MICROALGAL VEGETATION IN THE SELECTED MANGROVE ECOSYSTEMS OF KERALA

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Dedicated to My Parents

Certificate

*This is to certify that the thesis entitled "**Microalgal vegetation in the selected Mangrove Ecosystems of Kerala**" is an authentic record of the research work carried out by Mr. REJIL T., under my supervision and guidance in the Department of Marine Biology, Microbiology and Biochemistry, Cochin University of Science and Technology, in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Marine Biology of Cochin University of Science and Technology and no part of this has been presented for the award of any other degree, diploma or associateship in any university.*

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Declaration

I hereby declare that the thesis entitled ***Microalgal vegetation in the selected Mangrove Ecosystems of Kerala"*** *is an authentic record of research work done by me under the supervision of Prof. (Retd.) Dr. K.J. Joseph, Department of Marine Biology, Microbiology and Biochemistry, Cochin University of Science and Technology and no part of this has been presented for any other degree or diploma earlier.*

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Contents

Chapter 1

GENERAL INTRODUCTION

1.1 What are Mangroves?

The word 'mangroves' has its origin from the Portuguese word, 'mangue' or the Spanish word, 'mangle' which means trees or shrubs of the genus *Rhizophora* in association with the English word for a stand of trees, 'grove'. They can be described as tropical tidal wet lands distributed generally between 20^0 N and 20^0 S latitudes. These are the tropical analogues of temperate salt marshes. Macnae (1968) proposed the term mangal to describe the forest community (which includes the plants, animals, microbes, fungi etc.) and mangroves to describe the plant species. Mangal and its associated abiotic factors constitute the mangrove ecosystem. These are infact highly specialized ecosystems characterized by salt resistant plants growing in the intertidal areas along sheltered sea coasts and estuaries. These are important transformative interfaces between land and sea which import inorganic matter from the terrestrial system and transport organic matter, both dissolved and particulate, to the marine ecosystems. This detritus based ecosystem is self sufficient in production and utilization of food materials. It can be described as a 'pass through' or open type of ecosystem which interacts with other ecosystems and extends its influence far beyond the intertidal zone. Such an ecosystem is quite significant in itself as it is in the confluence of land, sea water and fresh water and therefore an excellent reservoir of plant, animal and microbial species. The major components of this ecosystem, mangroves or mangrove trees belong to

terrestrial plant families which are adapted to survive under high salinity, low oxygen, wave actions, unstable substratum, periodical tidal submergence etc.

1.2 Historical Background:

Mangroves have been known and studied since ancient times. Descriptions of Rhizophora mangroves in Red sea and Persian Gulf by Nearchus (325 BC) and Theophrastus (305 BC) are the earliest known records. There were writings on *Rhizophora* by Plutarch (70 AD) and Abou'l Abbas (1230) according to Macnae (1968) and Chapman (1976). The bibliography of mangrove research (Rollet, 1981) shows 14 references of mangroves before 1600 AD, 25 from 17^{th} century, 48 from eighteenth century and 427 from the nineteenth century. In contrast, there were 1500 mangrove references during the period from 1900 to 1975 and about 3000 between 1978 and 1997.

Mangroves have a long historical link with human culture and civilization. In Solomon islands, the dead bodies are disposed of and special rites are performed in mangrove waters (Vannucci, 1997). In third century, a Hindu temple was erected in South India in honour of the mangrove, *Excoecaria agallocha.* Even today, it is believed that a dip in the temple pond cures leprosy. Shrines built in the mangrove forests are worshipped in Kenya also. The letters from the Viceroys to the King of Portugal reveal that the Portuguese learned the traditional Indian technique of rice- fish-mangrove farming from the mangrove forests of Indian Ocean. About 600 years ago, this technology was transferred to the African countries like Angola and Mozambique through Jesuit and Franciscan priests. Even though the evolutionary history of mangroves is problematic with a number of theories, it is believed that they evolved from terrestrial rather than marine plants. Anyway,

mangroves are quite old, possibly arising just after the first angiosperms, around 114 million years ago (Duke, 1992).

1.3 Distribution:

These ecosystems are mostly restricted to tropical and sub tropical zones on sheltered shorelines covered with soft intertidal sediments. These are distributed circumtropically and occur in 112 countries and territories. Mangrove ecosystems are estimated to cover 181,000 km worldwide (Spalding *et al*., 1997). The best-developed mangroves grow along humid sheltered tropical coastlines. They are seen in the delta systems formed by major rivers like the Ganges-Brahmaputra, Irrawaddy and Niger, and on coastlines protected by large landmasses, for example, the Malacca Straits, Borneo and Madagascar. Such areas are often strategic sites for dense human settlements and receive high population pressure. These are largely restricted to latitudes between 30^0 N and 30^0 S. Their distribution is strongly affected by temperature (Duke, 1992), moisture (Saenger and Snedaker, 1993) and large scale currents (De Lange and De Lange, 1994). They have broader ranges along the warmer eastern coast lines of the America and Africa than along the cooler western coastlines. Mangroves prefer a humid climate and fresh water inflow that brings in abundant nutrients and silt. They grow luxuriantly in alluvial soil and are abundant in broad, sheltered, low lying coastal plains where topographic gradients are small and tidal amplitudes are large. Repeatedly flooded and well drained soils support good mangrove growth and high species diversity (Azariah et.al, 1992) and they grow poorly in stagnant water (Gopal and Krishnamoorthy, 1993).

This ever replenished soil nursed by the inflow of water, saline or not, supports the growth of various micro algae. They have significant role in

determining the bioproductivity of the entire mangrove ecosystem. The macroflora protects and provides substrata for the microalgae. While studying the microalgae and productivity of the ecosystem, an understanding of the macroflora is imperative. Hence attention is given in the study to identify and classify mangroves and associated plants.

Two main types of mangroves have been recognized- those from the Indo-Pacific region called old world mangroves and those from the Atlantic region called New world mangroves. The dominant world mangrove zones are restricted to the Indo-West Pacific region of the old world and the most important old world mangroves are distributed in South East Asia, North East Australia and South East Africa. In the new world zone, mangroves are distributed in North America, Pacific coast of North West Mexico, Bermuda islands and Pacific coast of South America (Mcintosh, 1984).

Globally, these ecosystems are thought to consist of 60 species of herbs, shrubs and trees and more than 20 additional species frequently associated with the above true mangrove flora, but not necessarily to it (Barth, 1982 and Lawrence, 1984). According to Chapman (1975), there are 90 species of mangroves in the world, out of which 63 are seen in Asia and Pacific islands. In the report of UNESCO (1986), the mangrove species are reported to be 65. According to Tomlinson (1986), there are only 48 true mangroves in the world, out of which 40 are reported from Indo- West Pacific regions(old world) and only 8 are reported from the new world. This statistical difference is due to the difference in interpretation of the term 'True mangrove'.

Mangroves occur in almost all countries of the world except Europe and Antartica and almost 40% of the world's mangroves are concentrated in Asia. In Asia, mangroves are mainly seen in Bangladesh, Indonesia, Pakistan,

Srilanka, Philipines and India. India, now, has an area of 4461 sq.kms. under mangrove vegetation. About 60 % of Indian mangroves is found along the east coast (Bay of Bengal), 25% on the west coast (Arabian sea) and 15% on the Bay islands. Kerala with a coastal line of about 560 kms and 41 rivers possess a mangrove area of about 25 square kilometers.

1.4 Mangrove Forest Types:

Riverine forests, the most productive, are those that lie along river and creek channels**.** These forests are the largest in stature and experience a constant flow of water in the dry season through daily tidal activity and in the wet season from terrestrial runoff.

Fringe forests are moderately productive intertidal mangrove wetlands that occupy protected shorelines and the mouths of channels. Fringing mangroves are known for their capacity to trap sediments from both marine and terrestrial sources.

Overwash forests are subtidal to intertidal marine-dominated systems that have productivity values resembling fringe forests. This forest type is commonly found in the form of a small island that is constantly washed by tides.

Basin forests are also moderately productive forests that are found in more inland areas. These mangroves are rarely inundated by tidal action nor terrestrial runoff.

Dwarf (scrub) forests are the least productive. This forest type is dominated by a stunted form of mangrove (usually *Rhizophora mangle*). These wetlands, although long in hydroperiod, are low in both nutrients and hydrologic energy.

Hammock mangrove wetlands appear as tree islands along fringing coastlines. They grow in depressions and have characteristics similar to basin and dwarf mangroves (Lugo and Snedaker, 1974).

Recently, a few investigators have modified this into a three category scheme: riverine, fringing (including overwash), and basin (including dwarf and hammock) forests (Cintron *et al*., 1985).

1.5 Zonation:

One of the most distinctive features of mangrove vegetation is the occurrence of species or groups of species in discrete bands or zones running across the marine – terrestrial environmental gradient. Each such zone is typically dominated by a single species. However, there is no universal zonation scheme for this group of plants

These zonation patterns and "associations" are thought to be an artifact of several unique ecosystem properties that mangroves possess. As individuals, mangrove species have a number of unique features (both morphological and physiological) that separate them from other flora. The summation of these features over a large spatial scale results in something that not only benefits the individual mangrove but also a number of other species that utilize these habitats.

1.6 Productivity and Food Chains:

In the past few decades, mangroves have been investigated as a source of energy to mangrove fauna and to adjacent coastal communities. It was believed that carbon in the form of detritus was "outwelled" to coastal systems by way of tidal action.

After investigating the feeding habits and gut contents of a number of different species in and around coastal mangrove wetlands, Odum and Heald (1975A) found that mangrove-derived detritus was an important part of the diets of numerous primary and even secondary consumers. These organisms were then the source of food for higher consumers, many of which are endangered or commonly hunted by man.

Another hypothesis was offered concerning the fate of estuarine detritus -whether it was outwelled or not. The concept of detritus food chains (Odum, 1980) explained the tight coupling between bacterial/meiofaunal communities and plant detritus. This close association was believed to result in a more efficient cycling of nutrients and was used as an explanation for high estuarine salt marsh/mangrove production. However, it appears that the primary production and the export or import of organic carbon into mangrove systems are governed by the movement of water and the geophysical characteristics of the system.

1.7 Importance of the Ecosystem:

Eventhough the term "mangrove" refers to a tidally influenced wetland ecosystem within tropical and subtropical latitudes, they can also occur in areas without a tidal regime e.g. in some choked coastal lagoons and in the supralittoral zone. These marine tidal forests contain trees, shrubs, palms, epiphytes and ferns (Tomlinson, 1986).

For much of history, many people have regarded mangroves as wastelands and the scale of human impact on mangroves has increased dramatically in recent years, with many countries showing losses of 50-80% or more, compared to the mangrove forest cover that still existed even 50 years

ago. Mangrove ecosystems have been degraded or converted into agriculture, aquaculture or for industrial or urban development.

Recently however, society has begun to appreciate the benefits of mangroves and there is a growing awareness of their values such as coastal protection, coastal subsistence of coastal dwellers and commercial fisheries. There are also increasing efforts by governments, NGOs and local communities around the world to conserve, rehabilitate and manage mangroves sustainably, but the literature and success stories are still limited. The mangrove forests have been shown to sustain more than 70 direct human activities, ranging from fuel-wood collection to fisheries (Dixon, 1989; Lucy, 2006). Traditionally, local communities in mangrove ecosystems collected fuel wood, harvested fish and other natural resources. However, in recent decades many coastal areas have come under intense pressure from rapid urban and industrial development, compounded by a lack of governance or power among environmental institutions. Mangroves have been overexploited or converted to various other forms of land use, including agriculture, aquaculture, salt ponds, terrestrial forestry, urban and industrial development and for the construction of roads and embankments. Mangroves can be affected by several different activities simultaneously, or over time as land use patterns change. Over and above the chronic loss of mangrove area worldwide, mangrove habitats have also declined in terms of their biological diversity, forest structure and economic value.

Mangrove associated fisheries and aquaculture have worldwide importance in providing subsistence food and income, as well as commercial benefits, for a wide range of stakeholders, from very poor fisher communities and coastal farmers, to major companies that have invested in aquaculture and seafood processing. Thus, the importance of effective management in relation

to mangrove fisheries and aquaculture development cannot be overestimated. It should also be recognized that lack of enforcement of existing fisheries regulations to protect mangrove nursery sites is one of the major causes of unsustainable fishing. Similarly, many of the problems associated with mangroves and coastal aquaculture stem from poor aquaculture management practices and/or lack of enforcement of environmental regulations.

These plants that live at the edge of the sea play a significant role in mitigating the fury of tsunami and the monstrous waves generated by it. Because mangroves are very dynamic systems occupying marginal coastal environments, it is necessary to update resource assessment data frequently. Since only their direct goods and services have been included in economic calculations, they are consistently been undervalued. There are harmful repercussions on these and other ecosystems, when common ecological processes are compromised through poor management decisions involving mangroves.

1.8 The Research Approach

Having been branded in the past as a wasteland, better to be destroyed and converted to other uses, the scientific community has at last rediscovered the many opportunities that this ecosystem offers for interesting basic research and the environmentalists have perceived the importance of understanding better its structure and dynamics for a wise management of these tropical coastal tidal forests.

In studying mangroves for either basic or applied purposes, it is important to focus on the analysis of the system as a whole, since neither trees nor other plants or animals can survive , except as part of this very peculiar system.

Any sound developmental or managerial practice is based on the analysis of the system as a whole. No rational developments nor any increased yield on a sustained basis nor any rational management can be achieved except on a system analysis approach. System analysis can only be possible, if there is sound knowledge on the component parts of the system.

1.9 Geomorphological & Hydrological Factors:

Although many investigators have focused on salinity in coastal wetland zonation and development, fewer have looked at the two factors - geomorphology and hydrology, that underlie salinity and a multitude of other abiotic factors in coastal systems. Geomorphology is a physical/geological characterization of a system, and hydrology is a description of the dynamics of the water in the system. A system's geomorphology and hydrology are determined by a number of abiotic elements including: local geology, sea-level change, tide, freshwater inputs, shoreline structure, watershed morphometry, groundwater influence, natural disturbance regimes, and climate. Therefore, these two features not only govern the development of a system (Orson and Howes, 1992; Woodroffe, 1993; Kjerfve, 1990) they should also control rates of primary production and as a result of this, the cycling of organic carbon. However, since these are aquatic systems, we would expect hydrology to be the most important.

Mangrove wetlands, in general, are considered to be highly productive systems. Nonetheless, there is much variability in these data among the various "types" of mangrove systems. For example, Lugo and Snedaker (1974) reported that different mangrove forest types in south Florida and Puerto Rico had gross primary productivity values anywhere from 1.4 to 13.9 g C m^{-2} day^{-1}. More recently, it has been reported that GPP values (in various South Florida

mangrove systems) comes to 2.8 to 24.0 g org. matter m^{-2} day^{-1}. The discrepancies in these data are not a result of variation in time, they are merely a function of the different mangrove forest types, not only found in Florida and Puerto Rico, but around the world. However, these studies include only the contribution of mangrove plants and the microflora has not been taken into consideration. These differences in forest types are believed to be a result of the topographic gradients and hydrologic variation within a given mangrove system. In areas where topographic gradients are steep, geomorphology appears to have more of an impact on mangrove physiognomy. And, where these gradients are not as visible, local hydrology seems to determine physiognomy (Lugo and Snedaker, 1974).

1.10 Biotic Components

Mangroves create unique ecological environments that host rich assemblage of species. Since they occupy the intertidal zone , they interact strongly with aquatic, inshore, upstream and terrestrial ecosystems and offer suitable habitat to a wide variety of organisms including many species of vertebrates and invertebrates (Odum and Heald, 1972). The muddy and sandy sediments of the mangal are home to a variety of epibenthic, infaunal, and meiofaunal invertebrates. Channels within the mangal support different communities of planktonic and benthic microalgae, zooplankton and fishes. Being surrounded by loose sediments, the submerged roots, trunks and leaves are islands of habitat that attract abundance of epibenthos like bacteria, fungi, macro algae, micro algae and invertebrates. The aerial roots, trunks, leaves and branches also host a plethora of organisms. As such mangrove forests are among the world's most productive ecosystems producing organic carbon well in excess of the ecosystem requirements and contributing significantly to the

global carbon cycle. They enrich coastal waters, yield commercial forest products, protect coast line and support coastal fisheries.

1.10.1 Floral Components:

The floral components of mangrove ecosystem include the cardinal components, the eumangroves, associated plants, planktonic microalgae and microphytobenthos.

1.10.1.1 'The mangroves':

'Mangroves' can be of three broad categories- True mangroves, minor species of mangroves and mangal associates.

True mangroves are mainly restricted to intertidal areas between the high water levels of neap and spring tides. There are about 80 species of true mangroves belonging to at least 17 families. About 50-60 among them provide significant contribution to the structure of mangrove forests.

Minor species are unable to form conspicuous elements of vegetation and they rarely form pure communities.

Mangal associates are salinity tolerant plants which are not exclusively found in the proximity of mangroves. However, they interact with true mangroves.

1.10.1.2 Mangrove algae:

A large number of micro and macro algae occur in association with mangroves. It includes planktonic microalgae present in the overlying waters, benthic micro algal communities, epiphytic algae that grow on the pneumatophores and stilt roots of mangroves and some forms of macro algae which are washed into the mangals from adjacent areas and continue growth in

the sheltered mangrove areas. All these algal communities make important contributions to the functioning of mangrove ecosystems.

It is an established fact that the tropical estuarine brackish waters bordered by mangroves posses a dense standing stock of planktonic microalgae in the lower reaches where it is dominated by diatoms. Diatoms and blue green algae form the obvious forms of epiphytic micro algae in the mangals. Macro algae are lesser in number and those which are epiphytic on mangrove roots are fairly similar in form and structure all over the world.

Micro algae also inhabit the few top centimeters of the sediment and live interstitially between sediment grains. According to Alongi (1990) and Laegdsgaard and Johnson (1995), a large number of algae occur in association with mangroves , some on the above ground roots, and some free living on the mud and pelagic water column.

Of these, the microalgae are of great significance to coastal processes including nutrient and oxygen cycling and form an important component of the mangrove food web, fed up on by secondary consumers. For several reasons micro algae are good environmental indicators also.

1.11 The Present work:

Even though mangroves and mangrove ecosystems have been studied extensively, they remain poorly understood even today. With continuing destruction and degradation of mangroves, there is a critical need to understand them better. Elevated nutrient levels in these ecosystems support the growth of large number of microalgae, both planktonic and benthic, which contribute substantially to the productivity of the ecosystem. Due to the high nutritional quality of microalgae, they are critical in supporting the higher trophic levels in the ecosystem. Their biomass, productivity and and size are closely tied to the

diversity and abundance of higher trophic levels. Salinity, temperature, desiccation, tidal inundation, wetting frequency, nutrient levels and light intensity are all physicochemical factors that produce patterns of horizontal and vertical distribution seen in many mangrove algae. The sediment and the overlying waters in the ecosystem offer a new frontier of research for marine biologists. Eventhough the phytoplankton and benthic microalgae inhabiting the mangrove ecosystems make very important contributions to the functioning of the ecosystem, they still remain to be an ignored group as far as biological research is concerned. Literature review revealed that despite the importance of microalgae in terms of productivity and functioning of the mangrove ecosystem, research todate has concentrated on the macro floral and faunal communities in the ecosystem.

There is paucity of information on the diversity and composition of microalgae in the mangrove ecosystems in our country. In this context, the present study tries to examine the diversity, abundance, distribution and biomass status microalgae associated with six selected mangrove ecosystems in Kerala. A survey of the cardinal components of the ecosystem, mangrove plants has also been undertaken, since these are the keystone species that protect and make the life of other species possible.

1.12 Objectives of the Study:

1. Studying the present status of major and minor mangrove species in Kerala along with the mangrove associates.
2. Identifying the benthic and planktonic microvegetational forms present in the selected mangrove stations.
3. Analysing the contribution of microphytobenthos and planktonic microalgae to the primary productivity of different mangrove

ecosystems using light and dark bottle Oxygen technique (Gaarder and Gran, 1927), and chlorophyll estimation (Strickland and Parsons, 1972) technique.

4. Analyzing the seasonal and spatial distribution of different photosynthetic pigments present in planktonic and benthic micro vegetation of selected mangrove stations.
5. Examining the impact of different hydrographic parameters in the growth, distribution and productivity of microphytobenthos and planktonic microphytes of the selected mangrove ecosystems.
6. Analysing the nutrient elements present in different stations and their role in the distribution of microalgal vegetation.

This work, therefore, is an attempt to study the importance of mangrove wetland geomorphology and hydrology in determining mangrove production, cycling of mangrove-derived organic carbon and the diversity of species with special reference to one of the highly neglected components of mangrove ecosystems, the microalgal vegetation.

Chapter 2

MATERIALS AND METHODS

2.1 Mangrove stations selected for the study

Mangrove forests are the silent victims of the so called development boom in Kerala, especially in Cochin. Of the total 1650 hectares of mangrove forests in the state, Kochi ranks third with a mangrove vegetation spread over 260 ha. (Forestry Information Bureau of the Forest and wild life dept, Govt of Kerala, 2003). It has been included along with metros like Kolkatta and Mumbai, where there is massive destruction of mangroves.

In Ernakulam district, mangroves are now mainly found in Mangalavanam, Panangad, Kumbalam, Nettoor, Puthuvypu, Mulavukadu, Murikkinpadam, Kannamaly, Chellanam and Panambukadu.

Six among these stations were selected for the present study. These are Kumbalam, Panangad, Nettoor, Puthuvypu, Murikkinpadam and Mangalavanam. While the first three have their daily flushing from the back waters, Puthuvypu and Murikkinpadam are connected directy to the sea through a canal. The sixth station is a highly sheltered one which is connected to the backwaters through a narrow canal link.

Kumbalam: (Station 1)

It is a region in the urban agglomeration of Kochi, in the state of Kerala, India (9° 55′ 0″ N 76° 18′ 0″ E). A water bound country-side, bound by the Vembanad Lake, as well as the fast encroaching city of Kochi, its just 5 minutes

ferry ride to Kochi city. Kumbalam is progressively being transformed into an urban region and becoming part of the city. It is more or less completely surrounded by Cochin backwaters. This is a thickly populated area and mangrove ecosystem of this region is subject to population pressure. Extensive land filling has affected the mangrove vegetation. This station extends upto Panangad.

Panangad: (Station 2)

Panangad is one of the islands that make up the urban agglomeration of Cochin. The river Periyar flows through this place which is bordered by mangrove patches. The mangrove areas in this thickly populated place are subjected to high population pressure.

Nettoor: (Station 3)

This station is near Thirunettoor Railway station (9° 55′ 37.2″ N, 76° 18′ 36″ E). **A** number of creeks and canals are found to traverse the area fringed with mangrove plants. Ernakulam - Alapuzha railway line and National highway 47 are also passing through this area. Extensive land filling has been made in this station through very thick mangrove forests.

Puthuvypu: (Station 4)

It is a sea accreted area about 3 kilometers north of Vypin on the western side of Vypin – Munambam road and half kilometer away from the Vypin light house. Accretion is reported to have taken place after the opening of Cochin bar mouth 1929. Now it is a mangrove nursery maintained by Kerala Agriculture University and is therefore free from sewage input and other pollutants. It is located 100 meters away from the estuarine front. *Avicennia officinalis* and *Bruguiera gymnorrhiza* are the dominant mangroves. An extent of 20 ha. of

land supporting mangroves in patches exist at Puthuvypu. There are several tidal channels, sand pits and creeks which support good mangrove vegetation.

Murikkinpadam: (Station 5)

It is a densely populated fisher folk settlement. Discharge of sewage and disposal of garbage and solid wastes are the major sources of pollution in this area. It is very close to the Arabian Sea. Along with Puthuvypu it forms part of Vypeen Island which is one of the most densely populated coastal zones. The pressure of the growing population poses severe threat to the mangroves of this area.

Mangalavanam: (Station 6)

It is a patchy mangrove forest with an area of about 2.74 hectares, in the heart of the Cochin city (9° 54′ 0″ N, 76° 18′ 0″ E). This represents an almost closed system with a single, narrow canal link to the estuary which is the only source of tidal propagation. During low tide, water in the system is completely drained. There is a shallow tidal pond surrounded by dense mangroves. This area is considered to be functioning as the lungs of the city. Large scale storage tanks for petroleum products of Indian Oil Corporation are situated very close to this station. It is home to many exotic and rare varieties of migratory birds and is declared as a bird sanctuary by the Government of Kerala.

The vegetation primarily consists of *Avicennia officinalis* with occasional patches of *Acanthus ilicifolius* and *Rhizophora mucoronata.*

2.2 Identification of Mangrove Plants

Flowering twigs of mangroves and associated species were collected from all the six stations. Analysis of habit, vegetative characters, morphological features and adaptations were done. The species of mangroves and associated flora were identified based on their vegetative and floral morphological characteristics with reference to the published flora (Gamble, 1967; Matthew, 1983) and by comparing with the herbarium specimen.

2.3 Planktonic microalgae

2.3.1 Measurement of hydrographic parameters

Hydrographic parameters such as temperature, salinity, pH and dissolved oxygen were measured.

2.3.1.1 Temperature

Temperature was measured using a precision mercury thermometer with an accuracy of $\pm 0.01^{o}$ C.

2.3.1.2 Salinity

Salinity was measured using a hand-held refractometer (Atago, S/Mill – E, Japan)

2.3.1.3 pH

pH measurements were made using a portable pH meter (Perkin Elmer, accuracy, $\pm$ 0. 01).

2.3.1.4 Dissolved oxygen

Samples were collected in 50 ml ground stoppered BOD bottles and fixed using Winkler's A&B solution. D.O was determined by Winkler's method.

2.3.2 Sampling and analysis

30 litres of surface water was filtered through phytoplankton net of 20µ mesh size made of bolting silk. The filtrate was preserved in 3% neutralized formaldehyde/Lugol's iodine solution. Quantitative analysis was done employing Sedgewick-Rafter counting cell. Species identification was done using a Nikon E200 light microscope.

2.3.2.1 Enumeration by Sedgewick-Rafter counting cell

The planktonic microalgae filtered from 30 L of surface water was made up to a fixed volume concentrate. One ml of this sample was transferred to the Sedgewick-Rafter counting cell (the volume of this chamber is 1ml). The number of microalgae present in all the thousand grids was calculated. Repeated the counting for three times and took the average. The total number of planktonic algal species present in one litre of water sample was calculated using the formula,

$$N = \frac{n \times v}{V}$$

where,

N = no. of planktonic algae per litre of water filtered

n = average no. of planktonic algae in one ml of sample

v = volume of plankton concentrate in ml

V = total volume of water filtered in litre

2.3.3 Estimation of primary productivity

Photo-autotrophic organisms are able to synthesize organic compounds from simple inorganic compounds utilizing the energy obtained from solar radiation. This photosynthetic process is termed as primary production or it can be defined as the total amount of organic materials synthesized in unit time per unit volume of water.

$$6CO_2 + 6H_2O \xrightarrow{\text{Light}} C_6H_{12}O_6 + 6O_2$$

Light and dark bottle method (Gaarder and Gran, 1927) was used for the estimation of primary productivity. The "Winkler" method of determining dissolved oxygen is normally used in the 'light and dark bottle' technique for studying production rates.

Procedure

A set of three ground stoppered oxygen bottles of 50 ml capacity was used in the experiment. Out of these, one was treated as light bottle, one as control bottle (initial bottle) and the third one served as dark bottle. Water samples from the surface were collected using clean plastic buckets. Water was siphoned into the sampling bottles using a siphon tube; the end of the tube was fitted with nylon net/bolting silk of 200-300 pore size in order to remove the zooplankton, if present; which may otherwise interfere with the oxygen content in the experiment bottles. Care was taken to avoid agitation of water. All the bottles were simultaneously filled with water samples using polythene tube, which touched the bottom of the bottle while filling to avoid the formation of air bubbles. The bottles were properly stoppered without trapping air bubbles inside the bottle.

The control bottle (initial bottle) containing water sample was immediately fixed with 0.5 ml of manganese sulphate and 0.5 ml of alkaline

potassium iodide (fixatives normally used in determination of oxygen by Winkler's method). The dark bottle was wrapped with aluminum foil and kept in a black polythene bag so as to be protected completely from sunlight. The light and dark bottles were kept suspended in a transparent acrylic chamber. These bottles were incubated for a period of 3 hours in the chamber by keeping the exact light penetration and temperature as in the sampling area from which samples were collected.

After the period of incubation, the bottles were taken out and were fixed as in the same manner as for the control bottle. The oxygen content of different bottles was determined by Winkler's chemical titration method. The oxygen content of the light bottle relates the amount of oxygen evolved during photosynthesis minus the amount of oxygen consumed in respiration by the entrapped phytoplankton. The amount of oxygen utilized by the phytoplankton for the respiration can be estimated by using measurements of oxygen changes concurrently in control/initial and light bottles. Oxygen decreased in dark bottle (compared to that of control bottle) was only due to respiration. Hence to get the estimate of total amount of photosynthesis (gross production), negative change in O_2 content of the dark bottle has to be added with the positive change in the O_2 content of the light bottle.

The Light and Dark bottle method assumes a fixed photosynthetic quotient (PQ). It is the number of molecules of oxygen liberated during photosynthesis divided by the number of molecules of CO_2 assimilated during photosynthesis. Theoretically PQ is considered to be one, assuming the product of photosynthesis as starch (hexose sugars). Since it is not possible to determine the nature of photosynthetic product, a PQ value of 1.25 is invariably applied for fieldwork.

Calculations

Gross production = O_2 content of light bottle - O_2 content of dark bottle. ……A

Net production = O_2 content of light bottle - O_2 content of control bottle…..B

Respiration = O_2 content of control bottle - O_2 content of dark bottle….C

The period of incubation is 3 hours, then

Gross production (mgC/L/Hr) = A x 0.375 / PQ x 3……....D

Net Production (mgC/L/Hr) = B x 0.375 / PQ x 3……E

Gross or net production (mgC/L/Day) = D or E x12 ……...F

Gross or net production (gC/ m^3 /day) = F x 1000 x1000

2.3.4 Estimation of pigments

For the estimation of chlorophylls, samples were collected using clean plastic buckets from the surface and transferred into one litre black plastic can and stored in refrigerator until further analysis.

The water sample free of zooplankton was filtered through GF/C glass filter paper and the pigments- chlorophyll *a, b* and *c* were extracted from the phytoplankton by using 90% acetone. The resulting coloured acetone extract is measured in a spectrophotometer (Hitachi U-2001, UV-visible spectrophotometer). Before filtering, a thin bed of magnesium carbonate ($MgCO_3$) was applied to the glass filter paper and then applying low suction the $MgCO_3$ was sucked out to a dry bed. After the formation of thin film of

$MgCO_3$, one litre of sample was filtered through Whatman GF/C filter paper using a filtration apparatus fitted with vacuum pump.

The filter paper was then placed in an acid free test tube containing 10 ml of 90% acetone and kept in a refrigerator for 24 hours. Then it was taken out from the test tube, ground well in a mortar and transferred to a centrifuge tube. The sample was then centrifuged for five minutes in 4000 rpm. Made up the clear supernatant extract to 10ml with 90% acetone.

The clear acetone extract was measured spectrophotometrically against 90 % acetone as blank at wave lengths of 750, 665, 645, 630 and 450 nm, i.e. the maximum absorption wavelengths of the pigments (Strickland and Parsons 1972).

All the extinction values are corrected for a small turbidity blank by subtracting the optical density of 750nm from the 665, 645 and 630nm absorptions.

The following equations are used to find out the chlorophyll contents.

Chlorophyll *a* (C*a*) = $11.85\ E_{665} - 1.54\ E_{645} - 0.08\ E_{630}$

Chlorophyll *b* (C*b*) = $21.03\ E_{645} - 5.43\ E_{665} - 2.66\ E_{630}$

Chlorophyll *c* (C*c*) = $24.52\ E_{630} - 1.67\ E_{665} - 7.60\ E_{645}$

where 'E' is the absorbance at respective wavelengths.

Chlorophyll *a* µ/lit. = $\frac{Ca \times v}{V \times l}$

Chlorophyll *b* µ/lit. = $\frac{Cb \times v}{V \times l}$

Chlorophyll *c* µ/lit. = $\frac{Cc \times v}{V \times l}$

For the estimation of carotenoids, the above procedure was followed and the absorbance was measured at wave lengths 510 and 480nm.

$$\text{Caroteniodes (C}p\text{) } \mu\text{/lit.} = 7.6\,[(E_{480}-E_{750}) - (1.49\,E_{510}-E_{750})]$$

$$= \frac{Cp \times v}{V \times l}$$

Where 'v' is volume of acetone (ml), 'V' is volume of water (lit.) filtered for extraction and 'I' is the path length (cm) of cuvette used in spectrophotometer.

2.4 Nutrients

Nutrients (nitrite, nitrate, phosphate and silicate) were analyzed as per Strickland & Parsons (1972).

2.4.1 Estimation of Nitrates and Nitrites:

It is based on the principle of reduction of nitrate to nitrite, which is then determined by diazotizing with sulphanilamide and coupling with N(1-naphthyl)-ethylene diamine (NED) to form a highly coloured Azo dye, the absorbance of which is measured at 540 nm.

Commercially available granulated Cadmium is sieved and the fraction between 40 and 60 mesh size is retained and used. The cadmium granules are freed from oxides by washing with about 2 molar HCl. They are then shaken vigorously in a beaker with about 100 ml $CuSO_4$ for about 3 minutes. The copperised Cd granules are thoroughly washed with distilled water under gentle shaking. The water is decanted. Washing is continued until the water contains no colloids or finely dispersed copper. The reductor is filled with water with the aid of a funnel. The copperised Cd granules are then slowly poured into the reductor. It is then activated by passing about 250 ml ammonium chloride

buffer solution through it. After rinsing thoroughly with the buffer solution, the reductor is ready for use. Ammonium chloride buffer and the sample are taken in 1:1 proportion and passed through the reductor.

The fraction used for rinsing the flask (10 ml) is discarded and after that 10 ml is taken in a test tube. To that, added 0.2 ml sulphanilamide. After mixing and about 2 min. reaction time, 0.2 ml NED solution is added. A pink colour is developed and the colour is allowed to develop for 15 minutes. The absorbance at 540 nm is measured within an hour.

For nitrite, the reagents are added to the unreduced sample to allow colour development and OD is measured at 540 nm.

2.4.2 Estimation of phosphates:

Add 1ml ascorbic acid and 1ml mixed reagent (a mixture of ammonium heptamolybdate tetrahydrate and potassium antimony tartrate in H_2SO_4) to 50 ml of the sample and mix thoroughly after each addition. The absorbance of the blue phosphorous compound is measured using a wavelength of 880 nm. The concentration of phosphate in the sample is determined using the standard graph prepared using known concentrations of potassium dihydrogen phosphate.

2.4.3 Estimation of Silicates:

The determination of silicates is based on the formation of a yellow silicomolybdate when the acidified sample is treated with a molybdate solution.

Add 1 ml H_2SO_4 to 50 ml of the sample drop by drop until the solution remains pale yellow. Add 2 ml of the molybdate reagent (ammonium heptamolybdate tetrahydrate) to 50 ml of the acidified sample. Swirl and allow to stand for 10-20 minutes. Add 2 ml of oxalic acid and 1ml ascorbic acid with

gentle mixing between additions. Measure absorbance at 810 nm after a reduction time of 30-60 minutes. Determine the concentration of the nutrient using astandard graph prepared with disodium hexaflouro silicate.

2.5 Microphytobenthos

2.5.1 Sampling and analysis

Microphytobenthos samples were taken from the same stations from where planktonic microalgae were collected. Both samplings were done simultaneously. Samples were collected in triplicate from sediments for a period of two years (two cycles of seasons) on a bimonthly interval.

Samples of the upper 6 cm of sediment were collected using a glass hand-corer with an inner diameter of 25 mm. These 6 cm core samples were sectioned into three blocks using a thin stainless steel knife. 1 cm^3 size sediment from each of the three strata was placed in a screw-capped glass bottle containing 10 ml of 90% acetone and kept at -4^0C in darkness for 24 hrs. Extracted pigments were measured spectrophotometrically before and after acidification with a Hitachi U-2001 UV-visible spectrophotometer and quantified using Lorenzen's equations for chlorophylls *a*, *b*, and *c*, and pheopigment and carotenoids (Lorenzen, 1967).

Sediment samples for species identification and abundance analyses were preserved in 3% formaldehyde solution. For microalgal species identifications, each layer of samples was diluted with a known volume of filtered estuarine water (Delgado, 1989) and sub-samples analyzed using a Nikon Eclipse E 200 light microscope. The lens-tissue separation technique (Eaton and Moss, 1966) was also employed for harvesting motile microphytobenthos from the sediment surface.

Microalgal cells were quantified using a Sedgewick-Rafter counting cell at 200X magnification and their cell dimensions recorded.

2.5.2 Sampling of Epiphytic algae:

Epiphytic samples were collected from the submerged stilt roots and pneumatophores of *Rhizophora* and *Avicennia*. The samples were scraped from the substrata with a clean knife, preserved in 5% neutralized formalin and analysed under the microscope.

2.5.3 Culture of Microalgae:

The motile microphytobenthos trapped in the lense tissue were cultured in the laboratory to have a better idea during identification. Allen and Nelson, BG 11 and Ward and Parish media were used.

2.6 Statistical Analysis

MS Excel, Kyplot 7 and SPSS 11 were used for statistical interpretation of data.

Chapter 3

MANGROVE TRACHEOPHYTES

Mangroves are native flora of saline environments and as such come within the general definition of halophytic plants. Thus it can be described as an ecological group of plants. They belong to a variety of plant families and genera and are found in aquatic environments ranging from slightly brackish to salinities well in excess found in sea water.

The confusion about the definitions of mangroves is illustrated by the trend to define exclusive and non exclusive species of mangroves. (Saenger *et al.*, 1983)

It is generally considered that mangroves are distinguished from glycophytes by their ability to accumulate ions in high concentrations, particularly in leaf cells.

Since mangrove ecosystems are very complex harboring a plethora of organisms belonging to different groups, the study of the system will be comprehensive only when these components are studied in toto, emphasizing the relation between one another and also with the physical factors.

Even though the main focus of the present work is on the microalgal vegetation, a study on the different types of mangrove higher plants and their associates in and around the ecosystem has been made as a first step. It has its significance since, the type and abundance of the microflora has a bearing on the type of the macroflora. Moreover, factors like salinity, pH, dissolved oxygen etc are also dependent to some extent on these higher plants. Any study

on mangrove ecosystems would be incomplete if mangrove macrophytes or the 'mangroves' are not made part of it.

In the present investigation the distribution and diversity of the mangrove vegetation and the varying hydrological conditions of the ecosystem were studied for 2 years from January 2003 to December 2004. In the first phase of the study, a detailed survey of mangrove flora was conducted during the year 2003.

Flowering twigs of mangroves and associated species were collected from all the six stations. Analysis of habit, vegetative characters, morphological features and adaptations were done. The species of mangroves and associated flora were identified based on their vegetative and floral morphological characteristics with reference to the published flora (Gamble, 1967; Dewit, 1967; Matthew, 1983) and by comparing with the herbarium specimen.

Indian mangroves can be classified into three types- Deltaic mangroves, Coastal mangroves and Island mangroves. The mangroves in Kerala belong to the coastal type which grow on the intertidal zones and mouths of several minor estuaries and back waters.

The mangroves of Kerala are isolated and far in between and confined to the upper reaches of estuaries, lagoons, back waters and creeks. These are scattered and confined to very small pockets.

The research into the mangrove macro flora has been extensive and is still continuing on a massive scale. Undoubtedly, these are the most important components of the ecosystem, which support the complex biodiversity of the system.

Even when the total number of publications on mangroves exceeds 10000, it still remains a source of puzzlement and controversy that how many

mangrove species exist in the world. Knowledge of the exact plant species composition in any mangrove ecosystem is a basic and important pre requisite to understand all the aspects of structure and functions of mangroves.

The answer to the question "How many mangroves are there?" varies according to the authors.

Saenger *et al*. (1983) considered that there are 83 mangrove species of which 60 coming under 21 genera are true or exclusive mangroves, and another 23 species are non exclusive or semi mangroves.

Blasco (1984) considered that the total flora of woody plants usually found in mangroves include 23 genera and 56 species belonging to 16 families.

Chapman (1984) pointed out that there are only 55 species belonging to 16 genera and 11 families which can be considered as true mangroves.

Lin (1987), listed 83 species of mangroves which belong to 30 genera.

Both Aksornkoac *et al*. (1992) and Duke (1992) thought that the mangrove species found so far include 108 species in 36 genera.

Chang (1993, 1995) mentioned that there are 58 mangrove species of which 47 are true mangroves.

Tomlinson (1999) listed 54 species belonging to 20 genera as components of mangroves, of which only 34 species from 9 genera are exclusive mangroves.

Fan (2000) considered that there are 70 mangrove species in the world.

Wang Bo Sun *et al*. (2003) suggested that the world's mangrove plants have 84 species, including 12 varieties in 24 genera and 16 families of which true mangrove plants have 70 species coming under 16 genera.

Obviously, these differences in statistics result from the different angles of understanding of the concept of mangroves.

In India also the reported number of mangrove species varies among researchers. While Blasco *et al*. (1975) counts it as 50-60, Untawale (1987), considers the number of true mangroves to be 35.

Thirty five true mangroves, 28 associates and seven back mangals were identified by Naskar *et al*. (1987)

Jagtap *et al*. (1993) consider 50 species as mangroves in India. According to Naskar (1993), in the West coast of India, Cochin estuary with 32 species , 24 genera and 19 families, despite negligible area coverage has the second highest number of species after Zuary estuary, Goa.

There have been various classifications of the mangrove macro flora. Mepham and Mepham (1984), classified them into three –

Major elements of mangroves

Minor elements of mangroves

Mangrove Associates

The major elements described by Mepham can be called as exclusive mangroves or true mangroves or eumangroves and Tomlinson (1986) defined them as follows:

1. Those having complete fidelity to the mangrove environment, i.e., they grow only in mangal core areas and do not exist in the terrestrial communities.
2. Those playing the major role in the community and which occurs as pure strands.

3. Those having morphological specializations fitted to the peculiar environmental conditions.
4. Those which are taxonomically isolated from the terrestrial relatives at the generic level.

Minor elements of mangroves are:

1. Those that do not grow as conspicuous elements of the vegetation
2. Those occupying the peripheral habitats and which very rarely form pure strands.

Mangrove associates or back mangals are:

1. Non arborescent, herbaceous, sub woody plants and climbers which are present in the tidal zones.
2. They can grow in the open Pasture or in naked lands within tidal limits.
3. They are mostly patchy and normally cannot dominate over true mangroves. (Tomlinson, 1980, Mepham and Mepham, 1984 and Naskar, 1993)

Wang *et al*. (2003) defined mangroves as woody plants growing in tropical and sub tropical intertidal habitats subjected to tidal influences and having specially adapted morphological structures and physiological mechanisms. According to them true mangroves are restricted to typical mangrove habitats where salinity is often 17-36.4 ppt and are not found in drier terrestrial areas subjected only to spring or storm higher tides.

By considering the above definition, WANG Bo Sun (2003) classified mangrove plants as typical mangroves, semi mangroves, mangrove associates and consortive plants. Consortive plants or mangrove commensals are herbaceous plants like *Acrostichum aureum*, which are srtrictly restricted to

mangrove habitats, but will not fall within the definition suggested by Wang *et al*.

In 2008, Mandal and Naskar evaluated 63 species of probable mangroves from India based on their anatomical and morphological modifications of stem, roots and reproductive organs to suit a halophytic life and classified them as major mangroves, mangrove associates and back mangals. While 30 species fall under major mangroves, 21 are mangrove associates and 12 back mangals. In the region wise list prepared by Naskar and Mandal (2008), after this evaluation the number of mangrove species in Cochin estuary has been revised to 29 after excluding 3 species – *Ardissia littoralis, Cerebera odolum* and *Aeluropus legopoides.* Thus there are 18 major mangroves, seven mangrove associates and 4 back mangals in Cochin estuary, according to Mandal & Naskar (2008).

However, after an extensive survey in the mangrove ecosystems along Cochin back waters, it appears that Mandal's list of mangroves pertains not to Cochin estuary, but to the entire Kerala coast.

Heliotropium currassavicum and *Ipomoea pes caprae* which are listed as not present in Cochin estuary, have been encountered during this study from stations 4 and 5. Limitting the back mangals to 7 in India and 3 in Cochin estuary seems inappropriate. Mandal and Naskar have included only *Dolichandrone spathaceae, Derris trifoliate* and *Caesalpinia* crista as back mangals in Cochin estuary. Nothing seems to be wrong in considering the three plants - *Cayratia triloba, Cerbera odolum, Ardissia littoralis*- which have been present at all stations during this study, closely associated with mangroves, as back mangals. Of these, *Cerbera sp*. have been cited by many authors as a semi mangroves or mangrove associates (Tomlinson, 1999., Saenger *et al*. 1983).

Also, it seems appropriate to classify *Acrostichum aureum* as a consortive mangrove as suggested by WANG Bo Sun (2003).

Considering all the above aspects the mangroves and associated plants identified and classified during this study are presented below: (Table 1)

Table 1: True mangroves encountered

Sl.No	Name	Family	1	2	3	4	5	6
1	*Rhizophora apiculata* Blume	Rhizophoraceae				+	+	
2	*Rhizophora mucoronata* Lamk.	Rhizophoraceae	++	+		+	+	+
3	*Avicennia officinalis* L.	Avicenniaceae	+	+++	+++	+++	+	+
4	*Avicennia marina* (Forsk.)Vier	Avicenniaceae			+		+	
5	*Bruguiera gymnorrhiza* (L.)Lamk	Rhizophoraceae			+	+	+++	+
6	*Bruguiera cylindrica* (L.) Blume	Rhizophoraceae				++	++	
7	*Bruguiera sexangula* (Lour.) Poir	Rhizophoraceae			+		+	
8	*Sonneratia caseolaris* (L.) Engler	Sonneratiaceae	+	+	+			
9	*Excoecaria agallocha* (L.) Sweet	Euphorbiaceae			++	+	+	+
10	*Kandelia candel* (L.) Druce	Rhizophoraceae			+			
11	*Aegiceras corniculatum*(L.) Blanco	Myrsinaceae		+				

\+ Present

++ Shows dominance

+++ Abundant presence

In the study area along the Cochin back waters, 11 true mangrove species belonging to 7 genera were enumerated through the survey (Table 1)**.** The most abundant species in the study area is *Avicennia officinalis* followed by *Rhizophora apiculata, Rhizophora mucoronata,* and *Bruguiera gymnorrhiza. Kandelia candal L.* were found in minimum.

Maximum diversity was noticed at Murikkinpadam station. Different mangrove species of Cochin area are known by different local names based on their colour and special features. Accordingly red mangrove *(Rhizophora* species), orange mangrove *(Bruguiera* species), black mangrove *(Avicennia* species) and milky mangrove *(Excoecaria* species) are recognized. *Kandelia candel* L. was observed only at Nettoor. *Bruguiera gymnorhiza* lamk was observed in Puthuvypu. However this plant was also scarcely distributed at Mangalavanam. *Avicennia officinalis* was encountered at all the stations. It was noticed that mangroves of Mangalavanam station are terribly affected by the urbanization and oil spill form the nearly located storage tanks of Indian Oil Corporation. A depletion of mangrove area of Nettoor site was noticed due to the newly constructed Eranakulam - Alapuzha railway line and Ernakulam Thiruvananthapuram bypass road.

Different plant species growing in different stations follows difference in their growth and distribution pattern. In the present study, frequency of *Avicennia officinalis* was maximum and *Kandelia candel* was minimum in the study area. Whenever *Rhizophora* species were present, they were seen along the banks of' water logged areas such as ditches and ponds. Marked variation in the density of different Mangrove species was noticed in all the stations (Table 1). Similarly, different plants dominated different stations.

Avicenia officinalis dominated the mangroves at stations 2, 3 and 4. *Bruguira gymnorrhiza* was the dominant species at station 5. *Rhizophora mucoronata* dominated station 1. There was no such domination of any of the species in station 6. While *Kandelia candel* was very much limited and restricted to station 3, *Agaeceras corniculatum* was noticed only at station 2. This is for the first time that *Aegiceras corniculatum* is reported from the mangrove areas along the Cochin back waters.

In the community structure mangrove plants resembled climax species. Occurrence of competition was limited and if at all present was intraspecific. Maximum number of mangrove plants was noticed at station 5. At Kumbalam eventhough only three species were represented they showed maximum possible natural diversity. In station 6, the water front is occupied by a gregarious formation of *Acanthus ilicifolius* in the form of a broken belt. This is followed by rows of *Avicennia officinalis* with large terrestrial trees in the background. A very few number of Rhizophora occur within the *Avicennia* zone. Even though the station is little disturbed compared to the other stations, lowest species diversity was noted in this station. Because of limited extent of mangrove areas in all the six stations, zonation was observed to be feeble and indistinct. *Ceriops tagal, Lumnitzera racimosa, Rhizophora stylosa, Sonneratia apetala* and *Xylocarpus granatum* common in the east coast are conspicuous by their absence.

The mangrove associates, back mangals and consortive mangroves encountered during the study and their distribution pattern are shown in table 2. Out of the 8 mangrove associates listed by Mandal and Naskar (2008) as present in Cochin estuary, 7 were encountered during this study.

Table 2

Sl. No	Name of True mangrove	Family	1	2	3	4	5	6
	Mangrove Associates							
1	*Sesuvium portulacastrum*	Aizoaceae				#		
2	*Hibiscus tiliaceous*	Malvaceae	#	#				
3	*Thespesia populnea*	Malvaceae						
4	*Acanthes illicifolius*	Acanthaceae	#	#	#	#	#	#
5	*Clerodendron inermae*	Verbenaceae	#		#	#	#	
6	*Heliotropium curassavicum*	Boraginaceae				#	#	
7	*Ipomoea pes-caprae*	Convolvulaceae				#	#	
	Back Mangals							
1	*Derris trifoliata*	Fabaceae	#	#	#	#	#	#
2	*Cerebera odolum*	Apocynaceae	#	#	#	#	#	#
3	*Cayratia triloba*	Vitaceae	#	#	#	#	#	#
4	*Ardissia littoralis*	Myrsinaceae	#	#	#	#	#	3
	Consortive Mangroves							
1	*Acrostichum aureum*	Pteridaceae	#	#	#	#	#	#

Mangrove vegetation in Cochin area are seen along with the back water channels and along the banks of estuarine water bodies, in the form of patches or narrow continuous belt. Data were collected by field observations, actual measurements, personnel interviews and photography. During this survey, it was observed that these unique mangrove habitats of Kerala have been facing tremendous threats due to indiscriminate exploitation. Overexploitation by the traditional users, conversion for agriculture purpose, urban and tourism development, garbage, sewage and effluent disposal have all caused serious damages to the ecosystems in the stations studied. In station 1 and 4 mangroves are almost at the verge of extinction, which require immediate attention.

Chapter 4

HYDROGRAPHY

Mangroves are complex and dynamic ecosystems which reflect even the slightest changes in their immediate environment by changing the species composition, biomass and community structures. The seasonal cycles of biological parameters are usually driven by physical factors through physico chemical processes referred to as physical- biological coupling.

There is also a close microbe-nutrient- plant relationship that functions as a mechanism to recycle and conserve nutrients in the mangrove ecosystem. The highly productive and diverse microbial community living in tropical and subtropical mangrove ecosystems continuously transforms nutrients from extracellular products of microalgae, faecal matter of micro and macrofauna and dead mangrove vegetation into sources of nitrogen, phosphorus, and other nutrients that can be used by the plants. Besides, the luxuriant growth of cyanobacteria increase the nitrogen budget of the ecosystem.

The mangrove community is not uniform structurally or floristically because of the number of environmental factors that influence on individual mangrove species differently. As the hydrological changes have an immense effect on the on emergent vegetation, soils and co-dependent flora and fauna, these are extremely important in analyzing the status of an ecosystem.

Temperature, sunlight, salinity, pH, nitrate, nitrite, phosphate, silicate, dissolved oxygen and primary productivity are the major physico chemical variables that individually or collectively influence the life cycle and ecological balance of the ecosystem.

The present work is an attempt to study the dynamics of physico chemical variables of the selected stations and their relation with the species diversity of the ecosystem.

The variables were studied for a period of two years from premonsoon of 2003 to monsoon of 2004.

4.1 Temperature:

Spatial and seasonal variations of both sediment temperature and that of overlying water were recorded. (Fig. 1- 4)

In 2003, the sediment temperature at station 1 touched the 29.5^0C mark during the pre monsoon and it was the highest temperature noted in the station during the year. The lowest mud temperature noted was 23^0C during the monsoon. As regards the temperature of the overlying water, the highest of 32^0 C was noted during premonsoon and lowest of 25^0C during the monsoon. In 2004, the highest and lowest mud temperatures were 30.5^0C (pre monsoon) and 27^0C (monsoon) respectively. The highest water temperature noted was 31^0C during premonsoon and the lowest was 27.5^0C during both monsoon and premonsoon.

At station 2, the sediment temperature touched the 29^0C mark during the pre monsoon in 2003 and it was the highest in the station during the year. The lowest sediment temperature noted was 26^0C during the post monsoon. As

regards the temperature of the overlying water, the highest of 30^0 C was noted during pre monsoon and lowest of 26.5^0C during the monsoon. In 2004, the highest and the lowest mud temperatures were 30.5^0C (pre monsoon) and 28^0C (monsoon). Both highest and lowest water temperature during the premonsoon varied from 31^0C to 27.5^0C.

At station 3, the sediment temperature touched the 29^0C mark during the pre monsoon and post monsoon in 2003 and it was the highest temperature noted in the station during the year. The lowest sediment temperature was 24^0C, recorded during the monsoon. As regards the temperature of the overlying water, the highest of 31^0 C was noted during premonsoon and lowest of 26^0C during the monsoon.

In 2004, the mud temperature varied from 24^0C in monsoon to 29^0C in pre monsoon. 30^0C (premonsoon) 26^0C (monsoon) were the maximum and minimum water temperatures.

At station 4, in 2003, the sediment temperature was 28^0C during the pre monsoon and it was the highest temperature noted in the station during the year. The lowest mud temperature was 24^0C, noted during the post monsoon. As regards the temperature of the overlying water, the highest of 28^0 C was noted during premonsoon and monsoon and lowest of 24^0 C during the post monsoon.

In 2004, the highest and lowest sediment temperatures were 27.5^0 C (post monsoon) and 24.2^0 C (monsoon) respectively. 28^0 C (pre and post monsoon) and 25^0 C (monsoon) were the maximum and minimum water temperatures.

At station 5, in 2003, the mud temperature registered the highest of 30.1^0C during the monsoon and the lowest mud temperature of 26^0C was noted

during the post monsoon. As regards the temperature of the overlying water, the highest of 30^0 C was during premonsoon and lowest of 25^0C during the pre and post monsoon. In 2004, both the highest and lowest mud temperatures were 32^0C (monsoon) and 26^0C (monsoon). 33^0C (monsoon) 27^0C in the same season were the maximum and minimum water temperatures.

Even though the highest temperature in the station during the study period was noted in the monsoon, it does not reflect the average monsoon temperature of the station. An unusually high temperature was noted on a non rainy day in the monsoon season.

At station 6, in 2003, the maximum sediment temperature recorded was 29^0C during the pre and post monsoon. The lowest mud temperature was 25^0C, noted during the monsoon. As regards the temperature of the overlying water, the highest of 28^0 C was noted during pre and post monsoon and the lowest of 25.5^0C during monsoon.

In 2004, the sediment temperature varied from and 26^0C in post monsoon to 29.5^0C in pre monsoon. The water temperature varied from 26^0C during monsoon to 30.5^0C during pre monsoon.

A three way ANOVA was performed for temperature against season, year and station. Both the sediment temperature and water temperature showed significant variation with the season, the p values being 0.005 and 0.019.

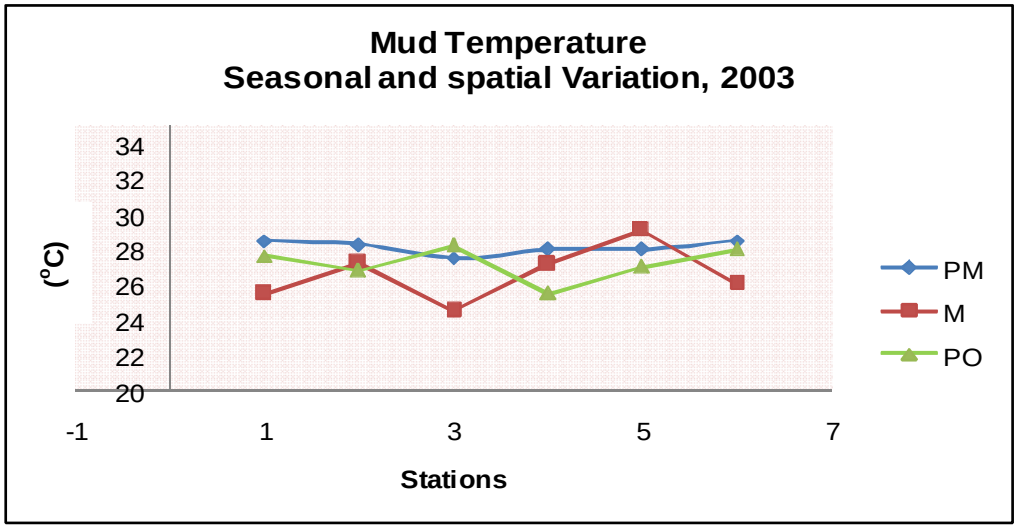

Mud Temperature
Seasonal and spatial Variation, 2003
34
32
30
28
26
24
22
20
(°C)
-1
1
3
5
7
Stations
PM
M
PO

Fig.1

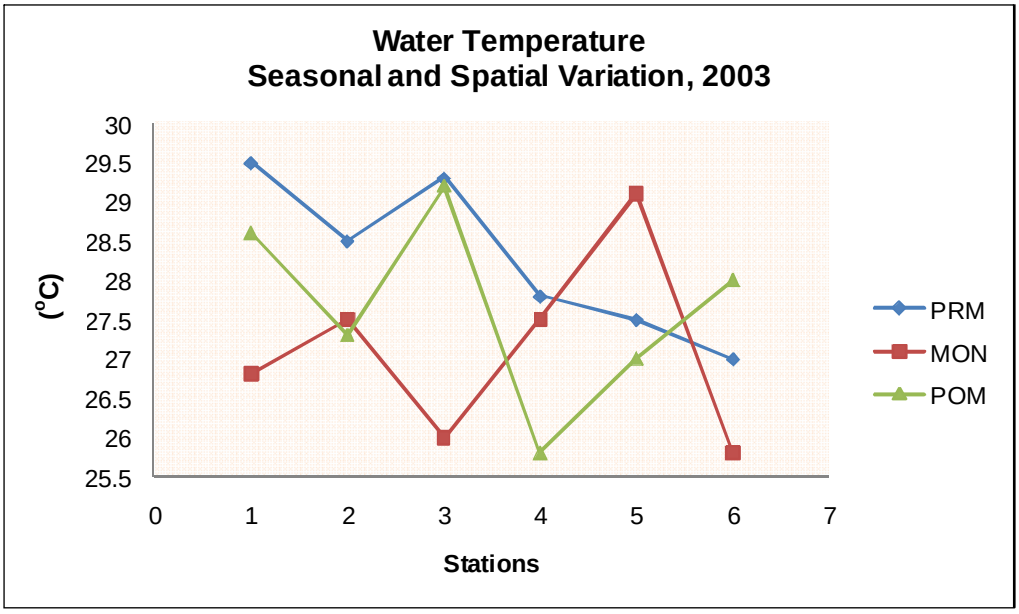

Water Temperature
Seasonal and Spatial Variation, 2003
30
29.5
29
28.5
28
27.5
27
26.5
26
25.5
(°C)
0
1
2
3
4
5
6
7
Stations
PRM
MON
POM

Fig.2

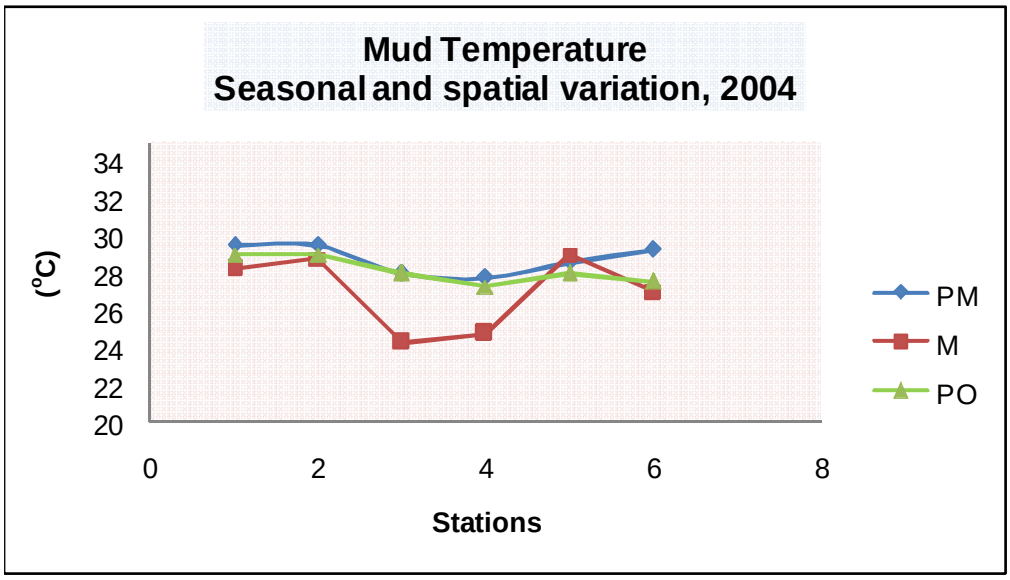

Mud Temperature
Seasonal and spatial variation, 2004
34
32
30
28
26
24
22
20
(°C)
0
2
4
6
8
Stations
PM
M
PO

Fig. 3

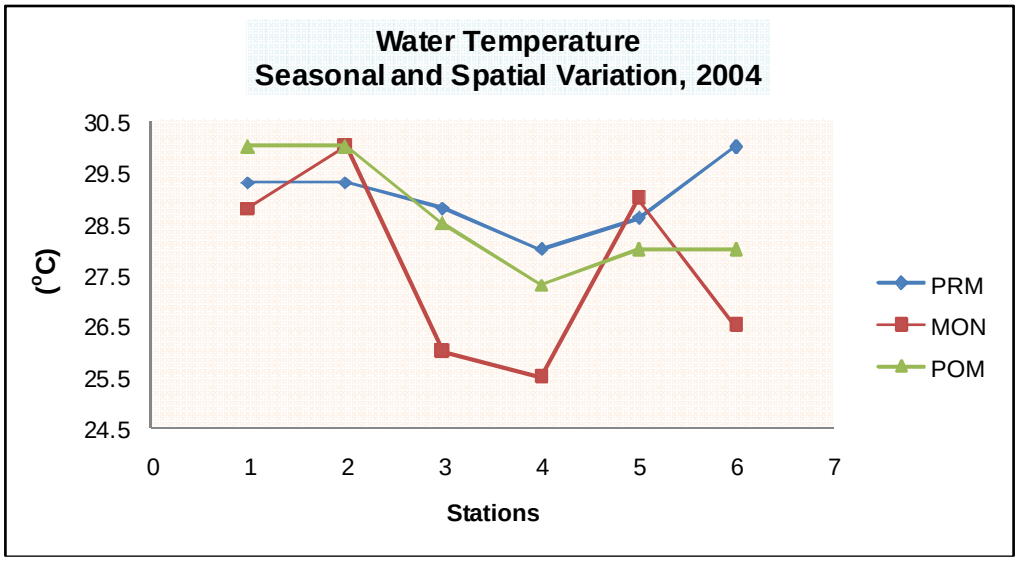

Water Temperature
Seasonal and Spatial Variation, 2004
30.5
29.5
28.5
27.5
26.5
25.5
24.5
(°C)
0
1
2
3
4
5
6
7
Stations
PRM
MON
POM

Fig. 4

4.2 Salinity:

The salinity showed remarkable variation, both seasonal and spatial, during the period of study.

In 2003, the highest value of salinity was recorded in Station 5 during post monsoon and it was 22 ppt. The lowest salinity value of 3 ppt in the year 2003 was recorded in stations, 1 and 4. Lowest values in all stations were recorded during monsoon. (Fig. 5)

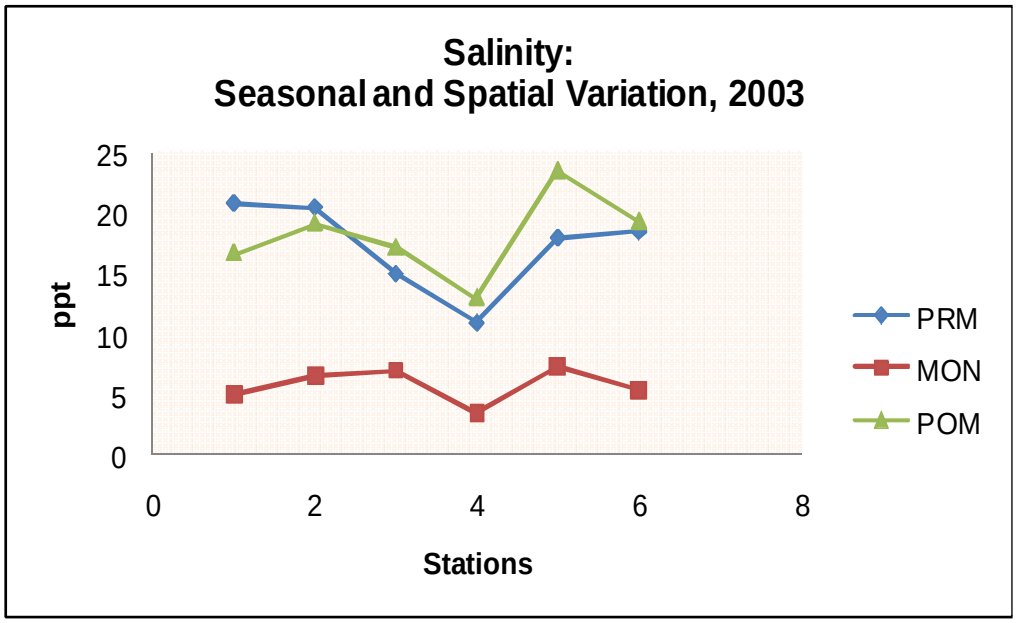


Fig.5

In 2004, the highest value of salinity, 22 ppt, was recorded in Stations 1, 2 and 5. While it was during pre monsoon in stations 1 and 2, station 5 showed the reading during post monsoon. The lowest salinity value in this year also was 3 ppt and it was recorded during the monsoon in three stations- 2, 4 and 5. (Fig. 6)

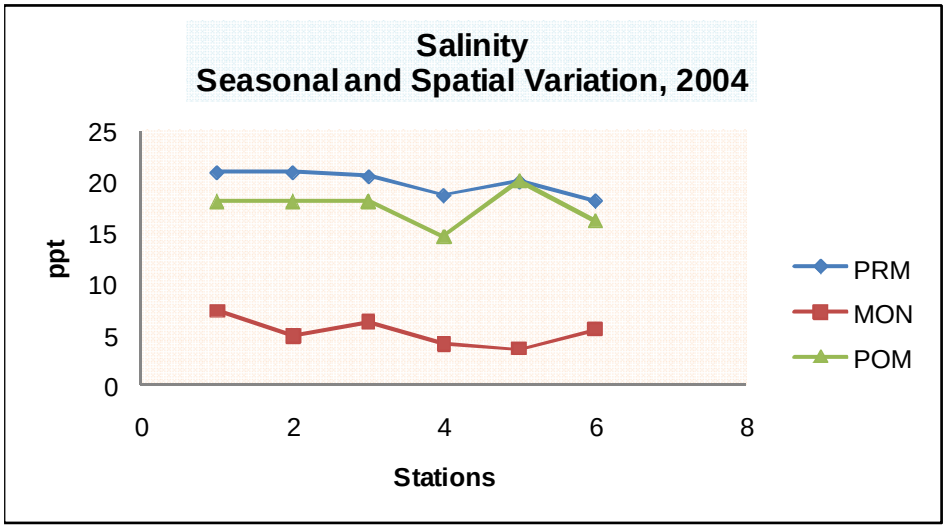


Fig.6

The three way ANOVA for salinity showed significance only with season, the p value being 0.00. It was neither significant for station nor for year.

4.3 pH:

The pH did not show much variation during the period of study. The seasonal and spatial variations in pH were of less magnitude.

In 2003, the lowest pH value of 6.11 was recorded in Station 2 during monsoon and highest of 8.4 was recorded in Station 6 during post monsoon. In all stations except 4 and 6, the lowest pH values were recorded during monsoon. In stations 4 and 6, the lowest values were recorded during pre monsoon. A comparatively high pH value of 8 was recorded in Station 4. (Fig. 7)

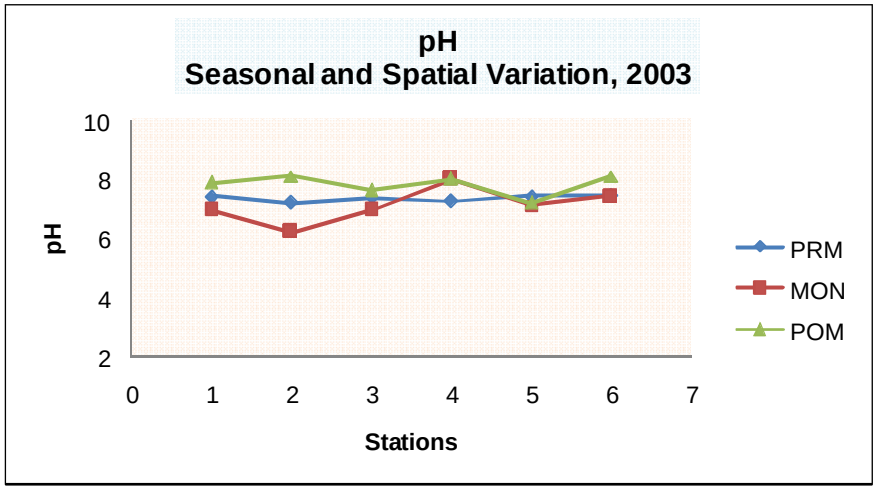


Fig. 7

In 2004, the lowest pH value of 6.1 was recorded at stations 1& 2. Both were during the monsoon period. The highest value of pH was recorded at station 4 during post monsoon.

In both the years, the highest pH values in all stations except one in each were recorded during post monsoon. In 2003, it was recorded during pre monsoon at station 5 and in 2004, it was during the same season at station 3. (Fig.8)

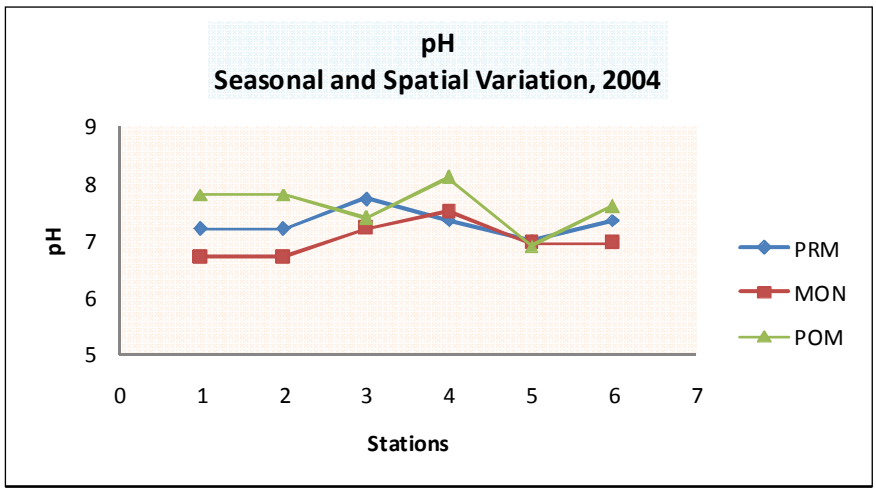


Fig. 8

The three way ANOVA for pH showed significance only with season. The p value was 0.038. (Table 3)

4.4 Nutrients:

There have been a number of studies on the nutrient concentration of mangrove ecosystems and according to Alongi (1996), nutrient fluxes in these environments are closely dependent upon plant assimilation and microbial mineralization. Two major elements (N and P) are of great significance for the growth of mangroves. Another important nutrient which plays a significant role in the ecosystem is silicate. The relevance of estimating the nutrient concentration as part of this study is that they are one of the most important parameters that influence the mangrove environment and its phytoplankton distribution.

4.4.1 Phosphates:

The concentration of phosphates ranged from 0.547 $\mu molL^{-1}$ to 35.39 $\mu molL^{-1}$ during the study period.

In 2003, the minimum value of 0.547 $\mu molL^{-1}$ was recorded during monsoon at station 2 and the maximum of 34.3 $\mu molL^{-1}$ was recorded at station 1 during the same season, indicating that the variations were spatial rather than seasonal. Except in station 1, the lowest values in all stations were recorded either during monsoon or during post monsoon. Similarly, in all stations, the highest phosphate concentration was noted either during monsoon or during pre monsoon. (Fig.9)

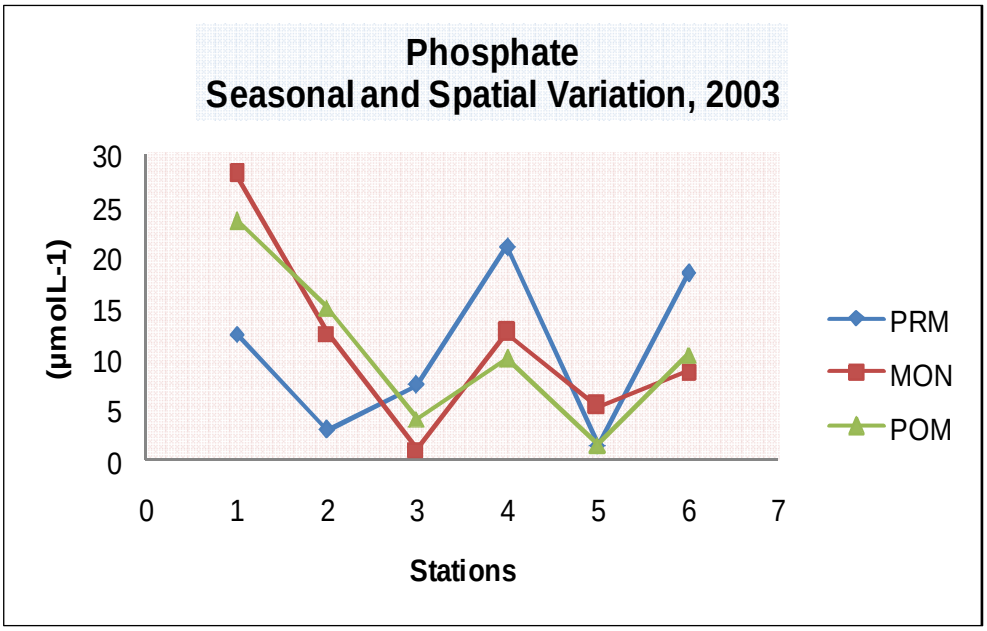


Fig.9

In 2004, the minimum value of phosphate concentration noticed was 0.711 µmolL^{-1} at station 2 during post monsoon. The highest value was recorded at station 5 during monsoon. It was 35.398 µmolL^{-1}. Like in the other year, the lowest values of all stations except station 1 were recorded either during post monsoon or during monsoon. The trend with the highest values was also the same in both the years. (fig.10)

The three way ANOVA for phosphates showed significance only with station, the p value was 0.002. (Table 3)

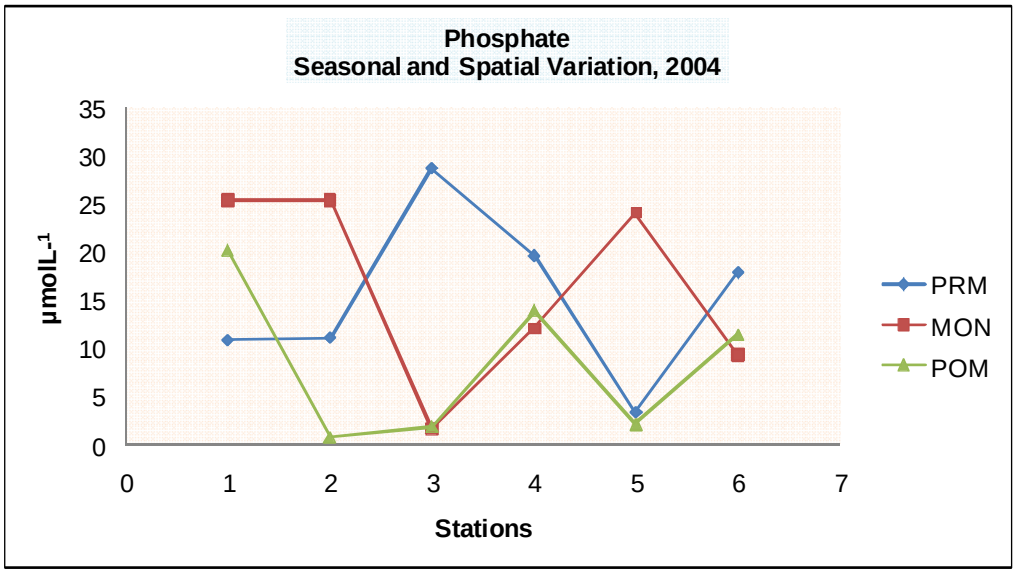


Fig. 10

4.4.2 Silicates:

When compared to the other nutrients, the concentration of silicates was higher in all stations and during all seasons. The values ranged from 3.5 µmolL^{-1} to 122.6 µmolL^{-1}.

In 2003, the minimum concentration of 3.5 µmolL^{-1} was recorded at station 1 during post monsoon and the maximum of 122.6 µmolL^{-1} was recorded at station 4 during monsoon. In station 4, the concentration was comparatively higher irrespective of the season, the minimum being, 60.87 µmolL^{-1}. The highest values at stations except at station 5 were obtained during monsoon. (Fig.11).

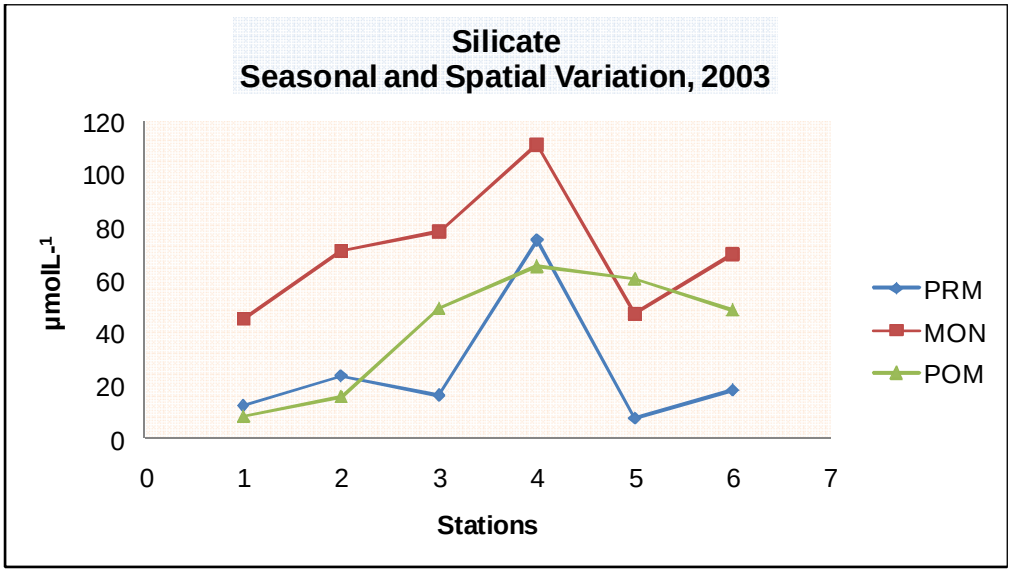


Fig.11

In 2004, the minimum value of 5 µmolL^{-1} was recorded at station 1 during the pre monsoon. The highest value of 80.3 µmolL^{-1} was recorded at station 4 during monsoon. Station 4 remained to be rich in silicates during 2004 also, with a minimum of 62.51 µmolL^{-1} recorded during post monsoon. The highest values at stations except at station 2 and 5 were obtained during monsoon.

In most of the stations, there was a considerable increase in the concentration of silicates during monsoon. (fig. 12)

The three way ANOVA showed significance with station and season. (Table 3)

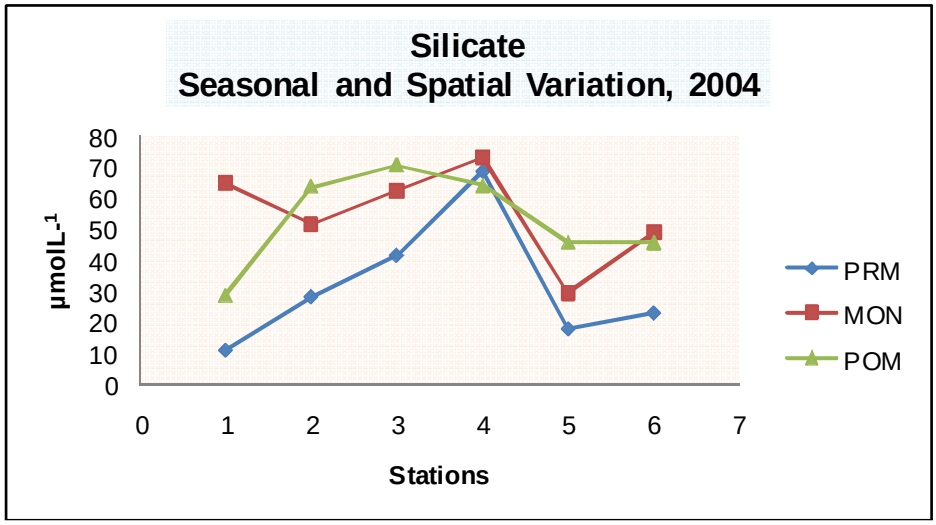


Fig. 12

4.4.3 Nitrates:

Except in Stations 3 and 4, all stations recorded a comparatively low concentration of nitrates in 2003. The lowest value of 0.1545 µmolL^{-1} was recorded at station 1 during post monsoon. The highest value of the year was 40.90 µmolL^{-1} recorded at station 4 during monsoon. (Fig. 13)

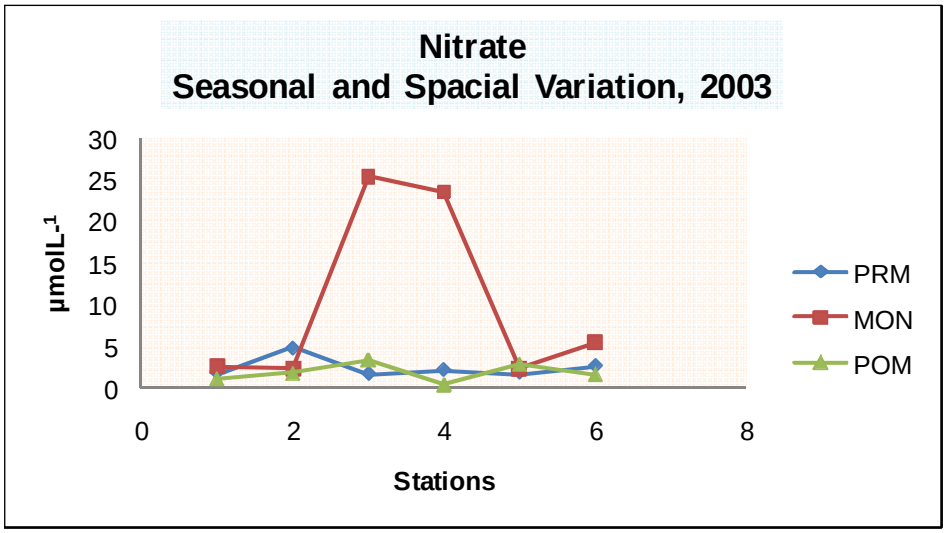


Fig. 13

In 2004, stations 3, 4 and 5 showed a comparatively higher concentration of nitrates. At station 4, it varied from 0.3061 µmolL^{-1} (post monsoon) to 21.5µmolL^{-1} (monsoon). In both the years, the lowest values from all stations except one (station 5) were obtained during post monsoon. This also indicates a seasonal impact on nitrate concentration of the ecosystem. (Fig. 14)

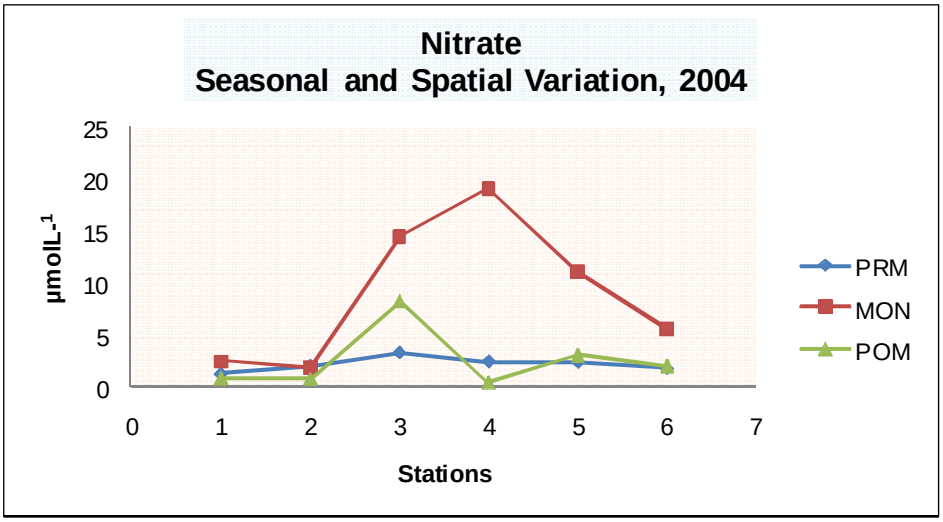


Fig. 14

4.4.5 Nitrites:

The concentration of nitrites was very low when compared to the other nutrients and in some stations, it was negligible. However the seasonal change in the concentration is visible from the values.

In 2003, the minimum value was obtained from station 1 during post monsoon and it was 0.034 µmolL^{-1}. The highest value was 5.3 µmolL^{-1} recorded at station 6 during post monsoon. Pre monsoon and monsoon seasons generally recorded lower values of nitrites. (Fig. 15)

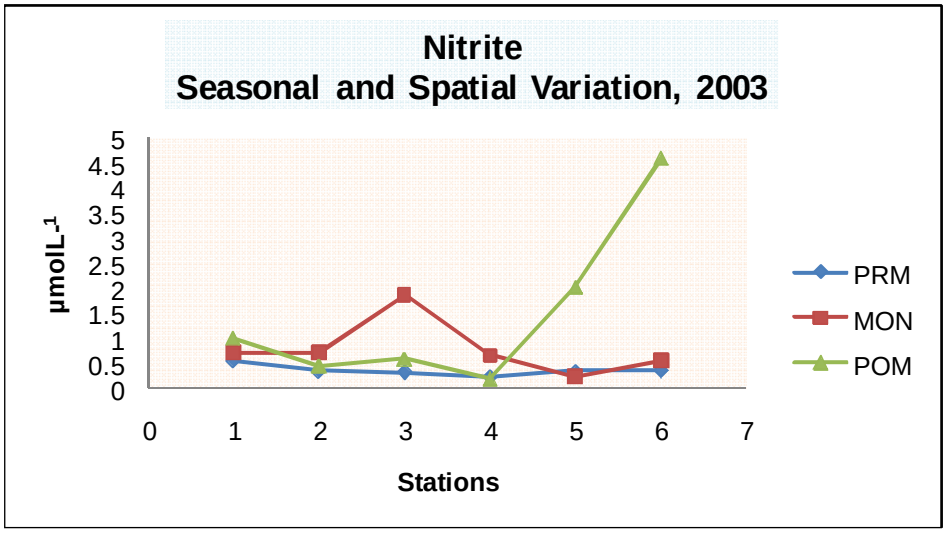


Fig. 15

In the following year, the lowest value of 0.125 µmolL^{-1} was recorded from station 2 during pre monsoon. In this year an unusually higher value of nitrite concentration was recorded during post monsoon at station 3. Even though, there were some higher values during monsoon, the concentration of nitrites was low during monsoon and pre monsoon. (Fig. 16)

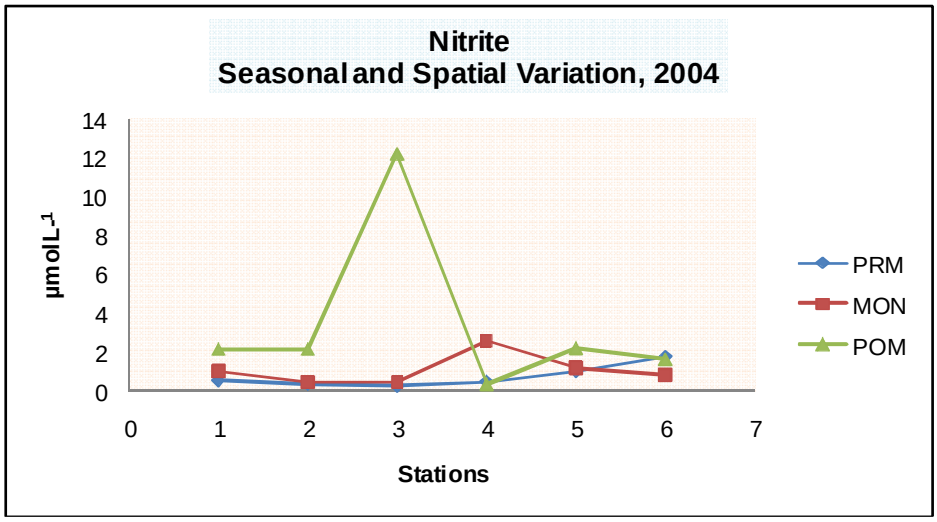


Fig. 16

While the three way ANOVA for nitrates showed significance with season and station (p values 0.013 & .000), that for nitrites showed significance only with season (p value was 0.048)

4.4Dissolved Oxygen:

The amount of dissolved oxygen present in an ecosystem is an index of its health. The amount of dissolved oxygen present in the overlying waters of all the selected stations were determined using light and dark bottle method.

During the first year, the highest dissolved oxygen value of pre monsoon season was recorded at station 3 which was 9.18 mgL^{-1}. The lowest pre monsoon value was 1.22 mgL^{-1} recorded at station 1. During monsoon, the highest value of 5.31 mgL^{-1} was obtained from station 2. The lowest monsoon value of dissolved oxygen, 1.47 mgL^{-1}, was recorded at station 6. During post monsoon, the highest value of dissolved oxygen was recorded from station 3 which was 11.42 mgL^{-1}. The lowest value was 1.57 mgL^{-1} recorded at station 6. Values show that the concentration of dissolved oxygen is comparatively high in station 3 irrespective of the season. (Fig. 17)

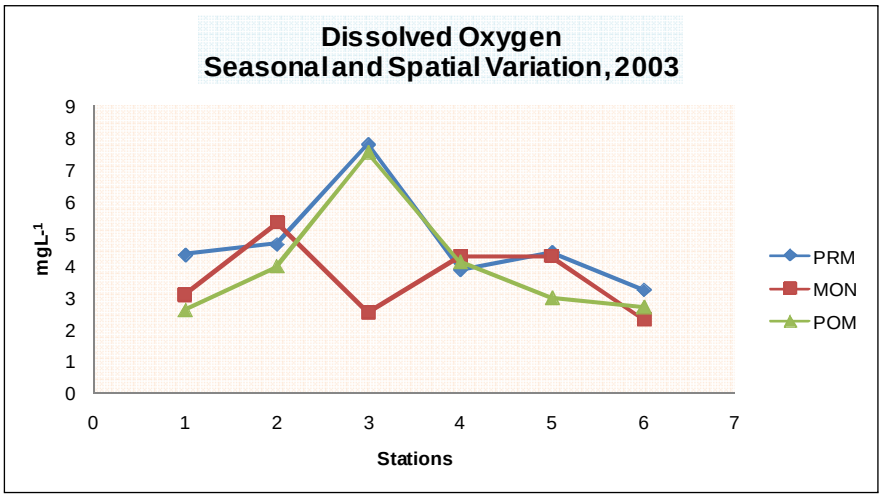


Fig. 17

During the second year, premonsoon values showed spatial variations and the highest of 8.67 mgL^{-1} were recorded at station 3. The lowest pre monsoon value was 2.01 mgL^{-1} recorded at station 6. During monsoon, the highest value of 8.57 mgL^{-1} was recorded at station 3 and the lowest of 2.1 mgL^{-1} at station 6. The same two stations recorded the highest and lowest values of dissolved oxygen during post monsoon also, the values being 12.81 mgL^{-1} and 1.68 mgL^{-1}. It is observed that station 3 showed higher values and station 6 recorded lower values irrespective of the season. (Fig. 18) The three way ANOVA showed significance with station only and the p value was 0.005.

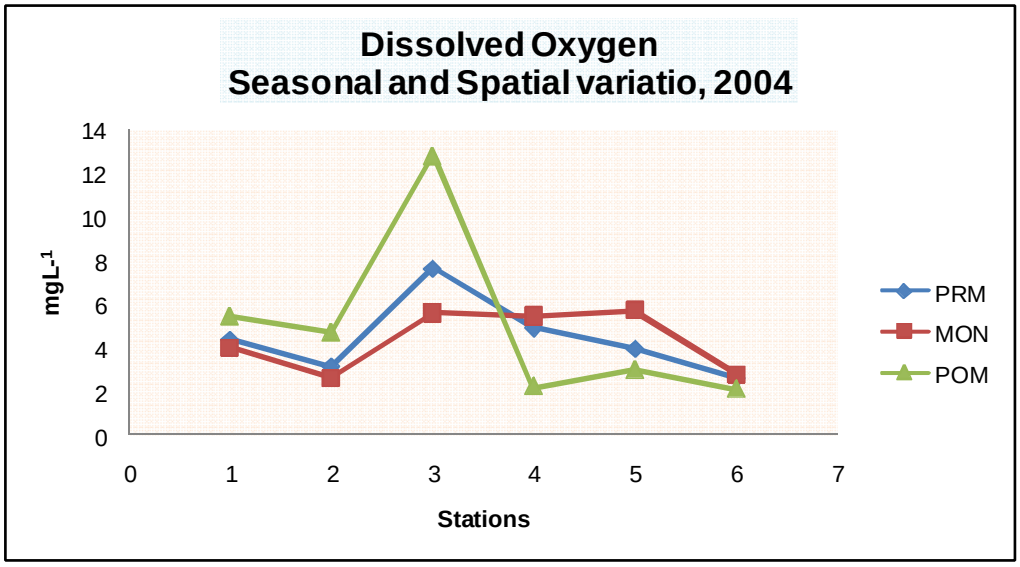


Fig. 18

4.5 Primary Productivity:

In an aquatic ecosystem, Primary production is defined as the rate of synthesis of organic matter by the phytoplankton through the uptake of carbon and utilization of solar radiation as a source of energy (Odum 1971, UNESCO 1973, Barnes and Mann 1980 and Parsons *et al*. 1984). To understand the

ecology of an ecosystem, information on the phytoplankton biomass as food and rate of primary production is required.

Even though there have been many studies on the total productivity of the mangrove ecosystems, since it is neither a pure terrestrial nor pure aquatic system, the assessment is not that easy. Even though all would agree that mangroves are one of the most productive marine ecosystems, the contribution of planktonic and benthic algae to the total production of the ecosystem is a controversy and in this study an attempt has been made to assess the primary productivity of the ecosystem benthic and planktonic algae of the ecosystem.

The seasonal and spatial variation of primary productivity was measured during the two years of study.

During the pre monsoon, in 2003, the lowest NPP of 0.61 gC/m^3/day was recorded at station 5 and the highest value of 7.65 gC/m^3/day was noted at station 3. During monsoon, the highest productivity of 1.62 gC/m^3/day was noticed at station 3 and the lowest of 0.28 gC/m^3/day was noticed at station 5. In post monsoon, the highest productivity of 2.35 gC/m^3/day was noted in station 3 and the lowest of 0.09 gC/m^3/day in station 5.

In all the seasons, the contribution of planktonic algae to the total primary productivity showed the highest value in station 3 and the lowest in station 5. (fig. 19)

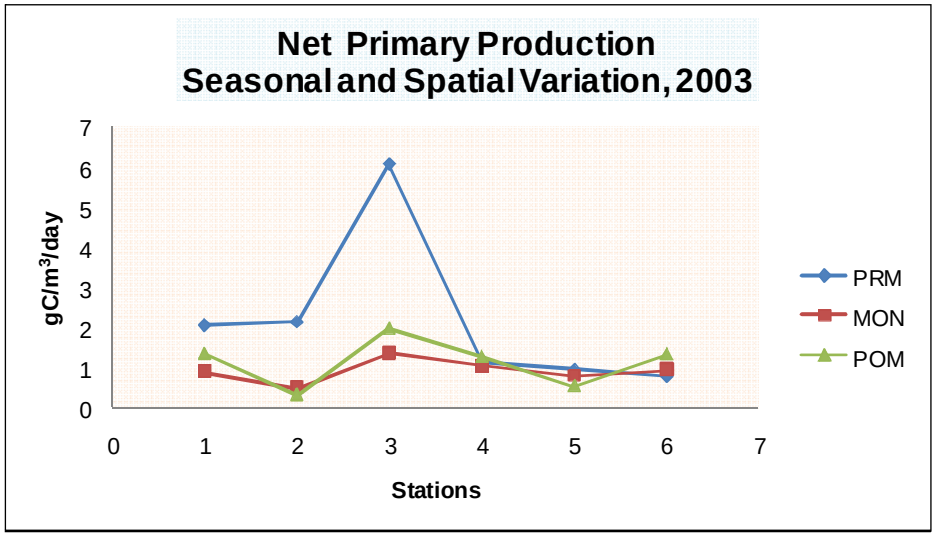


Fig. 19

During the pre monsoon in 2004, the highest productivity of 5.4 gC/m^3/day was noted at station 3 and the lowest of 0.3061 gC/m^3/day at station 2. During monsoon, the highest productivity of 8.99 gC/m^3/day was noticed at station 5 and the lowest of 0.2355 gC/m^3/day at station 2.Station 3 showed the highest NPP of 5.27 gC/m^3/day during post monsoon and lowest of 0.1177 gC/m^3/day was noticed at station 2. (Fig. 20)

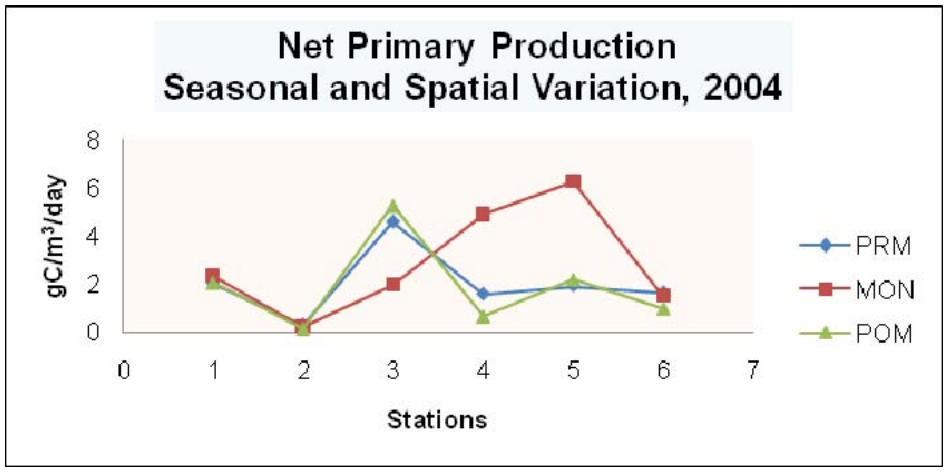


Fig. 20

4.6 Statistical analysis:

The three way ANOVA was done for all the hydrographic parameters with season, year and station. (Table 3).

Table 3:

Sediment Temperature					
Source of Variation	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Station	27.288	5	5.458	2.328 ^{NS}	0.053
Year	4.550	1	4.550	1.941 ^{NS}	0.168
Season	27.452	2	13.726	5.856 ^{S}	0.005
Error	147.668	63	2.344		
Total	206.959	71			
Water Temperature					
Source of Variation	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Station	27.351	5	5.470	1.894 ^{NS}	0.108
Year	9.173	1	9.173	3.176 ^{NS}	0.080
Season	24.401	2	12.201	4.223 ^{S}	0.019
Error	181.991	63	2.889		
Total	242.917	71			
Salinity					
Source of Variation	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Station	168.053	5	33.611	1.692 ^{NS}	0.150
Year	16.056	1	16.056	0.808 ^{NS}	0.372
Season	1718.170	2	859.085	43.249 ^{S}	0.000
Error	1251.421	63	19.864		
Total	3153.700	71			
pH					
Source of Variation	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Station	1.626	5	0.325	0.877 ^{NS}	0.502
Year	0.882	1	0.882	2.378 ^{NS}	0.128
Season	2.567	2	1.284	3.460 ^{S}	0.038
Error	23.370	63	0.371		
Total	28.445	71			

Phosphate					
Source of Variation	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Station	1512.162	5	302.432	4.276 S	0.002
Year	78.671	1	78.671	1.112 NS	0.296
Season	85.176	2	42.588	0.602 NS	0.551
Error	4455.580	63	70.723		
Total	6131.589	71			
Silicate					
Source of Variation	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Station	18315.532	5	3663.106	10.501 S	0.000
Year	83.616	1	83.616	0.240 NS	0.626
Season	10296.471	2	5148.235	14.758 S	0.000
Error	21976.518	63	348.834		
Total	50672.136	71			
Nitrate					
Source of Variation	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Station	567.806	5	113.561	3.145 S	0.013
Year	4.624	1	4.624	0.128 NS	0.722
Season	684.977	2	342.489	9.485 S	0.000
Error	2274.778	63	36.108		
Total	3532.185	71			
Nitrite					
Source of Variation	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Station	12.279	5	2.456	0.923 NS	0.472
Year	4.746	1	4.746	1.783 NS	0.187
Season	16.951	2	8.476	3.185 S	0.048
Error	167.647	63	2.661		
Total	201.623	71			
Dissolved oxygen					
Source of Variation	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Station	95.019	5	19.004	3.791 S	0.005
Year	3.233	1	3.233	0.645 NS	0.425
Season	10.638	2	5.319	1.061 NS	0.352
Error	315.803	63	5.013		
Total	424.693	71			

NPP					
Source of Variation	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Station	47.991	5	9.598	3.918 S	0.004
Year	11.830	1	11.830	4.830 S	0.032
Season	11.704	2	5.852	2.389 NS	0.100
Error	154.320	63	2.450		
Total	225.845	71			

S ➔ Significant

NS ➔ Not Significant

4.7 Discussion:

Physico chemical parameters such as temperature, pH, salinity dissolved oxygen and nutrients showed distinct seasonal variations during the period of this study. In all the six stations, rainfall received during the monsoon season influenced the physico chemical characters of the study area. While monthly rainfall ranged between 13.5 $\pm$ 6.45 mm (pre monsoon) to 43.75$\pm$ 21.82 mm (monsoon) in 2003, the highest and lowest mean values of monthly rainfall during 2004 were, 20.75 $\pm$ 29.48 (post monsoon) and 36.25 $\pm$ 15.45 mm. (monsoon). Standard deviation values suggest an almost uniform pattern of rainfall during the monsoon months.

The variations in the phytoplanktonic abundance and distribution observed during the present study can be attributed to the variations in the physico chemical parameters. Rainfall is the key phenomenon that influenced the distinct pattern of variation in the hydrographic parameters in all the stations. In India, the rainfall is influenced either by the south west monsoon or by the north east monsoon. In Kerala, it is the south west monsoon that greatly influences the rainfall and the stations received heavy fresh water inflow from the land drainage, which in turn caused abrupt changes in the physico

chemical parameters and in the biotic community. The variations were not so conspicuous during dry months.

The surface water and mud temperatures varied from 33^0C to 24^0C and 32^0C to 23^0C respectively. On an average, it was the monsoon temperature that was lower when compared to the pre and post monsoon temperatures. Even though, the pre and post monsoon temperatures were almost identical; the pre monsoon temperature had a slight edge. The maximum water and mud temperatures recorded during summer could be due to high atmospheric temperature, high intensity of solar radiation falling on the surface water and its high penetration into the water and mud columns.

The recorded low average temperature during monsoon could be due to strong breeze and cloudy sky and humidity (Karuppasamy and Perumal, 2000; Govindasami *et al*., 2000)

The observed spatial variation in temperature could be due to the variable intensity of currents and the consequent mixing of water (Reddi *et al*., 1993)

Salinity showed wide variations in the ranges of 3ppt to 25 ppt. It is the main chemical parameter that can be attributed to the plankton diversity which acts as a limiting factor which influences the distribution of planktonic community (Kouwenberg, 1994; Ramaiah and Nair, 1997; Chandramohan and Sreenivas, 1998; Balasubramanian and Kannan, 2005; Sridhar *et al*., 2006). Generally changes in the salinity in brackish water habitats like mangroves are due to the influx of fresh water from land run off caused by monsoon or by tidal variations. The high summer values of salinity recorded during the present study could be due to the high degree of evaporation and also due to neritic water dominance from sea (Subramanian and Mahadevan, 1999; Senthil Kumar *et al*., 2002). The moderate reduction in the level of salinity during monsoon

might be due to heavy rain fall and resultant fresh water inflow from the land. Thus it could be concluded that the variations in salinity recorded in the present study (Fig.) were influenced by rainfall and entry of fresh water as reported earlier by Vijayalekshmi *et al*. (1993) in the Gulf of Kachchh; Saisastry and Chandramohan (1990) in the Godavari estuary, and Mitra *et al*. (1990) in the Bay of Bengal.

In 2003, the highest average value of dissolved oxygen was recorded during pre monsoon followed by post monsoon and monsoon. Regarding the pattern of variation of DO, there are different views and different observations. Raj Kumar *et al*. (2009) while studying the phytoplankton diversity in Pichavaram mangrove waters observed higher DO values during monsoon and suggested an inverse trend of DO against temperature and salinity. Higher monsoon values of dissolved oxygen were reported by Nedumaran and Prabu (2009) and Nedumaran and Perumal (2009) at Pichavaram mangroves. The results obtained for Nair and Ganapathy (1983) and Jagadeesan (1987) were also in the same line.

However, a result almost similar to the present study was obtained at Cochin backwaters (G.S.D Selvaraj *et al*.,2003), with a dissolved oxygen concentration of PRE>POM>MON. The same author also suggests dissolved oxygen of low ranges from 2 to 4 ml/L in mangrove ecosystems, which may increase towards upstream and seaside. The result obtained for Cochin mangroves in the present study is almost in line with the above study (Fig 17).

Even though, the amount of dissolved oxygen generally increases during monsoon, this could not be generalized for mangrove systems. Here, the amount of flow and agitation of water are restricted by the presence of interlocking stilt roots and pneumatophores of mangrove plants. Moreover, the

detritus based food chain reduces the oxygen content of the system as a whole. These could be the factors for the low concentration of DO during monsoon at almost all stations during the year. (Fig)

In 2004 also, the average monsoon values of DO were less when compared to the other two seasons, however the magnitude of variation was less (Fig.18). This is indicative of the spatial nature of variation rather than seasonal. High pre and post monsoon DO at station 3 during both the years is also indicative of spatial nature of variation of dissolved oxygen. The mean annual value of DO obtained for different stations ranged between 2.733 $\pm$ 1.678 mgL^{-1} to 5.93 $\pm$ 2.838 mgL^{-1} in 2003 and between 2.51 $\pm$ 1.526 to 8.683 $\pm$ 3.246 mgL^{-1} in 2004. Variation in dissolved oxygen obtained for Prabhu *et al*. (2008) for Pichavaram mangroves ranged between 2.4 to 5.0 ml l^{-1}. This is indicative of almost similar DO content irrespective of the spatial difference.

The higher DO observed during monsoon at stations 2 and 4 in 2003 and at stations 4, 5 and 6 in 2004 could be explained on the basis of high wind velocity coupled with heavy rain fall and resultant fresh water mixing. Das *et al*. (1997) and Saravanakumar *et al*. (2007) mainly attributed seasonal variation of DO to fresh water influx and ferruginous impact of sediments. High dissolved oxygen concentration at station 3 irrespective of the season could be due to the abundance of photosynthesizing microflora.

Hydrogen ion concentration remained alkaline throughout the study period i.e., the average pH in all stations was above 7 and this could be due to the fact that there is heavy uptake of CO_2 by both phytoplankton and macrophytes. Similar observations were made earlier by Santha Joseph, (1975) and Nedumaran and Perumal (2009). However, a comparatively low pH was recorded at all stations during monsoon and it could be attributed to the influence of fresh water, reduction of salinity and decomposition of organic

matter (Nedumaran and Perumal, 2009). Upadhyay, (1988), Rajasekhar, (2003) and Paramasivam and Kannan, (2005) also attributed the above factors as reasons for variation in pH. According to Routray *et al*. (1996), during the rainy season, soil without plants was more acidic than soils colonized by mangrove trees.

High summer pH values observed during the study could be due to the influence of sea water inundation and high density of phytoplankton present, as explained by Das *et al*., (1997) and Subramanian and Mahadevan, (1999).

The concentration of nutrients varied independently during the period of study. Their distribution is mainly based on season and fresh water flow from land. Inorganic nutrient concentration was comparatively high during monsoon. This could be due to heavy rainfall, land drainage, input of fertilizer from adjoining areas. The reduction nutrients during other seasons could be due to their utilization by the autotrophic components in the ecosystem. (Krishnamurthy, 1961). Two concentration peaks observed for phosphates during monsoon, one during each year, might possibly be due to intrution of upwelling sea water. Nair *et al*. (1984) made a similar observation while studying the phytoplankton productivity at the Alappuzha mud bank. Regeneration and release of total phosphorus from bottom mud into the water column during rains may also be reason for higher phosphate value during monsoon (Chandran and Ramamoorthy, 1984). The low phosphate values obtained in the study during post monsoon could be due to decreased run off and due to utilization by phytoplankton (Ramakrishnan *et al*., 1999). As stated by Das *et al*. (1997) and Senthil Kumar *et al*. (2002)fertilizers added to the agricultural field and alkyl phosphates used in households as detergents can also be source of increased amount of inorganic phosphate. This seems to be

applicable in the case of Puthuvypu, where the mangroves are seen very near to the agricultural farm.

While four of the selected stations recorded highest values of nitrates during monsoon in 2003, five stations exhibited the same in 2004. It could be due to fresh water inflow, leaf litter decomposition and terrestrial run-off during the monsoon season (Karuppasamy and Perumal, 2000). Anthropogenic input of organic matter brought from catchment area as explained by Mishra *et al*. (1993) could also be the reason for high monsoon concentration of nitrates. Another possible reason for high nitrate values is by the oxidation of ammonia into nitrate by nitrifying bacteria (Rajasegar, 2003). The low values recorded during non-monsoon periods may be due to the utilization by phytoplankton as evidenced by high photosynthetic activity and also due to the neritic water dominance, which contained negligible amount of nitrate (Rajashree Gouda and Panigrahy, 1995; Das *et al*., 1997; Govindasamy *et al*., 2000).

Even though, there were some higher values during monsoon, the general trend was lower values of nitrites during monsoon and pre monsoon. This is in contrast to the results obtained by Ashok Prabu (1997), Nedumaran and Prabu (2009), and Rajkumar *et al*. (2009) for the Pichavaram mangroves, South East coast of India. They explained high nitrite values of monsoon season using increased phytoplankton excretion, oxidation of ammonia and reduction of nitrate and by recycling of nitrogen and bacterial decomposition of planktonic detritus present in the environment (Swami *et al*., 1996; Govindasamy *et al*., 2000).

The denitrification and air-sea interaction exchange of chemicals were also stated responsible for this increased values as explained by Mathew and Pillai, (1990) and Choudhury and Panigrahy (1991). The recorded high nitrite value during post monsoon in the present study could be due to increased planktonic excretion, oxidation of ammonia and reduction of nitrate and also

due to bacterial decomposition of planktonic detritus (Govindasami *et al*., 2000). Denitrification and 'air-sea interaction exchange' could also be reasons for high nitrite value during post monsoon (Chaudhury and Panigrahy, 1991). The recorded low nitrite value during monsoon season may be due to less fresh water inflow and low salinity (Murugan and Ayyakkannu, 1991).

Silicate content in the stations selected for the present study was much higher when compared to the other three nutrients.

Except station 5 in 2003 and station 2 and 5 in 2004, all other stations recorded the highest values of silicate during monsoon. It might be due to heavy influx of fresh water through land drainage that that carried silicate leached out from rocks and also from the sediment (Mishra *et al*., 1993). The abundance of diatoms which possess siliceous cell wall can also be the reason for higher values of silicate during all seasons. The decrease in the concentration of silicate during the non monsoon months could be due to its uptake by phytoplankton for their life activities.

Thus it can be smmarised that the ecosystem substrata at all stations are unsteady with respect to the physico chemical factors. Hydrobiological studies are pre requisite to any aquatic system for assessing its potentialities and to understand the relations between the members of different trophic levels. The above information gathered during this study on the physico chemical characteristics of selected mangrove ecosystems might form a useful tool for further ecological assessment and monitoring.

Chapter 5

PLANKTONIC MICROALGAE

5.1 Introduction:

Organisms that are adapted to spend part or all of their lives in apparent suspension in the open water of the sea, of lakes, ponds and rivers are called planktons. It usually comprises those living organisms that are only accidentally and temporarily present, imported from adjacent habitats but which neither grew in this habitat nor are suitably adapted to survive in the truly open water, apparently independent of shore and bottom (Reynolds, 2006).

Microalgae are the photoautotrophic part of the plankton and the major primary producers of organic carbon in the pelagic of the seas and of inland waters (Raymont, 1963, Reynolds, 1984, 2006). Phytoplankton comprises a diverse, polyphyletic group of single-celled and colonial aquatic photosynthetic organisms that drift with the currents (Falkowski and Raven, 1997). Even though the marine phytoplankton constitutes less than 1% of Earth's photosynthetic biomass, they contribute more than 45% of our planet's annual net primary production (Field *et al.* 1998). Their evolutionary trajectories have shaped trophic dynamics and strongly influenced global biogeochemical cycles (Katz *et al.*, 2004).

These microalgae constitute the major components in the primary trophic level of most aquatic food webs and it is therefore mandatory to incorporate this component in any food relation study. Phytoplankton generally go unnoticed until a 'bloom' occurs, when physical conditions concentrate cells

to very high levels or increased light and/or nutrient availability allows the dense growth of a single species resulting in water discolouration and a decline in ecosystem health may occur. Nutrient and light availability are 'bottom-up' controls on phytoplankton productivity and biomass. These are responsible for the process of primary production in water bodies and perform one quarter of world's plant photosynthesis as the "Pastures of sea" (Koblentz *et al.*, (1970). According to Steeman (1975), they contribute about 95% of the total marine production. They can be used as bioindicators with reference to water quality and thus serve as a tool for assessing the health of aquatic ecosystems. Their distribution in the inter-tidal areas of different geographical regions of the world depends on various environmental factors such as temperature, light, salinity nutrient and substrate.

In mangroves, the planktonic microalgae make important contributions to the functioning of the ecosystem, and their contribution to total estuarine production vary in different regions. Along with the emergent flora and benthic microalgae, they play a very significant role in the bioproductivity of the mangrove environment. According to Robertson and Blabber (1992), the contribution of plankton to the total net production in the mangrove habitats ranges from 20-50%. In south India, according to Selvam *et al.* (1992), the phytoplankton productivity is four times higher in mangrove waters than in the adjacent marine waters. Besides contributing to the total productivity of the estuarine mangrove systems, these are also critical in supporting higher trophic levels because of their higher nutritional quality relative to mangrove detritus.

Phytoplankton distribution and productivity depend on various physico – chemical factors such as temperature, salinity, dissolved oxygen, pH and nutrients like nitrite, nitrate, phosphate and silicate. These photosynthetic plants exist as single motile and non-motile cells or as chains of cells and are

important ecologically and economically. Their biomass, productivity and size are closely related to the diversity and abundance of higher trophic levels.

The scaling system and nomenclature of Sieburth *et al*. (1978), has been widely adopted in phytoplankton ecology to distinguish functional separations within the phytoplankton. The classification of phytoplankton according to the scaling nomenclature (size range) of Sieburth (1978) is as follows:

0.2–2 µm	:	Picophytoplankton
2–20 µm	:	Nanophytoplankton
20–200 µm	:	Microphytoplankton
200 µm–2 mm	:	Mesophytoplankton
>2 mm	:	Macrophytoplankton

Identification and quantification of planktonic microalgae is carried out through microscopic examination, which is time-consuming and requires a high level of taxonomic skill. However, small cells, especially flagellates, belonging to nano- or picophytoplankton are easily overlooked or sometimes bonded together as one group. Alternatively, photosynthetic pigments can be used for studying the composition and physiological status of phytoplankton, as certain pigments serve as taxon-specific indicators of major taxonomic groups. For phytoplankton, the major diagnostic photopigments are chlorophyll *b* (chlorophytes), fucoxanthin (diatoms), 190-hexanoyloxyfucoxanthin (haptophytes), 190-butanoyloxyfucoxanthin (pelagophytes and haptophytes), peridinin (dinophytes), alloxanthin (cryptophytes) and zeaxanthin (cyanobacteria) (Jeffrey and Vesk, 1997). Phytoplankton communities are comprised of many different taxonomic groups that have differential influences on the total primary productivity and trophic interactions). (Wulf and Wangberg, 2004)

Marine phytoplankton includes representatives from several classes. Among the massive species of planktonic microalgae, most common and important phytoplankton are diatoms and dinoflagellates in the microplankton (20–200µm) size range, and coccoid cyanobacteria in the picoplankton (0.2–2µm) size range. Small nanoflagellates (2–20µm) can play an important role in tropical and subtropical oceans and in temperate oceans during summer stratification. Each group of phytoplankton exhibits characteristic colours, depending on its relative abundance of the major groups of photosynthetic pigments like green chlorophylls, yellow carotenes, or pink or blue phycobilins. The relative abundance of phytoplankton groups varies seasonally and geographically, so representatives of all groups are seldom found in the same plankton sample. Pigment characteristics along with species composition and abundance of phytoplankton are among the most informative indicators for hydrobiological monitoring of aquatic ecosystems (Kirillova *et al.*, 2006). Phytoplakton studies of mangrove systems at West Bengal, India have revealed 46 species of Bacillariophyceae, Dinophyceae and Cyanophyceae (Santra *et al.*, 1991). *Coscinodiscus, Rhizosolenia, Chaetoceros, Biddulphia, Pleurosigma, Ceratium* and *protoperidinium* were the dominant genera existing almost year round. Another important mangrove ecosystem in India which have been investigated for phytoplankton diversity was Pichavaram and at least 82 phytoplankton species were identified from that station (Kannan and Vasantha, 1992). Dinoflagellate assemblages have been particularly well studied in Belizean mangrove habitats where a diverse collection of benthic and epiphytic species exist (Faust, 1993a). Like in any other aquatic ecosystem, the identification of these microautotrophs requires knowledge about their classification system as well as skill.

The names of divisions and classes of algae more often contain a reference to the colour of the organisms, like, Blue-green algae – Cyanophyta; Green algae – Chlorophyta; Golden algae – Chrysophyta; Red algae – Rhodophyta; Brown algae – Phaeophyta. The kinds and combinations of photosynthetic pigments present together with chemical nature of storage products and cell wall also play an important role in algal classification. There are four classes of algae, frequent in the southwest coast of India, which are as follows.

Class: Cyanophyceae

Class Cyanophyceae, contains about 150 genera and 2000 species, found in most diverse habitats, in freshwater and in the sea; on damp soil, glaciers, deserts and can grow over a wide range of temperatures such as hot springs. The species can also occur as symbionts of protozoa, diatoms and lichen-forming fungi, and vascular plants.

A considerable proportion of marine phytoplankton includes blue-green algae, particularly in the picoplankton (0.2-2µ) size range. Coccoid blue-green algae appear to be everywhere in temperate and tropical parts of the ocean and even be the main contributors to photosynthetic primary production (Fogg, 1987). They are most abundant in nutrient rich coastal and estuarine waters where they occur along with diatoms and dinoflagellates. They are also found in oligotrohic parts of tropical and sub-tropical seas. *Trichodesmium sp*. can often form extensive blooms in tropical and sub-tropical oceans and are visible as orange-brown wind rows on the surface of water. This species is capable of fixing atmospheric nitrogen and probably the most important biological fixer of nitrogen in the open ocean.

Cyanophytes have a capacity to change their colour in relation to the wavelength of the incident light. Very often characteristic blue or red colouration is imparted to the marine environment when the bloom of blue green algae appear consequent to eutrophication. Several species of blue green algae produce toxins, which may be either neurotoxic or hepatotoxic.

However, this ubiquitous group of algae is more widely distributed in the fresh water habitats like lakes, ponds and streams than in the marine environments. Both fresh water and marine cyanobacterial populations form integral and major components of the microbiota of every mangrove ecosystem.

Class: Chlorophyceae

The class chlorophyceae comprises of diverse forms of algae, which enjoy a wide distribution in aquatic and terrestrial habitats. This includes about 500 genera and approximately 8000 species (van Den Hoek, *et al*., 1995). Most of them are prone to freshwater habitat and many are reported to thrive well in marine and terrestrial environments. Great range of somatic differentiation occurs in chlorophyceae. Thallus organisation varies from microscopic unicellular to multicellular macroscopic forms; may be colonial, coccoid, palmelloid, sarcinoid, siphonaceous, filamentous, thallose, or pseudo-parenchymatous.

Aquatic green algae show wide variation in their habit, being distributed in pelagic and benthic environments. While some benthic species grow attached to rocks, some others are seen on other plants as epiphytes. Many filamentous green algae are attached to the substratum during the early stages of development, but later become free floating, forming mats or balls composed of many intertwined filaments. On rocky shores, several species are often seen completely covering the rocks on the upper part of the intertidal zone.

Green algae are the major primary producers of the freshwater ecosystems. In estuarine systems like mangroves, they are frequently distributed during the monsoon periods and provide high biomass and productivity.

Class: Bacillariophyceae (Diatoms)

The diatoms are one of the most easily recognisable groups of major eukaryotic algae, because of their unique silicified cell wall, which consists of two overlapping thecae, each in turn consisting of a valve plus a number of hoop-like or segmented girdle bands. The word diatom has its origin from one of the genera coming under this group, '*Diatoma*'. They are unicellular or colonial; occur in soil, damp rocks, fresh water, brackish water and in the Ocean. Diatoms are microscopic algae which are found in virtually every habitat where water is present and are the major component of phytoplankton community. However, they are also found in the benthic environments of aquatic ecosystems. They are the key in the biogeochemical cycle of carbon, as they can account for 40% of the total primary production in the Ocean. One estimate of total primary production on earth is $1.4x10^{14}$ kg dry mass per year and Werner (1977) suggested that marine diatoms themselves contribute 20 to 25% of world net primary production and 15-20% by other planktonic algae.

The number of known diatom species is often given as ca. 10^4 (Hendey, 1964); with a narrower species concept, this would rise to 10^5. Altogether, the total number of diatom species worldwide is probably not less than $2x10^5$ (Mann and Droop, 1996). Diatoms would thus be confirmed as the group of algae showing the highest species diversity.

Majority of diatoms are planktonic, especially coming under the order Biddulphiales (Centrales) and are generally the most important primary

producers of marine and freshwater systems. By absorbing CO_2 in the production of organic material during photosynthesis they play decisive role in the global carbon cycle. The empty siliceous cell wall of dead algae may be deposited in the sediments of lakes and oceans and be preserved as a valuable record about past environments and climate changes; as such they are important fossils for the reconstruction of millions of years of the Earth's history. The consistent 'rain' of dead diatom frustules to the bottom of highly productive part of the oceans, result in the accumulation of oozes, and these fossil deposits from the past geological periods are now mined as 'diatomaceous earth', which is used for many industrial usages (Stoermer and Smol, 1999).

Recent phylogenies constructed from nuclear-encoded small-subunit ribosomal RNAs place the diatoms within the pigmented heterokont algal lineages (Bhattacharya *et al.*, 1992; Leipe *et al.*, 1994, Medlin *et al.*, 1997b), most closely related to the new algal class, the Bolidophyceae, which are picoplanktonic algae with a simplified cellular organization (Guillou *et al.* 1999).

Classification of diatoms is mainly based on the morphology of the valve, along with type of sexual reproduction, structure of auxospore envelope and type of habitat (Agardh, 1824; Kutzing, 1844, 1849; Rabenhorst, 1853; Ralfs, 1864; Patrick and Reimer, 1966; Simonsen, 1979; Von Stoch, 1982; Round *et al.*, 1990). Several workers in India have followed the classification of Schutt (1896) modified by Hustedt (1930) that is broadly based on the symmetry and structure of the valve. To facilitate the proper identification, organic contents of the frustule can be removed by acid treatment (Sournia, 1976).

The class Bacillariophyceae is sub-divided into two orders ie., Centrales and Pennales. The latter group is believed to have evolved from the centric forms owing to their first appearance later in the geological record. However, according to the rules of ICBN (1999), the name of any taxa should start with a name of a genus present in those taxa. Hence Centrales and Pennales are designated as Biddulphiales and Bacillariales respectively.

Like in other aquatic systems, diatoms form the major components of mangrove microflora either in the form of plankton, or as microphytobenthos or as epiphytes on the mangrove roots and trunk.

Class: Dinophyceae

Class: Dinophyceae or pyrrhophyceae (Gk. "*Pyrrhos*" means flame-coloured) includes a large number of unicellular, eukaryotic and biflagellate algal species of varying size and shape. This includes 130 genera with about 2000 living and 2000 fossil species (Van den Hoek *et al.*, 1995).

Dinoflagellates are distributed in freshwater, estuaries and seas and are adapted to pelagic and benthic habitats from arctic to tropical seas. They are found in numerous habitats; many species are planktonic while several other species are attached to sediments, sand, corals, macroalgae or to other plants. Certain species are present as parasites in marine invertebrates and fish. Some even serve as symbionts, providing organic carbon to their hosts: reef-building corals, sponges, clams, jellyfish, anemones and squids.

Dinoflagellates exhibit a wide variety in morphology and size ranging from 0.01 to 2.0 mm. Their cell covering structure known as theca differentiates them from other algal groups. Cells are either armoured or unarmoured, and the former have thecae divided into plates composed of cellulose or polysaccharides. The cell covering of unarmoured species is comprised of a

membrane complex. The theca may be smooth and simple or laced with spines, pores and/or grooves and may be variously ornamented.

Dinoflagellates share features common to both plants and animals: they can swim, many have cell walls, and both photosynthetic and heterotrophic species are known. Blooms of dinoflagellates impart a discolouration of water, mostly a reddish-brown color known as "red tide". Red tides can have harmful effects and certain species of dinoflagellates produce potent toxins. These toxins are carried up in the food chain, ultimately to humans and can, sometimes result in permanent neurological damage or even death (Fukuyo, 1981).

Recently there was a comprehensive study on the role of epiphytic and benthic dinoflagellates and their varied distribution and habitat preference in a coral reef mangrove ecosystem in Belize, USA by Maria A. Faust (2009). The study examined the Ciguatera Fish Poisoning dinoflagellates seen on macrophytes, in sand and floating detritus.

Presence of dinoflgellates has been noted in most of the phytoplankton studies related with mangrove ecosystems and their distribution and abundance show seasonal and spatial variations.

Several investigations have been carried out on planktonic microalgae and its relationships in Indian waters including some works in mangrove habitats (Venkataraman, 1939; Nair, 1959; Subrahmanyan, 1946, 1958a, 1958b, 1959, 1971; Subrahmanyan and Viswanatha Sharma, 1960, 1965; Gopinathan, 1972, 1975a, 1975b, 1984; Gopinathan, *et al*., 1974, 1994, 2001; Joseph, 1989; Joseph and Pillai, 1975; Joseph and Nair, 1975; Joseph and Sreekumar, 1993; Joseph *et al*., 1984; Nair *et al*, 1968, 1975; Krishnamurthy *et al*., 1974; Mani,

1992; Chaghtai and Saifulla, 1992; Santhanam *et al.*, 1975; Desikachary *et al.*, 1987a 1987b, 1988; Gowda *et al.*, 2001).

Available data indicate that the waters along the west coast of India are more fertile than that along the east coast, mainly due to upwelling and other favourable factors conducive for phytoplankton growth. It is therefore naturally expected that the mangroves along the South west coast of India shoe more species diversity than those along the east coast.

In the present study, the spatial and seasonal distribution of phytoplankton species and their abundance and diversity with respect to the hydrological parameters and their contribution to the total productivity were studied for two years from 2003 from six mangrove stations in Kerala, South west coast of India.

5.2 Review of Literature

There are several thousand papers published on different aspects of planktonic microalgae. Publications started to come even during the 1800s. Some of the important papers referred during this study are listed here.

Kutzing, (1844, 1849), in his *Species Algarum*, described the diatoms and contributed several new genera and species to the biological world. Thwaites, in 1848, have done further observations on the Diatomaceae with descriptions on new genera and species.

Greville (1857, 1859, 1863), reported several new diatom species from West Indies and California. Brightwell, (1858, 1859) described some of the rarer or un-described species of diatoms and made further observations on the genera *Triceratium* and *Chaetoceros*. In 1861, Pritchard, in his detailed study along the British coasts, mentioned the history of *Infusoria* including the *Desmidaceae* and

Diatomaceae, Ralfs, in 1864, described several new species from marine diatomaceae found in Hong Kong waters. Lewis, 1861, evaluated some new and rare species from Diatomaceae along the seabed of United States.

Cleve, (1873, 1878, 1894, 1896), a well reputed diatomologist, recorded a number of new species from Java sea, West Indian Archipelago, Baffin Bay and coastal Sweden.

Grunow, (1877, 1880), extensively studied the genus *Nitzschia* and invented several new species. Van Heurck, (1885, 1896, 1899), described the morphology of diatoms and recorded several new species.

Castracane, 1886, reported the scientific results of the voyage of *H.M.S. Challenger* during the years 1873-76, especially from the family Diatomaceae.

Viktor Hensen, in 1887, applied quantitative methods to estimate the distribution, abundance and productivity of the microscopic organisms of the open oceanic waters. He also envisaged a simple linear relationship between hydrography, plankton, and fish.

Peragallo, (1891, 1892), prepared a monograph on diatoms and described the genera such as *Pleurosigma and Rhizosolenia.* Boyer (1900, 1916), studied the Biddulphioid diatom forms from North America and Philadelphia. Boyer, (1926-27), composed a synopsis of the family Diatomaceae, from North American coasts.

Hustedt, (1927, 1930, 1931-32), revised the *Kryptogamen* flora of Rabenhorst. Lebour, in 1930, illustrated the planktonic diatoms of Northern Sea. Allen and Cupp, in 1935, studied the planktonic diatom species from the Java Seas.

Biswas, in 1932, made a casual reference to the distribution of diatoms in the algal flora of Chilka Lake. In 1949, Botanical Survey of India published a monograph on common Fresh and Brackish water algal flora of India and Burma by Biswas.

Cupp (1937), most probably was the pioneer phycologist who made a comprehensive study on diatoms in the United States. He studied the seasonal distribution and occurrence of marine diatoms and dinoflagellates from Alaska. His monograph (1943), *Marine plankton diatoms of the west coast of North America*, which has even now, being used as a key text book on diatom taxonomy worldwide.

In 1939, Venkataraman made a systematic study of south Indian diatoms and gave an account of both fresh water and estuarine diatoms in and around Madras, with a quite explicable taxonomic description with hand drawn plates.

Subrahmanyan and his colleagues (1946, 1958a,b, 1959, 1960 & 1965) gave outstanding contributions in the taxonomic study of phytoplankton in the Indian inshore seas. Subrahmanyan described over 500 species of phytoplankton belonging to different groups, representing over 150 genera from both the coasts of India. In 1946, he described 171 forms of marine planktonic diatoms at Madras, representing 15 families, 64 genera and 134 species.

The pioneering study on the ecology and seasonal succession of the diatom flora of the estuarine waters of India was that of Iyengar and Venkataraman, in 1951. They studied the estuarine parts of river Cooum near Madras.

Studies by Andersson *et al.* (1966) on the succession and growth limitation of phytoplankton in the Gulf of Bothnia (Baltic Sea) revealed the role of phosphorous as a regulating factor of phytoplankton growth.

Depending on the hydrographical situation of the mangrove system (especially on the tidal currents), a part of the litter is exported directly or after its partial degradation to the neighboring coastal areas (Odum & de la Cruz 1967).

Nair, *et al.*, in 1968, calculated the potential production of phytoplankton in terms of carbon for the west coast of India as $46x10^6$ tons and for the east coast as $15x10^6$ tons.

Lind (1968) gave a description on the distribution of major planktonic algae in Kenyan waters. He gave an account on the relation between plankton productivity and rain fall.

Qasim and Gopinathan (1969) studied the tidal cycle and environmental features of Cochin back water (a tropical estuary) and found that the environmental features such as pH, dissolved oxygen, nutrients, alkalinity and chlorophyll are greatly influenced by the tidal rhythms.

In 1972, Gopinathan made a qualitative and quantitative analysis of phytoplankton in the Cochin estuary and described 120 species.

Qasim (1973) made a comparison between the annual cycle of primary productivity and the seasonal variation in the environmental features of Cochin backwaters and revealed that the peaks in production are independent of the high and low values of solar radiation falling on the surface of water, however, the changes in salinity are important in favouring phytoplankton productivity. The peaks in primary production occur during the monsoon months when salinity in the backwater is low.

Gopinathan (1975a) gave an account of the diatoms present in various estuarine systems in India, particularly in Cochin backwaters and gave a description on their occurrence, seasonal fluctuations and distribution.

Vijayalakshmi and Venugopalan (1975) studied the diversity of phytoplankton species, pigments and succession with a note on primary production at a tidal zone in the Velar estuary, East coast of India.

Joseph and Nair (1975) analysed the growth constants, mean generation time and chlorophyll in relation to cell numbers and ^{14}C uptake in few unialgal cultures of selected phytoplankters isolated from Cochin estuary.

Nair *et al.* (1975) studied the primary production in the Vembanad Lake and observed that the annual gross production ranged from 150-650 $gC/m^2/day$ and the total organic production in the Vembanad Lake was estimated as 100,000 tons of carbon.

In 1975, Joseph and Pillai studied the seasonal and spatial distribution of phytoplankton in Cochin backwaters.

According to Odom (1975), faunal communities in mangrove ecosystem have traditionally been considered to be driven by large production of mangrove litter.

Pant *et al.* (1980) studied the contribution of phytoplankton photosynthesis in a mangrove ecosystem and found that there is no apparent casual relationship between phytoplankton biomass and either benthic animal populations or edible fish catch.

The contributions of Desikachary and his colleagues, (1986, 1987, 1987a, b, 1988, 1989) to the Indian Phycology are of immense magnitude. Their Atlases of diatoms are considered as the most valuable and authentic reference books by diatom taxonomists all over the world.

Due to its refractorial nature the organic material produced by mangroves, it is not used directly by most herbivores, instead it is channelled to decomposers (Lee 1990).

In the open water of the upper Golfo de Nicoya, the studies conducted by Gocke *et al. (*1990) showed that the oxygen concentration increased strongly

during the day, since the production of organic material largely exceeded its consumption in the entire water column.

Selvam *et al.* (1992) found phytoplankton productivity to be four times higher in mangrove waters than in adjacent marine waters in south India.

Kannan and Vasantha (1992) studied the species composition and population density of microphytoplankton in the Pichavaram mangals , south east coast of India and found that phytoplankton population density exhibited a wide seasonal fluctuation with minimum during monsoon and the maximum during summer. They identified 82 species of phytoplankton which included 67 diatoms, 12 dinoflagellates and 3 blue green algae.

In a Study made by Kivi *et al.* (1993) in the Baltic sea off the south west coast of Finland on the nutrient limitation and grazing control of phytoplankton community, Nitrogen was found to be the basic limiting nutrient for phytoplankton throughout the productive season.

In addition to the production of organic material by the mangrove trees, a certain production of organic material by planktonic algae also occurs in the inundated parts of the mangrove swamp. This fraction, however, has received little attention in past and current research even though it comes to about 55% (Cebrián & Duarte 1994)

In a review about mangrove out welling, Lee (1995) concluded that in the past the particulate organic matter export from the mangrove systems may have been overestimated sometimes, whereas the very important export of dissolved organic matter has not been taken into account until quite recently.

Newell *et al.* (1995) studied the relative importance of benthic micro algae, phytoplankton and mangrove detritus as source of nutrition to coastal invertebrates from Malasia and have pointed out that the importance of

phytoplankton and benthic algae may have been underestimated in the detritus based food web of mangrove ecosystems.

According to Duarte & Cebrián, (1996) the organic material produced by phytoplankton is directly accessible to higher trophic levels of the marine food chain and therefore, if phytoplankton organic carbon is produced in the mangrove system and exported to the adjacent areas, this material is more important in the carbon fluxes of the receiving systems than one would judge from its amount.

Loneragan *et al.* (1997) used multiple stable isotope analysis to investigate the importance of mangroves, sea grasses and other primary sources like algae to the food supporting Pineid prawns in the Embley river estuary, Australia and established that the contribution of mangroves to the food webs of prawns appears to be confined to a very small spatial area.

While studying the nutrient and phytoplankton dynamics in two mangrove tidal creeks of the Indus river delta, Pakistan, Harrison *et al.* (1997), reported that there was no apparent seasonal cycle in chlorophyll *a* or primary productivity. The phytoplankton species observed by them were predominantly centric diatoms which were presumably kept in suspension by tidal currents. According to them, since nutrients are rarely limiting, there is an export of nutrients from the creeks to the coastal area which may stimulate the phytoplankton productivity.

Córdoba Muñoz (1998) who performed productivity measurements in the mouth of the main channel of the Estero de Morales and obtained a higher annual NPP of 439 g C m^{-2} a^{-1} (NPP per day ranged between 0.69 and 2.53 g C m^{-2}). She made the incubations always at high tide.

While studying the role of fishes in modifying the trophic pattern of phytoplankton, Komarkova (1998) pointed out that the phytoplankton diversity depends on a number of factors other than nutrient supply and predation constitutes a strong top down control on phytoplankton assemblage.

Zimba P.V (1998) developed Nutrient enrichment bioassays to test for nitrogen (N), phosphorus (P), and silica (Si) limitation of epiphytic biomass in eutrophic Lake Okeechobee, Florida, USA. Quarterly assays on artificial (plastic) Hydrilla plants exposed to lake water for 7 days prior to nutrient addition were evaluated by changes in chlorophyll-a relative to controls. Epiphytic biomass was measured at 24-h intervals for 72 h. Nitrogen and silica additions had a stimulatory effect on biomass during all experiments, whereas phosphorus additions were never stimulatory. These results suggest that silica should be considered as a limiting nutrient for microalgal communities dominated by diatoms.

Trott and Alongi (1999) examined the surface water concentration of dissolved nutrients and phytoplankton biomass (as chlorophyll *a*.) in relation to the physic chemical characters in two tropical mangrove creeks of Queensland, Australia. It was observed that phytoplankton biomass and dissolved nutrient concentration peaked during summer with no or little significant change throughout the rest of the year.

In a recent study on some aspects of the carbon cycle in an Indian estuarine mangrove ecosystem, zooplankton exhibited larger spatial and seasonal variation in productivity than did the total suspended organic matter and attributed this to the variability in productivity of phytoplankton (Dehairs *et al.*, 2000 and Bouillon S. *et al.*, 2000)

There is a large seasonal and spatial variation in the primary productivity of estuarine systems and the knowledge of the variations may be crucial in interpreting the productivity data of higher trophic levels. Monthly rainfall pattern has a significant role in determining these variations (S. Bouillon & F.Dehairs, 2000)

After analyzing the ecological aspects of mangrove habitats, G.S.D Selvaraj (2000) opined that mangroves are one of the most productive ecosystems of the world and the algal colonies associated with mangrove root surface and moist intertidal flats and the phytoplankton communities in the associated bays and lagoons contribute significantly to the primary production of the ecosystem. According to him 6% of the total organic production in the mangrove ecosystems is contributed by phytoplankton.

The seasonal variation of planktonic primary productivity was measured using light and dark bottle method by Klaus Gocke *et al.* (2001) during one year in the main channel in the interior part of the mangrove forest of the Estero de Morales (Estero de Punta Morales), a mangrove system located in the Golfo de Nicoya at the Pacific coast of Costa Rica. The annual gross primary productivity (PPg) was 457 and the net primary productivity (PPn) was 278 g C m–^{2} a^{-1}. Daily PPg ranged from 0.29 to 3.88 and PPn from 0.12 to 2.76 g C m^{-2} d^{-1}. The planktonic primary productivity inside the mangrove forest was completely restricted to the open channels. A simultaneous measurement demonstrated that PPn of the phytoplankton could not take place under the canopy of the mangroves. The studies revealed that even when the oxygen concentration of the water which entered the system in the early morning, was quite low due to the oxygen consumtion in the gulf at night, it decreased still more inside the mangrove forest during high tide and the following ebb phase.

Under the canopy of the mangrove forest, however, the respiration processes in the water were far greater than the processes, which lead to a liberation of oxygen, i.e. photosynthesis. The oscillation of the oxygen concentration in the mouth of the main channel during a tidal cycle shows that the consumption of organic material within the water column of the mangrove forest exceeds by far the production. (Klaus Gocke, 2001)

According to Gina Holguin *et al.*(2001), there is evidence to propose a close microbe-nutrient-plant relationship that functions as a mechanism to recycle and conserve nutrients in the mangrove ecosystem. The highly productive and diverse microbial community living in tropical and subtropical mangrove ecosystems continuously transforms nutrients from dead mangrove vegetation into sources of nitrogen, phosphorus, and other nutrients that can be used by the plants. In turn, plant-root exudates serve as a food source for the microorganisms living in the ecosystem with other plant material serving similarly for larger organisms like crabs.

Alongi (2002), in his study on the present and future of the world mangrove forests remarked that mangroves are the only woody halophytes dominated ecosystem situated at the confluence of land and sea, they occupy a harsh environment, being daily subject to tidal changes in temperature, water and salt-exposure and varying degree of anoxia.

Gopinathan *et al.* (2005) enumerated the micro algae of selected mangrove ecosystems in India and described 48 genera of diatoms and two genera of Cyanophyceae. Acording to them, the true planktons are brought to the mangroves during high tide.

Micro algal composition, abundance, diversity and biomass of the Qua Iboe estuary mangrove swamp were studied by Essien *et al.* (2008) where an

assemblage of brackish water micro algae belonging to six major taxonomic classes were encountered. Variations between pelagic and sedimentary habitats were also analysed during this study.

Nedumaran and Prabu (2009) studied the ecology of phytoplankton from Pichavaram mangroves, South East coast of India.91 species of phytoplankton were recorded of which 73 were diatoms. Species such as Coscinodiscus centralis, Pleurosigma elongatum, Thalassionema nitzschioides, Skeletonema costatum, Triceratium favus, Odentella sinensis, Navicula longa and Ceratium furca constituted the bulk of the population density.

Raj Kumar *et al.* (2009), studied the phytoplankton diversity in Pichavaram mangrove waters, South –east coast of India and identified 94 species of phytoplankton, among which the diatoms formed the predominant group. Maximum phytoplankton diversity and density were observed during summer season which possesses stable hydrographic conditions.

Manna *et al.* (2010) studied the dynamics of Sundarban estuarine ecosystem and observed that the phytoplankton community is dominated by diatoms followed by dinoflagellates and chlorophyceae. They identified a total of 46 taxa belonging to 6 groups and indicated that dissolved oxygen, nutrients and turbidity are the limiting factors for the phytoplankton biomass. They also suggested a threshold salinity level for phytoplankton biomass production and observed a close microbe-plant-nutrient relationship that functions as a mechanism to recycle and conserve nutrients in the mangrove ecosystem.

L.T. P Hoa *et al.* (2010) studied the fatty acid profiles of mangrove micro algae and their potential use as food and noticed that many of them possess high content of poly unsaturated fatty acids and other compounds of potential interest to the food, cosmetic and pharmaceutical industries. They

successfully identified and purified three such diatoms, Amphiprora alata, Gyrosigma limosum and Melosira nummuloides based on morphological properties and 18S rDNA sequence analysis.

Boyce *et al.* (2011) combined the available ocean transparency measurements and *in situ* chlorophyll observations to estimate the time dependence of phytoplankton biomass at local, regional and global scales since 1899. They observed declines in eight out of ten ocean regions, and estimated a global rate of decline of ~1% of the global median per year. The analyses further revealed interannual to decadal phytoplankton fluctuations superimposed on long-term trends.

5.3 Results

5.3.1 Species Composition and Diversity

The distribution of planktonic microalgae with temporal and spatial variation of the species composition, the impact of the changes in the physico chemical variables on species abundance and composition and variations in pigments were studied for a period of two years from 2003 to 2004. It was found that there is considerable spatial and seasonal variation in cell density and species composition.

In the first year, at station 1 (Kumbalam), the highest cell density was recorded during post monsoon (9150 cellsL^{-1}) and the lowest of 53 cellsL^{-1}during the pre monsoon (Table). During one of the collections in October, 2003 (post monsoon), the maximum cell density went upto 26134 cellsL^{-1}. *Nitzschia closterium, Navicula mutica* and *Pleurosigma aestuarii* were noted during all the seasons. The only dinoflagellate, *Ceratium* was present in the premonsoon. In the second year the highest and lowest standing crop was recorded during monsoon and the figures were 3828 cellsL^{-1} and 847 cellsL^{-1} respectively. *Gyrosigma tenuissimum, Cyclotella striata, Navicula mutica, Nitzschia closterium* and *Pleurosigma angulatum* were the dominant species. (Table 4)

At station 2 (Panangad), in 2003, the highest cell density of 14342 cellsL^{-1} was recorded during monsoon and the lowest of 534 cellsL^{-1} during post monsoon. None of the species recorded was present in all three seasons. *Amphora coffeaeformis, Pleurosigma aestuarii, Pleurosigma angulatum* and *Nitzschia closterium* were the dominant species identified. *Spirulina* and *Oscillatoria chalybea* were present during pre monsoon and post monsoon respectively. In the second year, the highest cell density of 11442 cellsL^{-1} was recorded during monsoon and the lowest of 815 during post monsoon. Against a total of 22 species present in 2003, there were 23 species in the second year. *Amphora laevis, Melosira lumuloides, Nitzschia closterium* and *Navicula mutica* were the common species present. Both the Chlorophycean members- *Closteriumkutzingii* and *Chlorella vulgaris* appeared during the monsoon. (Table 5)

At station 3 (Nettoor), there was a considerable increase in the standing crop when compared to the other stations in all seasons. In the first year the highest cell density was noticed during a collection in pre monsoon and it read 28325 cellsL^{-1}. The lowest value of 2473 cellsL^{-1} in this station was obtained during post monsoon. The highest species richness was also noted at this station. *Coscinodiscus centralis, Gyrosigma scalproides, Navicula henneidyi, Nitzschia closterium* and *Pleurosigma normanii* were the dominant species present. Like in the previous year, there was cell abundance during all seasons in the second year also. While the highest cell density was recorded during monsoon (20942 cellsL^{-1}), the lowest was recorded during pre monsoon (2873 cellsL^{-1}). While the number of cells increased during monsoon and post monsoon in the second year, there was a reduction in cell abundance during the premonsoon. Two Cyanophycean members which were not present in the previous two stations- *Phormidium* and *Microcystis aeruginosa* were identified from this station. Altogether, there were 38 sps. of planktonic algae recorded from station 3. (Table 6)

At station 4 (Puthuvaipu), there was a clear seasonal variation in cell density during the first year of this study, with the highest value for monsoon. The average cell density in the station during monsoon was 47762 cellsL^{-1}. The

lowest value of 364 cellsL^{-1} was recorded during post monsoon. *Cocscinodiscus centralis, Diploneis littoralis, Licmophora juergensii ,Gyrosigma tenuissimum, Navicula halophila* and *Navicula forcipata* were the common species appeared in this year. In the second year, the highest density was recorded during monsoon (31765 cellsL^{-1}) with a seasonal average of 18357 cellsL^{-1}. The lowest value of the year 421 cellsL^{-1} was recorded during post monsoon. *Nitzschia closterium, Gyrosigma scalproides* and *Mastogloia pumella* were the dominant species. For the first time during this study, three dinoflagellates were noted at this station. The total number of species was 33. (Table 7)

In the first year, at station 5, Murikkinpadam, the trend was different with one of the pre monsoon collections showing the highest cell density of 35894 cellsL^{-1}, the average seasonal cell density being 20892 cellsL^{-1}. The lowest cell density of the station was recorded during post monsoon and the number was 922 cellsL^{-1}. In the second year, however, the monsoon density of cells was very high compared to other seasons and a figure of 67324 cellsL^{-1} was obtained in one of the collections. The lowest density of 606 cellsL^{-1} was obtained during post monsoon. A total of 29 species were identified from this station, diatoms leading the table with strength of 24 members. *Asterionella japonica*, three species of *Coscinodiscus marginatus, Bacillaria paradoxa, Licmophora juergensii, Gyrosigma tenuissimum* and *Navicula mutica* were abundant in both the years. (Table 8)

At station 6, Mangalavanam, the cell density was comparatively low during all seasons. While the highest density of 1258 cellsL^{-1} in the first year was noted during post monsoon, the lowest of 194 cellsL^{-1}was recorded during pre monsoon. In the second year, the highest value of 3532 cellsL^{-1} was obtained during monsoon and the lowest of 794 cellsL^{-1} during pre monsoon. The least cell density and species richness were noted at this station. There were only 22 species of planktonic microalgae identified from this station. *Nitzschia sigma, Nitzschia closterium, Navicula henneidyi* and *Gyrosigma tenuissimum* were the dominant species. (Table 9)

Table 4: Station 1 Kumbalam

		2003			2004		
	Bacillariophyceae	**PRM**	**MON**	**POM**	**PRM**	**MON**	**POM**
1	*Achnanthes coarctata*					188	
2	*Amphora coffeaeformis*			182			
3	*Amphora decussata*			368			137
4	*Asterionella japonica*			473			221
5	*Bacillaria paradoxa*			232			191
6	*Biddulphia mobilensis*		32	286	249	387	
7	*Chaetoceros brevis*			379			
8	*Coscinodiscus centralis*		49				
9	*Coscinodiscus marginata*	357	42			365	
10	*Cyclotella striata*		34	411			356
11	*Cymbella hustedtii*	332				295	
12	*Diploneis littoralis*	321		541			
13	*Diploneis puella*	489			347		165
14	*Gyrosigma balticum*	352					
15	*Gyrosigma tenuissimum*		34	490	245	401	169
16	*Navicula longa*			523			214
17	*Navicula mutica*	759	47	878	423		479
18	*Nitzschia closterium*	630	29	789		447	479
19	*Nitzschia panduriformis*			301	389		83
20	*Pleurosigma aestuarii*	925	33	692			
21	*Pleurosigma angulatum*				647		98
22	*Pleurosigma normanii*					298	
23	*Rhizosolenia robusta*			643	341		
24	*Surirella fastuosa*			367			9
25	*Synedra affinis*				420		
26	*Thalasionema nitzschioides*						306
27	*Thalassiosira subtilis*	493		562			
28	*Triceratium favus*			453			
	Chlorophyceae						
1	*Staurastrum asteroideum*					321	
2	*Cosmarium quadrum*					264	
3	*Chlorella vulgaris*		39			358	
	Cyanophyceae						
1	*Spirulina labyrinthiformis*		41	580			199
2	*Oscillatoria formosa*						204
	Dinophyceae						
1	*Ceratium furca*	372					
	Grand Total	5030	380	9150	3061	3324	3310

PRM-Pre Monsoon, MON – Monsoon, POM-Post Monsoon

Table 5 Station 2. Panangad

	Class	2003			2004		
	Class: Bacillariophyceae	**PRM**	**MON**	**POM**	**PRM**	**MON**	**POM**
1	*Achnanthes brevipes*		361	112			67
2	*Amphora coffeaeformis*		682	130			
3	*Amphora laevis*	341				1045	122
4	*Caloneis madraspatensis*		97			92	
5	*Cymbella hustedtii*	263			932		
6	*Diploneis dydima*	245				532	
7	*Gyrosigma balticum*		358	113			
8	*Melosira numuloides*	397			672	671	
9	*Navicula cincta*		568			524	
10	*Navicula forcipata*			161			
11	*Navicula mutica*					1069	89
12	*Navicula halophila*					301	
13	*Navicula henneidyi*			127			78
14	*Nitzschia closterium*	251		357		973	153
15	*Nitzschia sigma*					304	
16	*Pleurosigma aestuarii*	556	72				152
17	*Pleurosigma angulatum*	318	733			578	
18	*Pleurosigma normanii*		342			591	
19	*Skeletonema costatum*	19				764	
20	*Synedra affinis*				515		
21	*Thalassiosira decipiens*			83			
22	*Triceratium favus*		367	133			113
	Class:Dinophyceae						
1	*Ceratium furca*					865	
	Class: Cyanophyceae						
1	*Spirulina labyrinthiformis*	467				82	
2	*Oscillatoria chalybea*			193			41
	Class: Chlorophyceae						
1	*Closterium kutzingii*		673			367	
2	*Chlorella vulgaris*	255				635	
	Grand Total	3112	4253	1409	2119	9393	815

PRM-Pre Monsoon, MON – Monsoon, POM-Post Monsoon

Table 6 Station 3. Nettoor

	Class	2003			2004		
	Class: Bacillariophyceae	**PRM**	**MON**	**POM**	**PRM**	**MON**	**POM**
1	*Achnanthes coarctatus*		327			408	1408
2	*Amphora coffeaeformis*	209		339			
3	*Amphora ovalis*			502			2384
4	*Bacillaria paradoxa*			364		794	734
5	*Caloneis madraspatensis*	343					
6	*Chaetoceros brevis*		486	574		1009	
7	*Coscinodiscus centralis*	1582	349		652		
8	*Cyclotella striata*					863	
9	*Cymbella hustedtii*	567					
10	*Diploneis dydima*			382		538	
11	*Gyrosigma balticum*					1304	1411
12	*Gyrosigma scalproides*	1973	741				
13	*Navicula cincta*	171				682	
14	*Navicula forcipata*			762	918		
15	*Navicula henneidyi*	1133	1087				
16	*Navicula mutica*					764	2284
17	*Navicula rhombica*					121	567
18	*Navicula sp.*		334				
19	*Nitzschia closterium*	2954	467	878	582	1839	1968
20	*Nitzschia longissima*	451				83	
21	*Nitzschia lorenziana*	283				937	
22	*Nitzschia sigma*		357	591			
23	*Planktoniella sp.*	449				2564	
24	*Pleurosigma aestuarii*	1103			951	967	
25	*Pleurosigma angulatum*						1687
26	*Pleurosigma normanii*	2605	1084				
27	*Podosira montagnei*					1349	
28	*Rhizosolenia robusta*	1110					798
29	*Surirella fustuosa*					1297	
30	*Thalassionema nitzschioides*			824			
31	*Thalassiosira decipiens*					861	
	Chlorophyceae						
1	*Chlorella marina*	940					
2	*Chlorella vulgaris*	1230					
3	*Closterium kutzingii*		243				
	Cyanophyceae						
1	*Microcystis aeruginosa*					957	
2	*Phormidium*			496			
	Dinophyceae						
1	*Ceratium furca*					1403	
2	*Gymnodinium sp.*			927			
	Grand Total	17103	5475	6639	3103	18740	13241

PRM-Pre Monsoon, MON – Monsoon, POM-Post Monsoon

Table 7 Station 4 Puthuvaipu

		2003			2004		
	Class: Bacillariophyceae	**PRM**	**MON**	**POM**	**PRM**	**MON**	**POM**
1	*Achnanthes brevipes*		1267				64
2	*Amphora laevis*			730			
3	*Biddulphia aurita*		927			967	
4	*Cocconeis placentula*		658	641		1209	
5	Coscinodiscus centralis	286	2389			1001	
6	Coscinodiscus eccentricus					985	
7	*Coscinodiscus marginata*	134				204	
8	Coscinodiscus radiatus				259		51
9	Cymbella marina		1963				
10	Diploneis littoralis	246	2196				43
11	*Diploneis puella*						48
12	*Gramatophora marina*		2253			454	
13	Gyrosigma scalproides					1578	61
14	*Gyrosigma tenuissimum*		3964	834			
15	*Licmophora juergensii*	115	2536			689	
16	*Mastogloia pumella*					1937	73
17	*Melosira numuloides*		1208		301		
18	*Navicula forcipata*		1987	764			
19	*Navicula halophila*		1638	563			
20	Nitzschia closterium	54			197	2554	57
21	*Nitzschia longissima*					391	
22	*Pleurosigma normanii*			867	586	1127	
23	*Rhizosolenia robusta*		1598				85
24	*Skeletonema costatum*				51		
25	*Thalassiosira subtilis*			956			
26	*Triceratium favus*		1189			1378	
	Class: Chlorophyceae						
1	*Cosmarium quadrum*		2387				
2	*Chlorella vulgaris*					1256	
	Class: Cyanophyceae						
1	*Oscillatoria chalybea*						45
2	*Nostoc punctiforme*		1934				
	Class: Dinophyceae						
1	*Ceratium furca*					1498	
2	*Gymnodinium*		2104				
3	*Protoperidinium*				234	1159	
	Grand Total	835	32198	5355	1628	18387	527

PRM-Pre Monsoon, MON – Monsoon, POM-Post Monsoon

Table 8 Station 5. Murikkinpadam

		2003			2004		
	Class: Bacillariophyceae	**PRM**	**MON**	**POM**	**PRM**	**MON**	**POM**
1	*Amphora coffeaeformis*			296			
2	*Amphora laevis*				961		64
3	*Asterionella japonica*	1151			1010		
4	*Bacillaria paradoxa*	989				4461	268
5	*Cocconeis placentula*					384	
6	*Coscinodiscus centralis*	357				992	
7	*Coscinodiscus eccentricus*	436			1349	1564	
8	*Coscinodiscus marginatus*	3129	1776			4109	
9	*Cymbella marina*					1976	157
10	*Diploneis littoralis*				1243		245
11	*Fragilaria oceanica*					873	
12	*Gramatophora marina*					981	
13	*Gyrosigma tenuissimum*	2563		385		5249	
14	*Licmophora juergensii*	2436				3381	
15	*Mastogloia pumella*			381			
16	*Navicula halophila*	536	142				
17	*Navicula mutica*	3367				4030	209
18	*Nitzschia closterium*	1698			1163	1967	
19	*Nitzschia panduriformis*	396			927	134	
20	*Planktoniella sol*	1039					
21	*Pleurosigma normanii*	324	862			1954	
22	*Podosira montagnei*					1873	304
23	*Synedra affinis*	145					
24	*Thalassiosira decipiens*						284
	Class: Chlorophyceae						
1	*Staurastrum asteroideum*					3004	
	Class: Dinophyceae						
1	*Ceratium furca*		954				
2	*Gymnodinium*						156
3	*Protoperidinium*	1203				2401	
	Class: Cyanophyceae						
1	*Oscillatoria labyrinthiformis*	1123		372			
	Grand Total	**20892**	**3734**	**1434**	**6653**	**39333**	**1687**

PRM-Pre Monsoon, MON – Monsoon, POM-Post Monsoon

Table 9. Station 6 Mangalavanam

		2003			2004		
	Class: Bacillariophyceae	**PRM**	**MON**	**POM**	**PRM**	**MON**	**POM**
1	Amphora coffeaeformis			195			
2	Amphora laevis				231		47
3	Bacillaria paradoxa						96
4	Caloneis madraspatensis		14	163			
5	Cocconeis placentula		56			176	
6	Cyclotella striata						127
7	Diploneis dydima	69			159		
8	Gyrosigma tenuissimum		189			359	174
9	Naviccula forcipata				214		
10	Navicula cincta			104			
11	Navicula henneidyi		228			299	239
12	Navicula longa				256		154
13	Navicula rhombica			164			
14	NItzschia closterium			378		231	167
15	Nitzschia longissima	94				84	
16	Nitzschia sigma					383	379
17	Pleurosigma normanii						43
18	Skeletonema costatum	58					
19	Thalassionema nitzschioides						160
20	Thalassiosira subtilis			51	196		
	Class: Cyanophyceae						
1	Oscillatoria formosa			148		41	121
2	Phormidium						57
	Grand Total	**221**	**487**	**1203**	**1056**	**1573**	**1764**

PRM-Pre Monsoon, MON – Monsoon, POM-Post Monsoon

5.3.2 Pigments:

5.3.2.1 Chlorophyll *a*:

Chlorophyll *a* is the most common pigment present in every plant, algae and cyanophyceae that perform photosynthesis. Chlorophyll *a* measurements have historically provided a useful estimate of algal biomass and its spatial and temporal variability.

In 2003, Station 1 showed highest average concentration of chlorophyll *a* during post monsoon followed by premonsoon. The average monsoon value was quite low when compared to the other two values. The concentration was very high (104.44 μgL^{-1}) during one of the post monsoon collections in October. The lowest chlorophyll *a* value recorded at this station was 2.74 μgL^{-1} in premonsoon.

In station 2, the highest average concentration of chlorophyll *a* (14.17 μgL^{-1}) was recorded during monsoon and the lowest (9.48 μgL^{-1}) during post monsoon. However, there was not much seasonal variation in the concentration of chlorophyll *a* at this station.

In station 3, chlorophyll *a* concentration showed the highest value during pre monsoon and the lowest during monsoon. There were two peaks in chlorophyll *a* concentration, one during premonsoon month of February and the other in post monsoon month of December, the values being 100.26 μgL^{-1} and 82.58 μgL^{-1} respectively.

In station 4, there was an extreme high value of chlorophyll *a* during one of the monsoon collections, 167.64 μgL^{-1}. While the highest average concentration of chlorophyll *a* was recorded during monsoon, the value obtained during pre monsoon was very low. An intermediate value was noticed

during post monsoon. The average values were 5.46 µgL^{-1}(PRM), 102.88µgL^{-1}, (MON) and 20.75 µgL^{-1}(POM).

In station 5, the highest chlorophyll *a* concentration was noticed during pre monsoon and the lowest during post monsoon. The average chlorophyll *a* value during pre monsoon was 155 µgL-1 and that in post monsoon was 17.75 µgL^{-1}. Monsoon value was an intermediate one, 103.1 µgL^{-1}. Two unusually high values were noticed at this station, one in pre monsoon (264.23 µgL^{-1}) and the other in monsoon (119.68 µgL^{-1})

Station 6 showed a comparatively low concentration of chlorophyll *a* during all seasons. The highest average concentration was recorded during post monsoon and lowest in pre monsoon. The highest value of 15.09 µgL^{-1} was obtained during the post monsoon month of October. (Fig. 21)

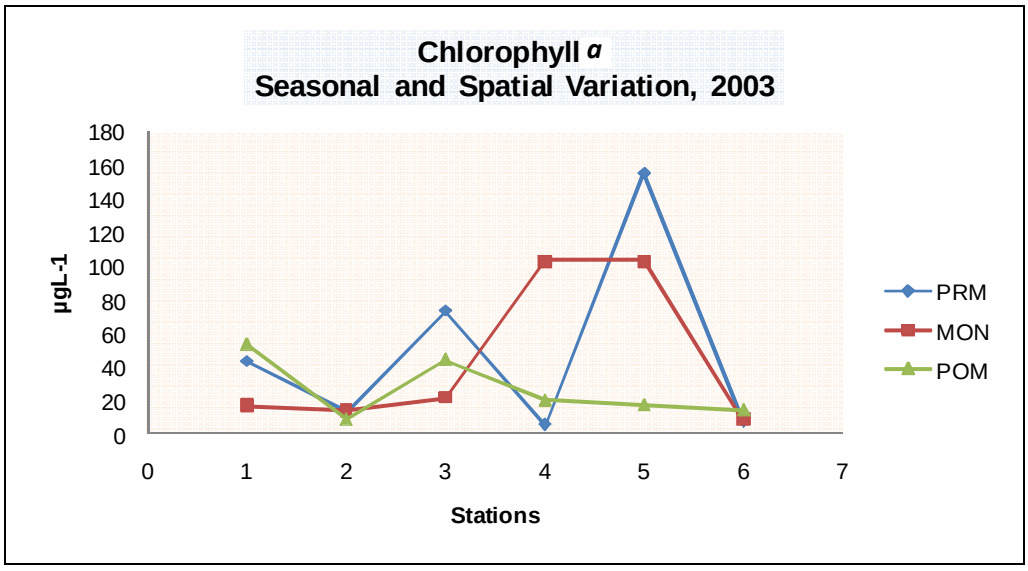


Fig. 21

In 2004, the chlorophyll *a* values showed not much seasonal variation in station 1. Both the highest and lowest values (53.71 µgL^{-1} and 32.55 µgL$^{-1)}$

were recorded during monsoon. On taking the average, the post monsoon did have an edge over the other two stations.

In station 2, the chlorophyll *a* concentration during monsoon was almost double when compared to that of the other stations. While the highest value was 31.35 μgL^{-1} recorded during monsoon, the lowest value was 10.65 μgL^{-1} recorded during post monsoon.

In station 3, there was not much difference between the chlorophyll *a* values of monsoon and post monsoon seasons, which were 48.25 μgL^{-1} and 43.72 μgL^{-1} respectively. However, the pre monsoon concentration of chlorophyll *a* was much lower, i.e., 18.86 μgL^{-1}.

In Station 4, the monsoon concentration of chlorophyll *a* was much higher (45.142 μgL^{-1}) when compared to the pre monsoon (8.55 μgL^{-1}) and post monsoon (4.82 μgL^{-1}) concentrations.

There was a concentration peak of chlorophyll *a* in station 5, during monsoon, the average value being 106.413 μgL^{-1}. The pre monsoon value was twice as that of post monsoon. While the former was 49.04 μgL^{-1} the latter was 24.095 μgL^{-1}.

There was not much seasonal variation in the concentration of chlorophyll *a* at station 6. The average values from pre monsoon to post monsoon were 14.105 μgL^{-1}, 14.7589 μgL^{-1} and 15.643 μgL^{-1}. (Fig.22)

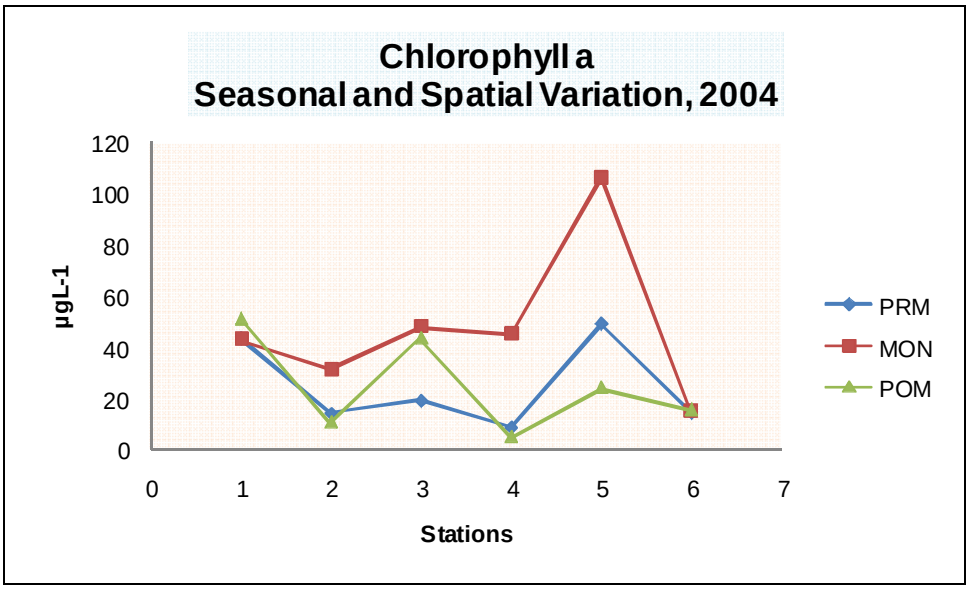


Fig.22

5.3.2.2 Chlorophyll *b*:

Chlorophyll *b* is a kind of chlorophyll that occurs only in "green algae" and in the plants. It is the major accessory pigment in chlorophytes, charophytes and euglenophytes.

The chlorophyll *b* values were very low or nil in most of the samples. (Fig. 23)

In 2003, it was present in none of the seasons at station 5 and only during monsoon at station 1. A chlorophyll *b* concentration of 0.8545 μgL^{-1} and 2.5621 μgL^{-1} were recorded at station 2 during monsoon. Station 4 was the only place from where chlorophyll *b* was detected during all the three seasons. During monsoon, this station recorded a chlorophyll *b* value of 13.591 μgL^{-1} which is very high when compared to the other values obtained during this study. While very low concentrations of chlorophyll *b* was recorded during monsoon and post monsoon at station 2, its presence in low quantities was detected during monsoon and pre monsoon at station 6.

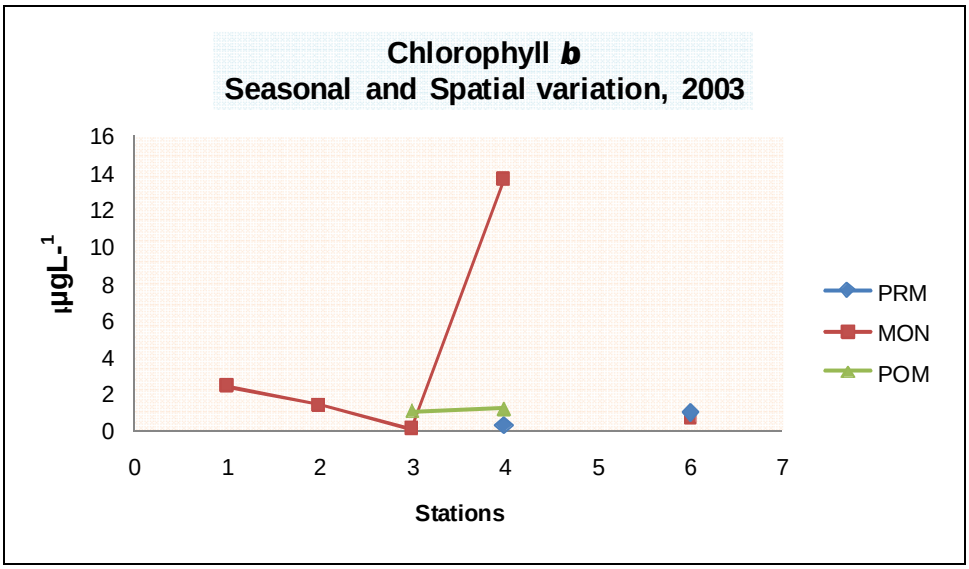


Fig. 23

Contrary to the result in 2003, the presence of chlorophyll *b* was detected more frequently in 2004. Its presence was detected in all stations, but in very low concentrations, except on three occasions. The average chlorophyll *b* values of monsoon season at station 1, 2 and 3 were 6.63 μgL^{-1}, 5.005 $\mu gL^{-1}$and 5.52 μgL^{-1} respectively. (Fig. 24)

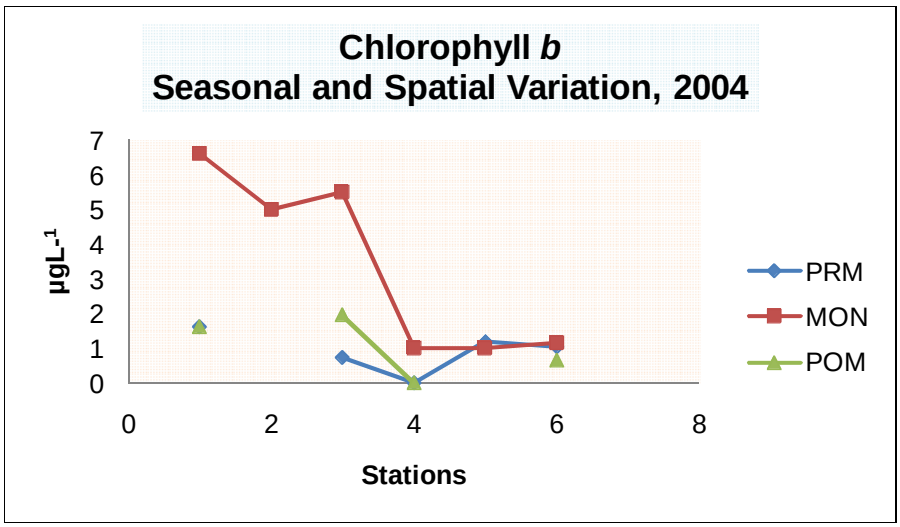


Fig. 24

5.3.2.3 Chlorophyll *c*:

It is a chlorophyll-like pigment, also known as chlorofucine and chlorophyll y. It is found along with chlorophyll a, in certain brown algae, yellow algae, diatoms, and some symbiotic algae. The two most abundant of these groups- the diatoms and dinoflagellates play a predominant part in the world-wide production of carbon compounds.

In the present study the presence of Chlorophyll *c* was observed in the samples taken from all stations during all seasons. (Fig.25). At station 1, in 2003, the highest concentration of chlorophyll *c* was recorded during pre monsoon (8.9546 μgL^{-1}) and there was practically no chlorophyll *c* during one of the post monsoon collections. In station 2, the highest concentration of 6.95 μgL^{-1} was recorded during monsoon and the lowest of 0.2146 μgL^{-1} during post monsoon. The average chlorophyll *c* concentration during pre monsoon was 2.60365 μgL^{-1}.

In station 3, there was a peak chlorophyll *c* reading during pre monsoon (19.244 μgL^{-1}). The lowest value of 2.32 μgL^{-1} was recorded during monsoon. There was a clear reduction in the amount of chlorophyll *c* during monsoon when compared to other seasons. In station 4, there was a very high chlorophyll *c* concentration during one of the monsoon collections (83.76 μgL^{-1}). The other values were moderate and the lowest of 0.82 μgL^{-1} was recorded during pre monsoon.

At station 5, the highest chlorophyll *c* value of 48.664 μgL^{-1} was recorded during pre monsoon and the lowest of 2.477 μgL^{-1} during post monsoon. There was a moderately high average value of 17.61 μgL^{-1} during monsoon. The Chlorophyll *c* values of Station 6 were comparatively low, the highest being 3.0836 μgL^{-1} recorded during post monsoon.

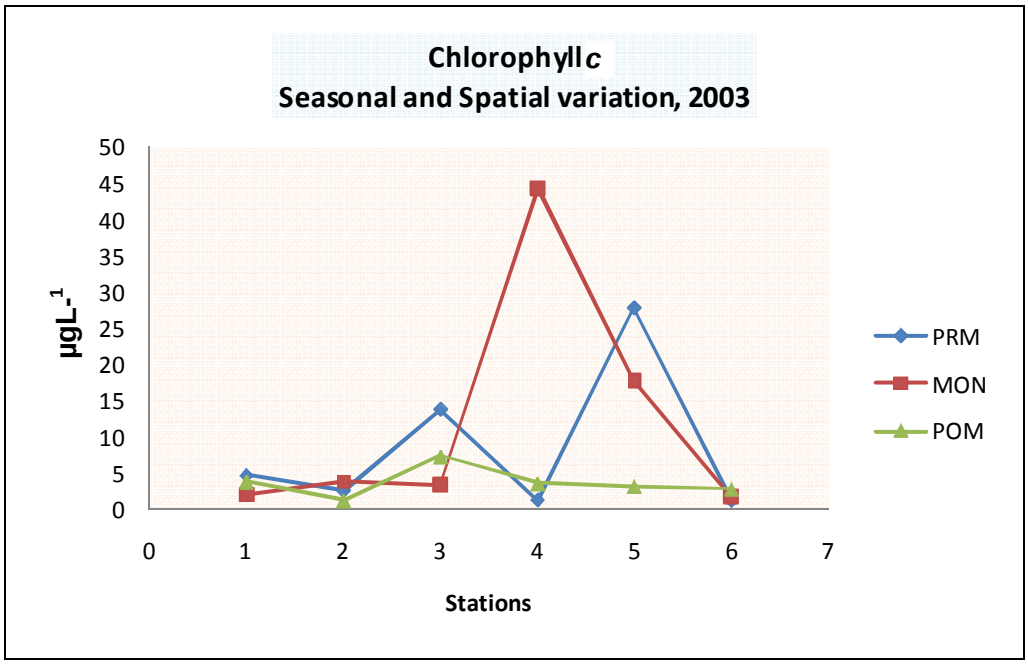


Fig. 25

In 2004, at station 1, there were high chlorophyll *c* values during monsoon and post monsoon, the highest being 21.58 μgL^{-1} recorded during monsoon. The pre monsoon value of 5.042 μgL^{-1} was the lowest.

At station 2, the highest chlorophyll *c* value of 14.854 μgL^{-1} was recorded during monsoon and the lowest of 1.18 μgL^{-1} during pre monsoon.

At station 3 also, the highest value was recorded during monsoon and it was 15.753 μgL^{-1}. The lowest value was 2.58 μgL^{-1} recorded during pre monsoon. At station 4, there was only one value that was considerably high and it was 10.76 μgL^{-1} recorded during monsoon. The lowest value was 0.94 μgL^{-1} recorded during post monsoon.

High chlorophyll *c* values were recorded during pre monsoon and monsoon at station 5. The highest was 18. 75 μgL^{-1} recorded during monsoon and the lowest was 2.09 μgL^{-1} measured during post monsoon. Station 6 was

having low chlorophyll *c* values throughout the year. While the highest was 2.75 μgL^{-1} recorded during monsoon, the lowest was 1.41 μgL^{-1} recorded during the same season. (Fig. 26)

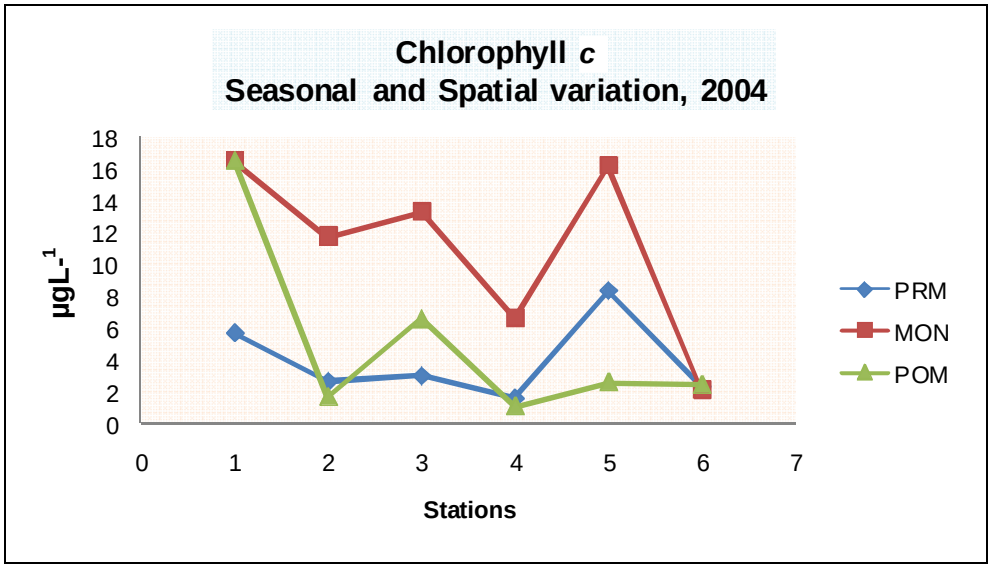


Fig. 26

5.3.2.4 Carotenoids:

Carotenoids are a group of over 600 natural lipid-soluble pigments that are primarily produced within phytoplankton, algae, and plants. The carotenoids of algae have always attracted biochemists because of their diversity as compared with those present in the leaves of higher plants.

Trace amounts of carotenes were estimated during all seasons and at all stations during this study. (Fig. 27)

In 2003, the highest concentration of carotenoids was 11.74 μgL^{-1} noted at station 4 during monsoon. The highest pre monsoon value of 5.116 μgL^{-1} was recorded from Station 1.The highest post monsoon value itself was very low and it was 1.877 recorded at station 3.

On average basis, the highest premonsoon value of 2.00 µgL¯1 was recorded at station 3 and the lowest of 0.13 µgL¯1 at station 4. While the highest monsoon average of carotenoids was 6.46 recorded at station 4, the lowest of 0.3346 µgL¯1 was recorded at station 2. The highest post monsoon value of 1.533 µgL¯1 was recorded at station 3 and the lowest of 0.2846 µgL¯1 at station 2.

While the highest values of pre monsoon and post monsoon were recorded at station 3, the lowest values of monsoon and post monsoon were recorded at station 2.

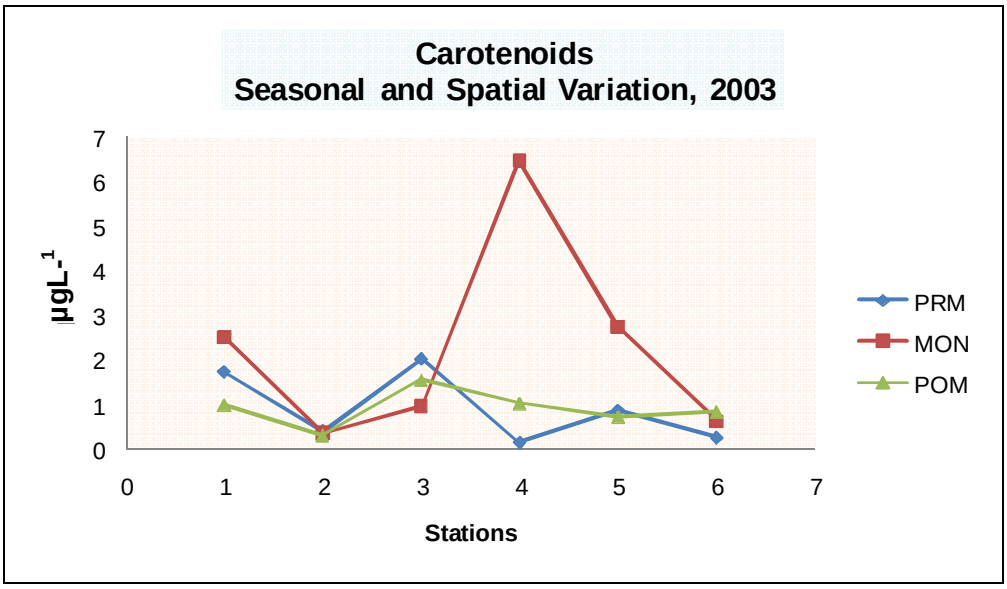


Fig. 27

In 2004, the highest premonsoon concentration of carotenoids was 2.18 recorded at station 1 and the lowest was 0.511 μgL^{-1} recorded at station 4. The highest monsoon value of the year was recorded at station 3 (2.96) and the lowest of 0.6823 μgL^{-1} at station 2. In the post monsoon of 2004, the highest carotenoid concentration of 2.32 μgL^{-1} was recorded at station 3 and the lowest

of 0.1828 µgL^{-1} at station 5. The highest carotenoid values of monsoon and post monsoon were recorded at station 3. (Fig. 28)

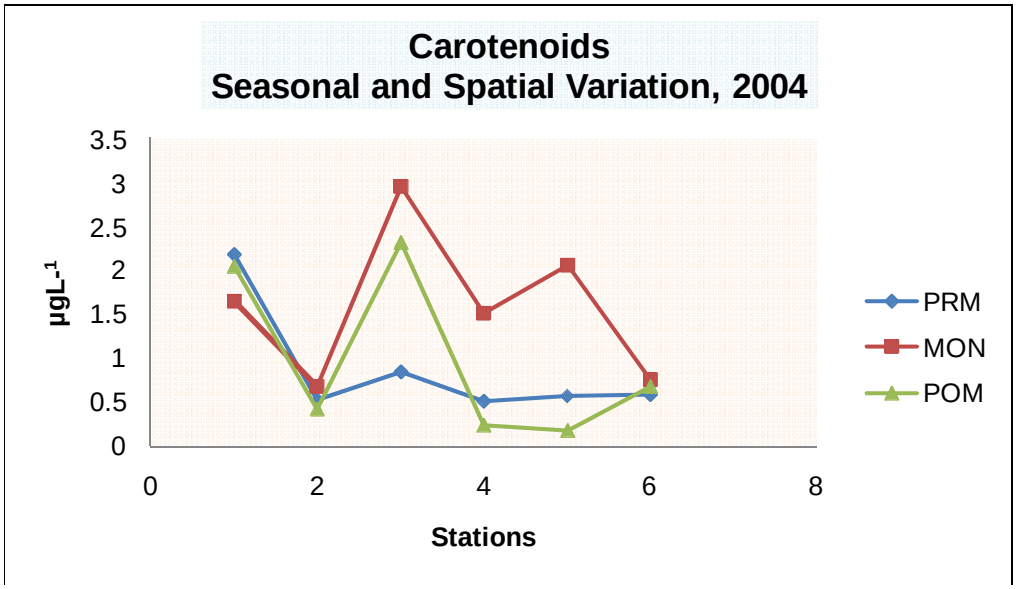


Fig. 28

Mean annual spatial variation of pigments during the year 2003 is shown in fig. 29. The highest value of chlorophyll *a* was found at station 5 with 91.95µgL^{-1} and lowest being 10.33µgL^{-1} in station 6. Chlorophyll *b* was highest in station 4, with 5.005µgL^{-1} and the lowest of 0.5354µgL^{-1} was recorded in station 3. The highest chlorophyll *c* was recorded from station 4 with 16.243µgL^{-1} and lowest being 1.78µgL^{-1} at station 6. Carotenoid pigments showed the highest value of 2.53µgL^{-1} at station 4 and the lowest of 0.3364µgL^{-1} at station 2.

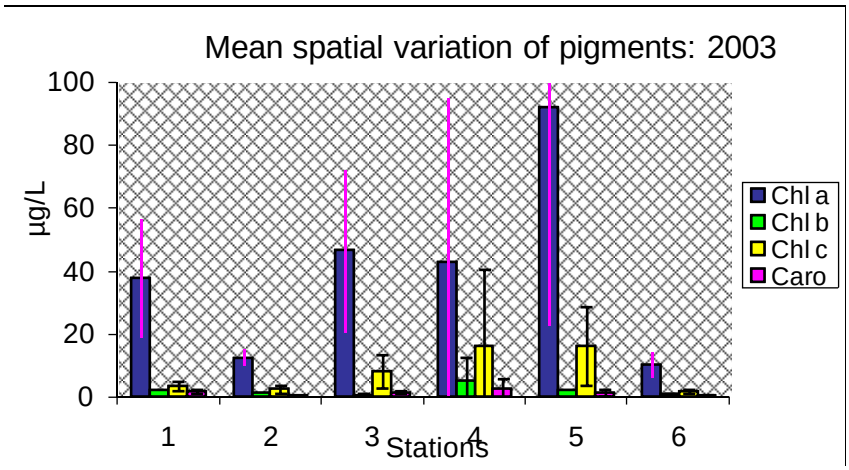


Fig. 29

Mean annual spatial variation of pigments recorded at various stations during 2004 are shown in fig. 30. The highest value of chlorophyll *a* was 59.84µgL^{-1}, at station 5 and the lowest was 14.83µgL^{-1} at station 6. The highest chlorophyll *b* was in station 2, with 5.005µgL^{-1} and the lowest of 0.3381µgL^{-1} was recorded in station 4. The highest chlorophyll *c* was 9.02µgL^{-1} in station 5 and the lowest being 2.24µgL^{-1} at station 6. The mean highest value of carotenoid pigments was 2.04µgL^{-1} recorded at station 3 and the lowest being 0.548µgL^{-1} at station 2.

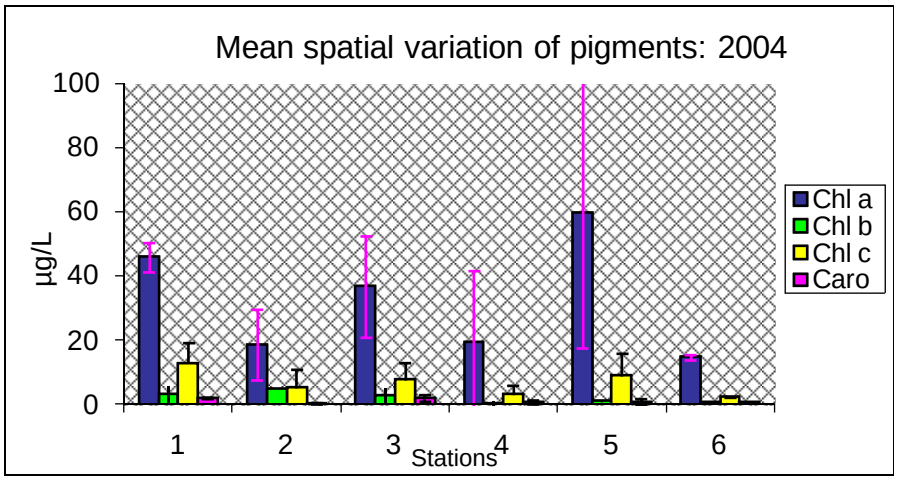


Fig. 30

5.3.3. Spatial variation of chlorophyll *a*, standing crop and primary production

The mean annual chlorophyll *a* was found to be directly proportional to the standing crop during the first year in all stations except station 5. (Fig.31). The highest chlorophyll *a* was found in station 5 (91.95 ± 69.30 mgm^{-3}) and highest cell abundance was at station 4 (11344 ± 17135 $cellsL^{-1}$). The primary productivity was found to be comparatively high in station 3 (3.126 ± 2.561gCm^3 day 1).

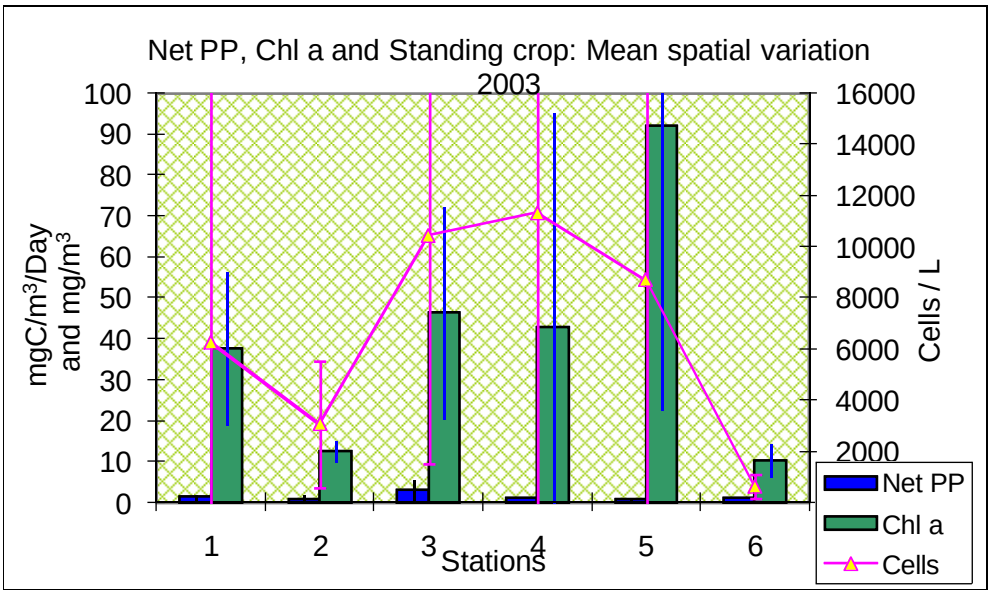


Fig. 31

The mean annual chlorophyll *a* in the second year was found to be directly proportional to standing crop, except in station 1. The highest chlorophyll *a* concentration (59.84 ± 42.21mgm^{-3}) and cell abundance (15558 $cellsL^{-1}$) were observed in station 5. The highest primary productivity being 3.94 ± 1.75gCm3 /day was observed at station 3. (Fig. 32)

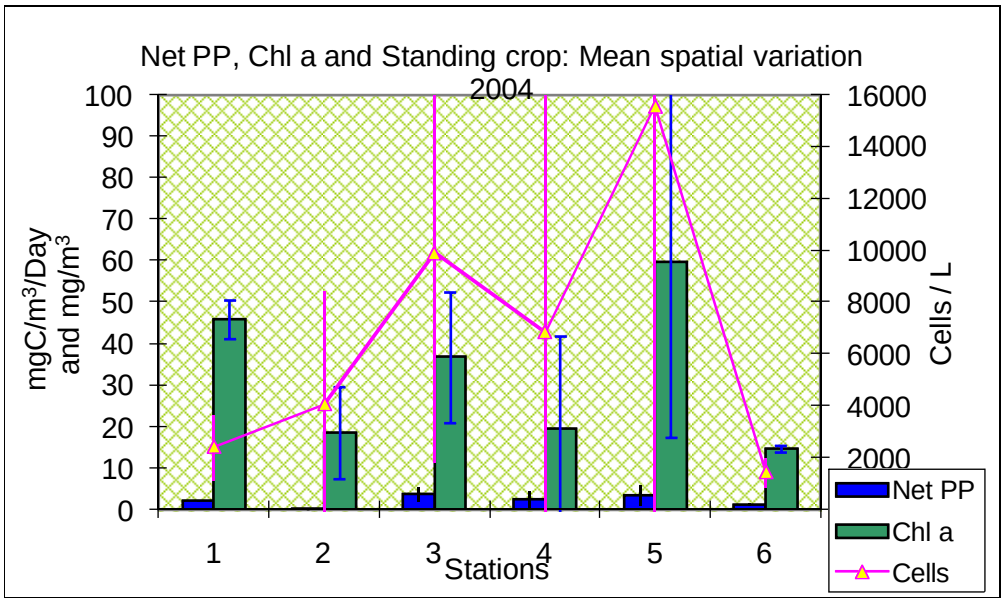


Fig. 32

5.3.4 Nutrients, chlorophyll *a* and primary productivity

Mean values of nutrients (nitrate, phosphate and silicate), chlorophyll *a* and net primary productivity during the year 2003 are shown in fig. 33.

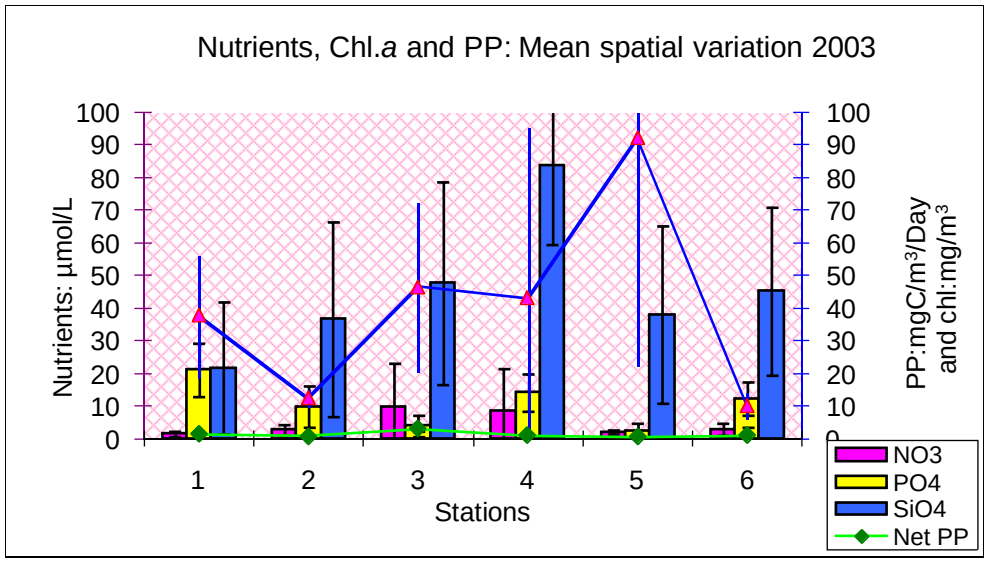


Fig. 33

Mean values of nutrients (nitrate, phosphate and silicate), chlorophyll *a* and net primary productivity during the year 2004 are shown in fig. 34.

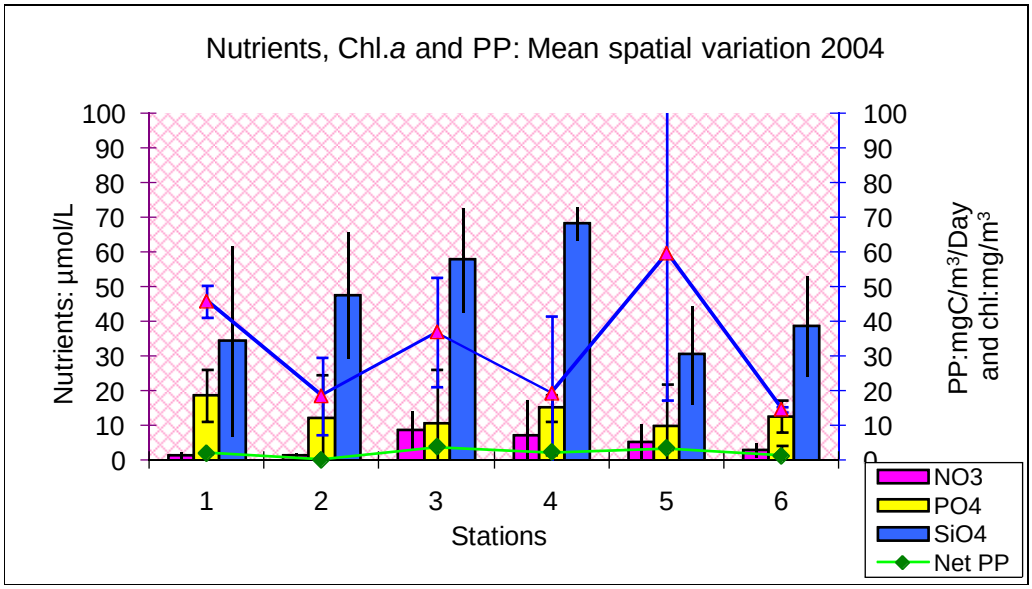


Fig. 34

5.3.5 Statistical Analysis

The three way ANOVA of pigments with station, season and year have been carried out and the results are shown in table 10.

Table 10: Chlorophyll *a*

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Station	32004.437	5	6400.887	2.523 ^{S}	0.038
Year	4365.922	1	4365.922	1.721 ^{NS}	0.194
Season	7019.839	2	3509.919	1.383 ^{NS}	0.258
Error	159832.722	63	2537.027		
Total	203222.919	71			

Chlorophyll *b*

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Station	268.809	5	53.762	1.823 NS	0.121
Year	247.392	1	247.392	8.387 S	0.005
Season	99.338	2	49.669	1.684 NS	0.194
Error	1858.227	63	29.496		
Total	2473.766	71			

Chlorophyll *c*

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Station	902.774	5	180.555	1.291 NS	0.279
Year	43.068	1	43.068	0.308 NS	0.581
Season	533.900	2	266.950	1.909 NS	0.157
Error	8812.013	63	139.873		
Total	10291.755	71			

Carotenoids

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Station	22.609	5	4.522	1.824 NS	0.121
Year	3.138	1	3.138	1.266 NS	0.265
Season	7.720	2	3.860	1.557 NS	0.219
Error	156.182	63	2.479		
Total	189.649	71			

The Pearson Correlation of all the parameters studied, are presented below: (Table 11)

Table 11

	Temp. Mud	Temp. water	Salinity (ppt)	PH	Phos.	Silicate	Nitrate	Nitrite	DO	NPP	Chl.a	Chl.b	Chl.c	Carotenoids	Active Chl.	Stng. Crop
Temp. Mud	1.000															
Temp.	.863**	1.000														
Salinity	.370**	.256*	1.000													
PH	0.081	0.072	0.177	1.000												
Phosphate	0.231	.268*	-0.193	-0.037	1.000											
Silicate	-.357**	-.303**	-.486**	-0.041	-0.147	1.000										
Nitrate	-.339**	-0.203	-.467**	-0.027	-0.165	.406**	1.000									
Nitrite	0.027	0.071	0.092	-0.043	-0.158	0.167	0.111	1.000								
DO	0.067	0.181	0.077	0.079	-0.084	0.093	0.098	.320**	1.000							
NPP	0.067	0.194	-0.077	-0.076	0.110	-0.082	.264*	0.231	.626**	1.000						
Chl.a	0.183	.261*	-0.202	0.165	-0.011	0.045	0.071	-0.029	.288*	0.190	1.000					
Chl.b	-0.178	-0.178	-0.189	-.337**	0.128	.377**	0.066	0.133	-0.053	-0.066	-.275*	1.000				
Chl.c	0.142	0.208	-.247*	0.084	0.019	0.193	0.048	-0.016	.277*	0.136	.908**	0.073	1.000			
Carotenoid	0.085	0.203	-0.195	0.137	-0.015	0.178	0.110	0.025	.362**	.254*	.842**	0.016	.833**	1.000		
Active Chl.	0.182	.276*	-0.157	0.204	-0.090	-0.084	0.103	-0.040	.327**	.271*	.911**	-.499**	.764**	.631**	1.000	
Stng. Crop	0.038	0.183	-.358**	-0.035	0.061	0.051	.382**	0.011	.311**	.500**	.779**	-.233*	.637**	.656**	.768**	1.000

5.4 Discussion:

In the first year, at station 1 (Kumbalam), the highest average cell density was recorded during post monsoon (9150cellsL^{-1}) and the lowest of 53 cellsL^{-1}during the pre monsoon (Table 4). During one of the collections in October, 2003(post monsoon), the maximum cell density went upto 26134 cellsL^{-1}.

While the highest average cell density (9150 cellsL^{-1}) was obtained during the post monsoon months of October, November, December and January, the lowest average was recorded during monsoon (380 cellsL^{-1}).

In general, the distribution and abundance of phytoplankton vary remarkably in tropical waters due to seasonal variations in hydrological parameters and these variations are highly pronounced in mangrove habitats (Raj Kumar *et al*., 2009) and this has been reflected in the above observations. 24 species of phytoplankton were identified from station 1 in 2003, out of

which 21 were diatoms. There was one species each from Chlorophyceae, Dinophyceae and Cyanophyceae.

None of the microalgae except *Nitzschia closterium, Pleurosigma aestuarii* and *Navicula mutica* was present during all three seasons. This indicates the steno-haline nature of these diatoms.

High population density during post monsoon was due to the predominance of diatoms – *Pleurosigma aestuarii, Nitzschia closterium, Asterionella japonica, Chaetoceros brevis,* and *Navicula mutica*. The abundance of these algae during the post monsoon months with an average temperature of around 29^0C indicates their thermophilic nature.

A comparatively high salinity, pH, temperature and light penetration could be the favourable conditions for the growth of these micro algae (Mani and Krishnamurthy, 1989). It has to be noted that two highest values of cell density have been received in the year when the salinity levels were high, but within the threshold limit of 21 ppt. Manna *et al*. (2010) reports similar results from Sundarban mangroves.

The low abundance of phytoplankton during monsoon could be due to the unusual stratification of water column, reduced salinity due to rain fall, high turbidity, low temperature and low pH. Presence of fresh water algae during monsoon shows a change in floral composition in accordance with change in salinity due to the dilution or mixing of fresh water. Generally during the monsoon, the floral composition will change in accordance with the lowering of salinity in estuarine conditions (Gopinathan, 1972; Joseph and Pillai 1975; Gao and Song, 2005). The only dinoflagellate noticed in the year was *Ceratium furca* and according to Tailor *et al*. (2008), *Ceratium* spp. is the most abundant dinoflagellate in tropical waters.

In 2004, the highest and lowest standing crop from station 1 was recorded during monsoon and the figures were 3828 cellsL^{-1} and 847 cellsL^{-1} respectively.

The phytoplankton species encountered at station1 in 2004 was 25. There were 22 species of diatoms and 3 chlorophyceaen members. No cyanophyceaen and dinophycean species was encountered during this year. All the three chlorophycean members were present during the monsoon, indicating the reduction in salinity that occurred in the system. The highest average cell abundance was noted during pre monsoon and lowest during post monsoon. In this station, the highest concentration of standing crop was obtained during monsoon and this could be due to the high silicate: nitrate ratio as suggested by Piehler *et al.*, (2004). Here the Si: N ratio was 34:1 which would have favoured luxuriant growth of diatoms.

Selvaraj *et al.* (2003) while studying the seasonal variation of phytoplankton and productivity in the surf zone and back waters at Cochin observed a trimodal pattern in the cell count with peaks during October (POM), January (POM) and April- May (PRM). The pattern observed in the present study during 2003, can be taken as a bimodal one with peaks in October and April.

At station 2 (Panangad), the highest cell density of 7342 cellsL^{-1} was recorded during monsoon and the lowest of 534 cellsL^{-1} was recorded during post monsoon in 2003. In 2004, the highest cell density of 11442 cellsL^{-1} was recorded during monsoon and the lowest of 815 cellsL^{-1} during post monsoon.

It is evident that the result was different in station 2 on comparison with station 1. *Nitzschia closterium* and *Pleurosigma aestuarii* were seen in large numbers during this period. There was a single peak in cell count during each

year which was in contrast with the bi modal pattern observed in the first station. Unlike in station 1, the highest individual and average values of cell density were observed during monsoon. The biomass values represented by chlorophyll concentration were also high during these peaks. In both the occasions, salinity was comparatively low and the phytoplankton number was contributed significantly by chlorophycean and cyanophycean members and by those diatoms like *Nitzschia* and *Pleurosigma* that usually bloom during monsoon. (Selvaraj *et al*., 2003).

There were 22 species of phytoplankton identified from station 2 during 2003 which showed distinct seasonal variations. Besides diatoms, there were two Cyanophycean and two Chlorophycean species encountered in 2003 at this station. Like in station 1, the diversity of species has increased during the second year. The non diatom members were two Chlorophyceae, two Cyanophyceae and one Dinophyceae.

High Si: N ratio appears to be the common factor present during the two peaks which fell in two different seasons. While it was 0.031 in 2003, 0.176 in 2004. While salinity was as high as 18 ppt during the peak density in 2003, it was 6.4 in 2004. This change in salinity is reflected in the floral composition. Another important observation made at this station was the decrease in number of cells with a high silicate value during one of the monsoon collections in 2003. According to Piehler *et al*. (2004), if the nutrient ratios go beyond an optimum, it will adversely affect the distribution of micro algae and this could be the reason for reduced number of cells with increase in concentration of silicates.

The presence of *Spirulina* in station 1 and 2 deserves to be emphasized due to its high nutritional significance.

At station 3 (Nettoor), there was a considerable increase in the standing crop when compared to the other stations in all seasons in both the years. However, the highest cell density was noticed during a collection in pre monsoon and it read 28325 cellsL^{-1}. The lowest value of 2473 cellsL^{-1} in this station was obtained during post monsoon. While the highest cell density in 2004 was recorded during monsoon (20942 cellsL^{-1}), the lowest was recorded during pre monsoon (2873 cellsL^{-1})

The high values of cell density irrespective of the season point to the favourable conditions that are extended by the station to the plankton growth. The station was having stable environment with good water quality. The optimum salinity and high Si: N ratio could be the reasons for high diversity and density of phytoplankton observed in the study during pre monsoon (summer). High macroalgal densities during summer were recorded by Nedumaran and Perumal in 2009 while studying the temporal and spatial variation in the structure of macroalgal communities associated with mangroves of Pichavaram. Nedumaran and Prabhu (2009) made similar observations for microalgae at Pichavaram mangrove waters.

In 2004, the nitrate concentration was exceptionally high and the ratio between Si and N was high in monsoon. This could be the reason for high cell number. Even though the cell density was high, the species richness was low, with only 18 diatoms, during this period. This could be due to low salinity.

Another important observation made at station 3 was that there occurred a considerable decrease in the standing crop when the salinity value exceeded 21 ppt. This is in agreement with the findings of Manna *et al.*, (2010) in Sundarban mangroves, which states that a threshold in biomass production of phytoplankton is reached at salinity level around 21 ppt. Two samples taken at

a salinity of 20.5 ppt also showed reduction in phytoplankton density and these are the only occasions when cell count went below a moderate level at station 3. It can therefore be inferred that salinity acts as a limiting factor of cell density in station 3.

A total of 38 microalgae were observed in this station out of which 31 were diatoms. In 2003, it was 23 diatoms + 3 Chlorophyceae + 1 Cyanophyceae + I dinoflagellate. The class composition during 2004 was 23 diatoms + 1 Cyanophyceae + 1 Dinoflagellate. The Cyanophycean members *Phormidium* and *Microcystis* made their appearance during this study in this station. Cyanobacteria, a group of photosynthetic prokaryotes, are vital components of the microbiota which functions as a source of nitrogen in every mangrove ecosystem (Kathiresan and Bingham, 2001). This is one of the ignored groups where only a very few studies have been conducted. Their ability to fix atmospheric nitrogen make them natural candidates for future reforestation and rehabilitation of destroyed mangroves (Bashan *et al.*, 1998). Nedumaran *et al* (2009) have enumerated both *Phormidium* and *Microcystis* from Pichavaram mangroves.

At station 4 (Puthuvaipu), there was clear seasonal variation in cell density with the highest value during monsoon. The average cell density in the station during monsoon in 2003 was 47762 cellsL^{-1}. The lowest cell abundance of 364 cellsL^{-1} was recorded during post monsoon. During the next year, the highest density was recorded during monsoon (31765 cellsL^{-1}) with a seasonal average of 18357 cellsL^{-1}. The lowest value of 421 cellsL^{-1} was recorded during post monsoon.

Here, the highest standing crop in both the years was recorded during monsoon and lowest in post monsoon. The seasonal variation is clearly evident

and the high standing crop during monsoon could be due to the entry of high amount of nutrients into the ecosystem. Majority of the phytoplankton, number wise, were diatoms with good representation from chlorophyceae and cyanophyceae. There was a high Si: N ratio on both occasions of high standing crop. Out of the 33 species of planktonic microalgae, 26 were diatoms. Three dinoflagellates were identified from this station- *Ceratium, Protoperidinium* and *Gymnodinium*. According to Subramaniyan (1971) and Gopinathan (1972), *Protoperidinium* are abundant in Indian waters. The appearance of this flagellate in this station could be due to its closeness with the sea. An observation similar to that made by Essien *et al*. (2008) in the Qua Iboe estuary mangrove swamp of Nigeria, was made from this station. Centric diatoms like *Coscinodiscus centralis, C. eccentricus, C. marginata, Thalassiosira subtilis* and *Triceratium favus* along with green algae- *Chlorella* and *Cosmarium* and blue green alga- *Nostoc punctiforme* were encountered at this station during monsoon. Essien encountered some centric diatoms including the above ones and some green and blue green algae in greater numbers during the wet season. The presence of fresh water alga, *Cosmarium* is an indication of low salinity (average 4ppt) associated with diluting influence of rain water and flooding. The presence of *Melosira numuloides* in the station need special mention since the centrale isolated from the mangrove forests of Xuanthuy National park has been found to possess high amounts of poly unsaturated fatty acids (Hoa *et al*. 2010).

In the first year, at station 5, Murikkinpadam, the trend was different with one of the pre monsoon collections showing the highest cell density of 35894 cellsL^{-1}, the average seasonal cell density being 20892 cellsL^{-1}. The lowest cell density of the station was recorded during post monsoon and the abundance was 922 cellsL^{-1}. In the second year, however, the monsoon density

of cells was very high compared to other seasons and a figure of 67324 cellsL^{-1} was obtained in one of the collections. The lowest density of 606 cellsL^{-1} was obtained during post monsoon. A total of 29 species were identified from this station, diatoms leading the table with a strength of 24 members. *Asterionella japonica,* three species of *Coscinodiscus, Bacillaria paradoxa, Licmophora juergensii*, *Gyrosigma tenuissimum* and *Navicula muticum* were abundant in both the years.

Occurrence of 16 species of planktonic microalgae during the premonsoon in the first year of this study needs to be highlighted. In a similar study conducted at the Sundarbans, Manna *et al.* (2010) observed a decline in diversity index and phytoplankton biomass during the pre monsoon season. On analyzing the hydrographic parameters prevailed in the station during that premonsoon period, it is found that the temperature and salinity were moderately high and the hydrogen ion concentration was slightly alkaline. This points to the fact that these microalgae present during the summer (pre monsoon) were thermophilic and euryhaline - many of them were not present in the monsoon - in nature. The concentration of nutrients was uniform and no unusual fluctuations were noticed. This points to the stability of the system and the uniform utilization of nutrients by the different floral components. High summer biomass of phytoplankton as noticed here, was earlier reported by Nedumaran and Prabu (2009) in the Pichavaram mangroves.

The least cell density and species richness were noted at Station 6. There were only 22 species of planktonic microalgae identified from this station. *Nitzschia sigma, Nitzschia closterium, Navicula henneidyi and Gyrosigma tenuissimum* were the dominant species. Mangalavanam has become a highly polluted area due to anthropogenic activities and due to the release of industrial effluents. The acidity to the soil brought by the faecal matter of the permanent

and migratory bird community adds to its hostility. Excessive abundance of *Navicula* (3 species), *Nitzschia* (3 species) and centrales like *Thalasiosira* and *Cyclotella striata* is an indication of the degree of pollution that threatens even the existence of this patchy mangrove pocket. Diatoms have been used as indicators of pollution from very old days and it was Kolkwitz and Marsson (1908) who pioneered this aspect of diatom study. Munawar (1970) reported that diatoms like *Navicula, Pinnularia* and *Nitzschia* develop profusely in waters rich in pollution of animal origin and the abundant presence of two of them in Mangalavanam supports this view. Disappearance of *Achnanthes* and presence of *Nitzschia* had been reported by Schoeman (1976) as an indication of anaerobic condition while studying diatoms as indicator groups in the assessment of water quality in a river system in South Africa. The same observation in the present study confirms the hypoxic condition that prevails in the Mangalavanam mangroves.

Overall, 72 planktonic microalgae were identified from the six mangrove ecosystems studied during 2003-2004. They belong to 42 genera and 4 classes, viz. Bacillariophyceae, Chlorophyceae, Cyanophyceae and Dinophyceae. While there were 30 genera from Bacillariophyceae, 5 were from Cyanophyceae, 4 from chlorophyceae and 3 from dinophyceae. Bacillariophyceae dominated the planktonic microalgae in all the mangrove ecosystems studied. Out of the 72 species, 57 were diatoms (79.16%), followed by blue greens with 7 species (9.72%), green algae with 5 species (6.94%) and Dinophyceae with 3 species (4.16%). Among the diatoms, *Navicula* was represented by 8 species, *Nitzschia* by 5 species, and *Amphora* and *Coscinodiscus* with 4 species each. All these genera represented by more species are usually encountered in coastal waters (Van den Hock *et al*. 1995., Tomas, 1997). Among Dinophyceae, there were three genera each represented by one species. These were *Ceratium furca,*

Gymnodinium and *Protoperidinium. Oscillatoria* which is reported by Desikachary (1959) and Thajudin and Subramanyan, (2005) as common species found in both fresh water and marine habitats in India, was encountered (3 species) during this study. Chlorophycean members appeared in all the stations during monsoon. Though appeared mainly during monsoon, some blue greens like *Phormidium* and *Oscillatoria* were present during post monsoon also. This is in contradiction to the findings of Gowda *et al*. (2001) who reported that blue green algae are practically nil during monsoon and post monsoon in Netravathy estuary.

5.4.1 Pigments

5.4.1.1Chlorophyll *a:*

In 2003, concentration of chlorophyll *a* showed wide fluctuations, both seasonally and spatially. The pre monsoon values were quite low and values of post monsoon were slightly higher than pre monsoon. In the next year, the peak chlorophyll *a* concentration was found at station 3, in the monsoon and post monsoon.

Chlorophyll *a* values were low at station 1, 3 and 6 and were comparatively low at station 5 during monsoon in 2003. Even though the highest chlorophyll *a* value at station 2 was recorded during monsoon, it also was a moderate value. This indicates a general trend of low chl.a value in monsoon. The reduction in chlorophyll values during south west monsoon may be due to dilution of water due to the entry of fresh water, which causes high turbidity and low light availability. This view is supported by the observations made by Raj kumar *et al.* (2009), Kawabata *et al.* (1993), Godhantaraman (2002), and Rajasekhar *et al.*(2005). However, there were two monsoon peaks of chlorophyll *a*, one each at station 4 and 5. Both were not during the peak

monsoon and hence the turbidity of water was less and the salinity was not too low. Nutrient rich land run off might also have contributed to the high chlorophyll *a* value during monsoon. There were high values of chlorophyll *a* during pre and post monsoon at station 3. It was the station that recorded highest species richness and density. This was a station with optimum salinity and high SI: N ratios that favour microalgal growth and these could be the reasons for high chlorophyll *a* value.

In 2004, there was one peak concentration of chlorophyll *a* during monsoon at station 5. Low chlorophyll *a* values irrespective of the season were noted at station 6, and this could be due to the high rate of pollution at that station. Since it is a sheltered station, there was not much seasonal variation also.

The seasonal average of chlorophyll *a* values in 2003 were: 49.68 μgL^{-1} during pre monsoon, 58.51 μgL^{-1} during monsoon and 26.84 μgL^{-1} during post monsoon. In 2004, the values were 24.6 μgL^{-1}, 48.15 μgL^{-1} and 25.04 μgL^{-1} respectively.

Raj Kumar *et al.* (2009) have estimated a chlorophyll *a* value ranging between 0.24 μgL^{-1} - 69.82 μgL^{-1}, 0.20 μgL^{-1} - 105.60 μgL^{-1}, and 0.20 μgL^{-1} to 94.80 μgL^{-1} in three stations of Pichavaram mangroves.

The surf water off Gopalpur, in the Bay of Bengal, chlorophyll *a* was found between 3.31 to 99.12μgL^{-1} (Panigraphy *et al.*, 2006). The concentration of surface chlorophyll *a* varied between 0.21 to 30.82μgL^{-1} off Mangalore, west coast of India (Lingadhal *et al.*, 2003). The highest chlorophyll *a* value observed during the post monsoon off Cape Comorin was 8.28μgL^{-1} (Gopinathan *et al.*, 2001).

The highly seasonal nature of monsoon rains and the associated land runoff and nutrient loading determines the balance of organic to inorganic loadings which act as major factors controlling community responses of microalgae (Hopkinson and Vallino 1995).

Another observation made during this study was that there was a trend of high chlorophyll *a* values during the post monsoon climatic conditions. Some of the high chlorophyll *a* values noted are:

104.44 μgL^{-1}	October, 2003	Station 1
100.26 μgL^{-1}	February, 2003	Station 3
82.58 μgL^{-1}	December, 2003	Station 3
167.64 μgL^{-1}	August, 2003	Station 4
264.2 μgL^{-1}	March, 2003	Station 5
128.8 μgL^{-1}	September, 2004	Station 5

While the first three were in the post monsoon season itself, the other three were either during the last phase of monsoon or during the first phase premonsoon. This observation goes in tune with that of Manna *et al.* (2010). While studying the dynamics of Sundarban mangrove ecosystem, the authors observed high chlorophyll *a* concentrations during the winter months which correspond to the post monsoon season of this study. As explained by Jones *et al.* (1982), this could be due to the eutrophic conditions prevailed during post monsoon.

Pearson correlation analyses reveal high degree of correlation of chlorophyll *a* with chlorophyll *c*, active chlorophyll and standing crop. The correlation was significance at 0.01 level. Three way ANOVA with stations, seasons and year showed significant variation with stations (p value was 0.038

while the reference value is .05). However, no significant variation was noticed with season or year. The annual average of chlorophyll *a* varied from 37.74 $\mu gL^{-1}$to 227.69 μgL^{-1}between stations. The seasonal average calculated for the different seasons in 2003 are 49.68 μgL^{-1} (PRM), 44.54 μgL^{-1} (MON) and 26.84 μgL^{-1} (POM). In 2004, the respective values were 24.63 μgL^{-1}, 48.15 μgL^{-1}, and 25.04 μgL^{-1}. The high chlorophyll *a* values obtained for monsoon season may be the result of nutrient rich land run off from the adjacent areas.

5.4.1.2 Chlorophyll *b*:

It was only in station 4 that chl. *b* was detected during all three climatic seasons in 2003. A chl.*b* value as high as 13.6 μgL^{-1} was recorded from this station during monsoon. Even though presence of chlorophyll *b* is an indicator of chlorophyceae, no chlorophycean member could not be enumerated in stations 2 ad 6 even when chlorophyll *b* was there. A relatively high chlorophyll *b* indicates the presence of ultra or nano-planktonic microalgae coming under the class Chlorophyceae /Euglenophyceae /Prochlorophyceae, (Van den Hoek *et al.* 1995) in these stations which could not be counted using a Sedgewick-Rafter counting cell. Pre and post monsoon concentrations of chlorophyll *b* were substantially negligible in all stations. The high abundance of chlorophyceae during monsoon at station 3 emphasizes the origin of chl.*b* from this group of algae.

Another important observation was that the station which recorded high concentration of chl.*b* also recorded high values of chlorophyll *a*. Gopinathan *et al.* (2001) while studying the concentrations of chl. *a* and chl.*b* in the west coast of India has noticed that there is a positive correlation between chlorophyll *a* and *b* as noticed in the present study. High values of chlorophyll *b* observed at

Calicut and Wadge Bank area of the south west coast and off Goa and Mumbai coincided with high concentrations of chlorophyll '*a*'.

Though chlorophyll *b* is considered to be an accessory photosynthetic pigment of chlorophyll *a*, its concentration is significant for assessing the fertility of the area.

In 2004, high concentration of chl.*b* was observed in stations 1, 2, 3 during monsoon and this could be due to the favourable conditions developed in these stations for the growth of chlorophycean members during monsoon. Salinity in these stations ranged between 5 and 8 and this low salinity could have encouraged the growth of green algae like *Chlorella, Cosmarium* and blue greens like *Oscillatoria*. These three stations are located away from sea when compared to the others and this could be the reason for low salinity. Chlorophyll *b* showed negative correlation with temperature, salinity and pH., however it was having significant positive correlation with the concentration of silicates, with the level of correlation at 0.01 level. Three way ANOVA showed significant variation only with the year, the p value being 0.005.

5.4.1.3 Chlorophyll *c*:

In station 3 there was a clear reduction in the amount of chlorophyll *c* during monsoon in 2003. This could be due to the decreased abundance of diatoms in low salinity conditions.

There were some high chl.*c* values in station 4 and 5. These are the stations nearer to the sea and naturally salinity is comparatively high in these stations. This might have caused an increase in the number of diatoms. Standing crop is very high in accordance with the hike in chl.*c* concentration in these stations.

It is evident that chlorophyll *c* is a major accessory pigment of diatoms (Hendey, 1964, van den Hoek *et al.*, 1995) and hence it would increase when the standing crop of diatoms increased and vice versa.

Seasonal variation of chl. *c* was evident in 2004 also. Its low concentration always matches with the decreased abundance of diatoms. Analysis of variance showed no significant variation with station, season or year. Chlorophyll *c* showed 0.01 level of correlation with chlorophyll *a*, standing crop and dissolved oxygen, which is a sign of diatom abundance in the standing crop.

5.4.1.4 Carotenoids:

Presences of carotenoids have been recognized at all stations during all seasons and they exhibited distinct spatial variations. In both the years, its concentration was comparatively higher in stations 4 and 5. These were the stations with high diatom abundance which was supported by high salinity. These are the stations close to the sea.

The major pigment in the carotenoids was fucoxanthin, which is the key accessory pigment for diatoms. During monsoon, the abundance of diatoms was comparatively lower except in station 4 and 5 and hence the concentrations of carotenoids were also found to be lower. No prominent variation was found during pre and post monsoon.

The seasonal variation of pigment concentration was prominent during the entire period of study. The Pearson Correlation analyses have shown that the pigments are having significant positive correlation with each other at 0.01 level. The most significant correlation was shown between chlorophyll *a* and *c* (0.908) and between chlorophyll *c* and carotenoids (0.833). This also confirms high diatom abundance. Lingadhal *et al.*, (2003), noticed a positive correlation

between chlorophyll pigments in the selected light depths off Mangalore, west coast of India.

Another important correlation was between chlorophyll *a* and standing crop. These were highly correlated with a coefficient of 0.779, which is far above the p value of 0.05.

It can be summarized that when standing crop increases, chlorophyll *a* also increases and vice versa. Present investigation is supported by several studies worldwide (Gu *et al.*, 1995; Balkis, 2003; Huang *et al.*, 2004; Aktan *et al.*, 2005).

5.4.2 N:P and Si:N ratios and relationships with standing crop and chlorophyll *a.*

Predicting phytoplankton dynamics and devising management strategies in estuarine waters often involves the use of stoichiometric relationships of inorganic nutrient concentrations (Piehler *et al.*, 2004). The so called Redfield ratio (Redfield, 1934), 106 C: 16N: 1P (by atoms) has long been used as a canonical value to predict phytoplankton- nutrient limitation in aquatic ecosystems (Falkowski, 2000). According to Aktan *et al.*, (2005) the total nitrogen and total phosphorus availability leads to the minimal N:P ratios under in the theoretical assimilation ratio of 16:1 for the world's oceans.

In the present study, the N: P ratios were very low with the highest value of 2.021 recorded at one of the stations in 2003. Aktan *et al*, (2005), in their study conducted in Izmit Bay, Turkey. reported that N:P ratio would vary from 8.2 to 45 depending on ecological conditions and further stated that the Redfield N:P ratio of 16 is not a biochemical optimum but represents an average of species-specific N:P ratios. It is also noted that recent research on

algal physiology elucidate that the structural N: P ratio is species specific (Klausmeler *et al.*, 2004).

Another important aspect of nutrient relation was Si:N ratio which if less than 1 will limit the growth of diatoms according to Piehler *et al.* (2004). The coastal and estuarine waters along the southwest India prevails a comparatively higher Si: N ratio during 2005-08 which promoted the abundance of diatoms species (Sanilkumar, 2009, Sanilkumar *et al.*, 2009) In the present study, this ratio was always higher ranging from 4.71 to 16.86 in 2003 and 5.54 to 30.55 in 2004 and favoured the growth of diatoms.

5.4.3 Primary Productivity:

Mangrove areas are among the most productive ecosystems of the world. The average rate of production of organic material according to Kathiresan (1995) is 29g/m^2/day and the annual litter fall normally ranges from 10000 to 14000 Kg. dry weight per hectare.

This is in agreement with the findings of Klaus Gocke *et al.* (2001) while studying the planktonic primary production in a tidally influenced mangrove forest on the pacific coast of Costa Rica. Here, the NPP was significantly high during dry seasons than during the peak of monsoon. The annual NPP was 278 gC/$m^{2.}$

According to Rajagopalan *et al.* (1986), the productivity values of mangroves of Cochin back waters ranged from 0.37 to 1.37 g.C./m^3/d with an annual average production rate of 0.66 g.C./m^3/d while the highest values reached upto 2.15 g.C./m^3/d.

As per the studies conducted by Selvaraj (2000), the seasonal average primary productivity values in the waters of Godavari mangrove ecosystem around Kakinada (Andhra Pradesh) ranged from 0.25 to 0.75 g. C/m^3/d with the mean value of less than 0.5 gC/m^3/d although the highest value at some areas

reached upto 2.5 gC/m^3/d; In the Pichavaram mangrove waters (Tamil Nadu), the seasonal averages ranged from 0.36 to 3.3 g.C/m^3/d with the mean value of 1.67 gC/m^3/d while the highest value reached upto 5.3 gC/m^3/d; And In the Dharmadam estuarine waters associated to the mangroves (Kerala State), the seasonal average values ranged from 0.24 to 1.14 gC/m^3/d with the mean production rate of 0.63 gC/m^3/d and the highest value reaching upto 2.07 gC/m^3/d in summer months.

For Pichavaram mangroves on the east coast, Krishnamurthy and Sundararaj (1973) have given an average primary production rate of 7.5 gmC/m^3/day, indicating high production in the ecosystem.

Regarding the primary productivity of the mangrove associated waters, Gopinathan and Rajagopalan (1983) have reviewed the productivity potential of the Andaman-Nicobar mangrove zones. According to them, the values ranged from 0.2 to 0.8 g. C/m^2/day in the Northern Andamans, slightly higher values of 0.5 to 1.0 gC/ m^2/day in the shallow mud flats and mangrove zone of Car-Nicobar and very high production rate of 2.0 to 3.6 gC/m^2/day recorded in and around the mangroves of Port Blair.

While studying the nutrient and phytoplankton dynamics in two mangrove tidal creeks of the Indus river delta, Pakistan, Harrison *et al.*(1997) reported a primary productivity that ranged from 0.15 to 1 gm carbon /m^2/ day in Isaro creek. These authors also reported low productivity during monsoon.

As such different values have been presented by different authors for the primary productivity of mangrove associated waters in different areas. It is interesting to note that entirely different values have been presented by different authors for the same area and this might be due to the different methods adopted for the same study.

In the present study, the monthly net primary productivity of the selected stations showed a high degree of scattering. In 2003, the seasonal average of productivity was low during monsoon when compared to the other two seasons. The average seasonal productivity values for the year were 2.193 gC/m^3/day (pre monsoon), 0.9206 gC/m^3/day (monsoon) and 1.112 gC/m^3/day (post monsoon). The unusual hike in chlorophyll values, especially during monsoon (e.g. August, 2003) was not proportionately reflected in the primary productivity values. This may be due to the origin of chlorophyll from detritus and from partly dead cells in suspension, resulting from sudden changes in the hydrographic components. Primary productivity in mangrove ecosystems of Cochin back waters, in terms of the total number of cells showed strong seasonal trends even though generalizations are not possible due to spatial differences. The mean spatial values of primary productivity in 2003 ranged from 3.126 $\pm$ 2.56 gC/m^3/day recorded at station 3 to 0.7576 $\pm$ 0.2180 gC/m^3/day recorded at station 5. The mean planktonic primary productivity value for the entire mangrove stations studied can be arrived at 1.4088 $\pm$ 0.870 gm C/m^3/day or 514.212$\pm$ 317.55 gm C/m^3/year. In the second year the mean productivity values for the different stations ranged from 3.9426 $\pm$ 1.75 gm C/m^3/day recorded for station 3 to 0.21 $\pm$ 0.095 gm C/m^3/day recorded for station 2. The mean planktonic primary productivity value for the entire mangrove stations studied becomes 2.2576 $\pm$ 1.358 gC/m^3/day or 824.024 $\pm$ 495.67 gC/m^3/year.

This clearly shows the significance of plankton productivity in the mangrove ecosystem which has usually been neglected. Any productivity estimate of mangrove ecosystem should therefore invariably include the contribution of planktonic algae present in the system.

Chapter 6

MICROPHYTOBENTHOS

6.1 Introduction

Microphytobenthos are unicellular eukaryotic algae and cyanobacteria that grow within the upper several millimeters of illuminated sediments, typically appearing only as a subtle brownish or greenish shading (MacIntyre *et al.* (1996). Since their presence in the sediment is not always obvious, MacIntyre *et al.* aptly called this group of organisms as the "secret garden" of the apparently unvegetated, shallow water habitats. While the microscopic algae which remain suspended in the water column are classified as planktonic, those that live in association with some substrata are grouped under benthic microalgae. In many shallow ecosystems the biomass of benthic microalgae often exceeds that of the phytoplankton in the overlying waters. Like phytoplankton, microphytobenthos also use light energy for photosynthesis. Several species of microphytobenthos are proved to be mixotrophic. Inspite of their characteristic adaptations to the specific habitat, planktonic or benthic, many of them are found both in benthic and pelagic environments. Even though an algal species may be benthic or planktonic at one time or another, several of them are characteristically adapted for either benthic or pelagic environments. Though the taxonomy and eco-physiology of planktonic microalgae in the Indian mangroves have been investigated, practically no such work has been done on benthic microalgae but for a few isolated observations.

It is an established fact that the surface layer of the sediment is a zone of intense microbial and geochemical activity and of considerable physical

reworking. Even though the main primary producers in the sea are the planktonic microalgae, the role of microbenthic production in shallow marine areas is very much significant and accurate estimates of it are needed for an understanding of the carbon flow of such environments. In most such habitats the biomass estimated as a measure of chlorophyll *a* and light availability appears to be the principal determinants of benthic primary production.

Intertidal sediments like that in the mangroves are highly productive, representing important nursery and feeding grounds for higher organisms including birds, fish and shellfish. Large number of secondary consumers like wading birds gets attracted by the rich supply of food, especially sediment-dwelling invertebrates, which in turn depend upon the presence of a diverse assemblage of phototrophic microalgae (*microphytobenthos*) present at the sediment surface. Microphytobenthos recruits organic matter to the ecosystem by the process of photosynthesis, and also influence nutrient fluxes in and out of the sediment. The microphytobenthos are most frequently dominated by diatoms, with lesser representation from cyanobacteria, euglenoids, chlorophycean and dinophycean species. Even though the microalgal cells are only active in a thin surface layer of the sediment subject to rapid fluctuations in light, temperature and salinity, more than 50% of primary production in estuaries can take place on sediments. Although microphytobenthos activity is restricted to the uppermost surface sediment layer, they have a large impact on the whole estuarine morphology and ecosystem functioning. In addition to their impact on sediment chemistry and bentho-pelagic nutrient exchange, diatoms together with their associated communities of bacteria and animals can produce copious amounts of extracellular polysaccharides. These sticky substances can bind and trap sediment particles and cause the formation of cohesive surface biofilms that eventually become strong enough to stabilise the mudflats against

erosion. In this way they can influence the morphology of coastal zones, and can play an important role in the sediment balance of estuaries. Thus, microphytobenthos exert their effect over a range of different spatial scales going from the hundred micron thick photic zone where photosynthesis occurs, to the scale of whole estuaries of many square kilometers where biofilms are able to influence the shape of the coastline.

The word 'benthos' (Greek- '*Bevoo*' = bottom) refers to an assemblage of organisms living in the benthic habitat of various aquatic ecosystems and naturally, both flora and fauna come under this term. In order to distinguish these different components of the 'benthos,' the word "phytobenthos" is used to describe the primary producers including various algae and other aquatic plants and "zoobenthos" for referring to all consumers comprising of protozoa and benthic animals. Bacteria, fungi and many protozoans of this environment also form part of benthic microbial community and function as the decomposers of the system.

In general, benthic communities include haptobenthos and herpobenthos. Haptobenthos are the organisms that grow on organic or inorganic solid substrata . The herpobenthos grow in or on mud, and easily penetrate to the substratum. The term periphyton is now used in a wide sense as a synonym to haptobenthos, designating the entire micro flora on substrata (Sladeckova, 1962; Wetzel, 1964; De Felice and Lynts, 1978). Periphyton includes microscopic algae, bacteria, and fungi found associated with any substrata submerged in water, excluding the rooted macrophytes (Brown and Austin, 1973; Wetzel and Westlake, 1974; Sreekumar and Joseph, 1995 a).

Phytobenthos can be classified into larger benthic macroalgae or seaweeds and smaller benthic microalgae or microphytobenthos. Microalgae

found attached to any inert material such as rock, coral, sand particles and those attached to detritus or living organisms come under benthic microalgae. The benthic microalgae are very small with an average size of about 62µ (Underwood and Kromkamp, 1999).

Microphytobenthic photosynthesis takes place in a thin layer called the photic zone at the sediment surface. Rates of photosynthesis are affected by many factors, varying from the position of the cells with respect to the gradient of light, the sediment surface temperature, and the availability of sufficient nutrients to build enzymes. According to Porchat *et al.* (2006), they go beyond the so called "photosynthetically active layer" and are found in substantial quantities to depths of 10 cm and more in the sediment. This may be due to active migration (Cadée & Hegeman, 1974) or hydrodynamic forces and bioturbation (Cadée, 1976).

Benthic diatoms, the major components of microphytobenthos are often classified into epipsammic and epipelic types, depending on their mode of attachment and motility in sediments. Epipsammic species are usually very small, virtually non-motile, and live closely attached to depressions and crevices in sand grains by mucilage pads or short stalks. Epipelic diatoms are non-attached and are highly motile (Round *et al.* 1990). In the natural environment, the distinction between these two growth forms is blurred, as sands and muds are found together and an assemblage can consist of both epipelic and epipsammic taxa (Hamels *et al.* 1998). Some large, motile naviculoids such as *Navicula rostellata*, *N. peregrina* and *N. arenaria*, are found in sandy muds, and sand can support dense populations of motile *Hantzschia* species (Kingston 1999; Underwood 2002) as well as the smaller, more typical epipsammic taxa. Where sands are scoured and moved by currents, the density of epipelon is reduced (Hamels *et al.* 1988; Sabbe 1993; Vilbaste *et*

al. 2000,) and epipsammic species dominate the assemblage. In estuaries, the location of sand flats and mudflats will depend partly on hydrodynamics (Dyer 1998; Flemming 2000) and in partially-mixed estuaries, sandier sediments will be more abundant towards the mouth of the estuary (Viles and Spencer 1995). Thus spatial changes in diatom flora along estuarine gradients may also reflect increasing sediment grain size, as well as increasing salinity and a dilution of riverine nutrient inputs.

Contribution by microphytobenthos can be a significant fraction of the total estuarine primary production. Estimates of primary production by microphytobenthos in the estuaries range from 27 to 234 gC m^{-2} year-1 (Heip *et al.* 1995; Macintyre *et al.* 1996; Underwood and Kromkamp 1999) while those for phytoplankton range from 7 to 875 gCm^{-2} year-1 (Boynton *et al.* 1982; Underwood and Kromkamp(1999). This primary production drives a rich food web, making estuaries ecologically important areas and of crucial importance for shorebirds and fisheries. Benthic microalgae are recognized as important primary producers in shallow aquatic ecosystems (Marshal *et al.*, 1973; Colijin and Dijk, 1981; Colijin and de Jonge, 1984; Bjork and Anell, 1985; MacIntyre *et al.*, 1996; Miller *et al.*, 1996; Cahoon *et al.*, 1993; Cahoon, 1999; Underwood and Kromkamp, 1999), and their biomass and production can equal or exceed those of phytoplankton in shallow waters (Cadee & Hegeman, 1974; Lukatelich and McComb, 1986; Pinckney and Zingmark, 1993; De Jonge and Colijn, 1994; Sivadasan and Joseph, 1998a; Sanil Kumar et.al; 2011). Besides serving as the primary food source for higher trophic levels, microphytobenthos also play a very important role in sediment dynamics as they are important stabilizers of estuarine sediments through the excretion of extracellular polymeric substances (Paterson 1989; Paterson and Black 1999; Blanchard *et al.* 2000; De Brouwer *et al.* 2000;). The contribution of the microalgae in the benthic environment is

very significant providing about one-sixth of the pelagic productivity. Global annual benthic microalgal productivity was estimated to be 500 million tonnes of carbon (Cahoon, 1999), as against approximate pelagic productivity of 3000 million tonnes of carbon (Raymont, 1980).

The important aspects of the ecology of benthic microalge that distinguish them from planktonic microalgae are their concentration in the sediment water interface microhabitat and their physical alteration of that microhabitat. Phytoplankton are of course dispersed by physical processes throughout the water column and typically reach concentration of the order of 0.1-1µg chlorophyll *a* L^{-1} (0.0001 – 0.001µg cm^{-3}) in neritic waters. Benthic microalgae are often 10^4 – 10^5 times as concentrated in sediments. The very high concentrations of microalgal biomass in small volumes results from *in situ* production, settling of resuspended cells, incorporation of phytoplankton or tychopelagic forms in settling material and active migration of motile microalgae.

Benthic microalgae have a significant role in stabilising the substrata (Holland *et al.*, 1974). Several species of benthic microalgae such as pennate diatoms and blue green algae while growing on the surface layer of the bottom sediments get attached to the sand and detritus by the mucilaginous substances secreted by this flora. Once held together by these traversed mucilaginous strands the substrata are less likely to move even when the bottom currents increase. (Grant *et al.*, 1986; Decho, 1990).

All these microalgae have been found to develop adaptations to suit particular habitat. Benthic algae live on or in association with some substrata while planktonic algae remain suspended in the water column. Though many of the algal species develop mechanism to survive in both the environments,

certain species maintain their characteristic affinity to a specific habitat. When several species can successfully grow in benthic habitats with slow currents, planktonic species cannot flourish in the benthic environment (Hanson, 1992). The physiological difference between these two groups may be, planktonic species cannot grow as fast as benthic species in low resource still water benthic habitats. The physiological resemblance observed among them for the survival in the benthic habitat probably be in the mode of nutrition as several planktonic and benthic species are found to be facultative heterotrophs. Other benthic adaptations include the raphe of the pennate diatoms, mucilage pads and stalks, or the holdfast of several filamentous algae, which facilitate them to attach to substrata.

Benthic microalgae may settle faster than planktonic algae because they have greater specific gravity (De Jonge and van Beusekom, 1992). One of the most important differences in benthic and planktonic habitats is the mode of nutrient supply. The benthic habitats probably have a greater diversity in nutrient conditions than the pelagic habitats. Here the microalgae exposed to water currents may have higher supplies of nutrients than algae in still waters. In the muddy bottom light will always be a limiting factor for the algae where they are surrounded by organic substance. As microalgae in the benthic environment is exposed to very low intensity of light and high concentration of organic substances including dissolved organic carbon, the autotrophic algae may resort to heterotrophic mode of nutrition.

A few typical benthic species belonging to various taxonomic classes are found distributed in pelagic environment. Similarly some pelagic species are found in benthic habitat due to the process of sinking. Microalgae are said to be 'tychopelagic' when they have a close association with the benthos, but found as plankton due to resuspension of sediments (Bold and Wynne, 1985).

Several free-living cells in intertidal sediments have diel rhythms of vertical migration, moving to the surface when the sediment is exposed at low tide and descending before it is flooded. Many species of benthic microalgae can metabolize both autotrophically and heterotrophically. These two different methods of nutrition act as complementary to each other serving as an effective survival mechanism for the microalgae in the benthic environment where light becomes a limiting factor.

Planktonic microalgae during their natural process of sinking, reach beyond the compensation depth and light becomes a limiting factor for their autotrophic metabolism. Similarly, the presence of cloud in the sky and turbidity of water and even mutual shading of cells may inhibit the process of photosynthesis as the effective illumination available to the cells may be below the optimum. Very often, epipsammic and epipelic species when buried in sediments have to survive in darkness. Their facultative heterotrophic mode of nutrition would be beneficial for their survival and growth.

The distribution of microalgae even beyond the compensation depth indicates their very low requirement of light intensity for growth and survival. Even in shallow region, when the microalgae remain buried in the bottom sediment or mud, practically no solar radiation would be available to them for phototrophic metabolism. However, high concentration of these microalgae is found in the bottom sediment for a considerably long period of darkness. In fact, it is quite surprising that the growth and survival of many species of microalgae especially of benthic environment depend more on heterotrophic nutrition than on autotrophy. The photosynthetic pigment present in these facultative heterotrophic microalgae may be considered as a "stand by" on accidental exposure to illumination during their heterotrophic growth and survival in the benthic environment. Several planktonic species are also found to be facultative heterotrophs. This would

probably explain the reason why certain planktonic species are found distributed in the benthic environment. The frequent occurrence, survival and growth of such species in the benthic habitat as observed by Cahoon and Cooke (1992) and their capability of facultative heterotrophism include these species under benthic microalgae.

Several organic substances synthesized and stored in algae such as carbohydrate are liberated into the medium as extra-cellular product. The carbohydrates released by microalgae are utilized by these benthic algal species, compensating the loss of energy due to extra-cellular release of organic substances. In heterotrophic nutrition, exogenous carbon sources are taken up by the cell through passive diffusion and are assimilated. When the organic substances in the water column are usually too low in concentration to get an entry into the cells via passive diffusion; organic matter gets accumulated in the benthic environment and provides sufficient exogenous carbon for this process.

Hellebust and Lewin (1977) reviewing the specific mechanism of the uptake of organic substrates in diatoms observed that even though the growth rate of some species was reduced in the dark, certain species were able to assimilate organic compounds very efficiently and grow in dark at rates equal to their growth in autotrophic conditions. Day *et al.*, (1991) showed that some species of diatoms exhibited faster growth heterotrophically.

Estuarine ecosystems, with generally well-illuminated shallow bottoms and moderate to high nutrient loadings, can be optimal environments for the development of high concentrations of benthic microalgae. Studies of the ecology of infaunal and above ground benthic biota in tropical mangroves have been few compared with the number of investigations of benthic communities in temperate intertidal habitats. Most of the early (pre-1975) mangrove studies

focused on description of new species (e.g. Gerlach, 1957) and on changes in species composition of macroepifauna with tidal height (e.g. Macnae and Kalk, 1962). Various reviews are available, but most have either summarized the benthic fauna along with the entire mangrove dependent biocoenoses (Macnae, 1968; Milward, 1982) or have provided an overview of only one specific component, such as crabs (Jones, 1984).

Benthic microalgae of the marine and brackish water habitat belong to various taxonomic divisions such as Cyanophyta, Heterokontophyta, Haptophyta, Dinophyta, Euglenophyta and Chlorophyta (Vanden Hock *et.al.,* 1995). Hackney *et al*., (1989) described an assemblage of various algae such as diatoms, cyanobacteria, and microscopic filamentous chlorophytes, phaeophytes and rhodophytes in benthic environment. According to Cahoon (1999), microphytobenthos are composed of diatoms, cyanobacteria, chlorophytes and other microscopic algae living at the sediment/water interface in neritic ecosystems. Besides cysts of several benthic and planktonic species, which are physiologically active may also contribute to benthic algal biomass (Sicko-Goad *et al*., 1989).

The taxonomy and ecology of benthic microalgae are distinct from those of the phytoplankton (MacIntyre *et al*., 1996; Miller *et al*., 1996). Among the taxonomically diversified group of benthic microalgae the dominant species are of diatoms on which considerable work has been carried out, such as, those of Hustedt, (1927, 1931-32, 1955); Round, (1979); Kennett and Hargraves, (1984); Krammer and Lange-Bertalot, (1985, 1986); Laws, (1988); Sabbe and Vyverman, (1991) , Cahoon and Laws, (1993); Sivadasan, 1996, and Sanil Kumar *et al*.,2009,2011. Lewin and Lewin (1960) observed that certain species of *Cyclotella*, *Navicula*, *Amphora*, *Podosira* and *Nitzschia* were found to grow in darkness with organic substances. The dominant representatives of this algal assemblage include

several species of the genera *Amphora, Cocconeis, Diploneis, Navicula* and *Nitzschia* (Cahoon, 1999). Although pennate diatoms are more prone to benthic habitat, some centric genera such as *Coscinodiscus, Skeletonema, Biddulphia* and *Thalassiosira* are also found on the benthic substrata.The survival of these centric diatoms may be due to their mixotrophic characteristics.

Studies on cyanobacteria from the benthic habitat include those of Meadows and Anderson, 1968; Sournia, 1976; Asmus, 1982; Zedler, 1982 and Hackney *et al*., 1989. Several cyanobacterial species occur as planktonic as well as benthic belonging to the genera *Anabaena*, *Aulosira*, *Calothrix*, *Nostoc*, and *Rivularia* (Bastia, *et al*., 1993). Zedler, 1982 and Hackney *et al*., 1989, described chlorophytes from the benthic sample. Reports are available on the occurrence of *Chlorella* sp. (Lalucat *et al*., 1984), *Dunaliella tetriolecta* (Oliveira and Huynh, 1990), *Haematococcus pluvialis* (Kobayashi *et al*., 1992) and *Pediastrum duplex* (Berman *et al*., 1977) in the benthic environment.

Burkholder *et al*., (1965) and Fukuyo, (1981) described a few species of dinoflagellates belonging to benthic environment. Contribution of benthic cysts to the population dynamics of *Scrippsiella* spp. of Dinophyceae, in North Eastern Japan was carried out by Ishikawa and Taniguchi (1996). *Amphidinium carterae* also exhibited growth in the absence of light but with organic substance.

Taxonomic composition or divisions of algae are distinguished by a variety of chemical and morphological differences (Bold and Wynne, 1985; Lee, 1989). Algae, being autotrophic, invariably have the primary photosynthetic pigment chlorophyll *a*. Chlorophylls *b*, *c* and accessory pigments such as phycobilins and fucoxanthin are characteristics of different taxonomical divisions of algae. As various accessory pigments impart

particular colouration, taxonomical divisions may be distinguished from their colour. Pigment ratios, chl. *b*:chl *a*, chl. *c*:chl. *a* and chl. *d*:chl. *a*, can be used to compare changes in proportions of green algae, diatoms and red algae respectively (Archibald, 1972). The similarity of the taxonomic compositions of the benthic microalgae and phytoplankton indicated by pigment ratios suggest that some fraction of the "phytoplankton" is resuspended benthic microalgae (Baillie & Welsh 1980; Shaffer and Cahoon, 1987; Shaffer and Sullivan 1988).

The effort and expense of counting microalgae and the difficulty of calculating biomass from cell abundance preclude the use of cell counts in most investigations. Instead, the photosynthetic pigment chlorophyll *a* is used as an index of microphytobenthos biomass. Despite variability in the relations amongst chlorophyll *a*, biomass, and cell abundance, this pigment provides a useful index of the photosynthetic potential of a population. However, photopigmets are not ideal indicators of microalgal biomass because the amount of pigment per cell varies with the physical state of the alga, species, pigment/cell carbon ratio etc. (Falkowski and LaRoche, 1991; Pinckney and Lee, 2008). In the present investigation the biomass is estimated from both cell counts and from pigments to avoid speculative figures.

In spite of the important roles that microphytobenthos play in estuarine environments, research on these organisms is still at an early stage. It is apparent that benthic diatom species differ from phytoplanktonic diatoms in their photosynthetic responses, ability to move, and in a greatly increased resistance to environmental stressors such as ultraviolet radiation. However, the biochemical and genetic mechanisms underlying these differences are not known. At the ecosystem level, the contribution of microphytobenthos to the

dynamics of estuaries is apparent, but integration of biological processes with hydrodynamic models of sediment movement has rarely been attempted. This is partly because of the highly dynamic nature of estuarine ecosystems and partly because of the extremely complex interplay between biological, physical and sedimentological processes. An interdisciplinary approach is clearly needed in order to come to a more thorough understanding of these processes.

No studies have so far been reported on the microphytobenthos in the mangrove ecosystems of Kerala. The present study is an attempt to enumerate and identify the microphytobenthos in the selected mangrove ecosystems in Kerala, to analyse their pattern of distribution in accordance with physico chemical variables and to examine the biomass of these ubiquitous components at different depths of the sediment column.

6.2 Review of Literature:

Microphytobenthos caught the attention of marine biologists after Steele and Baird (1968) revealed the presence of low water mark viable diatom populations at a depth of 20 cm in the sand in Loch Eve in the west of Scotland. This was probably the first authentic study on microphytobenthos.

Mangrove sediments were subjected to observation almost at the same time, and while studying the phosphorus relationships in a mangrove swamp in Sierra Leone, Hesse, (1963) made an observation that mangrove sediments are highly anoxic. While presenting an account of the flora and fauna of the mangrove swamps and forests in the Indo Pacific region, Macne (1968) generalized that the mangrove sediments are highly anaerobic, sulphidic muds.

In 1970, a study was carried out by Leach, on the epibenthic algal production in an estuarine mud flat in the Ythan estuary on the northeast Scotland, using ^{14}C method. The study revealed that the Standing crop of living

plant material in the sediments was equivalent to 15% of organic carbon in summer and 10% in the winter.

Fenchel and Kofoed (1976) studied the theory of limiting similarity of co existing competitors and stated that diatoms of a given size range, which constitute the most important food of snails, show a "logistic" growth response to grazing, and individual growth of the snails is linearly related to diatom density. The previous observation that the snails show size dependent selection for ingested particle sizes is extended to show that this mechanism leads to a real resource partitioning between snails of different sizes.

Round (1979) studied the assemblages of species living on and in intertidal sand flats at Barnstable Harbor, Massachusetts (USA) and described endopsammic assemblage of diatoms, mainly Amphora species, living below the surface, for the first time, from such a marine habitat.

Pant *et al.* (1980) measured the primary production in a fringing mangrove ecosystem and estimated the contribution of benthic microalgae by taking the difference between the gross oxygen production and community metabolism based on dial difference in dissolved oxygen concentration and the amount of carbon assimilated in the water column.

Based on his studies on water logged saline soils, Boto (1984) suggested that the tropical mangrove sediments possess reduction and oxidation properties and other physico chemical characters like pH, grain size etc. typical of other marine and estuarine intertidal deposits.

After analyzing the role of diatoms in the mangrove habitats, Cooksey (1984) observed that little work has been published on planktonic and benthic algae of mangrove environment.

Paterson (1986) studied the migratory behavior of diatom assemblages in a laboratory tidal micro ecosystem using a low temperature scanning electron microscope. Data on the depth distribution of diatoms in the sediment, derived from sediment samples that had been frozen and then fractured, supported the hypothesis that light is the factor controlling the onset of diatom migration and that different diatoms have different thresholds triggering their movement.

Lukatelich and McComb (1986) studied the development of diatom and cyanophycyan algal blooms in a shallow Australian estuary and reported that there is an inverse relation between sediment nutrients and benthic primary production.

Thibodeau and Nickerson (1986) studied the differential oxidation of mangrove substrate by *Avicennia germinans* and *Rhizophora mangle* and reported that these species of mangroves oxidized the soil in the rhizosphere and thereby ameliorated the detrimental effects of hydrogen sulfide in the soil.

The works of Alongi (1987 a.) in Indian, South East Asian and Australian mangroves suggest that soil texture and subsequent physico chemical properties vary greatly among forest types and with tidal elevation. The pH readings, according to him, in all deposits are consistently within the range of 6.2 to 7.2.

Alongi (1987 a.) suggested that the monsoonal rains can drastically alter sediment characteristics of mangrove ecosystems. During his studies in Claudie River of northern Australia, it was found that grain size of low intertidal deposits increased from coarse silt in the winter dry season to the coarse sand in the summer wet season.

A review by Alongi (1989) provided a critical account on the associations of microalgae and meiofauna in floating detritus at a mangrove island, Twin Cays, Belize

Conceptcion Rodriguez & Allan W. Stoner (1990) studied the distribution and biomass of epiphytic algal community on mangrove roots and stated that algae serve as an additional important source of carbon in the mangrove food web and their rate of turnover is several times higher than that of the mangroves and as such contribute as much or even more to primary production than them.

Boto and Robertson (1990) studied the nitrogen fixation by algal mats and algae covering the parts of mangroves such as prop roots in a tropical mangrove ecosystem in Australia and reported that 1-3.5 % of nitrogen requirement for forest net primary production is contributed by these algae.

According to Alongi (1990 a.), the low dissolved nutrient levels in mangrove pore waters are similar to pore waters in other tropical sedimentary environments, but the reasons for this phenomenon are not wholly understood. It may be due to uptake by mangrove themselves, by bacteria, high redox potential or low quality of deposited organic matter.

According to de Jonge & van Beusekom (1992, 1995), Middelburg *et al.* (2000) and Kang *et al.* (2006), the intertidal microphytobenthos resuspensed by tidal currents and waves in estuaries, often makes its way into food webs through suspension- and deposit feeders. Phytoplanktivorous fish may also use resuspended microphytobenthos and thus transfer benthic production to the pelagic food web.

According to Alongi and Sasekumar (1992), two main features of mangrove sediments are typical of other tropical marine and estuarine deposits. While the first one is the low concentration of dissolved pore water nutrients, the second one is the presence in the intertidal water of soluble and condensed tannins derived from leaching roots and litter on the forest.

Ewa-Oboho, I.O. & Abby-Kalio, N.J. (1993) conducted studies on distribution, Biomass and community dynamics of algal species epibenthic on the arching roots of Rhizophora mangle L. at the Bonny Estuary (S. Nigeria) in relation with some physico-chemical parameters and identified four species of algae viz. Bostrychia tenella, Catenella opuntia, Caloglossa leprieurii, Rhizoclonium sp. on the prop roots.

Pinckney and Zingmark (1993) studied the photophysiological responses of intertidal benthic microalgal communities and concluded that the fixed depth interval method provides a more realistic representation of photophysiological response of benthic microalgae and accordingly, productivity is not the only parameter that determines total production.

McKee *et al.* (1993), studied the soil physiochemical patterns and mangrove species distribution and reported that mangrove zones dominated by Rhizophora mangle alone or in combination with Avicennia germinans are characterized by moderately reducing soils.

Montagna *et al.*, in 1995, found that the intertidal meiofauna, particularly harpacticoids, have a dependent relationship with their autotrophic food resources i.e, microphytobenthos, in intertidal habitats and can regulate their behavior to maximize intake of food.

Underwood and Chapman (1995) and Essien and Ubom (2003) dicussed the presence of large densities of photosynthetic protists (diatoms, dinoflagellates and flagellates) Cyanobacteria and filamentous green and brown algae that live interstitially within the sediment particles of the tidal mudflats.

According to Underwood and Chapman(1995), microalgae inhabit the few top millimetres of the sediment and live interstitially between the sediment grains in estuaries and so they are able to conduct photosynthesis

Maria and Rose (1995) examined the associations of benthic microalgae and meiofauna affected by temperature, salinity and dissolved oxygen concentrations in floating detritus in a shallow mangrove embayment and found that floating detritus exhibits a diurnal movement: it rises to the surface via oxygen bubbles generated by attached microalgae at sunrise and sinks down at sunset.

Gerardo Toledo *et al.* (1995) inoculated an isolate of filamentous Cyanobacterium, *Microcoleus* obtained from the pneumatophores of black mangrove, onto the young mangrove seedlings to evaluate N_2-fixation and root colonization capacities of the bacterium under in vitro conditions and found that the level of N_2 fixation in the presence of the plant was significantly higher than the amount of nitrogen fixed by a similar quantity of cyanobacterium on a N-free growth medium.

Sivadasan (1996) and Sivadasan and Joseph, (1995 1997, 1998a, b) made a comprehensive study on the benthic microalgae of Cochin Estuary. Whereas Sreekumar (1996) and Sreekumar and Joseph (1995a, b, 1996, 1997) studied the periphytic flora and their community structure in Cochin estuary.

In 1996, MacIntyre *et al* published a comprehensive paper on the role of microphytobenthos in shallow marine water habitats giving indepth information on the distribution, abundance and primary production of this group of organisms. The authors used the term "secret garden"as a literary allusion to describe these inhabitants of unvegetated habitats.

As a continuation of this paper, Miller *et al.* (1996) published another paper on the role of these organisms in sediment stability and shallow water food webs.

Barranguet *et al.* (1997) studied the biomass and community composition of microphytobenthos by the use of pigment biomarkers at a tidal flat in the Netherlands and found that there is a seasonal shift in the community composition of diatoms and he attributed this to the change in concentration of silicate in the overlying waters.

While studying the Soil-plant interactions in a neotropical mangrove forest, Sherman *et al.* (1998) suggested that mangroves can supply oxygen to the otherwise anaerobic subsoil by transporting oxygen through their aerial roots.

While studying the primary production of benthic microalgae in a tropical semi enclosed brackish water pond in South west coast of India, Rajesh *et al.* (2001) reported that the sediment chlorophyll *a* concentration fluctuated from 0.39 to 1.48 mg g^{-1} sediment with no clear pattern of seasonal variation, although higher values were found in May, December and September. The phaeopigments varied from 3.48 to 17.92 mg g^{-1} sediment. The total annual benthic production was found to be 33.59 gCm^{-2}, while primary production of water was only 10.51 gCm^{-2}.

According to Sullivan and Currin (2002), benthic microalgae are a ubiquitous feature in sediments directly exposed to full sunlight or shaded by a vascular plant canopy in coastal salt marshes and their contribution to the total production would range from 28 g C m^{-2} y^{-1} beneath *Juncus roemerianus* to 314 g C m^{-2} y^{-1} beneath *Jaumea carnosa*

Essien and Ubom (2003) investigated the microalgal species represented in the tidal mud flat (epipellic habitat) of the mangrove swamp in Qua Iboe Estuary, located in the Southeastern coastal zone of Nigeria and reported that *Amphora ovalis, Campylodiscuscus cibrosus, Cymbella lanceolata, Navicula radiosa, N. rhynocephala, Pleurosigma sp, Stephanodiscus sp, Pinnularia viridis, Tabellaria sp, Actinoptychus undulatus, Closterium sp, Oscillatoria nigroviridis,* and *Nodularia spumigena* are the epipelic diatoms in that habitat.

Essien and Ubom (2003) studied the epipellic algae profile of Qua Iboe Estuary. The results of the phytoplankton studies revealed variation in the density of the microalgae within the microalgal Orders and the epipellic algae community was predominated by pinnate diatoms. While *Actinoptychus undulatus* and *Tabellaria* sp. predominated the microalgae community, *Amphora ovalis*, *Campylodiscus cibrosus*, *Cymbella lanceolata*, *Navicula radiosa*, *N. rhynocephala*, *Pleurosignma* sp., *Pinnularia viridis*, *Stephanodiscus* sp., *Closterium* sp., *Oscillatoria nigroviridis* and *Nodularia spumigena* were also present in sufficient numbers.

Ubom R.M.; Essien J.P. (2003) studied the Distribution and Significance of Epipsammic Algae in the Coastal Shore (Ibeno Beach) of Qua Iboe River Estuary, Nigeria and the results revealed the presence of *Actinoptychus undulatus, Aphanizomenon flos-aquae, Astasia fustis, Chromulina globosa,*

Cocconeis pediculus, Cymatopleura solea, Cymbella lanceolata, Euglena intermedia, Lyngbya majuscula, Microcystis sp., *Nodularia spumigenra, Navicula rhynocephala, Oscillatoria nigroviridis, Pinnularia viridis, Rhoicosphenia curvata, Trachelomonas volvocina and Urceolus cyclostomus* in the sandy beach. According to the authors, The occurrence of *A. flos-aquae* and other toxin producing cyanobacterial species of *Lyngbya majusculata, Microcystis sp.*, *N. spumigena* and *O. nigroviridis* in the sandy beach are of serious health significance.

In 2003, Mundree *et al* investigated the seasonal variations in the vertical distribution of benthic microalgae in the upper sediment of the Mdloti estuary, South Africa. The spatio temporal distribution of microphytobenthos, the impact of pheopigment to chlorophyll *a* ratio and the changes in the physicochemical environment were studied.

Essien and Antai (2005) investigated the direct effect of oil spill on the abundance of microalgae in the coastal shore of the Qua Iboe Estuary and made a concerted effort to apply epipsammic microalgae indices as a biological indicator of crude oil pollution and natural remediation.

S.M. Saifullah and Waqar Ahmed (2007) estimated the epiphytic algal biomass on pneumatophores of the grey mangrove Avicennia marina from the Indus Delta region for the first time. The studies conducted during the northeast monsoon season showed the average value 8.38±0.27mg DW cm^{-2} of pneumatophores surface area and 132.84±7.79 gm DW m^{-2} of mud surface comparable to some other areas in the world.

Sanilkumar *et al*, (2009) studied the vertical distribution of microphytobenthos in Cochin estuay and analysed the flora along the vertical zone upto a depth of 5 cm. They reported that the benthic chlorophyll *a* concentration in Cochin estury decreased during monsoon compared to their planktonic counterparts.

Sanilkumar *et al*. (2011) studied the monsoon effects on the biomass and composition of microphytobenthos diatoms in Cochin estuary. Microphytobenthos biomass declined throughout the top layers of the sediment column concurrently with declines in abundance of most pennate diatom taxa, particularly larger forms, as well as some macrobenthos taxa due to the heavy deposition of mud via land run off.

Rejil and Joseph (2011) studied the microphytobenthos in the mangrove ecosystems along the Cochin estuary, South West coast of India and listed 21 epipelic 8 epipsammic and 5 epiphytic algae associated with this dynamic ecosystem.

6.3 Results:

6.3.1 Standing crop

The species variation and abundance of microphytobenthos in the six mangrove stations along the Cochin backwaters was studied for 2 cycles of seasons extending over two years, 2003 and2004.

Station wise seasonal fluctuation of microphytobenthos, in the probable 'phytozone', which is found to be 6 cms from the surface of the sediment column, is given below. The phytozone depth has been fixed after three months

of trial, standardization experiments and it was observed that there is no significant presence of chlorophyll and viable cells beneath that depth.

The sediment was collected using a using a glass hand-corer with an inner diameter of 25 mm. The corer was introduced into the sediment and a core sample of 6 cm length was collected. It was partitioned into 3 blocks of 2cm size and each piece of sediment was examined for microphytobenthos. The phytozone, the depth upto which the plants survive has been fixed after standardisation tests for 3 months and beyond this depth there were practically no viable algal cells.

At station 1, in 2003, the total number of cells in the phytozone of 6 centimeter sediment during pre monsoon was found to be 224 cells/cm^3. 13 species were identified during this season, the strata wise distribution being 114 cells/cm^3 in the first stratum (0-2cm), 89 in the second (2-4 cm) and 21 in the third and deepest stratum of 4-6 cm depth. Among the 13 species, *Amphora laevis, Nitzschia closterium and Navicula hennedyei were* the abundant ones. While there were 7 species in the upper stratum, the number of species in the lowest stratum was 4.

In the monsoon, the total number of cells in the phytozone sediment column was 294. The vertical distribution in the 3 strata from surface (1^{st} stratum) to the bottom (3^{rd} stratum) was 168 cells/cm^3, 79 cells/cm^3 and 47 cells/cm^3 respectively. 16 microalgal species were identified during this season. *Gyrosigma balticum, Diploneis dydima and Nitzschia closterium were* the dominant species present. There were two cyanophycean members- *Oscillatoria labyrinthiformis* and *Microcystis aeruginosa* on the uppermost stratum during monsoon. During post monsoon the highest standing crop

was observed in the middle stratum and it was 82 cells/cm^3.When compared to the other two seasons, the total number of cells was lesser, 124. The distribution of microphytobenthos in different strata of the sediment from top to bottom was 24 cells/cm^3, 82 cells/cm^3 and 18 cells/cm^3. There were representatives from 9 genera. *Amphora laevis, Nitzschia closterium and Diploneis littoralis* were the most abundant species.

In the second year, there were 330 cells in the phytozone during pre monsoon, 295 cells during monsoon and 262 cells in the post monsoon season. During the pre monsoon, the stratum wise distribution of microphytobenthos was in such a way that the middle segment showed higher cell density than the upper segment. While there were 131 cells/cm^3 of the upper stratum, it was 167/cm^3 in the middle stratum. However, the species richness was same in both the strata carrying a total number of 8 species. *Nitzschia closterium* was present in all the three strata. *Amphora laevis* and *Diploneis littoralis* were the other two abundant taxa. During the monsoon and post monsoon also, the number of cells was higher in the middle statum of the partitioned sediment. While the stratum wise distribution of cells from top to bottom during monsoon was 62, 189 and 38, that during post monsoon was 83, 137 and 42. *Amphora laevis* and *Surirella flumiensis* were the abundant taxa during monsoon. *Navicula longissima* was present in all the three strata of the post monsoon sediment sample. *Navicula forcipata, Pleurosigma salinarum* and *Pleurosigma normanii* were the other abundant taxa during post monsoon. (Table. 12, Fig. 35)

Table12: Kumbalam

No	Name of Species	2003									2004								
		PRM			MON			POM			PRM			MON			POM		
		a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
1.	Achnanthes brevipes	13			21						16				21			14	
2.	Achnanthes haukiana					8										9			
3.	Amphora laevis	33	22				12		18	8		38	11		33	14		12	
4.	Biddulphia mobiliensis						3		6		11	17			20				
5.	Caloneis madrspatensis				22														
6.	Coscinodiscus marginatus				20			7						7					
7.	Cymbella marina			4						2		19	3			6			
8.	Diploneis dydima		11			24	12							9					
9.	Diploneis littoralis			2				17	22		27	37			22		11		
10.	Gyrosigma balticum	12			31	23			9		12				19		8		6
11.	Navicula forcipata	9				7				1	13		3			4	22		10
12.	Navicula hennedyei		24	10		9					15		2	4					5
13.	Navicula longissima											17					9	39	4
14.	Nitzschia closterium	28	25		34		11		19	7	24	15	13			5			
15.	Nitzschia lorenziana	8					4							7					
16.	Nitzschia panduriformis			5							13				18				
17.	Pleurosigma normanii					8											24	37	
18.	Pleurosigma salinarum		7									13						10	13
19.	Pleurosigms naviculaceum						5		8			11			21			12	
20.	Surirella flumiensis													22	35			13	4
21.	Cosmarium quadrum													11					
22.	Microcystis aeruginosa	11			19														
23.	Oscillatoria labyrinthiformis				21									8			9		
	Total	114	89	21	168	79	47	24	82	18	131	167	32	68	189	38	83	137	42

a-upper stratum, b-middle stratum, c-lower stratum

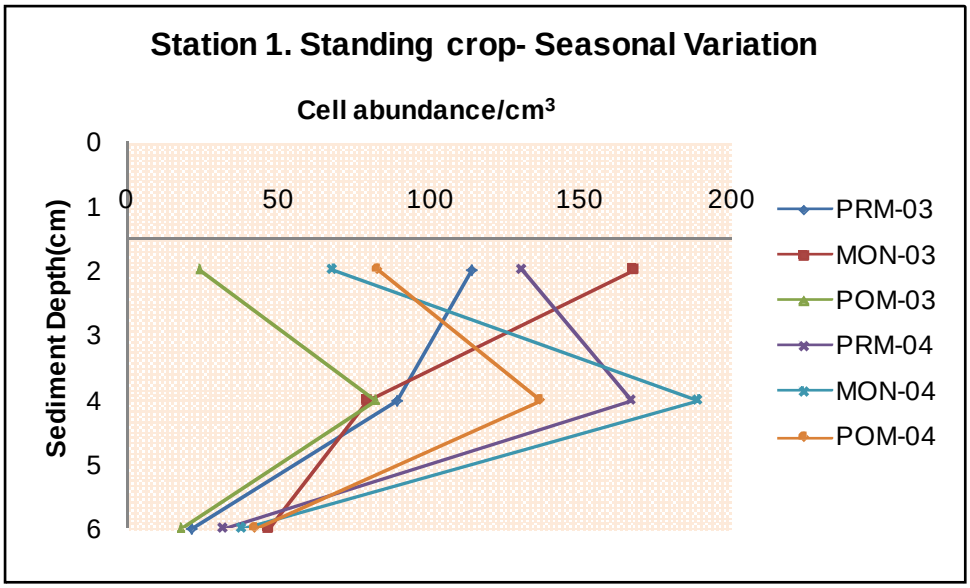


Fig. 35

At station 2, in 2003, there were a total of 306 cells in the phytozone during pre monsoon. 15 species were identified during this season. The cell abundance and species richness were high in the upper stratum of the sediment. While there were 196 cells in the first stratum, the second and third strata were having 81 and 29 cells respectively. While there were 10 species in the upper stratum, the number was 5 in the lower stratum. The abundant species observed during this season were *Gyrosigma balticum, Navicula cincta and Navicula laterostratum.*

In the monsoon, there were 234 cells in the phytozone sample, 124cells/cm^3 in the upper stratum, 87 cells/cm^3 in the middle and 23 cells/cm^3 in the bottom stratum. The species richness and cell abundance were low when compared to those of pre monsoon. *Pleurosigma normanii* was present in all the three strata. Other dominant species were *Diploneis dydima, Cocconeis placentula* and *Nitzschia closterium*. Two cyanophycean members were noticed

in the upper stratum. In the post monsoon, the strata wise distribution of cells was 312, 102 and 43 from the upper stratum down wards. While there were 11 species in the upper stratum, the number of species of microphytobenthos in the middle and lower strata were 5 and 6 respectively. *Amphora laevis* was the most abundant species that was present in all the three strata of the sediment.

In the second year of the study, the highest cell abundance was recorded during the post monsoon season, followed by pre monsoon and monsoon. While there were 14 taxa in the post monsoon season, it was 13 and 12 in the pre monsoon and monsoon. The stratum wise cell abundance during premonsoon was 101 cells/cm^3 in the upper, 132 cells/cm^3 in the middle and 39 cells/cm^3 in the lower. *Navicula cincta* and *Amphora laevis* were present in all the three strata. During monsoon, there were 63 cells in the upper stratum, 48 in the middle stratum and 29 in the lower stratum. *Pleurosigma aestuarii* was present in all the three strata and *Cocconeis placentula* was the other dominant taxa. During post monsoon, there were 149 cells in the middle stratum, 113 in the upper stratum and 21 in the lower stratum. While there were 9 taxa each in upper and middle strata, only 5 taxa could be noticed in the lower stratum. *Nitzschia closterium, Cocconeis placentula* and *Gyrosigma scalproides* were the abundant taxa. (Table. 13, Fig. 36)

Table13: Panangad

No	Name of Species	2003									2004								
		PRM			MON			POM			PRM			MON			POM		
		a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
1	Achnanthes brevipes			2	9			24			12	15		7					
2	Achnanthes haukiana	17	11														8	18	
3	Amphora laevis	15		4			1	42	28	9	23	28	4				11		3
4	Biddulphia mobiliensis																10		
5	Cocconeis placentula			3	18		4	21		7					16	13		31	11
6	Diploneis dydima		13		8		11	20				10				4		15	2
7	Fragilaria oceanica				10				15		11								
8	Gomphonema parvulum					14		23						8			13		
9	Gyrosigma balticum		23	13				47		14		8	5						
10	Gyrosigma scalproides	19				15			17		9	35				7	20	27	
11	Mastegloea dolosa				7							11		6					
12	Navicula cincta	28	12			11		44	29		21	7	15					11	4
13	Navicula halophila	19						19			10						12	13	
14	Navicula laterostrata	30	12				2					6	9		11				
15	Nitzschia closterium	17				31	3	22							9		23	10	
16	Nitzschia palea	18	10							7	8		6				7		1
17	Pleurosigma aesturii			7								12		20	12	5		12	
18	Pleurosigma normanii	19			19	16	2	24		6	7						9		
19	Nostoc punctiformeae				11			26	13					7				12	
20	Oscillatoria chalybea	14			9									6					
21	Spirulina labyrinthiformis				21														
22	Spirulina major													9					
23	Chlorella				12														
		196	81	29	124	87	23	312	102	43	101	132	39	63	48	29	113	149	21

a-upper stratum, b-middle stratum, c-lower stratum

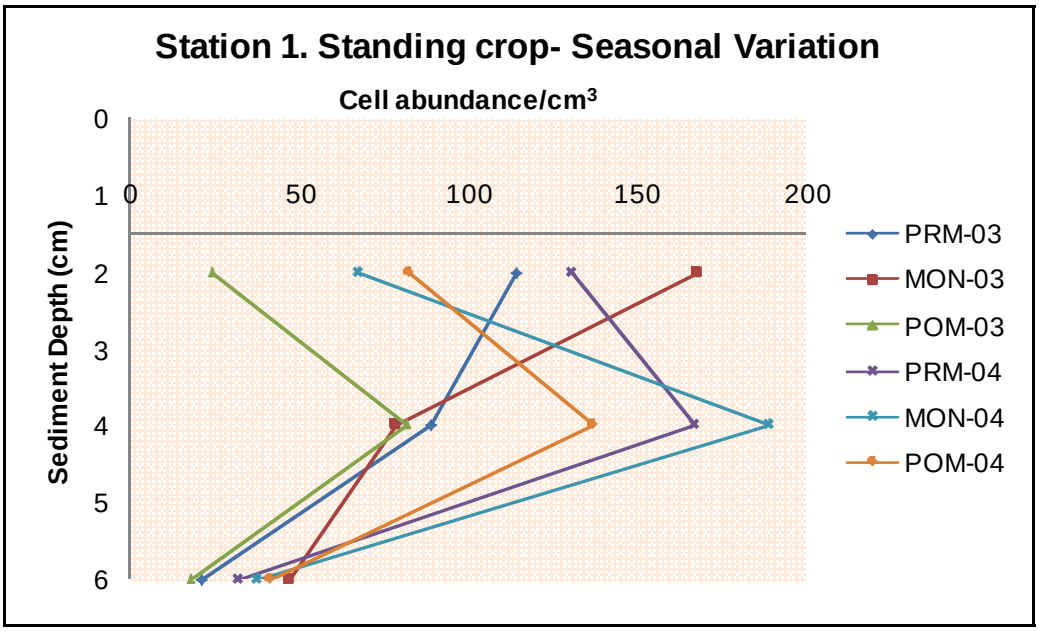


Fig. 36

At station 3, in the first year, there were 249 cells in the phytozone during pre monsoon, the strata wise distribution being 136 cells in the upper stratum, 69 cells in the middle stratum and 44 in the lower stratum. 28 species were identified during this season, with the maximum number of 14 in the upper stratum. Each of the other two strata was having 11 species. *Nitzschia closterium* was present in all the three strata. Other dominant species were *Amphora coffeaformis, Gyrosigma balticum, Nitzschia constricta* and *Nitzschia sigma.*

Cell abundance was found to have decreased during monsoon. There were a total of 151 cells comprising 23 species. The strata wise distribution of the species showed the highest number in the surface stratum, followed by the middle and lower strata. The actual numbers were 81, 54 and 16. There were only 5 species in the lower most stratum. A Chlorophycean member, *Chlorella* and a Cyanophycean species, *Microcysis aeruginosa* were found on the upper sediment layer. None of the species was present in all three strata. However,

Cocconeis littoralis, Diploneis littoralis and *Navicula longa* were seen in abundance. The cell density increased during post monsoon than that in the monsoon. However, the number of species decreased to 21. Middle layer of the sediment showed the highest cell density of 135 followed by upper stratum and lower stratum with 61 and 16 cells. *Nitzschia closterium* and *Navicula forcipata* were the dominant species present.

In the second year, station 3 showed high species richness and cell abundance. While the highest cell density was observed during post monsoon, there was not much seasonal variation. While there were 24 species recorded during monsoon, it was 21 and 20 in post and pre monsoon. While the upper stratum showed the maximum cell abundance during pre monsoon and monsoon, it was the middle stratum that showed the highest cell abundance during post monsoon. While *Mastogloia lanceolata* was present in all the three strata during pre monsoon, *Cyclotella striata* showed the similar distribution during post monsoon. The strata wise cell distribution in the three strata during different seasons was as follows:

Pre monsoon: 202 cells (upper stratum), 178 cells (middle stratum) and 38 cells (lower stratum)

Monsoon: 308 cells (upper stratum), 264 cells (middle stratum) and 87cells (lower stratum)

Post Monsoon: 281cells (upper stratum), 303 cells (middle stratum) and 92 (lower stratum)

Navicula mutica, Navicula forcipata, and *Nitzschia closterium* were the adundant species during pre monsoon. In monsoon, *Nitzschia panduriformis, Pleurosigma angulatum* and *Gyrosigma balticum* were the abundant species. Dominant species of the post monsoon season were *Amphora coffeaformis, Gyrosigma balticum* and *Nitzschia closterium*. (Table. 14, Fig. 37)

Table14: Nettoor

No	Name of Species	2003									2004								
		PRM			MON			POM			PRM			MON			POM		
		a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
1	Achnanthes coarctata	7			5			4			11			8		3	11	13	
2	Achnanthes haukiana. Grun.	9							10					4			13		7
3	Amphora coffeaformis	22	3			4		7			7	44		7		4	43	44	
4	Amphora turgida				3						9			3	14		7	18	
5	Asterionella japonica					2		3											
6	Bacillaria paradoxa		2			5			6		5	11						43	8
7	Caloneis madraspatensis	5													11		9		
8	Cocconeis littoralis		5		24	3		19		1	10			6	8			15	
9	Cocconeis sigmoides	6										9	3						
10	Cyclotella striata			1			2			2			1		6	30	5	57	29
11	Cymbella hustedtii				2				5	1				5					
12	Cymbella marina. Castracane.			3		4			12		34	14							
13	Diploneis dydima			1											3	7	10	17	
14	Diploneis littoralis	8			19	12					8				12				8
15	Diploneis puella (Schumann,1867) Cleve						8		7			13		8		26	12		
16	Gyrosigma balticum (Eher)Rabenhorst	22	14					5			9			50	71		38	51	
17	Gyrosigma scalproides (Rabh) Cleve.			1					4										
18	Mastegloea lanceolata			1		1					29	10	18						
19	Navicula hennedyei			3	4		3	4								1	9		5
20	Navicula mutica		4						9			32	4	12					
21	Navicula longa				6	14					6					2			
22	Navicula cincta		3			1	1		6					11	57		47	12	
23	Navicula forcipata	4			1				29	8	44		7						
24	Nitzschia closterium	20	4	10	7			17	35		6	30		9		5	45		27
25	Nitzschia frustulum var. perpusilla.	5												51	9				
26	Nitzschia constricta		12	11			2										6		1
27	Nitzschia palea								8		7		5	6		3			7
28	Nitzschia lorenziana			2	2					1		9					3	9	
29	Nitzschia panduriformis	6	2											61	8				
30	Nitzschia sigma		15	9		5			4		5							10	
31	Pleurosigma aestuarii	7		2		3		2								6	13		
32	Pleurosigma angulatum		5											50	65				
33	Pleurosigma salinarum.Grun.	6									12	6					10	14	
34	Thalasiosera decipience	9																	
35	Chlorella				3									7					
36	Microcystis aeruginosa				5									10					
	Total No.	136	69	44	81	54	16	61	135	13	202	178	38	308	264	87	281	303	92

a-upper stratum, b-middle stratum, c-lower stratum

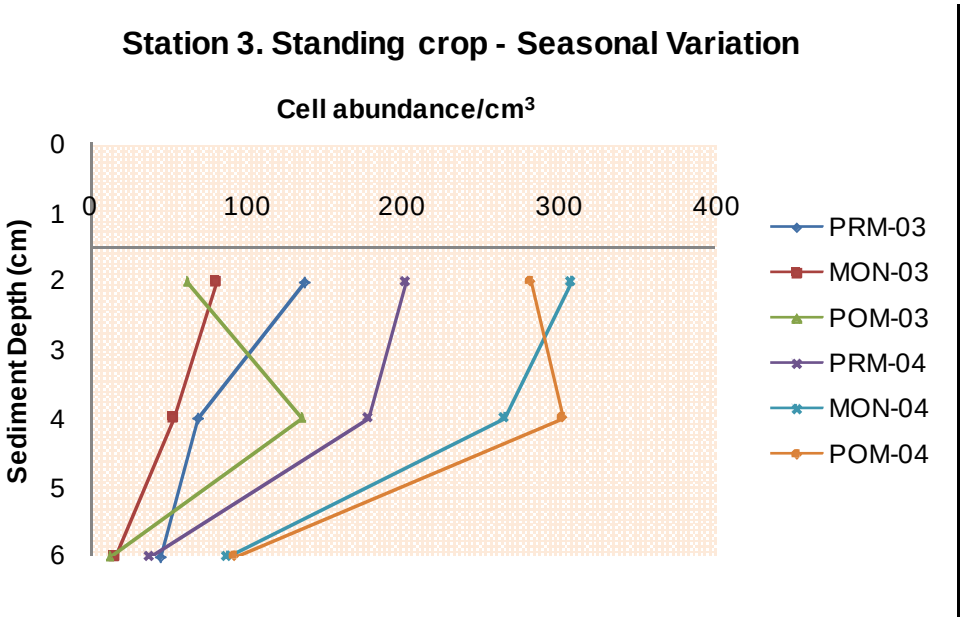


Fig. 37

At station 4, in 2003, there were 15 species of microphytobenthos in the phytozone sediment of 6 cm. depth during pre monsoon. While there was 10 species each in the first two strata, there were only 5 species in the bottom most stratum. The cell abundance recorded the highest number in the middle stratum with 163 cells/cm^3. The cells per cm^3 in the upper stratum was 89 and that in the lower stratum was 47. *Diploneis bombus*, *Coscinodiscus marginatus*, *Licmophora juergensii* and *Nitzschia closterium* were the dominant species. During monsoon, the number of species in the phytozone increased to 16 with the surface stratum having 11 representatives. While the upper stratum was having 73 cells/cm^3, the middle harboured 79 and bottom, 33. The species richness improved in the post monsoon season with 17 species distributed along the vertical length of 6 cm. sediment. While the upper stratum of the sediment

was having 411 cells/cm^3, that in the middle and lower strata were 196 and 83 respectively.

In 2004, cell abundance showed the highest number of 340 cells in the phytozone during monsoon. While the number of cells during pre monsoon was 188, that during post monsoon was 230. Even though the species were different, their number was the same during all the seasons. The stratum wise distribution of cells during pre monsoon was 104 cells/cm^3 in the upper segment, 63 in the middle and 21 in the bottom. During monsoon, it was 191, 94 and 55 cells/cm^3 from the upper to the bottom stratum. The vertical distribution during post monsoon was 123 cells/cm^3 in the upper stratum, 59 in the middle stratum and 48 in the lower stratum. *Coscinodiscus marginatus, Pleurosigma falx* and *Gyrosigma spencerii* were the dominant species during premonsoon. *Cocconeis placentula, Gyrosigma spencerii* and *Nitzschia closterium* were the dominant species during monsoon. *Amphora laevis, Navicula forcipata* and *Licmophora juergensii* dominated the benthic microalgal community during the post monsoon season. (Table. 15, Fig. 38)

Table15: Puthuvypu

No	Name of Species	2003										2004								
		PRM			MON			POM			PRM			MON			POM		
		a	a	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
1	Achnanthes clavata		14							9			11						
2	Amphora coffeaformis		11		4			21		8		5		14		5	9		13
3	Amphora laevis	5															34	14	
4	Asterionella japonicum				8		11		20										
5	Coconeis placentula						4			21	4			13	16		8	4	
6	Cosmioiscus asteromphalus				8						7								
7	Cosmioiscus marginatus	7	21		6	26		21				13	7	15		4	11		9
9	Cymbella marina	4								25	7	6						3	
9	Diploneis bombus	17	22	5				23			5	27	3		9	3	9		
10	Fragilaria oceanica	8				8													
11	Gomphonema parvulum		16		5			22						31	12				
12	Grunowia spencerii				7			54	27	22		12	6		21	22	10	2	
13	Hantzschia peregrina	21	14		14	10		52		4	8		2					18	3
14	Meuniera membranacea							20				4		10			8		
15	Navicula forcipata	8	17		12	8	13	48	24						13	7		5	14
16	Navicula hennedyi							23			24	5							4
17	Nitzschia closterium	4	23				9	21	45	18	5			33	9		12		
18	Nitzschia sigma			7						8			1	8		4		4	2
19	Pleurosigma angulatum		13	15	6	7					7			11			10		
20	Rhoicosphenia sp.	6		5	6		11	22	26			14	3					6	7
21	Surirella fastuosa	10				8				28	11				11	6			
22	Thalassionema nitzschioides		12					25		9			2	12	10		12	3	
23	Cosmarium				5									13					
24	Euastrum				2														
25	Staurastrum				4														
26	Ceratium furca							28						10					
		89	163	47	73	79	33	411	191	163	104	83	21	191	94	53	123	59	48

a-upper stratum, b-middle stratum, c-lower stratum

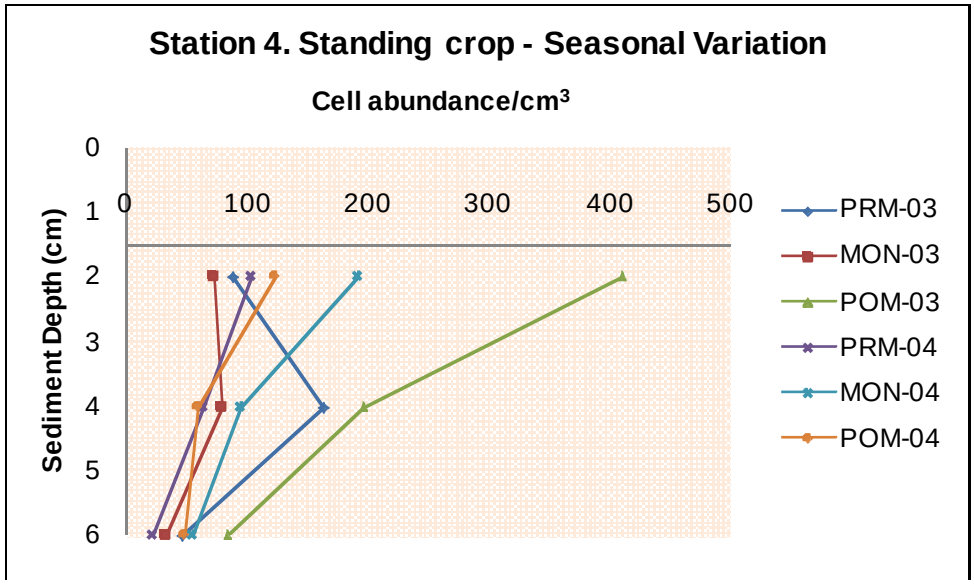


Fig. 38

At station 5, in the first year of the study, the cell number in the phytozone was 228 during pre monsoon, 373 during monsoon and 394 during post monsoon. During pre monsoon, 23 species of microphytobenthos were identified from this zone and they showed a vertical distribution of 105 cells/cm^3 in the first stratum of 2 cm depth, 63 cells/cm^3 in the second stratum of 2-4 cm. depth and 60 cells/ cm^3 in the third stratum of 4- 6 cm. depth. The dominant species recorded during pre monsoon were *Amphora coffeaformis, Diploneis dydima, Nitzschia closterium* and *Pleurosigma salinarum*. During monsoon, even though there was one species less compared to the pre monsoon, the cell density was higher. While 171 cells were counted from the 1 cm^3 top stratum, it was 93 from the middle stratum and 109 from the bottom most stratum. *Navicula hennedyei, Nitzschia closterium* and *Pleurosigma angulatum* were the dominant species. The 23 species identified during post monsoon were distributed vertically with a respective cell number of 214, 119 and 61 cells/

cm^3 in the top, middle and bottom strata. *Cocconeis placentula, Nitzschia panduriformis, Nitzschia sigma* were the dominant species during post monsoon.

In the second year of the study also, the highest species richness and cell abundance were observed during the post monsoon season. While 26 species appeared during post monsoon, there were only 19 species during pre monsoon. The cell abundance and species richness showed gradual increase from pre monsoon to the post monsoon. The strata wise distribution of cells during pre monsoon was, 61 cells/ cm^3 in the upper stratum, 32 cells/ cm^3 in the second stratum and 17 cells / cm^3 in the lower stratum. *Cocconeis placentula, Navicula cincta* and *Nitzschia closterium* were the dominant species observed during this season. 21 species of microphytobenthos were encountered during monsoon at station 5. There were 150 cells in the phytozone with the upper stratum showing the highest number of cells, 73/ cm^3. While 51 cells were found in 1 cm^3 of middle stratum sediment, it was 26 in the lower stratum. *Navicula hennedyei, Nitzschia sigma* and *Pleurosigma angulatum* were the dominant species encountered. During post monsoon, there were 202 cells/cm^3 in the upper stratum of the sediment core and 63 and 21 cells/ cm^3 respectively in the middle and lower strata. *Cocconeis placentula, Nitzschia closterium, Nitzschia panduriformis* and *Pleurosigma salinarum* were the dominant species. (Table. 16, Fig. 39)

Table16: Murikkinpadam

No	Name of Species	2003									2004								
		PRM			MON			POM			PRM			MON			POM		
		a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
1	Achnanthes brevipes	3				7		9			2						10		
2	Amphora coffeaeformis	6	16							4	5			3			9		
3	Amphora proteus	7				5		13			3		1		5				1
4	Asterionella japonica	4		3		6		33	14					2			11		
5	Caloneis madraspatensis				11							1							6
6	Ceratium furca	5						11									12		
7	Closterium kutzingii													4					
8	Cocconeis placentula	2	3			8		29		18	18	4			3	1	21	2	
9	Cocconeis sublittoralis				12			8									8		
10	Diplineis dydima	27	2			6		6			6				4		13		
11	Diplineis weissflogii			1	10		35			2			1	5		8			2
12	Diploneis littoralis		4		13										4			7	
13	Grammatophora undulata			3			8						2						1
14	Gyrosigma distortum		2																
15	Navicula cincta	7		5			4		11		8		8		2		9		
16	Navicula clementis		3														12		
17	Navicula henneedyei				23	23		4		3				16		7		4	
18	Navicula lyra	5	6		9				13			3						3	
19	Navicula mutica			7						6									
20	Nitzschia closterium	3	14	16		19	26	12				13	2	1		2		27	6
21	Nitzschia panduriformis			4			2		27	19			2		5		24		2
22	Nitzschia sigma		4		8			11	29			2		14	12			2	
23	Nostoc punctiforme													5					
24	Oscillatoria formosa				9														
25	Phormidium				11									6					
26	Pleurosigma angulatum		1	15	27	9	28	7			7				13	1	7		
27	Pleurosigma salinarum	23	1					5		5	4	1					25	5	
28	Raphoneis amphiceros																	4	
29	Scenedesmus quadricauda				10														
30	Skeletonema costatum							27	10					2	3				3
31	Surirella fastuosa				28	10		9				3		2		3	15	3	
32	Surirella flumiensis	7		4				8		4	5					3	14		
33	Thalassiosira decipiens	4	7	2			6		15				1	6		1		6	
34	Thalassiosira subtilis	2						10			3	5		3			12		
35	Staurastrum asteroideum													4					
		105	63	60	171	93	109	214	119	61	61	32	17	73	51	26	202	63	21

a-upper stratum, b-middle stratum, c-lower stratum

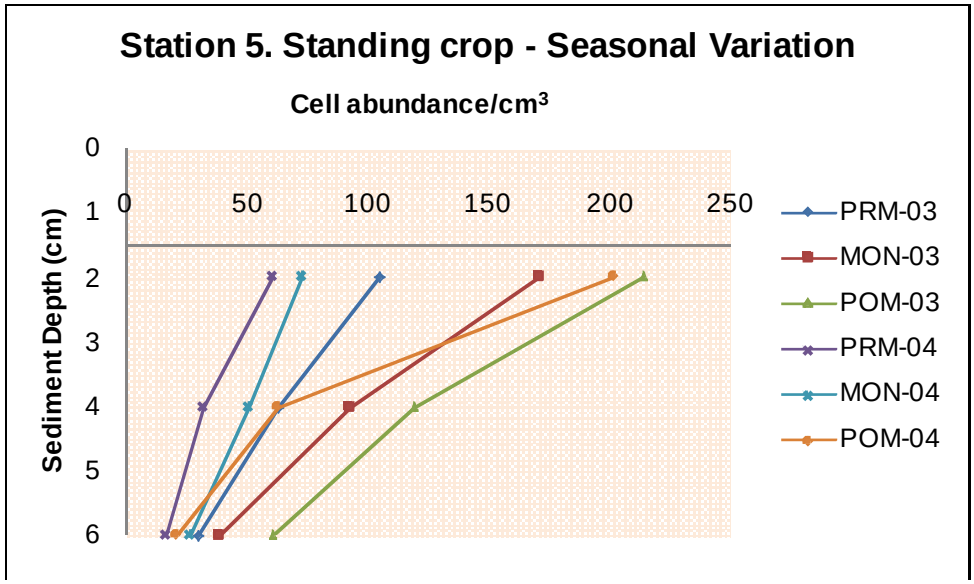


Fig. 39

The species richness and cell abundance of microphytobenthos were comparatively low at station 6. In the first year, there were 120 cells in the phytozone during pre monsoon with representation from 12 species. The strata wise distribution was, 61 cells/ cm^3 in the upper stratum, 36/ cm^3 in the middle stratum and 23 cells/ cm^3 in the lower stratum. *Navicula longissima, Nitzschia closterium, Diploneis dydima* and *Nitzschia panduriformis* were the dominand species during this period. During monsoon, the vertical distribution of microphytobenthos in the sediment core was in such way that there were 57 cells/ cm^3 in the upper stratum, 68 cells/cm^3 in the middle stratum and 39 cells /cm^3 in the lower stratum. *Nitzschia panduriformis, Pleurosigma normanii* and *Nitzschia closterium* were the dominant species. During post monsoon, the middle stratum of the sediment showed the highest number of cells, 52, per cm^3. There were 48 cells /cm^3 in the upper stratum and 23 cells/ cm^3 in the lower stratum of the sediment core. Amphora coffeaformis, Diploneis dydima and *Nitzschia closterium* (present in all three strata) were the dominant species during the season.

The pattern almost similar to that of the first year was noticed in the second year. 114 cells were enumerated from the phytozone during pre monsoon, 146 during monsoon and 110 during post monsoon. While cells belonging to 12 species were identified during pre monsoon, there were representatives from 15 species during monsoon. Cells of 14 species were noticed during post monsoon. The strata wise distribution of cells during pre monsoon was, 59/ cm^3 in the upper stratum, 37/cm^3 in the middle stratum and 18/ cm^3 in the bottom most stratum. *Navicula cincta* was present in all the three strata. Other dominant species were *Cyclotella striata, Diploneis dydima* and *Navicula longissima.* The vertical distribution of cells during monsoon was, 84/cm^3 in the upper stratum, 41/ cm^3 in the middle stratum and 21/ cm^3 in the lower stratum. *Navicula longissima, Amphora laevis*, *Nitzschia closterium* and *Pleurosigma normanii* were the dominant species. In the bottom most stratum of the sediment core, there were 63 cells/cm^3 in the upper stratum, 26 cells/ cm^3 in the middle stratum and 21 cells per cm^3 in the lower stratum. *Nitzschia closterium* was present in all the three strata. *Cocconeis placentula, Cyclotella striata* and *Diploneis dydima* were the other dominant species encountered. (Table. 17, Fig. 40)

Table17: Mangalavanam

No	Name of Species	2003									2004								
		PRM			MON			POM			PRM			MON			POM		
		a	b	c	a	b	c	a	b	c	a	b	c	a	b	c	a	b	c
1	Actinanthes brevipes				4						2			7			3		
2	Amphora coffeaformis			6	5	9		5	10					6				4	1
3	Amphora laevis	5	5				4				3		1		14	8	6		
4	Bacillaria paradoxa				8			2			5	3		5			2		
5	Cocconeis placentula	4		2			2	4		2								8	3
6	Cyclotella striata						5		3	11		9	6		3	1	14	6	
7	Diploneis didyma	15	4		4			19	13		18	1						1	6
8	Navicula cincta			1	5	7			4		21	4	5		1		4		
9	Navicula hennedyei	7				10		6				2		5		1	4	2	
10	Navicula longissima	5	16		7				3	4		12	3		4	3	5		
11	Nitzschia closterium	17		3		16	4	5	11		4		2	23	11		15	2	3
12	Nitzschia panduriformis		6	8		13	17		2	3		5		3		2	2		1
13	Nitzschia sigma	4			5			3		1	6		1		2		3		2
14	Pleurosigma normanii		5	3	15		7		5			1		2	1		5	3	
15	Thalassiosira subtilis	3				3		4							5	3			
16	Prorocidium spp				3					2				8					
17	Oscillatoria formosa													6					
		61	36	23	57	86	39	48	52	23	59	37	18	84	41	21	63	26	21

a-upper stratum, b-middle stratum, c-lower stratum

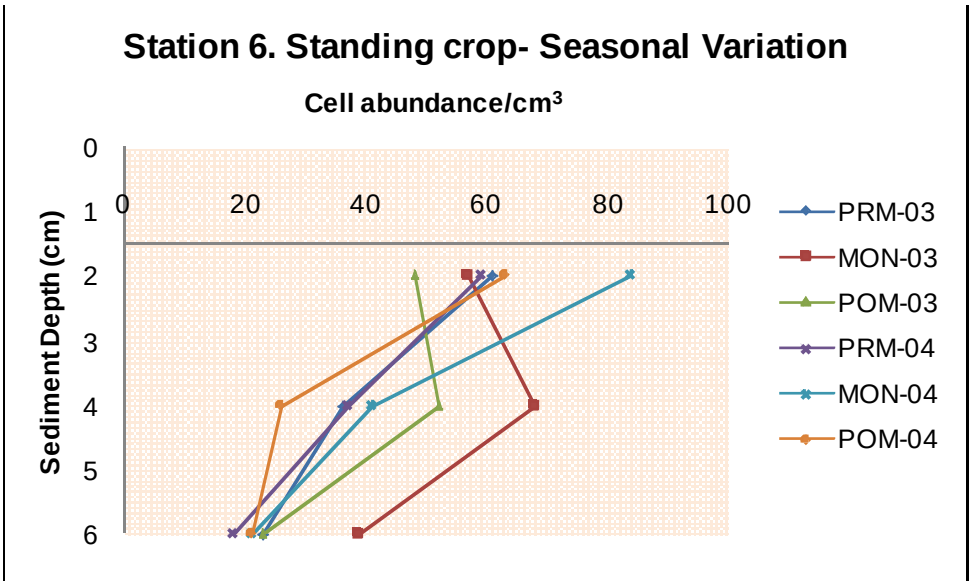


Fig. 40

6.3.2 Pigments:

6.3.2.1Chlorophyll *a*:

The biomass of microphytobenthos are often detected and quantified by sediment chlorophyll *a* analysis. This was done spectrophotometrically during this study and the extraction of the pigment was carried out by acetone method.

In the first year of this study at station 1, the highest chlorophyll *a* value of 14.364 µg/cm^3 was obtained during monsoon in the first stratum of the sediment. The lowest value of chlorophyll *a* recorded during this year was 2.859 µg/cm^3 in the lower stratum of the sediment during the post monsoon period. In two of the post monsoon samples (October and December, 2003), the middle stratum of the sediment showed higher chlorophyll *a* values than the upper stratum.

In the second year also, the highest average concentration of chlorophyll *a* of 12.281 µg/cm^3 was recorded during monsoon, but this time it was from the

middle stratum of the sediment. In this year, the chlorophyll *a* values of the middle stratum outscored that of the upper stratum during all the three seasons. The lowest value of the year, 3.99 µg/cm^3 was obtained from the lower most stratum during post monsoon. (Fig. 41)

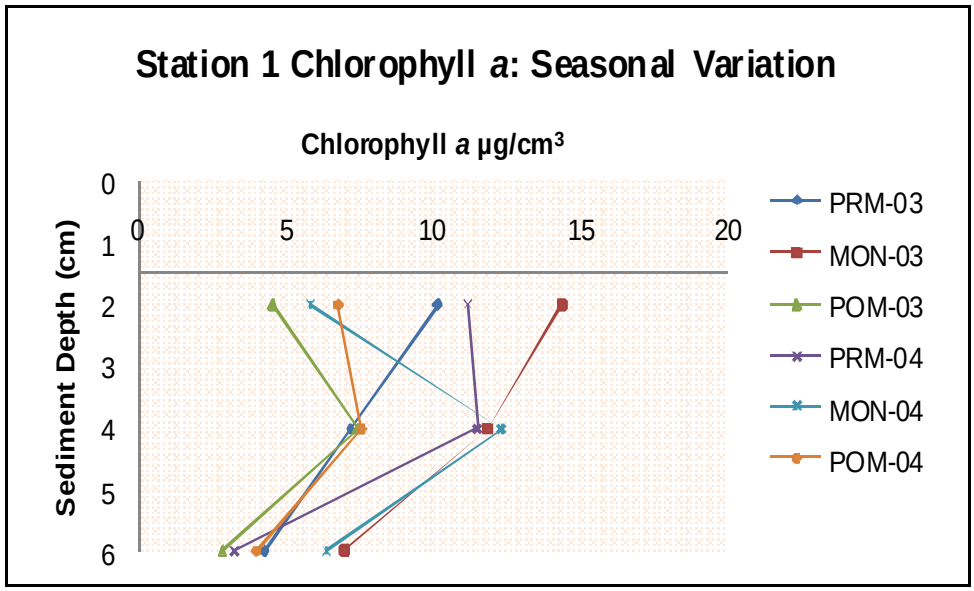


Fig. 41

In station 2, the chlorophyll *a* value increased upto 36.313 µg/cm^3 during one of the post monsoon collections in 2003. The highest average concentration of the pigment during the year was recorded from the upper stratum of the sediment during post monsoon, the value being, 26.873 µg/cm^3. Surprisingly, the lowest value, 1.6981 µg/cm^3 was also recorded in a post monsoon sample. The lowest average value of 3.277 µg/cm^3 was however, recorded from the lower stratum during monsoon. During all the seasons, there was a reduction in the concentration of chlorophyll *a* from the upper stratum to the lower one.

In the second year, however, the highest chlorophyll *a* value of 17.193 µg/cm^{3}was obtained from post monsoon middle stratum sediment. The lower stratum sediment of monsoon season showed the lowest value of the year, 2.302

µg/cm^3. The amount of chlorophyll *a* in the middle stratum was at par with that of the upper stratum during all the seasons. (Fig. 42)

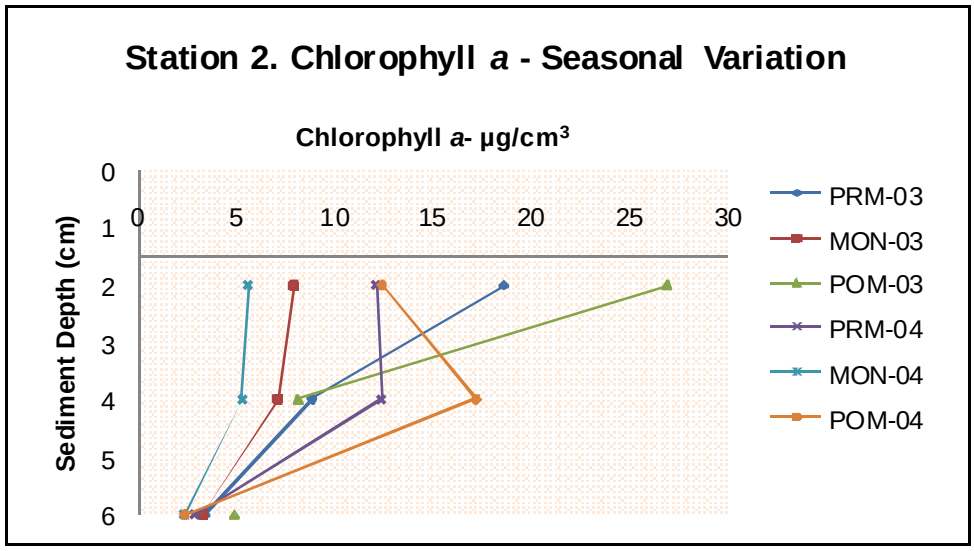


Fig. 42

In station 3, the highest chlorophyll *a* value of the first year, 14.479 µg/cm^{3}was noticed during premonsoon in the upper stratum of the sediment. The lower stratum value of 3.09 µg/cm^3 estimated during the post monsoon was the lowest. The average post monsoon value of the middle stratum, 10.257 µg/cm^3 was higher than that of the upper stratum which was only 7.821 µg/cm^3.

During the second year of the study, station 3 recorded unusual high values of chlorophyll *a* during all the three seasons and in all the three strata of the sediment. While the highest value of 31.23 µg/cm^{3}was recorded during monsoon in the upper stratum of the sediment, the lowest of 6.90 µg/cm^3 was noted in the lower stratum during pre monsoon. During pre and post monsoon seasons the middle stratum value was higher than that of upper stratum. (Fig. 43)

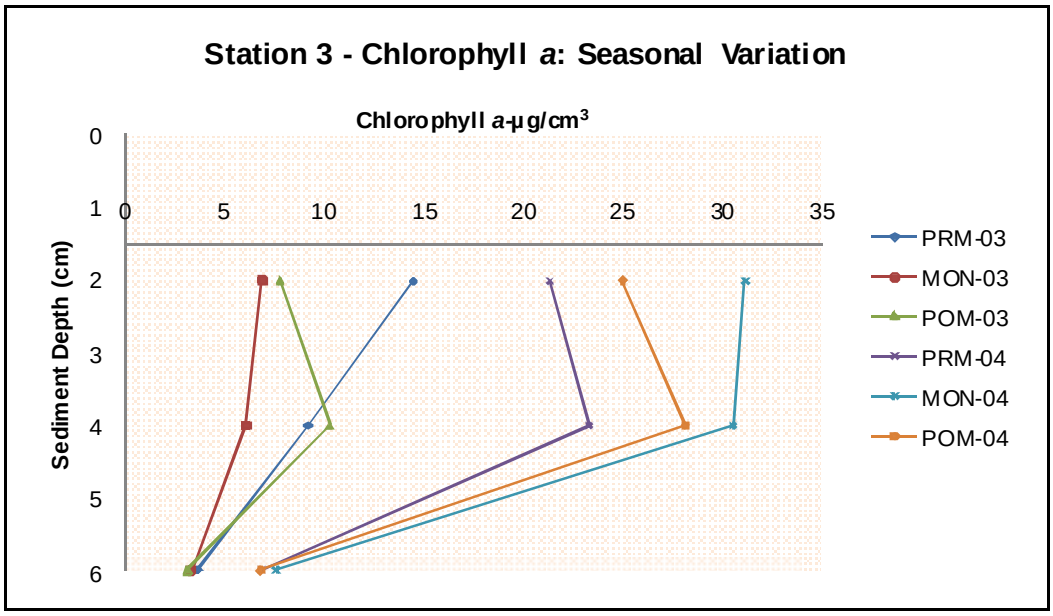


Fig. 43

In station 4, the highest chlorophyll *a* value of the first year, 25.98 µg/cm^3 was estimated from the middle sediment stratum during pre monsoon. The upper stratum of the sediment collected during monsoon recorded a very close value of 24.9 µg/cm^3. The lowest value of the year, 4.76 µg/cm^3 was also noted during monsoon, from the bottom most stratum. In the second year, the highest chlorophyll *a* value of 19. 39 µg/cm^3 was estimated from the upper stratum during post monsoon. The lower most value of the year was 4.01 µg/cm^3 estimated from the bottom segment during post monsoon. The chlorophyll *a* value of the upper stratum of sediment collected during monsoon also showed a higher value of 17.27 µg/cm^3. (Fig. 44)

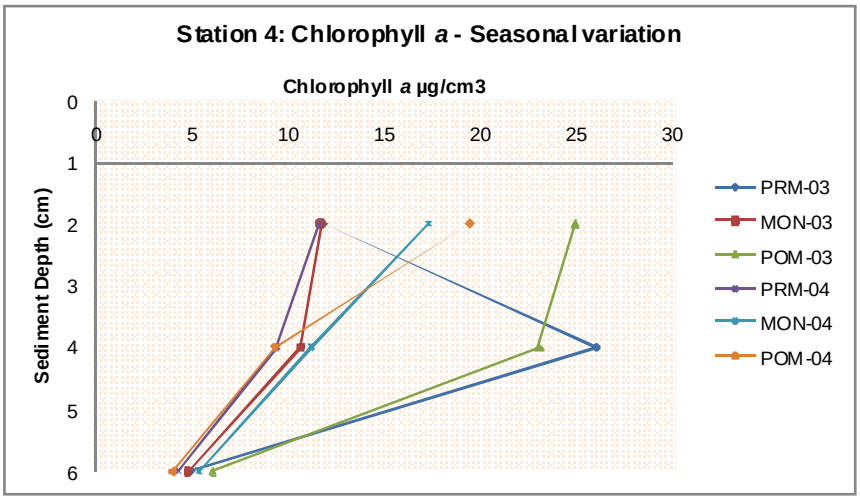


Fig. 44

In station5, one of the upper stratum sediment cores collected during monsoon showed the highest value of 23.113 µg/cm^3. recorded in the first year. However, the highest average of 21.71 µg/cm^3. was that of the post monsoon – upper stratum sediment. The lowest value of the year, 1.920 µg/cm^3 was obtained from the bottom stratum sediment of pre monsoon. In the second year, the highest value of 25.46 µg/cm^3 was obtained from the upper stratum sample of post monsoon season and the lowest value of 1.66 µg/cm^3 from the bottom most stratum of pre monsoon season. (Fig. 45)

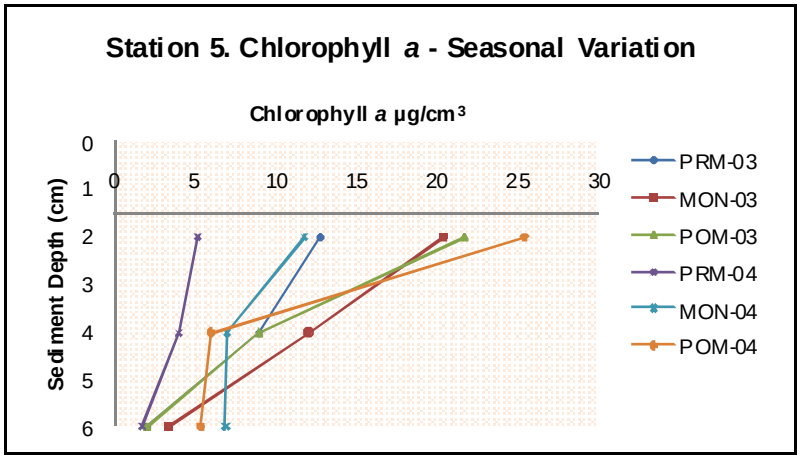


Fig. 45

The values were moderately low in station 6 during both the years with the monsoonal upper sediments showing the average higher values. While it was 10.623 µg/cm^3 in 2003, it was 11.627 µg/cm^3 in 2004. While the lowest value of the first year (1.431 µg/cm^3) was recorded from the bottom portion of premonsoon season, that of the second year, 1.982 µg/cm^3 was obtained from the lower most stratum of monsoon season. (Fig. 46)

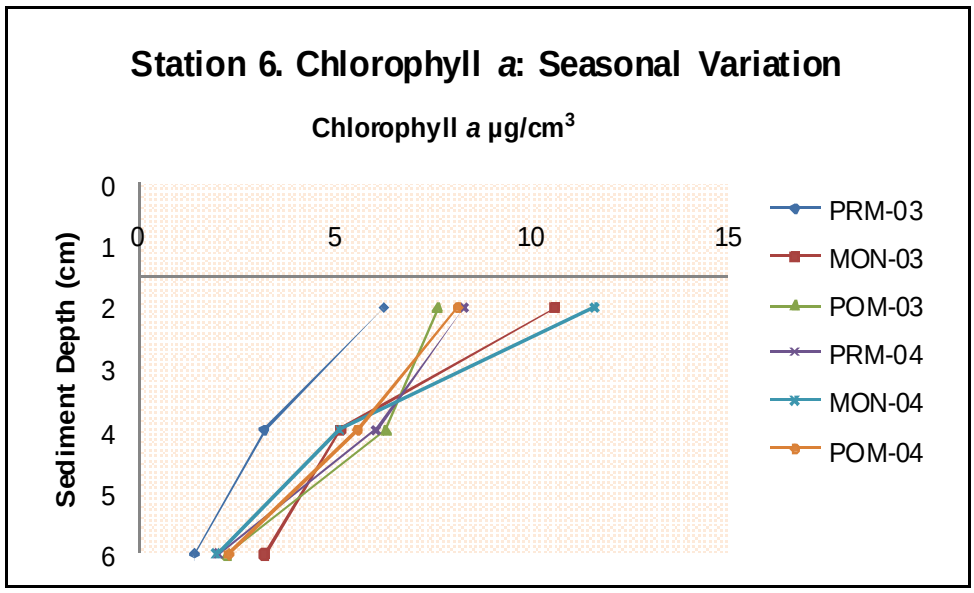


Fig. 46

6.3.2.2Chlorophyll *b*:

Chlorophyll *b* is the characteristic pigment of green algae which shows an increase in fluorescence on acidification and algae containing chlorophyll *b* generally have an acid factor slightly less than those without chlorophyll *b*, which will result in a slight underestimation of chlorophyll *a*.

Very low values of chlorophyll *b* were registered throughout this study. In many of the samples, it was practically nil.

At station 1, in 2003, the highest chlorophyll *b* value was 1.284 µg/cm^3, recorded from the upper stratum of the sediment sample collected during pre monsoon. Besides this, the presence of this accessory pigment could be traced in the middle and lower stratum samples of pre monsoon and in the upper sediment stratum of post monsoon. In 2004 also, the pigment could be traced only during pre and post monsoon seasons. The highest value was 1.488 µg/cm^3. recorded from the middle sediment stratum during post monsoon. (Fig. 47)

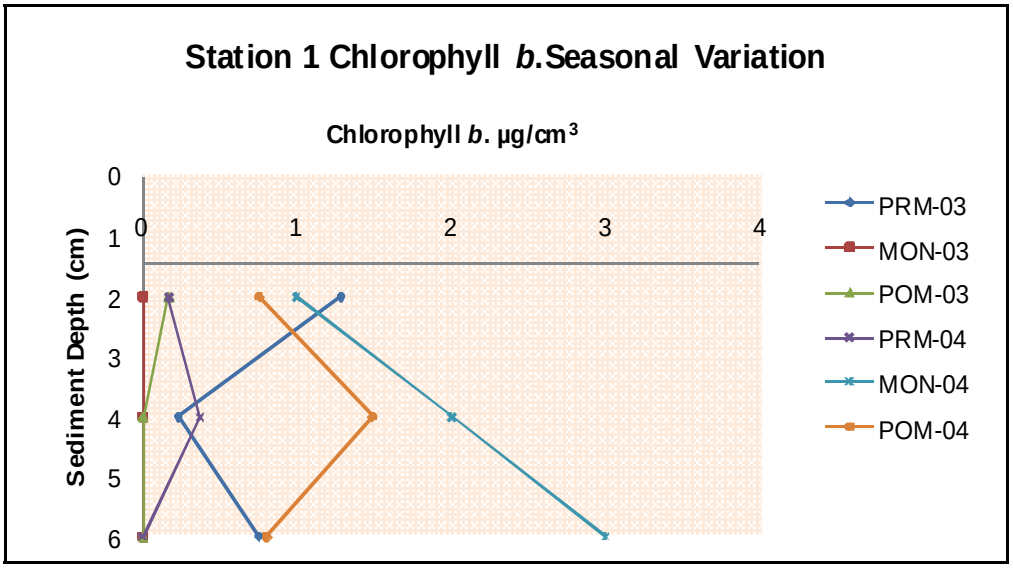


Fig. 47

At station 2, chlorophyll *b* was present in the sediment samples of both the years in considerable amount. In 2003, the highest value of 4.22 µg/cm^3 was obtained from the upper stratum of the sediment sample collected during pre monsoon. Except the upper stratum of post monsoon sample, all other seasonal sediment strata showed the presence of chlorophyll b. The case was not so different in the second year and there was no one stratum of any of the seasons without the presence of chlorophyll b. While the highest value of 4.1876 µg/cm^3 was recorded from the middle stratum of post monsoon sediment, the lowest value was 0.1251 µg/cm^3 recorded from the upper stratum of pre monsoon sediment. (Fig. 48)

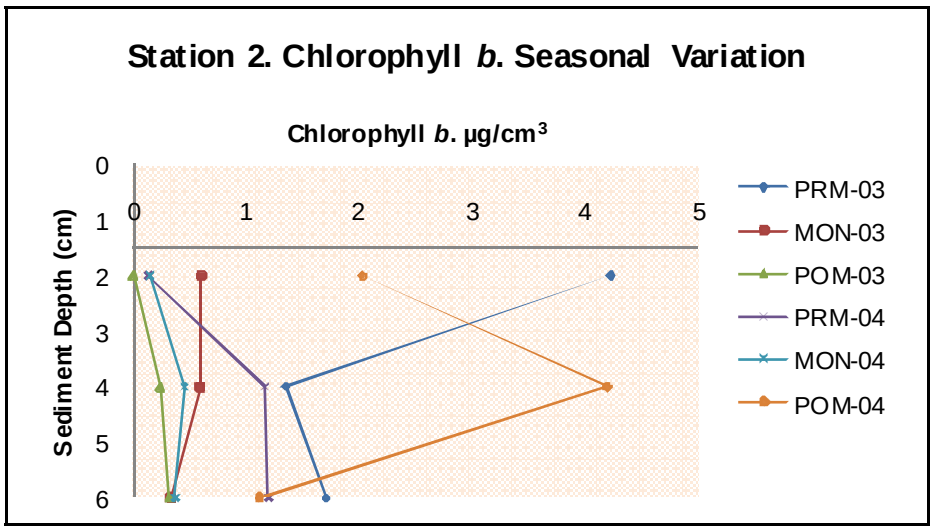


Fig. 48

At station 3, in 2003, its presence was hardly observed in any of the samples except in the upper stratum samples of all the three seasons. The highest value of 1.2152 µg/cm^3 was recorded during post monsoon. The trend was the same in the second year also, with the upper stratum of monsoon sample registering the highest value of 1.518 µg/cm^3. (Fig. 49)

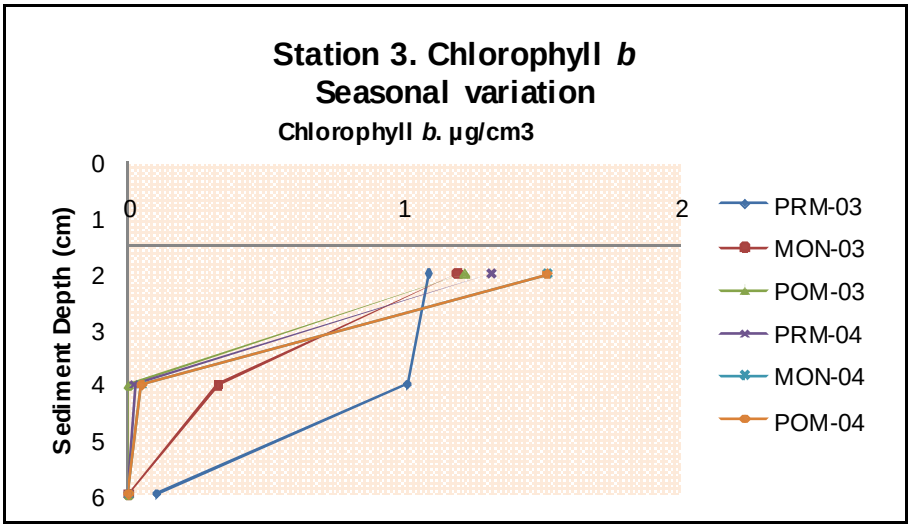


Fig. 49

At station 4, in 2003, the presence of chlorophyll *b* was practically nil in most of the samples. The highest value in the first year of the study (2.149 µg/cm^3) was registered in the upper stratum of the pre monsoon sediment. In 2004, only the upper and middle strata of the sediment collected during monsoon and the upper strata of the sediment collected during post monsoon showed the presence of chlorophyll *b*, the values being 2.6046 µg/cm^3 and 1.1173 µg/cm^3 and 0.0628 µg/cm^3.(Fig. 50)

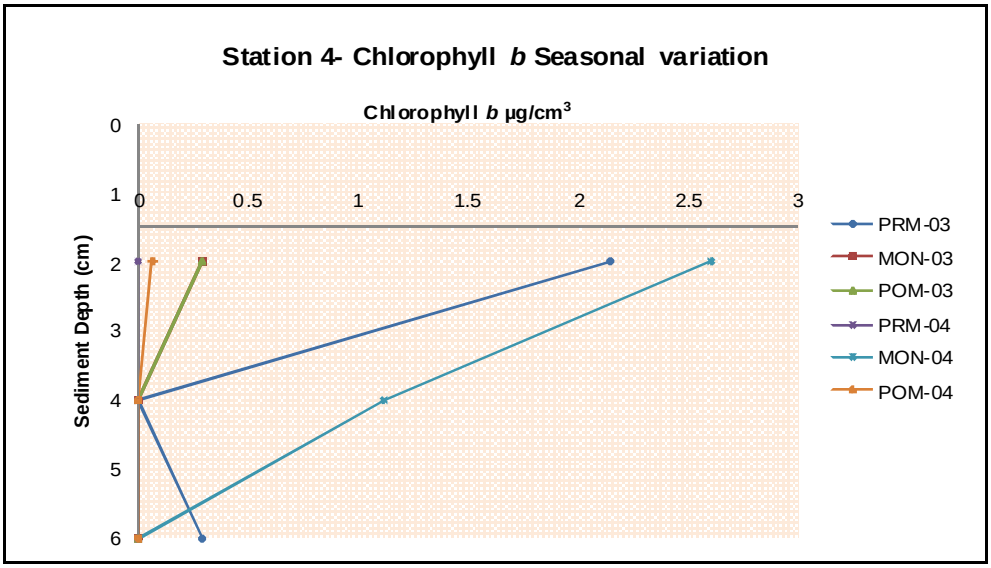


Fig. 50

At station 5, presence of chlorophyll *b* was noticed in all the three strata of the sediment collected during monsoon and post monsoon in 2003. While the respective monsoon values were 1.3066 µg/cm^3, 1.2857 µg/cm^3 and 0.7176 µg/cm^3, the post monsoon values were 0.6821 µg/cm^3 0.2321 µg/cm^3 and 0.0168 µg/cm^3. In 2004, the presence of chlorophyll *b* was noticed in all strata of sediment during all seasons. While the highest value was 1.5621 µg/cm^3 recorded during pre monsoon in the upper stratum, the lowest value was 0.4714 µg/cm^3 recorded during the same season in the lower stratum. (Fig. 51)

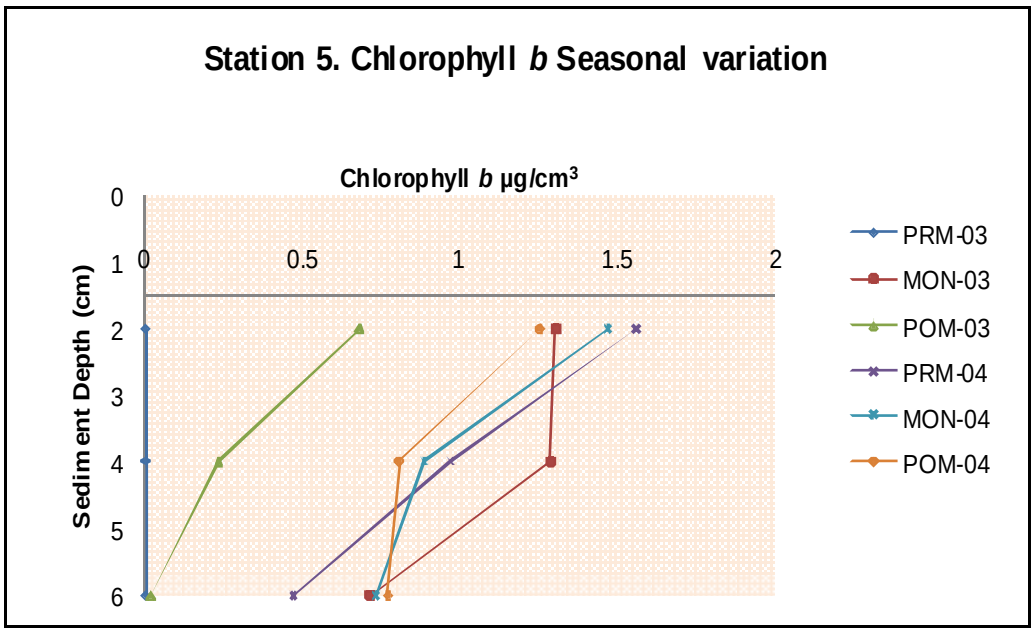


Fig. 51

At station 6, in 2003, the presence of chlorophyll *b* was noticed in the upper stratum of the sediment collected during premonsoon and monsoon, the values being 0.634 µg/cm^3 and 1.512 µg/cm^3 respectively. In the second year, the chlorophyll *b* was present much abundantly. All the three sediment strata of the monsoon season and the upper strata of the other two seasons showed the presence of chlorophyll *b*. The highest and lowest values, 2.010 µg/cm^3 and 0.125 µg/cm^3 in the upper and lower stratum respectively, were estimated during monsoon. (Fig. 52)

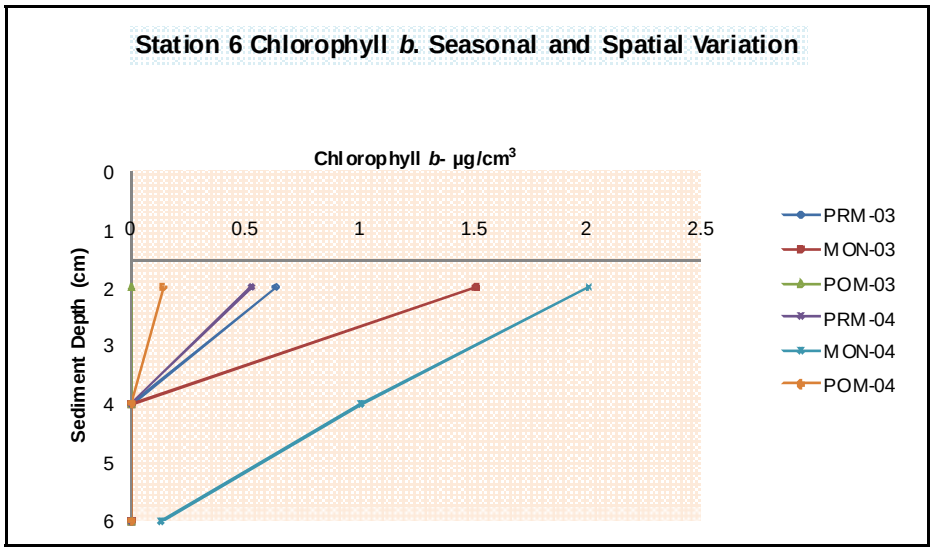


Fig. 53

6.3.2.3 Chlorophyll *c*:

Chlorophyll *c* is an accessory photosynthetic pigment present in both centric and pinnate diatoms as well as in dinoflagellates. With respect to the abundance, geographic distribution and to the importance in photosynthetic apparatus, it ranks equally with chlorophyll *b*. Earlier it was believed that chlorophyll *c* is a degradation product, but now it is evident it is a natural constituent of the cells rather than a postmortem product (Strain *et al.*, 1943). In the present study, the concentration chlorophyll *c* in the mud sample was measured spectrophotometrically.

At station 1, in 2003, all the three sediment strata showed the presence of chlorophyll *c* during pre monsoon. The values were 1.2142 µg/cm^3, 0.6915 µg/cm^3 and 0.9372 µg/cm^3 from upper stratum downwards. The monsoon chlorophyll *c* values were 2.896 µg/cm^3, 3.176 µg/cm^3 and 1.175 µg/cm^3 from surface to bottom. The values were comparatively low during post monsoon and they are 0.1364 µg/cm^3, 1.715 µg/cm^3 and 0.053 µg/cm^3 in the three strata from surface onwards. In the second year, the highest value of chlorophyll *c*

was recorded in the middle stratum of the post monsoon sediment, the value being 3.679 µg/cm^3. The lowest value of 0.087 µg/cm^3 was recorded from the upper most stratum of pre monsoon sediment. (Fig. 54)

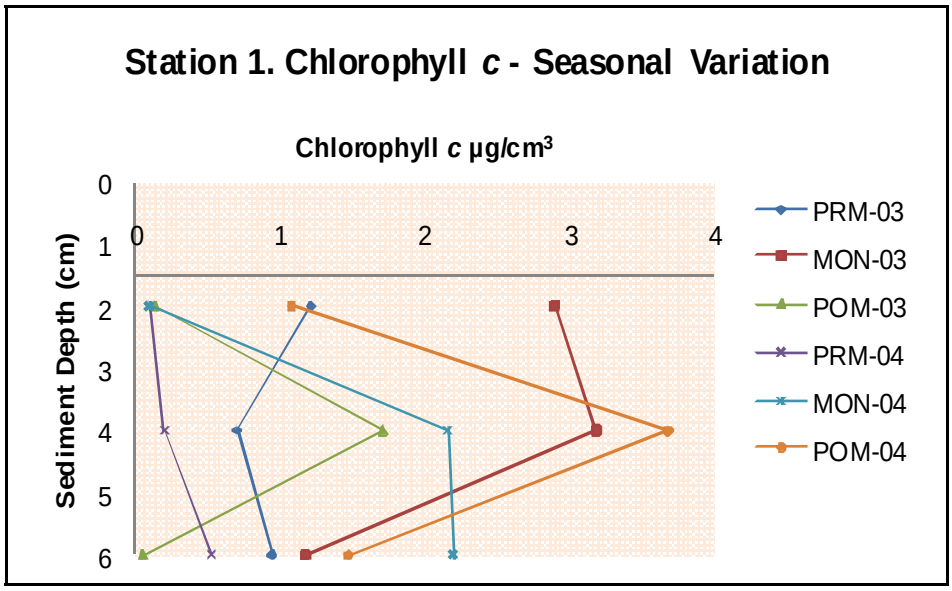


Fig. 54

At station 2, the presence of chlorophyll *c* could be detected in all the three strata of the sediment collected during all the seasons in both the years. While the highest value of the first year (2.350 µg/cm^3) was recorded in the upper most stratum of post monsoon sediment, the lowest value was 0.225 µg/cm^3 recorded from the lower most sediment stratum of the same season. In the following year, again, the highest chlorophyll *c* value was observed in the upper most stratum of post monsoon sediment, the value was 2.572 µg/cm^3. The lowest chlorophyll *c* value of the year was 0.3001 µg/cm^3 recorded during monsoon from the upper most sediment stratum. (Fig. 55)

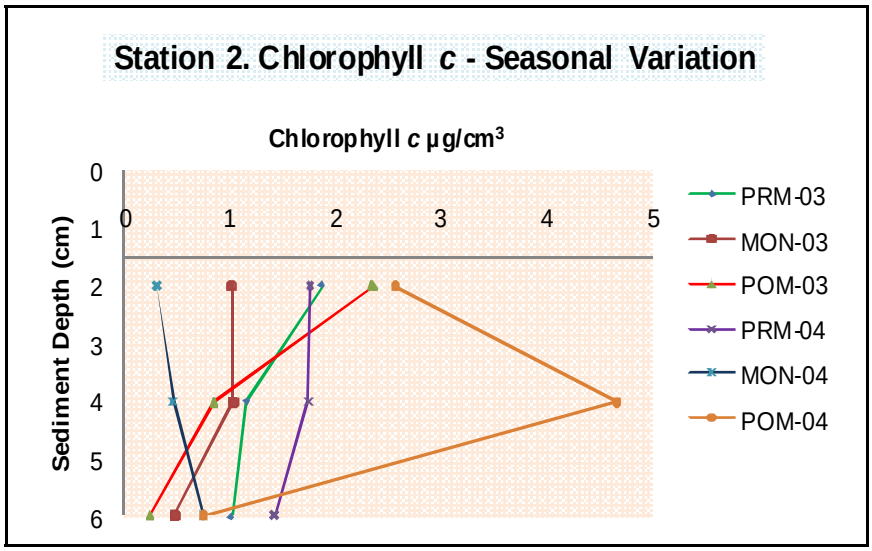


Fig. 55

At station 3, the highest chlorophyll *c* value of the first year (2.931 µg/cm^3) was noticed during pre monsoon from the upper stratum of the sediment. The lowest value of 0.459 µg/cm^3 was obtained for the bottom most stratum of post monsoon sediment. In the second year the values ranged between 12.424 µg/cm^3 in the middle stratum of monsoon sediment and 1.1393 µg/cm^3 in the bottom most stratum of pre monsoon sediment. (Fig. 56)

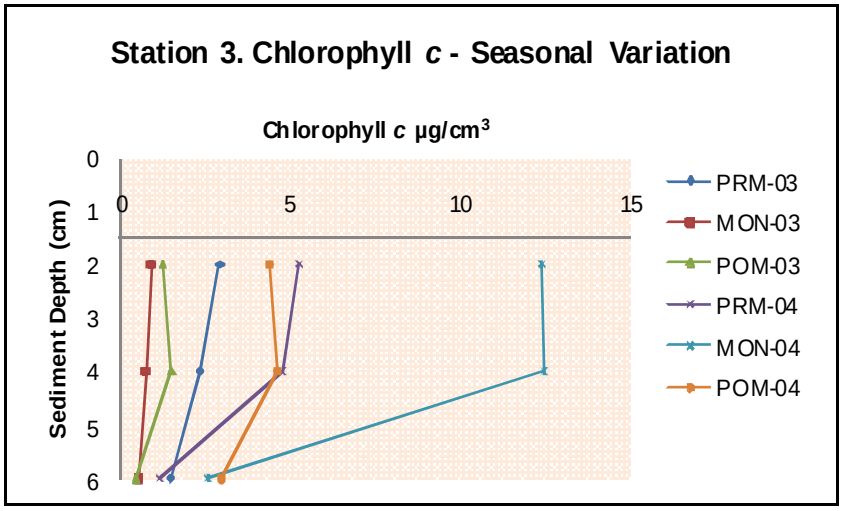
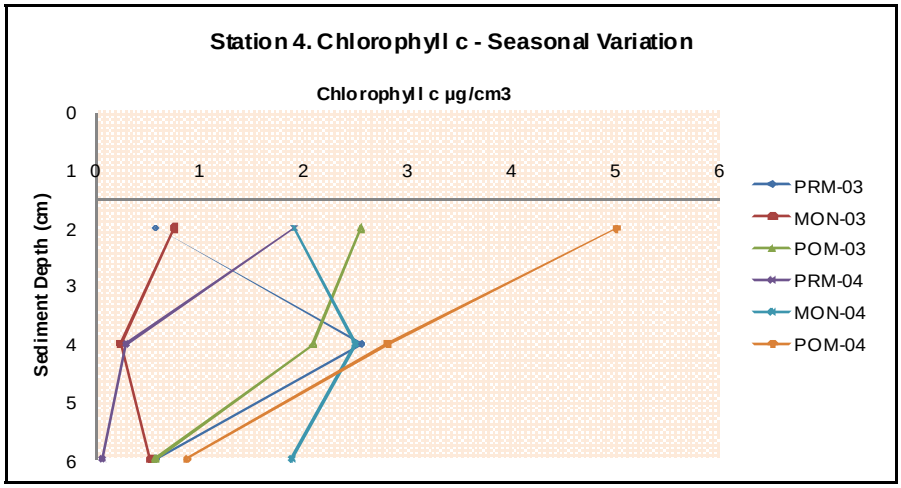


Fig. 56

At station 4, during the first year, the chlorophyll *c* was detected from only two samples, with a value of 0.584 µg/cm^{3}in the upper stratum of pre monsoon sediment and with a value of 0.215 µg/cm^3 in the second stratum of monsoon sediment. There was practically no chlorophyll *c* in any of the other samples. In 2004, the values ranged from 0.076 µg/cm^3 recorded in the bottom most stratum- pre monsoon sediment to 2.494 µg/cm^3 in the monsoon middle stratum.(Fig. 57)



(Fig. 57)

At station 5, all the examined samples showed the presence of chlorophyll *c*. In 2003, the values ranged from 2.428 µg/cm^3 in the upper stratum of pre monsoon sediment to 1.002 µg/cm^3 in the lower stratum of post monsoon sediment. The highest and lowest values of the second year were 3.351 µg/cm^3 recorded in the upper stratum of post monsoon sediment and 0.725 µg/cm^3 recorded in the middle stratum of monsoon sediment. (Fig. 58)

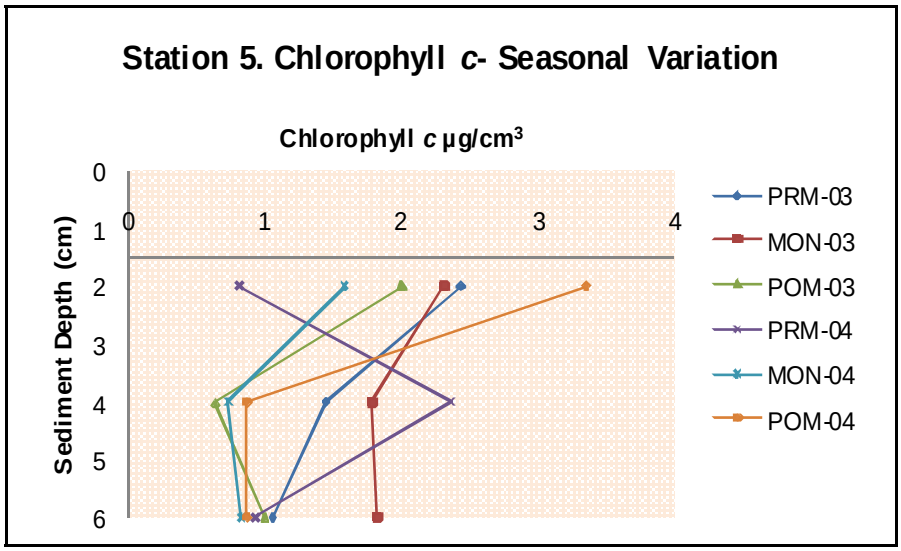


Fig. 58

At station 6, the chlorophyll *c* values of the first year ranged between 2.0156 µg/cm^3 estimated from the upper most stratum of monsoon sediment and 0.052 µg/cm^3 obtained from lower stratum sediment sample of the same season. In the second year, the values ranged from 2.519 µg/cm^3 recorded for the upper stratum of monsoon sediment to 0.052 µg/cm^3 recorded for the middle stratum of pre monsoon sediment. (Fig. 59)

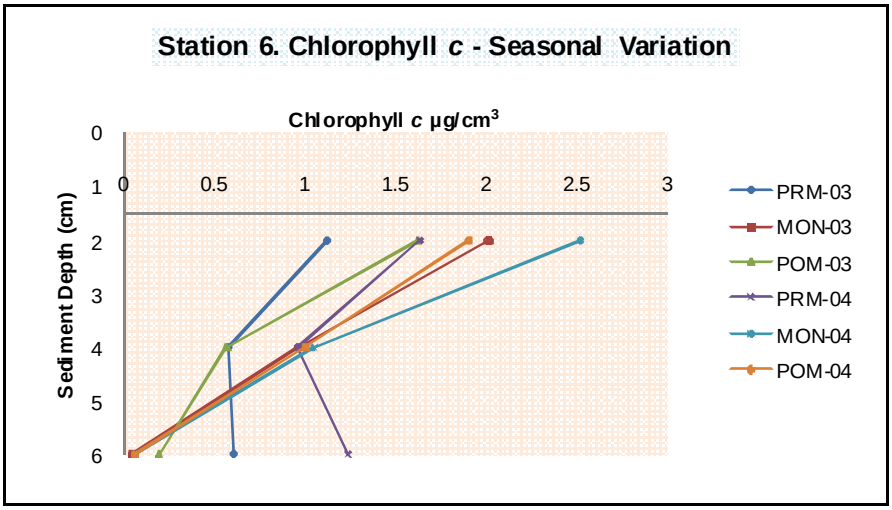


Fig. 59

6.3.2.4 Carotenoids:

Carotenoids are one of the most important photosynthetic pigments which prevent chlorophyll and thylakoid membrane from the damage of absorbed energy by photooxidation.

A moderately high amount of carotenoid pigments were found in almost all sediment samples. (Fig. 60)

At station 1, in the first year, the highest value of 0.991 µg/cm^3 was obtained from the middle stratum sediment collected during monsoon. The lowest value was 0.139 µg/cm^3 recorded in the middle stratum of post monsoon sediment. In the second year, the highest and lowest values of carotenoids were 1.275 µg/cm^3 (bottom stratum- pre monsoon) and 0.433 (upper stratum- monsoon). There was not much seasonal or strata wise variation in carotenoid concentration.

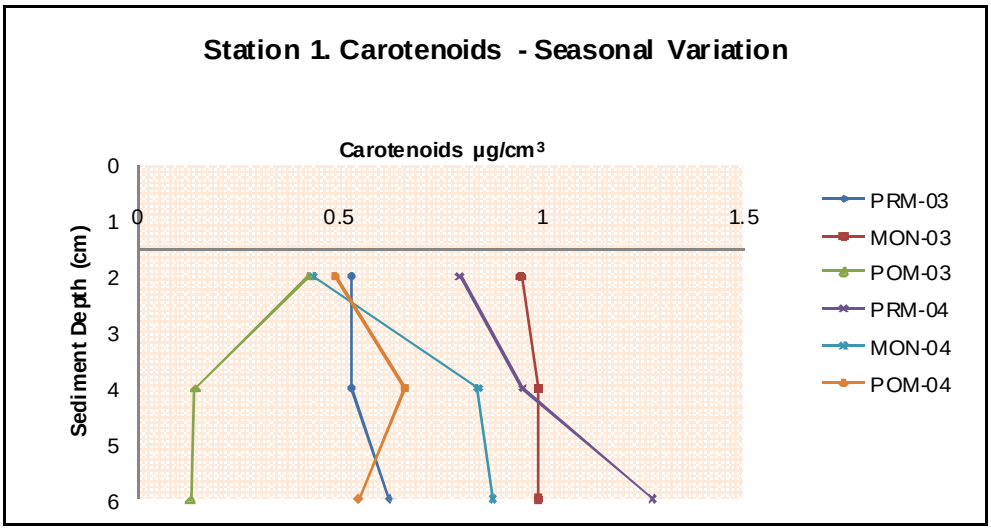


Fig. 60

At station 2, 1.978 µg/cm^3 estimated from the upper most stratum of sediment collected during post monsoon was the highest value of the first year. The lowest value was 0.281 µg/cm^3 estimated from the bottom most sediment

of pre monsoon season. In the second year, the highest carotenoid value was 1.785 µg/cm^3 recorded for the middle stratum of pre monsoon sediment and the lowest value was 0.019 µg/cm^3 for the bottom stratum- post monsoon sediment. (Fig. 61)

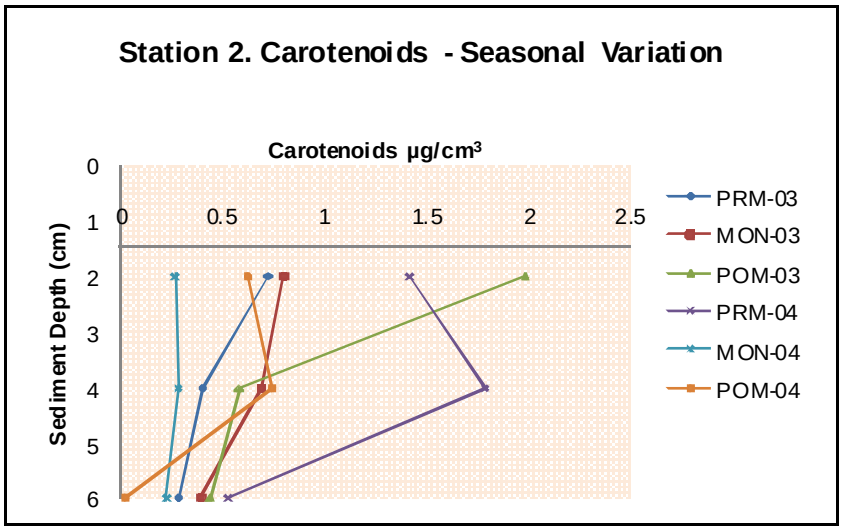


Fig. 61

At station 3, the highest and lowest carotenoid values of the first year were obtained from the post monsoon sediment. The highest was 1.046 µg/cm^3 from the middle stratum and lowest was 0.026 µg/cm^3 from the bottom most stratum. In the second year the values were comparatively higher during the entire period of this study. While the highest value was 2.503 µg/cm^3 of upper stratum- monsoon sediment , the lowest was 0.384 µg/cm^3 of lower stratum- pre monsoon sediment. (Fig. 62)

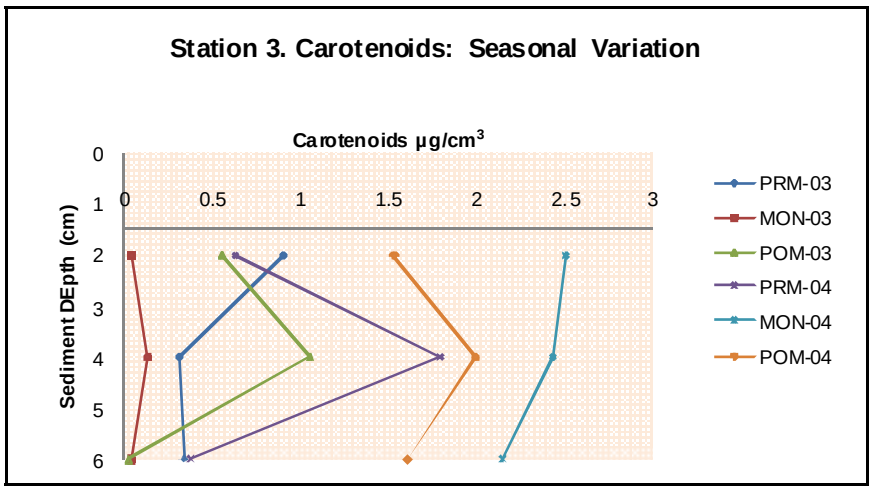


Fig. 62

At station 4, the carotenoid values ranged from 1.3121 µg/cm^3 (middle stratum – premonsoon) to 0.3308 µg/cm^3 (lower stratum- monsoon) in the first year. In the second year, the highest value of 1.0718 µg/cm^3 was recorded from the upper stratum of post monsoon sediment. The lowest value was 0.0522 µg/cm^3 recorded from the bottom stratum of pre monsoon sediment. (Fig. 63)

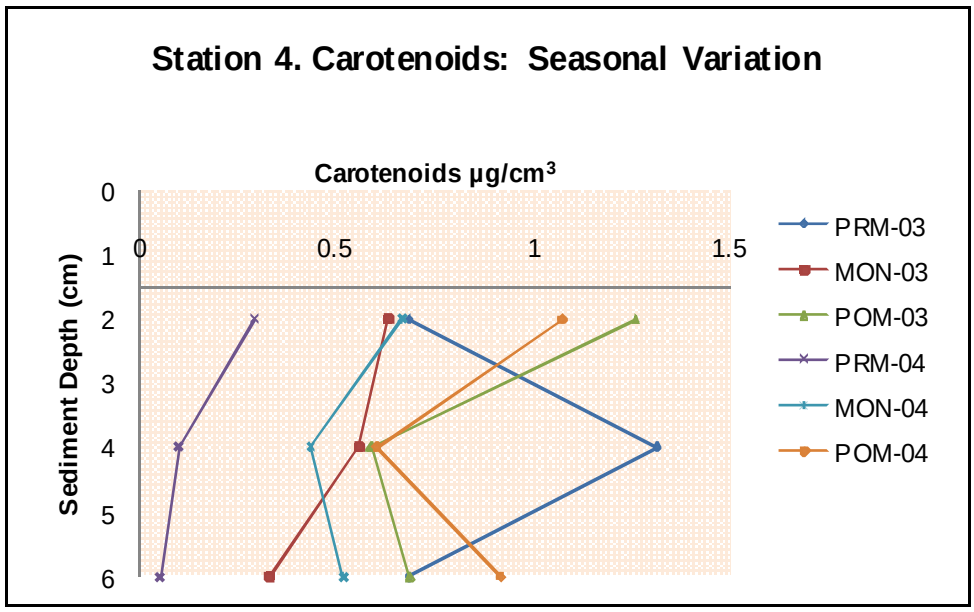


Fig. 63

At station 5, the carotenoid values ranged in the first year from 1.439 µg/cm^3 of upper stratum monsoon sediment to 0.700 µg/cm^3 of lower stratum pre monsoon sediment. In the following year, the highest and lowest values were 1.729 µg/cm^3 of upper stratum- post monsoon and 0.063 of µg/cm^3 of middle stratum- pre monsoon sediment. There was practically no carotenoids in the lower stratum of the sediment collected during pre monsoon. (Fig. 64)

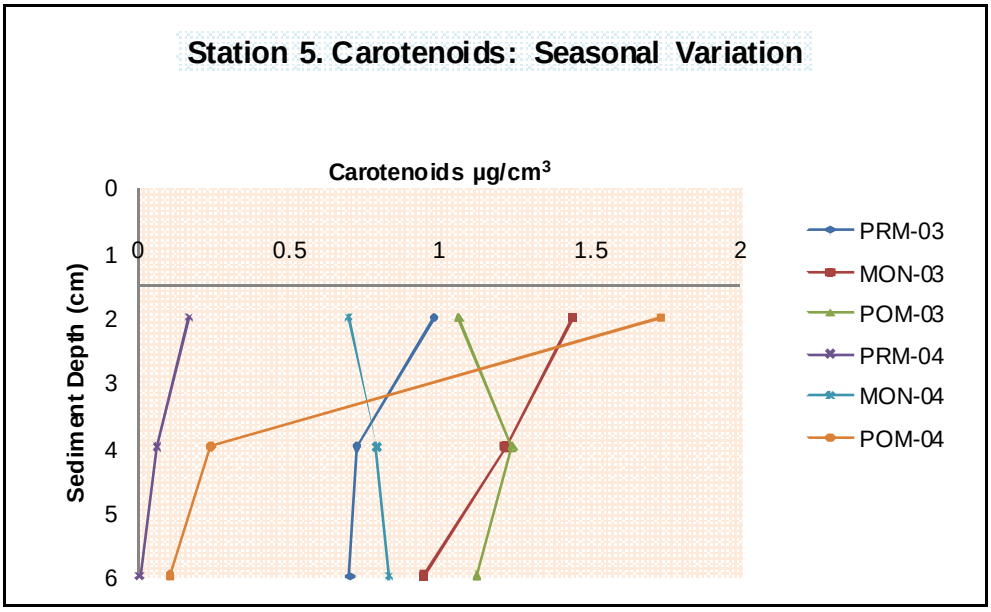


Fig. 64

At station 6, the highest first year value was 1.519 µg/cm^3 recorded from the upper stratum of monsoon season. The lowest value was 0.0538 µg/cm^3 from the bottom most stratum of post monsoon sediment. In the second year, the values ranged from 2.031 µg/cm^3 of upper stratum monsoon sediment to 0.3151 µg/cm^3 of lower stratum pre monsoon sediment. There was practically no chlorophyll in the lower stratum of the sediment collected during post monsoon. (Fig. 65)

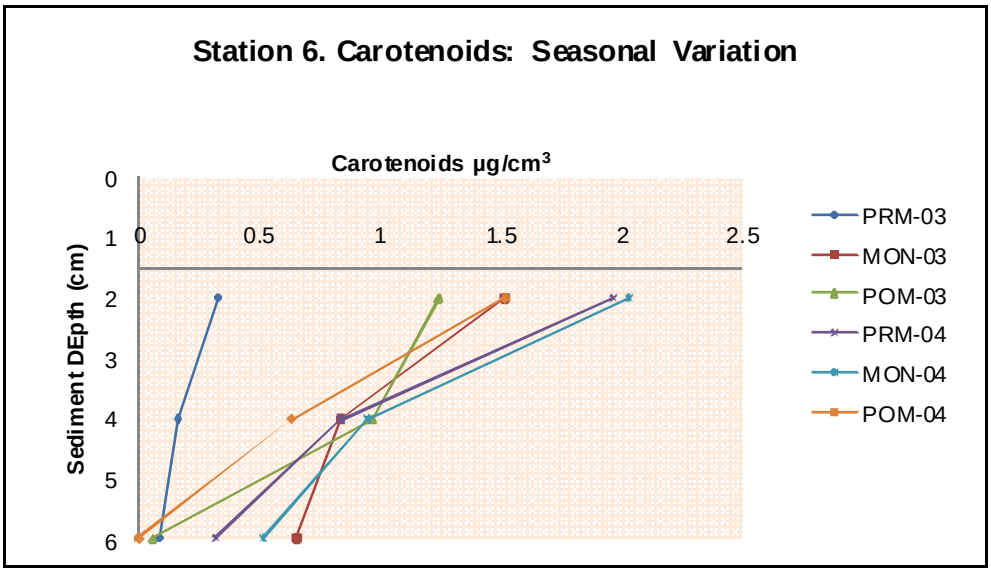


Fig. 65

6.3.2.5 Pheopigment:

It has been shown that chlorophyll degradation products may at times constitute a significant fraction of the total green pigments present in seawater (Yentsch and Menzel 1963; Lorenzen 1965; Yentsch 1965). These degraded forms, or inactive chlorophyll, absorb light in the red part of the spectrum; if they are present in high concentrations relative to chlorophyll *a*, a serious error may be introduced into chlorophyll data obtained through spectrophotometric techniques since the absorption of light by the degraded forms is not distinguished from that absorbed by active chlorophyll. Chlorophyll *a* can readily be converted to pheopigment simply by the addition of a weak or dilute acid, either oxalic acid or 1 N HCl, and when the reaction is carried out on a specific sample the absorbency of the solution is reduced (Vernon 1960). This method was used in this study for determining the phaeopigments present in the sample.

At station 1, the concentration of pheopigments registered the highest value of 4.806 µg/cm^3 in the surface stratum during monsoon and the lowest of 1.869 µg/cm^3 in the bottom stratum during post monsoon. In the following year, the highest value was recorded from the upper stratum sediment of pre monsoon season and the lowest from the upper stratum sediment of monsoon season, the values were 4.539 µg/cm^3 and 1.388 µg/cm^3 respectively. (Fig. 66)

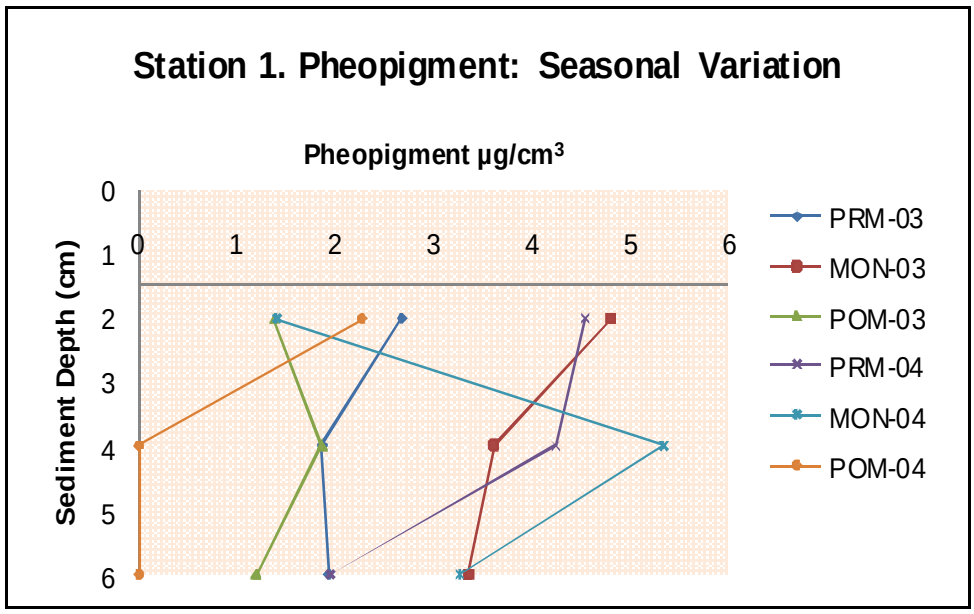


Fig. 66

At station 2, the highest pheopigment value (9.345 µg/cm^3) was observed during the first year of the study in the upper stratum of the sediment sampled during post monsoon. The lowest value of 0.053 µg/cm^3 was noticed in the lower most stratum of the sediment during the monsoon in the second year. (Fig. 67)

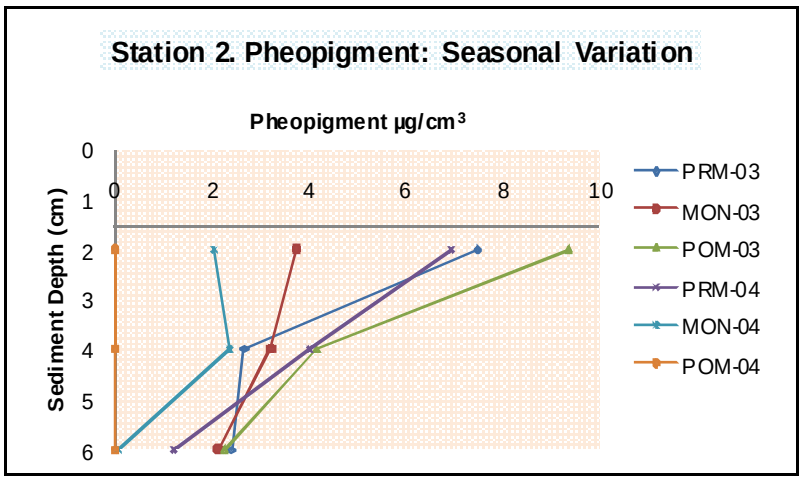


Fig. 67

At station 3, the pheopigment concentration of the first year sediment showed the highest value from the upper most stratum during pre monsoon. The lowest pheopigment content was estimated from the bottom stratum sediment during monsoon. The respective values were 5.34 µg/cm^3 and 0.081 µg/cm^3. Comparatively uniform levels of pheopigment were recorded during this year. In the second year the highest value of the pheopigment was noticed in the upper layer of the post monsoon sediment and the lowest in the bottom sediment of pre monsoon, the values being 8.472 µg/cm^3 and 2.937 µg/cm^3. (Fig. 68)

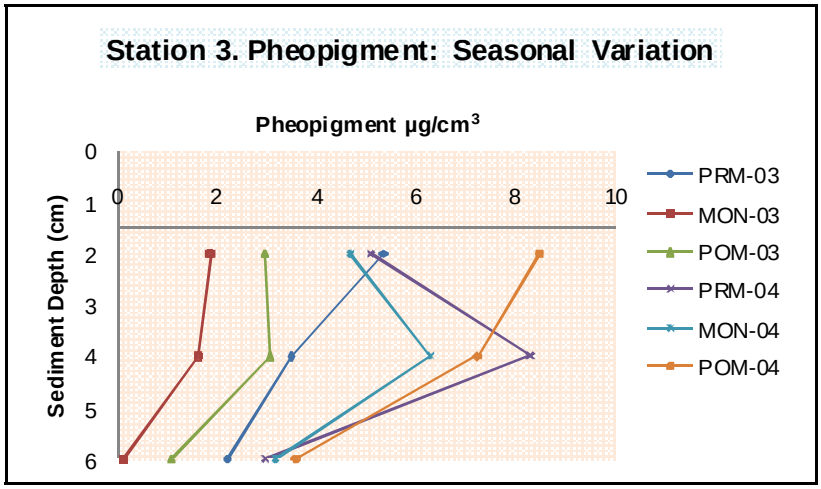


Fig. 68

At station 4, the highest pheophytin content of the first year sediment was in the uppermost stratum of the post monsoon season(12.816 µg/cm^3) and the lowest value of 2.073 µg/cm^3 was recorded from the bottom most sediment of the pre monsoon season. The highest pheopiment concentration of the second year was noticed in the surface stratum of post monsoon sediment. The lowest value of 0.801 µg/cm^3 was recorded from the bottom most stratum of the pre monsoon sediment. (Fig. 69)

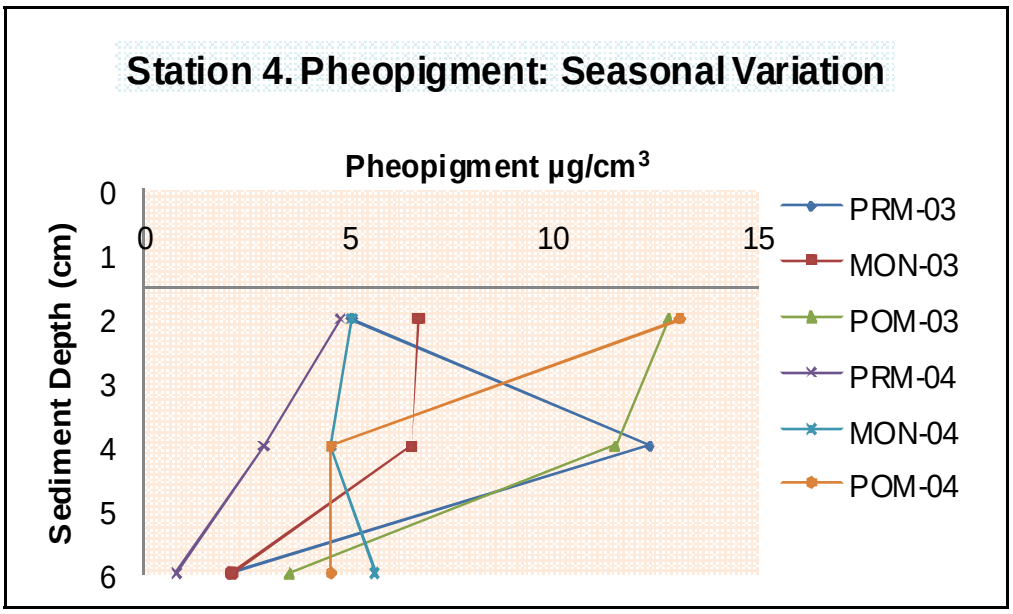


Fig. 69

At station 5, the highest pheopigment content of the first year was recorded from the surface stratum of monsoon sediment and the highest value of the second year was recorded from the surface stratum of the post monsoon sediment sample, the respective values being 10.68 µg/cm^3 and 11.214 µg/cm^3. The lowest value of the first year was 0.984 µg/cm^3 recorded from the bottom stratum – monsoon sediment and that of the second year was 0.534 µg/cm^3 recorded for the bottom stratum- pre monsoon sediment. (Fig. 70)

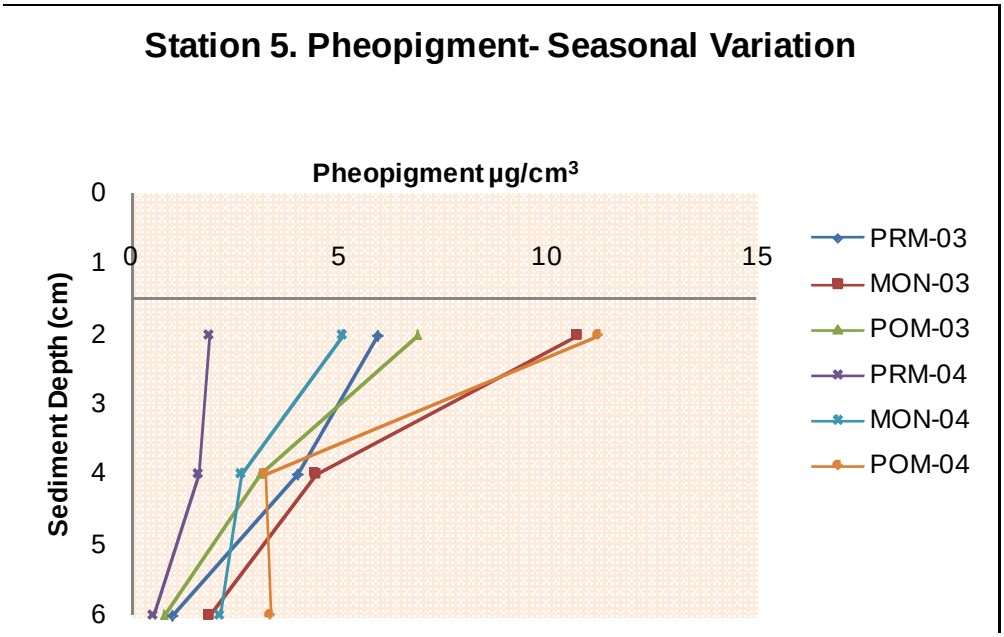


Fig. 70

At station 6, while the highest mud pheopigment value of the year, 2003, 3.630 µg/cm^3 was estimated from the surface stratum of the post monsoon sediment, the lowest (nil) was recorded from the bottom stratum of monsoon. The highest value of the second year was 4.109 µg/cm^3 recorded from the surface stratum sample collected during monsoon. The lowest value (nil) was also recorded during monsoon, from the bottom most stratum. (Fig. 71)

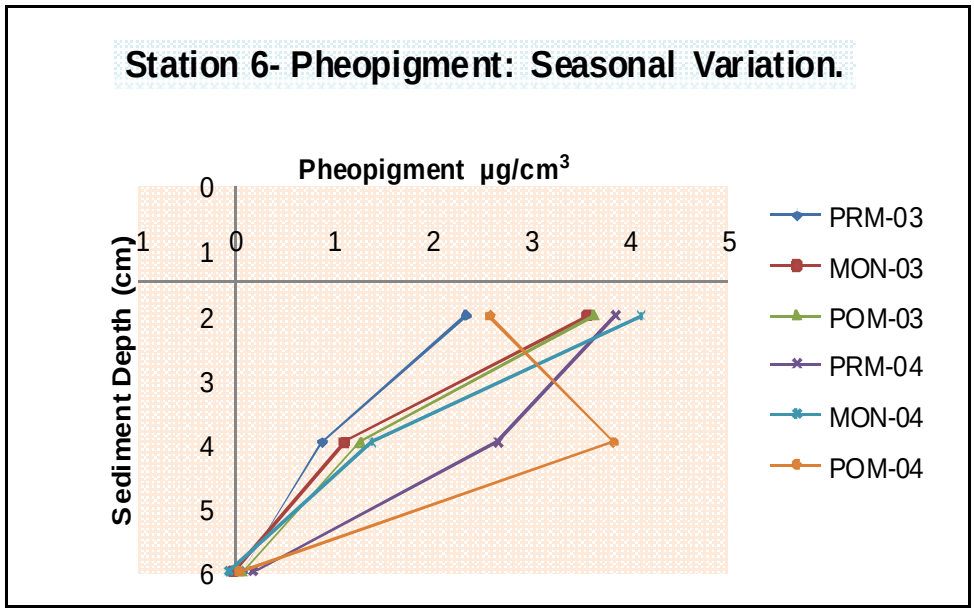


Fig. 71

Mean annual spatial variation of pigments recorded in all the stations during the first year of the study is given in figure 72. There was marked seasonal variations in all the sampling stations.

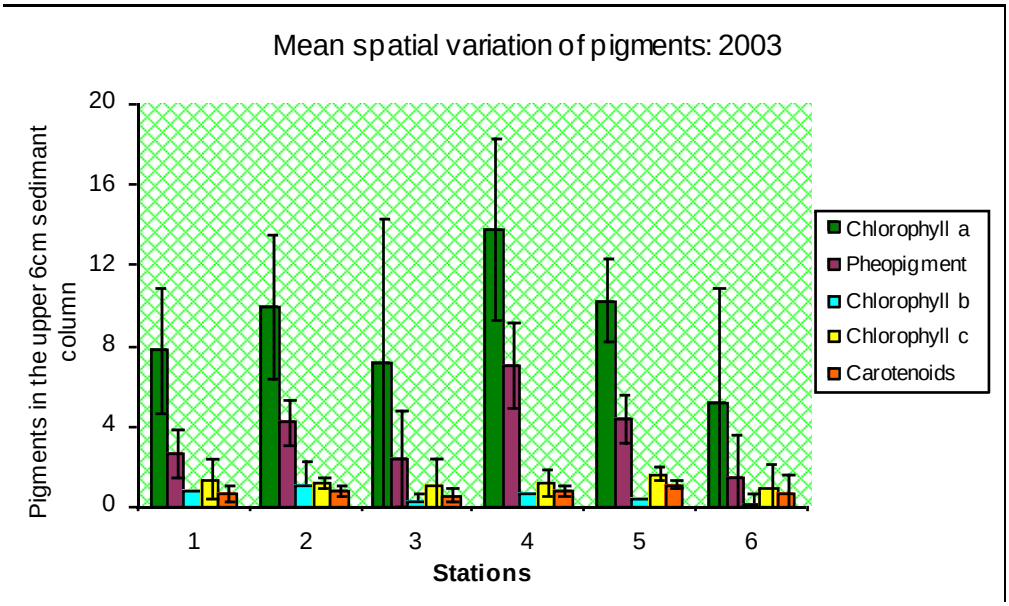


Fig. 72

In this year, the mean annual value of chlorophyll *a* in the 6 cm sediment core varied from 5.105 µg/cm^3 at station 6 to 13.77 µg/cm^3 at station 4. The pheopigment was found to be highest at station 4 with a value of 7. 014 µg/cm^3 and the lowest mean value of 1.420 µg/cm^3 was that of station 6.

As regards chlorophyll *b*, the values were very low as described earlier and ranged between 0.115 µg/cm^3 at station 6 and 1.044 µg/cm^3 in station 2. Annual mean chlorophyll *c* value of 0.859 µg/cm^3 recorded at station 6 was the minimum for that pigment and the highest value was 1.168 µg/cm^3 recorded at station 4. Carotenoid concentration showed the lowest annual value at station 3 and the highest at station 5, the values being 0.541 µg/cm^3 and 1.047 µg/cm^3 respectively.

Mean annual spatial variation of pigments recorded in all the stations during the second year of the study is summarised in Fig. 73.

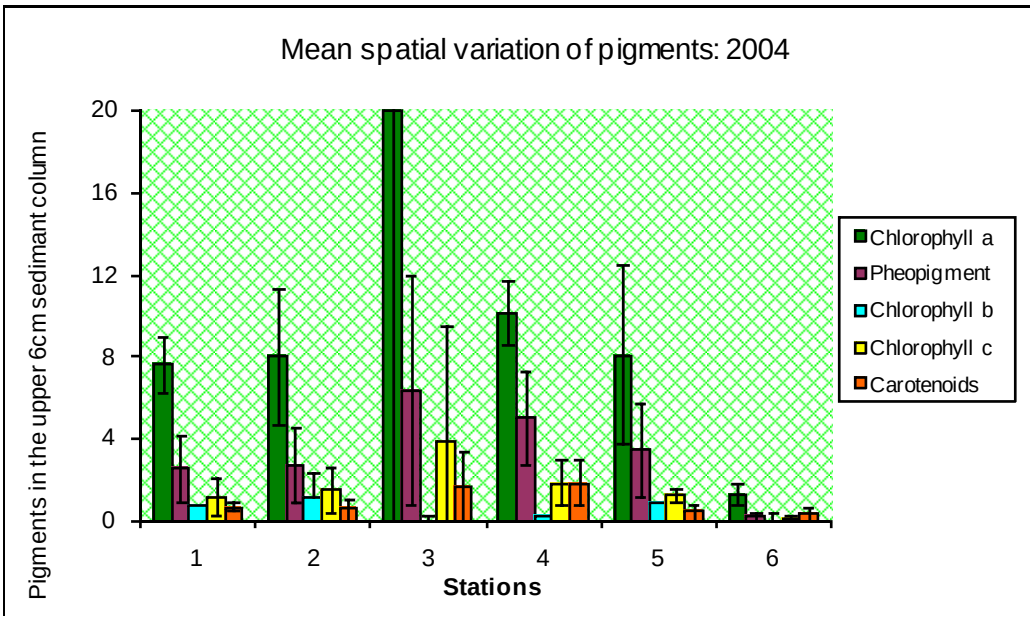


Fig. 73

Here, the highest chlorophyll *a* value was recorded at station 3 and lowest at station 6, the values are 20.025 µg/cm^3 and 1.365 µg/cm^3. Highest mean annual value of 6.430 µg/cm^3 was calculated for pheopigments at station 3, the lowest was 0.295 µg/cm^3 recorded at station 6. There was practically no chlorophyll *b* at station 3 and the highest mean annual concentration was recorded for station 2, the value being, 1.2 µg/cm^3. The chlorophyll *c* values ranged between 0.120 µg/cm^3 at station 6 and 3.974 µg/cm^3 at station 3. Carotenoid pigments also showed the minimum annual mean value at station 6, 0.416 µg/cm^3. The highest value for this pigment group was 1.921 µg/cm^3 recorded at station 4.

The mean values of all the pigments recorded during both the years of study are shown in Fig. 74. All the pigments except pheophytin showed higher values during the second year.

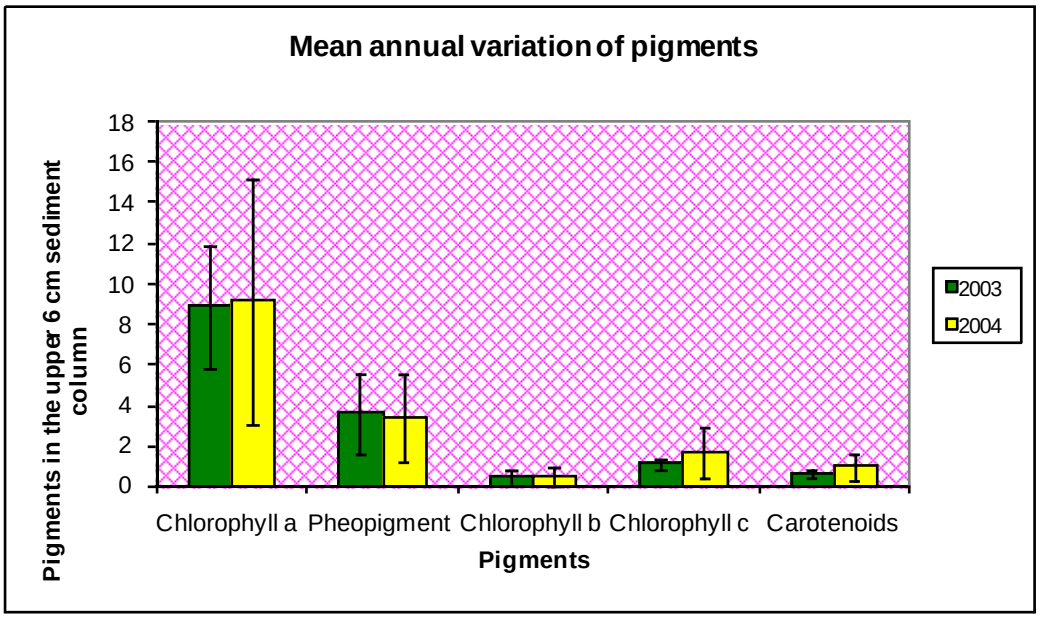


Fig. 74

6.3.3 Spatio-temporal Dynamics of Planktonic and Benthic microalgae:

The surface water and the surface sediment stratum chlorophyll *a* were analyzed to study the dynamics of benthic and pelagic microalgae. The results showed that, the mean benthic microalgal biomass as chlorophyll *a*, was lesser than the planktonic in all the stations except station 3 in 2003. The benthic chlorophyll *a* concentration ranged from 8.16 mg/m^3 to 18.26 mg/m^3 at stations 6 and 5 respectively. The planktonic chlorophyll *a* varied from 10.33 mg/m^3 (station 6) to 91. 95 mg/m^3, at station 5 (Fig.75).

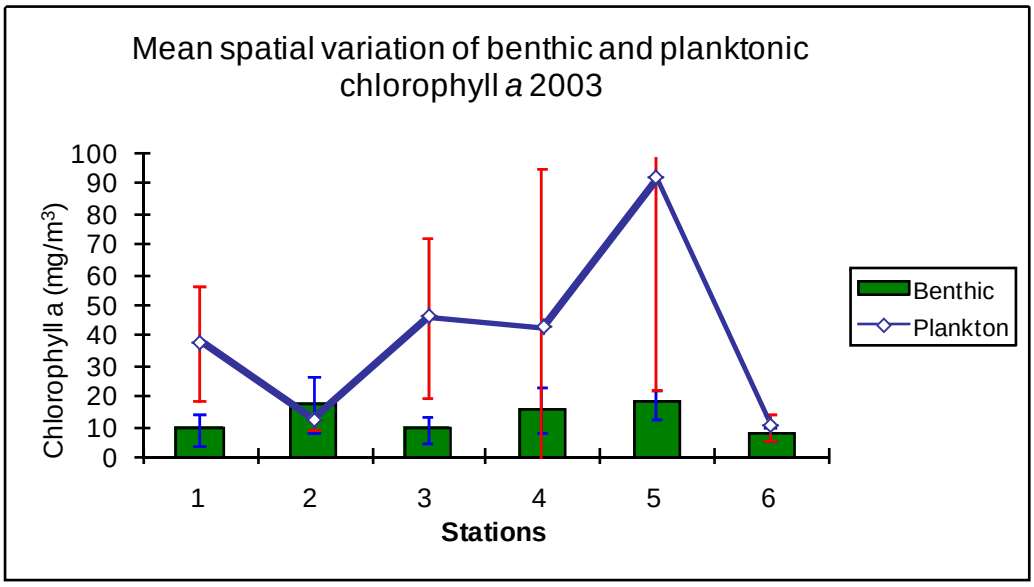


Fig. 75

In the following year also, the mean planktonic chlorophyll *a* showed higher values than that of benthic. The highest planktonic chlorophyll *a* (59.84mg/m3) was found in station 5 and the lowest being 14.83mg/m3 at station 6. Benthic microalgal chlorophyll *a* varied from 9.34mg/m3 at station 6 to 25.87mg/m3 in station 3 (Fig. 76).

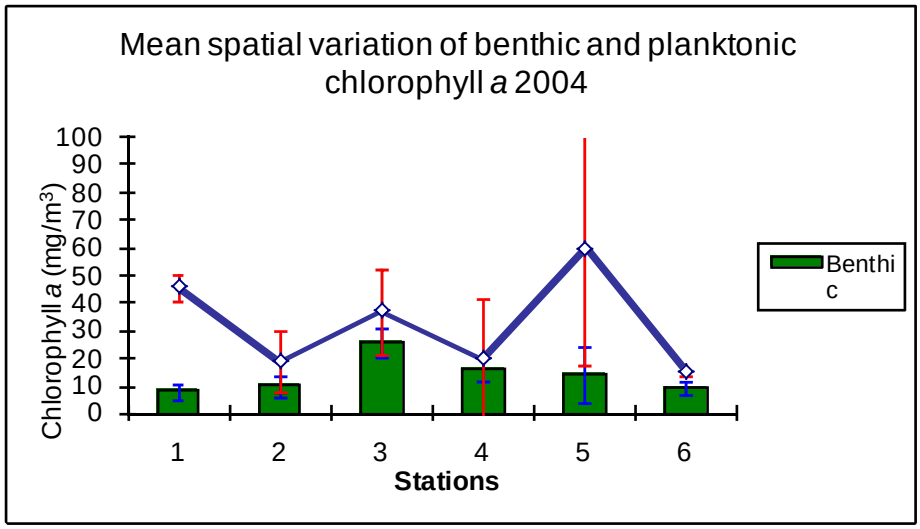


Fig. 76

6.3.4 Statistical analysis

A three way ANOVA was carried out to study the significance of variation of pigments in accordance with station, season and year. (Table 18)

Table 18: Chlorophyll *a*

Source of Variation	Sum of Squares	df	Mean Square	F	Sig.
Station	794.702	5	158.940	3.522 S	0.006
Year	25.867	1	25.867	0.573 NS	0.451
Season	52.310	2	26.155	0.580 NS	0.562
Error	4467.293	99	45.124		
Total	5340.172	107			
Chlorophyll *b*					
Source of Variation	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Station	19.814	5	3.963	3.393 S	0.007
Year	1.403	1	1.403	1.202 NS	0.276
Season	1.497	2	0.749	0.641 NS	0.529
Error	115.634	99	1.168		
Total	138.349	107			

Chlorophyll *c*					
Source of Variation	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Station	72.446	5	14.489	5.058 S	0.000
Year	21.943	1	21.943	7.660 S	0.007
Season	4.782	2	2.391	0.835 NS	0.437
Error	283.606	99	2.865		
Total	382.776	107			

Carotenoids					
Source of Variation	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Station	1.823	5	0.365	1.129 NS	0.350
Year	0.675	1	0.675	2.091 NS	0.151
Season	0.697	2	0.349	1.080 NS	0.344
Error	31.969	99	0.323		
Total	35.165	107			

Pheopigment					
Source of Variation	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Station	201.235	5	40.247	5.553 S	0.000
Year	1.043	1	1.043	0.144 NS	0.705
Season	5.491	2	2.746	0.379 NS	0.686
Error	717.509	99	7.248		
Total	925.278	107			

Standing Crop					
Source of Variation	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Station	78001.935	5	15600.387	3.040 S	0.014
Year	752.083	1	752.083	0.147 NS	0.703
Season	15737.352	2	7868.676	1.533 NS	0.221
Error	508022.065	99	5131.536		
Total	602513.435	107			

S ➔ Significant

NS ➔ Not Significant

The level of correlation of different pigments with one another was studied using Pearson correlation analysis. There was significant correlation among all the pigments. (Table 19)

Table 19: Correlation Analysis

	Chl.a	Chl.b	Chl.c	Carotenoid	Phaeophytin	Stng. Crop
Chl.a	1.000	0.105	.727	.649	.807	.912
Chl.b	0.105	1.000	0.127	-0.001	-0.066	0.079
Chl.c	.727**	0.127	1.000	.610**	.397**	.635**
Carotenoid	.649**	-0.001	.610**	1.000	.517**	.600**
Phaeophytin	.807	-0.066	.397	.517	1.000	.710
Stng. Crop	.912**	0.079	.635**	.600**	.710**	1.000

* Correlation is significant at 0.05 level.

**Correlation is significant at 0.01 level.

Epiphytic Microalgea

During the course of this study, certain diatom species that were present on the stilt roots of *Rhizophora mucoronata* and on the pneumatophores of *Avicennia officinalis*. Since their contribution to the total biomass was very meagre and since they occurred only once or twice during the study period, that spanned for two years(majority being encountered during the early pre monsoon of 2004), these are not mentioned in the text and not listed in the table. The photomicrographs of some of them are included in the annexure (plates). The major species that were seen as epiphytes include *Achnanthes javanica, Amphora angusta, Amphora costata, Caloneis liber, Caloneis linearis, Caloneis westii, Diploneis gorjanovici, Diploneis notabilis, Navicula distans, Navicula granulate, Navicula marina, Navicula transitrans, Nitzschia acuminate, Nitzschia marina, Nitzschia obtuse, Navicula granulate, Synedra robusta, Trachyneis Formosa, Chaetoceros dydimus, Oscillatoria sancta* and *Oscillatoria limosa.*

6.4 Discussion

6.4.1 Standing Crop:

The qualitative and quantitative analyses of microphytobenthos carried out during the two years of study revealed remarkable seasonal and spatial variation exhibited by this ubiquitous group of organisms.

In the first year of the study, at station 1, the recorded 20 species of microphytobenthos showed distinct seasonal and spatial variation. The number of species and cell abundance were found to be higher during monsoon. While 16 species were identified during monsoon, their number was 13 and 9 during pre and post monsoon periods. No species was found to be distributed in all the three strata of the sediment core. While *Amphora leavis, Nitzschia closterium* and *Navicula hennedyei* were the abundant species encountered during pre monsoon, *Gyrosigma balticum, Diploneis dydima* and *Nitzschia closterium* were the dominant species present during monsoon. *Amphora laevis, Nitzschia closterium* and *Diploneis littoralis* dominated the post monsoon sediment. *Amphora laevis, Gyrosigma balticum, Navicula forcipata* and *Nitzschia closterium* made their presence during all the three seasons. Of these *Nitzschia* is always a dominant species in the benthic microalgal community. Similar observation was made by Cahoon *et al.*, (1993). Species of *Navicula* and *Amphora* were found to have been reported from the Qua Iboe estuary of Nigeria and were identified as epipellic (Essien and Ubom, 2003 and Essien *et al.*, 2006). Two blue greens, *Microcystis aeruginosa* and *Oscillatoria labyrinthiformis* were also encountered from this station during the first year of the study. While *Oscillatoria labyrinthiformis* was present only during monsoon, *Microcystis aeruginosa* was present during pre monsoon also. Eventhough it is in the uppermost stratum that there is more

chances of finding higher number of microphytobenthos, it was in the second stratum of the sediment that the higher number of cells was present during post monsoon. The centric diatom, *Biddulphia mobilensis* was found in the bottom most stratum of the sediment during monsoon. It is one among the major planktonic microalgae and was enumerated from the overlying waters during this study. Its presence at a depth of 6 cms is quite interesting. This might have entered the sediment column along with the seepage of water into the sediment and the looseness of mud provided by the pneumatophores might have made this entry easier. Its presence in the benthic environment was earlier reported by Mitbavkar and Anil (2002, 2006) in the 0-15cm depth zone sediments of Goan coast. Lucas and Holligan (1999) also reported the presence of larger centric diatoms in the sediment samples of Molenplaat tidal flat in the SW Netherlands. It is not the mere presence, but the survival that is significant. It can be assumed that this species has a mixotrophic life.

In the second year of the study, 19 species of diatoms, one blue green and one green alga were identified from station 1. The green algal representative was *Cosmarium quadrum* present on the upper stratum of the sediment during monsoon. Eventhough it was mosoon, the average pH was above 7 and so it can be assumed that the cells of *Cosmarium* which were encountered might have been brought to this place from adjacent fresh water bodies through the rain water runoff. The blue green present was *Oscillatoria labyrinthiformis*. Similarly *Oscillatoria* was also reported to be present in the mangrove swamps of Qua Iboe estuary (Essien *et al.*, 2006). While *Nitzschia closterium, Diploneis littoralis* and *Amphora laevis*, were the dominant species present during pre monsoon, *Navicula forcipata, Pleurosigma salinarum* and *Pleurosigma normanii* were present abundantly

during the post monsoon. *Pleurosigma and Cymbella* encountered during this study were also reported to be present in the mangrove sediments of Qua Iboe estuary in Nigeria (Essien *et al.*, 2006), the species however, were different. It is also observed at station 1 during the second year that the number of cells in the middle sediment stratum was higher than that in the upper stratum during all three seasons. This might be due to the migration of the pennate diatoms to the sub surface (Kromkamp *et al*. 1998; Palmer and Round, 1965). Presence of such large number of cells at depths well below the maximum potential depth of light penetration appears to be a common feature in estuarine systems. It has been well documented and reported earlier in a temperate shallow water marine system in Port Philip Bay, Southern Australia (Light and Beardali, 1998) and in the Molenplaat tidal flat in the SW Netherlands (Lucas and Holligan, 1999). Wulff *et al.* (1997) studied the effect of sediment load on the microphytobenthic community of shallow water sandy sediment in Sweden and reported that microphytobentos have the ability to survive at low irradiance and even in darkness without damage to its photosynthetic capacity. Admiraal (1984) studied the ecology of diatoms that inhabit the estuarine sediments and explained that some microphytobenthic species can even compensate for low light levels by resorting temporarily to heterotrophy.

On evaluating the observations for six seasons, it is seen that there is a clear seasonal distribution of microphytobenthos in station 1. Among the 23 species of benthic microalgae, only *Amphora laevis* was present in all the six seasons. Majority of the diatoms present are cosmopolitan in benthic habitats and had been reported from many such coastal and estuarine areas.

At station 2, there were 21 species of microphytobenthos identified from the different strata of the 6 cm deep phytozone during the first year. While

there were 306 cells during pre monsoon, the cell number decreased to 234 during monsoon. It might be due to the resuspension of the benthic flora due to heavy, turbulent flow of water during monsoon season. However, the cell abundance was maximum in post monsoon and it was 457 in the phytozone. The season with high cell abundance was having the least number of species, 14, and the season with the least cell abundance accounted for the highest number of species, 16. *Pleurosigma normanii* (during monsoon) and *Amphora laevis* (during post monsoon) were present in all three strata of the sediment core. *Gyrosigma balticum, Navicula cincta, Navicula laterostratum* were the abundant species in the upper stratum. *Pleurosigma normanii, Diploneis dydima, Cocconies placentula* and *Nitzschia closterium* were the dominant species during monsoon. *Amphora laevis, Pluerosigma normanii* and *Navicula cincta* were seen in high percentage during post monsoon. Two species of *Spirulina* were encountered during monsoon. During post monsoon, the number of cells of *Amphora laevis* was especially high and this is the reason for high cell number even with less number of species. In the second year, there were 20 species of microphytobenthos in station 2. Like in the first year, the cell density showed the highest number during post monsoon and the lowest during monsoon. However, there was a positive correlation between cell number and species richness, with the post monsoon sediment registering the highest number of species. While *Navicula cincta* and *Amphora laevis* were present in all the three strata of the sediment core during pre monsoon, *Pleurosigma aestuarii* exhibited the same mode of occurrence during monsoon. There was no such species during post monsoon. The occurrence of some microphytobenthos throughout the entire length of the sediment column is indicative of their facultative heterotrophic nature. The occurrence of *Amphora laevis* in all the three strata during monsoon in 2003 and post monsoon in 2004

indicates its affinity to the sediment in the station. It is also indicative of the epipelic habit of this species. Another species of the same genus, *Amphora ovalis* was reported to be present in the Qua Iboe estuary in the epipelic condition (Esien *et al.*, 2006).

Altogether, there were 23 species of microphytobenthos identified from station 2, of which 18 were diatoms, 4 were blue green algae and one green alga. Cyanophyceae constituted 17% of the microphytobenthic community. These have been reported by several workers as a particularly important component of the mangrove microbiota, constituting a source of nitrogen in every mangrove system (Sheridan, 1991, 1992., Kathiresan & Bingham, 2001). The recorded low salinity during monsoon could have supported the growth of this nitrogen fixing algae as reported earlier in the Palk Bay region by Selvakumar and Sundararaman (2001) and in mangroves and estuaries of Tamilnadu coast by Ramachandra Rao (1992).

It was station 3 that recorded the highest species richness. 36 species were listed from this station during this study spread over 6 seasons. While all the 36 species recorded from this station were present in 2003, three of them were missing in the second year of the study. The species which were absent in the second year were *Asterionella japonica*, *Gyrosigma scalproides* and *Thalasiosira decipiens*. In the first year, the cell abundance in the phytozone showed the highest number during pre monsoon (249) and the lowest during monsoon (151). It was observed that even though there were 36 species distributed throughout the sediment core, none of them was present in high numbers which might be due to competition in the sub surface region. The only species that occurred throughout the entire length of the sediment core was *Nitzschia closterium*, during monsoon. All the species except *Amphora turgida*, *Asterionella japonica, Navicula longa*, *Nitzschia palea, Chlorella marina and*

Microcystis aeruginosa appeared during pre monsoon. However, out of the 36 species, 13 were not encountered during monsoon. Important among them were *Achnanthes haukiana, Caloneis madraspatensis, Cocconeis sigmoides, Nitzschia panduriformis* and *Pleurosigma angulatum*. 15 species including *Diploneis littoralis*, *Navicula henneidyi*, *Nitzschia panduriformis* and *Thalassiosira decipiens* were absent during post monsoon. Thus it was the pre monsoon season that was found to favour more microphytobenthos in this station during 2003.

In the second year, an increase in cell abundance from pre monsoon to the post monsoon was evident. While the cell abundance in the 6 cm phytozone was 418 during pre monsoon, it was 659 and 676 during monsoon and post monsoon. While *Mastegloea lanceolata* was present in all the three strata during pre monsoon, *Cyclotella striata*, a centric diatom, exhibited the same during post monsoon. *Cyclotella spp*. were reported by Admiraal and Peletier (1979) to have shown benthic life style with high sulphide tolerance. Eventhough, the cell abundance was slightly higher during post monsoon, the species richness was found to be high during monsoon. While 24 species were encountered during monsoon, only 21 were present during post monsoon.

The presence of *Amphora coffeaformis* at this station needs special mention. It was present during all the six seasons of this study at different strata of the sediment. It shows its inclination for a benthic life style. It is a facultative heterotroph (Hellebust and Lewin, 1977) and one among the ASP producing diatoms (Richardson, 1997). The high cell density and species richness exhibited by the microphytobenthos in station 3 is an indication of the health and stability of the ecosystem.

While the first three stations were directly connected to the back waters, the third and fourth stations were closer to the sea.

In station 4, there were 26 species of microphytobenthos identified from the sediment core. While all these species were encountered during the first year of the study, the diatoms, *Asterionella japonica* and *Diploneis bombus* and the chlorophytes, *Euastrum* and *Staurastrum* were absent in the second year. *Gomphonema parvulum*, a fresh water- brackish water diatom and a pollution indicator was encountered during this study on the upper sediment layers of station 4. This species has recently been found among the benthic diatoms in the Pearl River estuary, China (Zong *et al.*, 2010). Three Chlorophycean and one Dinophycean member was also identified from station 4. While *Cosmarium quadrum, Euastrum ansatum* and *Staurastrum asteroideum* were the chlorophytes present, *Ceratium furca* was the dinoflagellate. *Ceratium furca* is not a typical/common benthic microalga. However, it is one among the dinoflagellates found in the overlying waters of this station. Since there always is a water column above the sediment, it never becomes fully exposed.

Under calm conditions, the phytoplankton can sink to the bottom where they will continue to live as microphytobenthos (MacIntyre, 1996). Further, Palmer and Round (1965) have established that Cyanobacteria and flagellates can be abundant in less exposed habitats. This could well explain the the presence of *Ceratium sp.* in the sediment core.

During the first year monsoon, salinity was very low in this station, and this dilution might have favoured the growth of the three chlorophycean members on the surface of the sediment. The high cell density observed during the post monsoon in the first year of this study was due to the luxuriant growth of pinnate diatoms, *Diploneis bombus, Licmophora juergensii, Navicula*

forcipata, Nitzschia closterium and Pleurosigma flax. The optimum salinity and temperature recorded during this season could be the favourable factor for this increased cell number. Higher abundance of cells on the first stratum is quite natural, as microphytobenthos are typically concentrated in the upper few millimeters of the sediment (MacIntyre, 1996, Pinckney and Zingmark, 1993a.)

Station 5 was one that showed high species richness, even though the cell density was comparatively low. 35 species of microalgae were identified from the benthic sediment habitat. In both the years, the highest cell density was noticed during post monsoon. Even though the species were different, 31 out of the 36 recorded forms of microphytobenthos were present in both the years of the study. Six species were present during all the six seasons – *Amphora proteus, Diploneis weisflogii, Navicula cincta, Nitzschia panduriformis, Nitzschia sigma* and *Pleurosigma angulatum*. All of them were pennate diatoms, indicating the predominance of these forms in the benthic environment. Three blue green algae, three green algae and one dinoflagellate were encountered at this station along with 28 species of diatoms (80% diatoms, 8.5% green algae, 8.5% blue green algae and 2.8% dinoflagellates.

Station 6, Mangalavanam is different from all other stations which is an almost closed system with a single, narrow canal link to the estuary. Furthermore, it is a highly polluted system that might be the reason for low cell density and species richness observed at this station. There were only seventeen species of microphytobenthos recorded at this station. 15 of them were diatoms and the remaining two, cyanophycean members. Among the diatoms, only two, *Cyclotella striata* and *Thalassiosira subtilis* were centric forms and all the others were pinnate ones. While *Navicula cincta* was present in all the three strata of the sediment during the pre monsoon season of the second year, *Nitzschia closterium* was present in all the three strata of the post monsoon sediment. While all the 17

species recorded from the station were present in the second year, one species, *Phormidium sp.* was absent in the first year. The high degree of similarity in the floral composition and cell abundance indicate the feeble impact of physico chemical parameters on the distribution of microphytobenthos.

It is generally stated that light penetrates to a depth of 2-3 mms into the substrate (Garcia- Pichel and Bebout (1996) and most benthic microalgae are found in the top few millimeters of the sediment (MacIntyre, 1996). However, in the present study, it has been noticed that a substantial number of microalgal cells are found down to the depths of 6 centimeters. Several such observations have been made by previous workers. De Jonge (1992) had reported the presence of microalgae upto the depths of 10 cms. in Elms estuary. Mitbavkar and Anil (2002) encountered viable diatoms upto a depth of 15 centimeters at a low tide zone in Goa. Sanilkumar (2009), while studying the microalgae along different marine and estuarine stations along the south west coast of India has fixed the phytozone as 5cm. and Sivadasan and Joseph (1998) found Benthic microalgae from the surface to 7cm deep in the sediments of Cochin estuary. Several reasons are attributed to this paradoxical occurrence of photosynthetic microbes deep in the sediment. While Barranguet *et al.* (1997) and Lucas and Holligan (1999) attribute this to bioturbation by deposite feeders, MacIntyre *et al.* (1996) and Paterson *et al.* (1998) consider this as mainly due to the diel rhythms of vertical migration exhibited by the majority of microphytobenthos. Pinckney and Zingmark (1993) and de Jong and de Jong (1995) emphasizes the role of physical hydrodynamic conditions on this type of occurrence. It therefore seems that the depth distribution varies in different stations and at any given location; it is dependent on the extent of sediment mixing and the nature and behavior of benthic fauna. In the present study the phytozone was fixed at a depth of 6 cms after three months of standardization tests with different depths upto 10 cms.

According to a data published of the Goan coast (Mitbavkar and Anil, 2006), the diatom abundance was lowest during the monsoon and highest during post monsoon and early pre monsoon throughout the intertidal transect. Sanilkumar *et al.* (2009) also reported similar observations with occasional apparent higher abundance during monsoon. In the present study also three out of the six stations recorded higher standing crop during post monsoon and one during pre monsoon. Two stations however, registered their higher values during monsoon. If we examine the standing crop of planktonic algae during these monsoon seasons, it can be seen that there is a positive correlation between these two. This indicates that the high microphytobenthos population during these monsoon periods could be due to the settling of planktonic microalgae which will continue to be benthic afterwards. Most of the pennate diatoms recorded during this study such as *Pleurosigma angulatum, P falx, P aestuarii, Amphora coffeaformis, A turgida, Nitzschia closterium,* and *N. panduriformis* were encountered upto the last stratum of the sediment and these can be considered as typical benthic species (Vilbaste *et al.*,2000; Ribeiro *et al.*, 2003). As reported by Sivadasan and Joseph (1998) for the Cochin estuary, spatial variation of floral composition was also noted during this study.

While analyzing the annual mean standing crop, it can be seen that the highest mean number of cells per cm^3 of sediment during the first year of study was 391.33 $\pm$ 264.86 recorded in station 4 and that in the second year was 252.667 $\pm$ 78.49 recorded at station 3. While there were 36 species in station 3, the number came down to 17 in the last station, indicating spatial variation in the composition of microphytobenthos. This has been substantiated by the earlier work of Sivadasan and Joseph (1998) who reported spatial variation in the composition of microphytobenthos in the Cochin estuary.

As the overlying water changes with tides, the mangrove sediments are exposed to a wide range of salinities, and in the present study the effect of salinity on floral composition was evidenced. While optimum salinities around 20 ppt favoured the growth of diatoms, the dilution resultant of rain, favoured the growth of green algae and blue green algae. This is an indication that these different algal groups share a niche attribute of tolerance to changing salinities. The ability of mangroves to exclude salt may cause a check in salinity when the salinity level goes beyond the optimum required for most of the pennate diatoms and favour the growth of such algal forms.

During the course of this two year study that extended from the pre monsoon of 2003 to the post monsoon of 2004, 80 species of microphytobenthos coming under 36 genera have been identified. Of these, 64 species (80%) coming under 24 genera belong to Bacillariophyceae, 8 species coming under 5 genera (10%) belong to Cyanophyceae, 7 species coming under 6 genera (8.75%) belong to Chlorophyceae and 1 species (1.25%) was a Dinophycean member. The predominance of diatoms may be attributed to their small size, ability to migrate between strata, ability to lead a tychopelagic life and the possession of a highly fortified silicious wall. Majority of the isolates encountered were pennate diatoms such as those belonging to the genera *Navicula* (10 species), *Nitzschia* (7 species), *Pleurosigma* (species), *Diploneis* (5 species) and *Amphora* (4 species). Almost similar floral composition was reported by Essien *et al.* (2006) while studying the epipelic microalgae in the mangrove swamps of Qua Iboe estuary, Nigeria. The important diatoms identified during their study were *Amphora ovalis, Cymbella lanceolata, Pleurosigma sps*., *Navicula radiosa, Pinnularia viridis* etc. Like in the present study, Closterium and Ocillatoria were also isolated from the Qua Iboe estuary. While Essien *et al* (2006) reported the occurrence of *Cymbella* and *Pleurosigma*

in somewhat less saline niches, these two genera were encountered at salinities above 21 ppt. in the present study. While analyzing the seasonal impact on the standing crop, it was found that three out of six seasons in both the years registered the highest standing crop during post monsoon.

The same algal species have been found to live both as phytoplankton and as microphytobenthos during this study. Among the Bacillariophyceae, out of the 64 species present as microphytobenthos, 26 were not found as planktonic forms. However, this does not mean that all of them are exclusive microphytobenthos. As MacIntyre *et al.* (1996) opined, this distinction is artificial in shallow water systems where there is large exchange of living and non living matter between the sediment and water column. Phytoplankton can sink to the bottom and can get incorporated to the micropytobenthos and the microphytobenthos can become part of the phytoplankton when suspended by tidal currents (Garcia –Soto *et al.*, 1990, Arfi *et al.*, 1993). The distinction of microphytobenthos and phytoplankton is blurred in that sense. However, Cahoon *et al.*, (1990), Cahoon and Cooke (1992), Cahoon (1999) negates the argument of microphytobenthos as settled phytoplankton. On the basis of studies in Onslow Bay, they highlight the domination of pennate diatoms in the benthic zone.

Among the 26 species of diatoms which were encountered only in the benthic habitat, *Cocconeis sigmoides, Cocconeis littoralis, Cocconeis placentula, Cocconeis sublittoralis, Navicula lyra, Diploneis bombus, Diploneis weisflogii, Gyrosigma spencerii* and *Cymbella marina* are mostly found in benthic habitats. The rest can be treated as 'tychopelagic' (Cahoon and Laws, 1993), or 'tychoplanktonic' (Sylvestre *et al.*, 2001).

This information on the vertical distribution of microphytobenthos in the mangrove sediments of selected sampling stations would contribute significantly to the understanding of the trophic functioning of these ecosystems.

6.4.2 Pigments:

At station 1, in the year 2003, the highest mean concentration of chlorophyll *a* in the 6 centimeter sediment core was noted during the monsoon with a value of 11.047 ± 3.7751 and the lowest mean value was recorded during post monsoon, the value being 4.9541 ± 2.3233. In 2004, the highest mean chlorophyll *a* value was obtained during pre monsoon, the value being 8.6246 ± 4.6911.

Pheophytin has not shown any substantial variation during this study. While the highest mean value of 3.9187 ± 0.7802 was recorded in the monsoon sediment of 2003, the lowest mean value was that of post monsoon in the same year, 1.6465 ± 0.3854. The chlorophyll *b* value showed the highest mean value during the post monsoon of 2003, 1.0187± 0.408. There was practically no chlorophyll *b* during four of the six seasons studied. As regards chlorophyll *c*, the highest mean value was that recorded during pre monsoon, 2003, the value being 0.9476 ± 0.2615. There was substantial amount of carotenoids in the mud samples of station 1. While the highest value (1.0091± 0.2436) was recorded in the pre monsoon of the second year of the study, the lowest value was that of first year post monsoon, the value being 0.2294 ± 0.1669.

At station 2, the highest mean value of chlorophyll *a* was 13.275 ± 11.892 recorded during the post_monsoon of the first year. The lowest mean value was obtained during the monsoon of the second year, 4.3885 ± 1.8145. In both the years, the monsoon value of sediment chlorophyll *a* was less when compared to that of pre and post monsoon seasons. An interesting observation made at station 2 was with regard to the concentration of chlorophyll *b*. This pigment which is characteristic to the green algae was present in all the strata of the soil during all the seasons, except the uppermost stratum of post monsoon sediment in 2003. However, we could not find chlorophycean members in all

these strata of soil. It could be assumed that this chlorophyll *b* is the contribution of prochlorophytes and or euglenophytes which were not enumerated during this study. A similar result was obtained for Cartaxana *et al.*(2006) in the intertidal sediments of Tagus estuary. The highest mean value of chlorophyll *b* was 2.444 ± 1.5789 µg/cm^3 recorded during the second year post monsoon. The lowest value was also recorded during post monsoon, but in the first year. The value was 0.1862 ± 0.1659 µg/cm^3.

While the highest average chlorophyll *c* concentration of 2.6605 ± 1.969 µg/cm^3 was recorded during the post monsoon in the second year of the study, the lowest value of 0.5017 ± 0.228 µg/cm^3 was recorded during the monsoon in the same year. The pattern of distribution of chlorophyll *c* in both the years was almost similar.

Like chlorophyll *c*, the other accessory pigment group of diatoms, the carotenoids was also present throughout the whole depth of the sediment core. The highest mean value of carotenoids (1.2425 ± 0.6473 µg/cm^3) was recorded from the pre monsoon sediment of second year. The lowest mean was 0.256 ± 0.0307 µg/cm^3 recorded during the monsoon of the second year. The highest mean pheophytin value was 5.251 ± 3.666 µg/cm^3 recorded during the post monsoon in 2003 and the lowest 1.4863 ± 1.2496 µg/cm^3 recorded during the second year monsoon.

At station 3, the mean microgram chlorophyll *a* value per cm^3 registered appreciably higher values during all the three seasons in 2004, and there was not much seasonal variation. The highest value was 23.139 ± 13.435 µg/cm^3 (monsoon, 2004) and the lowest (5.443 ± 1.9032 µg/cm^3) recorded during the first year monsoon. The mean pheophytin value was also high at this station. It recorded the highest value of 6.4306 ± 2.5438 µg/cm^3 in the post monsoon

sediment of the second year and the lowest value of 1.184± 0.9645 µg/cm^3 during the first year monsoon.

The highest mean value of chlorophyll *b* (0.7308 ± 0.549 µg/cm^3) was recorded from the pre monsoon sediment of the first year and the sediments collected during post monsoon in both the years possessed little or no chlorophyll *b*. The concentration of chlorophyll *c* registered the highest mean value of 9.1335 ± 5.6932 µg/cm^3 during the second year monsoon and the lowest mean value of 0.7303 ± 0.1737 µg/cm^3 during the first year monsoon. While the highest carotenoid mean value was 2.3641 ± 0.1876 µg/cm^3 (monsoon-2004), the lowest was 0.0744 ± .0563 µg/cm^3 (monsoon- 2003)

At station 4, which is connected directly to the sea through a canal, there was comparatively higher biomass during all seasons, as evidenced by the presence of chlorophyll *a*. The highest mean value was 18.01 ± 10.33 µg/cm^3 recorded during the first year post monsoon. Presence of chlorophyll *b* was noticed only during the second year monsoon and during the first year pre monsoon, the mean values of which were 1.241± 1.309 µg/cm^3 and 0.566 ± 1.465 µg/cm^3 respectively. The standard deviation clearly indicates the poor presence of this pigment along the core depth of 6 cms. As in the other stations, chlorophyll *c* and carotenoids were present in all the three strata and during all the three seasons. While the highest mean value of chlorophyll *c* was 2.9 ± 2.066 µg/cm^3 recorded during the second year post monsoon, the lowest was 0.516 ± 0.264 µg/cm^3 recorded during the first year monsoon. Carotenoids also registered their lowest mean value during the first year monsoon, the value being 0.507± 0.157 µg/cm^3. The highest value of this accessory pigment group was recorded during the pre monsoon of the first year and the value read 0.893 ± 0.363 µg/cm^3. Considerable concentrations of pheopigments were estimated from this station. While the highest mean value of pheopigments, 9 9.271 ±

5.028 µg/cm^3 was estimated from the post monsoon sample of the first year, the lowest value of 2.848 ± 2.004 µg/cm^3 was estimated from the pre monsoon sediment sample.

Station 5 which showed the highest species richness registered moderately higher chlorophyll *a*, c and carotenoid values. The presence of chlorophyll *b* was conspicuous even in the sub surface layers. The highest mean value of chlorophyll *a* was 12.268 ± 11.426 µg/cm^3 registered during first year monsoon. The lowest mean chlorophyll *a* value was 3.5958 ± 1.778 µg/cm^3 registered during the second year premonsoon. The highest mean chlorophyll *b* value was 1.1033 ± 0.3342 µg/cm^3 recorded during the first year monsoon. This was the season during which the maximum number of chlorophytes appeared and this normally is the reason for the hike in chlorophyll *b* value. The chlorophyll *b* was practically absent in the pre monsoon sediment of the first year of this study. The highest mean value of chlorophyll *c* was 1.9707± 0.292 µg/cm^3 (monsoon, 2003) and the lowest was 1.0416 ± 0.4696 µg/cm^3 (monsoon, 2004). The standard deviation suggests very little variation in the amount of pigment within the different strata of the core. The trend was almost similar for carotenoids, suggesting the common source of their origin. While the monsoon values resulted in the highest mean of 1.994± 0.2484 µg/cm^3, the lowest mean of 0.0776± 0.0858 µg/cm^3 was obtained for second year pre monsoon sediment. The pheophytin values were almost similar to that of the previous station, which indicates the similar physiological condition of both the systems which are directly connected to the sea through a canal. While the highest mean was 5.9177± 4.5872 µg/cm^3 (Post monsoon, 2004), the lowest was 1.335 ± 0.7064 µg/cm^3 (pre monsoon- 2004).

Station 6 was the most polluted among the stations studied which is characterized by anoxic conditions. The highest mean value of chlorophyll *a*

was 6.3127± 3.8517 µg/cm^3 registered in the first year monsoon sediment and the lowest was 3.6235± 2.4405 µg/cm^3 estimated for the premonsoon sediment of the first year. The highest mean chlorophyll *b* value was 1.0468± 0.9432 µg/cm^3 estimated for the monsoon sediment of the second year. It was practically absent during three out of six seasons studied, indicating the total absence of chlorophytes during these seasons. The highest mean value of chlorophyll *c* was 1.2773 ± 0.3352 µg/cm^3 recorded during the pre monsoon of the second year. The lowest mean was that registered during the first year pre monsoon, 0.7708 ± 0.3086. The highest mean carotenoid value was 1.1634± 0.7811 µg/cm^3 registered during the second year monsoon and the lowest was 0.1884 ± 0.1238 µg/cm^3. Both the highest and lowest mean pheopigment values were registered during the second year pre monsoon.

On analyzing the pigment patterns in the sediment, the highest concentration, as expected, was exhibited by chlorophyll *a*, which is the pigment that is present all forms of microalgae. Chlorophyll *b*, which is an indicator pigment of green algae was found in very low concentrations, which shows that a non chlorophyll *b* bearing form is the dominant species in the benthic habitats and this has been found to be diatoms. Van Leeuwe *et al.* (2008) have remarked that the pigment patterns in the sediment is affected by the composition of microphytobenthic community.

Photosynthetic pigment chlorophyll *a* has been used in this study as an index of microphytobenthic biomass. Active chlorophyll *a* was found upto a maximum sampling depth of 6 centimeters, well below the photic zone. This indicates that viable microalgae are present upto such depths and standing crop from the bottom most strata confirmed this argument. No such depth limit can therefore be fixed as phytozone and it can be assumed that the depth distribution at any location depends on the extent of sediment mixing

(MacIntyre, 1996). The significance of this chlorophyll *a* is that it is a potential source of primary production. While analyzing the nature and ecological implications of algal pigment diversity on the Molenplaat tidal flat, SW Netherlands, Lucas and Holligan (1999) suggested that the depth integrated values of chlorophyll *a* would give an indication of the amount of biomass that could become available at a site. Mundree *et al.*(2003) after their studies on the seasonal variation in the vertical distribution of benthic microalgae in the upper sediment of Mdloti estuay in South Africa concluded that the large amounts of "buried" benthic microalgal chlorophyll *a* biomass are important seeding stocks of potential primary producers in temporarily open estuarine system and this would definitely hold good for the present study also.

While the highest values of chlorophyll *a* were observed from the intertidal areas by Sundback and Jonsson, (1988); Lukatelich and McComb, (1986) and Cahoon, (1999), Urban-Malinga and Wiktor, (2003), reported the highest values for the littoral zone. Even though a decrease a concentration is expected with increasing depth (Masini and McComb, 2001), the pattern of microphytobenthos chlorophyll *a* concentration during the present study was not always so and some deviations were observed. E.g. In station 4, while the chlorophyll *a* concentration in the upper stratum of the sediment during premonsoon was 11.85 µg/cm^3, that in the middle zone was 25.99 µg/cm^3. This might be due to the migration of diatoms to the subsurface area of the sediment or due to the presence of senescent chlorophyll *a* that is retained in the sediment prior to degradation.

At all stations, except on a few occasions, the chlorophyll *a* values were positively correlated with chlorophyll *c* and carotenoid values. Since both the latter pigments are characteristic to diatoms, this indicates that the major changes in the microphytobenthic biomass are due to diatom abundance. The presence of considerable amount of carotenoids in the sediment samples can

also be attributed to the stressful condition that prevails in these ecosystems which face threats of anthropogenic pollution and the resultant anoxic conditions. Donkin *et al.*, (1976), Martin *et al.*, (1991) and Grung *et al.*, (1992) suggested increased presence of carotenoids under stressful conditions. Another related observation was made by Leavitt and Carpenter (1990) that zooplankton processing may preferentially transport undegraded carotenoids to the sediment. According to Barranguet (1997), Fucoxanthin is the most abundant component of carotenoids present in sediments and is considered as good marker of diatoms. The fact that 80% of the microphytobenthos encountered during this study are diatoms, supports this view.

An algal pigment not present in diatoms, chlorophyll *b* has also been found during this study. Mostly its presence was a feature of monsoon sediments which are diluted with regard to salinity. However, there were instances where chlorophyll *b* was detected without encountering chlorophycean or euglenophycean members (post monsoon sediments in station 4 and 5). This is in agreement with the findings of Cartaxana *et al.*, (2006) according to which considerable concentration of chlorophyll *b* was seen in the substrata without identifying any species belonging to Chlorophytes, Prochlorophytes and/or Euglenophytes. Chlorophyll *b* was almost negligible in Cochin estuary due to the poor distribution of chlorophyll *b* bearing microflora (Sivadasan and Joseph, 1995). However, it can be assumed that substantial amount of chlorophyll *b* containing microalgae which could not be seen through the magnification used in this study, might be present in the sediment.

Being an accessory pigment in chlorophytes, prasinophytes and euglenoids, its presence in low salinity monsoon samples is the indication of presence of such algal groups. Identification of 7 species of chlorophyceae during this study, mostly during monsoon, underlines the above. The presence

of comparatively low levels of chlorophyll *b* absence during the major part of this study suggests that neither chlorophytes nor any other chlorophyll *b* bearing algae formed an important component of microphytobenthos in the stations selected. Thus the comparison of relative presence of pigments provide ample information regarding the floral composition of the microphytobenthic community of these mangrove ecosystems.

In the Mdloti estuary, South Africa, Mundree *et al.* (2003) reported that 80% of the benthic microalgal biomass was found in the upper 3 cm at the head and in the upper 4 cm in the middle reaches and in the mouth. In the present study also, 80 to 92% of the total chlorophyll *a* was found in the upper 4 cm of the sediment core. While it was 80% in station 1, it was 92% in the first year of the study at station 5. The dial rhythms of vertical migration exhibited by microphytobenthos may explain this biomass distribution. However, there were a very few occasions where the second stratum of the sediment showed higher biomass than in the surface stratum. This is in agreement with the views of Fielding *et al.*(1988) that greatest microphytobenthic biomass was not always found in the top layer of the sediment.

According to de Jong and de Jong (1995) the vertical distribution of the benthic microalgal chlorophyll *a* biomass in the sediment is associated with the degree of shelter or physical disturbance. In the present study, station 6 is a more sheltered site with comparatively lesser disturbance from tidal currents and waves and there was a steep decrease in the amount of chlorophyll *a* from the top stratum to the bottom.

Sediment chlorophyll *a* contents are usually reported as rather constant throughout the year with no clear pattern of seasonal variation (Varela and Penas (1985) and Goto *et al.* (2000). However in the present study, it was

subjected to clear seasonal and spatial variations. While three stations out of six in each year registered the highest chlorophyll *a* concentration during monsoon, two of the stations during each year had the highest chlorophyll *a* concentration during post monsoon. Thus there is no clear relation between the standing crop and the chlorophyll *a* value. Despite variability in the relation between chlorophyll *a*, biomass and cell abundance, the pigment provides a useful index of the photosynthetic potential of a population.

A depth distribution of benthic chlorophyll *a* concentration Mdloti estuary, South Africa revealed that 80% of the chlorophyll *a* is found in the upper 3 cm in the upper reaches and in the upper 4 cm in the middle reaches (Mundree *et al.*, 2003). In the present study, the percentage of chlorophyll *a* in the upper 2 cm of the sediment ranged from 40 to 60%. It means that about 40-60% of chlorophyll *a* is buried below the photic zone.

The three way ANOVA carried out revealed that Chlorophyll *a,b,* pheopigment and standing crop are having significant level of variation with station and not with season or year. While chlorophyll *c* showed significant variation with station and year, carotenoids showed significant variation with none of the parameters.

The pigments studied showed high degree of correlation among one another. The Pearson Correlation analysis revealed that chlorophyll *a*, Chlorophyll *c*, carotenoids and pheopigment have 0.01 level of correlation with all the other pigments except chlorophyll *b*. The cell abundance was also positively correlated with all the pigments except chlorophyll *b* with *a 0.01* level significance.

6.4.2.1 Chlorophyll *a* and Standing Crop:

Eventhough the standing crop increased with the concentration of chlorophyll *a*, there was no uniform pattern. This disproportionate relation may be

due to community composition and the great variety in cell size and volume. Sometimes high chlorophyll *a* values are obtained due to the presence of senescent chlorophyll *a* retained in the sediment prior to degradation (Mitbavkar and Anil, 2004). In Cochin estuary, Chlorophyll *a* and standing crop were found to be correlated only during monsoon (Sivadasan and Joseph, 1997).

6.4.2.2 Chlorophyll *a* and Pheopigment:

While analyzing the ratio between chlorophyll *a* and pheopigments, it can be observed that the ratio ranged from 0.27 to 0.5 during both the years. The ratio of pheopigment to chlorophyll *a* concentration gives a general indication of the physiological or grazing state of microalgal community. High ratio (range: 0.5 to 1) indicates a stressed or declined community, while low ratios (range 0 to 0.5) represent actively growing community relatively free of grazing pressure (Bidigare *et al.*, 1986; Light and Beardall, 1998; Mundree *et al.*, 2003). In the present study this ratio goes beyond the 0.5 mark at station 4 during both the years, indicating a stressed condition of the ecosystem. In station 5 and 6, there was a considerable increase in the ratio during the second year that is indicative of increasing pollution at these station.

High chlorophyll *c*: chlorophyll *a* ratios indicative of detrital or senescent algae (Lucas and Holligan, 1999) were not apparent during this study.

6.4.3 Plankton Vs Microphytobenthos: Spatio – Temporal Dynamics

An important observation made during this study was that the mean benthic microalgal biomass measured as sediment chlorophyll *a* was less than that of the planktonic sample. While the annual mean microphytobenthic biomass ranged from 8.165 mg/m^3 to 18.264 mg/m^3 in the first year, it ranged between 7.928 mg/m^3 to 25.876 mg/m^3 during the second year. Planktonic chlorophyll *a* biomass ranged from 10.33 mg/m^3 to 91.95 mg/m^3 in the first

year and 14.835 mg/m^3 to 59.84 mg/m^3 during the second year. This is in contrast to the many of the earlier reports. According to Perissinoto *et al.* (2003), benthic microalgal biomass is on average 1-3 orders of magnitude higher than planktonic biomass in three South African temporarily open estuaries. According to Cahoon *et al.* (1990), aerial sediment chlorophyll *a* concentration exceeded that of water column in 16 out of 17 stations studied by them in the Onslow bay, North Carolina. Sanilkumar (2008) reported the same result for benthic chlorophyll *a* in different stations along South west coast of India. The present study differs from the others in that it was carried out in mangrove habitats. Here, the sediment substratum is always subjected to stresses and turbulence caused by tidal influx. The thin layer of water that remains over the mud even during low tides makes the sediment slurry like. Naturally there will be resuspension of sediment into the water column, leading to higher biomass content in planktonic samples. Delgado *et al.* (1991) reported that upto 6% of sediment mass and 11% of sediment chlorophyll *a* in the upper 5 mm could be resuspended. In Branford harbor, Connecticut, resuspension of top millimeter sediment accounts for all of the water column chlorophyll (Baillie and Welsh, 1980). De Jong (1985) observed that the number of benthic diatoms of Elms estuary could exceed the number of upper 0.5 cm of sediment on an equal- area basis. Further, Raman and Tenore (1978) and Shaffer and Sullivan (1988) explained that displaced, resuspended microphytobenthos may contribute significantly to the water column primary productivity in shallow water columns.

The contribution of suspended microphytobenthos to the pelagic biomass in the Dollard (EMS estuary, the Netherlands) was about 60% (Cadee and Hegeman, 1974). De Jonge and Beusekom (1992) report that 92% of the phytoplankton biomass as chlorophyll *a* in the Dollard consisted of suspended

benthic diatoms and indicate that, re-suspended microphytobenthos is the main source of chlorophyll *a* in the water column.

Thus reduced benthic biomass content in terms of chlorophyll *a* observed during this study does not mean that their contribution to the productivity of the ecosystem is less. What happens is that it temporarily becomes part of the planktonic biomass and as such our estimation of planktonic biomass becomes higher than the actual.

Resuspension of benthic microalgae and their presence and importance as temporary members of phytoplankton have earlier been reported by de Jong and van Beusekom (1992) and Lucas *et al.* (2000). Thus it could be assumed that the microphytobenthos live at the sediment water interface and the magnitude of interation of the sediment with the overlying water can lead to distinct variability in the abundance of microphytobenthos. According to (MacIntyre *et al.* 1996), in shallow water environments, even the use of the term microphytobentos is misleading, since the benthos represent one end of a continuum between water and sediment rather than an entity distinct from the water column. Under such conditions benthic microalgae may spend a considerable portion of their life suspended in water column and this might be the reason for higher planktonic biomass observed during this study.

This study has attempted to bring to light a vital and too often neglected component of mangrove ecosystems. The benthic microalgae have a very important, even central role in the ecosystem in contributing to the primary production of the system which calls for a close scrutiny of this "secret garden" that thrives beneath the jagged, gnarled trees living at the edge of the sea.

Chapter 7

SUMMARY AND CONCLUSION

Mangroves are tropical tidal wetlands which form highly specialized ecosystems characterized by salt resistant plants growing in the intertidal areas along sheltered sea coasts and estuaries. Since it lies in the confluence of land, sea water and fresh water, it is an excellent reservoir of plant, animal and microbial species. The mangrove ecosystems in Kerala have depleted heavily in the recent past due to anthropogenic reasons and have become shrunk to a few small pockets. While studying mangroves as a part of research, it is important to focus on the analysis of the system as a whole and the present investigation was an attempt in that direction.

This study entitled "Microalgal vegetation in the selected mangrove ecosystems of Kerala" was an attempt to understand the microalgal diversity in the selected stations in relation to the ecosystem dynamics. The stations selected were Kumbalam, Panangad, Nettoor, Puthuvypu, Murikkinpadam and Mangalavanam.

The floral components of mangrove ecosystem include eumangroves, associated plants, planktonic microalgae and microphytobenthos. The research todate has mainly focused on the macrofloral and faunal communities, and inspite of their immense contribution to the bioproductivity of the system, the planktonic and benthic microalgae still remain to be investigated.

A survey and classification of the mangrove tracheophytes was carried out as the first part of this study. 11 true mangroves, 7 mangrove associates,

4 back mangals and one consortive mangrove were identified from the study area. *Aegiceras corniculatum* (L) Blanco, which has not been reported to be present along Cochin estuary, was encountered during this study. *Heliotropium curassavicum* L. and *Ipomoea pes caprae* L., two mangrove associates, which are listed as not present in Cochin estuary by Mandal and Naskar (2008), who proposed the latest classification for Indian mangroves, have also been encountered during this study. Based on their associate features, *Cerbera odolum*, *Ardissia littoralis* and *Cayratia triloba* are listed in this study as back mangals and *Acrostichum aureum* as a consortive mangrove.

The seasonal and spatial distribution of planktonic microalgae and microphytobenthos in the selected mangrove stations, the impact of physicochemical variables like temperature, salinity, pH, nutrients and dissolved oxygen on the distribution and abundance of these algal forms, the assessment of biomass and productivity potential of these micro algae and their identification were the key aspects of this study.

72 species of planktonic microalgae were identified from the six mangrove stations studied during 2003-2004. They belong to 42 genera and four classes viz, Bacillariophyceae, Chlorophyceae, Cyanophyceae and Dinophyceae. Class Bacillariophyceae was the dominant group among the mangrove planktonic algae, constituting 79.16% (57 species). Blue greens were represented by 7 species (9.72 %), green algae by 5 species (6.94%) and Dinophyceae by 3 species (4.16 %). Pennate diatom, *Navicula* was the most abundant genera represented by 8 species. There were 5 species of *Nitzschia* and four each of *Amphora* and *Coscinodiscus*.

The distribution and abundance of planktonic microalgae varied remarkably. *Nitzschia closterium*, *Pleurosigma aestuarii*, *Navicula mutica* and

Gyrosigma tenuissimum were present in all three seasons. The threshold limit of salinity for microalgal abundance was found to be around 21 ppt. Green algae showed their presence during monsoon in all the stations. A bimodal hike in standing crop was observed at station 1 and a unimodal pattern at station 2 as against a trimodal peak reported for Cochin estuary. Nitrogen fixing cyanobacteria encountered during this study offers the possibilities of using them as natural candidates for future reforestation and rehabilitation of destroyed mangroves. Thermophilic and eurihaline planktonic algae were observed during pre monsoon from one of the stations. Three way ANOVA revealed significant spatial variation in chlorophyll *a* concentration. The annual average biomass represented by planktonic microalgal chlorophyll *a* ranged from 37.74 μgL^{-1} to 227.69 μgL^{-1} between stations. It was found that post monsoon is usually characterized by high chlorophyll *a* values. Other pigments except chlorophyll *b* showed significant positive correlation with chlorophyll *a*. (Chlorophyll *a* values ranging between 0.20 μgL^{-1} to 105.60 μgL^{-1} were reported for Pichavaram mangroves.).

The mean planktonic primary productivity values for the entire stations studied was 2.258 gC/m^3/ day or 824.024 $\pm$ 495.67 gmC/m^3/year. (The reported values for Dharmadam estuarine waters is between 0.24 to 1.14 gC/m^3/ day and that for Pichavaram is 1.67 gC/m^3/ day).

The phytozone, the depth upto which the phosynthetic autotrophs can exist, for the stations studied has been found out after a series of trial standardization experiments. There found to be no significant biomass or viable cells below the depth of 6 centimeters and so a sediment depth of 6 centimeters was fixed as the phytozone. The sediment sample was subjected to strata wise analysis for studying the vertical distribution of microphytobenthos.

Eventhough the general trend of high biomass on the surface stratum of the sediment was followed, there were certain instances during which the subsurface stratum showed higher biomass than the surface stratum. The contribution of surface sediment to the total biomass is found to be 40 to 60 %. The remaining biomass was found to be buried inside the sediment. The ability of microphytobenthos to perform vertical migration and the potential to lead a facultative heterotrophic life were evidenced during this study through the paradoxical presence of these organisms well below the potential depth of light penetration. Some of the pinnate forms like *Pleurosigma angulatum, Pleurosigma falx, Amphora coffeaformis* and *Nitzschia closterium* were seen upto the last stratum of the sediment core.

80 species of microalgae were identified from the benthic habitat out of which 64 species (80%) were diatoms. 8 species coming under 5 genera (10%) represented the blue greens and seven species coming under 6 genera (8.75%)represented the green algae. There was only one species of dinoflagellates (1.25%) among the microphytobenthos. Among the microphytobenthic diatoms, majority were pennate forms. While there were 10 spp. of Navicula, 7 species were identified for Nitzschia.

Out of the 64 species of diatoms found as microphytobenthos, 26 were found to live exclusively in the benthic habitat. The presence of *Amphora coffeaformis* in all the strata of the sediment is worth mentioning. This ASP producing diatom is well accepted as a microphytobenthos, which lives as a facultative heterotroph. Diatom growth was found to be favoured by high Si:N ratio. Another important aspect of this study was the identification of pollution indicator diatoms like *Gomphonema parvulum* from the sediment sample. Some pennate diatoms which were present during all seasons and at all depths upto 6 cms could be having the basic benthic life style. *Cocconeis littoralis,*

Cocconeis placentula, Amphora proteus, Amphora turgida, Diploneis weisflogii, Amphora coffeaformis, Gyrosigma laterostratum, were the spp that showed such a type of occurrence and they can be described as typical microphytobenthos.

Some epiphytic diatoms that inhabited the surface of stilt roots of *Rhizophora mucoronata* and pnuumatophores of *Avicennia officinalis* were also identified during this study. Important among them are, *Achnanthes javanica, Amphora angusta, Amphora costata, Navicula marina, Navicula transitrans* etc.

Even though the standing crop increased along with chlorophyll *a*, there was no definite pattern.

Chlorophyll *a* to pheopigment ratio went passed 0.5 mark at station 4 indicating its stressed physiological state which calls for special attention.

Another important observation of the study was that the biomass estimated as chlorophyll *a* value was higher for planktonic microalgae than for the microphytobenthos. While the annual mean microphytobenthic biomass ranged from 8.165 mg/m^3 to 18.264 mg/m^3 in the first year, it ranged between 7.928 mg/m^3 to 25.876 mg/m^3 during the second year. Planktonic chlorophyll *a* biomass ranged from 10.33 mg/m^3 to 91.95 mg/m^3 in the first year and 14.835 mg/m^3 to 59.84 mg/m^3 during the second year. It is due to the peculiarity of the ecosystem that such a result has been obtained. The sediment in mangroves is always subjected to stresses by tidal flushing and in all the stations studied there was stagnation of water resulting in a column of water above the sediment. This causes resuspension of sediment into the water column leading to a higher biomass content in the water column or in the planktonic sample. Thus the actual microphytobenthos temporarily become part of the phytoplankton and

contribute to the water column chlorophyll. Such resuspension is a feature of shallow waters and this does not mean that the contribution of microphytobenthos to the productivity of the system is less. Hoewever it is irrelevant in this context to think who contributes more. Together the planktonic microalgae and microphytobenthos contribute a considerable % of biomass which is evidenced from this study and this need to be counted whenever we estimate the productivity of mangrove ecosystem and then only the estimation would be realistic.

This study has attempted to bring to light a vital and too often neglected component of mangrove ecosystems, the microalgae, which lies beneath the spreading mangrove trees as silent dwellers of the system.

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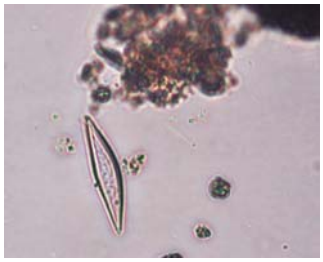
PLATE-I(α)

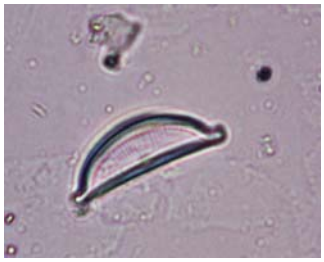
Class- Bacillariophyceae
(Pennales-Bacillariales)

Achnanthes coartacta var. parallela x 200

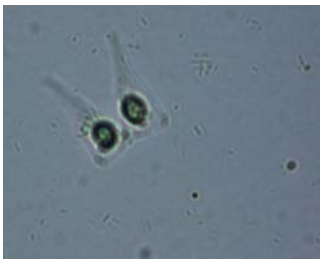
Achnanthes javanica x 200



Amphora angusta x 200

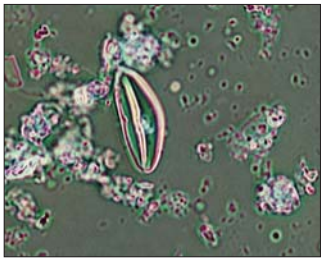


Amphora costata var. inflata x 200



Asterionella japonica x 200

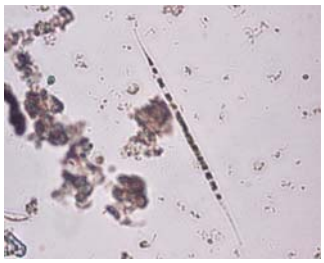
Caloneis liber x 200



Cymbella affinis x 200

Caloneis linearis x 200

Caloneis westii x 200

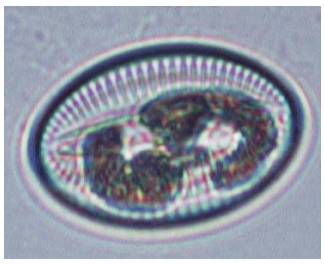


Cylindrotheca gracillis x 200

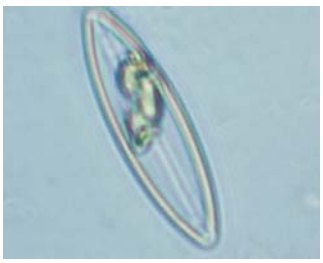
Cymbella marina x 200

Diploneis gorjanovici var.major x 200

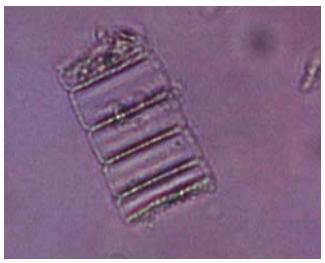
PLATE-I(b)



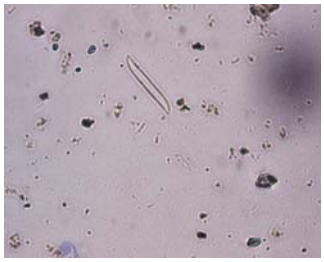
Diploneis notabilis x 200



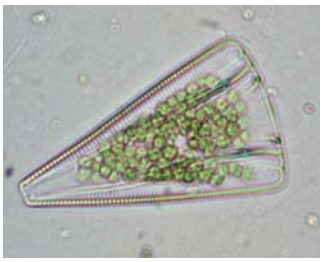
Trachyneis formosa x 200



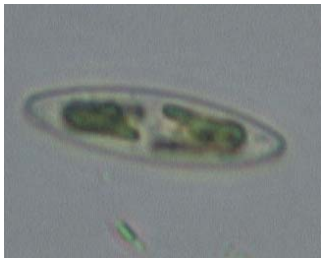
Fragilaria oceanica x 200



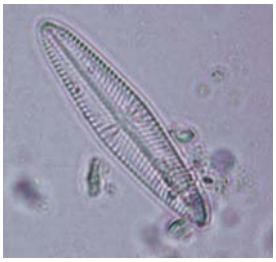
Gyrosigma scalproides var. eximia x 100



Licmophora juergensii x 200



Navicula cincta x 200

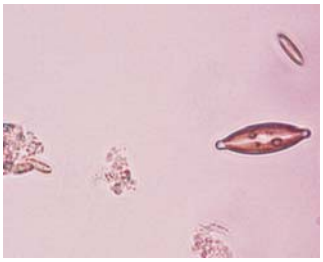


Navicula distans x 200

Synedra robusta x 200

Navicula granulata 1 x 200

Navicula marina x 200

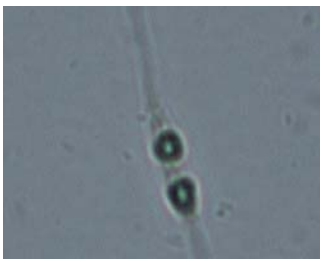


Navicula mutica x 200

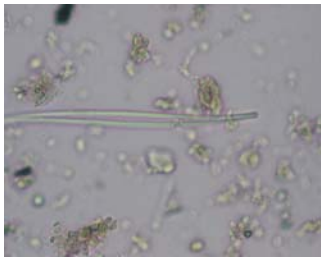
Navicula transitrans x 200

PLATE-I(c)

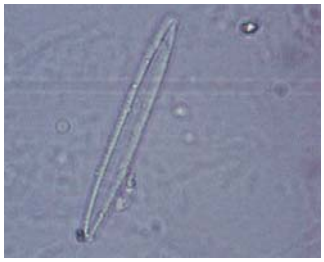
Nitzschia acuminata x 200



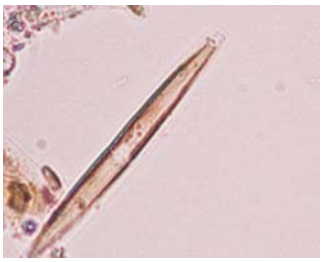
Nitzschia closterium x 200



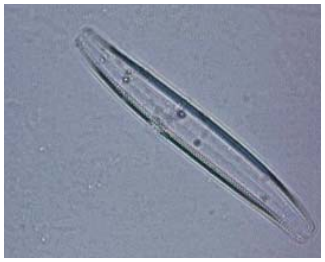
Nitzschia lorenziana x 100



Nitzschia marina x 200



Nitzschia obtusa x 200



Nitzschia sigma x 200

Nitzschia sigmoidea x 200

Pleurosigma sp x 200

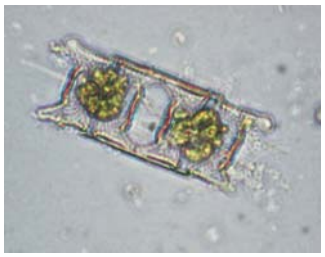
Pleurosigma estuarii x 200

PLATE-II

Class- Bacillariophyceae
(Centrales-Biddulphiales)

Coscinodiscus radiatus x 100

Chaetoceros didymus x 200

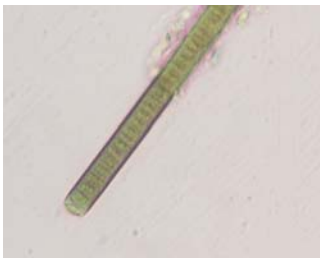


Biddulphia aurita x 200

Podosira montagnei x 200

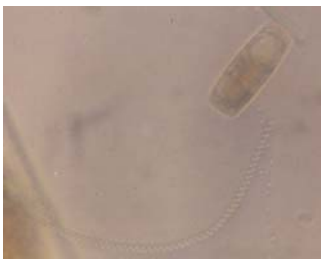
PLATE-III

Class- Cyanophyceae



Oscillatoria limosa x 200

Oscillatoria sancta x 200



Spirulina major x 100

Sonneratia caseolaris

Aegiceras corniculatum

Rhizophora mucoronata

Clerodendron inermae