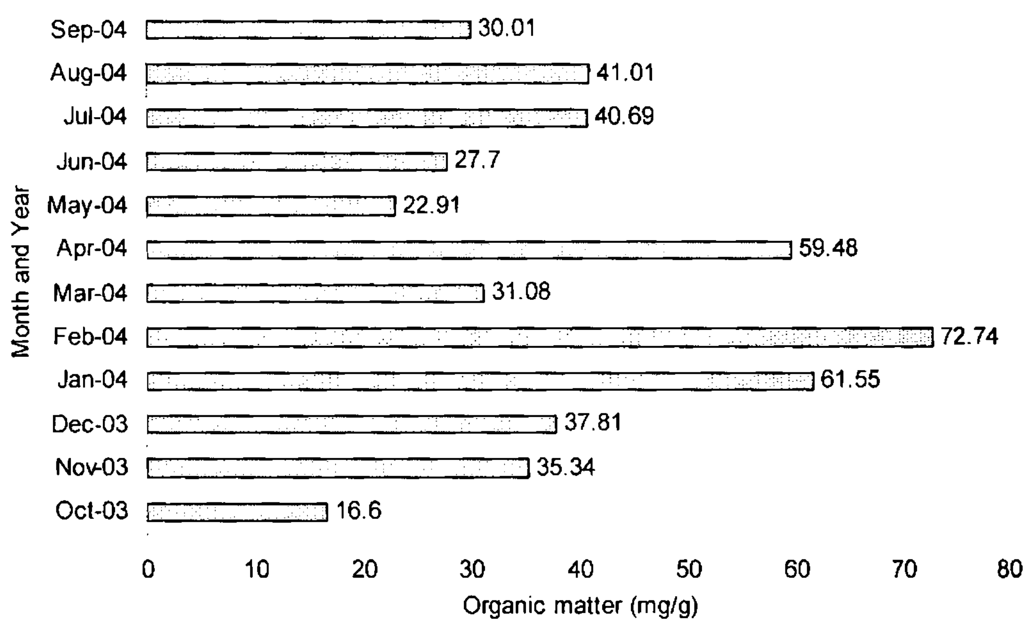


Figure 6.6 Variations in organic matter in sediment at Puduvypin

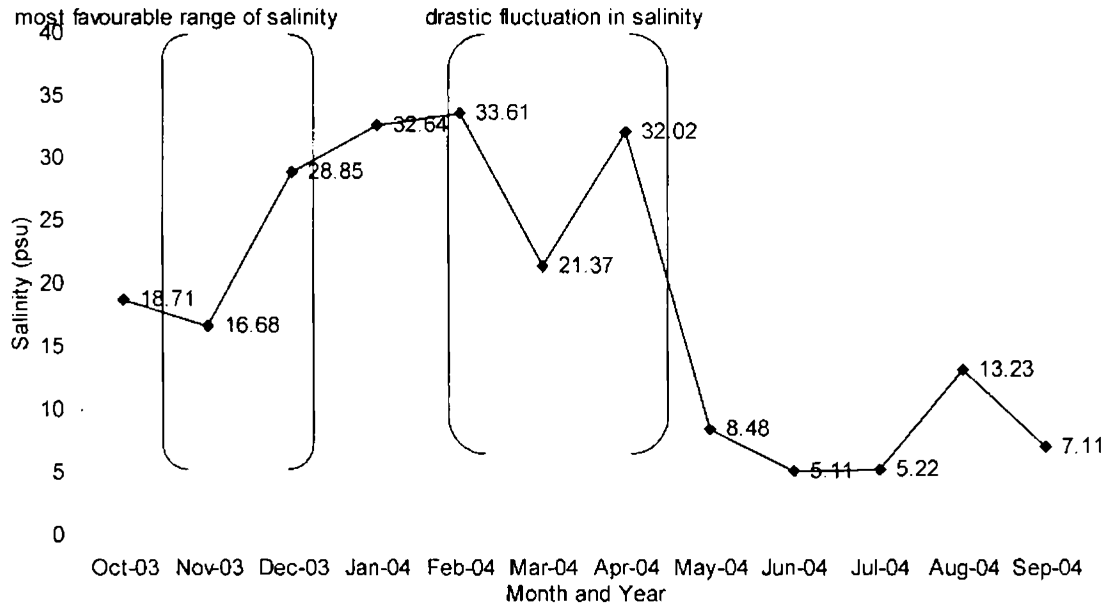


Figure 6.7 Salinity variations, showing the most favourable and adverse range in salinity from March-May at Puduvypin

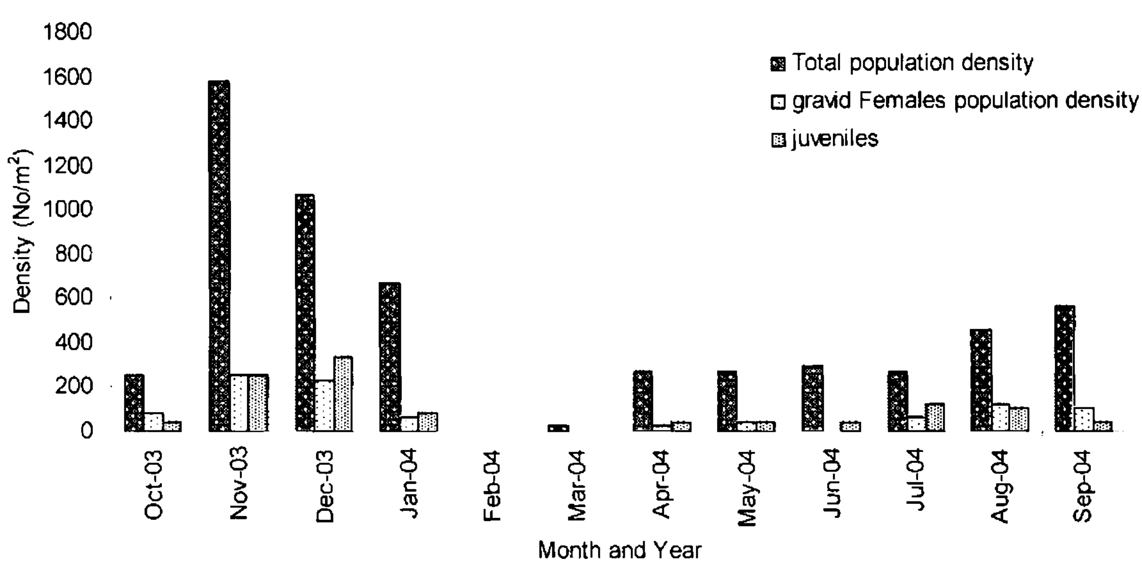


Figure 6.8 *E.chilkensis* total density, gravid females and juveniles

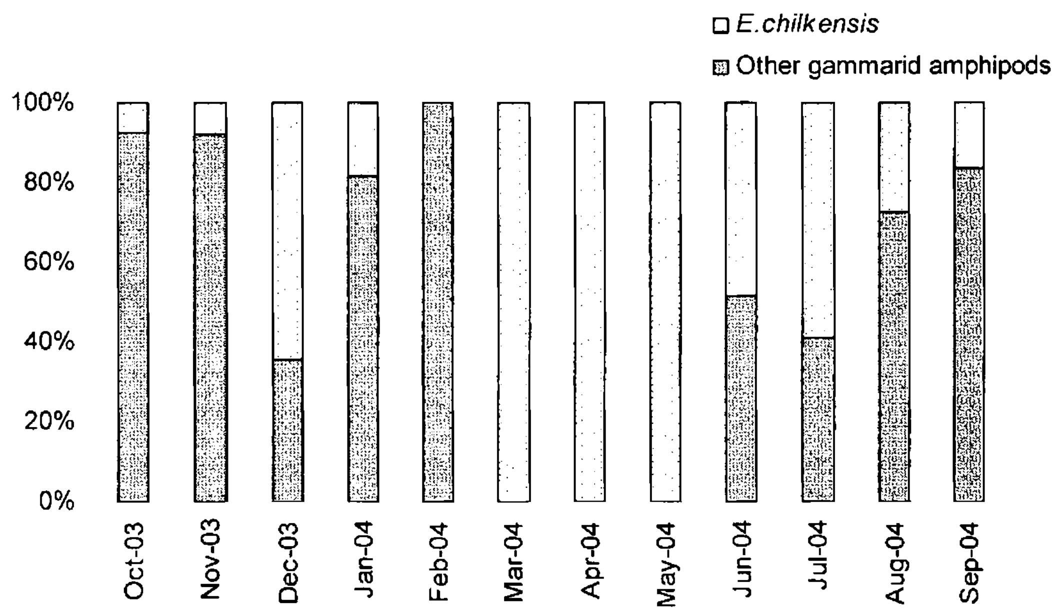


Figure 6.9 Percentage contributions of *E.chilkensis* towards other gammarid amphipods

Table 6.1 Life cycle criteria of *Eriopisa chilkensis*

Life -cycle criteria	M/F	Range	Mean	(±S.D)	n
Life span (days)	M	124 -175	132	22.88	8
	F	170 - 220	189	20.84	8
Number of moults	M	5 - 7	6.38	0.74	8
	F	6 - 9	7.63	0.92	8
Body length (mm)	M	11.44 - 15.2	13.4	1.45	6
	F	8.56 -14	10.38	1.79	8
Growth rate from 0 – 20 days (mm per day)	M/F	-	0.12	-	6
Broods per female	F	4 - 7	5.14	1.07	7
No. of juveniles per brood	F	4 - 29	13.72	7.39	33
Juveniles per female (sum)	F	35-139	72.16	39.74	6
Incubation time (days)	F	8 - 14	12	2.45	8
Sexual maturity of female (days)	F	30 - 49	39.25	5.99	16
Size (mm)		5.48 - 5.76	5.5	0.21	5
Sexual maturity of male (days)	M	20 - 38	26.5	5.55	8
Size (mm)		5.08 - 5.81	5.05	0.31	5

Table 6.2 *E. chilkensis* - mortality and sex ratio ('*' indicates total density in the finger bowls)

Culture set	Mortality of Juveniles	Mortality of Female with brood	Mortality of Male after copulation	Sex ratio at maturity M	Sex ratio at maturity F
A (8*)	1 (12%)	1 (50%)	1 (20%)	5	2
B (9*)	1 (11%)	1 (25%)	0	4	4
C (25*)	9 (33%)	0	1 (12%)	8	8
D (24*)	2 (8%)	0	1 (9%)	11	11
E (22*)	2 (9%)	1 (12%)	2 (16%)	12	8

Table 6.3 Correlation between age of the females and fecundity

Culture set	n	r	Significance
A	6	0.885272*	$P > 0.01$
B	7	0.738187*	$P > 0.05$
C	5	0.860559*	$P > 0.05$
D	5	0.492465	-
E	5	0.809762*	$P < 0.05$

Table 6.4 *E. chilkensis* major biochemical composition and energy contents in adults, juveniles and ovigerous females.

	Juveniles	Adults	Ovigerous females
Carbohydrate ($mg.g^{-1}$)	51.04	71.57	87.95
Protein ($mg.g^{-1}$)	27.12	20.74	21.38
Lipid ($mg.g^{-1}$)	63.05	70.25	89.75
Energy equivalent (K Cal. g-1)	0.93	1.03	1.31

Table 6.5 Population densities of total gammarid amphipods and *E. chilkensis* in (No.m^{-2}) as observed from the field data.

Date	Total number of (No.m^{-2})		*E.chilkensis* (No.m^{-2})				Percentage contribution of *E.chilkensis* among other gammarids
	Gammarid amphipods	*E.chilkensis*	Males	Gravid females	Females without brood	Juveniles	
Oct-03	3250	250	63	83	63	42	8
Nov-03	20416	1583	458	250	625	250	8
Dec-03	1646	1063	313	229	188	333	65
Jan-04	3605	667	229	63	292	83	19
Feb-04	21	0	0	0	0	0	0
Mar-04	21	21	21	0	0	0	100
Apr-04	271	271	83	21	125	42	100
May-04	271	271	83	42	104	42	100
Jun-04	605	292	104	0	146	42	48
Jul-04	459	271	42	63	42	125	59
Aug-04	1666	458	104	125	125	104	28
Sep-04	3459	563	167	104	250	42	16

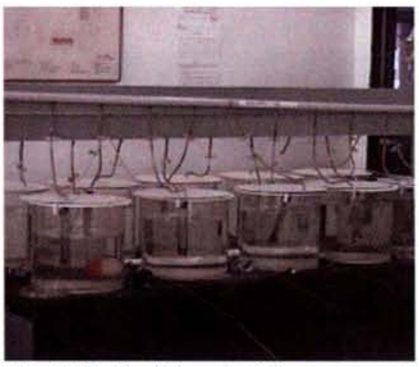


Plate 6.1 Tanks of the recirculating system used for mass culture of *Eriopisa chilkensis*

Plate 6.2 Finger bowls used to maintain isolated culture

Plate 6.3 Enlarged view of the finger bowl with *E.chilkensis*

Plate 6.4 *Chara* sp. (used as feed)

Enlarged view of male gnathopod

Enlarged view of female gnathopod

Plate 6.5

Plate 6.6 Female with brood

Plate 6.7 Enlarged view of the brood plates /lamellae

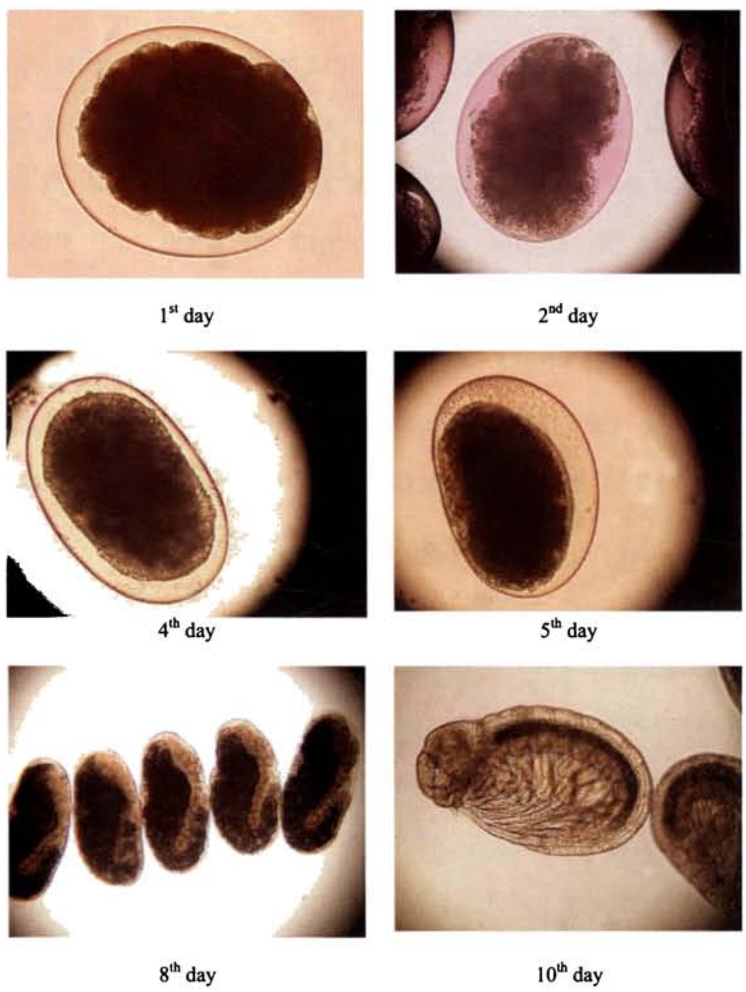


Plate 6.8 Different stages during the embryonic development of *E. chilkensis*

CHAPTER 7

Summary and Conclusion

Cochin backwaters situated at the tip of the northern Vembanad lake is a tropical positive estuarine system. The backwaters of Kerala support as much biological productivity and diversity as tropical rain forest and are responsible for the rich fishery potential of Kerala. Backwaters also act as nursery grounds for commercially important prawns and fishes. Recent changes brought about in the estuary like reclamation and consequent shrinkage of the backwaters and the discharge of pollutants have made an adverse impact on the potential of the aquatic ecosystem that used to support high levels of bioproductivity and diversity. Eloor industrial region is described as one of the most vulnerable industrially polluted 'hot spots' in the world. There are over 50 large and medium industries and over 2500 small-scale industries in this region. The industries located in Edayar-Eloor area consumes about 189343 cum water per day and discharge about 75% as used water along with large quantity of effluents and pollutants. The major types of these industries are fertilizers, pesticides, chemicals and allied industries, petroleum refining and heavy metal processing, radioactive mineral processing, rubber processing units, animal bone processing units, battery manufacturers, acid manufacturers, pigment and latex producers etc. The northerly connection, Azhikod, is at the mouth of the Periyar river. This connection takes care of half the discharge by the Periyar river. Central estuary also receives effluent discharge along with civic effluents from township. The estuary acts as a sink for the nutrients, flushing out only a portion of the pollution that it receives.

The usefulness of benthos in pollution monitoring programme to ascertain the health of estuarine and marine environments has been known since 1916. The longevity of benthos provides long-term exposure to toxic substances. They live in close contact with sediments, which enhances their intimacy with many pollutants. These infaunal organisms reflect the situations not only at the time of sampling but also during yesteryears. Among benthos, polychaetes are ideal indicator organisms, since they constitute well over half of the total number of organisms in and on the bottom and thus give a good indication of benthic conditions.

The thesis has been subdivided into seven chapters. The first chapter gives a general introduction about the topic and also highlights the scope and purpose of the study. The second chapter covers the methodology adopted for the collection and analysis of water quality parameters, sediment and the macrobenthic fauna.

Chapter 3 deals with hydrographic features, sediment characteristics and the spatial variation and abundance of macrobenthic fauna in the Cochin estuary. The study was conducted from 56 stations during three season namely pre-monsoon, early monsoon and monsoon in 2005. The study revealed the presence of high concentration of nutrients in industrial region of Eloor. High nitrite value of 1.53µM was recorded from the industrial region. Nitrate values ranged between 0.64 and 72.0 µM and high average was recorded at the central estuarine and the industrial region. NH_4 value ranged from 0-162.83 µM and high average was reported from the industrial region. High average (3.46 ± 2.18) in PO_4 was also reported from the industrial region during monsoon. High concentration of SPM and DIC was reported from the northern and central estuarine region. High SPM recorded was due to heavy sedimentation and discharge of sewage and industrial effluents. High chlorophyll a was recorded from the industrial and central estuarine region. Disposal of sewage and industrial waste is the major cause for nutrient enrichment resulting in domination of opportunistic algal species. Abundance of nano plankton (*Skeletonema costatum*) which grows quickly under eutrophic conditions has been reported from the estuary by earlier workers. Analysis of sediment texture showed that the northern region was dominated by high clay fraction throughout the sampling period. Central estuarine region was dominated by an equal proportion of sand and clay fraction during pre-monsoon where as it was dominated by clay during the other two seasons. Dominance of sand was reported from most of the stations in the southern region. High TOC and TN values were reported from the northern and central estuarine region. Altogether 73 species of macrobenthic organisms were identified during the study. Analysis of the macrobenthic community revealed the dominance of isopods from the northern region. High abundance of the isopod species *Cirolana fluviatilis* recorded from this region is a major threat as it might reduce the fish catch from this region as reported earlier in 1994 from Kumbalangi-Perumpadapppu area of the Cochin backwaters. Central estuary and industrial region were dominated by indicator organisms and pollution tolerant species which shows that this region is under stress. High abundance of *Villorita cyprinoides* was recorded from the southern region.

Chapter 4 explains the impact of organic enrichment on macrobenthic population in the Cochin estuary and includes the comparison of the present data with the earlier work in this region. This study was conducted to investigate the quality and composition of sediment organic matter and its impact on the macrobenthic population in a tropical estuary. Sediment TOC, TN and Clay were generally positively correlated with each other. TOC: TN ratio suggests that SOM quality is a combination of labile and refractory in the Cochin Estuary. The benthic infaunal communites recorded in the sewage polluted zone of Cochin estuary were characteristic of those generally seen in organically enriched sediments. As sediment organic matter increases above a critical level, changes in physiochemical properties of the sediment, caused by excessive organic matter leads to decreasing faunal densities. Regions receiving such high inputs of sewage have been reported to undergo drastic changes in the composition of benthic fauna, as observed in the present study. This has resulted in the dominance of more tolerant and opportunistic species of polychaete worms, especially deposit feeders belonging to the family capitellidae, which are reported to be the biological indicators of organic pollution. The long-term changes in the Cochin estuary give an indication as how anthropogenic influences have dominated the natural process and affected the benthic organisms. The former retting yards in the estuary showed ecological recovery, as an increase in species abundance due to reduced activities of retting in the recent years and subsequent reduction in levels of organic carbon in the sediments. This study is a clear indication that proper treatment and disposal of the effluents can bring about a positive change in the environment. Average TOC and TN was high in sewage polluted zone due to larger input of sewage. TOC/TN ratio was high at retting yard zone an indication of refractory organic input in this region in the mode of coconut husk. Thirty five species were identified from S-zone and 42 species from R zone during the present study compared to 45 and 19 species recognized in 1983. Polycheates with 27 species were the most abundant faunal group (90%) in S zone and was dominated by the highly pollution tolerant capitellids. The dominant species reported was *Capitella capitata*. Polycheates were the dominant group in the R-zone and both the zones supported high abundance of deposit feeders. Bray-Curtis similarities were calculated on (root transformed) species abundance data and two major macrobenthic assemblages were identified based on cluster analysis. The results of the present study showed that spionids (the dominant community) in early 80's was replaced by capitellids in 2005 at the sewage polluted zone. Species richess and diversity estimated based on Margalef, d' and Shannon-Wiener, H' ($\log_e$) indicated low species diversity at S-zone.

Chapter 5 deals with seasonal variability in abundance of macrobenthic species in the estuary. The study was conducted from 9 stations during three seasons (pre-monsoon, monsoon and post-monsoon) in 2003. High salinity was recorded during the pre-monsoon period and almost fresh water condition prevailed in the entire estuary during monsoon. The estuary is well mixed and homogenous condition prevailed in the estuary during pre-monsoon whereas during monsoon and post-monsoon period a clear stratification occurs in the water column with low saline water at the top and high saline water at the bottom. Low D.O (<1 mg/l) was recorded from the bottom waters at station 1 (Barmouth) during monsoon and post-monsoon season and subsequently low benthic abundance was recorded from this region compared to earlier works. In general high D.O was reported during monsoon. The results revealed that the concentration of nitrite, nitrate, phosphate and silicate exhibited pronounced seasonal variation and also indicated large inputs from industrial units, sewage works and agricultural runoffs. High values of nutrients reported during monsoon season indicated input from terrestrial origin induced by land runoff and industrial discharge. Bottom water indicated higher value of inorganic nutrients than surface especially during the post-monsoon period probably because of the obvious reason of through mixing enabling the release of nutrients from the sediment. High concentration of silicate was reported during monsoon and post-monsoon season due to river water influx. Chlorophyll *a* concentration was high which indicated that eutrophication was apparent in the estuary. High values were reported during monsoon. Increased grazing of phytoplankton by microzooplankton was reported as one of the reasons for relatively low level of chlorophyll *a* during pre-monsoon season. The substratum was dominated by sand during pre-monsoon and post-monsoon period whereas during monsoon the substratum was dominated by fine grained sediments. Organic carbon content in the sediment was high during monsoon followed by pre-monsoon and post-monsoon due to high productivity, settling of detritus, decay of vegetation and sewage disposal. Macrobenthic abundance was high during pre-monsoon and monsoon months. Fourty seven species belonging to nine taxa were encountered during the study period. In general the dominance of polychaetes were reported in the present study particularly those belonging to the family capitellidae through out the period, which is a clear indication of pollution stress. High benthic abundance was recorded from station 2, pollution indicator and tolerant species dominated this station. Stations 3 and 4 located nearer to the industrial region of Eloor reported low density and abundance. Abundance of *Villorita cyprinoides* was reported from station 6, 8 and 9.

Chapter 6 deals with Life history and Population Dynamics of *Eriopisa chilkensis* Chilton (Gammaridae-Amphipoda). The life cycle of the gammarid amphipod *Eriopisa chilkensis* from the Cochin estuary, south west coast of India was studied for the first time under laboratory conditions. Amphipods especially gammarids are known as potential live feed in fish culture more so for juveniles and this formed the base of our study. Live samples were collected and maintained in the tanks of the recirculating system of the laboratory for the experimental study and field sampling was conducted for one year (2003-2004) at the mangrove environment of Puduvypin. Females lived on average 1.4 times longer than males. Moulting rate was higher in females and growth rate was higher in males. Males attainted sexual maturity earlier than females. Embryonic development time ranged from 8 to 14 days and the different stages of embryonic development were identified. The number of broods produced in the life cycle ranged from 4 to 7. Total number of juveniles from a single brood varied from 35 to 139. The distribution and population dynamics of *Eriopisa chilkensis* was studied in the field and the density varied from 21 to 1583 m^{-2}. Maximum population density was observed during November. *E. chilkensis* tolerated a wide range of temperature and salinity of the medium. Gravid females were observed in high numbers during November and December indicating their preference for medium saline conditions. Study on E. *chilkensis* gives a basic knowledge about the life history and ecological aspects for evaluating the potential role of this amphipod as a test species in estuarine areas and to further develop assays for pollution at sub-lethal levels using this species.

Developmental activities around the estuarine environment resulted in the degradation of this ecosystem in recent times. Increasing population, urbanization and industrialization has had its share in degrading this fragile ecosystem by large-scale reclamation of land near estuaries, swamps marshes and mangroves for various purposes. Dredging activities in the estuaries for navigation, reducing the river discharges to a very less extent for various reasons, discharging untreated urban sewage and industrial effluents and the aquaculture activities around estuaries are the major threats for sustenance of the unique ecosystem. Major conservation measures that can be taken include:-

To have strict regulatory measures on the reclamation of estuarine areas for all purposes except aquaculture and strict adherence to coastal zone regulations

Prescribed water treatment by Pollution Control Board on urban sewage, industrial effluents, untreated water from aqua farms etc. may be strictly adhered through

Water flow by addition of check dams or release of water from the existing dams into the waterways may be facilitated so as to assure the sustenance of estuaries and adjoining water bodies

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List of Publications

- **Nisha. P. Aravind**, P. Sheeba, K.K.C. Nair and C.T Achuthankutty. Life history and Population Dynamics of an Estuarine Amphipod- *Eriopisa chilkensis* Chilton (Gammaridae). 2007, volume 74 *Estuarine coastal Shelf Science*. Pages 87-95.

- K.A Jayaraj, P.Sheeba, Josia Jacaob, C.Revichandran, P.K. Arun, K.S. Praseeda, **P.A. Nisha** and K.A Rasheed. Response of infaunal macrobenthos to the sediment granulometry in a tropical continental margin-southwest coast of India. (In Press) 2008. *Estuarine coastal Shelf Science*.

- **Nisha. P.Aravind,** Sheeba. P, K.K Balachandran, Kesavadas.V and C.T Achuthankutty. A comparison of macrobenthic variability in a tidal river estuary (Cochin backwaters) and an Enclosed basin (Kakinada Bay)- Paper presented in 7^{th} Asia Pacific Marine Biotechnology Conference (2^{nd} Nov.- 5^{th} Nov. 2006). Book of abstracts. 2006. 193pp.

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Life history and population dynamics of an estuarine amphipod, *Eriopisa chilkensis* Chilton (Gammaridae)

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Abstract

The life cycle of the gammarid amphipod *Eriopisa chilkensis* Chilton from the Cochin estuary, south west coast of India, has been studied for the first time under laboratory conditions. Amphipods, especially gammarids, are used as potential live feed in fish culture. *Eriopisa chilkensis* can withstand wide variations in salinity (5–35) and temperature (27.5–34 °C) of the medium. It was cultured in un-aerated finger bowls using dried algal matter (*Chara* sp.) as food. The life span of females was found to be higher (maximum: 220 days) than males (maximum: 175 days). Females were iteroparous and attained sexual maturity within 39.3 ± 6 days (mean ± SD), whereas males matured within 26.5 ± 5.6 days. Number of broods in a life span ranged from 4 to 7. The maximum number of juveniles produced in a single brood was 29 and the maximum number of juveniles produced by a single female over a lifetime was 139. The duration of embryonic development was 12 ± 2.45 days. The population dynamics of *E. chilkensis* was studied based on monthly sampling, over one year from the mangrove swamps of Puduvypin. It occurred in varying densities in the epifaunal community (21–1583 ind. m^{-2}). Extrapolation of laboratory data to the field suggests that *E. chilkensis* in Cochin estuary has a multivoltine life cycle.

Keywords: *Eriopisa chilkensis*; Amphipoda; life cycle; population dynamics; Cochin estuary; India

1. Introduction

The life-history traits of 214 amphipod species were reviewed by Sainte-Marie (1991), who stated that life-history patterns of gammarid amphipods are influenced by latitude, depth and salinity. Nelson (1980) reviewed the reproductive pattern in 65 species of gammaridean amphipods. Morino (1978) classified breeding activity and life history of amphipods into four categories and concluded that low latitude species tend to breed throughout the year and have short life spans. According to Cunha et al. (2000) low-latitude, warm-water amphipods show iteroparous, multivoltine life history patterns. Multivoltinism and continuous reproduction have been reported in many other species occurring in the tropical Indian Ocean (Chandani and Alan, 2004). Steele and Steele (1991) pointed out that tropical species are characterized by small size, low fecundity, short brood intervals and multivoltine life cycle. On the other hand low-latitude species are characterized by semi-annual or annual life histories, small body size and high reproductive potentials (Sainte-Marie, 1991). Krishnan and John (1974) have observed that the brackish-water amphipod *Melita zeylanica* breeds throughout the year in India. Asari (1983) has studied the biology of *Eriopisa chilkensis* and *Idunella chilkensis* from mangroves of Pitchavaram, India.

The Cochin estuary (Lat. 9°5′ to 10°N and Long. 76°15′ to 76°25′ E) is a bar-built tidal estuary, which is the northern extension of the Vembanad Lake along the Kerala coast of India. The mangrove swamps of Puduvypin are considered to be of great economic importance and act as good nursery grounds for shrimps and juvenile marine fishes (Rajagopalan et al., 1986). Fodder organisms like amphipods and tanaidaceans, support the growth, and production of estuarine fishes and prawns.

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Eriopisa chilkensis was first recorded from Chilka Lake by Chilton (1921), and Asari (1983) studied the biology of *E. chilkensis* and reported that they are filter feeders feeding on organic-rich detritus. The gammarid amphipods of Cochin backwaters were studied by Nair et al. (1983) who gave an account of their ecology and population dynamics. *Eriopisa chilkensis* occurs in large numbers in the organically-enriched sediments of the Cochin estuary and it can be regarded as a tolerant species of organic pollution (Nisha, unpublished). *Eriopisa chilkensis* was encountered in varying densities in the benthic epifaunal communities in the mangrove swamps of Puduvypin in the present study. It also has an important trophic role in these areas in shredding leaf litter. In spite of its ecological importance, no work on this species has been carried out in the Cochin estuary. In this paper, an attempt has been made to study the different traits of its life cycle in the laboratory, such as age at maturity, life span, number of broods per female, duration of embryonic development, life-time fecundity (based on number of juveniles released), growth rate and biochemical components. Along with this, the population dynamics was also studied in the Cochin estuary. This investigation was designed to find out whether this species could be cultured in large enough numbers economically to be used as a feed for fish culture.

2. Materials and methods

2.1. Amphipod collection and maintenance for laboratory culture

Live epibenthic samples were collected from Puduvypin, Cochin estuary (Fig. 1) using a van Veen grab (0.048 m^2 mouth area) and transported to the laboratory along with the sediments. In the laboratory, individuals of *Eriopisa chilkensis* were sorted out and kept in tanks of the recirculating system for 1 month, to acclimatize to experimental conditions. Pairs (males and females) of this species were later isolated and transferred to separate finger bowls, each containing 125 ml of un-aerated brackish water. Temperature was maintained at 26 ± 1 °C, salinity 19 ± 1 and pH 7.4–8.6. A few strands of dried algal matter were added to each bowl as food for the animals. These bowls were labelled for later identification. Individuals of 3 categories were studied: juveniles, males and females. The set of individuals released from a brood was reared together in finger bowls for further experiments.

2.2. Feeding rates

These were tested with different types of feeds like decaying mangrove leaves, natural detritus available at the sampling site, flesh of young mussel (*Villorita cyprinoids*), alga (*Chara* sp.) and blue-green alga scraped from the sides of the culture tanks. For further experiments *Chara* sp. (musk grass) was selected as feed based on its abundance and local availability, and also for the reason that the farmers in the field can culture these amphipods without much expense.

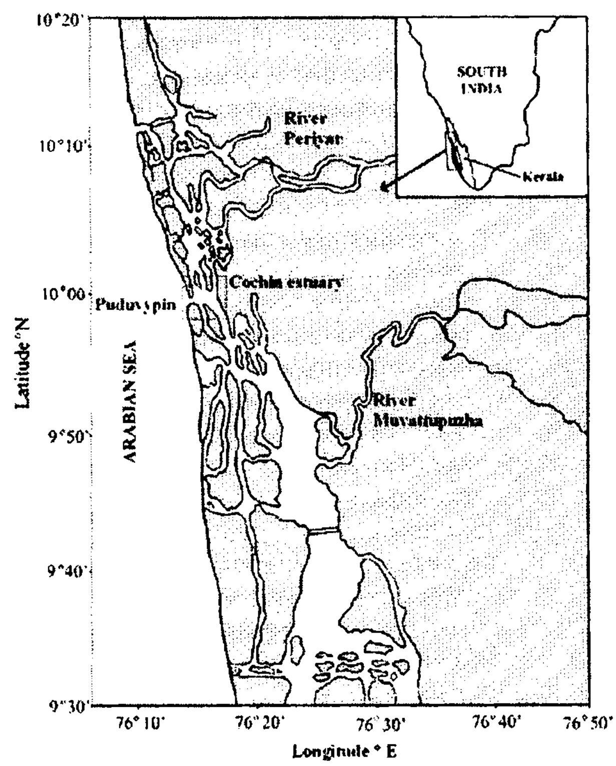

Fig. 1. Study region (Cochin estuary) showing the sampling site.

Feeding experiments were conducted in 125 ml finger bowls with unfiltered brackish water. *Chara* sp. was soaked in water, dried using blotting paper and weighed before introducing into the culture bowls. The quantity of feed used in each bowl ranged from 0.2 to 0.5 g w/wt (wet weight). Trials were run using 10 amphipods each for 2 sets of culture bowls (adults and ovigerous females). In treatment trials, they were allowed to feed for 24 h. Bowls containing alga without amphipods were used as controls. On termination of the experiment, the excess feed was netted (mesh size 10 μm) and re-weighed as before. Feeding rate was calculated as amount of feed consumed per day per individual.

2.3. Life span and mortality

Total life span was measured by rearing all the individuals released from a single brood together in un-aerated finger bowls until all of them died. Water was changed every day and fresh feed was added every alternate day. The time of birth and death was recorded to measure the total life span. Trials were run using five culture sets. Mortality in juveniles, females with brood and males after copulation were also assessed during this process.

2.4. Moulting and growth rates

Individuals released from a single brood were reared together in a finger bowl and the moulting rate was assessed separately for males and females. Growth rates were assessed as the average length increment in body size. Live animals were removed from the culture bowls soon after their release from the brood pouch and measured for total length at regular intervals. An ocular micrometer was used for the body length measurements. Body size (length) was measured as distance from tip of the cephalon to the tip of the telson. Growth rate measurements were not carried out separately for males and females.

2.5. Sexual maturity and sex ratio

Newly born juveniles from a single brood was separated into finger bowls and reared together. A mature female was added to assess the time required for male maturity. Adults were added only after 10 days when the juveniles have grown sufficiently, as they were found to consume newly born juveniles. The day at which the female was found to be ovigerous was recorded. Trials were run using 5 sets of culture bowls. This was the time for male maturity, similarly a fully matured male was added to the newly born juvenile set after 10 days and the time for female maturity was calculated. Number of males and females from a single brood was counted to find out the sex ratio. Males were identified based on the presence of an enlarged second gnathopod and females based on the presence of brood pouch/lamellae.

2.6. Fecundity, embryonic development

After 1 month of acclimation in the laboratory, pairs of amphipods (males and females) were removed from the initial tank and placed in separate finger bowls. They were observed daily until the female was found to be ovigerous. The fecundity of *Eriopisa chilkensis* was estimated as the total number of juveniles released by a female. The embryonic development time was recorded as the period from oviposition to release of juveniles from the brood pouch. The developmental stages were identified based on the description of Dick et al. (2002).

2.7. Biochemical analysis

Live samples maintained during the culture were sorted out into three groups, viz. juveniles, adults and ovigerous females, for biochemical analysis. The specimens were rinsed with distilled water to remove salt, lyophilized and stored in a desiccator. Before analysis, the samples were thoroughly homogenized using a pestle and mortar. The determination of protein and carbohydrate were followed as per the standard methods described by Raymont et al. (1964). Energy equivalents were calculated using the conversion factors given by Winberg (1971) and the values were corrected for biologically unavailable nitrogen oxidation energy according to Kersting (1972). Energy equivalents are expressed in kcal g^{-1}.

2.8. Sampling methodology to study the population dynamics in field

Population density and dynamics of *Eriopisa chilkensis* was studied from monthly samples collected over a period of one year (October 2003 to September 2004) at low tide from the sampling site (Puduvypin: 9°59′ N and 76°13′ E), adjacent to mangrove vegetation (Fig. 1) in the Cochin estuary. The selected area has a depth of 3–4 m and is influenced by tides. The mud samples were collected in duplicate using van Veen grab (mouth area 0.048 m^2), sieved using 500-μm screens and preserved in 4% formalin coloured with Rose Bengal. From these samples *E. chilkensis* specimens were separated and counted in the laboratory as juveniles (<5 mm) and adults (>5 mm). Sediment grain size was analysed using the pipette method of Krumbein and Pettijohn (1966) and organic carbon was estimated by the wet oxidation method (El. Wakeel and Riley, 1957). Organic matter was calculated as 1.724 times the carbon value (Trask, 1955).

Qualitative sampling consisted of recording the abundance of *Eriopisa chilkensis* from two sites separated by a distance of 3.5 km in the estuary. One was along the organically enriched central estuarine region (>3% sediment TOC) to estimate its presence in a polluted environment and the other along the mangrove of Puduvypin to study its population dynamics (site selected as *E. chilkensis* was abundant in this environment).

3. Results

3.1. Food and feeding

Experimentation with different feeds showed that the amphipods fed on a variety of feeds like decaying mangrove leaves, natural detritus available at the sampling site, flesh of young mussel (*Villorita cyprinoids*), alga (*Chara* sp.) and blue-green alga scraped from the sides of the culture tanks. Juveniles were found to survive only on the blue-green alga and natural detritus. Based on the observation made during the study, *Eriopisa chilkensis* can be categorized as an omnivore showing a preference for natural detritus and decaying mangrove litter. At times they showed cannibalistic behaviour by feeding on their own juveniles and also fed on moulted exoskeleton.

Feeding rates of adults on dried algal matter (*Chara* sp.) were calculated, after subjecting them to 24 h starvation. Average feeding rate was 615 μg day^{-1} $individual^{-1}$. Adults showed an average feeding rate of 1095 μg day^{-1} $individual^{-1}$ whereas females with broods showed lower rate of 205 μg day^{-1} $individual^{-1}$.

3.2. Life span and mortality

Females lived on average 1.4 times longer than males (average for females: 189 days and for males 132 days) (Table 1). Mortality was high towards the last weeks of the life span in both sexes. However in juveniles, mortality was relatively less (8–33%). In females, mortality was observed during the reproductive phase also, usually towards the end of embryonic development (7th to 9th day). Mortality in males was found to be related to copulatory behaviour as 10–20% of males died after copulation.

Table 1
Life cycle criteria of *Eriopisa chilkensis* (temperature 26 ± 1 °C, salinity 19 ± 1. M, male; F, female)

Life-cycle criteria	M/F	Range	Mean	(±)SD	*n*
Life span (days)	M	124–175	132	22.88	8
	F	170–220	189	20.84	8
Number of moults	M	5–7	6.38	0.74	8
	F	6–9	7.63	0.92	8
Body length (mm)	M	11.44–15.2	13.4	1.45	6
	F	8.56–14	10.38	1.79	8
Average growth rate from 0 to 20 days (mm per day)	M/F	–	0.12	–	6
Broods per female	F	4–7	5.14	1.07	7
No. of juveniles per brood	F	4–29	13.72	7.39	33
Juveniles per female (sum)	F	35–139	72.16	39.74	6
Incubation time (days)	F	8–14	12	2.45	8
Sexual maturity of female (days)	F	30–49	39.25	5.99	16
Size (mm)		5.48–5.76	5.5	0.21	5
Sexual maturity of male (days)	M	20–38	26.5	5.55	8
Size (mm)		5.08–5.81	5.05	0.31	5

3.3. Moulting and growth rate

Moulting rate was found to be higher in females, as the females always moulted after the release of juveniles from the brood pouch. Total number of moults in females ranged between 6 and 9 as against 5 and 7 in males (Table 1). A higher size increment per moult was observed in males compared to females as the males attained larger size in a shorter duration.

Newly-born juveniles were in the size range of 1.63–1.92 mm and the number of antennal segments was 6. Initially growth was exponential for about 20 days after hatching with a growth rate of 0.12 mm day^{-1} (Fig. 2). Individuals from the same brood exhibited different growth rates, even the number of antennal segments varied from one to another, as some 15-day-old individuals had 9 segments while others had 11 segments. Hence, size of individual or number of antennal segments cannot be taken as reliable measure of age. Growth rate was generally higher in early developmental stages than at later stages. The maximum length observed during the laboratory experiment was 15.20 mm for males and 14 mm for females, whereas in the natural population males attained up to 17.76 mm.

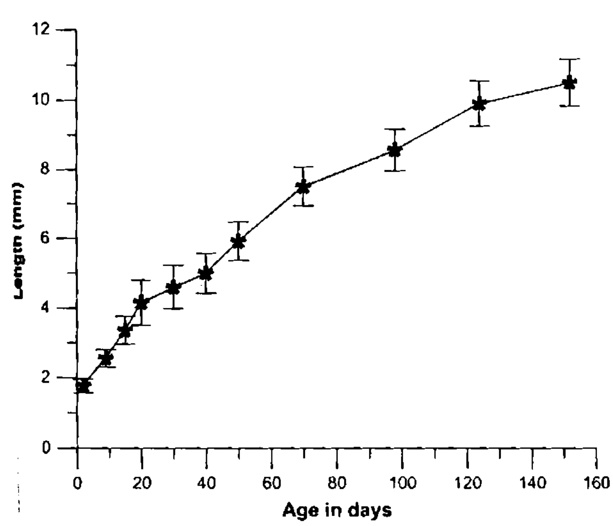

Fig. 2. *Eriopisa chilkensis* growth rate (mm day^{-1}) under temperature 26 ± 1 °C and salinity 19 ± 1.

3.4. Attainment of sexual maturity and sex ratio

Females of *Eriopisa chilkensis* attained sexual maturity within 30–49 days (39.25 ± 5.99) at sizes ranging from 5.48 to 5.76 mm. Males attained sexual maturity much earlier than females, within 26.5 ± 5.55 days and a size range of 5.08 to 5.81 mm. According to this observation, females attained a size of 5 mm within 39 days whereas males attained the same size within 27 days. This clearly indicates that the length increment per moult was higher in males compared to females and males grew faster than females. The sex ratio tended towards unity at the time of maturity attainment. The number of males decreased as they died at an earlier age and as a result, the number of males was relatively low in number than females towards the end of life span. This might be a reason for relatively low number of males in the natural benthic populations than females (Nair and Anger, 1979; Kemp et al., 1985; Moore and Francis, 1986). Age of the female at the time of brooding significantly affected the time required for the attainment of maturity in the next generation. Increased age of the female delayed the attainment of maturity of the offspring (Fig. 3).

3.5. Mating behaviour

Sexually mature males were observed to grasp mature females and mount them. Precopulatory riding behaviour, a condition known as amplexus, was not observed in this case. A mature female amphipod was available for fertilization only for a short time immediately after moulting when the cuticle was sufficiently flexible to allow release of the eggs into the brood pouch through the genital pores. The copulation process continued several times even after the release of eggs to ensure

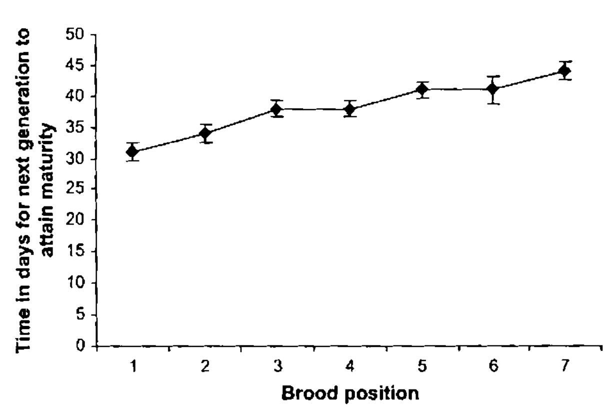

Fig. 3. *Eriopisa chilkensis*: Attainment of sexual maturity in the F1 (First) generation.

complete fertilization. The presence of a male was a prerequisite for the release of eggs into the brood pouch. It was observed that isolated culture bowls containing only females did not release eggs into the brood pouch in the absence of a male.

3.6. Embryonic development and hatching

The brood pouch, which was initially yellowish in colour (due to the presence of under-developed eggs), turned white as the embryo developed. The embryonic development time was recorded as the period from oviposition to release of juveniles from the brood pouch. Time between oviposition and hatching of juveniles (incubation period) varied from 8 to 14 days. There was no significant relationship between the state of the brood (early or late) and incubation period. Mature eggs hatched directly into juveniles that resembled adults. Different stages of embryonic development identified were as follows: 1st and 2nd day: Formation of morulla and blastula; 4th day: Eggs were black, homogeneous ovals with a clear zone beneath the egg membrane (chorion); 5th day: Movement of the early embryo towards the periphery of the membrane; 8th day: Curled very early embryos, eyespots and appendages were not visible and the embryo was tightly expanded within the egg membrane; 10th day: Eggs were slightly elongated at the head region of the embryo and appendages were well developed. The juveniles were released one at a time by the female and the whole process took several hours, depending upon the number of juveniles released.

3.7. Fecundity

The fecundity of *Eriopisa chilkensis* was estimated as the number of juveniles released by a female. Newly released juveniles were transferred immediately to new finger bowls so as to avoid cannibalization. The number of eggs/juveniles produced from a single brood increased with the age of the female. The number of broods produced during the life cycle ranged from 4 to 7 (Fig. 4). Females were able to carry eggs at a size of 5–6 mm. During the study, only one set was observed to produce 7 broods. Total number of juveniles produced in a brood ranged from 4 to 29 and the total number of juveniles over the lifespan of a single female varied from 35 to 139. In most cases

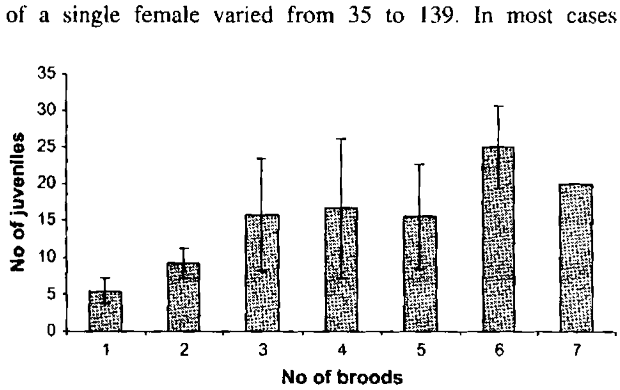

Fig. 4. *Eriopisa chilkensis* fecundity pattern. Mean ± SD.

a significant positive correlation was obtained between age of the female and fecundity.

3.8. Biochemical composition

Protein, carbohydrate and energy equivalents are given in Table 2. Carbohydrate content was higher in all the three categories studied as against the protein content. The highest carbohydrate content was in ovigerous females (87.95 mg g^{-1}) and the lowest in juveniles (51.04 mg g^{-1}). Protein showed a decreasing trend during the growth, i.e. higher in juveniles (27.12 mg g^{-1}) and lower in adults (20.74 mg g^{-1}).

3.9. Distribution and population dynamics in field

The distribution and population dynamics of *Eriopisa chilkensis* are concordant with previous records of the amphipods in the Cochin estuary (Nair et al., 1983). *Eriopisa chilkensis* was encountered in varying densities in the epifaunal community in the mangrove rich regions of Puduvypin (21–1583 ind. m^{-2}). Changes observed in the proportion of adults and juveniles over a period of 12 months are shown as individuals per m^2 (Table 3). These data were compared with the total gammarid population, comprised of *Eriopisa chilkensis*, *Corophium triaenonyx*, *Melita zeylanica*, *Quadrivisio bengalensis*, *Grandidierella gilesi* and *Grandidierella bonneri*. High densities of *E. chilkensis* have been attributed to its short life span (4–8 months) and continuous gonad maturation. It attained large standing stock in these areas due to high fecundity and survival. *Eriopisa chilkensis* population underwent considerable fluctuation during the annual cycle. Laboratory culture of *E. chilkensis* showed that it breeds throughout the year, but in the field they were absent during February. The maximum population density of 1583 ind. m^{-2} was observed during November. Total gammarid amphipod population (20,416 ind. m^{-2}) also peaked during the same month.

Temperature, salinity, pH, dissolved oxygen and ammonia, measured during different months, are given in Figs. 5 and 7. All the environmental parameters measured were subjected to considerable variations throughout the period of observation. Salinity values ranged from 5.11 (June 2004) to 33.61 (February 2004). High population density coincided with a salinity of 16.68 (November 2003). Sediment texture was characterized by high sand and clay fraction (mean: 43% and 38% respectively). The organic matter (Fig. 6) in the sediment was generally high, ranging from 16.6 (October 2003) to 72.74 mg g^{-1} (February 2004). High population density coincided with moderate (35.34 mg g^{-1}) organic enrichment (November 2003).

Table 2
Eriopisa chilkensis biochemical composition and energy contents in adults, juveniles and ovigerous females

	Juveniles	Adults	Ovigerous females
Carbohydrate (mg g^{-1})	51.04	71.57	87.95
Protein (mg g^{-1})	27.12	20.736	21.378
Energy equivalent (kcal g^{-1})	0.336	0.39	0.4

Table 3
Population density (ind.m $^{-2}$) of total gammarid amphipods and *Eriopisa chilkensis* in field

Date	Total no. of gammarid amphipods (ind. m^{-2})	Total no. of *E. chilkensis* (ind. m^{-2})	Gravid females of *E. chilkensis* (ind. m^{-2})	Juveniles of *E. chilkensis* (ind. m^{-2})	Contribution (%) of *E. chilkensis* towards other gammarids
Oct 2003	3250	250	83	42	8
Nov 2003	20416	1583	250	250	8
Dec 2003	1646	1063	229	333	65
Jan 2004	3605	667	63	83	19
Feb 2004	21	0	0	0	0
Mar 2004	21	21	0	0	100
Apr 2004	271	271	21	42	100
May 2004	271	271	42	42	100
Jun 2004	605	292	0	42	48
Jul 2004	459	271	63	125	59
Aug 2004	1666	458	125	104	28
Sep 2004	3459	563	104	42	16

Eriopisa chilkensis tolerated a wide range of salinity (5.22–35.35) and temperature (27.5–34 °C) conditions. Gravid females were observed in high numbers during November and December (250 m^{-2}; 229 m^{-2}, respectively) when the salinity was around 16.68 and 28.85 respectively, indicating a preference for medium saline conditions during the breeding period, but they were absent during February, March and June (Table 3). It may be also possible that ovigerous females were under recorded due to egg spillages during fixation. Females with broods accounted for 13% of the total *E. chilkensis* population. A maximum of 46 eggs were recorded during the study and the highest number of juveniles was also recorded during the same period (November–December). Juveniles were absent during February and March, but were present during the low saline period (May–October), indicating their ability to tolerate low to moderate saline conditions.

Eriopisa chilkensis was tolerating wide fluctuations in salinity whereas other gammarid amphipods were absent during March–May period (Fig. 7 and Table 3). In the laboratory, *E. chilkensis* maintained in the finger bowls were subjected to natural evaporation and the experiments confirmed that they could survive in a wide range of salinity, from 18.39 (initial) to 35.35 (final) over 4 days without any mortality. This implies that *E. chilkensis* could tolerate short duration salinity fluctuations in nature while other gammarid amphipods moved out to locations of preferred salinity. The percentage contribution of *E. chilkensis* to the total number of amphipods was 45.91% (Table 3). Population dynamics in the organic-rich environment of Cochin estuary followed a similar trend with the maximum abundance in November but at low densities (42–667 ind. m^{-2}).

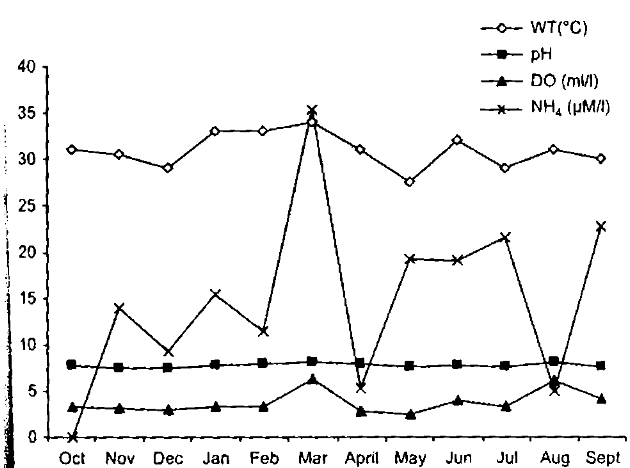

Fig. 5. Environmental conditions (Puduvypin).

4. Discussion

Eriopisa chilkensis can be cultured on different types of feeds like dead and decaying animals, algal matter and detritus. They also exhibited cannibalistic behaviour in the laboratory, by feeding on their own young ones. They even ingested moulted exoskeletons, which indicate that this species requires a high nitrogen food source at times (Agnew and Moore, 1986). According to our observation, the average feeding rate of brooding females on dried algal matter was relatively low compared to other adults. Body distension caused by crammed stomach or swollen ovaries might constrict the gut and mechanically impair feeding (Thruston, 1979).

Mortality was low in juveniles, but increased with age. Death of males after copulation was observed, which might be due to excess expenditure of energy during the behavioural activities associated with copulation. Mortality occurred even in females during brooding, which might be due to the energy expenditure during incubation and usually occurred towards the end of the developmental stages (7th to 9th day) of the embryo. The energy allocated for reproduction is divided between the reproductive output (brood size and egg volume) and behavioural activities associated with breeding (mating amplexus, fighting and brooding of embryos and juveniles). The costs of such activities can be substantial in amphipods and may vary with prevailing environmental conditions (Clarke, 1987).

There was a shift from an equal number of males and females in the population at the time of attainment of sexual maturity to a female domination towards the end of the life cycle.

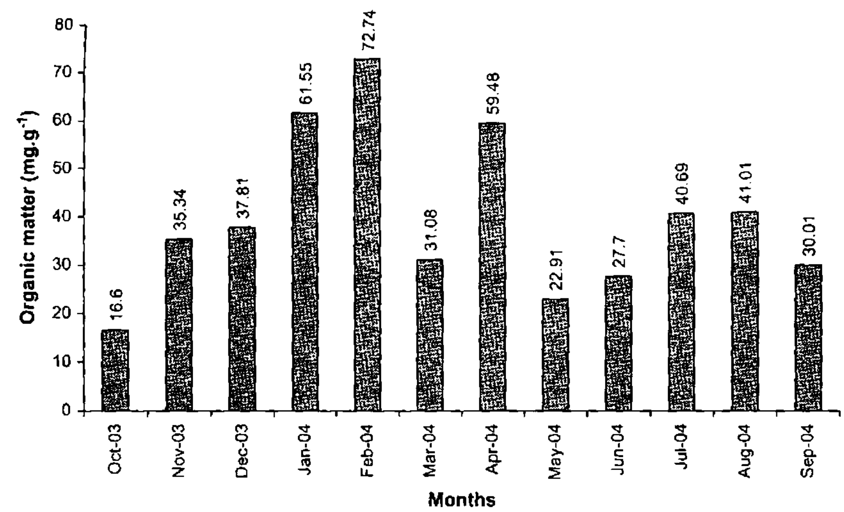

Fig. 6. Variations in organic matter in sediment.

According to Moore (1981), sex ratios in populations may either be 1:1, skewed towards females or males, or show seasonal variations. Female-biased sex ratio towards the end of life cycle indicates an increased female longevity.

The number of offspring produced from a single brood varied with the age of the female. Significant positive correlation was found between the number of juveniles released and the age of the female. The number of eggs carried by a female amphipod generally increased at each successive moult (Fincham, 1974). Brood size in gammarideans has often been found to be proportional to body length of females (Beare and Moore, 1996; Costa and Costa, 1999; Persson, 1999; Cunha et al., 2000). Age of the female at the time of breeding influenced life-cycle characteristics of its offspring, namely attainment of sexual maturity in the next generation. In *Eriopisa chilkensis*, individuals from early broods attained sexual maturity earlier than those from late broods, but in *Corophium insidiosum*, Nair and Anger (1979) have observed that the individuals from late broods attained sexual maturity earlier. In *E. chilkensis*, there was no significant relationship between age of the female and incubation period and again, this observation ran counter to the observation of Nair and Anger (1979), in *C. insidiosum* wherein early brood females were found to incubate their offspring for longer periods. Such contradictory observations may be due to phylogenetic and physiological constraints (Sainte-Marie, 1991).

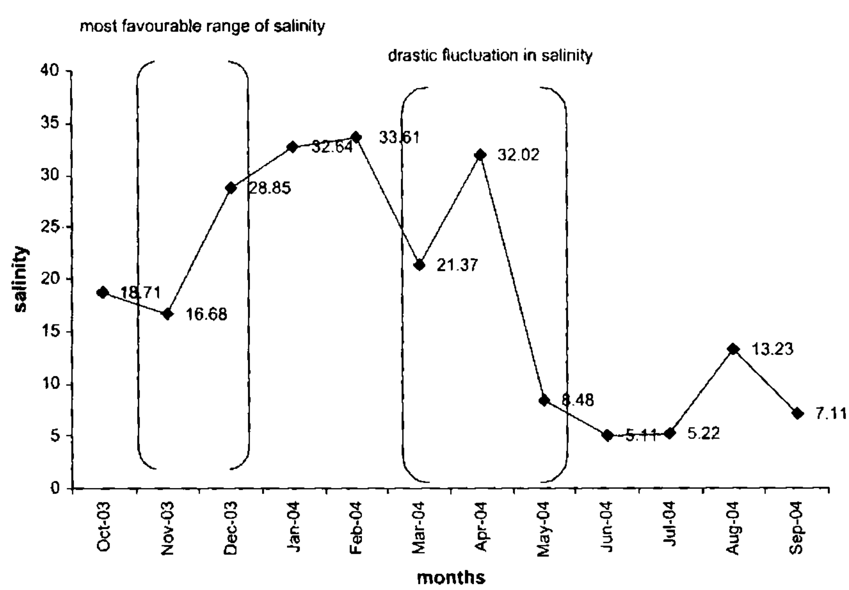

Fig. 7. Salinity variations, showing the most favourable and adverse range of salinity conditions from March to May.

Eriopisa chilkensis males and females attained different sizes at the same age, the males being larger. Based on our observations, females of *E. chilkensis* took an average of 39 days to attain a size of 5 mm whereas males attained this size within 27 days. According to Sainte-Marie (1991), about 97% of gammarids have larger males compared to females. Growth rates in the early stages were higher, and it is generally accepted that the growth is exponential (Welton and Clarke, 1980). The maximum body size attained by individuals under laboratory conditions was smaller (15.2 mm) than the size normally attained in natural environment (17.76 mm). Growth variations could also be associated with poor food quality. In addition to the quality of the food supplied, the small body size attained under laboratory conditions could also be due to stress. For example, Chen et al. (1990) observed lower growth rates of penaeid shrimps under culture conditions due to deterioration of water quality caused by ammonia build-up. A similar situation may also be applicable in the present case since the excess food supplied was removed only once every week, leading to contamination with ammonia.

The average protein content was less compared to other species of amphipods, whereas the carbohydrate content compared favourably (Nair and Anger, 1980). This might be due to the difference in the feeds used during the experimental set-up.

Eriopisa chilkensis was encountered in varying densities in the epifaunal community in the Cochin estuary. Although it tolerated a wide range of salinity (5.22–32.64) and temperature (27.5–34 °C), the preferred range of salinity appears to be 16 to 28. *Eriopisa chilkensis* could survive in water with DO levels ranging from 2.43 to 6.34 ml L^{-1} and ammonium concentration ranging from 4.9 to 35.32 μM L^{-1}. Maximum density of *E. chilkensis* including the gravid females and juveniles were obtained during November and December, when the salinity ranged between 16 and 28, organic matter ranged between 35–37 mg g^{-1} and the sediment was a mixture of sand and clay in almost equal proportion. Experimental studies that have been carried out with *Corophium multisetosum* have also established that temperature, salinity and sediment type affect survival, sexual maturation and production of offspring (Cunha et al., 2000). Nair et al. (1983) also reported the abundance of amphipods in the Cochin estuary during late monsoon and post-monsoon seasons (August–December) when low to medium levels of salinity were recorded.

Eriopisa chilkensis tolerated a wide range of salinity compared to other amphipod species. Although salinity is often considered to be less important for reproductive activities, some studies have shown its influence on amphipods' brood size. Vlasblom and Bolier (1971) stated that although embryos of *Echinogammarus marinus* could develop in salinities ranging between 4 and 7, the number of emergent juveniles was reduced. Cunha et al. (2000) also reported the significance of salinity on the brood size in field populations of *Corophium multisetosum*. When salinity does not vary significantly, other factors may determine the distribution of estuarine amphipod such as algal cover, shelter or inter-specific relationships (Nicolaidou and Karakiri, 1989). Tanks presently used for mass culture contained *Corophium triaenonyx* and *E. chilkensis* and it was observed that in the presence of *C. triaenonyx*, the number of *E. chilkensis* decreased drastically, possibly due to competition for food and space. According to the observations made during the present study, *E. chilkensis* seeks shelter under algal cover, leaves and detritus that were added to the culture tanks. Our study indicates the possibility of *E. chilkensis* producing several generations in one year.

Laboratory culture of *Eriopisa chilkensis* showed that it breeds throughout the year but in the natural population it was absent during February. Nair et al. (1983) stated that salinity was the predominant factor controlling the abundance of the gammarid amphipods in the Cochin estuary. The absence of this species in February might be due to the high salinity (33.61) and/or the high organic matter (72.74 mg g^{-1}) present during this month. According to the classic model of Pearson and Rosenberg (1978), an increase in organic matter above a critical level causes hypoxia, smothering and change in physiochemical properties of the sediment, leading to decrease in faunal density. The total benthic macrofauna was also less during this month. A distinct density peak, both of *E. chilkensis* and total gammarid amphipods was observed in November. During this month the salinity was 16 and organic matter was 35.34 mg g^{-1}. Steele and Steele (1975) observed a correlation between the quantity of organic matter in the sediment and the seasonal release of young in gammarids of the North-western Atlantic. They suggested that the release of young ones coincided with optimum conditions for their survival.

Eriopisa chilkensis reproduces almost year-round. Females produced broods consecutively (iteroparity) under laboratory conditions. Based on other observations (duration of embryonic development, maturation and life span), one could expect six or seven generations annually, thereby exhibiting a multivoltine life cycle. Fenwick (1984) emphasized the importance of phylogenetic constraints and concluded that there is no simple optimum life-history strategy, but a combination of different life-history traits may be equally successful in a given environment. That opinion was confirmed by Sainte-Marie (1991) who suggested that phylogenetic and physiological constraints should be best considered for the interpretation of gammaridean life-history patterns.

Analysis of the gut contents of the fish, *Daysciaena albida* (Bengal corvine), collected from the Cochin backwaters, showed that amphipods and isopods formed the major part of their diet (Kurup and Samuel, 1988). Gammarids like *Anisogammarus pugettensis*, *Gammarus lacustrus* and *Gammarus tigrinis* have already been examined for their potential in fish culture (Chang and Parsons, 1975; Reish and Barnard, 1979; Mathias et al., 1982). Similarly *Eriopisa chilkensis* also can be used as an alternative fish feed, as this gammaridean can tolerate wide ranges of temperature and salinity and consumes a wide variety of plant and animal material, in addition to scavenging dead and decaying organisms. The added advantage of this species is its resistance to handling stress. It therefore can easily be mass cultured in the laboratory for use as natural live feed. Our study provides a basic knowledge about the life history and ecological affinity for evaluating the potential role of this amphipod species as a test organism in estuarine areas.

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Response of infaunal macrobenthos to the sediment granulometry in a tropical continental margin–southwest coast of India

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Abstract

Surficial sediment samples, collected from the continental margin of the southwest coast of India in July 2004, were examined for the grain size and soft-bottom macrobenthic fauna, to understand the sediment granulometry and its effect on the faunal distribution. Samples were collected using Smith-McIntyre Grab, from 20 to 200 m depth range, consisting of mid-shelf, outer shelf and slope. Fine-grained sediment located in the mid shelf and supported low faunal abundance. Polychaetes constituted the bulk of the fauna. Feeding guild changed with depth and sediment granulometry. Coexistence of deposit feeders and carnivores in outer shelf and deposit feeders and filter feeders in the slope region indicated the effective utilization of different food resources. In general, richness and diversity were high in the southern region. Depth wise, the diversity and abundance were relatively high in the 50–75 m depth range. Correlation and BIO-ENV analysis showed that combination of different factors such as sediment texture, sediment sorting and depth were found to influence the distribution of macrobenthos. Hence, spatial variations observed in benthic community were presumably linked to the variations in sediment granulometry and the energy level conditions prevailing in the area.

Keywords: macrobenthic community; biomass; density; sediment granulometry; organic matter; continental margin; Arabian Sea; southwest coast; India

1. Introduction

Biological populations are typically distributed along habitat gradients in a complex set of continuums that can lead to community zonation. Remane (1940) formalized and generalized the concepts of marine benthic communities, which were classified according to the dominant species. The observed close relationships between an association and sediment type and depth led Jones (1950) to put forward an alternative classification of species groupings based on sediment and depth characteristics. Sediment composition is of vital importance to the biota of the marine environment (Sanders, 1958). Sediment provides both the substratum to live and food in the form of organic matter to the bottom-dwelling fauna. Generally, benthic sampling is stratified by depth because of its perceived importance in determining the structure of benthic infaunal assemblages (Thompson et al., 1987; Stull, 1995). Boesch (1977) emphasized that depth and sediment types are found to be the gradients in classification of benthic communities. Qualitative descriptions of assemblages based upon large dominant organisms indicated that the assemblages were separated by depth, sediment grain size, and geography (Bernard and Ziesenhenne, 1960; Allan Hancock Foundation, 1965). Recurrent group analysis by Jones (1964, 1969) suggested that depth and sediment grain size were important factors and later, these findings were supported by Fauchald and Jones (1979a,b, 1983). The earlier studies provided important information about the structure of benthic assemblages but did not designate any relationship between physical factors and community changes.

Community changes have often been correlated with depth, but in shallow marine environments, sedimentary or other

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physical as well as biological variables which are depth related are more likely to be the controlling factors than depth itself (Gray, 1981; Tsutsumi et al., 1990). According to Gray (1974) and Buchanan (1984), the distribution of macrobenthic communities is highly correlated with the type of sediment, which is related to a wider set of environmental conditions, such as current speed and organic content of the sediment. Although benthic assemblages are associated with depth and sediment grain size, Snelgrove and Butman (1994) suggested that, the amount of hydrodynamic energy and available organic material are more likely to be the primary driving forces. The energy profile of water flow immediately above the sediment-water interface determines the size of particle in surficial sediments. This in turn affects properties such as ease of burrowing, which may limit the number of species that can survive (Bergen et al., 2000). Depth affects the energy profile because the effects of wave energy on the bottom are usually greatest in shallow areas and decreases as the distance between the surface and bottom increases.

Over the last few decades, the relationships between the distribution and diversity of soft-sediment species and the sediment in which they reside have been the subject of numerous studies (Sanders, 1968; Rhoads, 1974; Snelgrove and Butman, 1994). Grain size parameters are used as indicators of sediment deposition in the aquatic environments (Folk and Ward, 1957). Grain size parameters can also be used to predict sediment transport in beach and near shore environments, with coarse grain size and poor sorting indicating a high-energy environment (Bascom, 1951). According to Gray (1974), heterogeneous sediment seems to have a higher diversity than homogeneous sediment. Ellingsen (2002) studied the macrobenthic infauna in relation to the environmental variability in Norway and found that the best correlative variable combination included depth, median grain size, and silt-clay content. Hence grain size, sorting and energy exertions at the bottom may influence the benthos and their distribution.

The continental margin of the west coast of India represents a complex variety of sedimentary environments. The depth of the shelf break occurs between 80 and 110 m, wider in the northern shelf and narrowing progressively towards south (Rao et al., 1983). Various physical, chemical and geological processes control the sedimentation in this regime. The west coast of India receives its fluvial input primarily from rivers, which drain from the Western Ghats. The role of rivers transporting detritus material from continent to ocean is paramount, being 10 times that of glaciers and 100 times that of wind (Goldberg, 1976). Studies carried out on the sediment characteristics of the shelf region of the west coast of India (Nair and Pylee, 1968; Nair, 1975; Hashimi et al., 1978; Paropkari et al., 1987; Narayana and Prabhu, 1993) have revealed that sand is the dominant sediment on the southwestern shelf. Hashimi et al. (1981) have shown that the deposition of clayey sediment in the near shore regions is caused by the process of flocculation, and also due to the trapping of coarse particles by estuaries and backwaters letting in only fine particles to the inner shelf in the Kochi-Kollam coast. The circulation of surface water in this region varied according to the prevailing wind. The winds in the coastal region off western India are in general northerly, with monthly mean wind speed of approximately 7 m s^{-1}. Shelf circulation in the study area is seasonally variable, between October and May, and the predominant flow is pole ward ($4-7 \times 10^6$ m^3 s^{-1}), while during the southwest monsoon (June–September), there is a reduced flow (0.5×10^6 m^3 s^{-1}) towards equator at shallow depths (<100 m) (Shetye et al., 1990). Below these surface currents, at 150 m depth, a pole ward underflow impinges on the slope. Upwelling is also recorded in the upper layers above 65 m during the southwest monsoon (Derbyshire, 1967; Banse, 1968; Shetye et al., 1990). These environmental features may have some effect on sediment characteristics and bottom living organisms. The aim of the present study is to evaluate the effect of the variations in the sediment textural characteristics on the abundance of bottom fauna and their feeding behavior from the continental margin of the southwest coast of India.

2. Materials and methods

2.1. Study area

The area is located between 8.5° and 13°N latitude and 74° and 77°E longitude (north off Mangalore and south off Vizhinjam) (Fig. 1). The continental shelf in this region has an average width of 45 km. The topography of the mid shelf is smooth, while the outer shelf is rugged, made up of ridges and depressions of around 6 m. Taking the topographic features into consideration, we have made the following divisions, as a function of depth: (a) mid shelf (20–50 m); (b) outer shelf (50–100 m); and (c) upper slope (100–200 m). The area can also be divided into northern (13–10.5°N) and southern regions (10.5–8.5°N), based on the approximate geographical centre of the study area. The adjacent land mass has a tropical humid climate. Annual rainfall in the coastal region (560 km wide) is about 4500 mm in the northern part of the study area and about 2000 mm in the southern part. Southwest monsoon, the principal rainy season of the west coast of India, accounts for about 73% of the total annual rainfall. Forty-one rivers drain into the study area; some major rivers discharge their load through estuaries while all other rivers open directly into the Arabian Sea, having a peak discharge during the southwest monsoon.

2.2. Sample collection and data analysis

A total of 132 surface sediment samples were collected in duplicate from 66 stations using a Smith McIntyre grab from the mid shelf to the slope region along 11 transects during July 2004, onboard *FORV Sagar Sampada*. Additional samples were taken for grain size analysis, oven-dried at 70 °C and analyzed at half-phi (0.5 Φ) intervals. Material coarser than 4 Φ (63 μm) was dry sieved, while the fine-grained material (>4 Φ) was analyzed using pipette analysis (Krumbein and Petti John, 1938), with 0.5 Φ interval. Sediment textural types were identified using Folk's (1954) classification, and statistical parameters such as mean grain size (MGS), sorting coefficient and skewness were calculated using Folk and Ward

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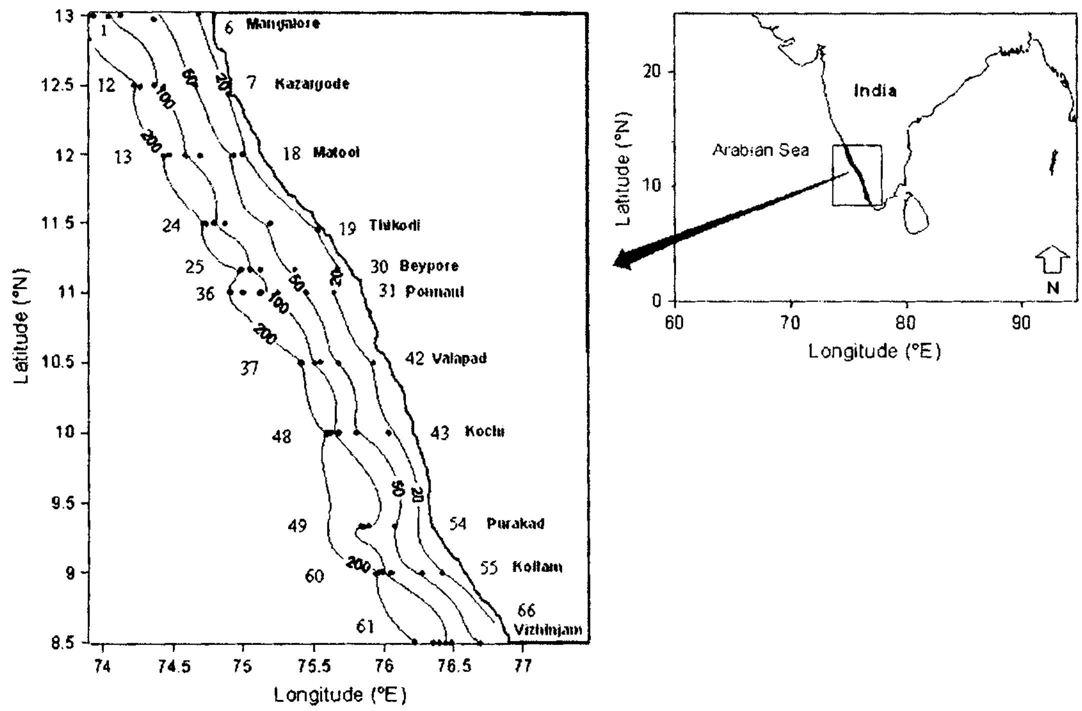

Fig. 1. Location map.

(1957) method. Organic carbon was estimated (El-Wakeel and Riley, 1957), and the values obtained were converted to organic matter (OM) (Trask, 1939) and expressed as percentage of sediment dry weight. Sediment samples for macrobenthos were washed, using a 0.5 mm mesh sieve, and all organisms retained on the sieve were collected and preserved in 5% neutral formalin mixed with Rose Bengal for subsequent identification (Birkett and McIntyre, 1971). In the laboratory, macrobenthic samples were analyzed up to species level using a binocular microscope. Those organisms, which cannot be identified up to species level, were classified in the generic level or up to the possible lowest taxonomic level. The average number of organisms of the duplicate samples was converted to number per m^{-2} (No. m^{-2}), and biomass (shell on) was estimated as wet weight (gm m^{-2}). The data were subjected to univariate analyses for studying the benthic community structure using Margalef's index (Margalef, 1968) for species richness, Pielou's index (Pielou, 1966) for species dominance, Shannon–Weaver index (Shannon and Weaver, 1963) for species diversity and Heip's index (Heip, 1974) for evenness. Multivariate analysis (Bray-Curtis similarity and Multi Dimensional Scaling (MDS)) was performed with fourth-square-root transformed data using PRIMER package programme version 5.2.8 (Clarke and Warwick, 1994). Spearman's correlation coefficient was used to examine the relationships between the benthos and environmental variables (OM, sand, silt, clay, MGS, sediment sorting and skewness), depth and latitude. Since a single environmental variable may not provide the best explanation of biological patterns, the BIO-ENV procedure was used to determine the set of variables that could best explain the biological matrices.

3. Results

3.1. Sediment characteristics and variation in textural parameters

Sediment analysis showed the presence of eight textural types, with varied levels of mixing of three textural grades of sand, silt and clay (Figs. 2a–c). Majority of the study area was carpeted by more than 50% of sand, especially in deeper depths (slope region) (Fig. 2c) and fine sand (1.5–2.5 Φ) was predominant (Fig. 3a). Sediment texture was relatively coarse in the southern region with a general fining towards the north. Fine-grained sediment (>4 Φ) was located at the 20 m depth contour (mid shelf), especially in the northern region. Sediment sorting was poor (1–2 Φ) in the study area (Fig. 3b). Fine skewed and strongly fine skewed (positively skewed) sediments were predominated in the study area. Symmetrically skewed, coarse skewed and strongly coarse skewed sediments were mainly restricted to the shallow regions along 10–12°N. Organic matter (OM) concentration of the sediment was high (4–7.56%) in the mid shelf. There was a tendency of higher OM content in fine-grained sediments of northern region (2.17–7.56%) compared to the southern region (0.21–3.0%).

3.2. Benthic fauna-biomass, population density and faunal composition

Generally, biomass decreased beyond 50 m depth, with a hike at 200 m depth (Fig. 4). However, a noticeable feature was the low biomass at the 20 m depth contour of the mid

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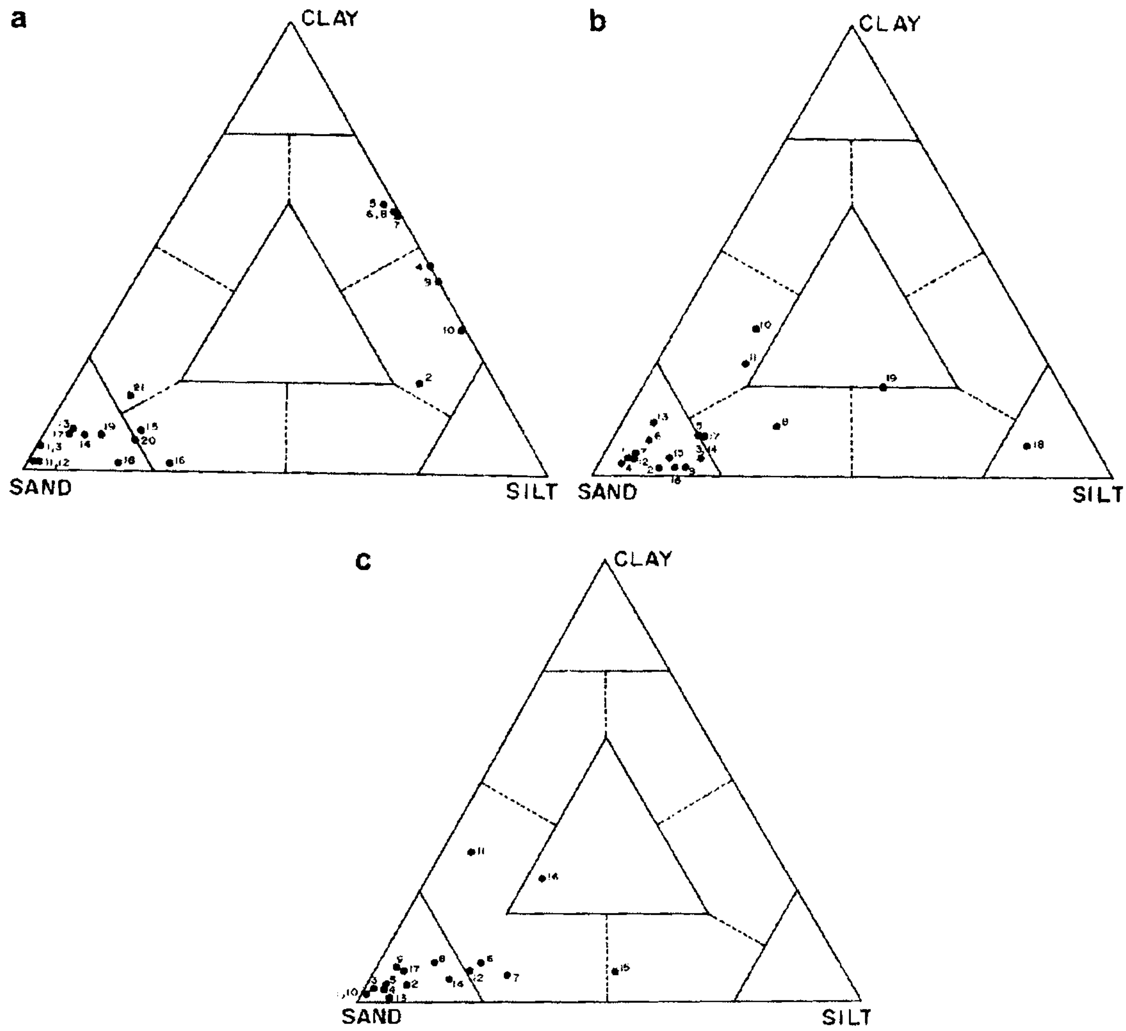

Fig. 2. Triangular diagram showing sediment texture in the study area. (a) Mid shelf. (b) Outer shelf. (c) Slope.

shelf. Benthic biomass was more in the southern latitude stations, especially off Vizhinjam, Kochi and Purakad (Table 1). In all the three depth zones, fauna was mainly constituted by polychaetes (70%), followed by crustaceans (17%) and the least by mollusks (11%). The rest of the organisms included sipunculids, nemertene worms, fish larvae, echinoids and ophiuroids. Abundance of benthic organisms particularly polychaetes, molluscs, and fish larvae were also high in the southern latitude stations. Organisms showed textural preference, and most of them preferred sand-dominating sediment (Table 2).

3.3. Community structure

Among the polychaetes, sedentary forms were dominant (86%) over errant forms. Members of family Spionidae contributed to the maximum (49%), followed by Cirratulidae (23%) to the total density. Depth wise variation was striking in faunal composition as evidenced by the abundance of deposit feeders in shallow depths (mid shelf), increased abundance of carnivores in the middle depths (outer shelf) and filter feeders in deeper depths (slope) (Table 3). Ophiuroids were abundant in the outer shelf especially in the southern region (off Vizhinjam). Species richness was high at 50 and 75 m depths, and drastically reduced beyond 100 m (Fig. 5). The highest diversity was observed at 50 m, which considerably decreased beyond 100 m. Species richness and diversity were relatively high in the southern region (3.88 and 2.08) than in the northern region (3.34 and 1.74).

3.4. Cluster analysis and biological interactions

Bray-Curtis analysis showed 4 distinct clusters at 85% similarity (Fig. 6). In general, cluster 1 mainly consisted of stations from the northern region having low benthic density (1482 ± 1984 ind. m^{-2}). Clusters 2 and 3 consisted of stations mainly from southern region. Cluster 2 represented deeper depth stations with high density (9535 ± 8404 ind. m^{-2}). Cluster 3 consisted of shallow and middle depth stations, with relatively high density (5597 ± 2859 ind. m^{-2}).

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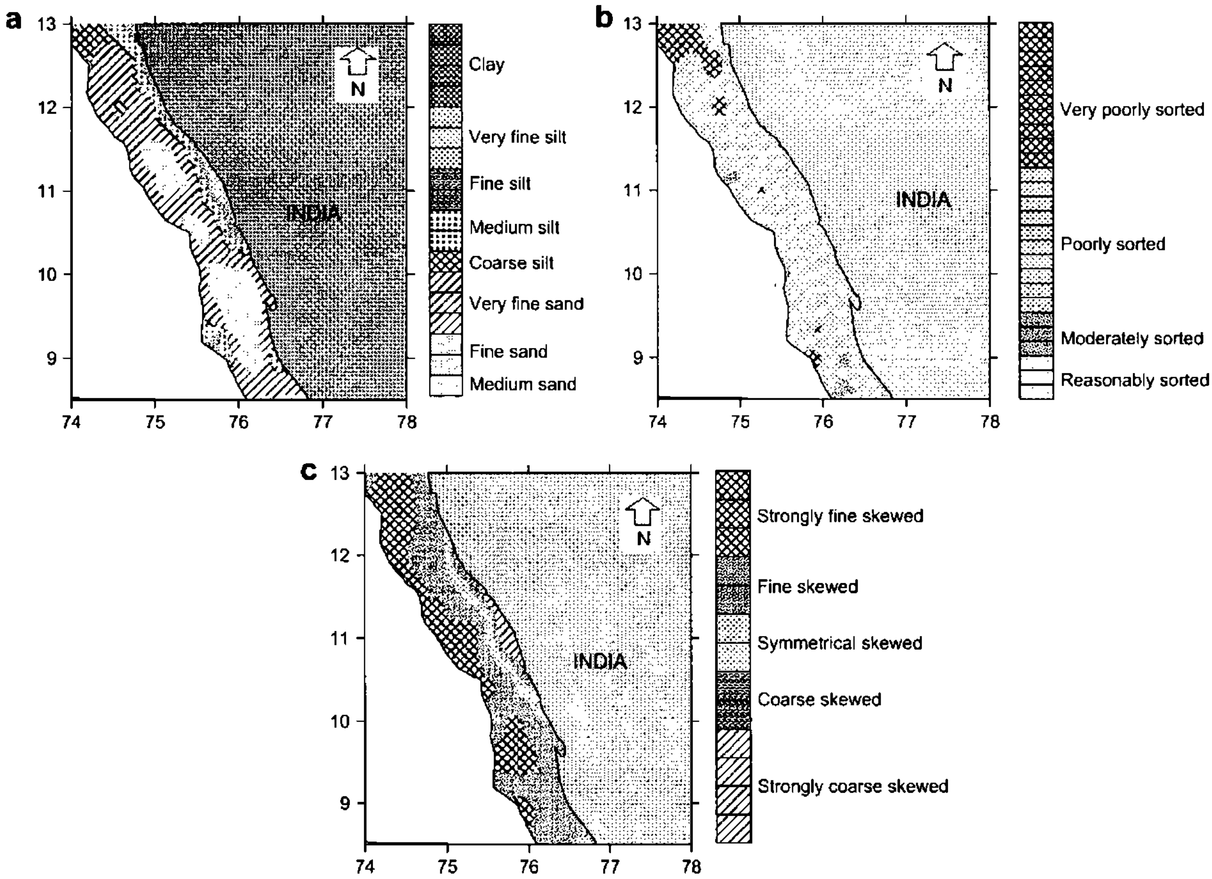

Fig. 3. Distribution of sediment parameters. (a) Mean grain size. (b) Sorting coefficient. (c) Skewness.

Species cluster was drawn, to study the interaction between the species, and 3 major clusters were obtained (Fig. 7). Most of the species of cluster 1 were from the deeper depth zone (outer slope), and they were absent in the middle depth zone (outer shelf). Deposit feeding polychaetes such as *Notomastus fauveli*, *Notomastus aberans*, *Capitella capitata*, *Cirriformia afer*, *Tharyx dorsobranchialis* and *Pista unibranchia* were abundant along with carnivore species *Glycinde kameruniana* in this cluster. Two sub clusters were distinguished in cluster 1. Subcluster 1 was formed due to the abundance of *G. kameruniana*, *C. afer* and *T. dorsobranchialis*. Subcluster 2 comprised of *N. fauveli*, *N. aberans*, *C. capitata*, and *P. unibranchia*. In cluster 2, all the species were abundant in mid shelf. Here also deposit feeding polychaetes *Prionospio cirrifera*, *Spiophane bombyx*, omnivore *Nereis indica*, and deposit-feeding crustaceans such as *Grandidierella gilesi*, *Melita* sp., and Tanaidaceans flourished. Maximum number of species was observed in cluster 3. Of the two sub clusters, sub cluster 1 consisted of species present in shallow and middle depths which included carnivore polychaetes such as *Nephtys dibranchis*, *Lumbrineris aberrans*, and *Lumbrineries hartmani*; deposit feeders such as *Prionospio polybranchiata*, *Prionospio cirrobranchiata*, *Polydora capensis*, *Syllis spongicola* and *Ophiuroid* sp. In sub cluster 2, species from all the three depths were present and dominated by deposit-feeding polychaete such as *Cirratulus cirratus*, *Magelona capensis*, *Cossura coasta*, and *Prionospio pinnata* and, the carnivore polychaete *Glycera longipinnis*. Filter feeding bivalves such as *Sunetta* sp. and *Tellina* sp. were abundant in deeper depth zone. There was a co-existence of deposit feeders and carnivores in the outer shelf and filter feeders and deposit feeders in the deeper depth zone.

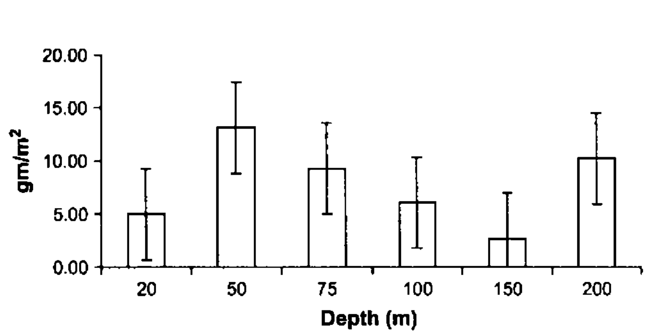

Fig. 4. Average biomass distribution in various depths.

3.5. Relationship with environmental variables

Spearman correlation analysis showed meager relationship between benthic groups and studied abiotic variables (Table 4). In general, polychaetes and crustaceans showed a negative

Table 1
Distribution of average biomass (gm m^{-2}) of major groups in various transects

Transects	Polychaete	Crustaceans	Molluscs	Fish larvae	Ophiuroids	Echinoids	Others*
Mangalore	2.56	1.04	0.00	0.04	0.00	0.00	0.81
Kazargode	1.48	1.02	0.00	0.00	0.00	0.65	1.63
Matool	2.92	2.83	0.00	0.00	0.00	0.00	0.00
Thikodi	1.50	1.00	0.00	0.00	0.00	0.00	0.00
Beypore	3.03	1.44	0.00	0.00	0.04	0.00	0.00
Ponnani	2.33	2.62	0.00	0.00	0.20	0.00	0.00
Valapad	3.66	1.38	0.00	0.66	0.09	13.10	0.00
Kochi	5.80	1.70	0.60	2.39	0.00	0.00	1.02
Purakad	4.13	3.30	0.02	0.00	0.02	0.00	0.12
Kollam	3.89	0.42	0.00	0.00	0.00	0.00	0.46
Vizhinjam	10.64	2.46	3.12	1.50	1.00	0.00	0.41

* Included sipunculids and nemertene worms.

correlation with depth while mollusks, fish larvae and ophiuroids had a positive correlation. Polychaetes, mollusk, fish larvae and ophiuroids were positively influenced by coarser sediment fraction (sand), while crustaceans, and echinoids were negatively correlated. Meager correlation shows that there could be many factors in combination that influence the benthic distribution. BIO-ENV analysis was carried out to identify the most important factors (Table 5). In general, latitude, sediment texture (especially the amount of sand and silt), MGS, mode of sediment sorting and depth were found to be the major factors influencing the distribution of organisms. The factors influencing the community structure were found to be more or less similar to that of density. For instance, species diversity was controlled by a combination of silt, MGS, and sorting coefficient of the sediment (Table 5).

4. Discussion

The present finding of high benthic biomass and density in the shallow region (50 and 75 m) that decreased towards deeper zones (beyond 75 m) agree with the earlier reports from Indian waters (Kurian, 1971; Parulekar, 1973; Harkantra et al., 1980; Parulekar et al., 1982; Jayaraj et al., 2007). Enrichment of coastal waters due to riverine flow and land runoff may be contributing to the high abundance of the fauna in the shallow region (Parulekar, 1973).

The existence of relatively high species richness and diversity up to 75 m depth that decrease towards greater depths corroborates the patterns observed in the northwest coast of India (Jayaraj et al., 2007). Similar reports are also available from other parts of the world such as off the Atlantic coast of North America, (Sanders, 1968; Boesch, 1979; Neff et al., 1989), Californian waters (Bergen et al., 2000), Canadian Archipelago (Carey, 1991) and Otago shelf, New Zealand (Probert and Wilson, 1984). The low richness and diversity observed beyond 100 m depth could be due to the decreased food availability and increased depth. According to the time-stability hypothesis of Sanders (1968), unpredictable physical stress would depress the species richness leaving only a few broadly adapted species or recurring colonizing species with great reproductive power.

Cluster analysis has delineated three major clusters, which were mainly segregated based on latitude and depth. Clustered stations in the southern region were densely populated than its northern counterparts. The increased richness, diversity and abundance of organisms, observed in the southern region, could be due to the increased proportion of coarser sediment (Long and Lewis, 1987). This could also be due to the high-energy conditions that keep the organic matter in suspension as food for filter feeders. In this case, the low biomass at very shallow depth (20 m), where the texture was silty with MGS of >4 Φ and high OM, suggests that fine sediment and high OM adversely affect the benthic fauna (Jayaraj et al., 2007). This could also be evidenced from the negative correlation of faunal groups obtained from the correlation analysis. Increased dominance in the deeper depths could be due to the

Table 2
Distribution (%) of benthic groups in various sediment textures

Sediment texture	Polychaete	Crustaceans	Molluscs	Fish larvae	Ophiuroids	Echinoids	Others*
Sandy	24.31	21.01	89.24	12.25	84.44	100.00	100.00
Sandy silt	27.90	23.70	0.00	0.00	15.25	0.00	0.00
Silty sand	8.81	10.71	11.11	0.01	0.00	0.00	0.00
Silty clay	7.96	16.96	0.00	0.00	0.00	0.00	0.00
Clayey sand	10.12	4.09	0.00	2.57	0.00	0.00	0.00
Clayey silt	6.08	1.09	0.00	0.00	0.00	0.00	0.00
SSC[1]	14.84	22.49	0.00	85.25	0.00	0.00	0.00

* Included sipunculids and nemertene worms.
[1] Mixed sediment (Sand, Silt, Clay).

Table 3
Species distribution (No. m^{-2}) with their feeding guilds in different depth zones. DF, deposit feeder; SF, suspension feeder; FF, filter feeder

Species Code No.	Species	Feeding guild	Mid shelf	Outer shelf	Slope
1	*Eurythoe* sp.	Carnivore	3	10	0
2	*Sthenelais boa*	DF	0	0	10
3	*Ancistrosyllis constricta*	DF	10	7	0
4	*Autolytus* sp	DF	10	0	0
5	*Syllis spongicola*	DF	20	13	0
6	*Nereis indica*	Omnivore	97	0	0
7	*Nephtys dibranchis*	Carnivore	30	50	0
8	*Glycera longipinnis*	Carnivore	17	30	5
9	*Glycinde kameruniana*	Carnivore	0	0	25
10	*Aglaurides* sp.	Carnivore	3	20	0
11	*Onuphis conchylega*	Carnivore	3	0	0
12	*Arabella iricolor*	Carnivore	0	10	0
13	*Diopatra neapolitana*	Carnivore	0	30	0
14	*Dorvillea gardineri*	Carnivore	10	23	5
15	*Lumbrineris* sp.	Carnivore	0	20	0
16	*L. aberrans*	Carnivore	13	50	0
17	*L. hartmani*	Carnivore	7	70	0
18	*Eunice indica*	Carnivore	3	0	0
19	*Epidiopatra* sp.	Carnivore	7	0	0
20	*Prionospio pinnata*	DF	170	130	10
21	*P. polybranchiata*	DF	30	10	0
22	*Spio* sp	DF	.10	7	10
23	*Spiophane bombyx*	DF	40	0	0
24	*Prionospio cirrobranchiata*	DF	60	7	0
25	*P. cirrifera*	DF	397	0	0
26	*P. ehlersi*	DF	3	0	0
27	*P. malmgreni*	DF	3	0	0
28	*Malacoceros indicus*	DF	13	20	0
29	*Scolelepis squamata*	DF	70	7	0
30	*Polydora capensis*	DF	10	5	0
31	*Magelona capensis*	DF	13	140	45
32	*Cirratulus cirratus*	DF	17	350	300
33	*Tharyx dorsobranchialis*	DF	0	0	435
34	*Cirriformia afer*	DF	0	0	50
35	*Orbinia* sp	DF	17	10	5
36	*Haploscoloplos* sp.	DF	7	0	0
37	*Cossura coasta*	DF	7	100	75
38	*Polyphysia* sp.	DF	3	10	0
39	*Notomastus fauveli*	DF	7	0	35
40	*N. aberans*	DF	5	0	15
41	*Capitella* sp	DF	3	10	0
42	*C. capitata*	DF	7	0	55
43	*Maldane sarsi*	DF	17	0	0
44	*Nicomache* sp.	DF	3	0	0
45	*Sternaspis scutata*	DF	0	0	5
46	*Chone collaris*	SF	3	0	0
47	*Pectinaria* sp.	DF	10	0	5
48	*Phyllocomus hiltoni*	DF	6	0	0
49	*Isolda* sp.	DF	20	0	0
50	*Sabellides capensis*	DF	3	0	0
51	*Trichobranchus* sp.	DF	3	0	0
52	*Pista unibranchia*	DF	10	0	25
53	*Eriopisa* sp.	DF	70	20	10
54	*Melita* sp.	DF	90	0	0
55	*Grandidierella gilesi*	DF	50	0	0
56	Tanaidacea	DF	23	0	0
57	Cumacea	DF	10	0	0
58	*Calappa* sp.	DF	17	0	0
59	*Acetes* sp.	DF	40	10	10
60	*Sunetta* sp.	FF	20	50	120
61	*Tellina* sp.	FF	30	70	90
62	*Cynoglosus* sp.	DF	30	10	3
63	*Ophiuroid* sp.	DF	30	80	0
64	Sipunculid	DF	13	0	0
65	Nemertene	DF	13	0	0

abundance of polychaete species of family Cirratulidae and Cossuridae. This showed the ability of these species to survive in adverse conditions, which was similar to the observation of Joydas (Pers. Comm.) from the western shelf of India. Tselepides et al. (2000) observed a decrease in diversity and abundance with depth in the continental shelf of Crete, South Aegean Sea and attributed it to the reduced food availability. Probert and Wilson (1984) who studied the benthos of the continental shelf of Otago peninsula, New Zealand, showed that species diversity varied markedly across the shelf and related primarily to the degree of sediment heterogeneity.

Biological interaction of benthos could be seen in the clustering of species. Three distinct feeding groups were observed in the present study: deposit feeders in shallow depth, carnivores in middle depth and filter feeders in deeper depths. However, a coexistence of deposit feeders and carnivores in outer shelf and deposit feeders and filter feeders in the slope region were also observed. This shows that the organisms are capable of utilizing different food resources in a particular niche. Obviously, the species interaction helps in the exploitation of different feeding niches in a particular habitat. The dominance of deposit feeders in shallow depth could be due to their preference to the fine-grained sediment. Specificity of deposit feeding polychaetes *Prinospio pinnata* and *Prionospio cirrifera* in shallow depth, and filter feeding bivalves *Sunetta* sp. and *Tellina* sp. in the deeper depth showed the effect of sediment granulometry on the distribution of organisms based on

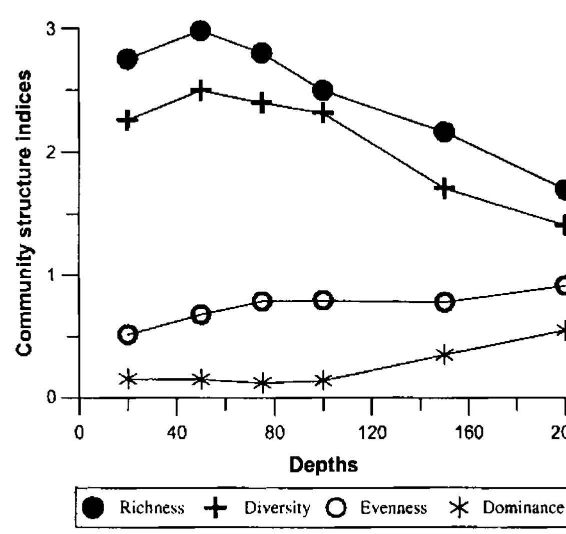

Fig. 5. Depth wise distribution of community structure indices.

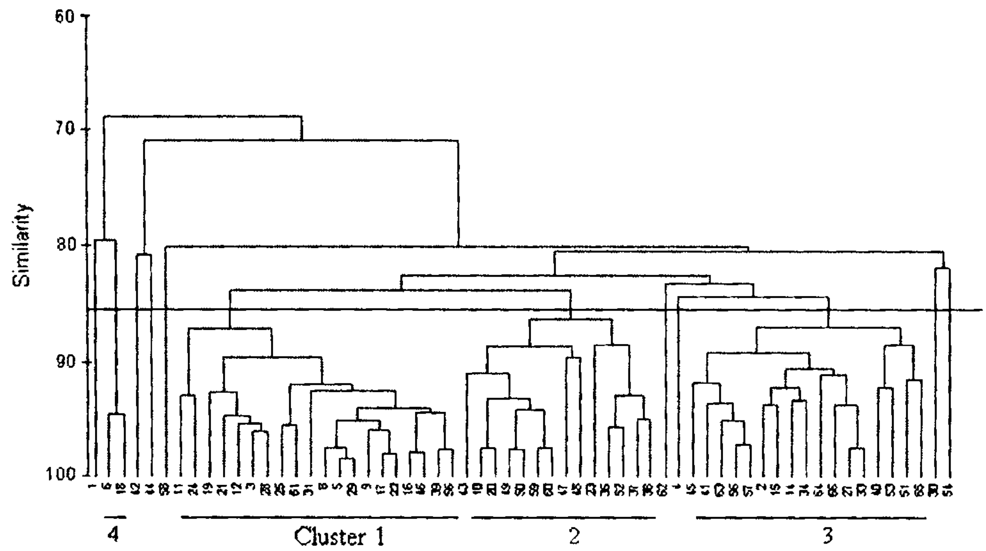

Fig. 6. Bray-Curtis similarity for stations.

their feeding habits. Dominance of spionid polychaete *P. Pinnata* and *P. cirrifera* in the fine-grained sediment has already been reported from the northwest coast of India (Jayaraj et al., 2007). Thrush and Townsend (1986) observed two distinct habitats in the fine and the coarse substrata of sub-littoral macrobenthic community of Ireland: deposit feeding spionid polychaete *Pseudopolydora pulchra* in the muddy regions and serpulid polychaete *Pomatoceros* sp. and gastropod *Onoba semicostrata* in the coarse sand areas.

The present study has shown that sediment texture is one of the prime factors controlling the benthic distribution, as most of the benthic groups especially polychaetes, mollusks, and fish larvae and ophiuroids preferred sand dominated sediment texture. Polychaete *Nephtys dibranchis* were abundant in the fine sand sediment in the present study. Hoey et al. (2004) observed abundance of *Nephtys cirrosa* from similar sedimentary environment in the Belgium shelf. Furthermore, the occurrence of the mollusk *Tellina* sp. in large numbers in the sandy

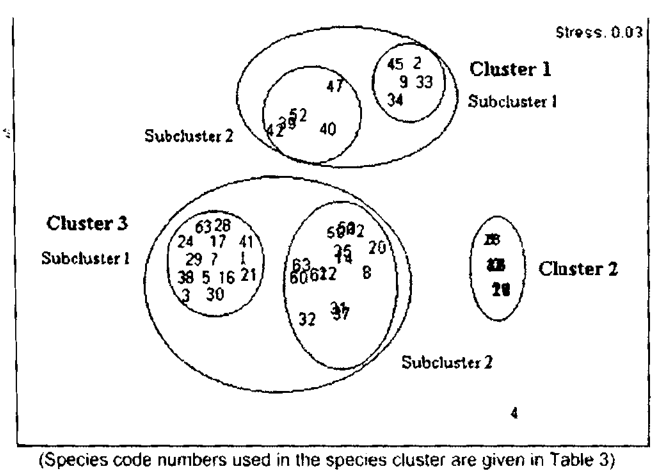

Fig. 7. MDS analysis for benthic species.

sediments of deeper depths suggests that this species is typical of this substratum. Species of genus *Tellina* were also reported from similar sedimentary environments of southern California (Bergen et al., 2000) and North Sea (Duineveld et al., 1991). Mollusk, *Tellinides timorensis* were the most abundant species from the sandy environments of Javanese waters (Warwick and Ruswahyuni, 1987). Ansari et al. (1977), Harkantra et al. (1980, 1982) and Jayaraj et al. (2007) have reported that benthos especially filter feeders prefer medium particle size sediment as clayey regions are not a favorable substratum for filter feeders. Sanders (1958) had suggested that fine sediment reflects the environment with feeble currents, which allow the fine particle to settle, so that only a small amount of organic matter in suspension is available as food for filter feeders, which in turn prevents them from inhabiting such environment. Thus, the abundance of benthic groups especially polychaetes, mollusks and fish larvae in the southern region indicated the prevalence of suitable sediment texture and also showed that the region is conducive for demersal fishes.

The high percentage of fine-grained sediment and organic matter in the northern region observed during the present study was remarkably similar to the sediment distribution pattern in the northwest coast of India (Jayaraj et al., 2007). It is worth noting that the distribution of organic matter is entirely governed by a set of physico-chemical, sedimentological and hydrographic conditions (Paropkari et al., 1987). The high organic matter in the mid shelf (4.86%) could be thus attributed to the high productivity of the overlying water (Qasim et al., 1978), and preservation of deposited organic matter by the fine-grained nature of sediments, coupled with higher rates of sedimentation (Zobel, 1973; Borole, 1988). Furthermore, the northern region of the study area receives relatively high annual rainfall, which brings organic load, through rivers. This might have also resulted in increased amount of fine sediment in this region. Concurrently, the coarse-grained nature of sediments in the southern region permitted easy diffusion of

Table 4
Spearman correlation analyses between environmental and biotic variables. Values with significant coefficients ($p < 0.05$) are given and others relations are expressed as '+' (positively influencing) and '–' (negatively influencing) signs. $N = 66$

	Polychaetes	Crustaceans	Molluscs	Fish larvae	Ophiuroids	Echiuroids	Total
Depth	–	–	+	+	+	−0.305	–
Latitude	–	+	−0.304	–	+	+	–
Sand	0.304	–	+	0.309	+	−0.352	+
Silt	–	+	–	–	–	0.326	–
Clay	–	–	–	−0.323	–	0.327	–
OM	−0.360	–	–	+	–	0.344	–
MGS*	−0.383	–	–	–	−0.306	0.309	−0.344
Sorting	+	+	–	–	–	+	+
Skewness	+	+	–	−0.334	+	–	–

* Mean grain size.

well oxygenated waters, and to some extent, even the washing out of fine-grained organic material by persistent strong currents (Sharma, 1968). Presence of ophiuroids in the southern region may also help in the abundance of other benthic groups. MGS and sediment sorting, which are the functions of hydrodynamic regime, also played a role in the benthic distribution (Snelgrove and Butman, 1994; Harkantra and Rodrigues, 2004).

It is well recognized that various physical processes like currents and waves influence sediment granulometry. McLaren and Bowles (1985) have suggested that the MGS, sorting and skewness of the sediment could be used to identify the direction of transport, sedimentary processes of winnowing and deposition. Variation in the sediment granulometry affects the distribution of benthos. In the present study, stations off southern region were dominated by coarser fraction of

Table 5
Summary of results from BIO-ENV analyses for all taxa pooled and for the dominant taxonomic groups. Spearman rank correlations (R_s) between the biotic and abiotic variables with highest correlations in bold face. Lower correlations are omitted from the table. n, number of variables. MGS, mean grain size

Data	n	Spearman's correlation coefficient	Variables
Total abundance	5	**0.242**	Latitude, longitude, depth, silt, sorting
	4	**0.241**	Latitude, depth, silt, sorting
	4	0.239	Latitude, longitude, depth, silt
	4	0.238	Longitude, depth, silt, sorting
	6	0.237	Latitude, longitude, depth, silt, MGS, sorting
Polychaetes	1	**0.153**	Sorting
	2	0.135	Longitude, sorting
	2	0.131	Latitude, sorting
	3	0.118	Latitude, longitude, sorting
	4	0.101	Latitude, longitude, depth, sorting
Crustaceans	1	**0.157**	Sorting
	2	0.137	Silt, sorting
	2	0.131	Latitude, sorting
	3	0.118	Latitude, silt, sorting
Molluscs	2	**0.733**	Longitude, MGS
	1	**0.685**	MGS
	3	0.673	Sand, MGS, skewness
	4	0.673	Latitude, Sand, MGS, skewness
	5	0.661	Latitude, longitude, Sand, MGS, skewness
Richness	3	**0.775**	Longitude, depth, skewness
	4	**0.775**	Longitude, depth, sorting, skewness
	5	0.771	Longitude, depth, MGS, sorting, skewness
	5	0.761	Latitude, Longitude, depth, MGS, skewness
	5	0.761	Longitude, depth, MGS, sorting, skewness
Diversity	4	**0.339**	Longitude, silt, sorting, skewness
	4	**0.325**	Longitude, silt, MGS, skewness
	4	0.311	Latitude, silt, sorting, skewness
	3	0.293	Longitude, silt, MGS
	3	0.293	Longitude, silt, skewness
	4	0.279	Longitude, silt, MGS, sorting

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sediment and northern stations by fine fraction. In fact, the northward flowing currents during the southwest monsoon season may carry fine sediment. The MGS of 2–3 Φ in southern transects and a general fining towards north with a MGS of 4–8 Φ in northern transects are indicative of this process. The fine-grained and negatively skewed sediment of 20 m depth may reasonably be considered to be due to the depository nature with low energy conditions. According to McLaren and Bowles (1985), negatively skewed sediment resulted from relatively low flow rates and low energy function. Moreover, the high percentage of sand in the southern region can also be attributed to the presence of Warkalli beds, which provide immediate source of coarser sediments (Hashimi et al., 1981).

Correlation analysis showed meager correlation with several abiotic factors. In general, the relationship mainly depended on feeding habits. Sediments with high MGS and poor sorting supported deposit feeders. Symmetrically skewed and coarse skewed sediments were poorly supporting the benthic fauna. High-energy conditions bring more food and replenish water with more nutrients and oxygen, which could enhance the abundance of organisms. BIO-ENV analysis showed a combination of different factors in the distribution of benthos among which sand, silt, grain size, sediment sorting and depth, were major factors. Massad and Brunel (1979) and Robert (1979) noticed increased abundance of benthos with sand content, which were independent of bathymetric position. But Bergen et al. (2000) and Ellingsen (2002) observed that depth was the primary habitat factor followed by sediment grain size, in organizing the benthic community of the southern Californian and Norwegian shelves, respectively. Wagner (1977) reported that distribution of molluscan species was associated with depth rather than sediment type in the southeastern Beaufort Sea. According to Snelgrove and Butman (1994) the amounts of hydrodynamic energy and available organic materials are more likely to be the primary driving forces, with depth and sediment grain size as secondary correlates.

5. Conclusion

From the present study, it can be deduced that benthic organisms primarily depend on the sediment texture, which in turn is influenced by currents, waves, sedimentation, particle size of sediment, sorting efficiency, etc. Low benthic biomass in the northern region of the study area, especially in the 20 m depth contour showed that high deposition of fine sediment and organic matter adversely affected the distribution of organisms. High richness and diversity in middle depths and decreasing trend towards deeper depths indicated a combination of sediment texture, depth, organic matter and availability of food affecting the benthic distribution. Preference of deposit feeders towards the fine-grained sediment and filter feeders towards the coarser fractions indicates the influence of sediment texture and organic matter on the feeding behaviour of the organisms. The present findings of decreased density, richness and diversity in deeper depths could be due to the reduced food and competition for the sparse food is probably severe, leading to low densities (Duineveld et al., 1991). Biological factors such as predator-prey relation, and larval settlement, may also be important but could not be assessed in the present study. From the present study and earlier reports, it is obvious that sediment granulometry and the factors influencing the accumulation of organic matter have a major role to play in the distribution, abundance, feeding behaviour and habitat preference of benthic organisms in the shallow continental margin of the southwest coast of India.

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P6-03

A comparison of macrobenthic variability in a tidal river estuary (Cochin backwaters) and an enclosed coastal basin (Kakinada Bay)

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Biomass, faunal density, and species diversity of benthic invertebrates in two different system modules viz. the Cochin backwaters (CBW)–a tidal river estuary (depth 1- 9m) located in the southwest coast of India (9° 30' to 10° 20' N and 76° 13' to 76° 50' E) and the Kakinada Bay (KB) - an enclosed basin (depth 1-5m) located in the east coast of India (16° 50' to 16° 58' N and 82° 16' to 82° 21' E) were studied and compared with respect to substratum characteristics. Samples were collected from 56 stations in CBW and 24 stations in KB in February 2005 and January 2006, respectively in CBW and KB. Mean salinity was 17.34 ± 6.6 psu in CBW and 22.41 ± 8.09 psu in KB. Mean benthic density (1285 ± 2197 No.m^{-2}) and biomass (148 ± 654 g.m^{-2}) were high in CBW compared to KB (839 ± 873 No.$m^{-2}$and 9.49 ± 31.69 g.m^{-2} respectively). Sediments in CBW were composed of almost equal proportion of clay and sand whereas in KB, sandy clay dominated. Sediment organic matter was also high in CBW (Mean 2.52 ± 1.74%) compared to KB (Mean1.26 ± 0.54%). In CBW, the macrobenthic community was composed of 51 species belonging to 10 taxa. In KB, 66 species representing 9 taxa were encountered during the study. Average species diversity (Margalef, *d*; Shannon - Wiener, *H'*) was relatively higher in KB (d = 2.5837; H' = 0.7456) than CBW (d = 0.9041; H' = 0.5948). Polychaetes dominated the faunal density in both the regions, which were represented by very few common species such as *Mediomastus capensis, Notomastus aberans, Heteromastus similis, Paraheteromastus tenius, Cossura coasta, Diopatra neapolitana, Prionospio cirrifera* and *P. pinnata*. Classification based on feeding habit suggests that deposit feeders dominated both locations, which was also strongly related to the sediment characteristics.