MICROALGAE IN THE SOUTHWEST COAST OF INDIA

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By

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Certificate

This is to certify that the thesis entitled **"Microalgae in the Southwest Coast of India"** is an authentic record of the research work carried out by Mr. Sanilkumar M.G., under our 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 **"Microalgae in the Southwest Coast of India"** is an authentic record of research work done by me under the combined supervision of Prof. (Retd.) Dr. K.J. Joseph and Dr. A.V. Saramma, 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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To

My dear Parents, Wife and Son

General Introduction

Aquatic ecosystems claim about half of the photosynthetic biomass production in our planet. The majority of this is represented by algae, both planktonic and benthic (Raven, 1991). Algae are highly diverse group of photo-autotrophic non-vascular plants with chlorophyll *a* and simple reproductive structures. They are either unicellular or multi-cellular, found frequently in fresh, brackish to marine habitats. They form a highly diversified group of photosynthetic thallophytes which have a very significant role in the bio-productivity of the marine, estuarine and freshwater ecosystems covering two-third of the earth's surface. These algae with their photosynthetic pigment, distributed in both pelagic and benthic habitats command unique significance as the primary producers, which initiate the food chain and generate the fishery resources. They include both micro and macroscopic forms and exhibit wide variation in size extending from less than 2μ to more than 60m (Van den Hoek *et al*., 1995).

Microalgae include the major primary producers in the first trophic level and are distributed in both pelagic and benthic environments. When extensive studies have been carried out on planktonic species, very little has been done on the taxonomy, distribution, abundance and productivity of benthic microalgae which contributed about 1/6 of the total primary production in the world oceans. In the absence of comprehensive studies on the microalgae in benthic habitats, a realistic estimate of the potential fishery resources becomes difficult. Hence an attempt is made to study the contribution of both phytoplankton and microphytobenthos so as to have a better representative of the primary trophic level as a whole.

The single celled algae exhibit a great range of shapes, colours and sizes. Some are mobile, swimming by means of flagella or gliding over the substrata. Others are non-motile-drifting in the plankton, fixing to a substratum or lying free.

Colonial algae also show a remarkable range of forms; globular clusters often embedded in a sphere of mucilage; simple or branched filaments of cylindrical cells joined end to end; encrustations on rocks or other plants; tufts, skeins or cushions of more complex filaments; gelatinous green blobs; irregular green tubes and many others.

The marine pelagic ecosystem is, perhaps, the greatest in size of all ecosystems on earth. The oceans comprise 71% of the earth's surface area of $5.1x10^8 km^2$ (Riley and Chester 1971), and if the marine pelagic environment is defined as comprising all ocean waters from the surface to the sediments with an average depth of 3.8 km, then its volume is very approximately 14 billion km^3, or 99% of the earth's biosphere volume (Norse 1994). Apparently, ecosystem size is not necessarily equated with importance, diversity, or environmental complexity, but from the perspective of environmental conservation (Verity *et al*., 2002).

Most of the planktonic microalgae are distributed throughout the euphotic zone, which is defined by its optical properties and extends to a depth where the incident radiation is attenuated to 1%. Many planktonic microalgae in the oceans are motile, and can undergo substantial vertical migrations in the water column to optimize their position with respect to the incident irradiance (Burns and Rosa, 1980, Tyler and Seliger, 1981). Since light intensity changes during the day and is modulated by a vetting cloud cover, aquatic organisms need to readjust constantly their positions in the water column to achieve optimal rates of photosynthesis.

Several dinoflagellate species have been observed to move to the surface during daytime and to lower layers at night (Estrada *et al*., 1987). In some cases, an endogenous component seems to be involved as the organisms start moving to the surface even before dawn, and the circadian rhythm persists even under constant ambient conditions (Yentsch *et al*.,1964; Taylor *et al*., 1966; Tyler and Seliger,1978). These factors affecting vertical migrations including concentrations of nutrients in lower layers (Watanabe *et al*., 1987; Villareal *et al*., 1993).

At noon, some species have been shown to avoid the layer immediately below the surface, to which they return later in the afternoon to avoid excess illumination (Eggersdorfer and Hader, 1991a; Eggersdorfer and Hader, 1991b). The active movements of some aquatic microalgae are superimposed on the passive relocations within the mixing layer, which extends down to the thermocline (Hader, 1995).

Diatoms and blue-green algae have been shown to concentrate in bands of optimal irradiances due to their limited active motility. These species utilize changes in buoyancy to move up and down in the water column. Cyanophycean species produce gas vacuoles while diatoms synthesize oil droplets to increase their buoyancy (Walsby *et al*., 1992). Some planktonic diatoms can also modify the ionic composition of the cells (Anderson and Sweeney, 1978)

Studies on biodiversity of microalgae in the marine environment are very limited compared to that of terrestrial flora. Similar to terrestrial vegetation marine phytoplankton diversity is a unimodal function of phytoplankton biomass, with maximum diversity at intermediate levels of phytoplankton biomass and minimum diversity during massive blooms (Irigoien *et al*., 2004). Large biomass standing stocks are generally associated with higher diversity in terrestrial ecosystems, the opposite seems to be the rule in pelagic marine ecosystems, where it is generally reported that increased production is associated with decreased diversity (Krebs, 1994).

Changes in species composition and diversity may produce changes in community level parameters, like phytoplankton growth rate and those variables regulating the photosynthetic response to irradiance or other limiting factors. It is important to understand how these changes are reflected in ecosystem functioning and ecosystem services (Duarte *et al*., 2006). Nutrient levels are important determinants of marine biodiversity, influencing the processes of competition and community structure in the marine environment. In the pelagic waters, concentration levels of inorganic nutrients, such as nitrate, phosphate and silicate in the water dictate population growth of planktonic primary producers. Seasonal variations of nutrient concentrations have been correlated with the abundance of microalgae.

As microalgae are exposed to ever-fluctuating physico-chemical parameters they exhibit wide diversity in species and abundance. Even after the extensive studies carried out on algae a plausibly reliable numerical estimate of their species still remains inconclusive. Works of Bold and Wynne (1985) and Stevenson (1996) concluded that there are about 26,000 species of algae all over the world and Norton *et al*., (1996) reported 37,300 species, whereas Mann and Droop (1996) estimated the number of diatom itself contributing more than 2,00,000. The sum total of species, belonging to different taxonomic classes distributed in various habitats, would naturally be higher than this number. The distributional record of microalgae registered in the present analysis is indeed a useful information.

The microscopic species, which remain suspended in the water column, are planktonic and those live in association with some substrata are benthic microalgae. Microalgae suspended in the pelagic environments are of various taxonomic groups such as diatoms, dinoflagellates, green algae, blue green algae silicoflagellates and coccolithophorids. Several such algal species in spite of their characteristic adaptations to the specific habitat have been found both in benthic and pelagic environments. Any individual alga may be benthic or planktonic at one time or another, but many species are characteristically adapted for either benthic or pelagic environments.

Microalgae exhibit seasonal fluctuations, many species are found at certain periods of the year, others are present for much of the time but their numbers may fluctuate, with massive abundance interspersed by periods of relative scarcity. Planktonic species are more seasonal and their seasons may last only a week or two in each year, with a succession of species waxing and waning throughout the year.

Microalgal studies undertaken covering a wider area of different habitats provided very useful basic information for the estimation of primary production and assessment of potential resources. The area of investigation includes coastal and estuarine stations and open sea stations along the southwest coast of India. Open sea collections were carried out onboard 'FORV Sagar Sampada' and stations were between latitudes 07^0 58 08 and 10^0 59 72 and longitudes 75^0 26 42 and 77^0 30 16 during the cruise no. 238 and between latitudes 9^0 22 66 and 15^0 07 32 and longitudes 72^0 51 18 and 75^0 24 98 during cruise no 241. The distribution, cell abundance, diversity, concentration of various pigments, primary productivity and ecology of microalgae in relation with physico-chemical variables were investigated. Taxonomy of new distributional records of microalgae from India was also incorporated.

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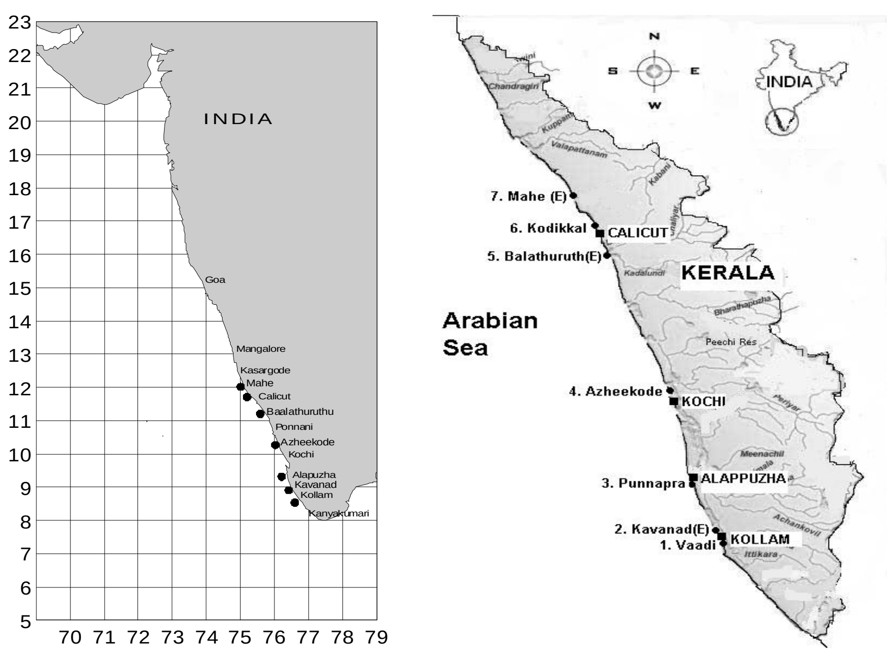
Chapter 1
Materials and Methods

Contents

1.1 Coastal and estuarine stations along the southwest India

Seasonal studies [pre monsoon, monsoon and post monsoon] were carried out from Vaadi in the south to north Mahe, for a period of two years (2006-07 to 2007-08) along the southwest coast of India (map 1). Station details are shown in table 1. Samples have been taken for qualitative and quantitative analysis for phytoplankton and microphytobenthos from each station. Physico-chemical variables were also measured. The terminology, **PRM, MON** and **POM** used in the figures stands for pre monsoon, monsoon and post monsoon respectively.

Map 1



1.1.1 Stations

Table 1. Station locations

Stations	Place	Latitude	Longitude
1	Vaadi	8^0 52’ 01N	76^0 34’ 26E
2	Kavanad-E*	8^0 55’ 55N	76^0 33’ 37E
3	Punnapra	9^0 25’ 23N	76^0 19’ 41E
4	Azheekode	10^0 11’ 02N	76^0 09’ 22E
5	Balathuruthu-E*	11^0 07’ 50N	75^0 49’ 57E
6	Kodikkal	11^0 28’ 43N	75^0 36’ 10E
7	Mahe-E*	11^0 42’ 18N	75^0 32’ 36E

E* stands for estuarine stations and the rest are coastal stations

1.1.2 Planktonic microalgae

Measurement of hydrographic parameters

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

1.1.2.1 Temperature

Temperature was measured using a precision mercury thermometer with an accuracy of ±0.01^o C.

1.1.2.2 Salinity

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

1.1.2.3 pH

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

1.1.2.4 Turbidity

Measurement of transparency of water was made with secchi disc, 20cm in diameter and the depth of illumination where secchi disc disappeared was noted.

1.1.2.5 Dissolved oxygen

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

1.1.2.6 Sampling and analysis

50 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.

1.1.2.7 Enumeration by Sedgewick-Rafter counting cell

The planktonic microalgae filtered from 50L. 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 the all 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

1.1.2.8 Estimation of primary productivity

Photo-autotrophic organisms are able to synthesize organic compounds from simple inorganic compounds utilizing the energy derived from solar radiation. Such 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) is 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 control bottle was incubated. The oxygen content of the 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) of molecules of oxygen liberated during photosynthesis was divided by the 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 was not possible to determine the nature of photosynthetic product, a PQ value of 1.25 is invariably applied for fieldwork.

Calulations

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

1.1.2.9 Estimation of pigments

For the estimation of chlorophyll, 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 is filtered through GF/C glass filter paper and the pigments chlorophyll *a, b* and *c* are 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 ($MgCO_3$) is applied to the glass filter paper and then applying low suction and sucking out the $MgCO_3$ 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 take out the filter paper from the test tube and grind it well in a mortar and transfer it a centrifuge tube, and centrifuge the sample for at least five minutes in 4000 rpm. Make 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, ie., 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 different wavelengths in the respective wavelengths.

Chlorophyll *a* µ/lit. = $\frac{Ca \times v}{V \times 1}$

Chlorophyll *b* µ/lit. = $\frac{Cb \times v}{V \times 1}$

Chlorophyll *c* µ/lit. = $\frac{Cc \times v}{V \times 1}$

Estimation of carotenoids

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

Careteniodes (C*p*) µ/ lit. = $7.6\ [(E_{480}-E_{750}) - (1.49\ E_{510}-E_{750})]$

$$= \frac{Cp \times v}{V \times 1}$$

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.

Nutrients

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

1.1.3 Microphytobenthos

1.1.3.1 Sampling and analysis

Microphytobenthos samples were taken from the same stations from where planktonic microalgae were collected (map 1). Both samplings were done simultaneously. Samples were collected in triplicate from sediments for a period of two years (Two cycles of seasons).

Van Veen grab (mouth area 0.025m^2) was used for the collection of sediment samples. Samples of the upper 5 cm of sediment were collected using a glass hand-corer with an inner diameter of 25 mm. These 5 cm core samples were sectioned at every 1 cm using a thin stainless steel knife. Each 1cm layer of sediment was placed in a screw-capped glass bottle containing 10 ml of 90% acetone and kept at -4^0C in darkness for 24 h). 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.

1.1.3.2 Particle size analysis of sediment

Sediment samples were analyzed for sand, silt and clay. Each sample was dispersed by stirring in a solution of sodium hexametaphosphate in distilled water overnight, after which sand was removed by sieving (180*u*m mesh), dried and weighed and the remaining suspension of silts and clays was sized using a SYMPATEC H70010 Sucell particle size analyzer (Germany).

1.2 Open sea stations along the southwest coast of India (FORV Sagar Sampada cruises)

Fisheries and Oceanographic Research Vessel (FORV) Sagar Sampada has been employed for the open sea surveys as a part of monitoring and surveillance of 'Harmful Algal Blooms in the Indian EEZ', Project funded by the Centre for Marine Living Resources & Ecology, Ministry of Earth Sciences, Government of India. The data of two cruises have been incorporated here (Cruise No 238, 241). The sampling was carried out in the predetermined stations (Maps 2 and 3).

1.2.1 Planktonic microalgae

50 liters of surface water (collected using a scientific deck-water pump attached with the vessel) filtered through 20µ bolting silk and the filtrate preserved in 3% formaldehyde solution.

1.2.2 Chlorophyll

One litre of surface water was filtered through Whatman GF/C filter papers using Millipore filtration unit and pigment was measured as per Strickland and Parson (1972).

1.2.3 Nutrient analysis

Carried out in the laboratory using Strickland and Parson's (1972) standard water analysis methodology.

1.2.4 Environmental variables

The Conductivity Temperature Depth profiler (CTD), was operated (*SBE Model 911 PLUS*, Sea-Bird Inc. USA) in all stations to collect temperature salinity and dissolved oxygen data. Surface meteorological parameters were recorded in the Automated Weather System.

The station details of cruise no. 238 and 241 are shown in table.2, map 2 and table 3 and map 3 respectively.

Table 2. Station locations (Cruise no. 238)

Sl.No.	Date	Time	Lat.	Long.	Stn. Depth (m)	Sampling Depth (m)
1	26.09.05	11:10 hrs	07^{0}.58’.08 N	77^{0}.30’.16 E	39	0
2	26.09.05	21:45 hrs	08^{0}.22’.11 N	77^{0}.00’.07 E	56	0
3	30.09.05	06:50 hrs	09^{0}.29’.04 N	76^{0}.03’.91 E	51	0
4	04.10.05	20:10 hrs	09^{0}.59’.70 N	75^{0}.49’.61 E	51.2	0
5	08.10.05	19:10 hrs	10^{0}.59’.72 N	75^{0}.26’.42 E	52	0

Map 2. Study Area

Cruise Track of FORV Sagar Sampada Cruise No. 238.

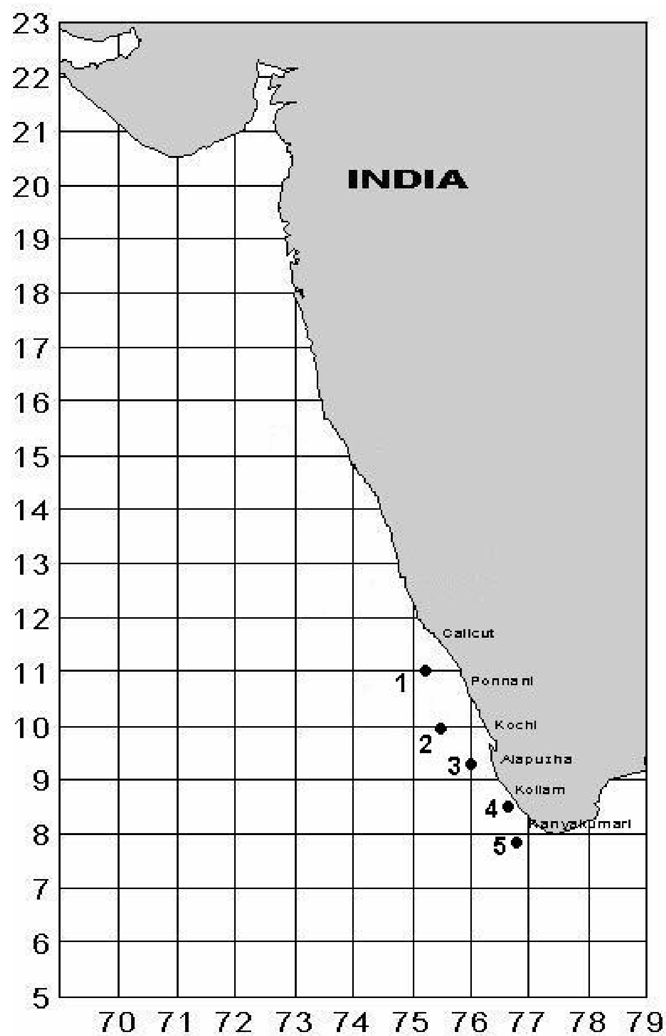
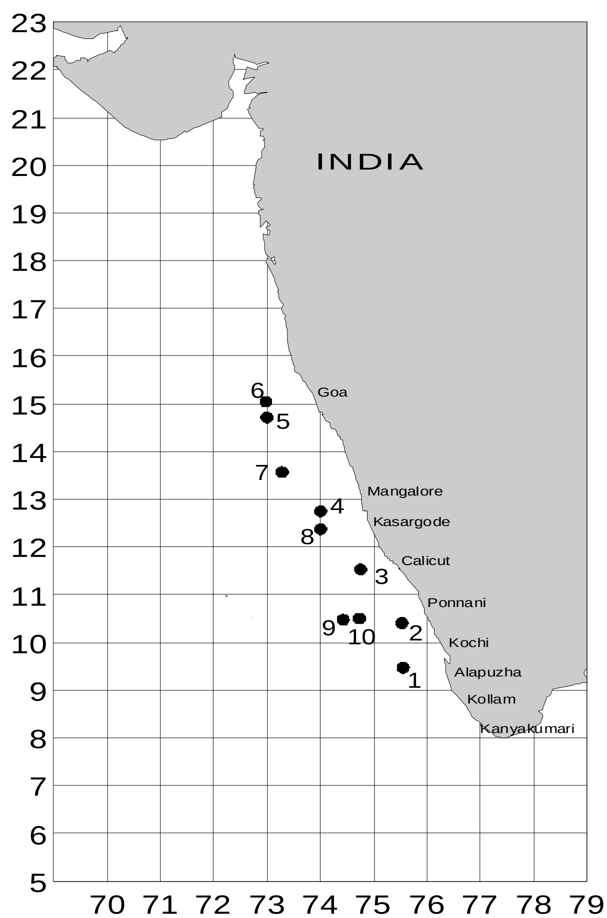


Table 3. Station locations (Cruise no. 241)

Stn. No	Date	Time	Lat.	Long.	Stn. Depth (m)	Sampling Depth (m)
1	23.01.06	22:05	9^0 22’66	$75^0$24’98	1578	0
2	24.01.06	17:02	10 38’09	75 21’41	176	0
3	25.01.06	15:05	11^0 23’17	74 48’37	187	0
4	27.01.06	17:35	12^0 49’30	74 02’46	246	0
5	29.01.06	16:03	14^0 45’27	$72^0$59’82	587	0
6	30.01.06	14:15	15^0 07’32	$72^0$51’18	422	0
7	03.02.06	15	13^0 34’91	73^0 19’63	880	0
8	04.02.06	15:03	12^0 26’49	74^0 05’86	848	0
9	06.02.06	16	10^0 39’32	75^0 15’30	754	0
10	09.02.06	7	10^0 32’27	75^0 17’50	811	0

Map 3. Study Area

Cruise Track of FORV Sagar Sampada Cruise No. 241.



Identification of Microalgae

Microalgae both benthic and planktonic were identified based on standard keys (Allen and Cupp, 1935, Venkataraman, 1939, Cupp, 1943, Subrahmanyan, 1946, Hustedt, 1955, Desikachary, 1959, Hendey, 1964, Simonsen, 1974, Gopinathan, 1984, Jin Dexiang *et al*., 1985, Desikachary and Sreelatha, 1989, Hallegraeff *et al*., 1995, Tomas *et al*., 1997).

1.3. Statistical analysis

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

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Chapter 2

Hydrography

Contents

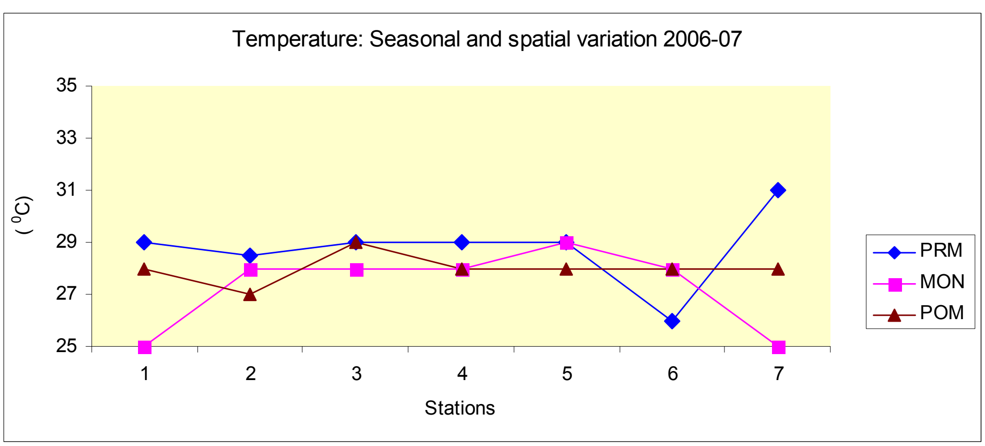
2.1 Coastal and estuarine stations along the southwest India

In ecological studies, hydrographic variables are extremely important to analyze the status of an ecosystem. The fluctuations of some of these factors cause drastic changes in the community structure of aquatic organisms and flora in particular. Physico-chemical variables such as temperature, salinity, pH, nitrate, nitrite, phosphate, silicate, dissolved oxygen, primary productivity, either individually or collectively influence the life cycle and distribution of microalgae. The variations of these factors are described below from pre monsoon 2006-07 to post monsoon 2007-08.

2.1.1 Temperature

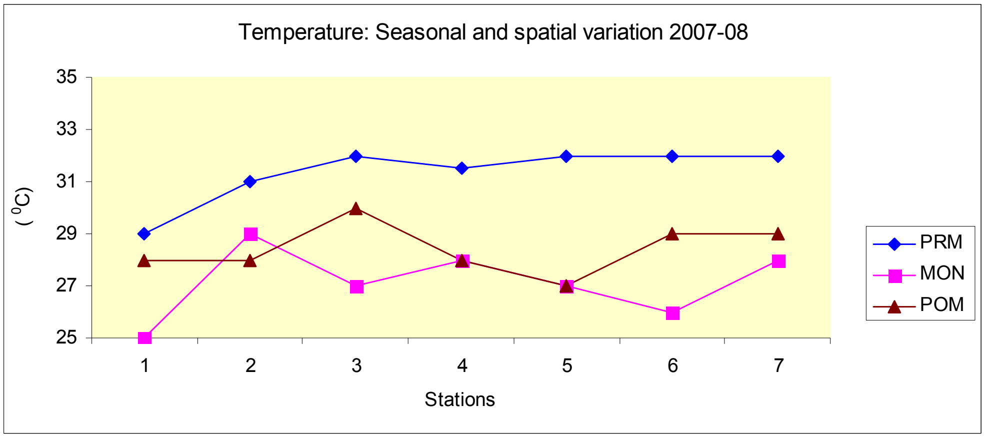
Both the spatial and seasonal variations of temperature were recorded. In 2006-07, the highest temperature of 31^{0}C was recorded during the pre monsoon period in station 7 and the lowest was recorded as 25^{0}C during the monsoon at station 1 and 7 (fig. 1)

Fig. 1



In 2007-08, the highest temperature of 32^{0}C was recorded in stations 3, 5, 6 and 7 during the pre monsoon and the lowest was from station 1 in the monsoon period with 25^{0}C (fig. 2). Two way ANOVA, significant with temperature and season (p<0.001) but not with stations.

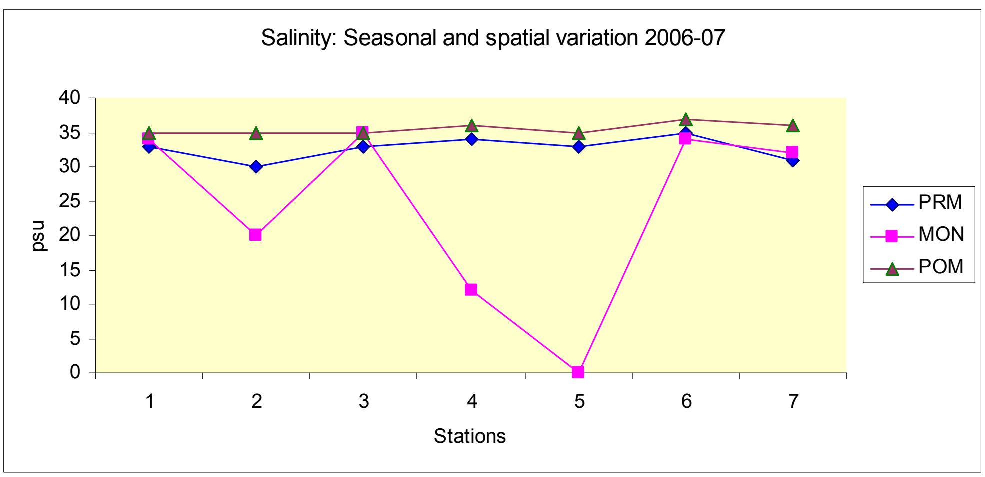
Fig. 2



2.1.2 Salinity

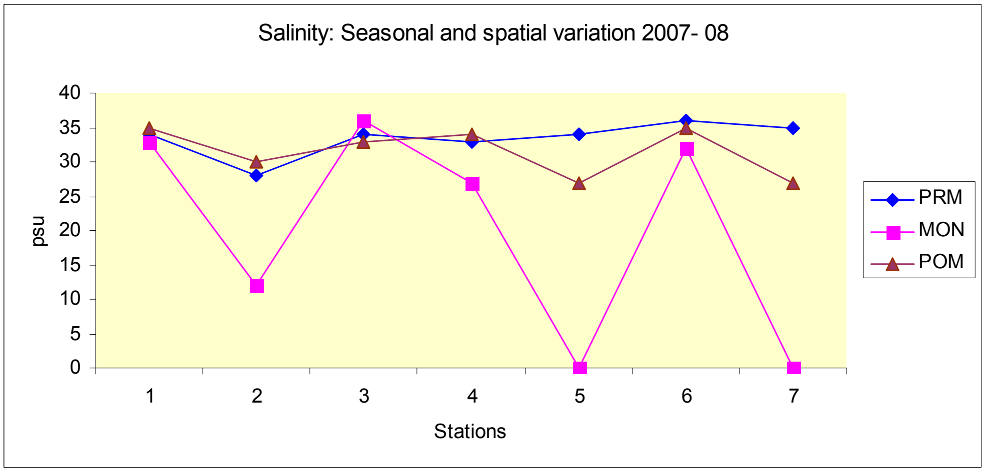
In 2006-07, the highest salinity of 37psu was observed in station 6, during the post monsoon and the lowest was recorded from station 5 Balathuruthu, in the monsoon where the salinity was nil (fig.3). The freshwater condition in this station is due to the influx of Kadalundy River during the monsoon.

Fig. 3



In 2007-08, the highest salinity recorded was 36psu at station 6 during the pre monsoon and at station 3, during the monsoon. The salinity was nil in station 5 and 7 (fig.4). Statistically, a significant relation was not found between salinity with stations and seasons. (Two way ANOVA, p>0.001).

Fig. 4



2.1.3 pH

The pH did not show much variation during the period of investigation. The pH remained alkaline throughout. (Fig. 5 and 6). Two way ANOVA showed significant differences with pH and season (p<0.001) and insignificant with stations.

Fig. 5

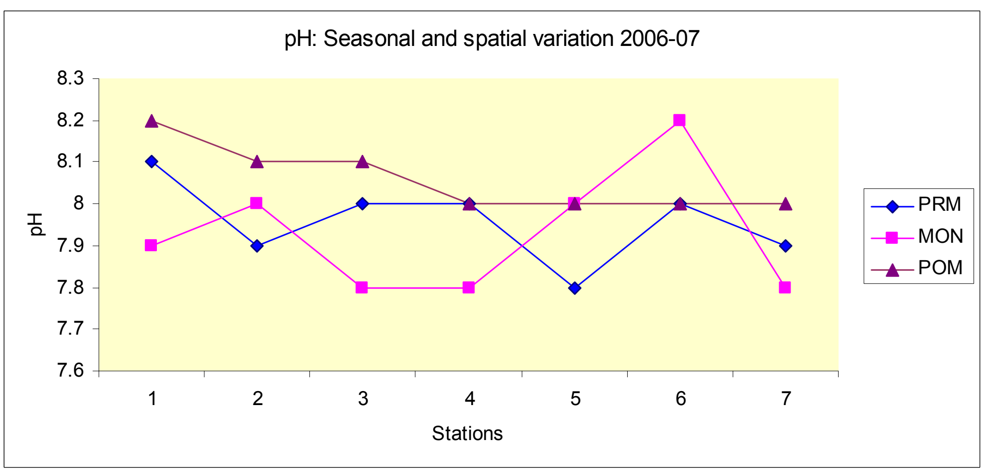
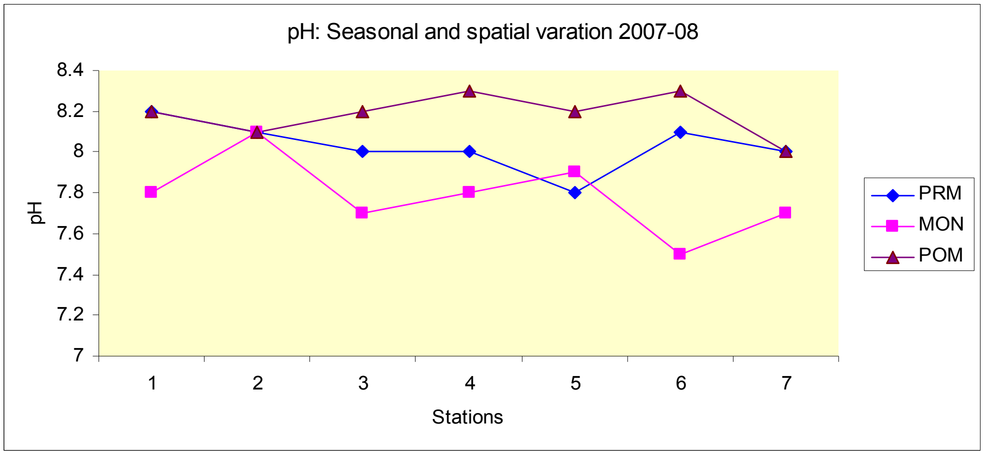


Fig. 6

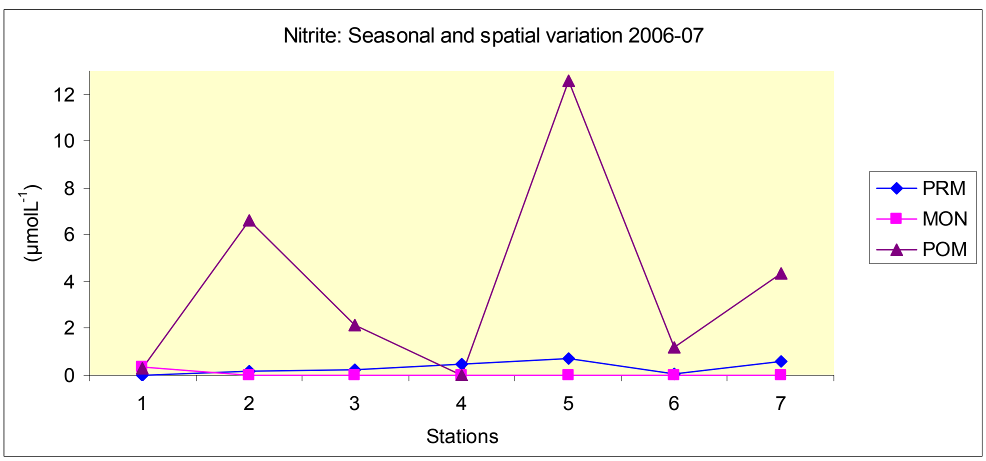


2.1.4 Nutrients

2.1.4.1 Nitrite

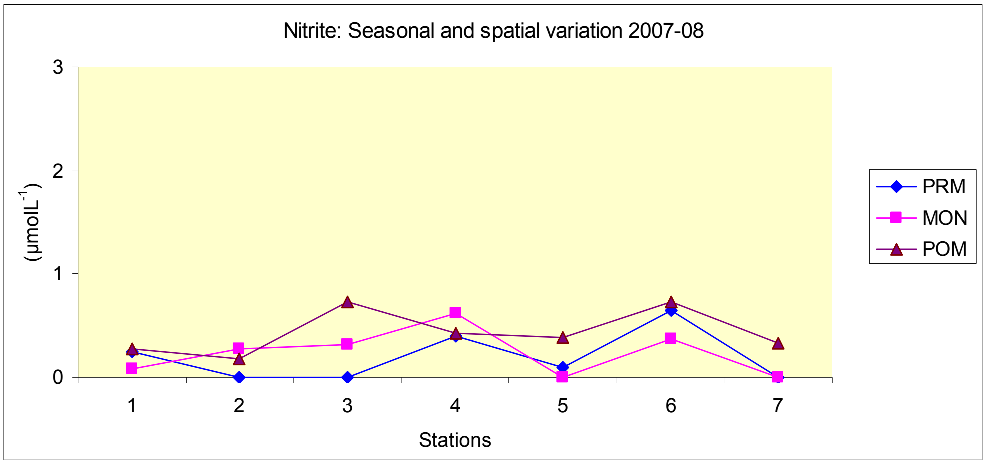
In 2006-07, the nitrite concentration was generally high in almost all the stations during the post monsoon. In pre monsoon and monsoon, the values were negligible except in station 1(fig. 7).

Fig.7



Similarly in 2007-08, during the post monsoon period the highest concentration of nitrite was 0.736µmolL^{-1} recorded in station 6. In pre monsoon, at stations 2, 3 and 7 and in the monsoon at stations 5 and 7, nitrite concentration was too low to be detected (fig. 8). Two way ANOVA not significant with station and season ($p<0.001$).

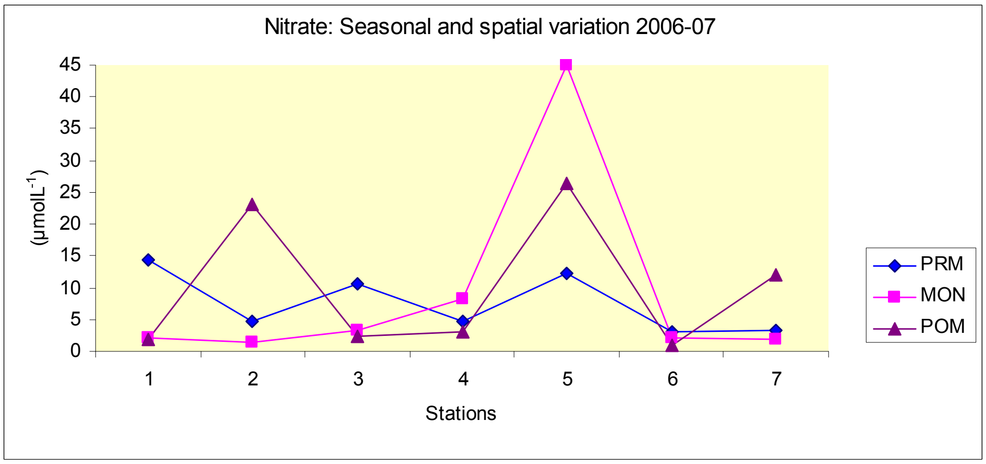
Fig.8



2.1.4.2 Nitrate

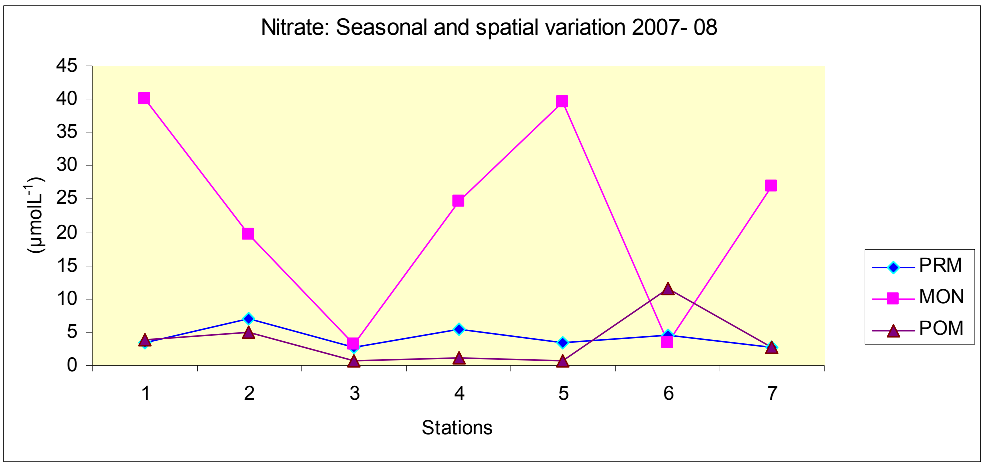
In 2006-07, during the pre monsoon the highest value of nitrate was recorded from station 5 (12.24µmolL^{-1}) and the lowest from station 6, (3.04µmolL^{-1}). In the monsoon, the highest was from station 5, (44.91µmolL^{-1}) and the lowest value from station 2, (1.39µmolL^{-1}). During the post monsoon, 26.43µmolL^{-1}was the highest value recorded from station 5 and the lowest value of 0.94µmolL^{-1} was observed at station 6 (fig.9)

Fig.9



In 2007-08, in the pre monsoon, the highest concentration of nitrate was recorded from station 2 with 7.1µmolL^{-1}and the lowest was found at station 7 (2.7µmolL^{-1}). During the monsoon period, the highest was observed in station 1 (40 µmolL^{-1}) and the lowest of 3.13 µmolL^{-1} was recorded in station 6. In post monsoon, at station 6, the highest value of 11.61 µmolL^{-1} was recorded and the lowest in stations 3 and 5 with 0.725µmolL^{-1} (fig.10). Two way ANOVA failed to reveal any statistical significance with stations and seasons (p>0.001).

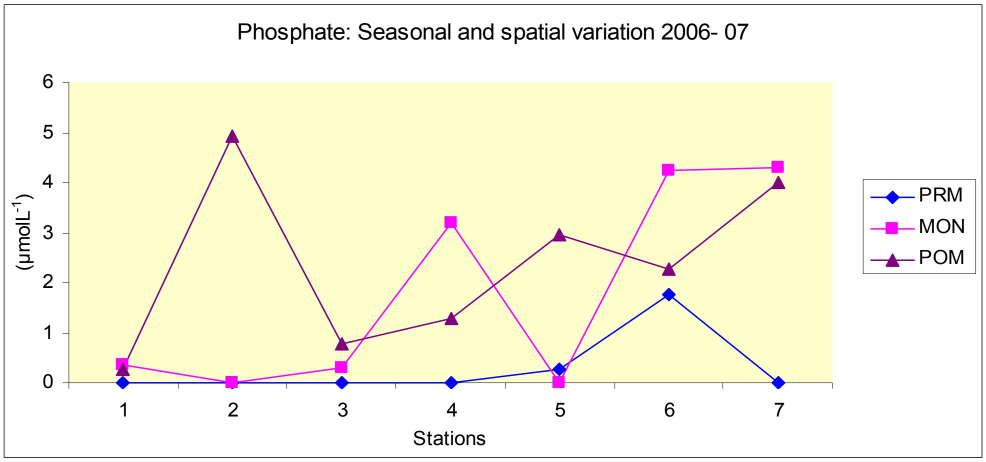
Fig.10



2.1.4.3 Phosphate

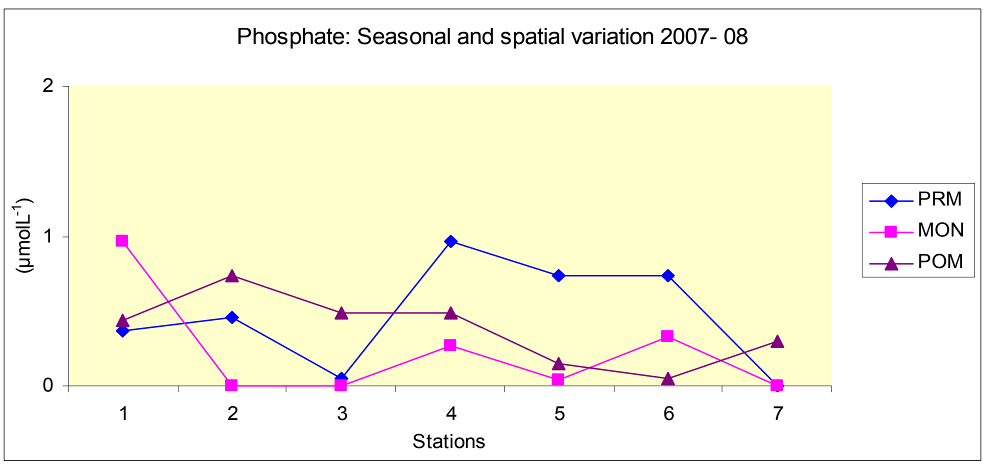
In 2006-07, most of the stations in pre monsoon had shown either below the detectable level or very negligible values of phosphate. In monsoon, the highest phosphate concentration was recorded from station 7 (4.3µmolL^{-1}) and the values below detectable range in stations 2 and 5. During the post monsoon, the highest concentration was 4.92µmolL^{-1} at station 2 and the lowest value of 0.28µmolL^{-1} was recorded at station 1 (fig.11).

Fig.11



During 2007-08, phosphate values recorded during pre monsoon, monsoon and post monsoon were negligible or low in almost all the stations. The phosphate values ranged from nil to 0.97µmolL^{-1} (fig.12). Two way ANOVA not significant with stations and seasons ($p>0.001$).

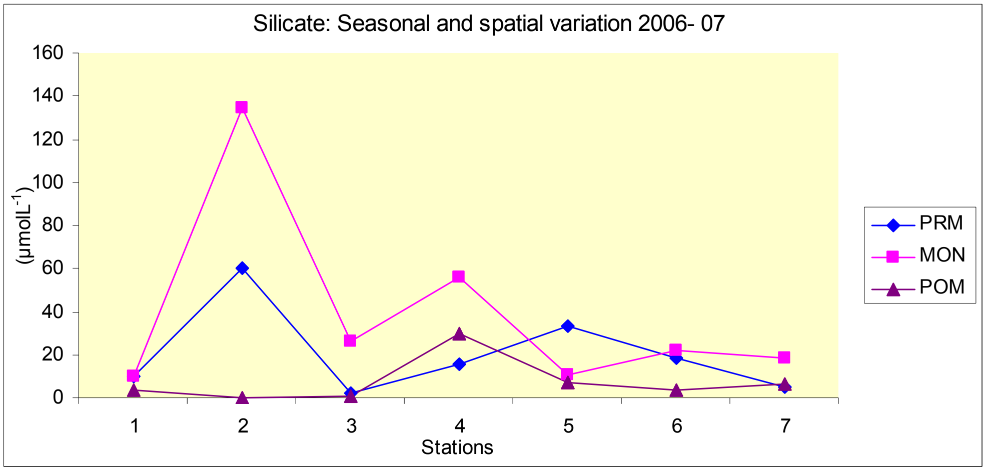
Fig.12



2.1.4.4 Silicate

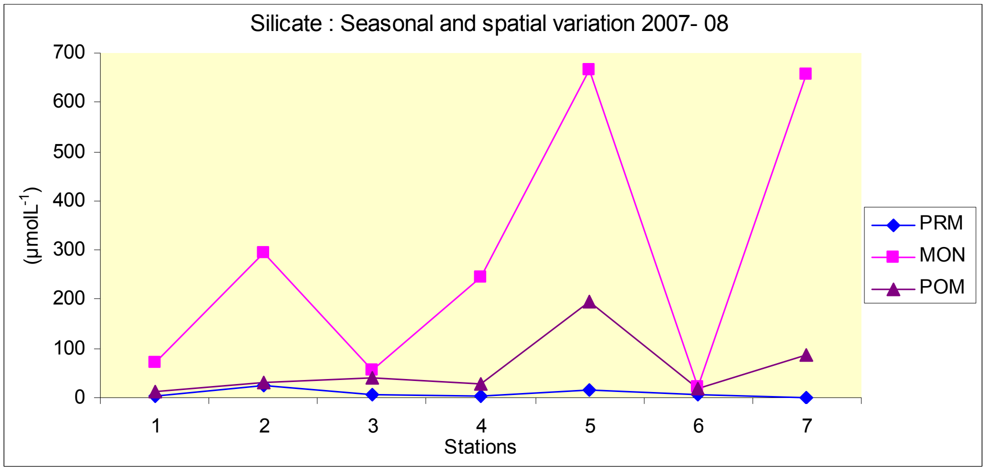
In 2006-07, during pre monsoon, the highest concentration of silicate was observed at station 2, with 60µmolL^{-1} and the lowest was 1.89µmolL^{-1} in station 3. During the monsoon, the highest value of 134.58µmolL^{-1} was found in station 2 and the lowest of 9.67µmolL^{-1} was recorded from station 1. In the post monsoon, the highest value of 29.78µmolL^{-1} was found in station 4 and the lowest was in station 2 with 0.32µmolL^{-1} (fig.13)

Fig. 13



In 2007-08, during pre monsoon, 24.04µmolL^{-1} was the highest value of silicate (station 2) and the lowest of 0.96µmolL^{-1} recorded at station 6. In the monsoon, the highest concentration was 294.9µmolL^{-1} and the lowest was 20.83µmolL^{-1} recorded in station 2 and 6. During the post monsoon, 195.8µmolL^{-1} was the highest value of silicate (station 5) and the lowest was recorded from station 1 (13.78µmolL^{-1}) (fig. 14). Two way ANOVA showed significant differences with season ($p<0.001$) and not with stations.

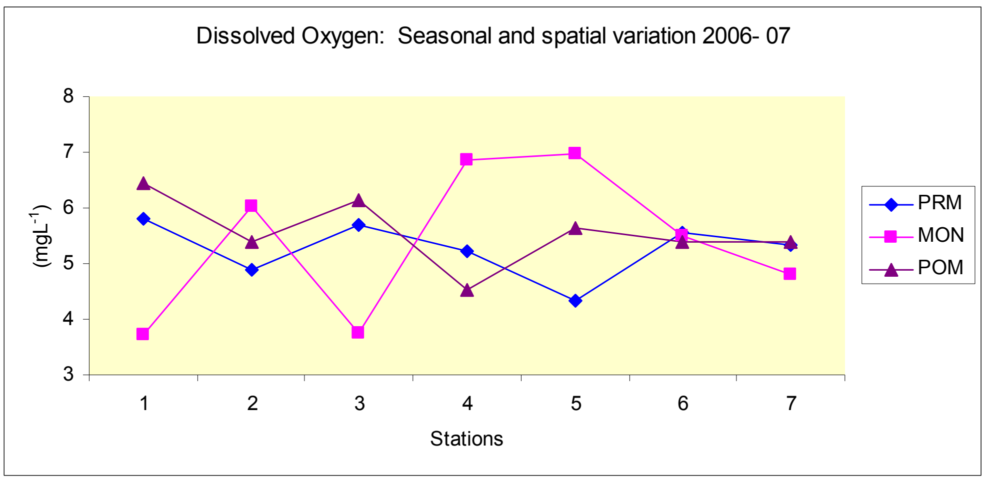
Fig.14



2.1.5 Dissolved oxygen

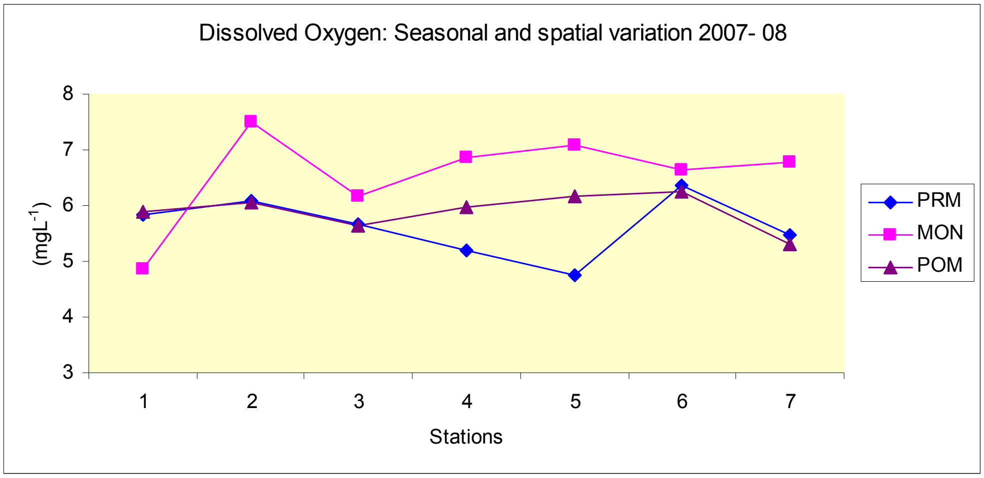
In 2006-07, during the pre monsoon, the maximum dissolved oxygen was 5.8mgL^{-1} recorded at station 1 and the lowest was in station 5 (4.32mgL^{-1}). In the monsoon, the highest value of DO was found in station 5 with 6.97mgL^{-1} and the lowest value was observed in station 1 (3.71mgL^{-1}). In the post monsoon the highest was 6.45mgL^{-1} at station 1 and 4.53mgL^{-1} was the lowest recorded from station 4 (fig. 15).

Fig. 15



In 2007-08, the highest value of 6.36mgL^{-1} was observed in station 6 and the lowest value of 4.74mgL^{-1} was recorded in station 5 during the pre monsoon. In monsoon, the highest value of DO was 7.51mgL^{-1} recorded from station 2 and the lowest value being 4.86mgL^{-1} in station 1. During the pre monsoon period, the highest value of dissolved oxygen was observed in station 6 (6.24 mgL^{-1}) and the lowest was 5.31 mgL^{-1} in station 7 (fig.16). Statistically there was no significant relationship with seasons and stations (Two way ANOVA, $p>0.001$).

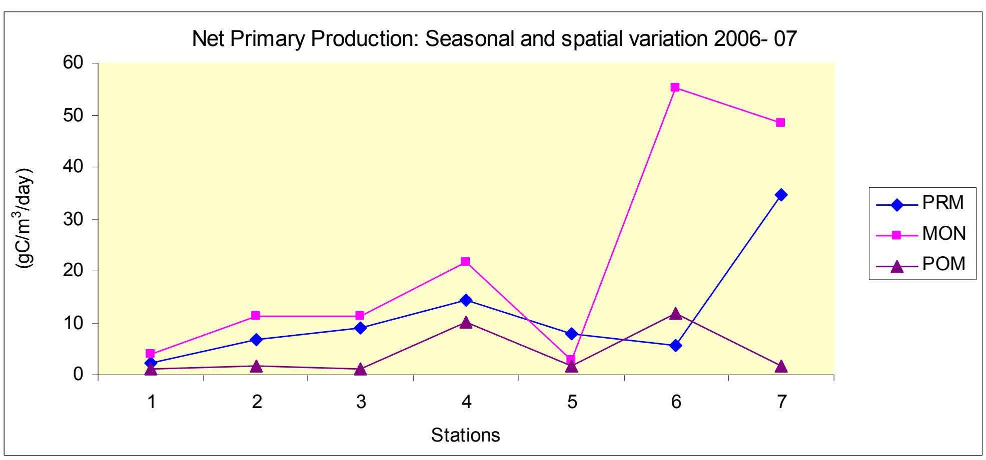
Fig.16



2.1.6 Primary production

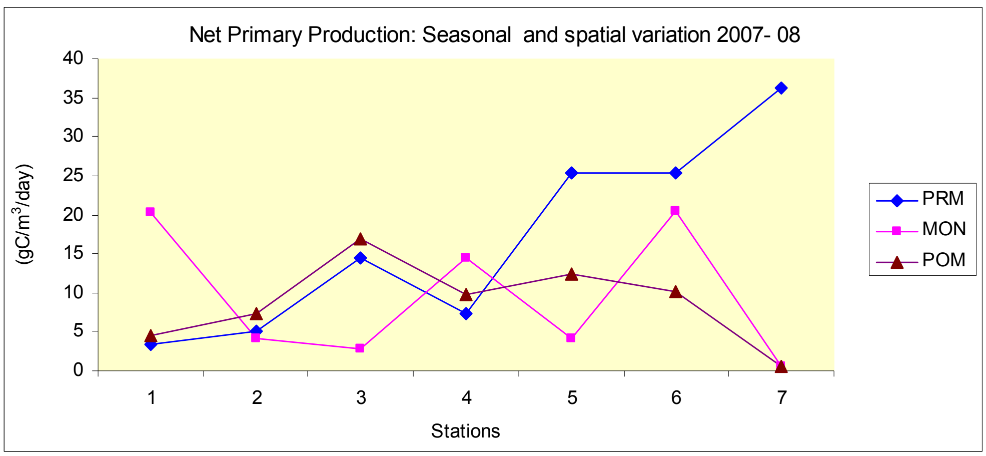
During the pre monsoon period of 2006-07, primary productivity varied from 2.28gC/m^3/day in station 1 to 34.68 gC/m^3/day in station 7. During monsoon it varied from 2.28gC/m^3/day in station 5 to 52.32gC/m^3/day at station 6. In the post monsoon the variation was from 1.08gC/m^3/day in stations 1 and 3 to 11.88 gC/m^3/day in station 6 (fig. 17)

Fig.17



In 2007-08, during the pre monsoon, the highest value of primary productivity was 36.24gC/m^3/day at station 7 and the lowest was 3.36gC/m^3/day in station 1. In the monsoon, 20.28gC/m^3/day was the highest recorded from station 6 and 0.6gC/m^3/day was the lowest, recorded from station 7. In post monsoon, 16.9gC/m^3/day was the highest in station 3 and lowest primary production was recorded as 0.56gC/m^3/day in station 7 (fig.18). Two way ANOVA not significant with stations and seasons ($p>0.001$). The Pearson Correlation analysis of the hydrographic parameters is shown in table 5.

Fig. 18



2.1.7 Statistical analysis

ANOVA of physico-chemical variable is shown in table 4.

Table 4.

Temperature						
Source of Variation	DF	SS	MS	F	P	Tabled value
Station	6	12.75	2.125	1.535	0.201	2.421
Season	5	82.714	16.543	11.948	<0.001	2.534
Residual	30	41.536	1.385			
Total	41	137	3.341			

Salinity						
Source of Variation	DF	SS	MS	F	P	Tabled value
Station	6	939.81	156.635	2.611	0.037	2.421
Season	5	1323.048	264.61	4.411	0.004	2.534
Residual	30	1799.619	59.987			
Total	41	4062.476	99.085			

pH						
Source of Variation	DF	SS	MS	F	P	Tabled value
Station	6	0.123	0.0205	1.287	0.293	2.421
Season	5	0.636	0.127	8	<0.001	2.534
Residual	30	0.477	0.0159			
Total	41	1.236	0.0302			

Nitrite						
Source of Variation	DF	SS	MS	F	P	Tabled value
Station	6	18.566	3.094	0.891	0.514	2.421
Season	5	77.574	15.515	4.467	0.004	2.534
Residual	30	104.193	3.473			
Total	41	200.334	4.886			

Nitrate						
Source of Variation	DF	SS	MS	F	P	Tabled value
Station	6	1207.801	201.3	2.341	0.057	2.421
Season	5	1640.659	328.132	3.817	0.009	2.534
Residual	30	2579.264	85.975			
Total	41	5427.724	132.384			

Phosphate						
Source of Variation	DF	SS	MS	F	P	Tabled value
Station	6	8.018	1.336	1.031	0.425	2.421
Season	5	28.442	5.688	4.39	0.004	2.534
Residual	30	38.871	1.296			
Total	41	75.331	1.837			

Silicate						
Source of Variation	DF	SS	MS	F	P	Tabled value
Station	6	114131.3	19021.88	1.513	0.208	2.421
Season	5	404748.5	80949.7	6.437	<0.001	2.534
Residual	30	377261.9	12575.4			
Total	41	896141.6	21857.11			

Dissolved oxygen						
Source of Variation	DF	SS	MS	F	P	Tabled value
Station	6	2.665	0.444	0.652	0.688	2.421
Season	5	6.888	1.378	2.021	0.104	2.534
Residual	30	20.444	0.681			
Total	41	29.996	0.732			

Primary Productivity						
Source of Variation	DF	SS	MS	F	P	Tabled value
Station	6	12.05	2.008	2.019	0.094	2.421
Season	5	11.602	2.32	2.332	0.067	2.534
Residual	30	29.846	0.995			
Total	41	53.498	1.305			

Pearson Correlation analysis of physico-chemical variables

Table 5.

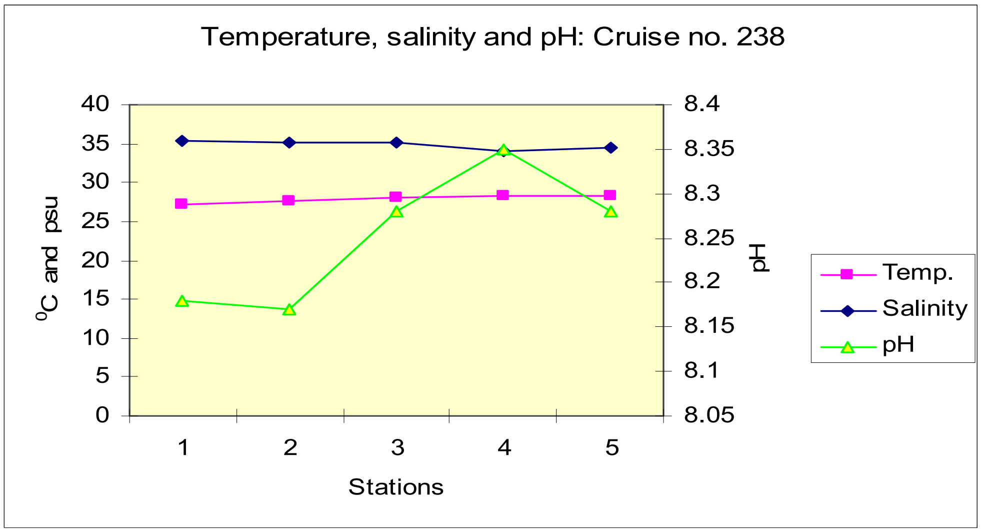
		Correlations								
		Temp	Salinity	pH	NO_2N	NO_3N	PO_4	SiO_4	DO	Net PP
Temp.	Pearson Correlation	1								
	Sig. (2-tailed)	.								
	N	42								
Salinity	Pearson Correlation	.076	1							
	Sig. (2-tailed)	.634	.							
	N	42	42							
pH	Pearson Correlation	.257	.219	1						
	Sig. (2-tailed)	.100	.164	.						
	N	42	42	42						
NO_2N	Pearson Correlation	-.089	.195	.087	1					
	Sig. (2-tailed)	.576	.215	.584	.					
	N	42	42	42	42					
NO_3N	Pearson Correlation	-.215	-.613(**)	-.206	.252	1				
	Sig. (2-tailed)	.171	.000	.191	.107	.				
	N	42	42	42	42	42				
PO_4	Pearson Correlation	-.332(*)	.184	-.033	.506(**)	.042	1			
	Sig. (2-tailed)	.032	.245	.837	.001	.794	.			
	N	42	42	42	42	42	42			
SiO_4	Pearson Correlation	-.185	-.757(**)	-.243	-.145	.491(**)	-.209	1		
	Sig. (2-tailed)	.240	.000	.122	.360	.001	.183	.		
	N	42	42	42	42	42	42	42		
DO	Pearson Correlation	.044	-.560(**)	.171	-.068	.312(*)	-.091	.443(**)	1	
	Sig. (2-tailed)	.782	.000	.280	.670	.044	.565	.003	.	
	N	42	42	42	42	42	42	42	42	
Net PP	Pearson Correlation	.089	.172	-.095	-.223	-.230	.285	-.159	.022	1
	Sig. (2-tailed)	.573	.275	.549	.156	.142	.068	.313	.891	.
	N	42	42	42	42	42	42	42	42	42

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

2.2 Open sea stations along the southwest coast of India (FORV Sagar Sampada cruises)

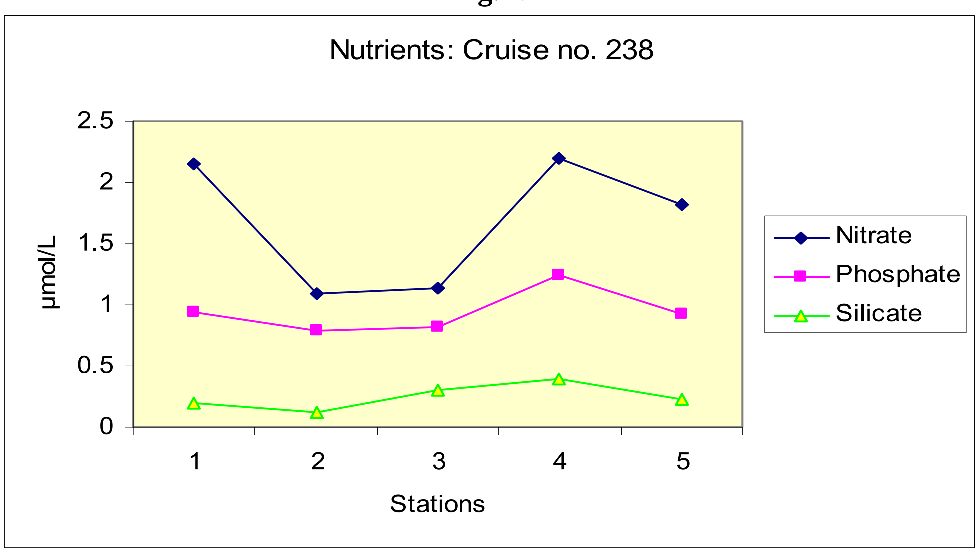
During the cruise no. 238, temperature and salinity did not show any marked variation. pH ranged from 8.1 to 8.3 (fig. 19).

Fig.19



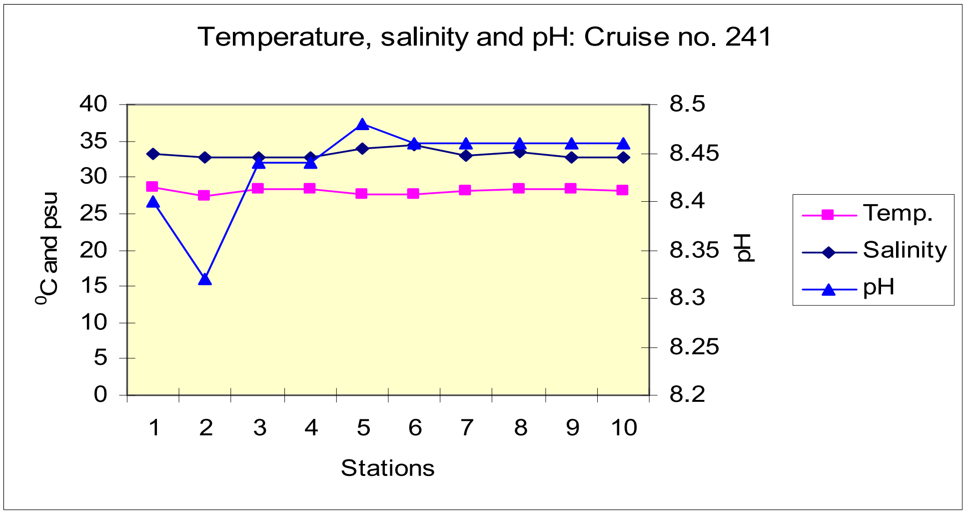
The nutrients showed variation. The value of nitrate was high when compared to phosphate and silicate. Silicate has the lowest values during cruise no. 238. The distribution of nutrients is shown in fig. 20.

Fig.20



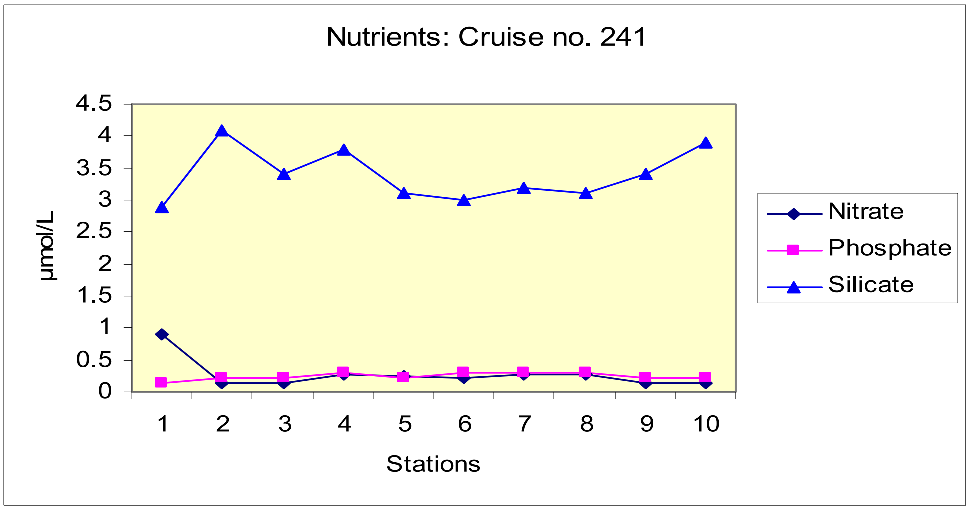
During the cruise number 241, the physical parameters showed slight variations. Temperature ranged from 27.3 to 28.7, salinity was varied from 32.6 to 34.4. pH was quite steady, except at station 2 (fig. 21).

Fig. 21



The value of silicate has observed as the highest and other nutrients have the minimal values. The concentrations of phosphate and nitrate was not varied considerably, while silicate values were high and showed marked variations. Spatial distribution of nutrients shown in fig. 22.

Fig.22



In coastal and estuarine stations, considerable fluctuations of salinity were observed during the monsoon, especially in the estuarine stations, where as in the open sea waters (Sagar Sampada cruises) salinity variation was meagre. In the case of nutrients, seasonal and spatial variation was observed both in the coastal and estuarine stations and open sea waters.

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Chapter 3
Planktonic Microalgae

Contents

3.1 Introduction

The term ‘plankton’ refers to the collective of *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. ‘Plankton’ normally 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 producer 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). Marine phytoplankton constitute less than 1% of Earth’s photosynthetic biomass, yet they are responsible for 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).

Planktonic primary production provides the base upon which the aquatic food chains culmunating in the natural fish populations exploited by man are founded, at the same time generating some 70% of the world’s atmospheric oxygen supply (Reynolds, 1984). Yields of marine fisheries increase linearly with annual rates of primary production. The high efficiency of conversion of solar energy into marine fish via photosynthesis (Nixon, 1988) indicates that availability of adequate resources is a significant force in the overall structure and function of marine pelagic ecosystems. The primary producers have always been at the base of the food web; hence, the evolution of organisms at higher trophic levels has depended on the evolutionary trajectories of the phytoplankton.

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

Phytoplankters are the primary producers of the pelagic marine ecosystems and some of the phytoplankton species may also reflect the ecological changes in the environment. Phytoplankton biomass, distribution and species composition change continuously with variations in environmental temperature, light, nutrient availability, grazing pressure, tide and water movements, seasons and even with time of day. Endogenous rhythms also affect the diel distribution patterns of phytoplankton (Sournia, 1974; Nelson and Brand, 1979; Kamykowski, 1981; Cullen and Horrigan, 1981; Kana *et al.,* 1985; Demers *et al.,* 1986; Hsiao, 1992).

Although the oceans cover 70% of the Earth's surface, our knowledge of biodiversity patterns in marine phytoplankton are very limited compared to that of plants in the terrestrial world. Similar to terrestrial vegetation, marine phytoplankton diversity is a unimodal function of phytoplankton biomass, with maximum diversity at intermediate levels of phytoplankton biomass and minimum diversity during massive blooms. Several studies have shown that biodiversity and production decreases with the rise of human influence (Lehman and Smith, 1991; Turner and Rabalais, 1994; Lehman, 2000; Huang *et al.*, 2004).

The present work is concentrated on estuarine, coastal and open sea stations along the southwest coast of India. Estuaries act as filters that trap both natural and anthropogenic materials transferring from the continents to the open sea. These environments frequently have high fertility and large phytoplankton populations and are enriched by nutrients from river water, organic pollution (locally within the estuary or remotely through runoff) and by the entrainment of coastal waters in a subsurface counter-current, transporting nutrients into the estuary (Ketchum, 1967). Nutrient enrichment from any of these sources can elicit either positive or negative responses in the ecological health of estuaries (Gianesella *et al*., 2000).

Environmental disturbances in aquatic systems, such as nutrient additions associated with inflow events, are known to influence phytoplankton community composition, species diversity, and biomass (Buyukates and Roelke, 2005). The astonishing species diversity in phytoplankton communities known as the paradox of phytoplankton diversity (Hutchinson, 1961), has stimulated many studies of the importance of competition for light and/or nutrients, or of the intermediate disturbance hypothesis (Elliott *et al*., 2001).

Environmental changes could prevent phytoplankton diversity from reaching a state of stable equilibrium if those changes are frequent enough to reverse competitive hierarchies before exclusion occurs (Hutchinson, 1961; Sommer *et al*., 1993; Floder and Sommer 1999).

Eutrophication as a result of anthropogenic input of nutrients has been reported in many aquatic systems (Smith *et al*., 1999). In many coastal waters, increasing nutrient enrichment accompanied by a variation in nutrient ratio profoundly affects the phytoplankton species composition and production, and eventually alters the ecosystem structure and function (Aktan *et al*., 2005). Many nutrients may potentially limit algal growth and accumulation in aquatic systems (Fisher *et al*., 1999).

During the last 40 years, nutrient concentrations have obviously increased in many estuaries and coastal waters in the world due to the influence of human activities and have become a serious environmental problem in the world (Justic *et al*., 2002). Increased N loading has been associated with eutrophication and declines in water quality. It has been well documented that initial changes in aquatic communities due to increasing eutrophication begin with the successions in the species composition and abundance of phytoplankton (Ignatiades *et al*., 1985, Smith *et al.*, 1999, Danilov and Ekelund, 1999).

As nutrients increase and the environment becomes mesotrophic, benthic algae become more important and may overgrow and displace corals and coralline algae for space. (Raghukumar and Anil, 2003). Rapidly growing, filamentous algae inhibit the settlement of coral planulae. There are many other factors that can influence the spatial distribution of phytoplankton besides nutrient availability, such as the magnitude and position of the turbidity, the tidal amplitude and freshwater discharge, water column stratification and grazing rates of zooplankton (Cloern *et al*., 1985; Harrison *et al*., 1991).

Thus the information obtained from phytoplankton communities can significantly contribute to assessing eutrophication levels in aquatic areas. Diversity and similarity indices are an approach to estimate biological quality through the structure of the community. Studies on phytoplankton diversity are an important contribution to the understanding of the system dynamics (Odum, 1971; Hillebrand and Sommer, 2000).

Planktonic microalgae are guided by a number of external chemical and physical stimuli during their vertical movements. Light and gravity are the main external factors. Several strategies have been developed in phytoplankton like upward movement is often guided by negative gravitaxis, in many cases supported by positive phototaxis at low irradiance (Nultsch and Hader, 1988; Hader, 1995).

The algae co-occur even though each species has a specific niche based on its physiological requirements and the constraints of the environment. These are many detailed descriptions of phytoplankton succession being correlated with changes in environmental parameters particularly temperature, light, nutrients availability and mortality factors such as grazing and parasitism. Because the variation of phytoplankton succession is strongly linked to meteorological and water stratification mixing processes, patterns in temperate ecosystems differ considerably from those of tropical waters (Wetzel, 2001). Coastal marine microplankton is composed of species with short life cycles, strongly affected by the seasonal fluctuation of the abiotic factors (Moscatello *et al*., 2004).

The distribution of phytoplankton biomass is largely associated to nutrients availability at large, medium and small spatial scales by biophysical processes like the light environment, water column stratification/turbulence, temperature and grazing. (Platt, 1972; Joint and Pomroy, 1981; Pennock and Sharp, 1994). In highly turbid coastal waters where nutrients are present at moderate to high concentrations, light availability is usually the limiting factor for primary production (Underwood and Kromkamp, 1999). In such conditions, the distribution of phytoplankton biomass can be expected to reflect horizontal gradients in those variables that modulate light availability (Pennock, 1985; Cloern, 2001). Changes in the phytoplankton community representing an ecological succession also occur associated to such environmental gradients (Underwood and Kromkamp, 1999) in estuaries and coastal waters and because of their hydrodynamics and massive human settlements, especially estuaries are susceptible to anthropogenic impact. Their integrity is currently under risk worldwide (Flindt *et al*., 1999; Kiddon *et al*., 2003).

Identification and quantification of planktonic microalge is through microscopic examination, which is very 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 various 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).

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.

Considerable proportion of marine phytoplankton consists of blue-green algae, particularly in picoplankton (0.2-2μ). 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 occur together 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.

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, they are frequently distributed during the monsoon periods and provide high biomass and productivity.

Class: Bacillariophyceae (Diatoms)

The word diatom came from the genus '*Diatoma*'. They are unicellular or colonial; occur in soil, damp rocks, freshwater, 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 1.4×10^{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.

Mann and Droop, 1996, estimated the existing diatom species diversity. 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 most species-rich group of algae.

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).

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, 1978).

The class Bacillariophyceae is sub-divided into two orders ie., Centrales and Pennales. 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.

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).

Several investigations have been carried out on planktonic microalgae and its relationships in Indian waters (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; Krishnamurty *et al*., 1974; Santhanam *et al*., 1975; Desikachary *et al*., 1987a 1987b, 1988; Gowda *et al*., 2001). The present investigation was intended to study the seasonal fluctuations of biomass and distribution of planktonic microalgae, along the southwest coast of India.

3.2 Review of Literature

Kutzing, (1844, 1849), in his *Species Algarum*, described the diatoms and contributed several new genera and species. 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, began to apply 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 studied well on the diatoms in 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.

Hendey (1937), described the plankton diatoms of the samples collected from the voyage of *'Discovery'*. In 1954, Hendey, published compiled check-list on British marine diatoms, which contained 771 species from 104 genera. In 1964, a monograph titled, *An introductory account of the smaller algae of the coastal waters. Part V. Bacillariophyceae (Diatoms)* was published. Later on in 1974, Hendey published a revised check-list of the British marine diatoms.

In 1939, Venkataraman, studied the systematic account of south Indian diatoms. He described both fresh 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) were the pioneers in the phytoplankton taxonomy, who made outstanding contributions to the Indian inshore seas. Subrahmanyan described over 500 species of the phytoplankton forms of all groups together representing over 150 genera from both coasts of India. In 1946, he described 171 forms of marine planktonic diatoms at

Madras, representing 15 families, 64 genera and 134 species. Subrahmanyan and Sharma (1960) listed a total of 291 phytoplankton species off Calicut.

The pioneer 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.

In 1959, Indian Council of Agricultural Research published a monograph on Cyanophyta by Desikachary. Nair (1959) studied the marine planktonic diatoms of Trivandrum coast quite extensively.

In 1959, Steemann Nielsen made a cursory attempt about the primary production in tropical marine areas. He described that low productivity is to be expected in lower latitudes in the central part of the anticyclonic eddies. On the other side high productivity is found where upwelling process taking place. He added that simplest estimate of oceanic production is easy by seeing the colour of the sea. The deep blue sea is the most unproductive water.

The majestic 'International Indian Ocean Expedition' - IIOE, was held during 1962-65. The IIOE expedition mainly analysed the plankton with a view to assessing organic production. After extensive measurements of primary production onboard the "*Anton Bruun*", Ryther *et al.* (1966) has experimentally proved that the Western Indian Ocean is one of the most productive oceanic region around the world.

Lind, in 1968, elaborately described on the distribution of phytoplankton from Kenyan waters.

Nair, *et al.*, in 1968, calculated the potential production of phytoplankton in terms of carbon for the westcoast as 46×10^6 tons and for east coast of India as 15×10^6 tons. Sankaranarayanan and Qasim (1969) studied the nutrients of the Cochin estuary in relation to environmental characteristics.

Gopinathan, in 1972, studied the qualitative and quantitative analysis on phytoplankton of the Cochin estuary and described 120 species.

Archibald, in 1972, studied the diversity in some South African diatom associations and its relation to water quality. Dooley, in 1973, investigated the phytoplankton of a sheltered inlet of Galway Bay on the west coast of Ireland in the winter and early summer of 1971. The diatom flora, of just over 70 species, was primarily neritic in character and shown much fluctuated seasonal variation.

Hasle, in 1973, vastly described some marine plankton genera of the diatom family Thalassiosiraceae. Simonsen, (1972, 1974, 1979), suggested a more natural system of the centric diatoms. He also made an elaborate study on the diatom plankton of the Indian Ocean Expedition of "R.V. Meteor"1964-1965.

Reynolds, (1973, 1984, 2006) one among the reputed scientist in contemporary phycology, has done very important studies on phytoplankton ecology. His publications (1984, 2006) are considered as referal monographs in phytoplankton ecology. Devassy and Bhattathiri, analysed the phytoplankton ecology in the Cochin estuary in 1974.

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

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.

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

Pillai *et al.*, in 1975 studied the plankton production in relation to the environmental parameters in Vembanad Lake. Seasonal fluctuations in the abundance of phytoplankton in the Cochin backwaters were studied by Kumaran and Rao (1975).

Gopinathan (1975a), described an account of the estuarine diatoms present in various estuarine systems in India, their occurrence, seasonal fluctuations and distribution in the various estuaries particularly from Cochin backwater. Gopinathan, (1975b), described some new distributional records of plankton diatoms from the Indian Seas.

In 1976, Taylor, described the dinoflagellates from the International Indian Ocean Expedition in *Bibiliotheca Botanica.* Hasle, and Fryxell, in 1977 studied about some species with linear array of areolation in *Thalassiosira spp.* Hasle, and Syvertsen, in 1980, studied on the morphology and taxonomy of the *diatom* genus *Cerataulina*.

In 1978, Qasim *et al*., examined the biological productivity of the coastal waters of India upto 50m depth and proved that the larger phytoplankton species contributed to greater spatial variation in the primary production than the smaller forms.

In 1980, Thresiamma and Nair, investigated the qualitative and quantitative analysis of planktonic diatoms of Vizhinjam, the southwest coast of India. Pant *et al*. (1980), studied the contribution of phytoplankton photosynthesis in a mangrove ecosystem.

Nair and Gopinathan, investigated the primary productivity of the exclusive economic zone (EEZ) of India and the factors governing phytoplankton production in 1981. The annual carbon production of the EEZ of India, comprising 2.02 million square kilometres has been estimated to be 283 million tons and the exploitable yield of living resources of the EEZ is estimated to be 5.5 million tons based on primary production.

In 1983, Robinson, conducted synoptic surveys of the plankton at a depth of 10 m in the North Sea. Krammer and Lange-Bertalot, (1985, 1986) carried out extensive work on the diatoms, especially to the family *Naviculaceae,* in their monograph, *Bibliotheca Diatomologica*.

Desikachary and his colleagues, (1986, 1987a, b and c, 1988, 1989) made massive contribution to the field of algology in India. Their Atlases of diatoms are considered as the most valuable reference books world wide.

Jayalakshmi *et al*., in 1986, studied the seasonal distribution of phytoplankton in Cochin backwaters. In 1989, Santra *et al*., studied the seasonal fluctuations of phytoplankton in Bhagirathi-Hoogly estuary, in West Bengal.

Sterrenburg, (1991, 1993, 1994), studied the genera *Gyrosigma* and *Pleurosigma* using light microscope and provided new features for taxonomy.

Sarupria and Bhargava (1993) recorded 109 species of phytoplankton during cruise of R.V.Gaveshini.

Jiyalalram and Goswami in 1993, observed the distribution of chlorophyll *a*, phaeopigments, zooplankton and physicochemical parameters in the surface waters from Southern Indian Ocean were carried out during 9th Indian Antarctic Expedition (1989-1990).

In 1993, Sarno *et al.,* investigated the phytoplankton populations at Fusaro lagoon (Mediterranean Sea) from 1989 to 1990 and assessed species composition, temporal succession and standing stock of the different species.

Gopinathan *et al*., in 1994 recorded the peak periods of primary production and chlorophyll *a* of the inshore area at Tuticorin.

Mann and Droop, 1996, stated that, the total number of diatom species worldwide may be at least 2 x10^5. Bode *et al.,* in 1996, studied chlorophyll *a* and primary production in the euphotic zone of the North-West shelf of Spanish coast.

Dahl and Johannessen, in 1998, regularly monitored the phytoplankton on the Norwegian Skagerrak coast since 1989. Eker *et al*, in 1999, studied the species composition, abundance, and biomass of micro and nano-phytoplankton in the western and eastern Black Sea and identified 142 species of phytoplankton.

Gwo-Ching Gong *et al*., in 1999, estimated the annual primary production in the Kuroshio region, northeast of Taiwan, using photosynthetic-irradiance model. The seasonally averaged annual production was estimated as $104 gCm^{-2} yr^{-1}$ ($285 mgCm^{-2}d^{-1}$). The established model may serve as a better regional algorithm in the assessment of primary production in Kuroshio waters.

In 1999, Tarran, *et al*., investigated the phytoplankton community structure in the Arabian Sea during and after the SW monsoon during 1994. They observed that Prochlorophytes were restricted to oligotrophic stratified waters during the SW monsoon period but were found at all stations along the transect during the inter-monsoon, dominating the phytoplankton standing stocks in the oligotrophic region during this period.

Rasheed *et al.,* in 2000, estimated the photosynthetic pigments at the dredged and non-dredged sites in the Cochin harbour and observed that the higher concentration of chlorophyll '*a*' in the bottom is indicative of the detachment of benthic flora from the sediments due to dredging.

Gopinathan *et al*., in 2001, studied the distribution of chlorophyll *a* and *b* in the 40 to 200 m depth zone of Varaval coastal waters during pre – monsoon.

Sarangi *et al.,* 2001, investigated the phytoplankton distribution in the Arabian Sea using IRS-P4 OCM satellite data. The study had revealed that higher chlorophyll values in the northern Arabian Sea are associated with the winter cooling phenomenon, normally reported to occur during January to March in the Arabian Sea.

Sarojini and Nittala, (2001), investigated the vertical distribution in phytoplankton in the upper 200m water column at five stations around the Andaman Islands.

Gowda *et al.* (2001), recorded the abundance and distribution of phytoplankton in the Nethravathy estuary. Diatoms were the dominant components of phytoplankton followed by green algae, dinoflagellates, blue green algae and silicoflagellates.

Nozais *et al*., (2001), investigated the annual cycle of microalgal biomass in a South African temporarily open estuary. Polat and Isik, (2002), recorded 135 species of phytoplankton from inshore to offshore of Karata, situated in the north-eastern Mediterranean.

Monsoonal influence on seasonal variations in the nutrients and phytoplankton biomass in the coastal waters of Hong Kong in the vicinity of Pearl River estuary was studied by Yin in 2002. The study revealed that the low phosphorous concentrations play an important role in controlling phytoplankton biomass production during the spring and summer.

Perissinotto, *et al*., in 2002, described the spatio-temporal dynamics of phytoplankton and microphytobenthos in Mpenjati estuary, a temporarily open estuary in South Africa. The study disclosed that, major differences in terms of phytoplankton and microphytobenthic biomass are clearly associated with the alternation of the opening and closing of the estuary and provided some basic information on the medium term effects of the peculiar dynamics of temporarily open estuaries.

Fiala *et al*., (2002), studied the dynamics of phytoplankton on the Indian sector of the Southern Ocean during the spring along a 62^0E meridian transect between $49^0$00S and $58^0$50S.

In 2002, Eswari and Ramanibai, analysed the distribution and abundance of phytoplankton from Adyar and Cooum estuaries of Chennai. The maximum abundance of total phytoplankton was recorded during the summer season at Cooum estuary. The low phytoplankton diversity and the abundance were mainly due to the waste inflow through various freshwater inputs in the estuarine region.

Wasmund and Uhlig, (2003), monitored data of phytoplankton abundance and biomass and Chl. *a* (1979– 2000) from surface samples of the Kattegat, belt Sea and Baltic were investigated for long-term trends.

Balkis in 2003 studied the phytoplankton seasonal variations and nutrient dynamics in the neritic water of Buyukcekmece Bay, Sea of Marmara.

Seasonal variation of phytoplankton abundance and productivity were studied in the surf zone of the sea at Cochin backwaters with reference to cell counts, chlorophyll a, photosynthesis and hydrographic parameters by Selvaraj *et al.* (2003).

Sheeba and Ramanujan in 2003, identified 38 genera of phytoplankton together with physicochemical parameters of water at monthly intervals in the estuarine environment of Ithikkara River, southern Kerala.

Alkershi *et al.,* in 2003, studied the contribution of size fractions of planktonic algae to the primary organic productivity in the coastal waters off Cochin. They found that the productivity in the coastal waters of Cochin was inversely proportional to the size of the planktonic algae except in the case of the size groups of <53-25µm and <25-10µm. During the pre and post monsoon seasons, the major contribution was that of planktonic algae <25µm in size.

Wulff and Wangberg, (2004), analysed the spatial and vertical distribution of phytoplankton pigments during the Scandinavian/South African Southern Ocean JGOFS expedition of the "S.A. *Agulhas*" from 31 December 1997 to 26 January 1998

Huang *et al.,* (2004) examined taxonomic composition, abundance, and spatial distribution of phytoplankton in the Pearl River estuary during cruises of July 1999 and January 2001.

In 2004, Geetha and Kondalarao, carried out the qualitative and quantitative distribution of phytoplankton with regional and seasonal variations in the coastal waters of east coast of India. The study revealed that the dinoflagellates were the dominant taxa with 131 species, followed by 111 species of diatoms and 7 species of cyanophytes.

Renjith *et al.*, (2004) studied the primary production at selected stations in Cochin Estuary and showed a trimodal annual variation with peaks during April, July and November. Maximum production was in November and minimum in June.

Calliari *et al.*, in 2005, recorded the distributions of phytoplankton taxa and biomass to assess their association to environmental variables in the Rıo de la Plata, a shallow and highly turbid estuary.

Aktan *et al.,* in 2005, carried out the qualitative and quantitative characteristics of phytoplankton community structure and the environmental factors that affect its distribution and the changes in Izmit Bay, an eutrophic bay of Marmara Sea. The results indicate that primary production of the Bay may be limited by nitrogen and silicate in some periods.

Phytoplankton taxonomic composition, abundance, diurnal variability and spatial distribution were examined in the Changjiang Estuary by Gao and Song, in 2005.

Marshall *et al.,* in 2005, based on a continuous 20-year data base of monthly sampling in Chesapeake Bay and tidal regions of its major tributaries, 1454 phytoplankton taxa have been identified.

Roy *et al.,* in 2006, investigated the spatial variation of phytoplankton pigments along the south west coast of India. Phytoplankton composition and abundance were studied along the southwest coast of India towards the end of upwelling season.

Madhu *et al.,* (2006) investigated the distribution of phytoplankton in western Bay of Bengal during summer, winter and spring inter monsoon period and found that there is a lack of pronounced seasonal variation in the phytoplankton standing stock (chlorophyll *a*) and primary production.

Bondarenko *et al.,* in 2006, studied the comparative analysis of phytoplankton population structures between the ancient lakes Biwa and Baikal. The floristic analysis shown that the green algae and diatoms were richest in species number.

Aubry *et al.,* in 2006, studied the spatial and temporal variations of phytoplankton community structure in the Gulf of Venice (Northern Adriatic Sea).

The spatial and temporal variation of phytoplankton pigments in the western part of Ria Formosa, Portugal, was investigated between by Pereira *et al*., in 2007. The analysis established that diatoms and other algal groups with a similar pigment profile dominated the phytoplankton community throughout the year.

Vanormelingen *et al*., 2008, made a review on the diversity and distribution of diatoms with a perspective from cosmopolitanism to narrow endemism. They hypothesized that the community structure and diversity of diatoms are influenced by geographical factors independent of environmental conditions.

Essien *et al.,* 2008, investigated the Microalgal biodiversity and biomass status in Qua Iboe Estuary mangrove swamp in Nigeria and found that they are an important component of the estuarine food web, fed upon by fish and birds have a larger effect on estuarine fisheries.

Taylor *et al*., 2008, reported that the number of living species of dinoflagellates are usually estimated to be approximately 2,000 with 1,555 free-living marine species and about 160 marine benthic species. 90% of the dinoflagellates are found in marine and 10% in freshwater.

Carneiro *et al.,* 2008, reviewed the trends in scientific literature on phytoplankton. From 1991 to 2005, they found 19,681 articles containing the word ‘‘phytoplankton’ in the title, keyword and/or abstract. Most studies were published in the form of articles (94.3%) and reviews (3.61%) in 978 journals. A high proportion of articles on phytoplankton were published in the *Marine Ecology Progress Series* (7.26%).

Ramdani, *et al*., (2009) studied the environmental influences on the qualitative and quantitative composition of phytoplankton and zooplankton in North African coastal lagoons. They evaluated the hydrological and other influences on the structure, composition and space-time development of plankton communities.

3.3 Results

3.3.1 Coastal and estuarine stations

3.3.1.1 Species composition and diversity

The distribution of planktonic microalgae, both the quantitative and qualitative fluctuations and variation of pigments were studied for a period of two year (2006-07 to 2007-08). There was considerable spatial and seasonal variation in cell density. In the first year, at station 1 (Vaadi), the highest cell density was recorded during pre monsoon (213cellsL^{-1}) and the lowest of 153 cells during the monsoon (Table 6). In station 2 (Kavanad), the highest standing crop of 149cellsL^{-1} was observed in the post monsoon and the lowest was 59cellsL^{-1} recorded in monsoon (Table 7). At station 3 (Punnapra), the highest cell density of 1949cellsL^{-1} during the monsoon and the lowest of 288cellsL^{-1} in the pre monsoon (Table 8). At station 4 (Azheekode), cell density of 537cellsL^{-1} in the pre monsoon and 186cellsL^{-1} in the monsoon were the highest and lowest respectively (Table 9). At station 5 (Balathuruthu), the highest cell density of 553cellsL^{-1} was recorded during the post monsoon and the lowest of 197 cellsL^{-1} during the pre monsoon (Table 10). The highest abundance of 4581cellsL^{-1} was in the monsoon and the lowest 206cellsL^{-1} in the pre monsoon were observed in station 6, at Kodikkal (Table 11). At station 7 (Mahe), the highest cell density of 1996cellsL^{-1} was recorded during the monsoon and lowest being 146cellsL^{-1} in the pre monsoon (Table 12).

During 2007-08, at station 1, the highest standing crop was observed in the post monsoon (2366cellsL^{-1}) and the lowest of 400cellsL^{-1} during the pre monsoon (Table 6). The highest abundance of 398cellsL^{-1} was found during the monsoon and post monsoon, where the lowest abundance was 148cellsL^{-1} during the pre monsoon at station 2 (Table 7). At station 3, 32342cellsL^{-1}, the highest abundance ever recorded in this study was during monsoon and the lowest of 54cellsL^{-1} in the post monsoon (Table 8). Standing crop of 3435cellsL^{-1}was the highest, observed during the post monsoon and the lowest of 840cellsL^{-1} during monsoon at station 4 (Table 9). At station 5, the highest cell density was

1258cellsL^{-1} during post monsoon and the lowest cell number of 750cellsL^{-1} found during monsoon (Table 10). At station 6, the highest standing crop (9371cellsL^{-1}) was recorded during pre monsoon and the lowest of 822cellsL^{-1}, during the monsoon (Table 11). The highest cell abundance of 1133cellsL^{-1} at station 7 was recorded during post monsoon, and the lowest of 795cellsL^{-1} found during the pre monsoon (Table 12). Qualitative and quantitative analysis of plankton microalgae are given below (Table 6 – 12).

Table 6. Staton 1. Vaadi

	Class	2006-2007			2007-2008		
	Class: Bacillariophyceae	**PRM**	**MON**	**POM**	**PRM**	**MON**	**POM**
1	*Asterionella japonica*		14		50		288
2	*Aulacodiscus orbiculatus*						
3	*Bacteriastrum comosum*						264
4	*Biddulphia aurita*						60
5	*Biddulphia mobilensis*		12				
6	*Biddulphia rhombus*						
7	*Calonies permagna*					25	
8	*Campylodiscus ecclesianus*			29			
9	*Cerataulina bicornis*	12					
10	*Chaetoceros affinis*	30					252
11	*Chaetoceros decipiens*		28				
12	*Chaetoceros socialis*						360
13	*Chaetoceros teres*						180
14	*Coscinodiscus eccentricus*						36
15	*Coscinodiscus marginatus*			13		55	
16	*Coscinodiscus radiatus*	12				50	
17	*Coscinodiscus rothii*					50	
18	*Cyclotella striata*			21			
19	*Diploneis bombus*				20		
20	*Ditylum brightwelli*					20	96
21	*Ditylum sol*						
22	*Eucampia cornuta*	6					
23	*Guinardia flaccida*						24
24	*Hantzschia marina*			23			
25	*Leptocylindrus danicus*	39					
26	*Navicula cinta*					20	
27	*Navicula lyra*						38
28	*Navicula maculosa*					14	

table continued….

29	*Navicula pygmoea*						12
30	*Navicula tuscula*	12					
31	*Pleurosigma angulatum*			13			
32	*Pleurosigma attenuatum*			24			
33	*Pleurosigma elongatum*					35	
34	*Pleurosigma falx*						72
35	*Pleurosigma intermedium*	6					
36	*Pleurosigma naviculaceum*				30		
37	*Pleurosigma strigosum*			34			
38	*Podosira montagnei*	6				30	
39	*Proboscia alata*						192
40	*Rhizosolenia castracanei*						72
41	*Rhizosolenia imbricata*	9					
42	*Thalassionema nitzschioides*	48				40	
43	*Thalassiosira coramandeliana*						72
44	*Thalassiosira decipiens*					75	
45	*Thalassiosira subtilis*				15	50	
46	*Triceratium dubium*					35	
47	*Thalassionema frauenfeldii*						
48	*Tropidonies longa*					30	
	Total	**180**	**54**	**157**	**115**	**529**	**2018**
	Class: Dinophyceae						
1	*Ceratium concilians*				10	25	
2	*Ceratium furca*	6	29		50		36
3	*Ceratium gibberum*						84
4	*Ceratium symmetricum*	9	9				120
5	*Dinophysis acuminata*		16				
6	*Dinophysis ovum*				25		
7	*Diplopsalis lenticula*		27				
8	*Gonyalux moniliana*				60		
9	*Prorocentrum arcuatum*				50		
10	*Prorocentrum micans*	12			55	50	
11	*Protoperidinium assymmetricum*		12				
12	*Protoperidinium leonis*		6				
13	*Protoperidinium oceanicum*	6					108
14	*Pyrophacus horologium*						
15	*Pyrophacus steinii*				35		
	Total	**33**	**99**	**0**	**285**	**75**	**348**
63	**Grand Total**	**213**	**153**	**157**	**400**	**604**	**2366**

Table 7. Station 2 Kavanad

	Class	2006-2007			2007-2008		
	Class: Chlorophyceae	**PRM**	**MON**	**POM**	**PRM**	**MON**	**POM**
1	*Scenedesmus arcuatus*					40	
	Class: Bacillariophyceae						
1	*Achnanthes brevipes*						12
2	*Achnanthes longipes*						12
3	*Asterionella japonica*	41					
4	*Aulacodiscus orbiculatus*		12				
5	*Bacteriastrum comosum*						20
6	*Bacteriastrum hyalinum*						15
7	*Bacteriastrum varians*						22
8	*Biddulphia aurita*					31	
9	*Campylodiscus ecclesianus*			11			
10	*Corethron criophilum*						16
11	*Coscinodiscus centralis*		13		17		
12	*Coscinodiscus curvatulus*						12
13	*Coscinodiscus marginatus*	14					
14	*Coscinodiscus nitidus*						26
15	*Coscinodiscus rothii*					78	
16	*Coscinodiscus lineatus*					52	
17	*Cymbella tumida*	7					
18	*Diploneis dydima*						14
19	*Diploneis notabilis*	10					
20	*Gyrosigma spencerii*	20					
21	*Gyrosigma tenuissimum*	7					
22	*Mastogloia braunii*						18
23	*Melosira sulcata*		10				
24	*Navicula cinta*					60	
25	*Navicula distans*						30
26	*Navicula forcipata*					15	
27	*Navicula inclementis*						28
28	*Navicula lyra*					22	
29	*Navicula perigrina*						22
30	*Nitzschia closterium*	17					
31	*Nitzschia longissima*						16
32	*Nitzschia paduriformis*						18
33	*Paralia sulcata*		8				
34	*Pleurosigma angulatum*				44		
35	*Pleurosigma aestuarii*	3		29			
36	*Pleurosigma elongatum*					32	
37	*Pleurosigma falx*			43			
38	*Rhaphoneis amphiceros*			18			
39	*Proboscia alata*				35		
40	*Skeletonema costatum*		8				
41	*Surirella fastuosa*				22		
42	*Synedra ulna*				13		
43	*Thalassionema nitzschioides*						22

table continued….

44	*Thalassiosira decipiens*					42	
45	*Thalassiosira subtilis*		8				
	Total	**119**	**59**	**101**	**131**	**372**	**303**
	Class: Dinophyceae						
1	Alexandrium affine						17
2	*Ceratium furca*			26	17	26	
3	*Dinophysis odiosa*						14
4	*Diplopsalis lenticula*						22
5	*Gonyalux moniliana*						6
6	*Prorocentrum micans*						12
7	*Protoperidinium oceanicum*			22			
8	*Pyrophacus steinii*						24
	Total	**0**	**0**	**48**	**17**	**26**	**95**
54	**Grand Total**	**119**	**59**	**149**	**148**	**398**	**398**

Table 8. Station 3 Punnapra

	Class	**2006-2007**			**2007-2008**		
	Class: Bacillariophyceae	**PRM**	**MON**	**POM**	**PRM**	**MON**	**POM**
1	*Achnanthes brevipes*					12	
2	*Achnanthes hauckiana*					20	
3	*Amphora turgida*			20			
4	*Asterionella japonica*						
5	*Biddulphia aurita*	12					
6	*Biddulphia regia*				20		
7	*Biddulphia reticulata*				44		
8	*Biddulphia rhombus*	5					
9	*Biddulphia sinensis*				16		
10	*Caloneis brevis*			12			
11	*Caloneis westii*			10			
12	*Cerataulus turgidus*						16
13	*Chaetoceros affinis*	41		72			
14	*Chaetoceros breve*	29					
15	*Chaetoceros decipiens*				44		
16	*Coscinodiscus asteromphalus*					35	
17	*Coscinodiscus centralis*		10				
18	*Coscinodiscus marginatus*	24					
19	*Coscinodiscus radiatus*	35			64		
20	*Coscinodiscus subtlis*		12			15	
21	*Cylindrotheca gracilis*		15				
22	*Cymbella hustedtii*	12					
23	*Diploneis smithii*		16				
24	*Fragilaria oceanica*			38			
25	*Grammatophora undulata*				16		
26	*Leptocylindrus minimus*	48					
27	*Mastogloia lanceolata*						20
28	*Navicula elegans*		12				18
29	*Navicula hasta*			32			

table continued….

30	*Navicula henneidyi*			48	40		
31	*Navicula lyra*			40			
32	*Nitzschia closterium*		46				
33	*Nitzschia longissima*	7					
34	*Nitzschia lorenziana*				22		
35	*Nitzschia paduriformis*	5					
36	*Nitzschia paduriformis* var. *minor*			10			
37	*Nitzschia paleacea*			44			
38	*Paralia sulcata*				20		
39	*Pleurosigma acuminatum*		15				
40	*Pleurosigma angulatum*					15	
41	*Pleurosigma naviculaceum*				28		
42	*Podosira montagnei*		5				
43	*Skeletonema costatum*		12				
44	*Surirella flumiensis*			60	40		
45	*Thalassionema nitzschioides*	34			80	30	
46	*Thalassiosira nordenskioldii*		17				
47	*Thalassiosira subtilis*			32			
48	*Thalassionema frauenfeldii*	36					
49	*Trachyneis aspera*				28		
	Total	**288**	**160**	**418**	**462**	**127**	**54**
	Class: Dinophyceae						
1	*Ceratium concilians*						
2	*Ceratium furca*		800	84	3390	1900	
3	*Ceratium gibberum*					435	
4	*Ceratium horridium*					8150	
5	*Ceratium kofoidii*					50	
6	*Ceartium pentagonum*					40	
7	*Ceratium symmetricum*					10600	
8	*Ceratium trichoceros*					9900	
9	*Ceratium vultur*					80	
10	*Dinophysis acuminata*					285	
11	*Dinophysis caudata*					135	
12	*Dinophysis fortii*		36	12	60		
13	*Diplopsalis lenticula*		920	32		45	
14	*Prorocentrum compressum*					80	
15	*Prorocentrum gracile*				16	210	
16	*Prorocentrum lima*			100			
17	*Prorocentrum micans*		33	104	48		
18	*Protoperidinium oceanicum*			120		305	
19	*Pyrophacus horologium*				28		
	Total	**0**	**1789**	**452**	**3542**	**32215**	**0**
	Class : Dictyochophyceae						
1	Dictyocha fibula				24		
	Total				**24**		
69	**Grand Total**	**288**	**1949**	**870**	**4028**	**32342**	**54**

Table 9. Station 4 Azheekode

	Class	2006-2007			2007-2008		
	Class:Chlorophyceae	**PRM**	**MON**	**POM**	**PRM**	**MON**	**POM**
1	*Coelastrum cambricum*		12				
2	*Pediastrum tetras*		16				
3	*Onychonema laeve*					77	
4	*Staurastrum leptocladium*					31	
	Class: Bacillariophyceae						
1	*Achnanthes brevipes*					21	
2	*Amphiprora alata*						44
3	*Amphiprora gigantea var. sulcata*	13	8				
4	*Amphora angusta*		12				
5	*Asterionella japonica*						127
6	*Aulacodiscus orbiculatus*	14					
7	*Bacteriastrum comosum*						82
8	*Biddulphia aurita*					39	
9	*Biddulphia heteroceros*	30					
10	*Biddulphia longicruris*						110
11	*Biddulphia mobilensis*						38
12	*Biddulphia rhombus*					32	
13	*Biddulphia sinensis*						82
14	*Caloneis madraspatensis*				14		
15	*Chaetoceros affinis*		10				
16	*Chaetoceros constrictus*						55
17	*Chaetoceros lorenzianus*	24					
18	*Corethron criophilum*						56
19	*Corethron inerme*						60
20	*Coscinodiscus asteromphalus*				56		
21	*Coscinodiscus eccentricus*						23
22	*Coscinodiscus granii*					64	
23	*Coscinodiscus marginatus*	59					
24	*Coscinodiscus nitidus*					12	
25	*Coscinodiscus radiatus*	54				14	16
26	*Coscinodiscus rothii*					35	
27	*Coscinodiscus nitidus*	54					
28	*Cylindrotheca gracilis*	41		16			
29	*Diploneis elliptica*	13					
30	*Ditylum brightwelli*				22		275
31	*Ditylum sol*		5				
32	*Eucampia zodiacus*		5				
33	*Grammatophora serpentina*						55
34	*Guinardia flaccida*						56
35	*Gyrosigma balticum*			20			
36	*Gyrosigma hippocampus*				45		
37	*Lauderia annulata*						148
38	*Mastogloia cochinensis*	26					
39	*Mastogloia exigua*						60
40	*Navicula bicapitata*						55
41	*Navicula granulata*						60

table continued….

42	*Navicula halophila*						56
43	*Navicula humerosa*					30	
44	*Navicula inclementis*					12	
45	*Navicula longa*						50
46	*Navicula marina*			16			58
47	*Nitzschia constricta*						55
48	*Nitzschia sigma*		14				
49	*Paralia sulcata*	13					
50	*Planktoniella sol*	10	6				
51	*Pleurosigma angulatum*			44			
52	*Pleurosigma aestuarii*	10					22
53	*Pleurosigma attenuatum*				14		
54	*Pleurosigma falx*	24					44
55	*Pleurosigma intermedium*						60
56	*Pleurosigma normanii*						66
57	*Podosira montagnei*					102	
58	*Proboscia alata*						71
59	*Rhizosolenia borealis*						66
60	*Rhizosolenia castracanei*						61
61	*Rhizosolenia robusta*						55
62	*Rhizosolenia setigera*				17		
63	*Rhozosolenia styliformis*						55
64	*Surirella flumiensis*			64	28		
65	*Surirella neumeyeri*						60
66	*Surirella striatula*	17	14				82
67	*Thalassionema bacillare*						22
68	*Thalassionema frauenfeldii*	37	10				110
69	*Thalassionema nitzschioides*	24					99
70	*Thalassiosira coramandeliana*			13	31		
71	*Thalassiosira subtilis*			10		140	
72	*Triceratium dubium*						82
	Total	**463**	**112**	**183**	**227**	**609**	**2576**
	Class: Dinophyceae						
1	*Alexandrium sp.*					26	
2	*Ceratium furca*	27	27	83	588		148
3	*Ceratium fusus*						110
4	*Ceratium gibberum*					39	110
5	*Ceratium horridium*					32	
6	*Ceratium symmetricum*					102	55
7	*Coolia monotis*						6
8	*Dinophysis acuminata*		24				
9	*Diniphysis caudata*				28		
10	*Dinophysis tripos*						12
11	*Diplopsalis lenticula*	24		19	59		
12	*Goniodoma sphaericum*				17		
13	*Prorocentrum gracile*			43			
14	*Prorocentrum micans*				70		110
15	*Protoperidinium brochii*						11
16	*Protperidimuim cerasus*				45		
17	*Protopridinium conicum*					32	

table continued….

18	*Protoperidinium leonis*		13				
19	*Protoperidinium mediterraneum*				48		
20	*Protperidimuim minutum*				12		
21	*Protoperidinium oblongum*			38			
22	*Protoperidinium oceanicum*	13	10	26	28		
23	*Pyrophacus horologium*	10					
24	*Pyrophacus steinii*						247
	Total	**74**	**74**	**209**	**895**	**231**	**809**
	Class : Dictyochophyceae						
1	*Dictyocha fibula*				224		50
	Total				**224**		**50**
101	**Grand Total**	**537**	**186**	**392**	**1346**	**840**	**3435**

Table 10. Station 5 Balathuruthu

	Class	**2006-2007**			**2007-2008**		
	Class: Cyanophyceae	**PRM**	**MON**	**POM**	**PRM**	**MON**	**POM**
1	*Aphanocapsa littoralis*		4			4	
2	*Aphanocapsa pulchra*		6			2	
3	*Chamaesiphon sideriphilus*					4	
4	*Chroococcus turgidus*		8			4	
5	*Gloeothece rupestris*		4				
6	*Lyngbya aestuarii*		3			4	
7	*Microcystis aeruginosa*		8				
8	*Oscillatoria brevis*					2	
9	*Oscilllatoria chalybea*		2			2	
10	*Oscillatoria formosa*		4			2	
11	*Phormidium valderianum*		4				
	Total		**43**			**24**	
	Class: Chlorophyceae						
1	*Arthrodesmus convergens*		6				
2	*Chlorosarcina minor*		24			60	
3	*Closterium kutzingi*					30	
4	*Coelastrum spaerium*		16				
5	*Cosmarium sp*		10				
6	*Dimorphococcus lunatus*		12				
7	*Euastrum angustum*					6	
8	*Euastrum didelta*					102	
9	*Gleobotrys limnetica*		36				
10	*Micrasterias americana*		6				
11	*Onychonema laeve*		36				
12	*Pediastrum biradiatum*		96				
13	*Phacus suecicus*					66	
14	*Selenastrum gracile*					216	
15	*Sphaerozosma granulatum*					108	
16	*Staurastrum asteroideum*		4			12	

table continued….

17	*Staurastrum gracile*		12				
18	*Staurastrum leptocladium*						
19	*Tetraedron trigonum*					30	
20	*Ulothrix zonata*		11				
21	*Xanthidium antilopaeum*					60	
	Total		**269**	**0**	**0**	**690**	**0**
	Class: Bacillariophyceae						
1	*Achnanthes coarctata var. parallela*					18	
2	*Amphiprora alata*						10
3	*Amphora coffeaeformis*			10			
4	*Asterionella japonica*			115			73
5	*Aulacodiscus orbiculatus*						
6	*Bacillaria paradoxa*			16			
7	*Biddulphia mobilensis*						
8	*Biddulphia rhombus*		8				34
9	*Biddulphia sinensis*			26			
10	*Campylodiscus ecclesianus*			48			
11	*Campylodiscus hodgsonii*		22				
12	*Chaetoceros affinis*			38			
13	*Chaetoceros constrictus*						43
14	*Chaetoceros curvisetus*						70
15	*Cheatoceros danicus*			58			
16	*Chaetoceros decipiens*						37
17	*Chaetoceros didymus*						50
18	*Cocconeis placentula var. euglypta*	22					
19	*Coscinodiscus asteromphalus*		22	10			
20	*Coscinodiscus centralis*		16				
21	*Coscinodiscus granii*				168		
22	*Coscinodiscus marginatus*						27
23	*Coscinodiscus radiatus*	16		42			18
24	*Coscinodiscus subtlis*	20					
25	*Cylindrotheca gracilis*	56					33
26	*Diploneis ovalis*	10					
27	*Diploneis smithii*		10				
28	*Ditylum brightwelli*						34
29	*Ditylum sol*						
30	*Guinardia flaccida*						27
31	*Gyrosigma fasciola*						37
32	*Gyrosigma tenuissimum*		6	22			
33	*Lauderia annulata*						37
34	*Licmophora flabellata*			16			
35	*Leptocylindrus danicus*		12				54
36	*Mastogloia dolosa*						12
37	*Melosira numuloides*				360		

table continued….

38	*Melosira sulcata*						
39	*Navicula digito-radiata*						16
40	*Navicula halophila*						22
41	*Navicula hasta*						34
42	*Navicula maculosa*						34
43	*Navicula marina*	10					
44	*Navicula mutica*						18
45	*Navicula pygmoea*						13
46	*Navicula rhombica*		10				
47	*Navicula spectabilis*					18	32
48	*Nitzschia closterium*	23					40
49	*Nitzschia sigma*						17
50	*Nitzschia tryblionella*						20
51	*Planktoniella sol*				40		
52	*Pleurosigma angulatum*						70
53	*Pleurosigma aestuarii*	7			96		
54	*Pleurosigma naviculaceum*				128		
55	*Pleurosigma normanii*						27
56	*Rhizosolenia hebetata*			27			
57	*Rhizosolenia stolterfothii*						66
58	*Skeletonema costatum*						103
59	*Surirella flumiensis*			54	48		
60	*Surirella neumeyeri*						33
61	*Thalassionema frauenfeldii*						
62	*Thalassionema nitzschioides*			51	48		53
63	*Thalassiosira coramandeliana*	20		10			
64	*Thalassiosira subtilis*						
65	*Triceratium affine*				56		
66	*Triceratium favus*				48		
	Class: Chrysophyceae						
1	*Dinobryon belgica*		18				
	Total	**184**	**124**	**543**	**992**	**36**	**1194**
	Class: Dinophyceae						
1	*Ceratium furca*				20		27
2	*Dinophysis acuminata*		13				
3	*Diplopsalis lenticula*	13		10			
4	*Prorocentrum gracile*						37
5	*Protoperidinium obovatum*				136		
	Total	**13**	**13**	**10**	**156**	**0**	**64**
104	**Grand Total**	**197**	**449**	**553**	**1148**	**750**	**1258**

Table 11. Station 6 Kodikkal

	Class	2006-2007			2007-2008		
	Class : Bacillariophyceae	**PRM**	**MON**	**POM**	**PRM**	**MON**	**POM**
1	*Amphora angusta*	2					
2	*Asterionella japonica*			31		72	100
3	*Biddulphia mobilensis*	2	8			42	
4	*Biddulphia rhombus*						15
5	*Campylodiscus ecclesianus*			10			
6	*Chaetoceros affinis*	42		28			
7	*Chaetoceros curvisetus*						75
8	*Chaetoceros lorenzianus*						60
9	*Coscinodiscus asteromphalus* var.*centralis*		2912				
10	*Coscinodiscus centralis*			10	150	34	45
11	*Coscinodiscus eccentricus*					54	
12	*Coscinodiscus marginatus*	9					
13	*Coscinodiscus radiatus*						
14	*Cylindrotheca gracilis*	4		19		18	
15	*Cymbella tumida*		10				
16	*Diploneis splendida*	15					
17	*Ditylum sol*	2			18		30
18	*Gyrosigma tenuissimum*			12			
19	*Navicula cincta*						16
20	*Navicula humerosa*						32
21	*Navicula longa*					18	
22	*Navicula maculosa*						40
23	*Nitzschia closterium*	15					
24	*Nitzschia sigma*	2					
25	*Pleurosigma acuminatum*		1612				15
26	*Pleurosigma angulatum*					30	
27	*Pleurosigma angulatum var. strigosum*					18	
28	*Pleurosigma aestuarii*		10			78	
29	*Pleurosigma falx*		29	12			
30	*Pleurosigma naviculaceum*				60		
31	*Pleurosigma strigosum*						35
32	*Podosira montagnei*						
33	*Pseudonitzschia seriata*						125

table continued….

34	*Skeletonema costatum*	46					
35	*Stephanopyxis turris*				18		
36	*Surirella fastuosa*				60		
37	*Surirella flumiensis*			48			
38	*Thalassionema frauenfeldii*	22					80
39	*Thalassionema nitzschioides*						45
40	*Thalassiosira subtilis*	4					
41	*Tropidoneis longa*	6					
	Total	**171**	**4581**	**170**	**306**	**364**	**713**
	Class: Dinophyceae						
1	*Ceratium concilians*					30	
2	*Ceratium furca*	4		180	8160	150	80
3	*Ceratium fusus*			36		32	
4	*Ceratium horridium*					42	
5	*Ceratium kofoidii*						55
6	*Ceratium symmetricum*					96	
7	*Ceratium tripos*				30		
8	*Dinophysis acuminata*					72	
9	*Diniphysis caudata* f *acutiformis*			17			
10	*Diplopsalis lenticula*	29		14	90		
11	*Noctiluca miliaris*				90		
12	*Prorocentrum micans*	2			69		
13	*Protoperidinium brochii*				270		
14	*Protperidimuim cerasus*				278		
15	*Protoperidinium compressum*			26			
16	*Protoperidinium granii*						35
17	*Protoperidinium minor*				60		
18	*Protoperidinium oceanicum*			7			
19	*Protoperidinium pellucidum*			24			
20	*Protoperidinium steinii*					36	
21	*Pyrophacus steinii*			48			
	Total	**35**	**0**	**352**	**9047**	**458**	**170**
	Class : Dictyochophyceae						
1	*Dictyocha fibula*				18		30
2	*Dictyocha octonaria*						30
	Total				**18**		**60**
64	**Grand Total**	**206**	**4581**	**522**	**9371**	**822**	**943**

Table 12. Station 7 Mahe

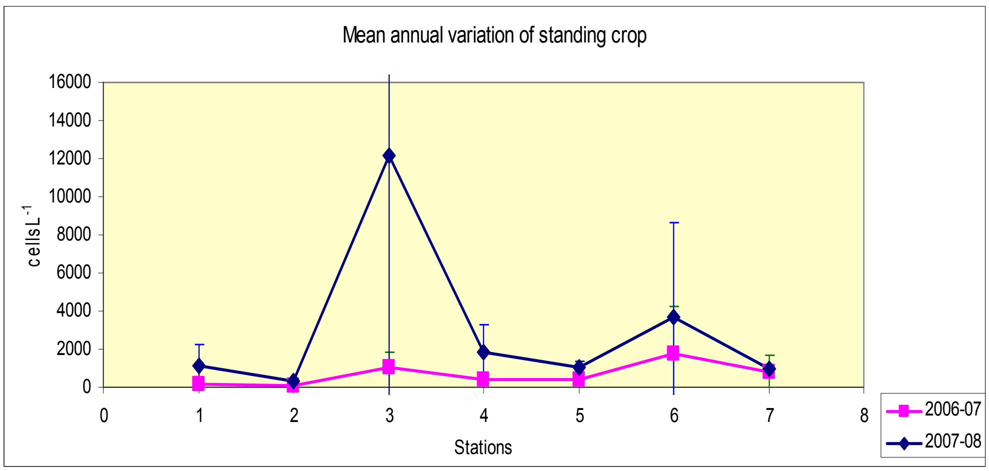
	Class	2006-2007			2007-2008		
	Class: Cyanophyceae	**PRM**	**MON**	**POM**	**PRM**	**MON**	**POM**
1	*Aphanocapsa pulchra*		3			6	
2	*Chroococcus turgidus*		8			6	
3	*Lyngbya majuscula*		2			2	
4	*Merismopedia glauca*					4	
5	*Microcystis aeruginosa*					6	
6	*Oscillatoria brevis*		4			2	
7	*Oscillatoria formosa*		4				
8	*Oscilllatoria chalybea*		2			2	
9	*Phormidium valderianum*		2			2	
	Total		**25**			**30**	
	Class: Chlorophyceae						
1	*Ankistrodesmus spiralis*					160	
2	*Arthrodesmus convergens*					18	
3	*Chlorosarcina minor*					96	
4	*Kirchneriella lunaris*					132	
5	*Scenedesmus armatus*					16	
6	*Scenedesmus dimorphus*					36	
7	*Spondylosium moniliforme*					48	
8	*Staurastrum cuspidatum*					18	
9	*Staurastrum glabrum*					32	
10	*Tetraedron hastatum*					42	
11	*Xanthidium cristatum*					60	
	Total		**0**	**0**	**0**	**658**	**0**
	Class: Bacillariophyceae						
1	*Achnanthes hauckiana*						14
2	*Amphora exigua*			18			
3	*Asteromphalus flabellatus*			19			
4	*Aulacodiscus orbiculatus*	23					
5	*Biddulphia aurita*						60
6	*Biddulphia mobilensis*				63		
7	*Biddulphia rhombus*			17			
8	*Biddulphia sinensis*			12	135		
9	*Campylodiscus hodgsonii*						60
10	*Chaetoceros decipiens*						82
11	*Coscinodiscus asteromphalus*		176				
12	*Coscinodiscus centralis*					78	
13	*Coscinodiscus granii*					36	
14	*Coscinodiscus marginatus*				54		
15	*Coscinodiscus nitidus*						45
16	*Coscinodiscus radiatus*	8					
17	*Cylindrotheca gracilis*	5					
18	*Ditylum brightwelli*				22		
19	*Grammatophora marina*	13					
20	*Gyrosigma nodiferum*						23
21	*Hantzschia amphioxys*						45

table continued….

22	*Licmophora juergensii*			14			
23	*Navicula cinta*					24	
24	*Navicula elegans*			4			
25	*Navicula forcipata*						12
26	*Navicula longa*						30
27	*Navicula lyra*						15
28	*Navicula mutica*						15
29	*Navicula perigrina*						15
30	*Navicula rhombica*						10
31	*Nitzschia closterium*	13	9	17			
32	*Nitzschia frustulum*						232
33	*Nitzschia lorenziana*	40					
34	*Nitzschia paduriformis*			4			
35	*Nitzschia sigma*						83
36	*Paralia sulcata*				135		
37	*Planktoniella sol*				27		
38	*Pleurosigma acuminatum*					48	
39	*Pleurosigma angulatum*		18				38
40	*Pleurosigma falx*		1760				
41	*Pleurosigma intermedium*				54		
42	*Podosira montagnei*	5					
43	*Pseudonitzschia seriata*						150
44	*Surirella fastuosa*			384			53
45	*Surirella flumiensis*					48	
46	*Surirella ovalis*				125		
47	*Surirella striatula*				90		
48	*Thalassionema nitzschioides*			12			60
49	*Thalassiosira nordenskioldii*						
50	*Thalassiosira coramandeliana*					42	
51	*Thalassiosira subtilis*	39					
52	*Triceratium dubium*				45		
	Coccolithophorids						
1	Syracosphaera sp			12			
	Total	**146**	**1963**	**513**	**750**	**276**	**1042**
	Class: Dinophyceae						
1	*Ceratium furca*			12	45		23
2	*Dinophysis odiosa*						45
3	*Dinophysis miles*		8				
4	*Prorocentrum micans*			7			
5	*Protoperidinium assymmetricum*						23
6	*Protoperidinium oceanicum*			26			
	Total	**0**	**8**	**45**	**45**	**0**	**91**
	Class : Dictyochophyceae						
1	*Dictyocha crux*			**10**			
	Total			**10**			
80	**Grand Total**	**146**	**1996**	**568**	**795**	**964**	**1133**

The mean annual variation of standing crop during 2006-07 and 2007-08 are shown in fig.23. In 2006-07, the highest standing crop was in station 6, with 1769 (SD ± 2439) cellsL^{-1} and the lowest was at station 2, with 109 (SD ± 45) cellsL^{-1}. Similarly, the mean annual highest during 2007-08 (12141 (SD + 17606) cellsL^{-1} was found in station 3, and the lowest recorded at station 2 with 314 (SD + 144) cellsL^{-1}.

Fig. 23

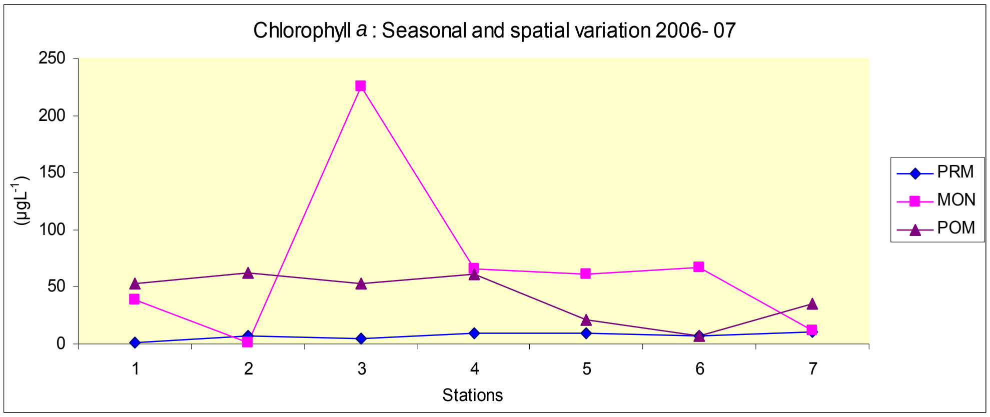


3.3.1.2 Pigments

3.3.1.2.1 Chlorophyll *a*

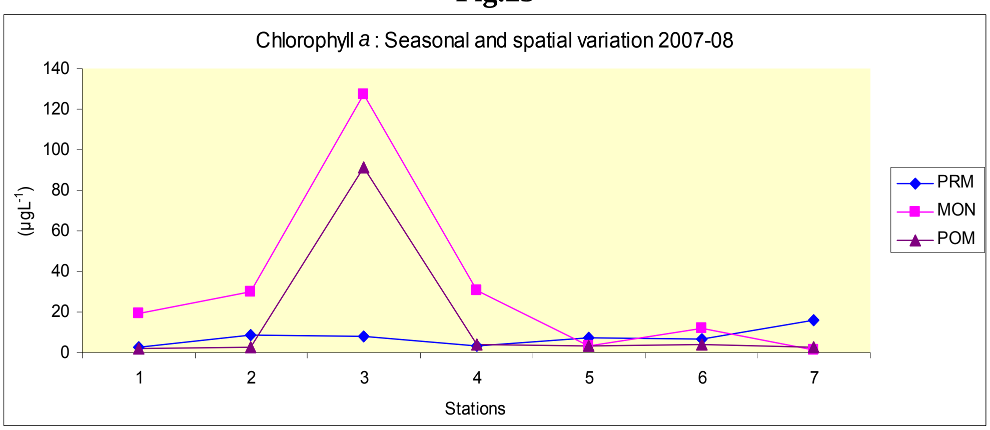
In the first year, the concentration of chlorophyll *a* was found to be the highest (10.82µgL^{-1}) in station 7 during the pre monsoon and the lowest being 1.48µgL^{-1} at station 1. During monsoon, the highest chlorophyll *a* of 225.26µgL^{-1} was recorded from station 3, and the lowest value of 1.6µgL^{-1} observed at station 2. In the post monsoon, the highest chlorophyll *a* value of 61.73µgL^{-1} was found in station 2, and the lowest value of 7.11µgL^{-1} was at station 6, (fig 24).

Fig.24.



During 2007-08, in the pre monsoon, the highest value of 16.25µgL^{-1} was recorded from station 7 and the lowest value of 2.68µgL^{-1} at station 1. During the monsoon, the highest value of chlorophyll *a* was 127.61µgL^{-1} recorded at station 3, and the lowest in station 7, with only 1.58µgL^{-1}. In the post monsoon, the maximum and minimum values of chlorophyll *a* were 91.4µgL^{-1} and 1.82µgL^{-1} recorded at station 1 and 3 respectively (fig 25).

Fig.25

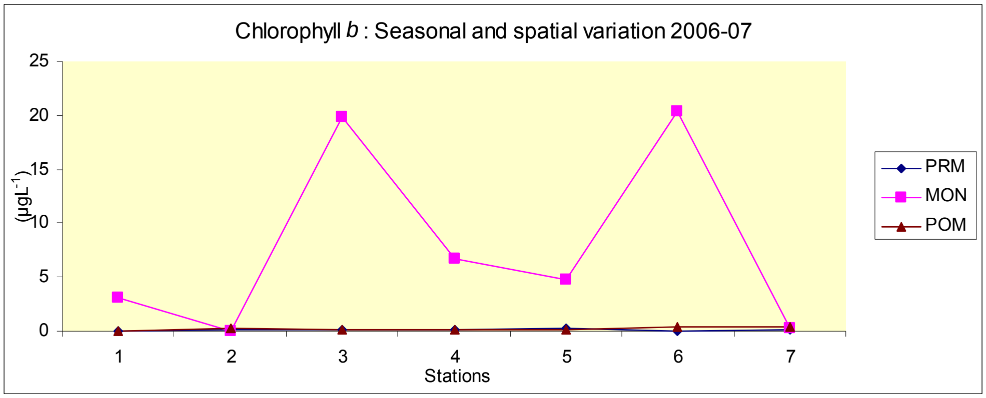


3.3.1.2.2 Chlorophyll *b*

In the first year, chlorophyll *b* was found to be the highest (0.32µgL^{-1}) in station 5, the pre monsoon and the lowest in station 1, with only 0.03µgL^{-1}. In the monsoon, it varied from 20.41µgL^{-1} in station 6, to practically nil in station 2.

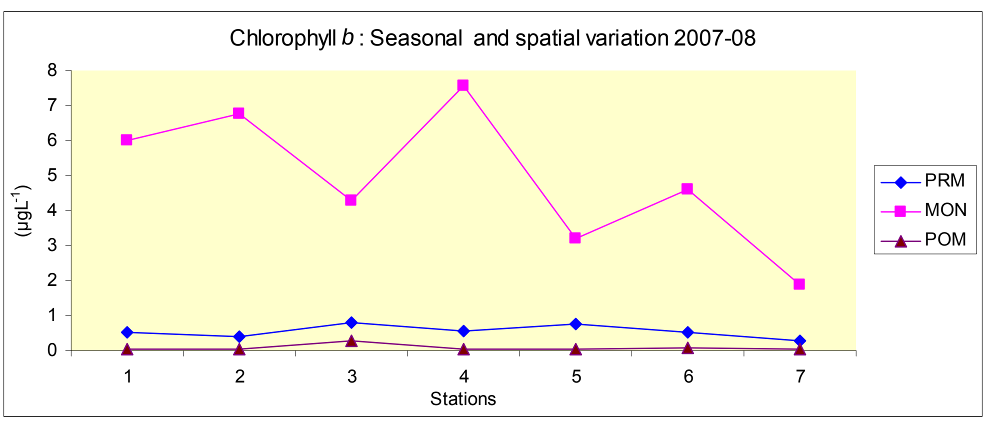
During the post monsoon, the highest concentration was 0.34µgL^{-1} found at station 7 and the lowest being 0.06µgL^{-1} at station 1(fig. 26).

Fig.26



In the following year, during the pre monsoon, chlorophyll *b* varied from 0.81µgL^{-1} in station 3 to 0.29µgL^{-1} in station 7. In monsoon, the maximum chlorophyll *b* was from station 4, (7.55µgL^{-1}) and the lowest was recorded in station 7, (1.87µgL^{-1}). During the post monsoon, the highest value of 0.29µgL^{-1} recorded at station 3 and the minimum of 0.04µgL^{-1} observed in station 2 (fig. 27).

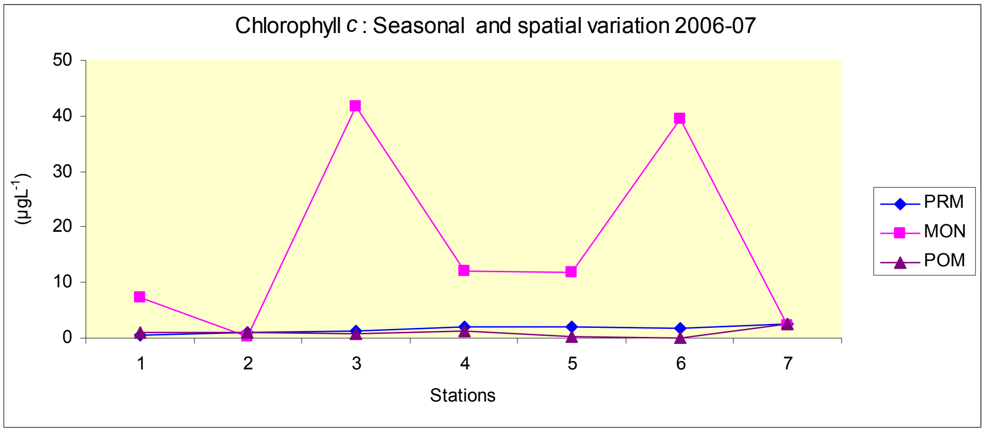
Fig. 27



3.3.1.2.3 Chlorophyll *c*

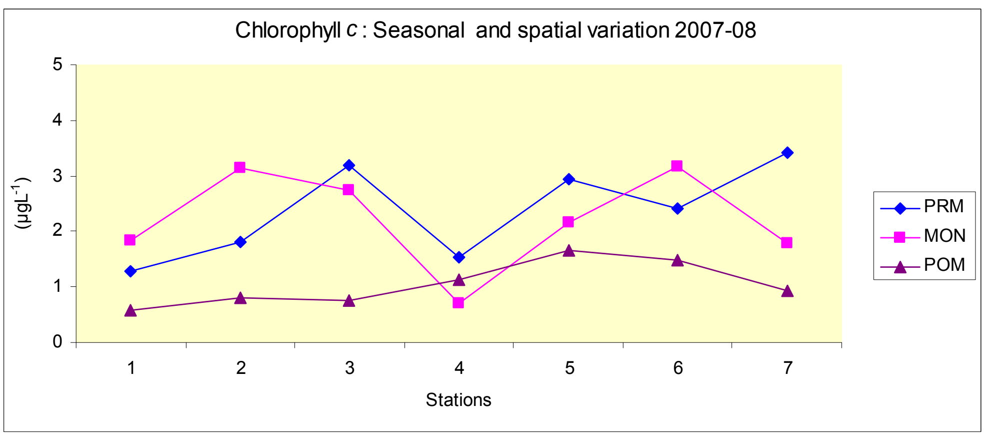
In 2006-07, in the pre monsoon chlorophyll *c* was found to be the highest in station 7, with 2.49µgL^{-1} and the lowest being 0.46µgL^{-1} in station 1. In monsoon, the highest was 41.8 in station 3 and lowest being 0.2µgL^{-1} at station 2. In post monsoon, the maximum value was 2.43 in station 7 and the lowest of 0.1µgL^{-1} recorded in station 6. (fig.28)

Fig.28



In the pre monsoon of the following year, the highest value was 3.42µgL^{-1} in station 7 and the lowest being 1.29µgL^{-1} at station 1. In monsoon, it varied from 3.14µgL^{-1} at station 2, to 0.72µgL^{-1} at station 4. In the post monsoon, the chlorophyll *c* value varied between 1.65µgL^{-1} at station 5 and 0.58µgL^{-1} in station 1 (fig.29).

Fig.29

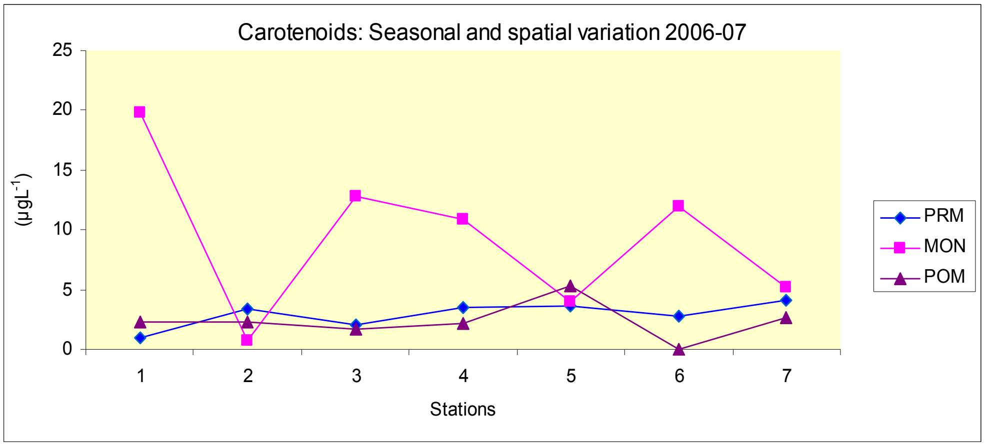


3.3.1.2.4 Carotenoids

In 2006-07, the maximum concentration of carotenoid pigments was 4.06µgL^{-1} obtained in station 7, and the minimum of 0.96µgL^{-1} was at station 1, in pre monsoon.

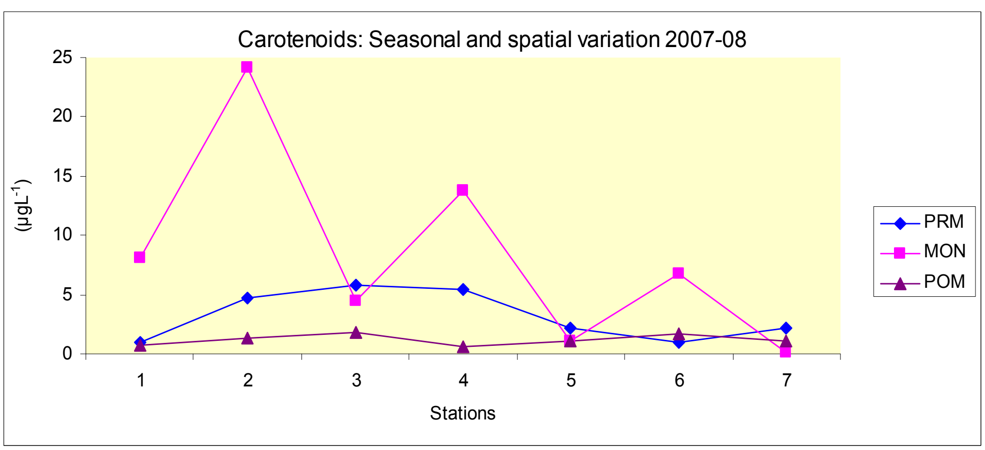
In the monsoon, the highest (12.84µgL^{-1}) and the lowest (0.73µgL^{-1}) values were found in station 3 and 2 respectively. During the post monsoon, the carotenoid pigment varied from 5.33µgL^{-1} in station 5 to 0.03µgL^{-1} in station 6 (fig. 30).

Fig. 30



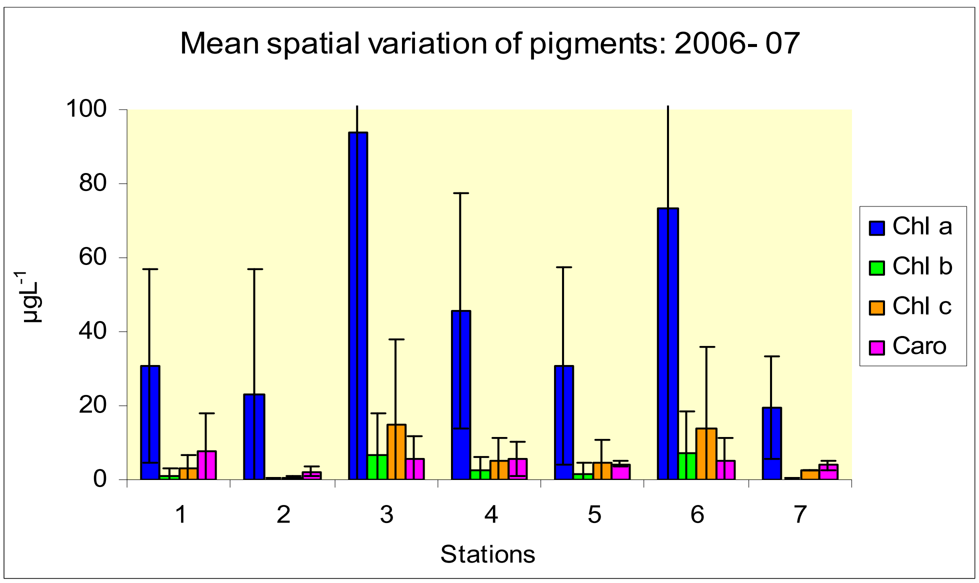
In the following year, in pre monsoon, the highest value of 5.84µgL^{-1} was found at station 3 and lowest being 1µgL^{-1} at station 1 and 6. During the monsoon, it varied from 24.13µgL^{-1} in station 2 to 013µgL^{-1} at station 7. In the post monsoon, the maximum value of 1.76µgL^{-1} was observed in station 3 and the minimum being 0.66µgL^{-1} observed in station 4 (fig. 31).

Fig.31



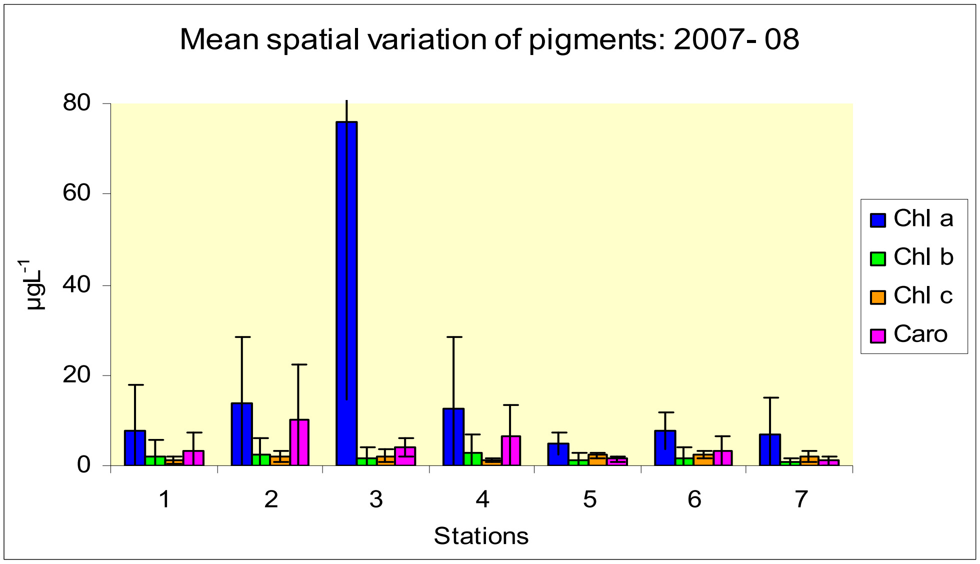
Mean annual variation of pigments during the year 2006-07 is shown in fig. 32. The highest value of chlorophyll *a* was found at station 3 with 94.06µgL^{-1} and lowest being 19.47µgL^{-1} in station 7. Chlorophyll *b* was highest in station 3, with 6.72µgL^{-1} and the lowest of 0.13µgL^{-1} was recorded in station 2. The highest chlorophyll *c* was recorded from station 3 with 14.65µgL^{-1} and lowest being 0.73µgL^{-1} at station 2. Carotenoid pigments shown highest value of 7.69µgL^{-1} at station 1 and the lowest 2.13µgL^{-1} at station 2 (fig.32).

Fig. 32



Mean annual variation of pigments in various stations during 2007-08 shows (fig. 33) that the highest value of chlorophyll *a* was 75.75µgL^{-1}, at station 3 and the lowest was 19.47µgL^{-1} at station 5. The highest chlorophyll *b* was in station 4, with 6.72µgL^{-1} and the lowest of 0.74µgL^{-1} was recorded in station 7. The highest chlorophyll *c* was 2.35µgL^{-1} in station 6 and the lowest being 1.13µgL^{-1} at station 4. The mean highest value of carotenoid pigments was 10.0µgL^{-1} 3 at station 2 and the lowest being 1.13µgL^{-1} at station 7 (fig.33).

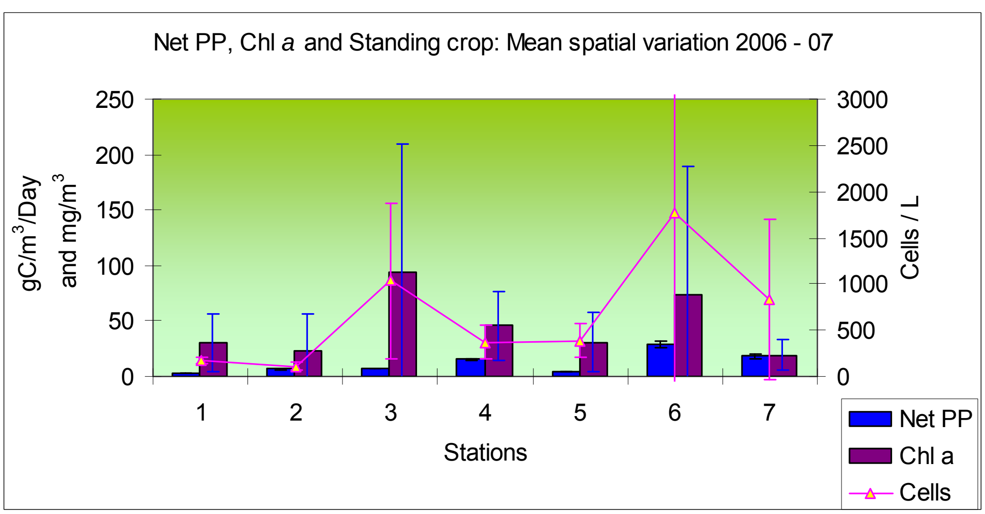
Fig. 33



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

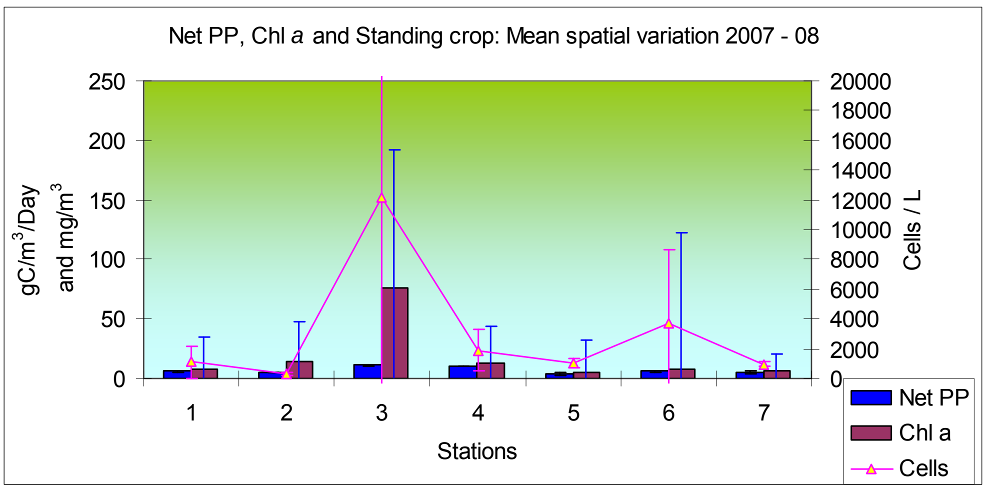
The mean annual chlorophyll *a* was found to be directly proportional to the standing crop during the first year (fig. 34). The highest chlorophyll a was found in station 3 (94 $\pm$ 116mgm^{-3}) and highest cell abundance was at station 6 (5309 $\pm$ 474 cellsL^{-1}). The primary productivity was found to be comparatively high in station 6 (2.36 $\pm$ 2.83gCm^{3} day $^{-1}$).

Fig.34



The mean annual chlorophyll *a* and cell abundance in 2007-08, was also found to be directly proportional to standing crop, except in station 2. The highest chlorophyll *a* concentration (75 $\pm$ 61mgm^{-3}) and cell abundance (5309 + 474 cellsL^{-1}) were observed in station 3. The highest primary productivity being 1.56 + 0.65gCm^{3} day $^{-1}$ was observed at station 6. (fig.35)

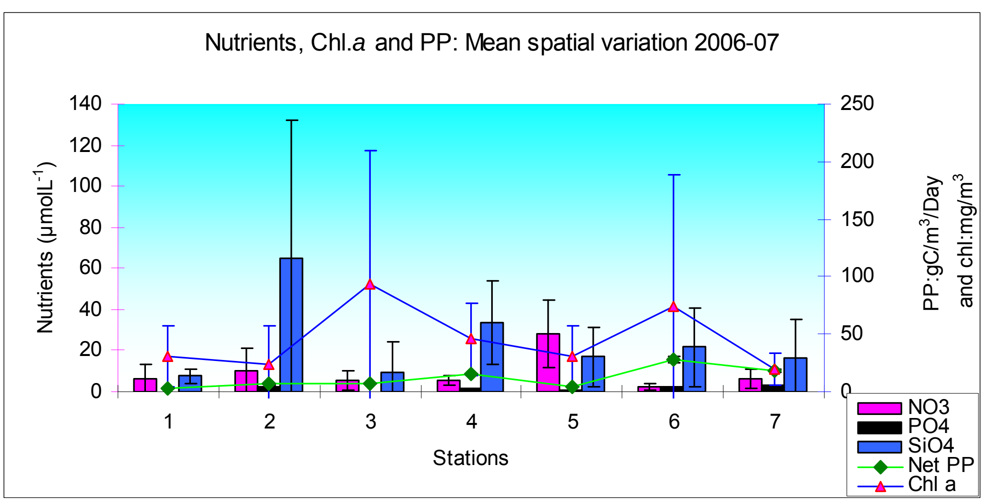
Fig.35



3.3.1.4 Nutrients, chlorophyll *a* and primary productivity

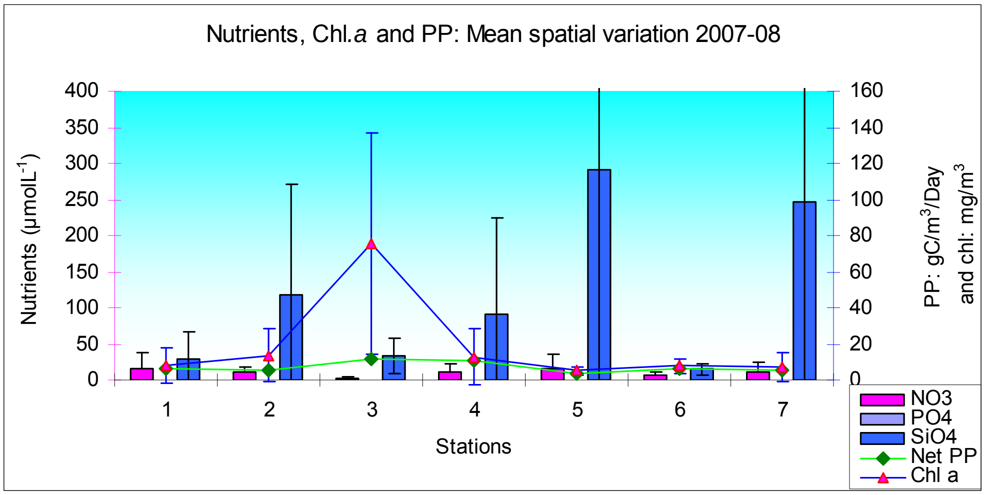
Mean values of nutrients (nitrate, phosphate and silicate), chlorophyll *a* and net primary productivity during the year 2006-07 are shown in fig. 36.

Fig.36.



Mean values of nutrients (nitrate, phosphate and silicate), chlorophyll *a* and net primary productivity during the year 2007-08 are shown in fig. 37.

Fig.37



3.3.1.5 Statistical analysis

The two way ANOVA between pigments, station and season are shown in table 13. Except in some seasons, a significant variation was observed, where as the stations and pigments haven't shown any significant relationships. (Table. 13)

Table 13. Two way ANOVA

Chlorophyll *a*						
Source of Variation	DF	SS	MS	F	P	Tabled value
Station	6	7386.059	1231.01	0.851	0.542	2.421
Season	5	38032.12	7606.423	5.256	0.001	2.534
Residual	30	43419.72	1447.324			
Total	41	88837.89	2166.778			

Chlorophyll *b*						
Source of Variation	DF	SS	MS	F	P	Tabled value
Station	6	80.434	13.406	1.01	0.437	2.421
Season	5	383.671	76.734	5.784	<0.001	2.534
Residual	30	398.01	13.267			
Total	41	862.115	21.027			

table continued….

Chlorophyll *c*						
Source of Variation	DF	SS	MS	F	P	Tabled value
Station	6	305.724	50.954	1.042	0.418	2.421
Season	5	1287.162	257.432	5.266	0.001	2.534
Residual	30	1466.554	48.885			
Total	41	3059.439	74.62			

Carotenoids						
Source of Variation	DF	SS	MS	F	P	Tabled value
Station	6	75.993	12.666	0.592	0.734	2.421
Season	5	404.13	80.826	3.779	0.009	2.534
Residual	30	641.677	21.389			
Total	41	1121.801	27.361			

Pearson correlation analysis of pigments is shown in table 14. All the pigments were positively correlated.

Table 14.

Correlations					
		Chl *a*	**Chl *b***	**Chl *c***	**Carotenoids**
Chl *a*	**Pearson Correlation**	1			
	Sig. (2-tailed)	.			
	N	42			
Chl *b*	**Pearson Correlation**	.937(**)	1		
	Sig. (2-tailed)	.000	.		
	N	42	42		
Chl *c*	**Pearson Correlation**	.992(**)	.915(**)	1	
	Sig. (2-tailed)	.000	.000	.	
	N	42	42	42	
Carotenoids	**Pearson Correlation**	.497(**)	.614(**)	.435(**)	1
	Sig. (2-tailed)	.001	.000	.004	.
	N	42	42	42	42

** Correlation is significant at the 0.01 level (2-tailed).

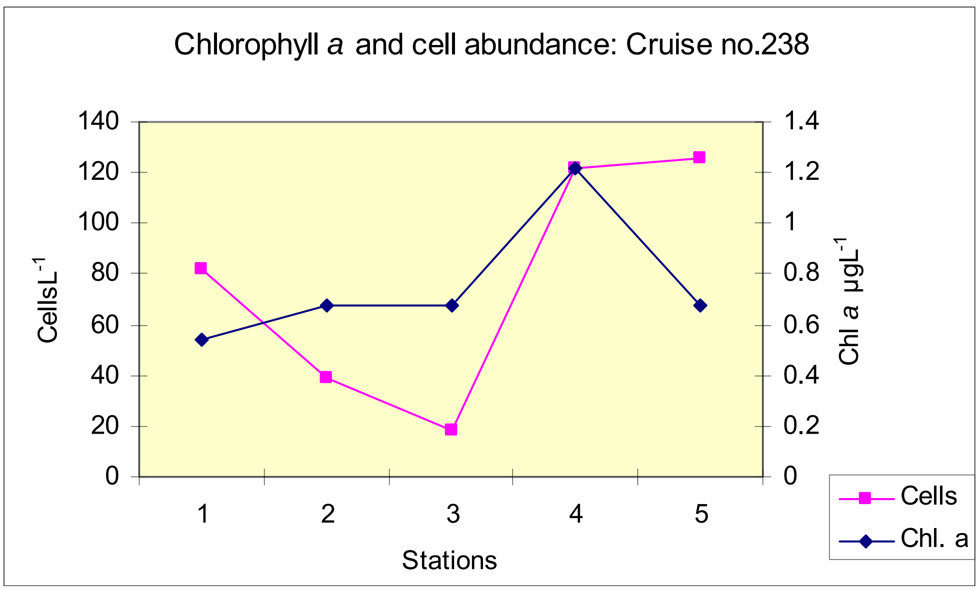
3.3.2 FORV Sagar Sampada cruises

The data collected during the two FORV Sagar Sampada cruises are given below.

Cruise no. 238.

The spatial distribution of standing crop and chlorophyll *a* is shown in fig.38. The highest standing crop was recorded from station 6 (126 cellsL^{-1}) and the lowest was from station 3 (18 cellsL^{-1}, table 15). Chlorophyll *a* ranged from 0.54µgL^{-1} to 1.2µgL^{-1} at stations 4 and 1, respectively

Fig. 38



Cruise no. 241

Spatial distribution of standing crop and chlorophyll *a* is shown in fig. 39. There were no significant relationship between cell abundance and chlorophyll. The highest standing crop was recorded in station 2 with 143cellsL^{-1} and the lowest was in station 5 with 38cellsL^{-1} (Table 16). Chlorophyll *a* was low and ranged from 0.1µgL^{-1} to 0.5µgL^{-1} in stations 9 and 1.

Fig.39

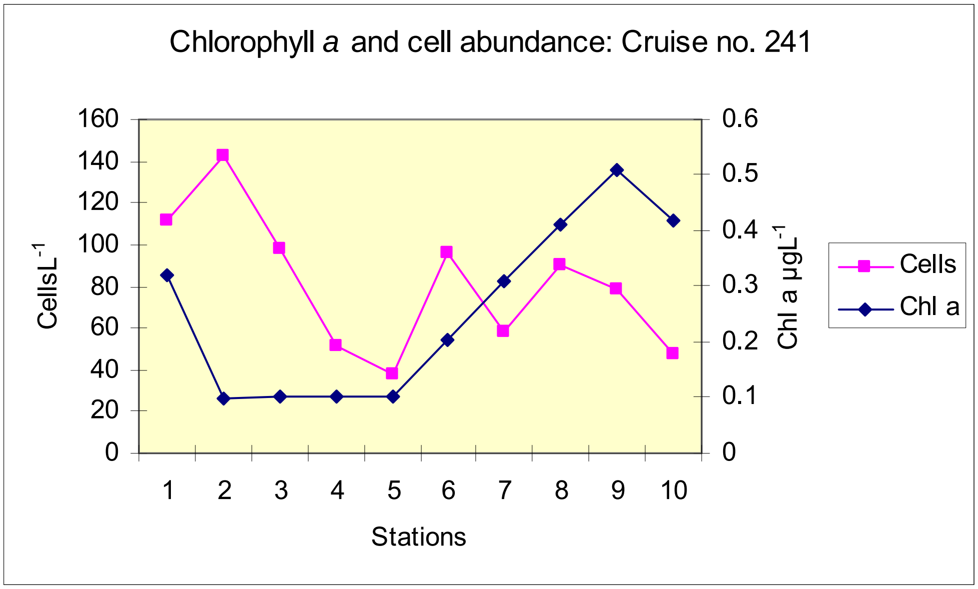


Table 15. Cruise No. 238

		Stations				
	Class. Bacillariophyceae	**1**	**2**	**3**	**4**	**5**
1	*Campylodiscus iyengarii*			4		
2	*Chaetoceros diversus*			2		
3	*Chaetoceros pseudocurvisatus*	14				
4	*Coscinodiscus marginatus*	25			2	
5	*Coscinodiscus radiatus*		3			
6	*Cyclotella stylorum*	3				
7	*Nitzschia palea*					3
8	*Planktoniella sol*					15
9	*Pseudosoleinia calcar avis*	3				
10	*Proboscia alata*			4		
11	*Rhizosolenia hebetata*	3	5			1
12	*Thalassiosira simensonii*					21
	Total	**48**	**8**	**10**	**2**	**40**
	Class: Dinophyceae					
1	*Ceratium furca*					3
2	*Ceratium fusus*					3
3	*Ceratium tripos*	3				
4	*Dinophysis caudata*				90	9

table continued….

5	*Protoperidinium oceanicum*					9
6	*Protoperidinium murrayi*	8		12		4
7	*Protoperidinium ovatum*	8	10			8
8	*Protoperidinium pyriforme*				14	
9	*Ceratium arietinum*	12		12		
10	*Ceratium candelabrum* var. *depressum*					14
11	*Ceratium contortum*		10	12		
12	*Protoperidinium pellucidum*			4		
13	*Pyrophacus horologium*	3	11	4		36
14	*Pyrophacus steinii*				16	
26	**Total**	**34**	**31**	**8**	**120**	**86**
	***Grand total**	**82**	**39**	**18**	**122**	**126**
	***cells/lit.**					

Table 16. Cruise No. 241

	Class. Bacillariophyceae	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	*Achnanthes coarctata*		13								
2	*Asterionella japonica*						43				
3	*Biddulphia mobilensis*		9								
4	*Coscinodiscus curvatulus*				4			8			
5	*Coscinodiscus marginatus*	13		13					8		
6	*Coscinodiscus radiatus*		23								
7	*Cyclotella meneghiniana*				14						
8	*Ditylum sol*							4			
9	*Eucampia zodiacus*	4					7				
10	*Navicula distans*						11				
11	*Navicula hsata*			18							
12	*Navicula marina*					8					
13	*Nitzschia paleacea*			13							
14	*Planktoniella sol*	21									8
15	*Rhizosolenia hebetata*	8									
16	*Rhizosolenia bergonii*					2					
17	*Synedra ulna*	13									
18	*Thalassiosira australis*		27								
19	*Thalassiosira eccentrica*		9							11	
20	*Thalassiosira subtilis*		9					4			
	Total	**59**	**90**	**44**	**18**	**10**	**61**	**16**	**8**	**11**	**8**
	Class: Dinophyceae										
1	*Alexandrium sp*								12		
2	*Ceratium arietinum*						7				
3	*Ceratium candelabrum* var. *depressum*										8
4	*Ceratium contortum*	12		6		8					
5	*Ceratium furca*			24							

table continued….

6	*Ceratium pentagonum*								12		
7	*Ceratium trichoceros*			8				10			
8	*Corythodinium tesselatum*										12
9	*Dinophysis fortii*		10				12			15	
10	*Dinophysis hastata*				14				12		
11	*Diplopeltopsis minor*	8						14			
12	*Diplopsalis lenticula*	12				20				20	
13	*Gymnodinium heterostriatum*			16				14		8	
14	*Gymnodinium sp.*		10								
15	*Noctiluca miliaris*								18		
16	*Ornithocercus magnificus*						16				
17	*Ornithocercus steinii*		20							18	
18	*Prorocentrum micans*				19				12		12
19	*Protoperidinium brevipes*								8		
20	*Protoperidinium depressum*	8									
21	*Protoperidinium murrayi*	13	13					4			8
22	*Protoperidinium ovatum*								8	7	
42	**Total**	**53**	**53**	**54**	**33**	**28**	**35**	**42**	**82**	**68**	**40**
	***Grand total**	**112**	**143**	**98**	**51**	**38**	**96**	**58**	**90**	**79**	**48**
	***cells /lit.**										

3.4 Discussion

3.4.1 Species composition and diversity

During the first year, at station 1, (Vaadi) there were 30 species of planktonic microalgae, 21 diatoms and 9 dinoflagellates distributed in three seasons. None of the diatoms was present throughout the three seasons. Dinoflagellates such as, *Ceratium furca* and *C symmetricum* were found during both the pre monsoon and monsoon. Pennate diatom *Thalassionema nitzschioides* was the dominant among the 30 species recorded. Toxin producing (DSP) *Dinophysis acuminata* was also recorded from station 1, in very less concentration (16cellsL^{-1}). Yasumoto *et al*, 1978, reported that this species induce intoxication when the cell density reach around 200 cellsL^{-1}. The mixotrophic mode of nutrition in *Dinophysis acuminata* helps to survive it in all the marine waters even at low/dim light conditions. *Dinophysis spp* were adapted to a wide range of salinity and temperature (Yasumoto *et al*, 1978). The species was recorded during the monsoon, when temperature was 24^{0}C and salinity was 34psu at station 1. Moderate species diversity (Shannon-Weiner index 1.99 $\pm$ 0.23) and low species dominance (Simpson dominance index 0.16 $\pm$ 0.03) were observed during 2006-07.

Forty three planktonic microalgal species were observed during 2007-08 was higher than the previous year. Dinoflagellates represented by only 10 species and rest were diatoms. During this period, none of the species was present in all the three seasons. Centric diatom *Chaetoceros socialis* was the most dominant species, followed by *Asterionella japonica* and *Bacteriastrum comosum*. *Chaetoceros socialis* was recognized as harmful species, which cause mechanical interruption of the gills of fishes by its tufts of chaetae (Hallegraeff, 1995). Harmful dinoflagellates such as *Ceratium furca, C gibberum* and *C symmetricum* which were also found to chock the gills due to its epithecal and hypothecal horns, were also recorded during 2007-08 at station 1. In tropical regions dinoflagellates are the dominant protist group and show their greatest diversity, particularly long-horned members of *Ceratium* (Taylor, 2004). The species diversity index

(2.52 $\pm$ 0.2) was much higher and the dominance index (0.09 $\pm$ 0.02) was lower when compared to 2006-07.

At station 1, sixty three species of planktonic microalgae were found distributed during two cycles of seasons. They included 48 species of diatoms and 15 species of dinoflagellates. A gradual increase in the abundance of cells was noted from pre monsoon 2006-07 to post monsoon 2007-08. The species diversity index increased from the first year to second year due to the occurrence of relatively large number of diatoms during the monsoon. It is to be noted that temperature salinity and pH showed only a slight variation from 2006-07 to the 2007-08. When the ratio of Si:N increases the standing crop of diatoms will also increase (Piehler *et al*.,2004; Aktan *et al*., 2005). Hence the higher standing crop during the monsoon 2007-08, especially diatoms were due to the higher values of nitrate and silicate, when compared to the previous year.

In the first year, at station 2, (Kavanad) only 19 species were recorded which included 17 diatoms and two dinoflagellates. Pennate diatom *Pleurosigma falx* was the dominant species. None of the species were recorded throughout the three seasons. This is an estuarine station, however, during the monsoon the salinity was not decreased considerably (20psu). 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). Such an effect was not observed here since the salinity was not lowered beyond 20psu. Mean Shannon-Weiner index (1.77 $\pm$ 0.06) was quite normal and Simpson index (0.19 $\pm$ 0.01) was somewhat low.

Thirty seven species of microalgae were recorded during the second year, which included 7 species of dinoflagellates and a chlorophycean species *Scenedesmus arcuatus*. Toxic microalgal species such as *Dinophysis odiosa,* and *Gonyalux moniliana* were recorded in lesser numbers and these species were listed as harmful algae (Intergovernmental Oceanographic Commission, UNESCO Paris, www.ioc-unesco.org). The centric diatom *Coscinodiscus rothii* was the dominant species. In the monsoon the Si:N ratio was high (12:1) which would normally increase the abundance of diatoms, however, the standing crop could not increase in accordance with the high Si:N ratio (Piehler *et al.*,2004, Aktan *et al.*, 2005). No species were found distributed throughout the year. Mean Shannon-Weiner index (2.31 $\pm$ 0.68) was moderately higher and Simpson index (0.12 + 0.08) was fairly low, however, both were higher compared to the previous year due to the numerical increase in the abundance and diversity of microalgae.

Fifty four species of microalgae were recorded from station 2, of which diatoms were dominant with 45 species, followed by dinoflagellates with 8 species and one chlorophycean species. The lowest abundance was recorded during the monsoon in 2006-07 and the highest abundance was recorded in the second year monsoon. If the nutrient ratio go beyond an optimum level it will adversely affect the distribution of microalgae (Piehler *et al.*, 2004). The Si:N ratio during 2006-07 was too high (89:1) and could not support the hike in standing crop. Toxic species were present only in the post monsoon 2007-08.

At station 3, (Punnapra) thirty nine species were recorded during 2006-07 which included 6 dinoflagellates and thirty three species of diatoms. None of them were present in all the three seasons. However, dinoflagellates such as, *Ceratium furca, Diplopsalis lenticula, Prorocentrum micans* and *Dinophysis fortii* were found in two consecutive season. *Diplopsalis lenticula* was the most dominant among these. All these species, except, *Dinophysis fortii*, were recorded by Calliari *et al.*, (2005) in their study at Rıo dela Plata, Uruguay. *Dinophysis fortii*, is a DSP producing harmful microalga, however, the concentration was too low (36 and 12 cellsL^{-1} during monsoon and post monsoon). *Prorocentrum lima* is considered as a widespread and common dinoflagellate species in both tropical and temperate benthic environments (Richardson 1997; Taylor *et al.*, 2008). The same species appeared as plankton during the post monsoon. This was probably due to the mixing of sediments, because station 3 is located near the bar mouth. None of the dinoflagellate species was present during pre monsoon. Moderate species diversity (Shannon-Weiner index 1.97 $\pm$ 0.64) and comparatively low species dominance (Simpson index 0.2 $\pm$ 0.16) were observed during 2006-07.

During 2007-08, thirty nine species were observed including *Dictyocha fibula* from dictyochophyceae, 17 dinoflagellate species and 21 species of diatoms. It is very significant to note that 8 species under the single genus *Ceratium,* viz, *Ceratium furca, C gibberum, C horridium, C kofoidii, C pentagonum, C symmetricum, C trichoceros, C vulture* were present only in the monsoon period. Taylor *et al*., (2008) reported that *Ceratium spp.* were the most abundant dinoflagellate species in tropical waters. The total standing crop during the monsoon was $3x10^4$. Smayda, (1997a, b) described that criteria of exceptional blooms is either those with >100mg Chl m^3 or the maximal standing crop levels is 10^4cellsL^{-1}. Even though, the standing crop and chlorophyll *a* were beyond this limit, in the present study, it was not treated as a bloom due to the lack of visible discoularation (ICES 1984, www.ices.dk). According to Lehman (2000), the flagellate species were commonly occurring at higher water temperatures; however, it was 27^0C during the monsoon when the highest abundance of dinoflagellates was found in the present study.

DSP producing *Dinophysis acuminate, D caudata* and *D fortii,* were also recorded but in reasonably lesser numbers. No species were found distributed throughout the year. Post monsoon season had a very low standing crop. Mean Shannon-Weiner index (0.94 $\pm$ 0.22) was relatively normal and Simpson index (0.53 $\pm$ 0.28) was somewhat high.

Sixty nine species were recorded from station 3 during the study period. Relatively high biomass was observed during the monsoon period and the lowest was from pre and post monsoon. *Ceratium furca* was observed continuously from monsoon 2006-07 to monsoon 2007-08. Three species of potent toxin producing dinoflagellate, ie., *Dinophysis acuminata, D caudata* and *D fortii,* were recorded from this station, however their concentrations were low and hence the threat of

HAB was not there. Benthic dinoflagellate *Prorocentrum lima* was recorded only from this station during the post monsoon 2007-08.

During 2006-07, thirty nine species of microalgae have been found at station 4 (Azheekode). They included 28 species of diatoms, 9 species of dinoflagellates and two chlorophycean species. Two species, *Ceratium furca* and *Protoperidinium oceanicum* were found throughout the year. *Protoperidinium spp.* are abundant in Indian waters (Subrahmanyan, 1971, Gopinathan, 1972). During the monsoon, salinity was only 12psu due to the strong freshwater influx, because the station 4 is situated near the bar mouth. Two chlorophycean species were recorded in which *Pediastrum tetras* was a typical freshwater species and recorded earlier from the Muriyad wetlands, central Kerala (Sanilkumar and Thomas, 2006) and the occurrence of the same species might be by the advection from upstream freshwater. DSP producing *Dinophysis acuminata* was also recorded during the monsoon in lesser number (24cellsL^{-1}). Mean Shannon-Weiner index (2.52 $\pm$ 0.3) was moderately high as far as this study is concerned and Simpson index (0.09 $\pm$ 0.03) was too low, indicating that in the given conditions, the diversity of species was high and no or a small group of microalgae were dominant, ie., the available species were distributed more or less evenly.

During the next year, 76 species were recorded during the 3 seasons. The microalgae included 54 diatoms species, 19 dinoflagellates, 2 chlorophycean and one dictyochophycean species. None of the species was present throughout the year. The highest species diversity and standing crop was found during the post monsoon. It is to be noted that the N:P ratio was 95:1 which is far above the optimum requirements. (The optimal N:P ratio will vary from 8.2 to 45, Klausmeler *et al*., 2004). For an effective growth and survival of microalgae, multiple resources are needed at its optimum levels (Arrigo, 2005). This would be the reason why the standing crop of diatoms during the monsoon was less. Whereas, in the post monsoon both diversity and standing crop were high compared to the rest of the seasons in the entire study period, due to low N:P and optimal Si:N ratios (2.4:1 and 25:1 respectively). It is evident that even when the concentrations of nitrate (1.05µmolL^{-1}) and phosphate (0.49µmolL^{-1}) were quite low, the hike in the diatom standing crop was due to the high Si:N ratio (Kristiansen and Hoell, 2002; Piehler *et al.*,2004). The standing crop of the dinoflagellates will increase when the N:P ratio is minimal (Aktan *et al.*, 2005) and hence the minimal N:P ratios provided the hike in the standing crop of dinoflagellates during the same season. Toxic species such as *Coolia monotis* and *Diniphysis caudata* were observed in negligible numbers. *Coolia monotis* was a benthic dinoflagellate (Richardson, 1997) which can cause ciguatera shell fish poisoning on blooming. However, the concentration of the cells was very less (6cellsL^{-1}) and probably this would have re-suspended from the underlying sediments. Joseph and Pillai, (1972) and Kumaran and Rao, (1975) reported that the standing crop of Cochin backwaters were high during the post monsoon period and in the present study also the same situation was found. It is to be noted that station 4 is at the northern end of Cochin estuary. (Mean Shannon-Weiner index (2.76 + 0.82) was high and Simpson index (0.12 + 0.11) was low.

In all, one hundred and one species of microalge were recorded from station 4 during the two year period of investigation. Diatoms were the dominant group with 72 species, followed by dinoflagellates (24), chlorophyceae (4) and dictyochophyceace with one species. Station 4 has shown moderately high diversity and standing crop throughout the study period.

In the first year, at station 5 (Balathuruthu), a total of 52 species were recorded including 9 species of cyanobacteria. Diatoms were dominant with 28 species, followed by 12 chlorophyceaen species; two species of dinophyceae and one species of chrysophyceae. All the cyanophycean and chlorophycean species were found distributed during the monsoon. The dominant taxa during the pre monsoon were diatoms which shifted to chlorphyceae during the monsoon where salinity was nil. *Gyrosigma tenuissimum,* which is a new distributional record from India, was present during both monsoon and post monsoon. It was considered as a typical marine species (Jin-Dexiang *et al*., 1985), the presence of the same in freshwater during the monsoon indicate its wide salinity tolerance. Mean Shannon-Weiner index (2.35 $\pm$ 0.45) was fairly high and Simpson index (0.13 $\pm$ 0.05) was quite low during the year.

In the second year, 62 species were recorded, of which dominant group was diatoms with 41 species, followed by 10 species of chlorophyceae, 8 species of cyanophyceae and 3 species of dinophyceae. During the monsoon, both chlorophycean and cyanophycean species were dominant and diatom being represented by only two species. *Microcystis aeruginosa,* a bloom forming noxious blue-green alga occurring as irregular colonies (Desikachary, 1959; Thajuddin and Subramanian, 2005; Padmakumar *et al*., 2008) was found in low density during the monsoon. In the same season, the value of phosphate was very low (0.04µmolL^{-1}) and the nitrate concentration was high (39.4µmolL^{-1}), which has given a high N:P ratio. Arrigo (2005), reported that the optimum N:P ratio for chlorophyceae is 27:1. In the present investigation, during the monsoon, it was far beyond the optimum. When the ratio was high, it will limit the microalgae (Falkowski, 2000). If the ratio was optimum, there should have higher standing crop of chlorophyceae. During the post monsoon, the abundance and diversity of diatoms were high. The N:P ratio was 0.19:1 which is below the optimum and Si:N ratio 271:1 far ahead the optimum. The shift towards an increase in the abundance of diatoms require a lower N:P ratio (Tyrrell and Lucas, 2002; Arrigo 2005). However, the increased Si:N ratio provided an ideal nutrient distribution for the dominance of diatoms. Mean Shannon-Weiner index (2.51 + 0.73) was higher than the previous year and Simpson index (0.12 + 0.07) was comparatively lower.

Thus, a total of 104 species were recorded from station 5. Diatoms were dominant with 66 species, followed by 21 chlorophycean, 11 cyanophycean, 5 dinophycean and one chrysophycean species. Salinity influenced the distribution of microalgae in station 5. Diatoms were found to be abundant during the pre and post monsoon seasons, while, during the monsoon chlorophycean and cyanophycean species have shown an almost complete dominance. Even though blue-green algae were recorded during the monsoon in both years, all the members of cyanophyceae except *Microcystis aeruginosa* were of typical estuarine/marine forms (Desikachary, 1959) and not the freshwater species. From this it is evident that the typical estuarine/marine blue-green algae got adapted to freshwater conditions or in the other hand, the estuarine flora persisted even in the monsoon where salinity was nil. None of the dinoflagellates were found during the monsoon 2007-08.

At station 6, (Kodikkal) only 33 species, 24 species of diatom and 9 species of dinoflagellate were found during 2006-07 period. The highest abundance was found during the monsoon. Diatoms such as, *Coscinodiscus asteromphalus* var. *centralis* (2912cellsL^{-1}), *Pleurosigma acuminatum* (1612cellsL^{-1}) were dominant in the monsoon. Dinoflagellates were not present during the monsoon. The abundance of diatoms was substantiated by moderately high Si:N ratio (10:1). High pH (8.2) also would have provided good survival condition of diatoms (Round *et al*., 1990). It is reported that *Coscinodiscus asteromphalus var. centralis* is a euryhaline species (Gopinathan, 1975). In the present study, the increased abundance of this species occurred during the monsoon period, when the salinity was 34psu. Mean Shannon-Weiner index (1.73 $\pm$ 0.87) was moderately low and the Simpson index (0.28 + 0.22) was fairly high during 2006-07.

During 2007-08, forty two species were recorded during the three seasons. They include 24 species of diatoms 16 species of dinoflagellates and 2 species of dictyochophyceae. The centric diatom, *Coscinodiscus centralis* and dinoflagellate, *Ceratium furca* were found distributed throughout the year. Their distribution was not affected by the seasonal fluctuation. The highest standing crop was seen during the pre monsoon, where *Ceratium furca* alone contributed 8160cellsL^{-1}. Moderately high surface water temperature (32^{0}C) appended to have supported the abundance of dinoflagellates. The abundance of flagellate species were commonly occurring at higher water temperatures (Lehman 2000). Oceanic species, *Dictyocha fibula* (Tomas, 1997) recorded during pre and post monsoon in lower abundances. Mean Shannon-Weiner index (2.01 $\pm$ 1.17) and the Simpson index (0.31 $\pm$ 0.39) were more or less high when compared to the preceding year. Altogether, sixty four species of microalgae were recorded at station 6, during six seasons. They include bacillariophyceae (41 species), dinophyceae (21 species) and dictyochophyceae (2 species).

At station 7 (Mahe), thirty nine species were recorded during the first year. Among them, diatoms were dominant with 18 species, 7 cyanophycean species, 4 dinophycean and one species each of dictyochophyceae and coccolothophores. The pennate diatom *Nitzschia closterium* was found in all the three seasons. DSP producing *Dinophysis miles* was found during the monsoon in lesser numbers. Highest standing crop was recorded during the monsoon and diatom *Pleurosigma falx* (1760cellsL^{-1}) was the dominant species. High Si:N ratio (8.2:1) could have provided the high standing crop (Piehler, 2004). Coccolithophore, *Syracosphaera sp* was found in the post monsoon, which is frequently occurring in the colder waters (Raymont, 1963). Coccolithophorids are commonly found in oceanic waters (Tomas, 1997), however the presence of the same was nominal and probably would have advected from the open sea. Vanormelingen *et al*., (2008) reported that wind and currents can carry smaller amounts of viable cells of microorganisms to remarkably longer distances. Shannon-Weiner index (0.97 $\pm$ 0.78) was too low and the Simpson index (0.58 $\pm$ 0.37) was high during the year.

During the second year, fifty seven species were recorded. Diatoms were dominant (35 species), followed by 11 species of chlorophyceae, 8 species of cyanophyceae, and 3 species of dinophyceae. Chlorophyceaen species observed only during the monsoon, made a considerable contribution to the total standing crop. *Pseudonitzschia seriata,* an ASP producing diatom (Lundholm, *et al*., 1994a and b) was found distributed (150cellsL^{-1}) during post monsoon. It was observed that chlorophycean species are well adapted to freshwater conditions. In the second year during the monsoon, when salinity was nil, chlorophycean members appeared. None of the species were found to be present in all the season. Shannon-Weiner index (2.53 $\pm$ 0.25) was comparatively high and the Simpson index (0.1 $\pm$ 0.02) was lowest.

In station 7, eighty species were recorded during the two years of seasonal investigation. The dominant group was diatoms with 52 species. Besides diatoms, chlorophyceae (11 spp.) cyanophyceae (9 spp.), dinophyceae (6spp.), one species each of coccolithophorids and dictyochophyceae were also observed.

The highest standing crop (32342cellsL^{-1}) ever recorded during this study was in the monsoon 2007-08, at station 3 and the lowest being 54cellsL^{-1}, during the post monsoon at the same station in the same year. The highest species diversity was observed at station 5 with 104 species followed by 101 species in station 4. The species diversity was 63, 54, 69, 64 and 80 in stations 1, 2, 3, 6 and 7 respectively. However, the mean species diversity index (Shannon-Weiner index) was observed to be the highest in station 4 with 2.76 and the lowest was 0.94 at station 3 during 2007-08.

Overall, two hundred and eighty five species were recorded during the period of investigation from pre monsoon 2006-07 to post monsoon 2007-08 (Annexure 3). These species come under 89 genera in 7 classes viz; Cyanophyceae (9genera), Chlorophyceae (22 genera), Bacillariophyceae (53 genera), Dinophyceae (11 genera), Chrysophyceae (1 genus), Dictyochophyceae (1 genus) and Coccolithophorids (1 genus). Class bacllariophyceae was the dominant group with 175 species (61.4%), followed by dinophyceae with 48 species (16.81%), chlorophyceae with 43 species (15%), cyanophyceae with 14 species (4.9%), dictyochophyceae with 3 species (1%) and coccolithophorids and chrysophyceae with one species each (0.35%).

Among bacllariophyceae, *Navicula* was dominant with 22 species, followed by other major genera such as *Chaetoceros* (10*spp.*), *Coscinodiscus* (11*spp.*) and *Nitzschia* (10*spp.*). All these are cosmopolitan genera found frequently in coastal waters (Hendey, 1964, Simonsen, 1974, Van den Hoek *et al*., 1995, Tomas, 1997). Among dinophyceae, *Protoperidinium* was dominant with 15 species and followed by *Ceratium* with 11 species. *Protoperidinium* and *Ceratium* are the dominant genera in tropical waters (Balkis, 2003; Taylor *et al*., 2008) *Staurastrum,* which is a cosmopolitan freshwater species (Coesel, 1996; Coesel and Krienitz, 2008) was dominant in the present investigation (5 species) in the class chlorophyceae and *Oscillatoria* was the dominant species in cyanophyceae with 3 species. *Oscillatoria* is a common species found in freshwater and marine habitats in India (Desikachary, 1959, Thajuddin and Subramanian, 2005). In dictyochophyceae, only one genus *Dictyocha* with 3 species were found. One species each from coccolithophorids (*Syracosphaera sp*) and chrysophyceae (*Dinobryon belgica*) were recorded.

In estuaries, the distribution of microalge is very much influenced by salinity and the microalgae may be classified into three, (1) the estuarine community, mainly diatoms, (2) mixing water community mainly composed of chlorophycean and cyanophycean species, when the salinity become very low or nil and (3) coastal community, mainly diatoms and dinoflagellates (Huang *et al*., 2004). Lehman (2007), reported that the differences in species composition, with greater percent diatom and green algal species biomass upstream and flagellate biomass in downstream in estuarine conditions. In the present investigation, variation in the salinity influenced the distribution of microalgae in two estuarine stations. During the monsoon, when the water was not saline, the chlorophycean members appeared in stations 5 and 7. At station 5, about 65% of the total biomass during the monsoon in 2006-07 and 94% of standing crop during monsoon in 2007-08 was the contribution of chlororphycean species; most of them are known to occur only in freshwater conditions. Gowda *et al*., (2001) recorded filamentous green algae during their study at Nethravathi estuary, however, in the present investigation except *Ulothix zonata*, no filamentous green algae recorded and all were either unicellular or colonial forms. These observations were in agreement with Joseph and Pillai (1975), in Cochin estuary, Gu *et al*., (1995) in the Changjiang estuary, Huang *et al*., (2004) in their study at Pearl River estuary and Lehman (2007) at San Joaquin River, California. The same was in the case of cyanophyceae, which were abundant only in the monsoon season of station 5 and 7. Though, at Nethravathi estuary, blue green algae were frequently found during the pre monsoon and it was less or practically nil during the monsoon and post monsoon (Gowda *et al*., 2001).

3.4.2 Pigments

3.4.2.1 Chlorophyll *a*

In 2006-07, during the monsoon, concentration of chlorophyll *a* showed wide fluctuation. There were two peaks, in station 3 and 6, while at stations 2 and 7 chlorophyll *a* concentrations were low. 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.

It is evident that, station 3 had a high chlorophyll *a* concentration during the monsoons and post monsoons. Monsoon 2006-07, supported a moderate concentration of chlorophyll *a* except at station 2 and 7. Station 6 attained the highest value during monsoon 2006-07 due to the dominance of *Coscinodiscus asteromphalus* var. *centralis*. Other stations did not show conspicuous fluctuations. Two way ANOVA revealed a significant difference between chlorophyll *a* and seasons ($p<0.001$), however, not with stations.

The annual average of chlorophyll *a* from the entire stations studied was 28.57μgL^{-1}. It was 13.4μgL^{-1} for the entire euphotic zone of EEZ of Arabian Sea from 1962 to 1988 (Sarupria and Bhargava, 1998). Seasonal average calculated in this study was 7.29μgL^{-1} during the pre monsoon, 49.6μgL^{-1} during the monsoon and 28.7μgL^{-1} in the post monsoon as against 18μgL^{-1}, 7.9μgL^{-1} and 8.3μgL^{-1} in the Arabian Sea. Whereas in 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). It ranged from 1.48 to 225.26μgL^{-1} during the present investigation, while it was 0.1 to 96.4μgL^{-1} in the Arabian Sea (Sarupria and Bhargava, 1998). The highest seasonal average was recorded during the monsoon due to the nutrient rich land run off/storm water runoff in to the coastal areas. The concentration of chlorophyll *a* was always high in the coastal/neritic waters when compared to open sea. 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). It is to be noted that Sarupria and Bhargava, conducted the study in the open sea where the effect of nutrient loading should not be remarkable.

3.4.2.2 Chlorophyll *b*

In 2006-07, the highest chlorophyll *b* concentration was seen in station 6 and it was practically nil in the monsoon. Moderately high standing crop was found at station 3 and 6, however, no chlorophycean species were enumerated. 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. During the pre and post monsoon substantially negligible concentrations were found.

The highest concentration of chlorophyll *b* (20.41μgL^{-1}) during the present investigation was recorded during the monsoon, 2006-07 at station 6. Gopinathan *et al*., (2001) recorded the highest chlorophyll *b* off Calicut, during the post monsoon season along the Arabian Sea.

In 2007-08, during the monsoon, relatively high values of chlorophyll *b* were recorded at stations 5 and 7 (estuarine stations) supported by high abundance of chlorophyceae. During pre and post monsoon, the values were lower in the absence of chlorophycean species.

The hike in chlorophyll *b* concentrations was found only during the monsoon seasons. It is clear that in the monsoon, when the salinity becomes lesser, chlorophyll *b* bearing microalgae would dominate in the standing crop. However, most of the *prochlorophyte*s couldn't be seen through a light microscope and hence could not be accounted. Apart from the monsoons, other seasons, didn't provide a considerable contribution of chlorophyll *b*. Differences between chlorophyll *b* and seasons were statistically significant (Two way ANOVA, $p<0.001$) and not with stations.

3.4.2.3 Chlorophyll *c*

In 2006-07, the variation of chlorophyll *c* during the monsoon was almost same as that of chlorophyll *a* and *b*. It is evident that, during the monsoon period the highest abundance of diatoms were recorded except in the estuarine stations and 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. Chlorophyll *c* recorded in lower concentrations during the pre and post monsoon seasons and didn't show any variation at all.

During 2007-08, chlorophyll *c* showed a clear seasonal and spatial variation and it was in significant concentrations in all the stations and seasons. A marked depression was found at station 4 during the pre monsoon and monsoon. Two way ANOVA found significant between chlorophyll *c* and seasons ($p<0.001$) and not significant between stations.

3.4.2.4 Carotenoids

In 2006-07, concentration of carotenoid pigments also showed spatial variation during monsoon and the estuarine stations such as, 2, 5 and 7 supported low values. 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 in estuarine stations, particularly in station 5 and 7 and hence the concentrations of carotenoids were also found to be lower. No prominent variation was found during pre and post monsoon.

During monsoon in 2007-08, a wide spatial fluctuation of carotenoid pigments was found. Stations, 5 and 7 have lowest values, due to low abundance of diatoms. In pre monsoon and post monsoon, carotenoids concentrations were moderate in accordance with the abundance of diatoms. The carotenoid pigments showed slight spatial variations during the monsoons. Statistically there was no significance in the carotenoid distribution with season or stations (Two way ANOVA, $p>0.001$)

In 2006-07, mean chlorophyll *a* values ranged from 19.47µgL^{-1} ($\pm$ 13.72) to 94.06µgL^{-1} ($\pm$ 116), whereas in the next year the highest mean values of chlorophyll *a* was found at station 3 (75.75µgL^{-1}) and all other stations showed normal concentrations (<14µgL^{-1}).

Thus, the variation of the pigments was quite clear during the monsoon seasons in the entire study period. The Pearson Correlation analyses have shown that, all the pigments have significant positive correlations with each other at 0.01 levels. Lingadhal *et al*., (2003), noticed a positive correlation between chlorophyll pigments in the selected light depths off Mangalore, west coast of India. The strongest positive correlation (0.992) was found between chlorophyll *a* and *c* and next to which (0.937) was between chlorophyll *a* and *b*. The lowest (0.435) was found between chlorophyll *c* and carotenoids.

Spatial and temporal distribution of planktonic microalgal standing crop and chlorophyll *a* was found to be proportional. Significant correlation was found between standing crop and chlorophyll *a* (Pearson Correlation, correlation coefficient $r = 0.34$, $p<0.05$). Strong positive correlation between cell density and chlorophyll *a* is characteristic of Indian seas (Gouda and Panigraphy, 1996, Panigraphy *et al*., 2006). Standing crop was directly related to chlorophyll *a* or in other words, mostly, when standing crop increases, chlorophyll *a* also increases and vice versa. Present investigation is supported by several studies world wide (Gu *et al*., 1995; Balkis, 2003; Huang *et al*., 2004; Aktan *et al*., 2005).

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

The mean annual values of chlorophyll *a* and standing crop were found to be directly proportional during the first year. However, the primary production values did not show any direct relationship with standing crop and chlorophyll *a*. The highest mean value of primary production and standing crop during the first year were found at station 6. Chlorophyll *a* and standing crop have shown a strong positive correlation during this year (Pearson Correlation, $r = 0.753$, $p<0.001$), however, there was no significant correlation found between standing crop, primary production and chlorophyll *a*.

During the second year, the biomass and chlorophyll *a* was found to be of low magnitude compared to those of the previous year. Pearson Correlation analysis revealed that chlorophyll *a* and standing crop was positively correlated ($r = 0.707$, $p<0.001$). A statistically significant correlation was not observed between standing crop with primary production and chlorophyll *a* with primary production.

The highest primary productivity value 67.32g/C/m^3/day was observed at station 6 during the monsoon 2006-07. In the first year, the productivity was high in monsoon while in the following year high values were observed during the pre monsoon. The annual average productivity during 2006-07 was, 2.44, 6.58, 7.16, 15.4, 4.2, 28.28 and 18.20g/C/m^3/day, from station1 to 7 respectively. In 2007-08, the average production was 6.3, 5.52, 11.4, 10.48, 4, 6.4 and 5.3g/C/m^3/day respectively starting from stations 1 to 7. Renjith *et al*., (2004) showed that the maximal net production in Panangad area of Cochin estuary was 111.46mg/C/m^3/hr, this was quite higher than the present investigation. Nair *et al*., (1975), reported that an average production in the Vembanad Lake was 1.2

g/C/m^3/day, which is more or less higher than the present study. Primary productivity was found to be statistically not correlated with temperature, salinity, pH and nutrients during the course of this study, which is in agreement with Renjith *et al*., (2004).

3.4.4 Temperature, salinity and pH

Temperature and pH (figs. 1, 2, 5 and 6) did not register any marked variation during this study. Temperature play a major role in determining the fluctuation and distribution of microalgae particularly diatoms in temperate latitudes. Whereas in tropical estuarine ecosystems, temperature was never be a limiting factor for diatoms (Gopinathan 1975). The variation of temperature was comparatively low with a range of 7^0C during this study. It was noted that the lowest temperature (25^0C) and the highest (32^0C) did not make any influence on the distribution and standing crop of microalgae during the present investigation.

Salinity is one of the important factors which determines the species composition and succession of planktonic microalgae in estuaries (Joseph and Pillai, 1975; Nair *et al*., 1975; Pillai *et al*., 1975, Huang *et al*., 2004). The advent of monsoon tilts the floral composition by inactivating the marine species and replacing marine species by freshwater species in estuaries (Joseph and Pillai, 1975). In the present study, it was observed that the salinity decreased during the monsoon seasons in estuarine stations (figs. 3 and 4). When salinity decreased during the monsoon, especially at stations 5 and 7, the major components of standing crop were green algae and when salinity increased, the chlorophycean species were replaced by diatoms. Joseph and Pillai (1975) reported that the freshwater species appear in large numbers during the monsoon periods, in Cochin backwaters. Green algae were abundant during low temperature and salinity at Nethravathi estuary (Gowda *et al*., 2001). The peak periods of diatoms were observed in the onset of monsoon and post monsoon periods in Cochin backwaters (Gopinathan, 1972). The shift of salinity from monsoon to post monsoon also alter the community structure of microalgae (Joseph and Pillai, 1975; Nair *et al.,* 1975). Thus the spatial and temporal distribution of microalgae varied with the salinity especially in the estuarine stations. The major chlorophycean species during the monsoon were *Staurastrum, Euastrum,* and *Scenedesmus.*

Temperature and pH didn't influence the concentrations of chlorophyll *a,* and primary productivity. Statistically, no significant correlations were found between physical variables with standing crop, chlorophyll *a,* and primary productivity. This is supported by Pillai *et al*., (1975) who reported that the correlation coefficients did not reveal any significant relationship between primary production, temperature and salinity in Vembanad Lake.

3.4.5 Nutrients

Apparently during the first year of investigation, no specific relationship was found between the nutrients such as nitrate (NO_2), phosphate (PO_4) and silicate (SiO_3) and chlorophyll *a* and primary productivity. The highest mean silicate concentration (64.97 $\pm$ 67.27µmolL^{-1}) was found at station 2, where chlorophyll *a* and primary productivity were less compared to those at other stations. Similarly, nitrate having the highest mean value (27.86 $\pm$ 16.38µmolL^{-1}) at station 5, did not support high productivity and chlorophyll *a*. The mean highest value of both primary productivity and chlorophyll *a* were found at station 6, where only silicate has shown a moderately high (21.61 $\pm$ 19.37µmolL^{-1}) concentration, while phosphate (2.28 $\pm$ 0.52µmolL^{-1}) and nitrate (2.29 $\pm$ 1.26µmolL^{-1}) showed minimal concentrations.

During the second year, the average concentration of silicate was higher in almost all the stations when compared to the previous year. The highest silicate concentration was found at station 5 (291.63 $\pm$ 335µmolL^{-1}) and the highest mean value of nitrate recorded from station 1 (15.68 $\pm$ 20.98µmolL^{-1}). Both these stations supported comparatively lower chlorophyll *a* and primary production. Station 3 supported highest chlorophyll *a,* and primary productivity where the mean silicate and nitrate concentrations were 34.09 $\pm$ 24.41µmolL^{-1} and

2.19 $\pm$ 1.29µmolL^{-1}) respectively. Yin, (2002) reported that low phosphorous concentrations play an important role in controlling phytoplankton standing crop in coastal waters. During this study, almost all stations in the entire seasons provided a very low phosphorous concentration and probably which would limit the excessive biomass production of planktonic microalgae along the southwest coast of India.

The dynamic relationship between phytoplankton and nutrients has long been of great interest in both experimental and mathematical ecology (Chattopadhyay *et al*., 2003). However, many other factors can influence the spatial distribution of phytoplankton besides nutrient availability, such as the magnitude and position of the turbidity maximum, the relative importance of tidal amplitude and freshwater discharge volume, water column stratification and grazing rates of zooplankton (Harrison *et al*., 1990, 1991; Gao and Song, 2005). This would be the probable reason why individual concentrations of nutrients didn't have any direct relationship with the standing crop and chlorophyll *a*. Gopinathan, (1975), reported that the nutrient requirement of diatoms may vary and high concentrations of phosphates and nitrates alone may not support a substantial increase in the production of diatoms. Calliari *et al*., (2005), pointed out that the role of nutrients separately could not be considered as a primary triggering factor for biomass and distribution of phytoplankton in most of the investigations. Liebig's law of minimum (only a single resource limits plant growth at any given time) was replaced by realization that multiple resources simultaneously limit planktonic microalgal growth in world oceans (Arrigo, 2005). Thus multiple resources or two or three nutrients play an important role and together control the growth and survival of microalgae.

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

Predicting phytoplankton dynamics and devising management strategies in coastal and estuarine waters often involves using stoichiometric relationships of inorganic nutrient concentrations (Piehler *et al*., 2004). The N:P ratio of Redfield

(16:1, Redfield, 1934) has long been used as a predictor of phytoplankton nutrient limitation in aquatic ecosystems.

Changes in nutrient ratios have altered phytoplankton species composition in coastal waters (Yin, 2002). 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 (Aktan *et al*., 2005). The mean spatial changes of N:P ratio along the southwest coast showed that the values of N:P ratios were ranging from 1.05 at station 6 to 29.56 at station 1 and among the total 7 stations, only 3 stations during 2006-07 (stations, 1, 3 and 5) showed the ratio above 16:1. The mean lowest N:P ratio was at station 6, where maximum standing crop and chlorophyll *a* were obtained in 2006-07. During 2007-08, in all stations, N:P ratios were higher than the Redfield ratio (16:1) except at station 3 (12.27) and station 3 supported the highest standing crop and chlorophyll *a*. During the present investigation, higher chlorophyll *a* values were found when N:P ratio was lower than 16. Fiocca *et al*., (1996) reported that these variations would occur regularly in coastal environments. These results were fully supported by Aktan *et al*, (2005), in their study conducted in Izmit Bay, Turkey. The 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).

Diatoms have an absolute requirement for silicon (Kristiansen and Hoell, 2002) and they are the most important silicifying algal group. Piehler *et al*., (2004) reported that the diatom growth in marine waters is likely to be limited by dissolved silica when Si:N ratios are less than 1. During the present investigation, the mean values of Si:N recorded were higher than 1, except at station 5 (0.6) during 2006-07, where the dominance of chlorophycean species were found during the monsoon and it was also noted that the diatoms were very less. The highest mean standing crop during 2006-07 was found at station 6, where the highest Si:N ratio (9.05:1) was observed. Similarly the highest mean standing crop during 2007-08 was recorded at station 3, in which the Si:N ratio was also higher (15.58:1). It is evident that coastal and estuarine stations along the southwest India yielded a moderately high standing crop and chlorophyll *a*. During this investigation it was well supported by the higher ratios of Si:N.

3.4.7 Species diversity and dominance index

All the species present in ecosystem are not equally important in determining the nature and the function of the community. Hence, out of tens of species inhabiting the ecosystem, there may be a few species which form the greater part or which control the flow of energy in the system, due the biological reasons such as their large number, volume and increased fecundity and such species are named 'dominants'. These control the natural balance of the community and are usually present in large numbers throughout the whole year or during their active reproductive season. The dominance in the community can be determined by 'Simpson index of dominance', the maximum value is 1 which means complete dominance

It is important to note that while the energy flow in the community depends to a large extent on the dominant species, the species diversity depends on the total number of species particularly those of less importance or rare species. Species diversity decreases in systems controlled by strong physico-chemical limiting factors while the diversity of species increases in biologically controlled communities and is directly proportional to the stability of the system. The diversity of species in the community can be determined by Shannon index of general diversity. The higher the value the greater the diversity.

Studies on phytoplankton diversity are important contribution to the understanding of the ecosystem dynamics (Hillebrand and Sommer, 2000). The species diversity is typically measured by the species count (richness) and sometimes with an evenness index. However, it may also be measured by a proportional statistic like Shannon–Wiener index ($H^{'}$, Shannon and Wiener, 1949.) that combines both measures (Stirling and Wilsey, 2001) and which is one of the most widely used diversity indices for measuring diversity (Gao and Song, 2005).

Strong correlation between evenness /Simpson index of dominance and Shannon–Wiener index was found in many investigations. Furthermore, the diversity can change with key ecological processes such as competition, predation and succession and each of which can alter Shannon–Wiener index through changes in evenness without any change in species richness (Stirling and Wilsey, 2001). Pearson correlation analysis showed that a significant strong negative correlation was found between Shannon and Simpson indices during the year 2006-07 (Correlation coefficient $r = -0.948$, $p<0.01$) and 2007-08 ($r = -0.964$, $p<0.001$). A statistically significant strong negative correlation was also observed when the two year data combined ($r = -0.936$, $p<0.001$). This is indicating that when one index increases the other decreases and which is a general pattern. Thus the study demonstrated that there was strong and apparent relation between species richness and the diversity index found along the southwest coast of India.

Species diversity within aquatic communities is closely related with the trophic state of the water body. If it is accurately identified and measured on the unified basis, variability (or stability) of structural and functional parameters such as Shannon Wiener index of plankton communities in the estuaries and coastal waters, can serve as an indicator for the modification of ecosystems under the eutrophication/pollution stress (Telesh, 2004).

Shannon–Wiener diversity index is a suitable indicator for water quality. Hendley (1977) used the Shannon–Wiener diversity index as pollution index of microalgal communities, especially diatoms and put forward the following scale: 0–1 for high pollution, 1–2 for moderate pollution, 2–3 for small pollution, and 3–4 for incipient pollution. In Taiwan, Wu (1984) using phytoplankton as bioindicator for water quality indicated that the diversity index of phytoplanktonic community was correlated with the degree of pollution.

The value of diversity index of a community in less polluted waters would be higher (Margalef, 1967; Gao and Song, 2005). These are coincided with the results obtained from the southwest coast of India during this study, where the mean diversity index at station 3, (0.94 + 0.22) which is the lowest, clearly corresponded to the highest standing crop ever recorded during this study and in which the 2-4 species contributed the major part.

The mean Shannon-Weiner and Simpson index of the year 2006-07 and 2007-08 are shown in (figs. 40 and 41**).** As per Hendley (1977), during 2006-07, the mean Shannon-Weiner index was came under the scale 1-3 (except station 7), indicating that a moderate to small pollution persisted along the sampling sites, where as in 2007-08 the scale was 2-3 indicating (except station 3) that level of pollution was minuscule. It may be noted that, the highest standing crops and species diversity (occurrence of most number of species and not species diversity index) was found during the year 2007-08.

Fig.40

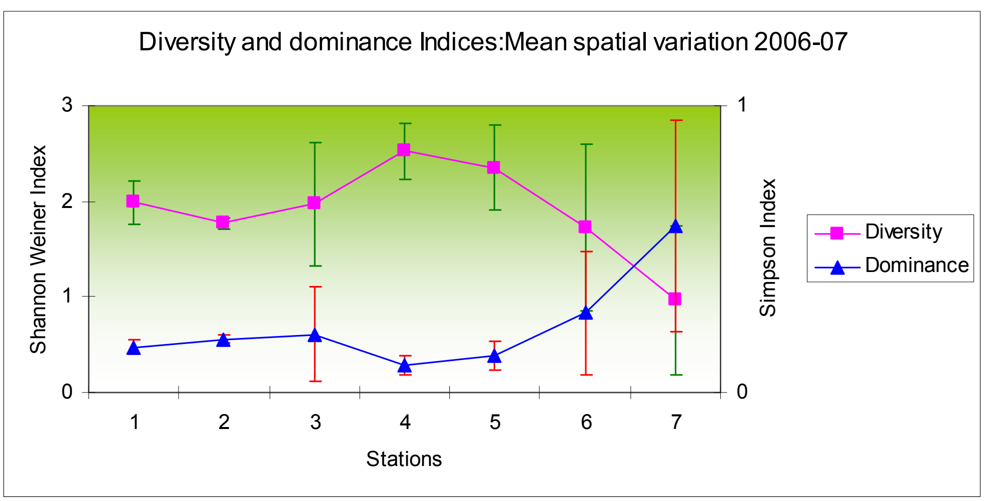
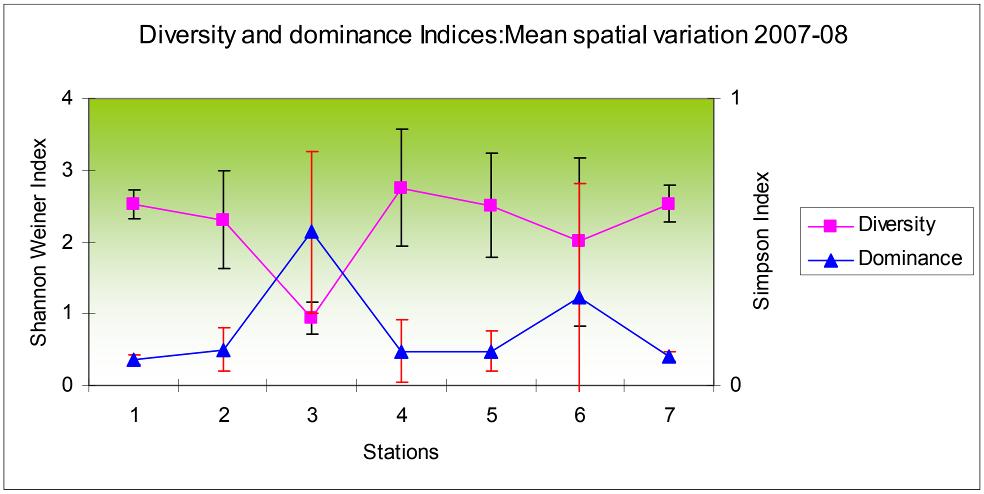


Fig.41



In the present study, 285 species of planktonic microalgae within seven classes/groups viz Cyanophyceae, Chlorophyceae, Bacillariophyceae, Dinophyceae, Chrysophyceae, Dictyochophyceae and Coccolithophorids were observed (Annexure 3). Diatoms and dinoflagellates were the abundant groups in terms of species diversity and density than the other taxonomic groups. Microalgae along the coastal and estuarine stations in the southwest India was dominated by diatoms but a shift to chlorophycean dominance was observed in some periods, particularly in the monsoon at station 6 and shift to dinoflagellates again during the monsoon at station 3. Significant correlations were found between the phytoplankton abundance/standing crop and chlorophyll *a*. Temporal and spatial distribution of phytoplankton was similar to that of chlorophyll *a*. Mostly diatoms were found to be numerically preponderant during the post monsoons. However, *Coscinodiscus asteromphalus* and *Pleurosigma acuminatum* was dominant at station 6 while *Pleurosigma falx*, was dominant species in station 7 during the monsoon in 2006-07. The abundance of dinoflagellates reaches its maximum in 2007-08 during the monsoon and the increase was caused by the dominance of *Ceratium spp.* (*Ceratium furca, C horridum, C symmetricum* and *C trichoceros*). Other taxonomic groups generally were in very low numbers, which were insufficient to depict their seasonal cycle in all six seasons studied.

In FORV *Sagar Sampada* Cruise no. 238, the distribution of microalge in five stations was studied. The highest cell abundance was found in station 5 with 126cells L^{-1}, and the lowest from station 3 with only 18 cells L^{-1}. Nutrients and chlorophyll *a* were found to be higher in station 3, however, statistically these were not significant. 26 species coming under two class, ie., Bacillariophyceae (12 spp.) and Dinophyceae (14spp) were recorded from the entire stations. Toxic dinoflagellate, *Dinophysis caudata* has shown the highest abundance (90cellsL^{-1}) at station 4.

The concentrations of physico-chemical variables such as temperature, salinity, pH, nitrate, phosphate and silicate were typical of open sea conditions (figs. 19, 20). The value of nitrate was high when compared to phosphate and silicate. None of these have shown a significant correlation with standing crop or chlorophyll *a*.

In FORV *Sagar Sampada* Cruise no. 241, ten stations were analysed. The cell abundance was found to be the highest at station 2 with 143 cells L^{-1}, and the lowest from station 5 with 38 cellsL^{-1}. A total of 42 species coming under both the classes Bacillariophyceae (20 spp.) and Dinophyceae (22spp) were recorded. Araphid pennate diatom, *Asterionella japonica* was the abundant species with 43cellsL^{-1} at station 6.

The Redfield ratio of (N:P) and (Si:N) were the lowest in most of the stations during Cruise 238. However, in cruise no.241, N:P ratios were lower while the Si:N ratio was higher. When the Si:N ratio is higher than 1, it would support more diatom species (Piehler *et al*., 2004).

It is noted that the diversity of dinoflagellates was higher than that of the diatoms. 57 species recorded belong to 29 genera (Annexure 4) within 2 classes, Bacillariophyceae (17 genera) and Dinophyceae (12 genera). Dinophyceae was the dominant with 30 species (53%) and bacllariophyceae with 27 species (47%). Among bacllariophyceae, centric diatom *Thalassiosira* was dominant with 4 species and *Ceratium* was dominant with 8 species in dinophyceae.

In the present investigation, 285 species recorded from 7 coastal and estuarine stations and 57 species from 2 FORV *Sagar Sampada* cruises, together contribute 311 species of planktonic microalgae, in which thirty one species were common (Annexure 5).

These 311 species belong to 101 genera in the following classes/groups viz., Cyanophyceae (9 genera), Chlorophyceae (22 genera), Bacillariophyceae (51 genera), Dinophyceae (16 genera), Chrysophyceae (1 genus), Dictyochophyceae (1 genus) and Coccolithophorids (1 genus).

Class bacllariophyceae was the dominant group with 185 species (59.4%), followed by dinophyceae with 64 species (20.57%), chlorophyceae with 43 species (13.8%), cyanophyceae with 14 species (4.5%). Dictyochophyceae with 3 species and coccolithophorids and chrysophyceae with single species each.

In the present investigation, diatoms were the dominant group providing 59.4% of the total microalgae. Vanormelingen *et al*., 2008, reported that the diatoms are one of the most successful contemporary groups of photosynthetic eukaryotic micro-organisms. They inhabit almost any kind of aquatic environment, and can also occur as endosymbionts in dinoflagellates and foraminifers (Round *et al*. 1990). Diatoms have global significance in biogeochemical cycles, and provide 20–25% of globally fixed carbon and atmospheric oxygen. The actual global diversity of diatoms may up to 200,000 extant species (Mann and Droop 1996). In the *Iconographia Diatomologica* series (edited by Lange-Bertalot) alone, more than 1400 new diatom taxa have been described since 1995, many of which were previously regarded to be part of a morphological continuum within a single species. Recent studies have revealed that diatom community structure and diversity are influenced by geographical factors independent of environmental conditions (Vanormelingen *et al*., 2008).

The second dominant group is dinoflagellates (20.57%). Taylor *et al*., (2008), reported that in tropical oceanic regions dinoflagellates are the dominant protist group and show their greatest diversity. The distribution dinoflagellate has been termed "*modified latitudinal cosmopolitanism*" ie; the same morphospecies occur within similar climatic zones in both northern and southern hemispheres or in other words, true endemicim is rare. Unlike diatoms, the entire microplankton community of dinoflagellates in the northern and southern temperate ocean waters is virtually identical. The Indo-Pacific region is richer in dinoflagellate species than the tropical Atlantic (Taylor, 2004). In the present investigation, the highest diversity and abundance of dinoflagellate species were recorded from the open sea cruises than from coastal and estuarine stations. Taylor *et al.,* (2008), reported that the Indo-Pacific region is richer in dinoflagellate species than the tropical Atlantic. For example, *Dinophysis miles* is unknown from the Atlantic Ocean. In this study the same species was collected from Mahe estuary in very low concentrations during the monsoon 2006-07.

Coesel, (1996) reported that Eastern Asia including India is one among the ten desmid floral regions of the world. Their contribution to the total algal biomass, desmids seem to play a more important role in tropical aquatic ecosystems. Chlorophyceae, especially desmids are the quantitatively dominant group of primary producers in tropical freshwater ecosystems. (Coesel and Krienitz, 2008). Sanilkumar and Thomas (2006) reported that chlorophycean species were the dominant group in a Ramsar site wetland in central Kerala and desmids are the most abundant among chlorophyceae. In the present investigation, 43 species of green algae were recorded including desmids when the salinity was practically nil or very low, especially in three estuarine stations. Even though the recorded species were frequently found in tropical waters, the same was also recorded from Arctic/temperate regions (Medvedeva, 2001).

Probably 20% of all known cyanobacteria occur in saline conditions and a majority of them are truly marine forms (Desikachary, 1959, Thajuddin and Subramanian, 2005). Except *Microcystis aeruginosa,* all the other 14 species recorded were estuarine/marine species. *Microcystis aeruginosa* was recorded during the pre and post monsoon at Muriyad wetland (Sanilkumar and Thomas, 2006). In the present investigation, the cyanophycean species occurred only during the monsoon periods at station 5 and 7.

In the class Bacllariophyceae, pennate diatom *Navicula* was the most abundant species (22spp.). Other major genera such as *Cheatoceros* (12 spp), *Cosciodiscus* and *Pleurosigma* (11spp. each) were also contributed to the total diversity. *Cheatoceros* was the dominant species in a study conducted in Marmara Sea (Balkis, 2003). In Dinophyceae, *Protoperidinium* was dominant with 20 species and followed by *Ceratium* (14spp) *Dinophysis* with 10 species. *Protoperidinium* and *Ceratium spp.* are the dominant dinoflagellate species worldwide (Subrahmanian, 1971; Balkis, 2003; Taylor 2004; Taylor *et al*., 2008)

Among the diatoms, species such as *Campylodiscus iyengarii* Subrahmanyan, *Chaetoceros diversus* Cleve, *Chaetoceros pseudocurvisatus* Mangin, *Cyclotella stylorum* Brightwell, *Rhizosolenia bergonii* Peragallo, *Thalassiosira australis* Peragallo, *Thalassiosira eccentrica* (Ehrenberg) Cleve, *Thalassiosira simensonii* Hasle and Fryxell, *Cyclotella meneghiniana* Kutzing and *Pseudosoleinia calcar avis* were recorded from the open sea waters and may be considered as oceanic species. Similarly, dinoflagellates, such as *Ceratium arietinum* Cleve, *Ceratium candelabrum* var. *depressum, Ceratium contortum* (Gourret) Cleve, *Ceratium pentagonum, Corythodinium tesselatum, Dinophysis hastata* Stein, *Diplopeltopsis minor* Pavillard, *Gymnodinium heterostriatum* Kofoid & Swezy, *Gymnodinium sp.* Stein, *Ornithocercus magnificus, Ornithocercus steinii* Schutt, *Protoperidinium brevipes, Protoperidinium depressum* Baily, *Protoperidinium murrayi* Kofoid, *Protoperidinium ovatum* Pouchet and *Protoperidinium pyriforme* Paulsen were the open sea species, which were not observed from any of the 7 coastal and estuarine stations. Two species, *Campylodiscus iyengarii* and *Cyclotella meneghiniana* were found in coastal and estuarine ecosystems around India (Joseph and Pillai, 1975; Desikachary and Prema, 1987). The latter species was considered as brackish/freshwater species by Gopinathan (1975). Probably this would be the first study which collected *Cyclotella meneghiniana* from open sea waters.

3.4.8 Distributional records

In the present study, 17 species of diatoms have been reported for the first time from Indian waters. The species include *Amphora angusta* Gregory, *A exigua* Gregory, *A turgida* Gregory, *Biddulphia regia* (Schultze) Ostenfeld, *Chaetoceros constrictus* Gran, *Cymbella tumida* Van Heurck, *Gyrosigma hippocampus* (Ehrenberg) Hassal, *G tenuissimum* (Smith) Griffith & Henfrey, *Navicula elegans* Smith, *N rhombica* Gregory, *Nitzschia constricta* (Gregory) Grunow, *N tryblionella* Hantzsch, *Pleurosigma intermedium* W.Smith, *Surirella striatula* Turpin, *Triceratium affine* Grunow, *Tropidonies longa* Cleve and *Thalassiosira australis* Peragallo. The introduction of a particular species to a new geographical area may be either by ship ballast water or aqua-cultural practices (Vanormelingen *et al*., 2008). The taxonomy of the above species (distributional records) is given in annexure 1.

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Chapter 4
Microphytobenthos

Contents

4.1 Introduction

The phytoplankters are generally defined as those micro-autotrophs found within the water column, and the microphytobenthos are those found within the sediments. Both phytoplankton and autotrophic microphytobenthos use light energy to fix CO_2, into organic matter (MacIntyre *et al*., 1996).

The term microphytobenthos refers to the entire microscopic, photosynthetic eukaryotic algae and cyanobacteria that live on the seafloor. The microphytobenthos grow in habitats ranging from wave swept beaches to detritus-laden backwater lagoons, habitats such as salt marshes, submerged aquatic vegetation beds, intertidal sand and mud flats, and subtidal, illuminated sediments (MacIntyre *et al*., 1996).

The microscopic species among the algae, which remain suspended in the water column, are planktonic and those live in association with some substrata are benthic microalgae. Microalgae suspended in the pelagic environments are of various taxonomic groups such as diatoms, dinoflagellates, coccolithophorids, silicoflagellates, green and blue green algae. Several such algal species in spite of their characteristic adaptations to the specific habitat, have been found both in benthic and pelagic environments. Any individual alga may be benthic or planktonic at one time or another, but several species are characteristically adapted for either benthic or pelagic environments. Though the taxonomy and eco-physiology of planktonic microalgae in the Indian Ocean have been investigated, practically no such work has been done on benthic microalgae but for a few isolated observations.

The benthos (Greek- ‘*Bevoo*’ = bottom) is an assemblage of organisms living in the benthic habitat of various aquatic ecosystems. These organisms include both flora and fauna; "phytobenthos" referring to the primary producers including various algae and other aquatic plants, whereas "zoobenthos" refers to all consumers comprising of protozoa and benthic animals. Benthic microbial flora, constitute the decomposer community -bacteria, fungi and many protozoa of the benthic environment.

In general, benthic communities include haptobenthos and herpobenthos. Haptobenthos are the organisms that grow on solid substratum, organic or inorganic object. The herpobenthos grow in or on mud, which 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).

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).

Benthic microalgae are always found associated with some kind of substrata in different coastal habitats within the sediment of intertidal areas. These habitats include estuaries, sand flats, muddy shores, salt marshes and deep soft substrate areas. In estuaries microalgae inhabit the few top millimeters of the sediment and live interstitially between the grains, so they are able to perform photosynthesis (Underwood *et al*., 1995). In muddy shores, large concentrations of benthic microalgae such as diatoms, dinoflagellates, other flagellates, cyanobacteria and filamentous green algae live within the sediment particles.

The benthic substrata may either be organic or inorganic. Based on the substratum affinity, phytobenthos can be classified as epilithon, attached to stones and rocks; epipelon, attached to silt or clay; epipsammon, attached to sand; endopelon, inside the sediment; endolithon, inside rock; epiphyton, attached to macrophytes; epizoan, attached to animals and psychropelon, attached to ice (Round, 1966, 1971, 1991). Epilithic algae grow on hard, relatively inert substrata such as gravel, pebble, cobble and boulder that are bigger than most algae. Epiphytic algae grow on plants and larger algae, which provide relatively firm substrata those are bigger than the epiphytic algae, but can be highly active metabolically and can be a great source of nutrients (Hynes, 1970).

Benthic microalgal species serve as the food of prawns and other crustaceans and oysters and they have a significant role in the bioproductivity of benthic environment. In fact, the contribution of benthic algae is more than that of any other type of algae in shallow water. On tidal flats benthic macro-organisms receive their nutritional needs by feeding on benthic microalgae and labile organic matter settling out of the overlying water. Surfacial algal covers are food sources for surface deposit feeders and act as interceptors for nutrients that are regenerated in sediments. When dividing production and respiration among benthic size groups, bacteria and microalgae are the most productive within tropical and temperate intertidal sediments (Gillespie *et al*., 2000).

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* 1^{-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 and other sediment associated microorganisms secrete extracellular polymeric substance (EPS) that act to bind sediments. Benthic diatoms are the major producers of EPS, which is a complex and still poorly described mix of polysaccharides and other compounds. Some diatoms and cyanobacteria also from chains or colonies that can bind sediment particles by direct contact and adhesion. Stabilization of the sediment at the interface by microalgal EPS secretion and growth forms may offer several adaptive advantages to microalgae themselves and is likely therefore to be a key feature of their ecology. Stabilization allows benthic microalgae to resist displacement and re-suspension which may sometimes carry them into less desirable habitats or expose them to suspension feeders. Stabilization may reduce damage to microalgal cells by abrasion and collision with otherwise unconsolidated sediment grains. Stabilization of the interface also allows benthic microalgae to remain fixed while overlaying water flows past, which constantly replenishes their nutrient supply even at low ambient nutrient concentrations and reduce the thickness of the diffusive boundary layer adjacent to cells, which might otherwise limit production and nutrient uptake.

These microalgae besides being the primary producers in the benthic ecosystem have several other ecological significance. They also serve as important habitats for smaller invertebrates such as chironomids, amphipods and several smaller meiofauna (Power, 1990; Dodds and Gudder, 1992). Benthic microalgae attached to macrophytes trap nutrients before they reach water column and returns them to the sediments when epiphytic algae settle to the bottom (Moeller *et al*., 1988; Burkholder *et al*., 1990). They serve as chemical modulators in aquatic ecosystems (Lock *et al*., 1984). The conversion of atmospheric N_2 to

NH_3 and amino acids by blue green algae and diatoms with endo-symbiotic blue-green algae may increase primary productivity in nitrogen deficient habitats (Fairchild *et al*., 1985; Peterson and Grimm, 1992).

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 carbohydrate released by microalgae is utilized by these benthic algal species, compensating the loss of energy due to extra-cellular release of organic substances. In heterotrophic nutrition, exogenous carbon source is taken up by the cell through passive diffusion and is 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 get accumulated in the benthic environment 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.

The fishery resources in the whole aquatic ecosystem are generated from various types of autotrophic plants, the most significant among them are the microalgae, which are either suspended or attached to some substrata. Solar energy is transformed into potential food energy by these producers at the primary trophic level. Benthic microalgae or microphytobenthos are, in fact, the dominant flora in the littoral zone and estuaries. 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, 1999; Cahoon *et al*., 1993; 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).

The abundance of microphytobenthos within the upper 5 mm to 10 mm of the sediment surface varies from about 10^5 cells/cm^3 to 10^7 cells/cm^3 depending on location, season, and sediment properties. The microphytobenthos may be stratified in species-specific patterns over vertical distances of tenths of a millimeter. In low energy, organic-rich environments, the microphytobenthos may be limited to the upper few millimeters of the oxygenated sediment. In contrast, viable microalgae can be found distributed uniformly to depths of tens of centimeters in the well-mixed sandy sediments found in high energy environments (Steele and Baird 1968; Fenchel and Straarup 1971; Fielding *et al*., 1988).

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 contribution of this group of microscopic algae is very significant in the productivity of shallow zone such as Exclusive Economic Zone. This zone includes continental shelf and other neritic environment form the most productive regions of the oceans. Considering that the neritic zone is upto a depth of 200m, Svedrup *et al*., (1962), calculated this area to be 7.6 % of the entire ocean. For Indian Ocean and adjoining seas the area with in <200m was calculated to be 2.622 x 10^6 km^2. This zone having considerably vast benthic habitat in the ocean with microphytobenthos therein serves as a perpetual generator of food energy.

Though the annual primary organic productivity in the EEZ of India, having an area of 2.02 x 10^6, was estimated to be 283 million tonnes of carbon, (Nair and Gopinathan, 1981); it was based exclusively on the contribution of planktonic microalgae. The annual potential benthic production in the Cochin estuary was estimated to be 40 x 10^4 tonnes of carbon (Sivadasan, 1996) as against the 10 x 10^4 tonnes of carbon (Nair *et al*., 1975). For a more realistic assessment of fishery resources and for valuable information on its potential it is also essential to have an understanding of the contribution of benthic microalgae or microphytobenthos.

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. So also is the case of shallow coastal waters of the seas, where the benthic productivity is higher than that of planktonic productivity. Exclusive Economic Zone especially the littoral zone by virtue of its comparatively shallow bottom, lie within the photic zone and is very productive.

Benthic microalgae of the marine and brackish water habitat belong to various taxonomic divisions such as Cyanophyta, Heterokontophyta, Haptophyta, Dinophyta, Euglenophyta and Chlorophyta. 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) and Cahoon and Laws, (1993). Lewin and Lewin (1960) observed that certain species of *Cyclotella*, *Navicula*, *Amphora*, *Porosira* 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.

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 unravel a clear understanding on microphytobenthos.

A two year study on the microphytobenthos in seven stations along the southwest coast of India, revealed their spatio-temporal variations, vertical distribution patterns and substratum affinities.

4.2 Review of Literature

Most probably, the first authentic study on microphytobenthos was by Steele and Baird in 1968, who revealed that at the low water mark viable diatom populations were found at a depth of 20cm deep in the sand.

Leach, in 1970, studied the epibenthic algal production in an estuarine mud flat in the Ythan estuary on the northeast Scotland by ^{14}C method. 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 Straarup, in 1971, investigated the vertical distribution of photosynthetic pigments along with the light penetration in the marine sediments. They concluded that the microflora in sandy sediments conditions are much like that of phytoplankton, but the latter live on more light absorbing medium. If the efficiency of light increases, the chlorophyll would be more per unit area in the sediments.

Round, in 1979, analysed a diatom assemblage living on and in the inertidal sand flats of Barnstable harbour at Massachusetts in US. An endopsammic assemblage of diatoms, mainly *Amphora* species, living below the surface is described for the first time from such a type of marine situation.

Gopinathan (1984) studied the littoral diatoms of South West Coast of India and described 105 species of diatoms. Desikachary *et al*., (1987a) investigated the diatom flora of sediments from Indian Ocean.

Sundback and Jonsson in 1988, quantified the sublittoral sediment-associated microflora (microphytobenthos) of Laholm Bay, southeastern Kattegat, for a period of 3 years by taking monthly sediment samples at depths of 2-20m.

In 1989, Delgado, a well known Spanish phycologist, studied the abundance and distribution of microphytobenthos in the Bays of Ebro Delta in Spain.

De Jonge, and Van Beusekom, in 1992, examined the contribution of re-suspended microphytobenthos to total phytoplankton in the EMS estuary and its expected role for grazers.

In 1994, Blanchard and Gall, investigated the microphytobenthos in Marennes-Oleron Bay, France and showed that the benthic microalgae did experience photo-inhibition in experimental conditions and there was no indication of a photo-inhibitory effect in situ.

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.

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, McIntyre *et al*., and Miller *et al.,* highlighted the ecological role of microphytobenthos. These two articles are the most quoted scientific articles describing any microphytobenthos investigations world wide.

Barranguet, in 1997, studied the production and biomass of microphytobenthos in a Mediterranean mussel farm during 1991–92.

Cahoon and his co-workers (1990, 1992, 1993a,b, 1994, 2002) have contributed tremendous inputs to the field of microphytobenthos. The role of benthic microalgae in neritic ecosystems was the most comprehensive one, published in 1999.

Wolfstein *et al*., in 2000, investigated the microphytobenthic biomass and primary production in the northern German Wadden Sea from October 1996 to September 1997.

Hillebrand and Sommer, in 2000, conducted in situ experiments in Kiel Fjord to analyze the response of microalgal diversity to colonization time and to artificial eutrophication.

In 2001, Masini and McComb, studied the microphytobenthos from shallow sand flats of the Swan–Canning Estuary, Perth, southwestern Australia. The sediment photic zone was estimated as 0-5 mm in fine sediments of the upper estuary and 3-5 mm in coarse sediments of the lower estuary.

Blanchard *et al*., (2001), investigated the dynamic behaviour of microphytobenthic biomass in a European intertidal mudflat. The observations hypothesized that the high productivity of the microphytobenthic community in intertidal mudflats is due to the tight coupling between physical and biological processes.

Sylvestre *et al*., in 2001, enumerated 6 tychoplanktonic and 8 planktonic species from the benthic diatom flora in a hypersaline coastal lagoon at the Lagoa de Araruama (R.J.), Brazil.

Mitbavkar and Anil (2002, 2004 and 2006) investigated on the vertical migratory rhythms and community structure of microphytobenthos of Goan mud flat.

In 2002, Blackford, made a modeling study on the influence of microphytobenthos on the Northern Adriatic Ecosystem and found that the light availability is the key factor limiting microphytobenthos, with self-shading dominating this effect in established populations.

Ribeiro *et al*., 2003, made a taxonomic survey of the microphytobenthic of two Tagus estuary mudflats. A total of 48 diatom taxa were identified to the genus or species level.

Parodi and Barria de Cao, in 2003, analyzed the distribution of microphytobenthos in the sediment layer depth of 0-40mm, in Bahia Blanca estuary, Argentina.

In 2003, Urban-Malinga and Wiktor, investigated the microphytobenthic primary production and chlorophyll *a*. The chlorophyll *a* concentrations varied between 0.88 and 12.18μg cm^{-3}.

Brotas and Plante-Cuny, in 2003, proposed the use of HPLC pigment analysis to study microphytobenthos communities. A total of 11 chlorophylline pigments and 19 carotenoids were identified.

Mundree *et al*., in 2003, studied the seasonal variations in the vertical distribution of benthic microalgal biomass in relation to major factors potentially controlling their dynamics in the sub-tropical temporarily open Mdloti Estuary, South Afriaca. The chlorophyll *a* concentrations in the upper 5 cm of sediment ranged from 259mg m^{-2} to 977mg m^{-2} during the closed phase and from 6.7 mg m^{-2} to 305 mg m^{-2} during the open phase.

In 2004, Migne *et al*., investigated the in situ measurements on seasonal variations and annual production of benthic primary production in the Bay of Somme (English Channel). Primary production and respiration were estimated by in situ measurements of carbon dioxide fluxes using infra-red analysis.

Gerbersdorf *et al*., in 2004, investigated the primary production of the microphytobenthos in two shallow estuarine areas different in their trophic status at the southern Baltic Sea.

Easley *et al*., 2005, studied the temporal patterns of benthic microalgal migration on a semi-protected beach. The species belong to diatoms, euglenoids, chlorophytes as well as cyanobacteria were reported. Murolo *et al*., in 2006, carried out the Spatio-temporal variations of microphytobenthic biomass in the Botafogo and Siri estuaries, Pernambuco - Brazil.

Cartaxana *et al*., in 2006, studied the abundance and distribution of microphytobenthic pigments determined by HPLC (chlorophylls and carotenoids) and was compared between muddy and sandy sediments of the Tagus estuary

(Portugal). Pigment analysis also revealed similar microphytobenthic communities in terms of algal classes.

Spilmont *et al*., in 2006, performed a two year survey of benthic primary production in two stations of an intertidal mudflat (a muddy-sand station and a muddy station) in the Seine Estuary (English Channel, France). Gross community production ranged from ca. 0 to 77 mg Cm^{-2} h^{-1} at the muddy-sand location and from ca. 0 to 122 mg Cm^{-2} h^{-1} at the muddy location.

In 2007, Reiss *et al.*, analyzed the surface sediment characteristics comparison between shallow and deep areas using phytopigment composition of the sediment microphytobenthos of the Dogger Bank, North Sea. High-performance liquid chromatography pigment analyses revealed that concentrations of chlorophyll *a*, chlorophyll *c* and fucoxanthin are mainly associated with benthic diatom flora at most parts of the Dogger Bank.

Meleder *et al*., 2007, investigated the spatio-temporal changes in microphytobenthos species composition in relation to structural variables in a shellfish macrotidal ecosystem at Bourgneuf bay, France. It is found that microphytobenthos dominated by 97% diatoms belonging to 89 taxa.

Van Leeuwe *et al*., (2008), described the photo-acclimation in microphytobenthos and role of xanthophylls pigments.

Davoult, *et al.,* (2009) studied the spatio-temporal variability of intertidal benthic primary production and respiration at Western English Channel, France. They found that microphytobenthic community was characterized by a self-limitation of its primary productivity by its own biomass.

4.3 Results

4.3.1 Standing crop

The species variation and abundance of microphytobenthos in seven stations along the southwest coast of India from Vaadi in the south to Mahe in the north, extended over a distance of 450km was analyzed for two consecutive years (2 cycles of seasons) 2006-2008.

Station wise seasonal fluctuation of microphytobenthos, in the 'phytozone', which is found to be 5cm from surface to deep in the sediment column is given below.

In 2006-07, during the pre-monsoon, at station 1, the total number of cells in the phytozone' of 5cm sediment column was found to be 46 belonging to 8 species. Their strata wise distribution being 25 cells/cm^3 in the first stratum (0-1cm), 11 in the second (1-2cm), 5 in the third (2-3cm), 3 in the fourth (3-4cm) and 2 cells/cm^3 in the fifth (4-5cm) and final sediment depth. Among eight species, *Amphora coffeaeformis,* and *Cymbella marina* were the abundant species. All the species were not recorded from all the strata. More species were found in the upper stratum, deeper the stratum lesser the number and species.

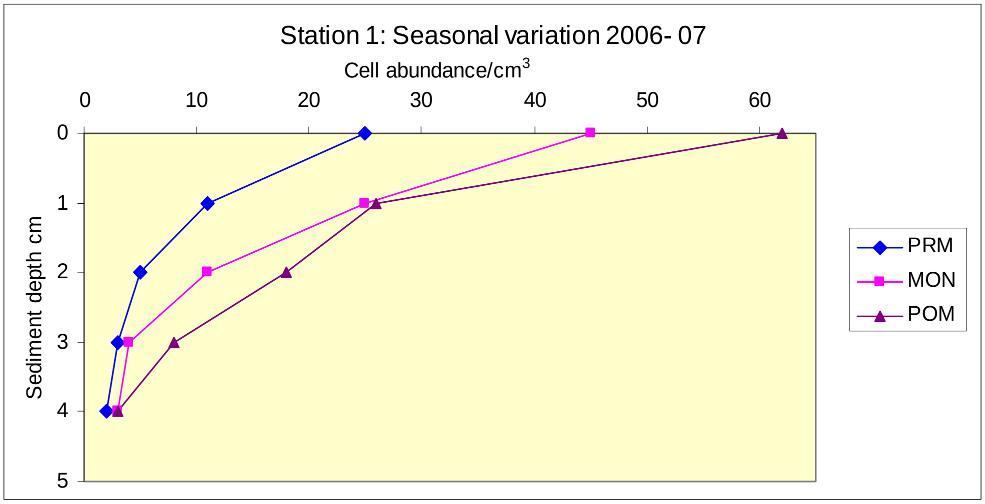
In the monsoon, the total number of cells in the phytozone of 5cm sediment column was 88 cells. The vertical distribution in the 5 strata from surface (1st stratum) to the bottom (5th stratum) was 45, 25, 11, 4 and 3 respectively. *Gyrosigma spencerii, Diploneis notabilis* were dominant among the nine species present and *Gyrosigma spencerii* was found distributed in all the strata. During the post monsoon month, the total number of microphytobenthos in the phytozone was 117 distributed in eleven species. The strata wise concentrations were 62, 26, 18, 8 and 3 from top to bottom. *Diploneis notabilis* and *Nitzschia frustulum* were found in all the five strata of sediment (Fig.42, Table 17).

Table 17. Station 1 Vaadi

		2006-07															2007-08														
		Pre monsoon					Monsoon					Post monsoon					Pre monsoon					Monsoon					Post monsoon				
	Class: Bacillariophyceae	A*	B*	C*	D*	E*	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
1	*Achnanthes brevipes*											3	1	4	1												3	2	2		2
2	*Amphora coffeaeformis*	7	3	2		1											5	3	2												
3	*Amphora turgida*		1									11	4	1								3		2	2	1	3	2	2	3	
4	*Aulacodiscus orbiculatus*						2										3	2	1												
5	*Biddulphia mobiliensis*						2										6	5	2	2	1										
6	*Caloneis permagna*											7	4	2																	
7	*Coscinodiscus marginatus*																										3				
8	*Cymbella aspera*																														
9	*Cymbella marina*	7	3	1	1												2	8	3	2	1	4	3	2	1						
10	*Diploneis littoralis*																										7	5	3	1	
11	*Diploneis notabilis*	2		1	1		8	10	2	1		4	2	2	2	1						8	6	4	3	2					
12	*Diploneis weissflogii*																														
13	*Gyrosigma nodiferum*																														
14	*Gyrosigma spencerii*	3	2				8	3	3	1	1	13	5	3	1												4		2	1	2
15	*Licmophora flabellata*																5														
16	*Navicula cincta*						7	3	1	1																					
17	*Navicula directa var. remota*												3																		
18	*Navicula forcipata*																6	2	2	2	2	2	3	1	2						
19	*Navicula hennedyei*	4										5		2	2	1		7	1			8	6	7	3	3	9	4	6	5	
20	*Navicula monilifera*											5	2	1	1																
21	*Nitzschia closterium*						9	2	2								5	3	2	1											
22	*Nitzschia frustulum*		2	1	1			2	2	1	2	4	2	2	1	1	8	2	1	2	1						6	3	2	2	
23	*Nitzschia longissima*																														
24	*Nitzschia panduriformis*											7	3	1			8	2			1						3	3			
25	*Nitzschia tryblionella*						6	5	1													4	4	2							
26	*Pleurosigma aestuarii*																														
27	*Pleurosigma angulatum*	2				1																2									
28	*Pleurosigma falx*											3																			
29	*Surirella fastuosa*																														
30	*Thalassiosira coramandeliana*						3																								
	TOTAL	**25**	**11**	**5**	**3**	**2**	**45**	**25**	**11**	**4**	**3**	**62**	**26**	**18**	**8**	**3**	**48**	**34**	**14**	**9**	**6**	**31**	**22**	**18**	**11**	**6**	**38**	**19**	**17**	**12**	**4**

A*, B*, C*, D* and E*, denotes the respective vertical strata as, 0 or surface, 1, 2, 3 and 4

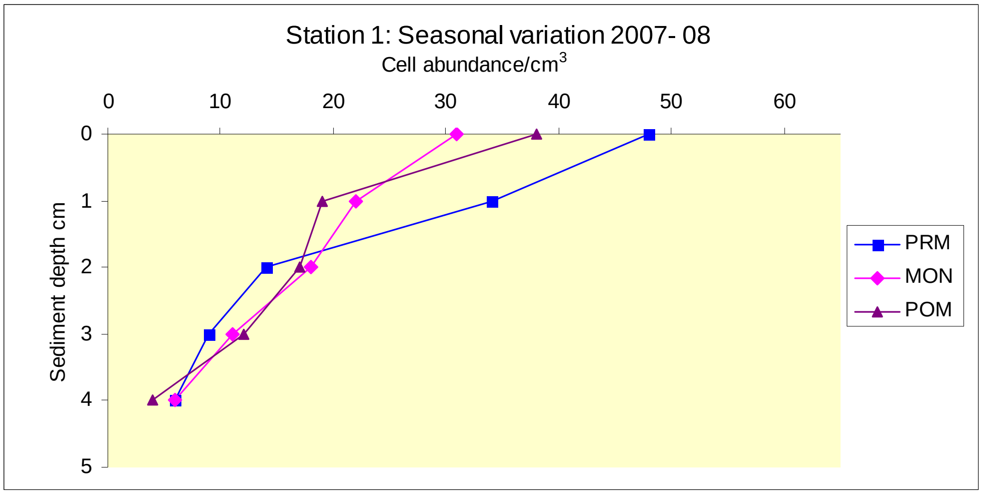
Fig.42



In 2007-08, during pre monsoon, at station 1, the total number of microphytobenthos in the phytozone of 5cm sediment column was 111 cells. The strata wise vertical distribution of microphytobenthos in the 5 strata from surface to bottom being 48, 34, 14, 9 and 6 respectively. Among the 10 species present, *Biddulphia mobiliensis, Cymbella marina, Navicula forcipata, Nitzschia frustulum* were found in all the sediment strata. In monsoon, the number of cells recorded was 31, 22, 18, 11 and 6 from the 1st to the 5th stratum of the phytozone. A total of 88 cells were found in the entire 5cm sediment column. Out of nine species observed, *Diploneis notabilis, Navicula hennedyei* were present in all strata. In the post monsoon, the total count in the 5cm column was 90 cells. The distribution of standing crop was 38, 19, 17, 12 and 4, from top to bottom. None of the eight species were found recorded in all the strata (Fig. 43, Table 17).

30 species of diatoms were recorded from station 1, Vaadi, during the entire period of six seasons. None of the species was observed in all the seasons. *Navicula hennedyei*, *Nitzschia frustulum* were observed in five seasons.

Fig.43



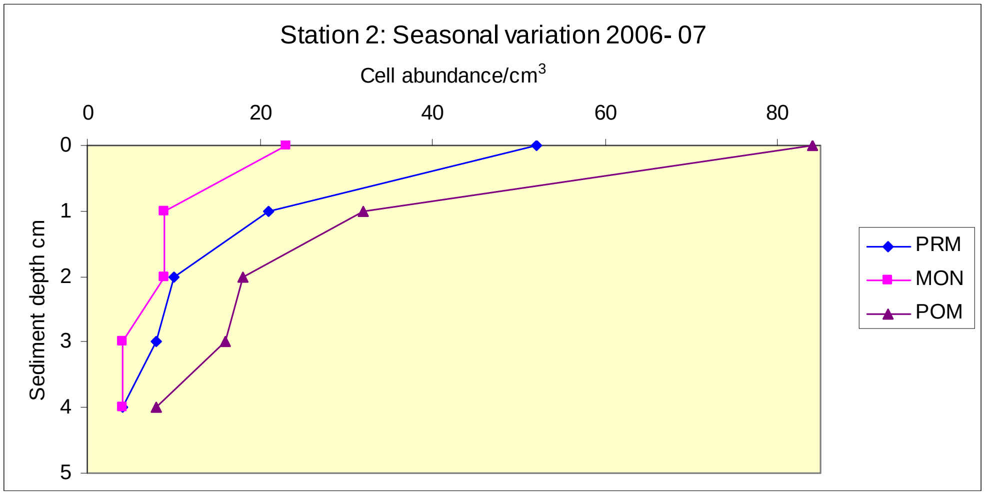
At station 2, during 2006-07, the total number of microphytobenthos in the phytozone was 95 cells, distributed in nine species in the pre monsoon. On strata wise analysis of the vertical column of the sediment, the distribution of microphytobenthos at various strata from surface (0-1cm) to the bottom (4-5cm) was found to be 52, 21, 10, 8, and 4 respectively. *Amphora coffeaformis, Pleurosigma angulatum, Navicula hennedyei* and *Gyrosigma spencerii* were recorded from all the 5 strata of mud. During monsoon, 49 cells were present in the 5cm vertical column of sediment distributed with five species. *Amphora coffeaformis, Nitzschia longissima*, *Diploneis weissflogii* were present in all the strata. The vertical distribution of microphytobenthos was 23, 9, 9, 4 and 4 in their respective sediment depths from surface to bottom.

In post monsoon, 158 cells were present in the 5cm phytozone. Among the nine species recorded, *Amphora coffeaeformis, Caloneis permagna, Diploneis notabilis, Nitzschia panduriformis* and *Pleurosigma falx* were found in all the five strata of sediment and the cell counts were 84, 32, 18, 16 and 8 respectively (fig.44, table 18).

Table 18. Station 2 Kavanad

		2006-07															2007-08														
	Class: Bacillariophyceae	Pre monsoon					Monsoon					Post monsoon					Pre monsoon					Monsoon					Post monsoon				
		A*	B*	C*	D*	E*	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
1	*Amphora coffeaeformis*	8	3	1	1	1	5	2	2	1	2	14	6	3	2	2	3	2				4	2	1	1	1	5	2		1	1
2	*Caloneis permagna*		2									8	1	1	1	1															
3	*Cymbella marina*											2					4	2	1	1	1						5	4	1	1	
4	*Diploneis notabilis*	7	2		2							15	3	2	2	1	7	3		2	2	3	2	2	2		3				
5	*Diploneis weissflogii*						5	2	2	2	1											3	2								
6	*Gyrosigma nodiferum*											7	3	3													3	3	1		1
7	*Gyrosigma spencerii*	11	3	3	1	1											4	3	2		2	1	1		1	1					
8	*Navicula directa var. remota*	4			1							8	2		2	1	2	2		1							3				
9	*Navicula forcipata*						3	2	2													3	1	1			6	4	2	2	1
10	*Navicula hennedyei*	5	2	2	2	1																									
11	*Nitzschia closterium*	4	3									8	5	3	3							2	2	2		1	5	5			1
12	*Nitzschia longissima*						4	1	1	1	1											1	2				8		2	2	2
13	*Nitzschia panduriformis*	3	2	1								6	6	2	2	1	8	5	3	3	1						8	4	2	1	
14	*Pleurosigma aestuarii*						6	2	2													3	2	3	2	1		2			
15	*Pleurosigma angulatum*	10	4	3	1	1											5	2	2								7	5	2		1
16	*Pleurosigma falx*											16	6	4	4	2	2	1	2								6		3	3	
	TOTAL	**52**	**21**	**10**	**8**	**4**	**23**	**9**	**9**	**4**	**4**	**84**	**32**	**18**	**16**	**8**	**35**	**20**	**10**	**7**	**6**	**20**	**14**	**9**	**6**	**4**	**59**	**29**	**13**	**10**	**7**
	A*, B*, C*, D* and E*, denotes the respective vertical strata as, 0 or surface, 1, 2, 3 and 4																														

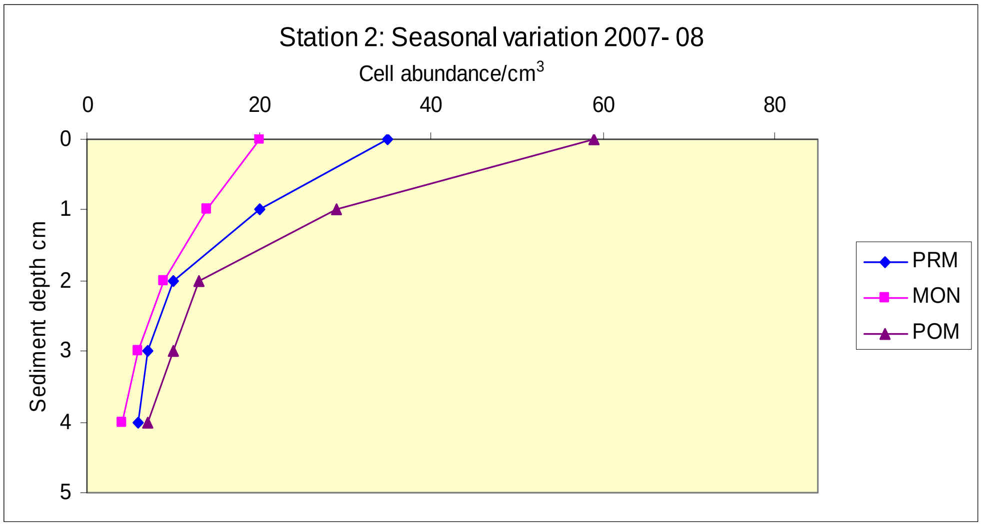
Fig.44



In the second year, during the pre monsoon, the total of 78 cells of microphytobenthos were found in the phytozone of 5cm depth. The strata wise analysis recorded 35, 20, 10, 7 and 6 cells respectively at various strata from top to the bottom of phytozone. Among the eight species found in the column of sediment, *Cymbella marina* and *Nitzschia panduriformis* were the two species present in the entire five strata.

During the monsoon, total microphytobenthos in the 5cm sediment column was 53. *Amphora coffeaeformis* and *Pleurosigma aestuarii* were found in all the strata among the eight species recorded. The microphytobenthos decreased from 20 to 4 from the surface to the last layer of the sediment. In the post monsoon, 118 cells were recorded distributed in 12 species, of which, only one species, *Navicula forcipata* was found in all the five sediment strata. Microphytobenthos present in various strata from surface to the bottom were 59, 29, 13, 10 and 7 cells respectively (Fig. 45, Table 18). Thus in the second station at Kavanad, the microbenthic flora includes sixteen species in the entire six seasons. *Amphora coffeaformis* was the only species found in all seasons.

Fig. 45



In 2006-07, at station 3, during the pre monsoon, 157 cells were present in the 5cm phytozone. Among the fifteen species recorded, *Caloneis permagna, Navicula directa var. remota, Nitzschia frustulum, Pleurosigma aestuarii* and *Pleurosigma falx* were found in all the strata of sediment. The benthic microalgae recorded at various strata were 82, 32, 20, 13 and 10 respectively in various strata from the surface layer to the bottom of the sediment column.

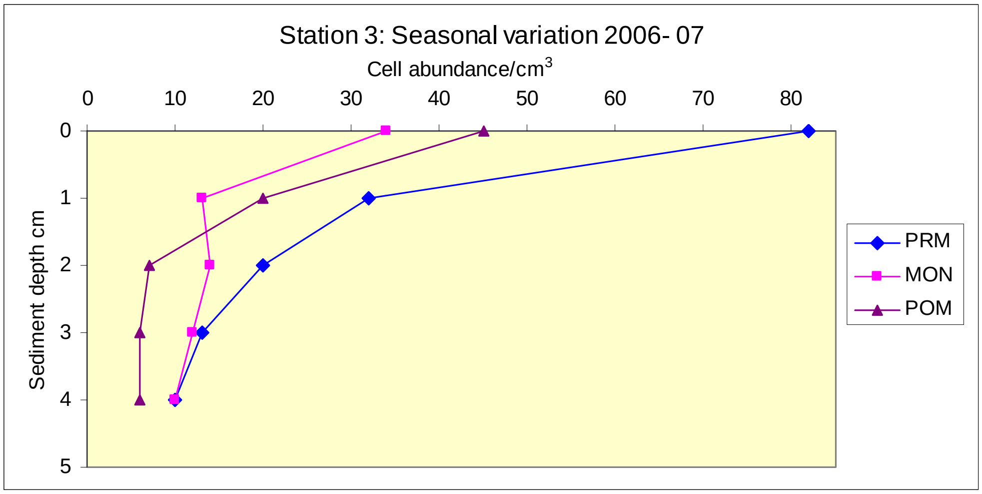
During the monsoon, eleven species were present and total number of cells was 83 in the phytozone. *Caloneis permagna, Gyrosigma nodiferum, Pleurosigma falx* and *Surirella fastuosa* were recorded from all the five sediment depths. The distribution of microphytobenthos at the various strata from top to bottom was 34. 13. 14, 12 and 10 respectively. In post monsoon, the total number of microphytobenthos in the 5cm sediment column was 84 distributed in ten species. The strata wise cell density was 45, 20, 7, 6 and 6 respectively from top to bottom (Fig.46, table 19).

Table 19. Station 3 Punnapra

	Class: Bacillariophyceae	2006-07															2007-08														
		Pre monsoon					Monsoon					Post monsoon					Pre monsoon					Monsoon					Post monsoon				
		A*	B*	C*	D*	E*	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
1	*Achnanthes coarctata var. parallela*											7	2		1	1	2										3	2	2	1	
2	*Amphora coffeaeformis*	9	2		2		3	2	1		1						3	2	2		1	2	2		1						
3	*Amphora turgida*						2					7				1											3		2	2	1
4	*Aulacodiscus orbiculatus*	2		1		1																									
5	*Biddulphia mobiliensis*	3		1	1							5	2	2		2	5				1						4	2			
6	*Caloneis permagna*	6	5	2	3	1	3	2	1	1	1						8	4	3			5	2	1	1	1					
7	*Ceratium symmetricum*																					18									
8	*Cymbella marina*	6	1									5	2														6	4	3	2	
9	*Diploneis weissflogii*																										3				
10	*Gyrosigma nodiferum*	9	7	4		1	4	2	2	2	2											5	2	2							
11	*Licmophora flabellata*	4	2										2	2	2	2	4	2	3	2	2										
12	*Navicula cincta*						2		1			7										2		1	1	1	5	3	3	2	2
13	*Navicula directa var. remota*	7	3	2	2	1																									
14	*Navicula forcipata*	4																													
15	*Navicula hennedyei*	6	2	2			4										5	2	2			4	1			1	5	3			1
16	*Nitzschia closterium*																	1		1	1										
17	*Nitzschia frustulum*	5	1	2	2	1	4		3	1	2	2	3		3			3		1											
18	*Nitzschia longissima*								2				3				9	4	2	3							3	2	1	1	1
19	*Nitzschia panduriformis*	6	2																								4				
20	*Pleurosigma aestuarii*	7	4	2	1	1	4	3		4		9	3				7					3	2	1	1	1	3	2	2		2
21	*Pleurosigma falx*	5	3	3	2	3	5	3	3	3	3	3	3	3								6	3	3		1					
22	*Surirella fastuosa*						3	1	1	1	1						8	5	2	2	2	3	1	1	1	1	3				
23	*Thalassiosira coramandeliana*	3		1		1																1	1					2			
	TOTAL	**82**	**32**	**20**	**13**	**10**	**34**	**13**	**14**	**12**	**10**	**45**	**20**	**7**	**6**	**6**	**51**	**23**	**12**	**7**	**5**	**49**	**14**	**9**	**5**	**6**	**39**	**18**	**13**	**8**	**7**

A*, B*, C*, D* and E*, denotes the respective vertical strata as, 0 or surface, 1, 2, 3 and 4

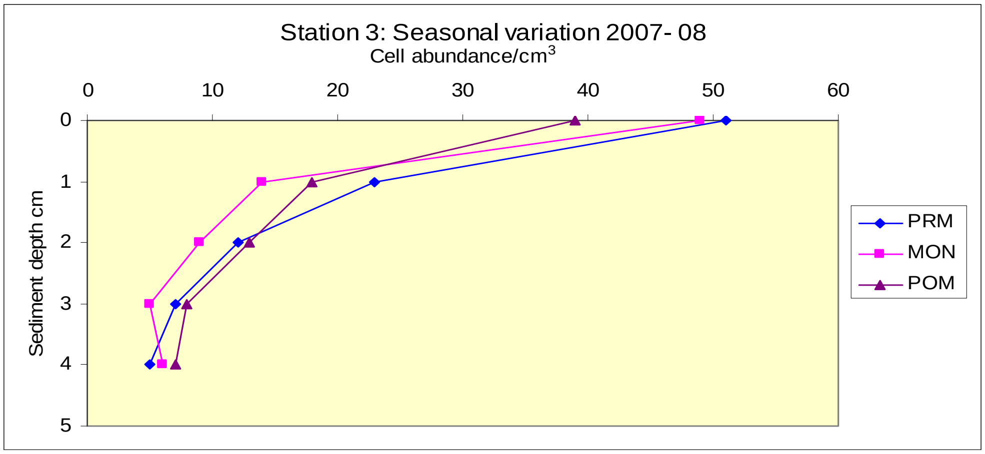
Fig.46



In the pre monsoon 2007-08, total number of cells found in the 5cm deep sediment column was 98, distributed in eleven species. On strata wise analysis, 51, 23, 12, 7 and 5 cells were found from top to the bottom depths. *Licmophora flabellata* and *Surirella fastuosa* were recorded from all the strata. During the monsoon, out of the ten species present *Caloneis permagna, Surirella fastuosa* and *Pleurosigma aestuari* were observed in all the strata. *Ceratium symmetricum,* a photosynthetic dinoflagellate was found in the surface segment. Total abundance of microphytobenthos in the entire 5cm deep sediment column was 83.

The cell abundance was 49, 14, 9, 5 and 6 in their respective depth zones from surface to bottom. In post monsoon, twelve species were recorded from the phytozone with a total number of 85 cells. *Nitzschia longissima* and *Navicula directa var. remota* were distributed in all the strata. The cell enumeration was 39, 18,13,8 and 7, in each segment of 5cm strata respectively. (Fig. 47, table 19). In station 3 at Punnapra, 23 species were recorded during the six seasons. None of the species were present in all the seasons. The dinoflagellate, *Ceratium symmetricum* was also recorded.

Fig. 47



During the first year of the study, at station 4, in the pre monsoon, the total number of microphytobenthos in the phytozone' was 61 belonging to 10 species. The cells were 37, 11, 3, 6 and 4 in respective strata from top to bottom. *Cymbella marina* was the only species present in all the strata. During the monsoon, total number of cells in the phytozone was 97 distributed in eight species. *Navicula elegans* was the only species found in all the strata of sediment. The microphytobenthos at various strata were 66, 16, 6, 5 and 4. In the post monsoon, the total cell count in the 5cm sediment column was 81 distributed among eleven species. Microphytobenthos at various strata were 45, 16, 8, 7 and 5. *Surirella flumiensis* was the only species recorded in all the strata (fig.48, table 20).

Fig.48

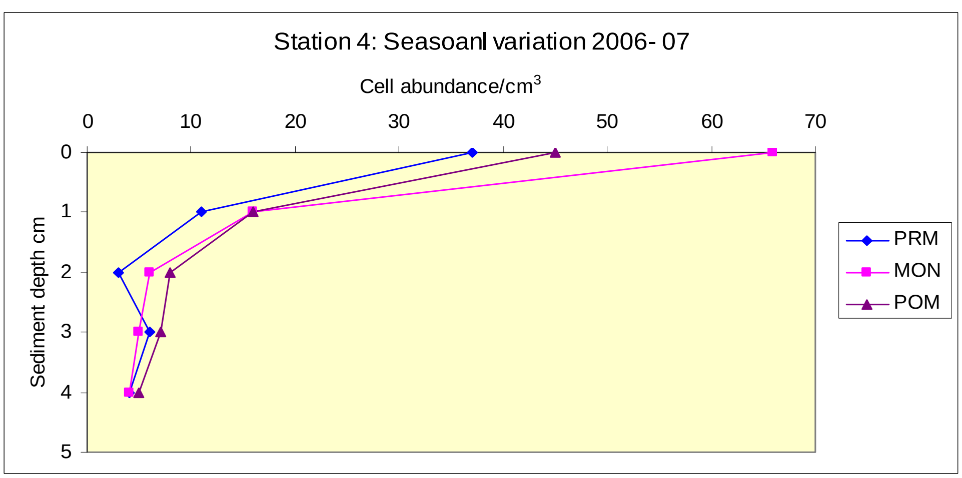


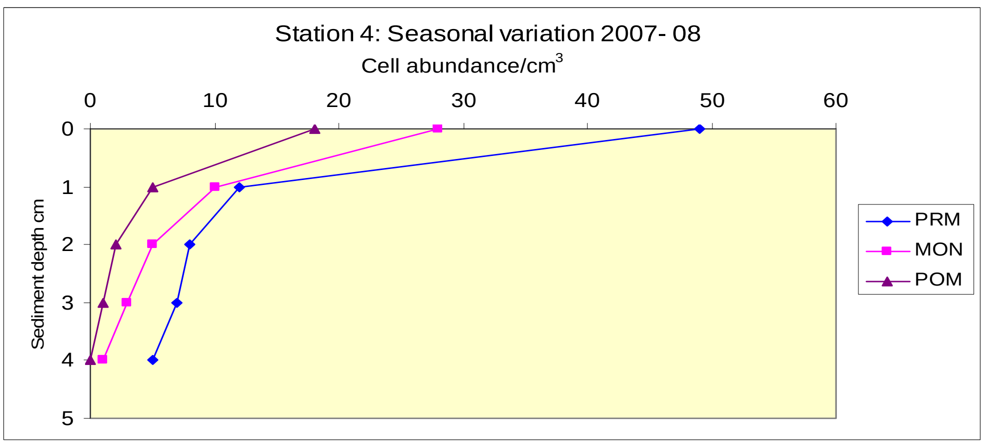
Table 20. Station 4 Azheekode

		2006-07															2007-08														
	Class: Bacillariophyceae	Pre monsoon					Monsoon					Post monsoon					Pre monsoon					Monsoon					Post monsoon				
		A*	B*	C*	D*	E*	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
1	*Achnanthes brevipes*	1																				10	4	2	1	1					
2	*Amphora angusta*						5	2			1																				
3	*Amphora turgida*	3	2		1	1						2	1		1	1											4		1	1	
4	*Caloneis permagna*											1		1																	
5	*Ceratium furca*											3	2	2			4	2		2	1						3				
6	*Cocconeis littoralis*																8														
7	*Coscinodiscus asteromphalus*						10										3														
8	*Cymbella marina*	4	1	1	1	1																									
9	*Diploneis littoralis*						2	1																							
10	*Diploneis notabilis*	5		2		1											4		1	1	1										
11	*Diploneis weissflogii*											4	2		2	1											3	1			
12	*Gyrosigma hippocampus*																12	4	3	2	2										
13	*Gyrosigma spencerii*	5	2		1	1																4	2								
14	*Licmophora flabellata*											2	1	2		1															
15	*Navicula cincta*																1														
16	*Navicula elegans*	2					12	2	2	2	1																				
17	*Navicula forcipata*																6	2	1	1	1						3				
18	*Navicula humerosa*											6	2	2	1							8	2	2	1						
19	*Navicula inclementis*	6	2		2																	6	2	1	1						
20	*Nitzschia closterium*	8	2				12	4	1		1																				
21	*Nitzschia frustulum*											5	2														3	2	1		
22	*Nitzschia panduriformis*											9	3		1	1															
23	*Nitzschia sigma*						8	2		2	1																				
24	*Pleurosigma acuminatum*						8	3				4	1		1		3	2													
25	*Pleurosigma angulatum*	1	1																												
26	*Pleurosigma falx*	2	1		1							3																			
27	*Surirella flumiensis*											6	2	1	1	1	8	2	3	1											
28	*Surirella striatula*						9	2	3	1																	2	2			
	TOTAL	**37**	**11**	**3**	**6**	**4**	**66**	**16**	**6**	**5**	**4**	**45**	**16**	**8**	**7**	**5**	**49**	**12**	**8**	**7**	**5**	**28**	**10**	**5**	**3**	**1**	**18**	**5**	**2**	**1**	**0**

A*, B*, C*, D* and E*, denotes the respective vertical strata as, 0 or surface, 1, 2, 3 and 4

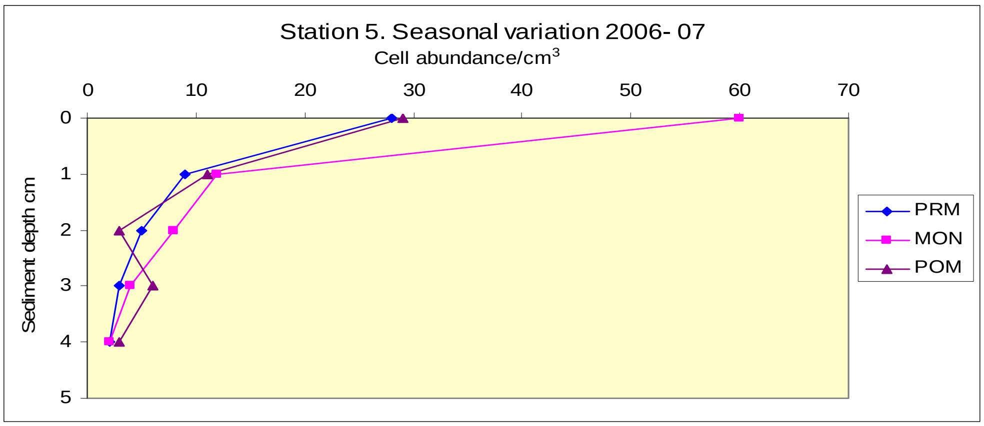
In 2007-08, during the pre monsoon, the microphytobenthos in the 5cm phytozone was 81. Among the nine species observed, *Gyrosigma hippocampus* and *Navicula forcipata* were found in all the strata. The standing crop of microphytobenthos was 49, 12, 8, 7 and 5 in their respective stratum from surface to bottom. In monsoon, the total standing crop in the 5cm sediment column was 47. On strata wise analysis, the number of cells in microphytobenthos was 28, 10, 5, 3 and 1 from top to bottom. Among the four species present, only one species, *Achnanthes brevipes* was found in all the strata. During post monsoon, total number of cells in the 5cm sediment column was 26. Among the six species recorded none of them was present in the entire strata of sediment. Microphytobenthos present in the 1st, 2nd, 3rd, 4th and 5th strata was 18, 5, 2, 1 and 0 respectively (Fig. 49, table 20). In station 4, at Azheekode, altogether, twenty eight species were recorded during the entire six seasons. None of these species was present throughout the seasons.

Fig. 49



In 1st year, at station 5, during the pre monsoon, a total of 47 cells were present in the phytozone of 5cm. Among the eight species recorded, *Nitzschia closterium* and *Surirella fastuosa* were found in all the strata. The cell counts were 28, 9, 5, 3 and 2 respectively from the surface layer to the last stratum with in the 5cm sediment column. In monsoon, the total cells in the 5cm sediment column was 86. The vertical distribution of cell densities were 60, 12, 8, 4 and 2 from top to bottom. Only eleven species were present in this season including four Cyanophycean species. *Surirella* *fastuosa* was recorded in all the sediment strata. In post monsoon, only six species were recorded and a total of 52 cells were found in the phytozone. Vertical distribution of microphytobenthos was 29, 11, 3, 6 and 3. *Surirella flumiensis* and *Pleurosigma aestuarii* were recorded in all the five layers of the sediment (fig.50, table 21).

Fig.50

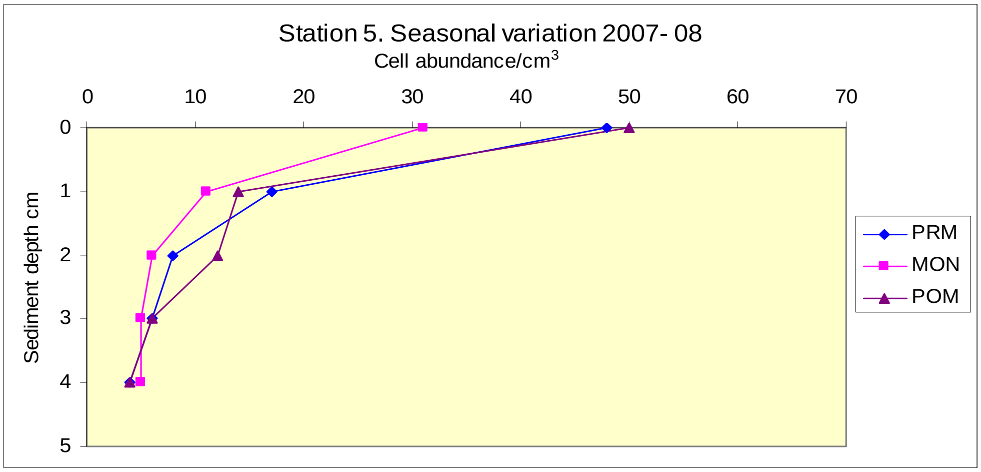


In the 2nd year (2007-08), during pre monsoon, a total of 83 cells were recorded from the 5cm sediment. Among the seven species recorded, viz; *Diploneis littoralis, Cocconeis scutellum, Navicula spectabilis, Pleurosigma aestuarii, Pleurosigma naviculaceum, Gyrosigma nodiferum* and *Amphora coffeaeformis,* last two species were found in all the sediment strata and vertical distribution was 48, 17, 8, 6 and 4. In the monsoon, eleven species were recorded and a total of 58 cells found in the phytozone. *Pleurosigma angulatum* and *Surirella flumiensis* were found in all the five sediment strata. The vertical distribution of microphytobenthos was 31, 11, 6, 5 and 5. In the post monsoon, eight species were observed from the sediment. The total cell count was 86 in the 5cm sediment. *Nitzschia panduriformis* and *Pleurosigma naviculaceum* were found in all the strata. The vertical density of microphytobenthos was 50, 14, 12, 6 and 4 (Fig.51, table 21). In station 5, Balathuruthu, twenty six species including Cyanophycean species such as, *Merismopdia elegans, Chroococcus turgidus, Oscilllatoria chalybea* and *Lyngbya aestuarii,* were recorded. None of the species was present in all the seasons. *Navicula spectabilis* was found in five out of six seasons studied (table 21).

Table 21. Station 5 Balathuruthu

		2006-07															2007-08														
	Class: Bacillariophyceae	Pre monsoon					Monsoon					Post monsoon					Pre monsoon					Monsoon					Post monsoon				
		A*	B*	C*	D*	E*	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
1	*Achnanthes brevipes*						2	1		1																					
2	*Amphora coffeaeformis*	2	2																			2	1				7	1	2	1	
3	*Amphora turgida*	2	1				7	2	1								4	2	2	1	1										
4	*Chroococcus turgidus*						4																								
5	*Cocconeis scutellum*																6														
6	*Cymbella marina*																										4	1	1		1
7	*Diploneis littoralis*						3	2	1			5	2		2	1	5	2	1	1		2		1	1	1					
8	*Diploneis notabilis*	2		1																											
9	*Diploneis weissflogii*																					2					9	3	2		
10	*Gyrosigma nodiferum*																8	6	2	2	2										
11	*Lyngbya aestuarii*						2															4									
12	*Merismopdia elegans*						8																								
13	*Navicula hennedyei*																										9		3	2	1
14	*Navicula spectabilis*	2					10	2	1	1		7	2		1		2	1				2	2								
15	*Nitzschia closterium*	8	2	1	1	1																									
16	*Nitzschia frustulum*																					2	1		1	1	4	3			
17	*Nitzschia longissima*																														
18	*Nitzschia panduriformis*																										7	2	1	1	1
19	*Nitzschia tryblionella*	2	1	1			4		1	1	1	1										2	2								
20	*Oscilllatoria chalybea*						4															4									
21	*Pleurosigma aestuarii*											4	1	1	1	1	9	2		2	1										
22	*Pleurosigma angulatum*						8	3	2													2	1	1	1	1	5	1	2		
23	*Pleurosigma falx*																														
24	*Pleurosigma naviculaceum*	2	1									4	2				14	4	3								5	3	1	2	1
25	*Surirella fastuosa*	8	2	2	2	1	8	2	2	1	1											4	1	2	1						
26	*Surirella flumiensis*											8	4	2	2	1						5	3	2	1	2					
	TOTAL	**28**	**9**	**5**	**3**	**2**	**60**	**12**	**8**	**4**	**2**	**29**	**11**	**3**	**6**	**3**	**48**	**17**	**8**	**6**	**4**	**31**	**11**	**6**	**5**	**5**	**50**	**14**	**12**	**6**	**4**
	A*, B*, C*, D* and E*, denotes the respective vertical strata as, 0 or surface, 1, 2, 3 and 4																														

Fig.51



In 2006-07, at station 6, during the pre monsoon, microphytobenthos were confined to twelve species of diatoms with a total of 99 cells in the phytozone. *Gyrosigma nodiferum, Nitzschia closterium* and *Pleurosigma angulatum* were found distributed in all the sediment strata. The concentration of microphytobenthos was 52, 21, 14, 7 and 5 in the surface, second, third, fourth and fifth strata respectively.

During the monsoon, a total of 105 cells were present in the 5cm sediment column within the nine species. The vertical distribution was 68, 13, 10, 8 and 6 from the surface to bottom. A centric diatom *Coscinodiscus asteromphalus* was found along with other pennate diatoms such as *Pleurosigma acuminatum, P. aestuarii* and *P. falx* in all the sediment strata.

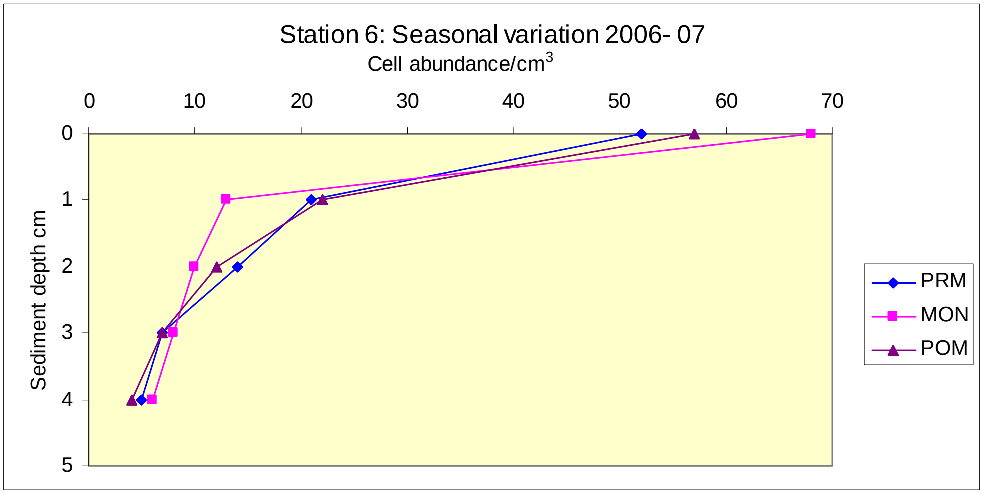
Eleven species were identified from the various sediment layers in post monsoon 2007. The total cell count was 102, in the phytozone. *Navicula hennedyei*, *Nitzschia panduriformis, Pleurosigma falx* and *Surirella flumiensis* were the species found in all the strata. The cell density of each layer was 57, 22, 12, 7 and 4 in their corresponding vertical strata (fig. 53, table 22).

Table 22. Station 6 Kodikkal

		2006-07															2007-08														
	Class: Bacillariophyceae	Pre monsoon					Monsoon					Post monsoon					Pre monsoon					Monsoon					Post monsoon				
		A*	B*	C*	D*	E*	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
1	*Amphora coffeaeformis*	2										4	2	1													3	1			
2	*Amphora turgida*	3	2	1	1		2																								
3	*Caloneis permagna*						2																								
4	*Ceratium furca*																10					5									
5	*Cocconeis sigmoides*																4														
6	*Coscinodiscus asteromphalus*						10	2	2	2	2	2										2					2	1			
7	*Cymbella marina*	4	1	1		1						5	3	2	1		2	1	1	1	1	2	1				2	1	1		
8	*Diploneis notabilis*	2	1																												
9	*Gyrosigma nodiferum*	5	3	2	1	1	2	1				4										2	1				2	1	1		
10	*Navicula directa var. remota*	3	1	1			3	1				2	1										1								
11	*Navicula hennedyei*	6	2	2	1		3	1	1	1		4	2	1	1	1						2					2				
12	*Navicula inclementis*																					8	3	2	2	1					
13	*Navicula monilifera*	3	1		1																										
14	*Nitzschia closterium*	10	4	2	2	2						7	2	2								3	1	1			8	2	2	1	1
15	*Nitzschia panduriformis*	4	2	2								6	3	1	2	1						2	1	1			6	4	2	2	2
16	*Pleurosigma acuminatum*						20	4	2	2	2	3	1				4	2	2			2	2	1			2				
17	*Pleurosigma aestuarii*						14	2	1	2	1											12	4	3	2	1	2	1	1		
18	*Pleurosigma angulatum*	7	3	2	1	1																16	4	4	1	2					
19	*Pleurosigma falx*						12	2	4	1	1	8	4	3	1	1						2	2	1	1		3	1			
20	*Pleurosigma naviculaceum*																14	4	4	1	1										
21	*Protperidimuim cerasus*																6										2	1			
22	*Surirella fastuosa*																12	4	2	2	2										
23	*Surirella flumiensis*	3	1	1								12	4	2	2	1											6	2	2	2	1
	TOTAL	**52**	**21**	**14**	**7**	**5**	**68**	**13**	**10**	**8**	**6**	**57**	**22**	**12**	**7**	**4**	**52**	**11**	**9**	**4**	**4**	**58**	**20**	**13**	**6**	**4**	**40**	**15**	**9**	**5**	**4**

A*, B*, C*, D* and E*, denotes the respective vertical strata as, 0 or surface, 1, 2, 3 and 4

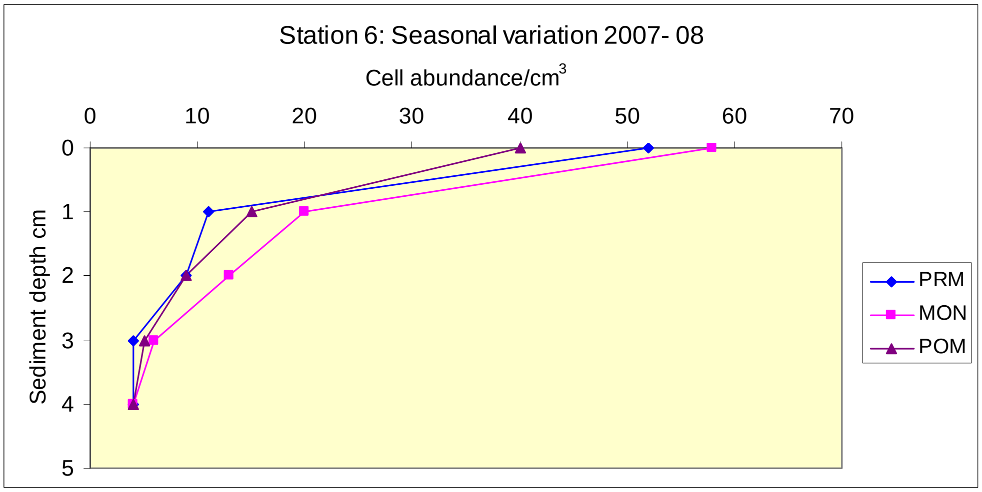
Fig.53



In the following year, in the pre monsoon, seven species were observed from the various sediment strata and the total cells in the 5cm deep phytozone was 80. Microphytobenthos found in the various layers were 52, 11, 9, 4 and 4. *Cymbella marina*, *Pleurosigma naviculaceum* and *Surirella fastuosa* were found distributed in all the sediment portions. In monsoon, thirteen species were recorded with a total of 101 cells from all the strata of which, three species, *Navicula inclementis Pleurosigma aestuarii* and *P. angulatum* were found in all the strata and the cell count was 58, 20, 13, 6 and 4.

In pre monsoon, the total microphytobenthos density in the phytozone was 73 distributed in twelve species. Among them, *Nitzschia closterium*, *N. panduriformis* and *Surirella flumiensis* were found in all the strata. The cell density of each stratum was found as 40, 15, 9, 5 and 4. (Fig.54, table 22). At station 6, Kodikkal, twenty three species were recorded from all the six seasons. None of the species was present in all the strata during the entire study period, but species like *Cymbella marina, Gyrosigma nodiferum*, *Navicula hennedyei*, and *Pleurosigma acuminatum* were observed in five seasons. A dinoflagellate *Ceratium furca* was also recorded from this station (table 22).

Fig.54



In 2006-07, at station 7, during the pre monsoon, only nine species were recorded from all the five strata, in which, *Nitzschia closterium* and *Pleurosigma aestuarii* were found distributed in all the sediment strata. The cell count in the entire sediment column was 81. The vertical distribution of microphytobenthos was found to be 43, 21, 10, 4 and 3 in their respective segment depth. In monsoon, the total cells in the 5cm deep phytozone was 117, distributed in ten species. *Nitzschia closterium Pleurosigma acuminatum* and *P. aestuarii* were seen in all the strata.

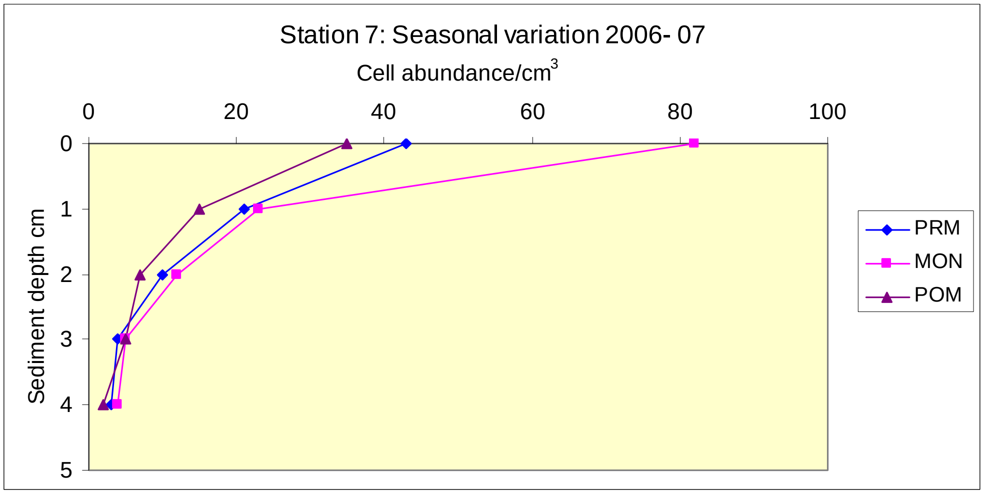
The cell density was 73, 23, 12, 5 and 4 in their corresponding vertical strata. Only five species were found in the post monsoon season, in which two species, *Nitzschia closterium* and *Surirella fastuosa* were recorded from all the strata. The total cell count in the phytozone was 64 and strata wise analysis shown that 35, 15, 7, 5 and 2 cells were present in the respective stratum from surface to the bottom sediment (fig.55, table 23).

Table 23. Station 7 Mahe

		2006-07															2007-08														
	Class: Bacillariophyceae	Pre monsoon					Monsoon					Post monsoon					Pre monsoon					Monsoon					Post monsoon				
		A*	B*	C*	D*	E*	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
1	*Amphora coffeaeformis*	4	2	1			2																				4	2	2	1	1
2	*Caloneis permagna*	3	2	1																											
3	*Ceratium furca*																4	2	2												
4	*Cocconeis placentula*																4														
5	*Coscinodiscus asteromphalus*						6					2	1														4	2	1		
6	*Cymbella aspera*	2	1	1	1												2	1													
7	*Diploneis notabilis*	6	4	2		1						4	2				2	1													
8	*Gyrosigma nodiferum*	3	3	1			4	2	2		1											2	2	1							
9	*Licmophora flabellata*						4																				2	2	1		
10	*Lyngbya aestuarii*						3																								
11	*Navicula cincta*																					5	2	1		1					
12	*Navicula forcipata*	3	2																												
13	*Nitzschia closterium*	12	3	2	1	1	10	5	4	2	1	8	5	3	2	1						6	2	1	1		5	2	1	1	
14	*Nitzschia tryblionella*																										2	1	1		
15	*Oscilllatoria chalybea*						6															2									
16	*Pleurosigma acuminatum*						16	6	1	1	1											8	3	2	2	1	3	2	1	1	
17	*Pleurosigma aestuarii*	6	2	1	1	1	8	3	2								3	1	1												
18	*Pleurosigma naviculaceum*																4	2													
19	*Pleurosigma falx*	4	2	1	1		23	7	3	2	1	6	4	2	2		2	1				2	1				3	2	1	1	
20	*Surirella fastuosa*											15	3	2	1	1															
21	*Surirella flumiensis*																					2	1				4	2			
22	*Surirella ovalis*																12	6	2	2	1						4	2	1	1	1
	TOTAL	43	21	10	4	3	82	23	12	5	4	35	15	7	5	2	33	14	5	2	1	27	11	5	3	2	31	17	9	5	2

A*, B*, C*, D* and E*, denotes the respective vertical strata as, 0 or surface, 1, 2, 3 and 4

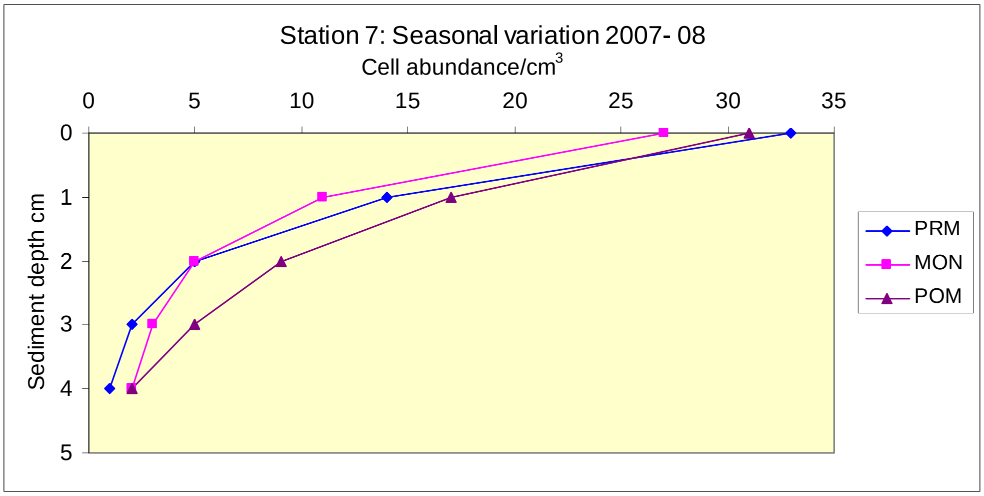
Fig.55



In the following year, during pre monsoon, total microphytobenthos present in the 5cm sediment column was 55 distributed among eight species. *Surirella ovalis* was found in all the strata of sediment. The cell count ranged from 33 to 1 from the surface sediment layer to the bottom sediment layer. During the monsoon, total cell present was 46 in the phytozone with seven species. *Pleurosigma acuminatum* was the only species distributed in all the strata. The cell abundance was 25, 11, 5, 3 and 2. A total of 62 cells were present in the 5cm deep sediment column and nine species were recorded from the post monsoon. *Amphora coffeaeformis* and *Surirella ovalis* were distributed in all the strata.

The standing crop of microphytobenthos was 31, 17, 9, 5 and 2 in their respective sediment layers (Fig. 56, table 23). In station 7, at Mahe, twenty two species, including two Cyanophycean species and one dinoflagellate were identified from various seasons during the period of 2 years. *Pleurosigma falx* was the only species found distributed in the entire seasons (table 23).

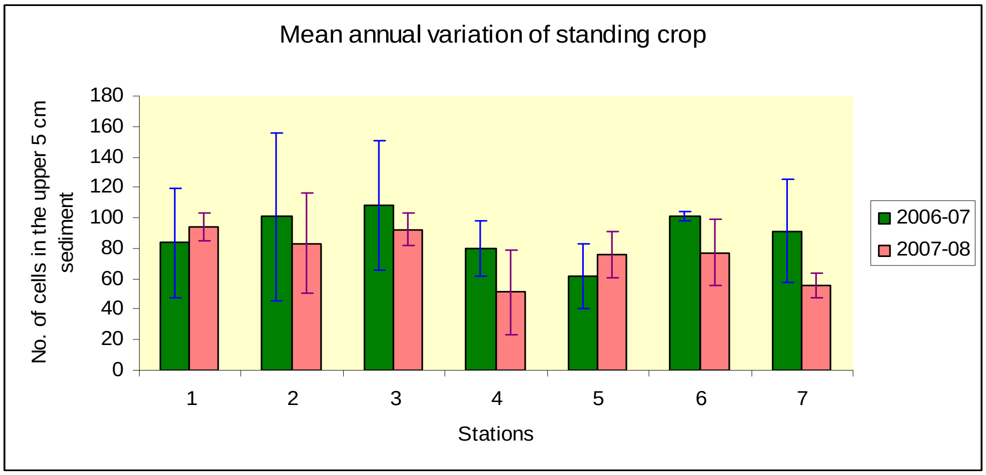
Fig. 56



During the two years of seasonal study, from pre monsoon 2006-07 to post monsoon 2007-08, 55 species of microphytobenthos were observed, of which, Division Bacillariophyta was dominant with 48 species, followed by Cyanophyta with 4 and Dinophyta with 3 species.

Mean annual variation of standing crop in the upper 5cm sediment column of the sediment is shown in fig. 57. Number of cells varies from 62 to 108 during 2006-07 and 51 to 94 in 2007-08.

Fig.57

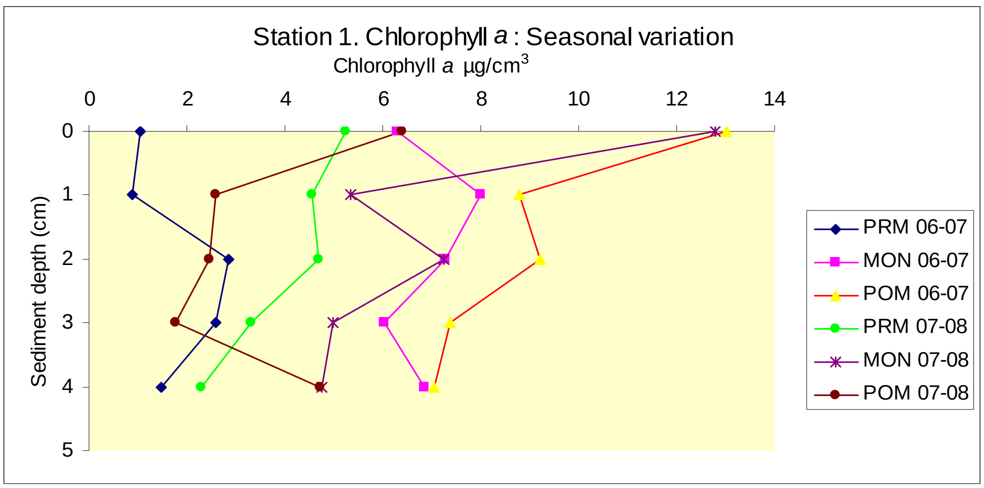


4.3.2 Pigments

4.3.2.1 Chlorophyll *a*

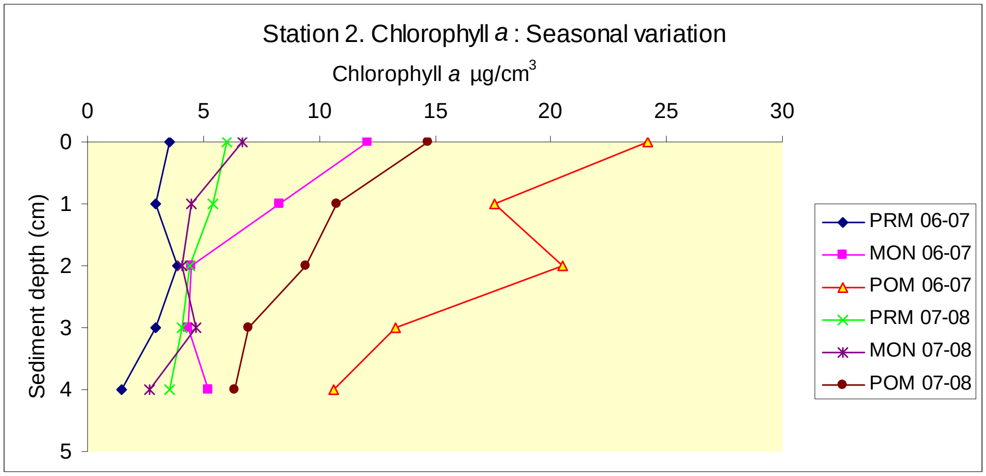
At station 1, the highest chlorophyll *a* value of 13.024µg/cm^3 was observed during the post monsoon 2006-07, in the first stratum of sediment. The lowest value of 0.879µg/cm^3 was found during the pre monsoon 2006-07 with in the second stratum. Generally, microphytobenthos pigment values showed a decreasing trend with an increasing depth (fig. 58).

Fig. 58



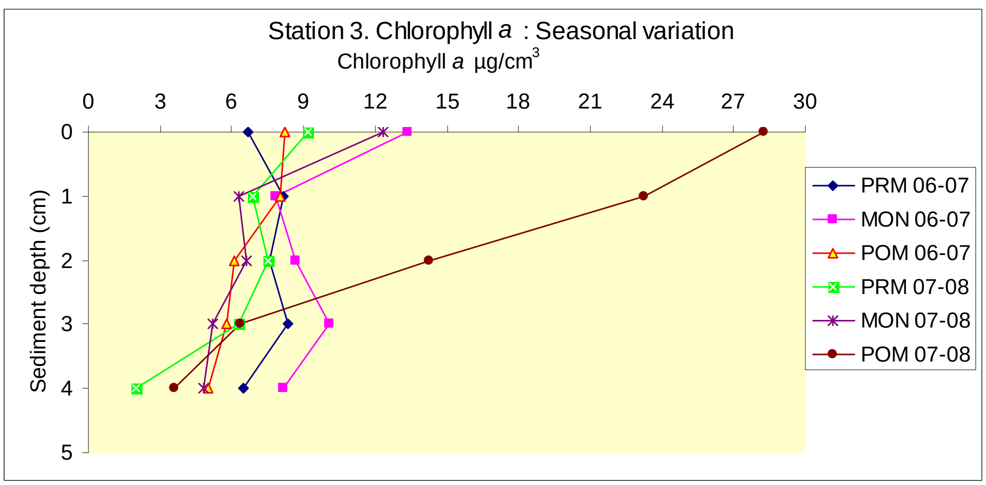
In station 2, the highest value of chlorophyll *a* (24.184µg/cm^3) was recorded from the surface stratum during the post monsoon 2006-07 and the lowest value of 1.46µg/cm^3 was recorded in the last stratum during the pre monsoon 2006-07. The chlorophyll *a* values are higher in station 2, compared to other stations. Here the values have decreased with increasing depth in most of the seasons. However, in the final stratum, a significant contribution of chlorophyll has observed (fig.59).

Fig. 59



At station 3, the highest value of chlorophyll *a* (28.28µg/cm^3) was recorded during the post monsoon 2007-08, in the surface stratum of the sediment. The lowest value of chlorophyll *a* in station 3 was obtained from the final stratum during the pre monsoon 2007-08 with 2.014µg/cm^3. Station 3 generally recorded a high concentration of chlorophyll *a* throughout the seasons and all the strata (fig. 60).

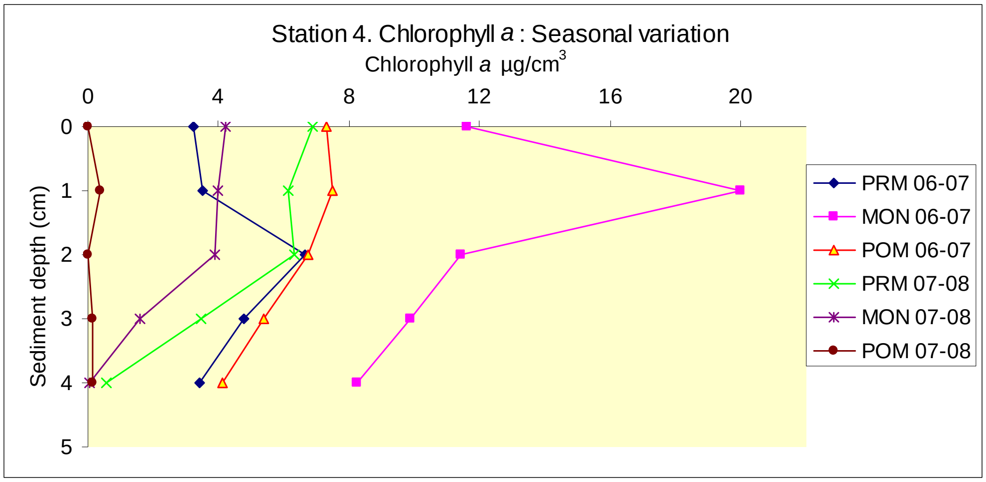
Fig.60



In station 4, the highest value is 20µg/cm^3, which was found in the second stratum (1-2cm) of the sediment during the monsoon 2006-07. The lowest value recorded during post monsoon 2007-08, in the surface stratum was 0.015µg/cm^3.

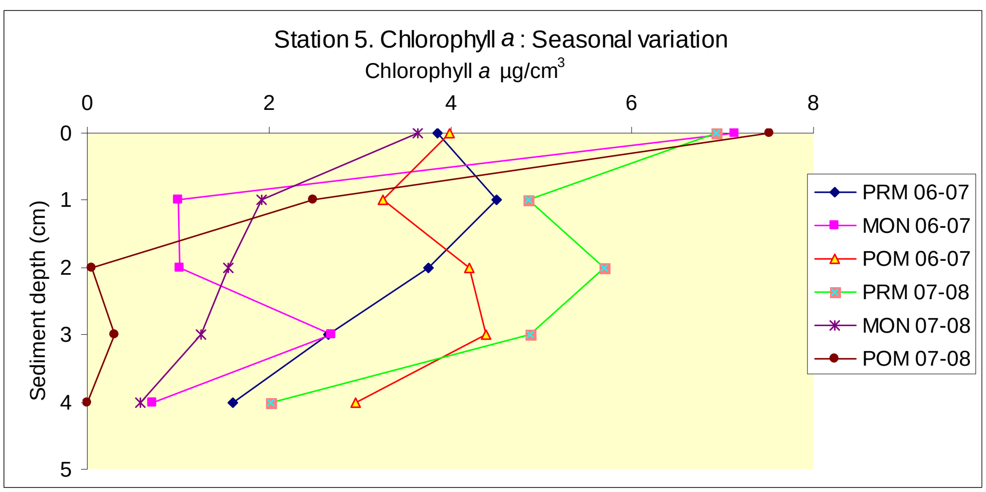
In the post monsoon 2007-08, the vertical distribution of chlorophyll a in all the depth strata was found to be negligible (fig. 61).

Fig. 61



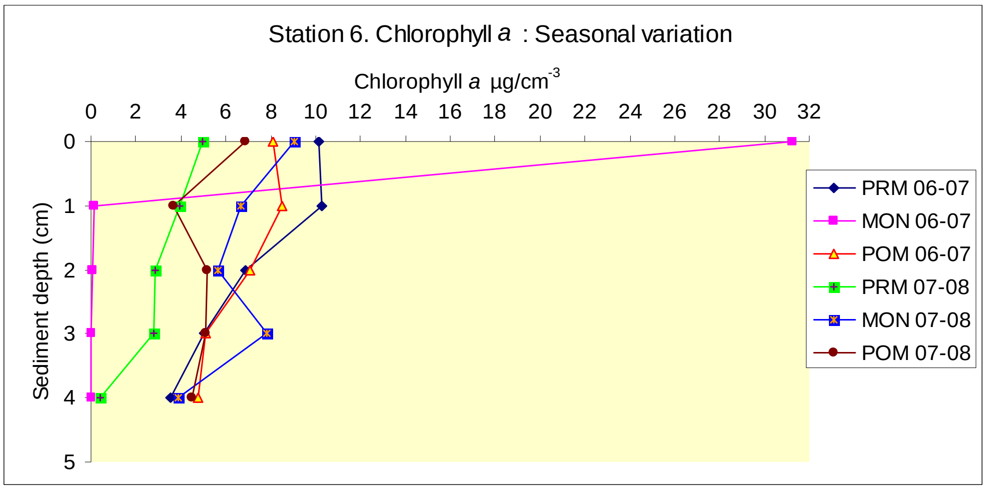
In station 5, the surface stratum showed relatively high pigment values. The highest chlorophyll a has found in monsoon, 2006-07, in the surface stratum with 7.133 µg/cm^3. It was nil, in the final stratum of post monsoon in the second year. During the post monsoon 2007-08 chlorophyll *a* in the last stratum was practically nil (fig. 62).

Fig.62



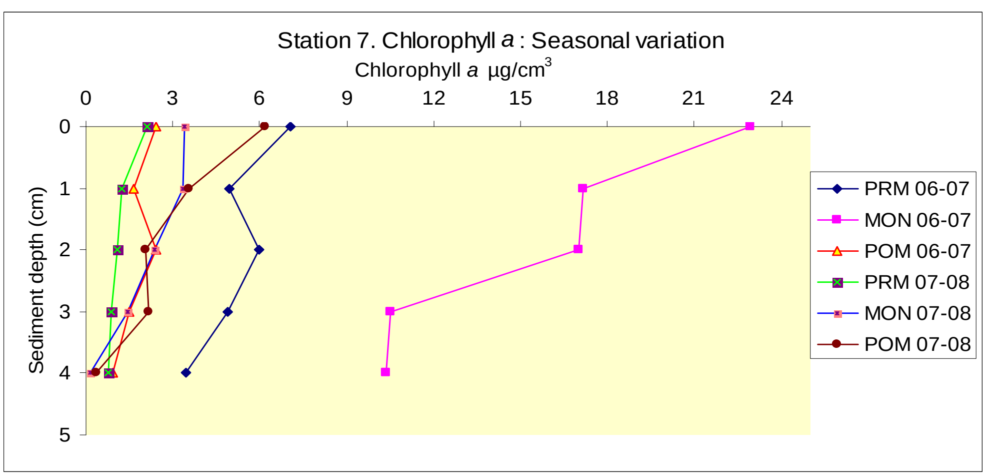
At station 6, all the seasons recorded higher values of chlorophyll *a*, particularly in the surface stratum. In the monsoon, 2006-07, all other strata except the surface stratum have low values. The highest value ever recorded during this study was 31.28µg/cm^3 in the surface stratum during the monsoon 2006-07 and the lowest concentration of 0.015µg/cm^3 was recorded from final stratum at the same season (fig. 63).

Fig. 63



At station 7, the highest value of 22.91µg/cm^3 was recorded from the surface stratum during the monsoon 2006-07 and the lowest value of 0.13µg/cm^3 during the monsoon 2007-08 in the final stratum. During the monsoon 2006-07, the vertical distribution of microphytobenthos chlorophyll *a* was higher when compared to the other seasons (fig. 64).

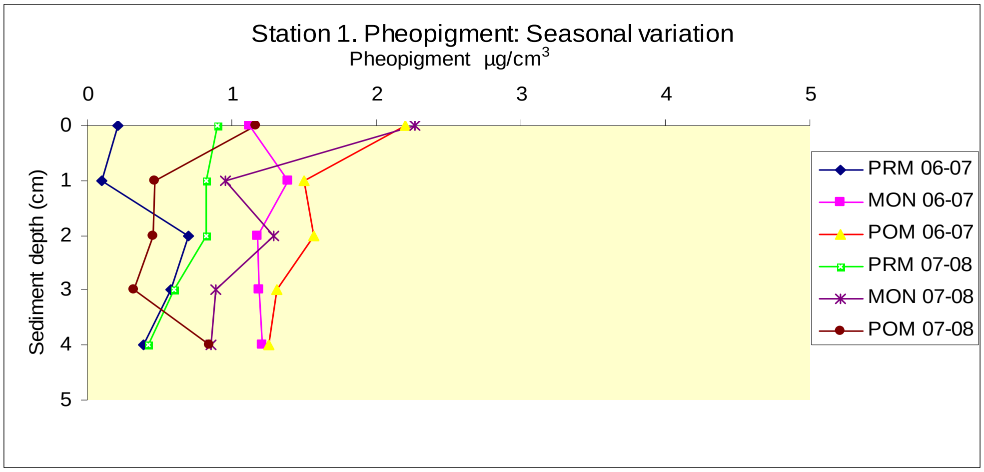
Fig. 64



4.3.2.2 Pheopigment

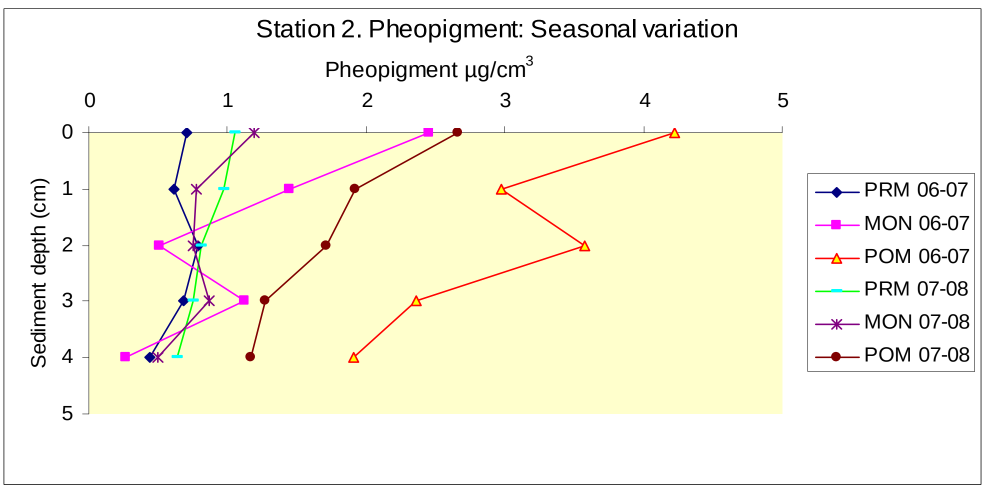
At station 1, the pheopigment value varied from 2.26µg/cm^3 the surface stratum during monsoon 2007-08 to 0.1µg/cm^3 in the second stratum during the pre monsoon 2006-07 (fig. 65).

Fig.65



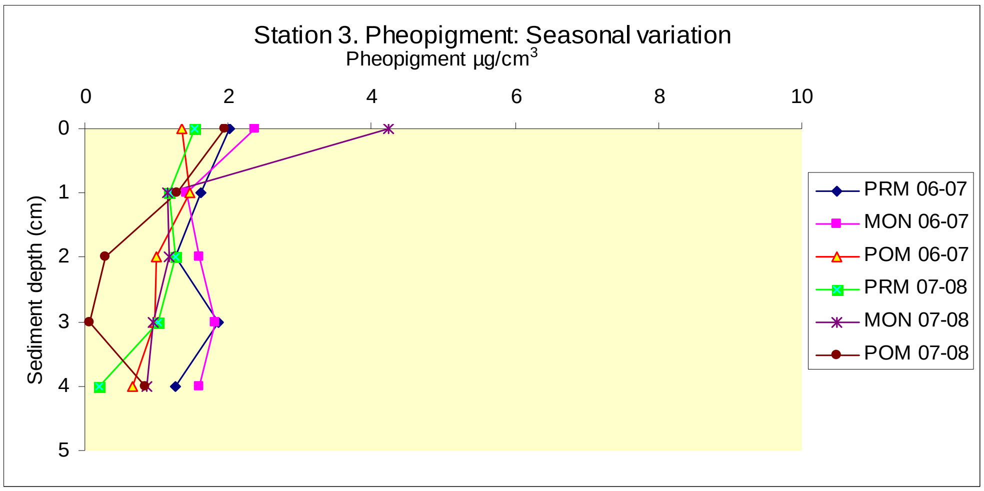
In station 2, the highest pheopigment concentration of 4.22µg/cm^3 was found in the first stratum, during the post monsoon 2006-07 and the lowest value of 0.26µg/cm^3 recorded from the final stratum of the sediment during the monsoon in the 1st year (fig. 66).

Fig.66



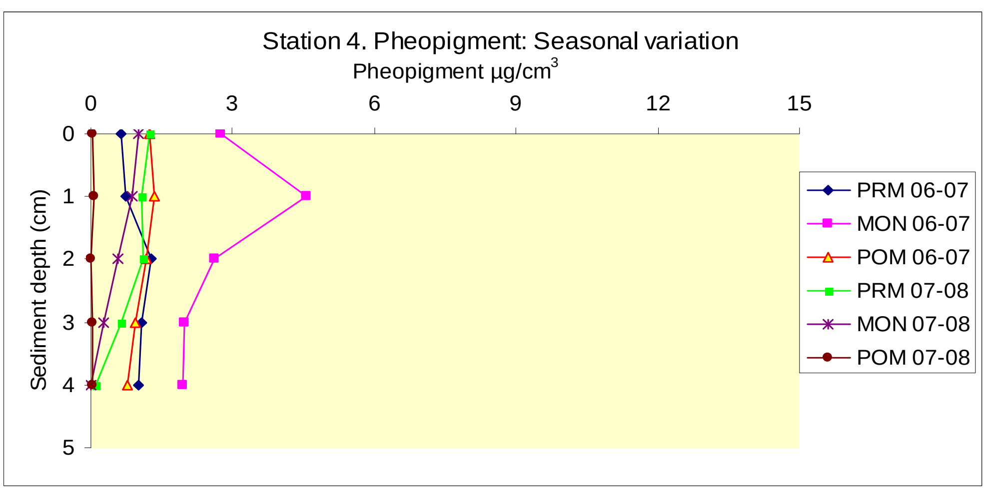
In station 3, the maximum pheopigment concentration of 4.24µg/cm^3 was during the monsoon 2006-07 in the first stratum and the lowest value of 0.057 µg/cm^3 was recorded from the fourth stratum during the post monsoon in the following year (fig. 67)

Fig. 67



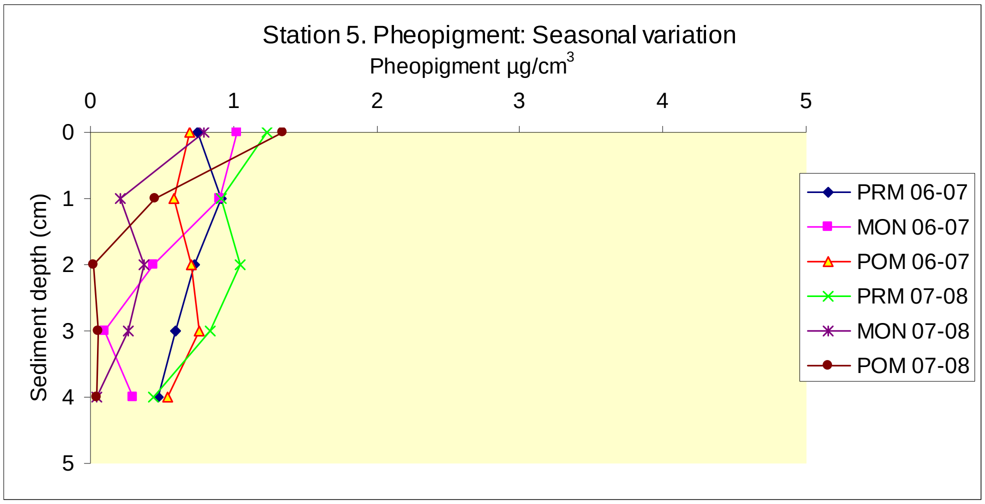
The highest pheopigment concentration was observed at station 4, during the monsoon in the second year with 4.56µg/cm^3 at the second stratum. The lowest was found in the final stratum during monsoon 2007-08 with 0.004µg/cm^3 (fig. 68)

Fig. 68



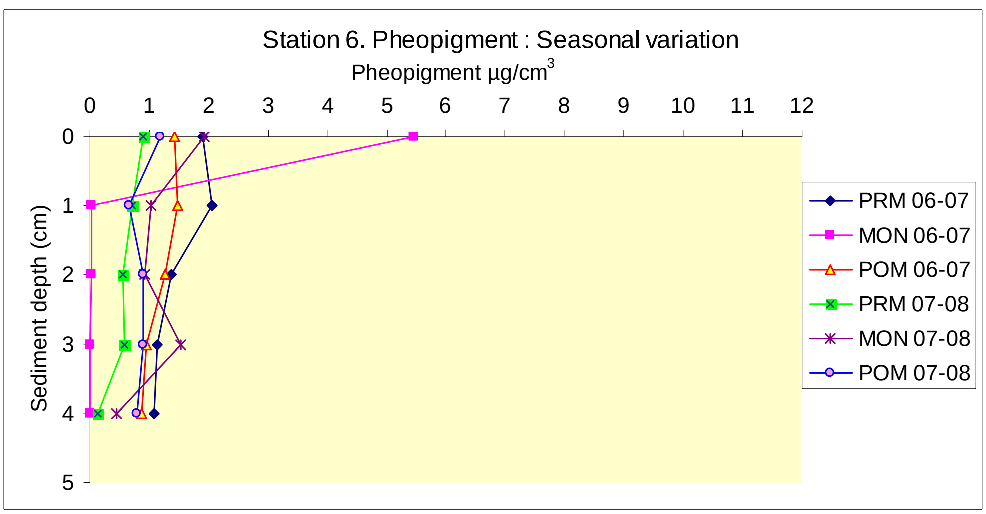
At station 5, relatively low values of pheopigment were observed. The highest value of 1.34µg/cm^3 was found in the surface stratum during post monsoon 2007-08. The lowest value was 0.027µg/cm^3, recorded during the post monsoon in the 1st year from the third stratum (fig. 69).

Fig. 69



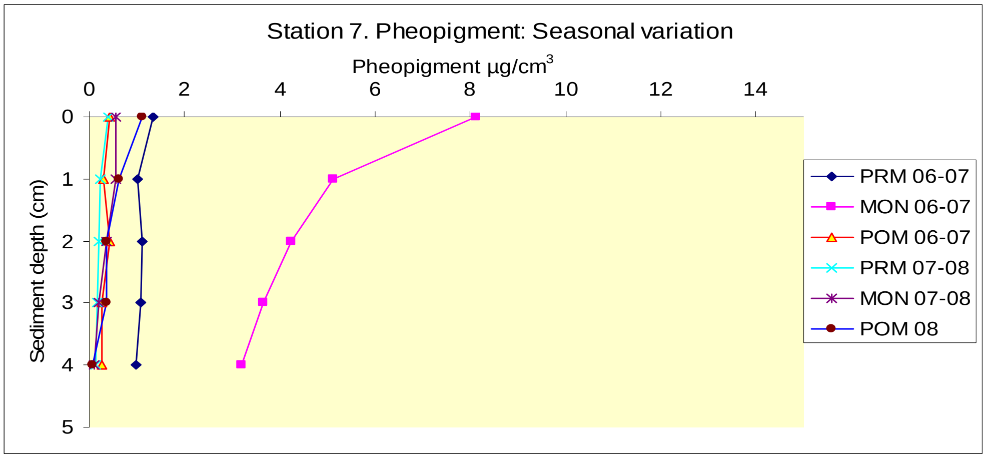
At station 6, the pheopigment value varied from 5.47µg/cm^3 found in the initial stratum during the monsoon 2006-07, to the lowest of 0.005µg/cm^3 in the last stratum (fig. 70).

Fig. 70



In station 7, the highest value of pheopigment ever recorded was found in the surface stratum during the monsoon 2006-07 with 8.12µg/cm^3 and the lowest value of 0.063µg/cm^3 observed in the final stratum during the post monsoon in the second year (fig. 71).

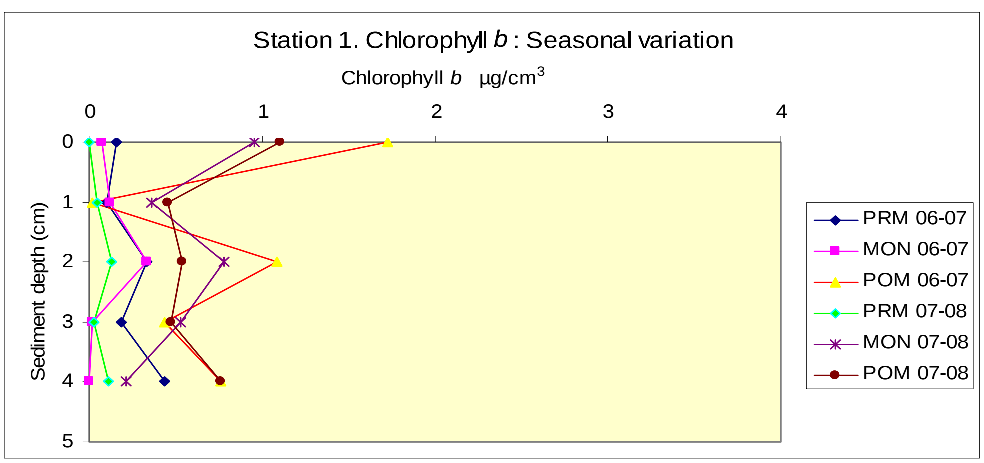
Fig. 71



4.3.2.3 Chlorophyll *b*

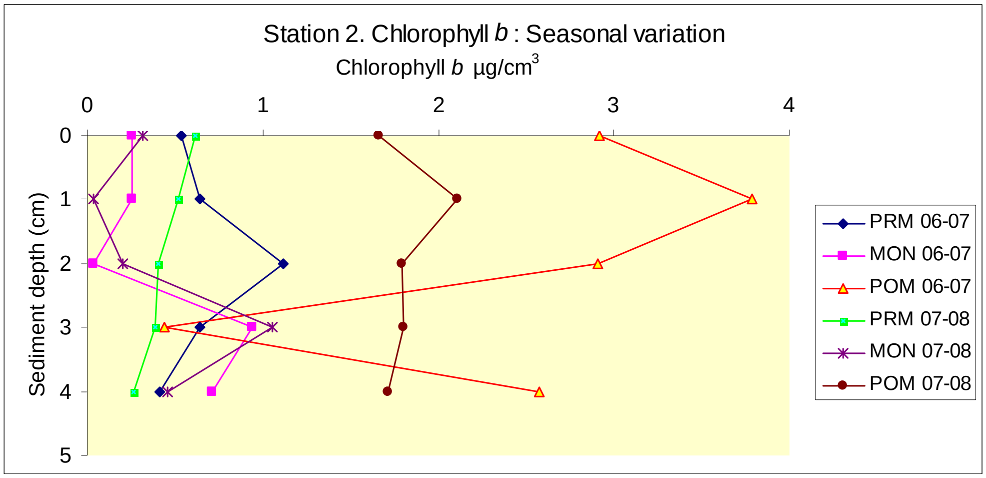
The spatio-temporal distribution of chlorophyll *b* registered low values through out the study. At several stations it was practically nil. In station 1, the highest value was 1.72µg/cm^3 found during the post monsoon 2006-07 in the first stratum. The lowest value of chlorophyll *b* recorded was 0.002µg/cm^3 in the final stratum of monsoon in the first year (fig. 72).

Fig.72



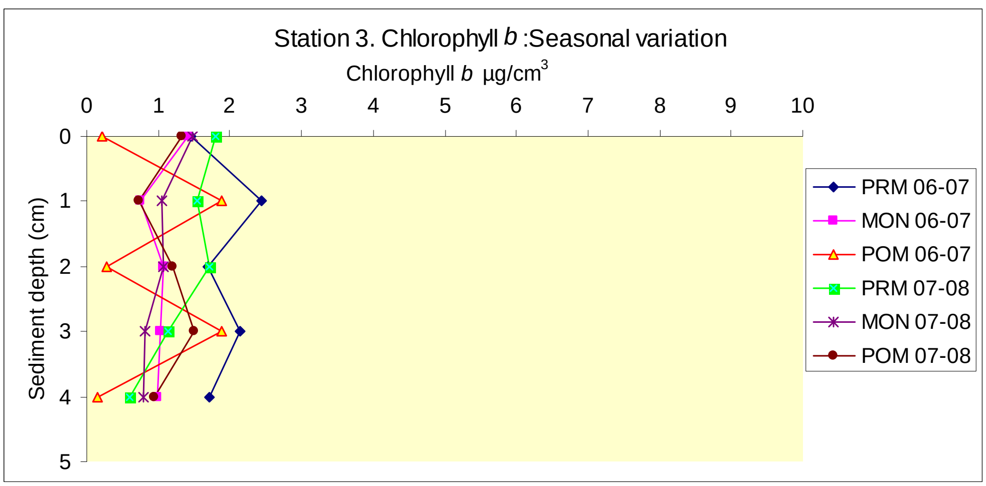
At station 2, the maximum chlorophyll *b* concentration of 3.7µg/cm^3 found in the second stratum during the post monsoon 2007-08 and lowest in the second stratum during monsoon in the second year with 0.036µg/cm^3 (fig. 73).

Fig.73



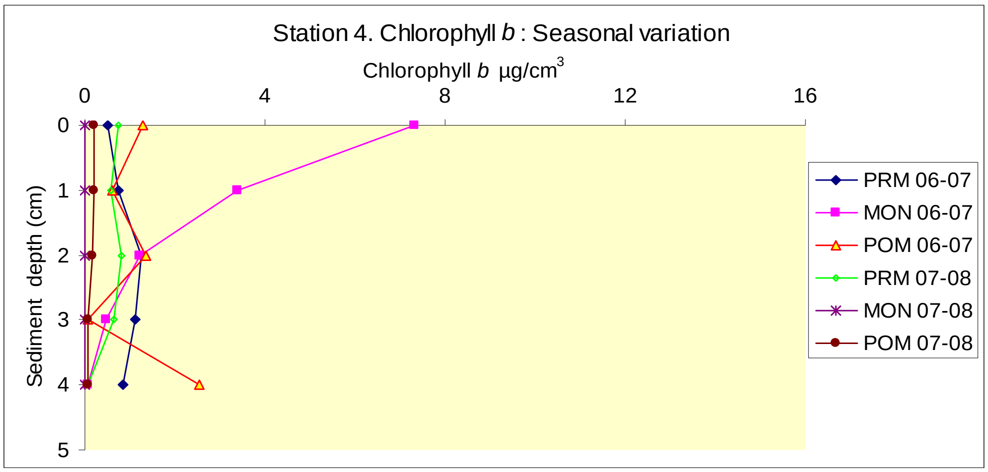
In station 3, the maximum concentration of chlorophyll *b* of 2.43µg/cm^3 was recorded in the second stratum during the pre monsoon 2006-07, and the lowest value of 0.158µg/cm^3 during the post monsoon in the final stratum of preceding year (fig. 74).

Fig. 74



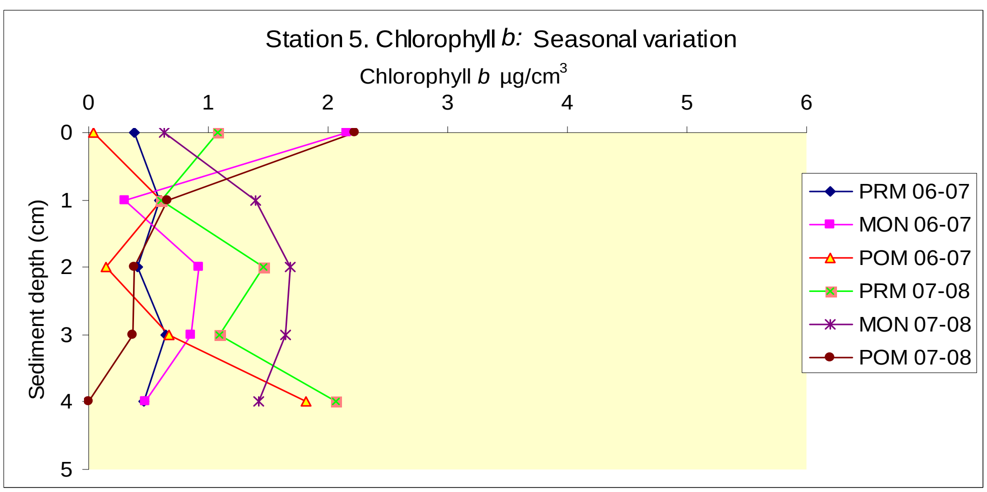
At station 4, chlorophyll *b* was varied between 7.32µg/cm^3 during the monsoon 2006-07, in the surface stratum to a nil value in the final stratum of monsoon 2007-08 (fig. 75).

Fig.75



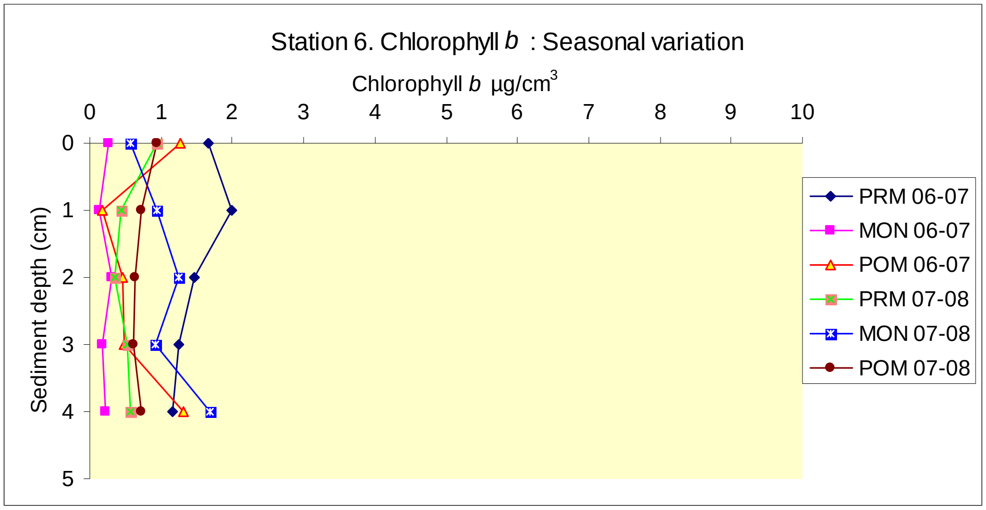
At station 5, the maximum value of 2.21µg/cm^3 was observed in the first stratum during the post monsoon 2007-08 and it was nil in the final stratum of the same season (fig. 76).

Fig. 76



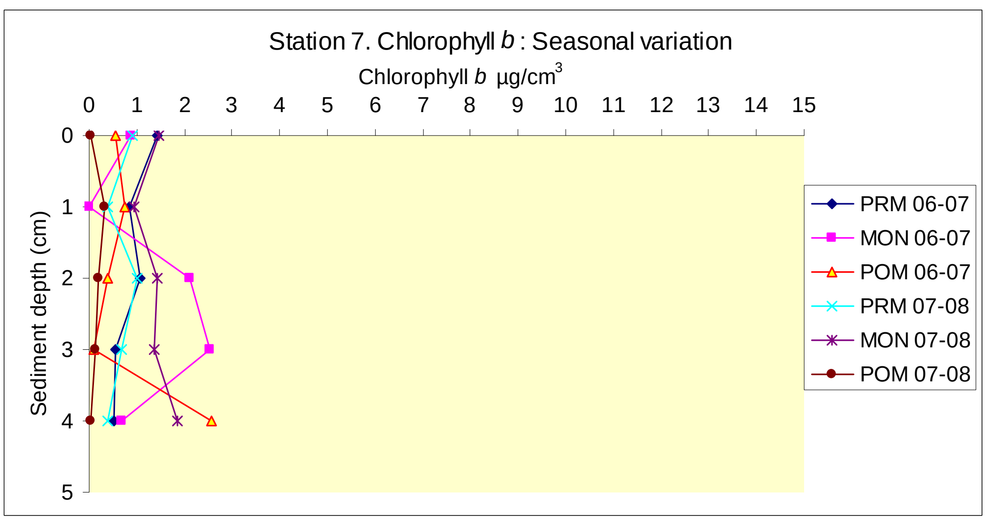
In station 6, the value varied between 2µg/cm^3 in the second stratum during the pre monsoon in the preceding year to the lowest of 0.12µg/cm^3 recorded from the second stratum of monsoon in the first year (fig.77).

Fig. 77



At station 7, the chlorophyll *b* values were varied between 2.55µg/cm^3 the final stratum during the post monsoon 2006-07 to the second stratum during the monsoon 2006-07 with 0.001µg/cm^3 (fig. 78).

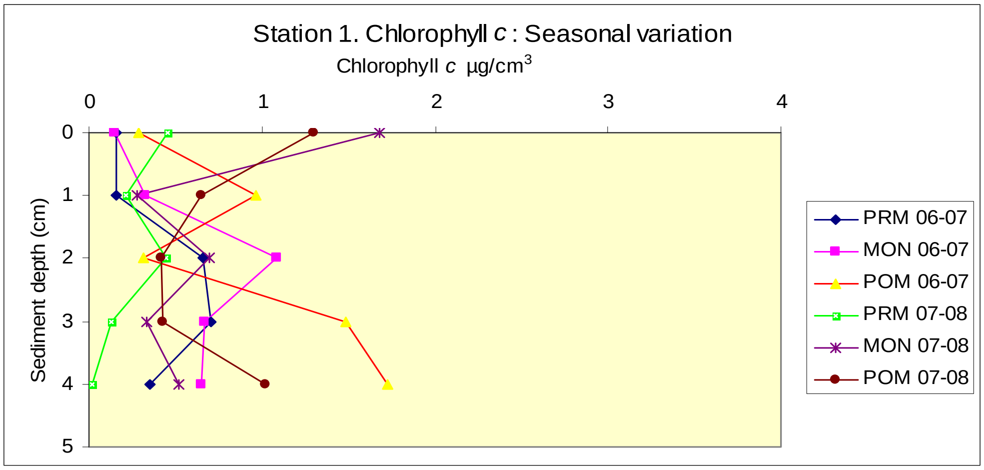
Fig.78



4.3.2.4 Chlorophyll *c*

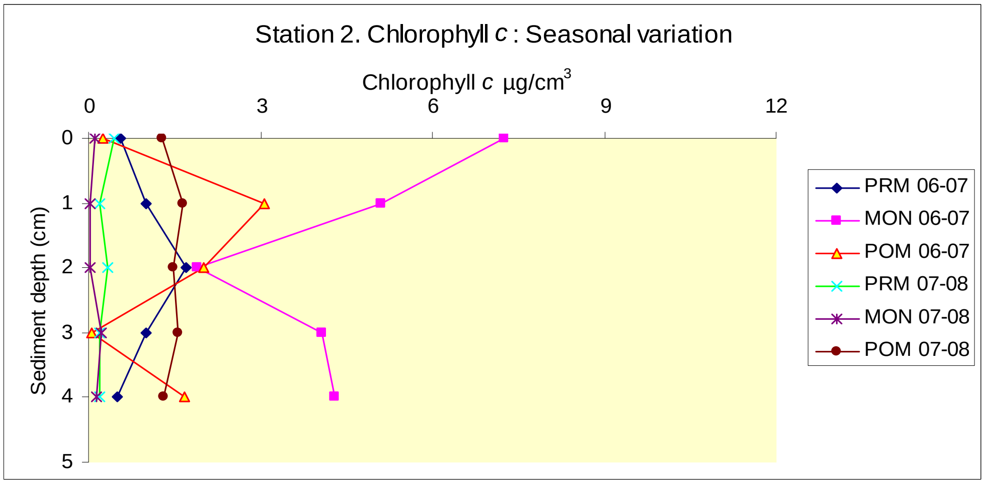
Chlorophyll *c*, values did not give any definite pattern of distribution. At station 1, the highest value of chlorophyll *c* was found during the post monsoon 2006-07, in the final stratum with 1.73µg/cm^3 and the lowest value of 0.022µg/cm^3 was recorded from the last stratum during the pre monsoon in the first year (fig. 79).

Fig. 79



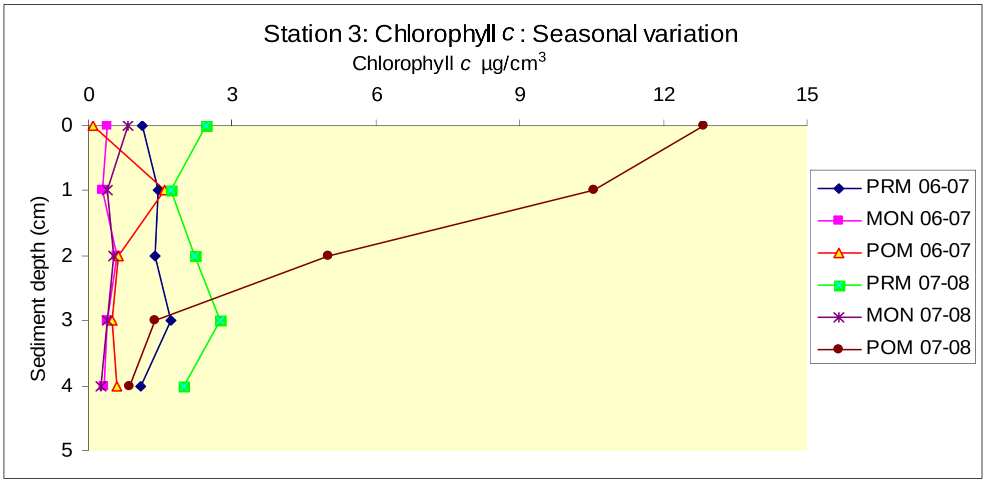
At station 2, the highest chlorophyll *c* concentration was observed at the topmost stratum during the monsoon 2006-07 with 7.25µg/cm^3 and the lowest value of 0.016µg/cm^3 in the second stratum during monsoon 2007-08 (fig. 80).

Fig.80



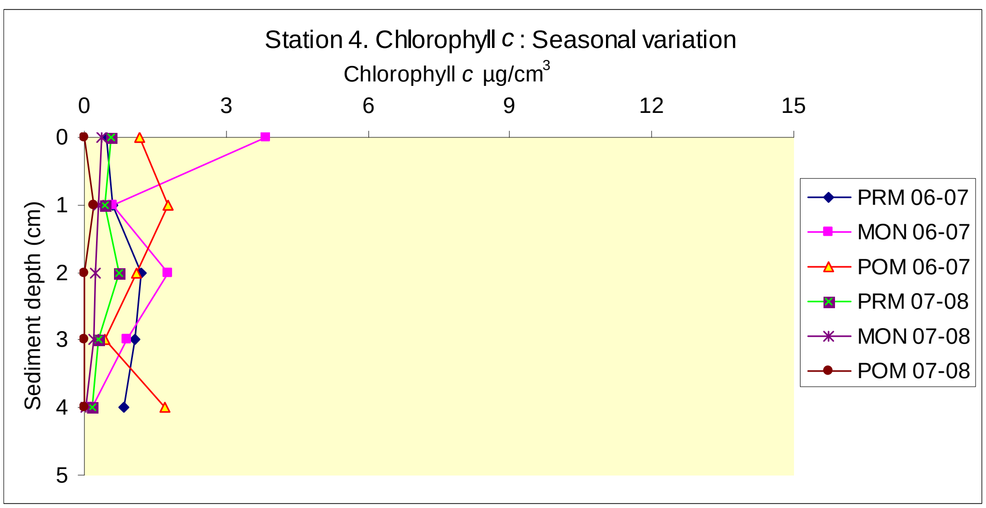
At station 3, the utmost chlorophyll *c* value of 12. 85µg/cm^3 was found in the first sediment segment during the post monsoon 2007-08 and the lowest in the first stratum (0.1µg/cm^3) during the post monsoon in the previous year (fig. 81).

Fig.81



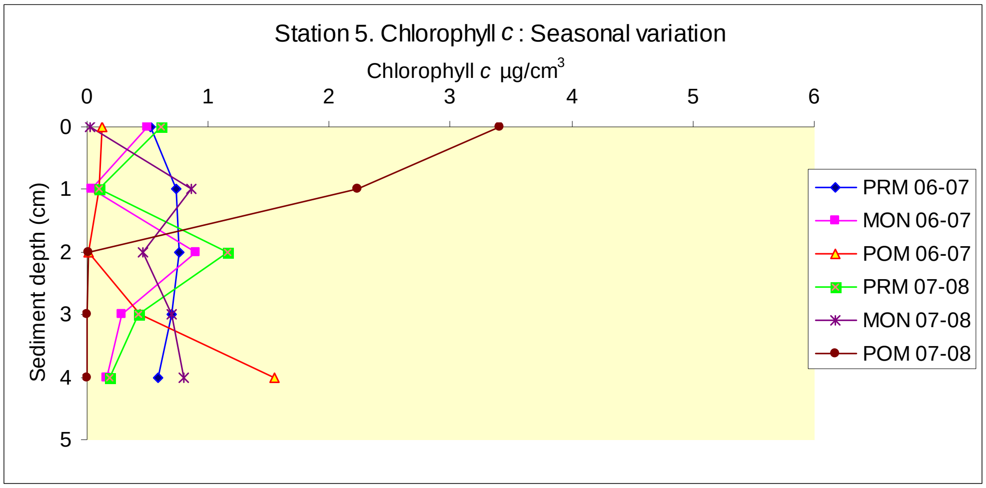
At station 4, chlorophyll *c* values varied from 1.78µg/cm^3 in the second stratum during the monsoon 2006-07, to the lowest (0.016µg/cm^3) in the third stratum during post monsoon 2007-08 (fig. 82).

Fig. 82



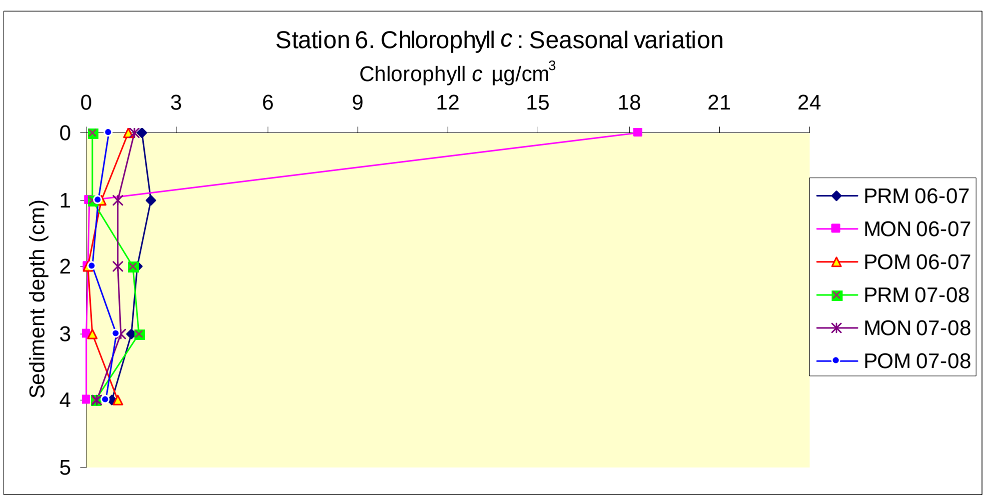
The maximum (3.41µg/cm^3) chlorophyll *c* at station 5 in the surface stratum during the post monsoon 2007-08 and nil in the last stratum during the post monsoon 2007-08 (fig. 83).

Fig.83



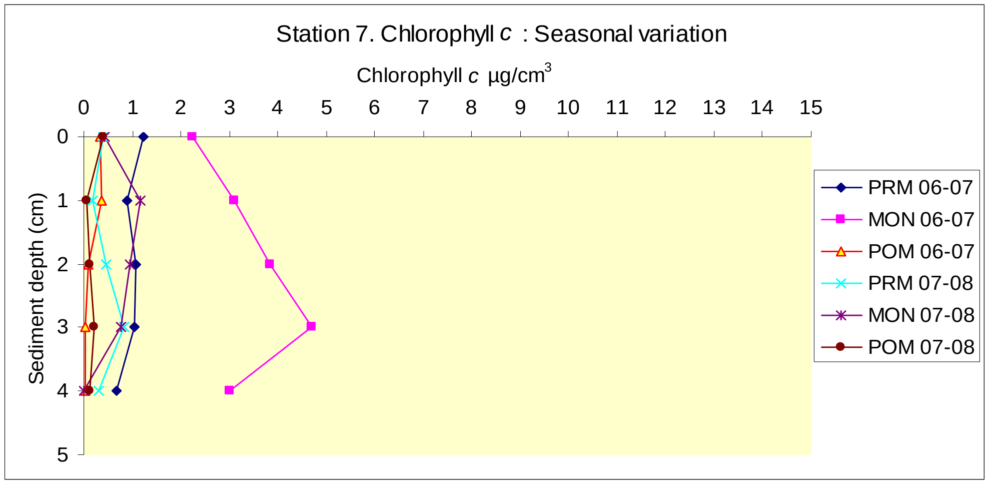
At station 6, the maximum chlorophyll *c* concentration (18.3µg/cm^3) was recorded from the first stratum during the monsoon 2006-07 and the minimum was found in the last stratum during the monsoon 2006-07 with 0.006µg/cm^3 (fig. 84).

Fig.84



At station 7, the upper limit of chlorophyll *c* was recorded in the fourth stratum with 4.71µg/cm^3 during the monsoon 2006-07 and the lower limit was found in the last stratum during monsoon 2007-08 with 0.014µg/cm^3 (fig. 85).

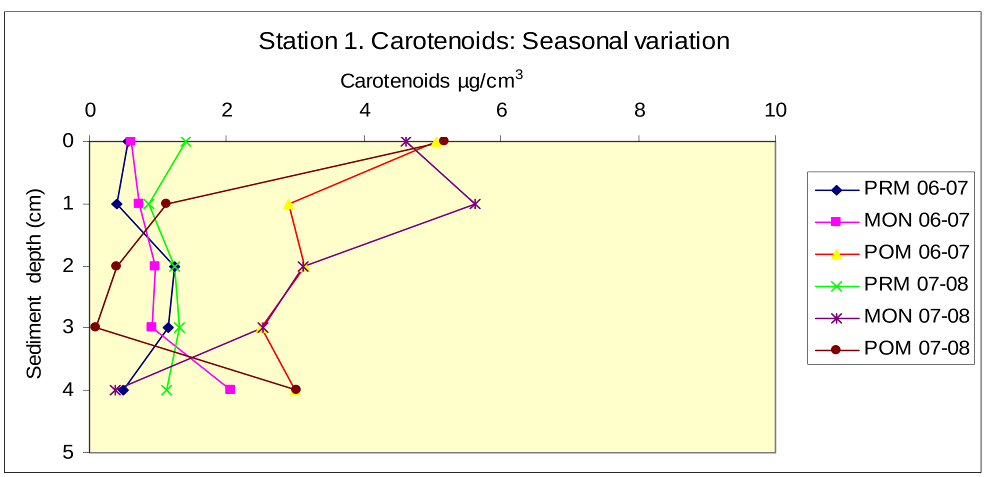
Fig. 85



4.3.2.5 Carotenoids

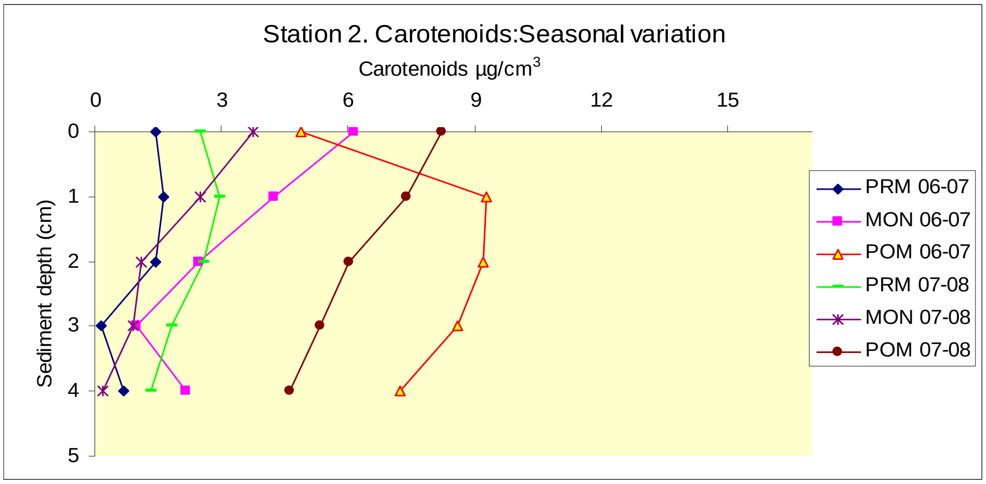
A moderately high carotenoid pigments were found throughout and which exhibited seasonal and spatial variation. At station 1, highest value of carotenoid pigments were found in the second stratum during the monsoon 2006-07 with 5.6 µg/cm^3 and lowest was recorded in the fourth stratum during post monsoon in the following year with 0.1µg/cm^3 (fig. 86).

Fig.86



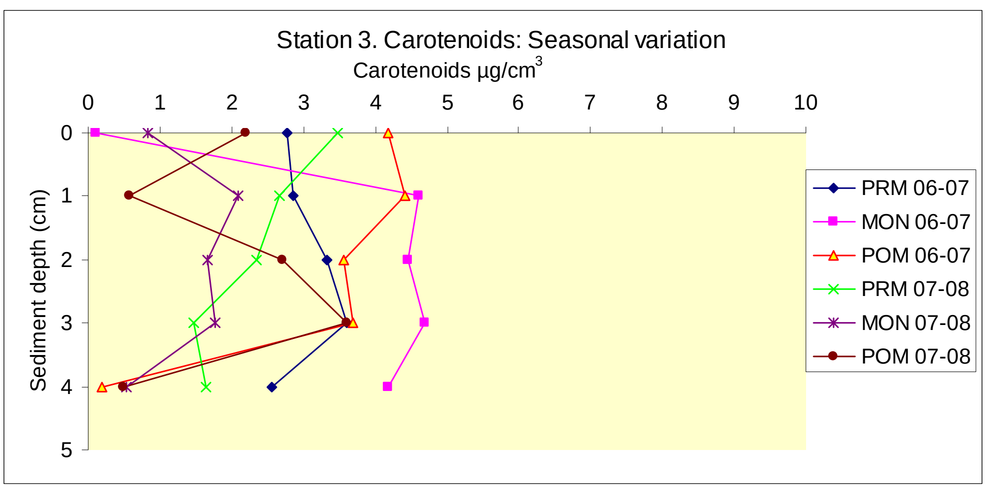
Carotenoid pigments were maximum in the second stratum during the post monsoon 2006-07 with 9.25µg/cm^3 at station 2. The minimum (0.669µg/cm^3) was recorded in the last stratum of pre monsoon 2006-07 (fig. 87).

Fig.87



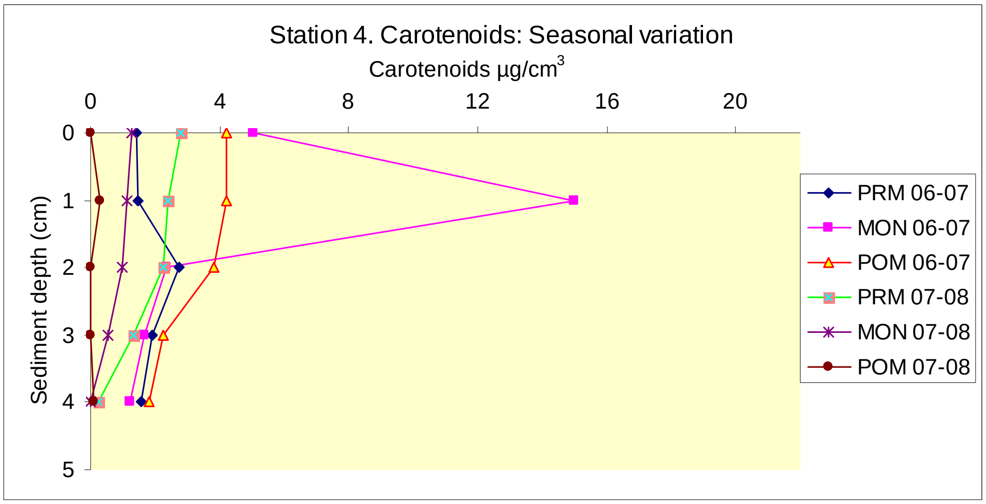
In station 3, the highest carotenoid concentration observed in the fourth stratum during the monsoon 2006-07 with 4.69µg/cm^3 and the lowest of 0.19µg/cm^3 in the last stratum of post monsoon in the first year (fig. 88).

Fig.88



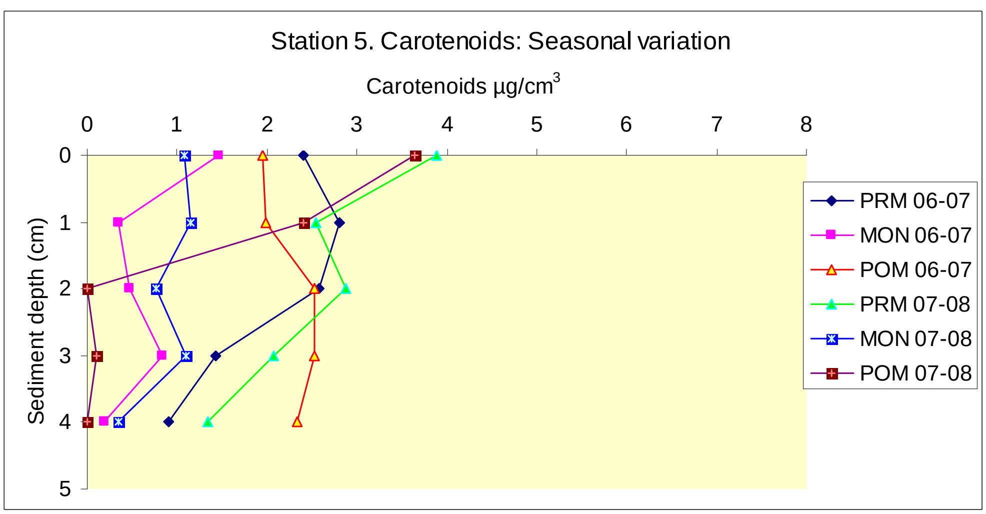
At station 4, the maximum carotenoids value of 14.99µg/cm^3, found in the second stratum during the monsoon 2006-07. The lowest value of 0.003µg/cm^3 of was found in the third and fourth strata during the post monsoon in the following year (fig. 89).

Fig.89



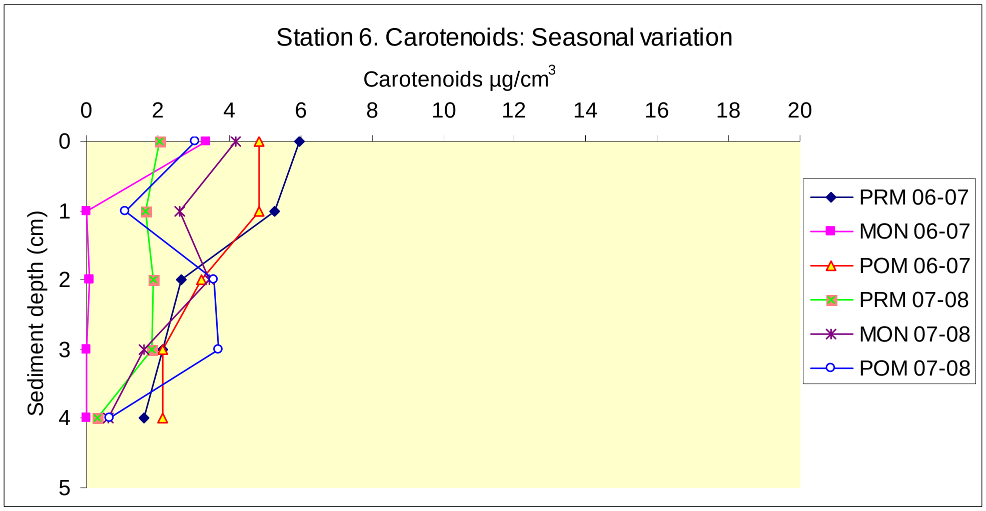
At station 5, the maximum concentration of carotenoids (3.88µg/cm^3) was found during the pre monsoon 2007-08 in the first stratum of sediment and it was nil in the bottom stratum during post monsoon preceding year (fig. 90).

Fig. 90



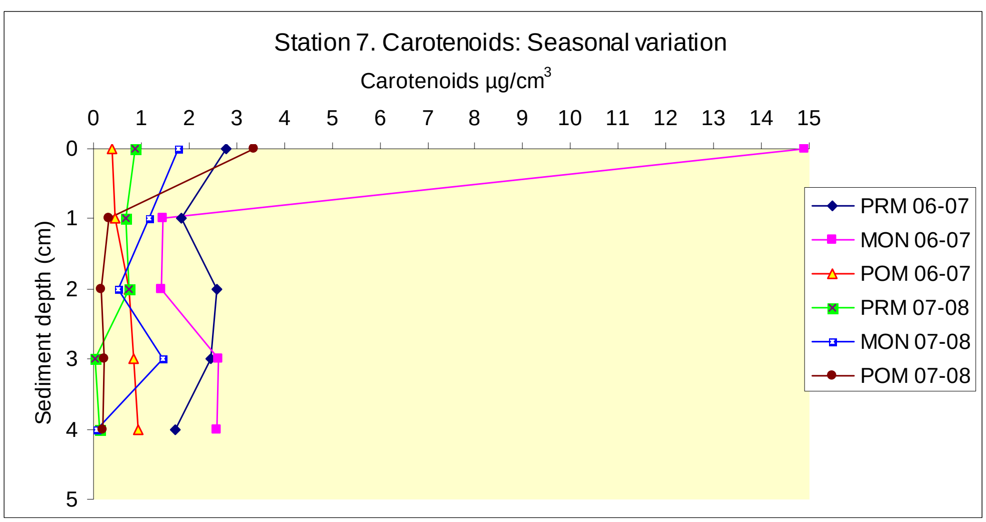
In station 6, the highest concentration of carotenoid was found in the surface stratum, during the pre monsoon 2006-07 with 5.95µg/cm^3 and the lowest 0.013 µg/cm^3 was obtained in the last stratum of monsoon in the previous year (fig. 91).

Fig. 91



Carotenoid pigments varied from 14.91µg/cm^3 at station 7, in the first stratum during the monsoon in the first year to the lowest value of 0.024µg/cm^3, were recorded from the fourth stratum of pre monsoon 2007-08 (fig. 92).

Fig. 92



Mean seasonal variation of pigments in each station are shown in figs. 93, 94, 95, 96, 97, 98 and 99. Marked variations were found in all the stations.

Fig. 93

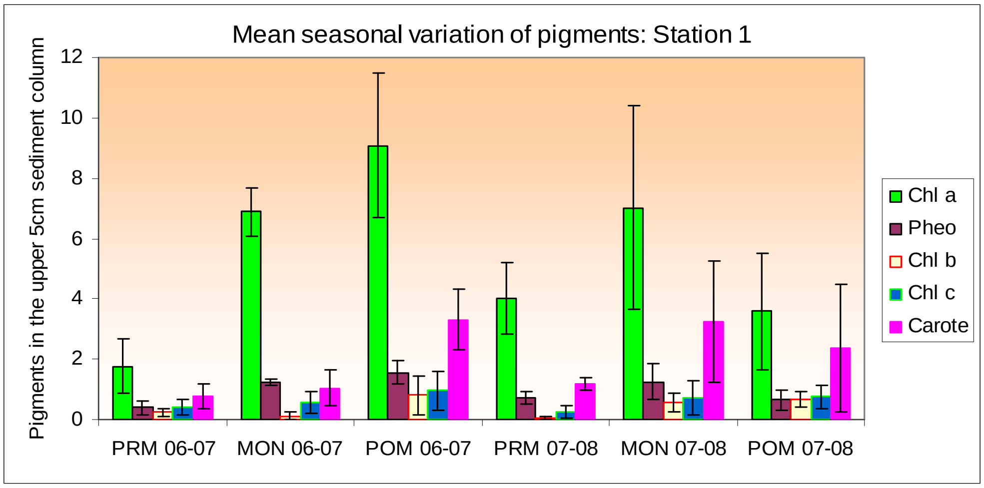


Fig. 94

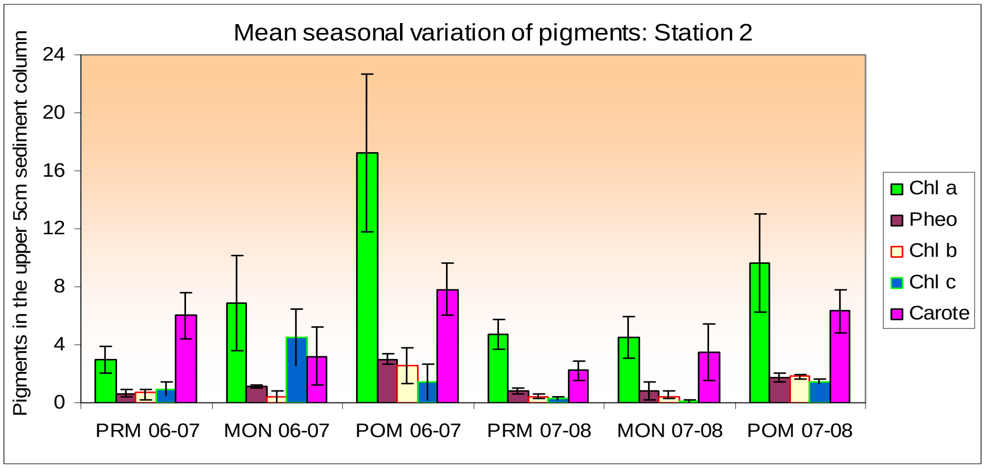


Fig. 95

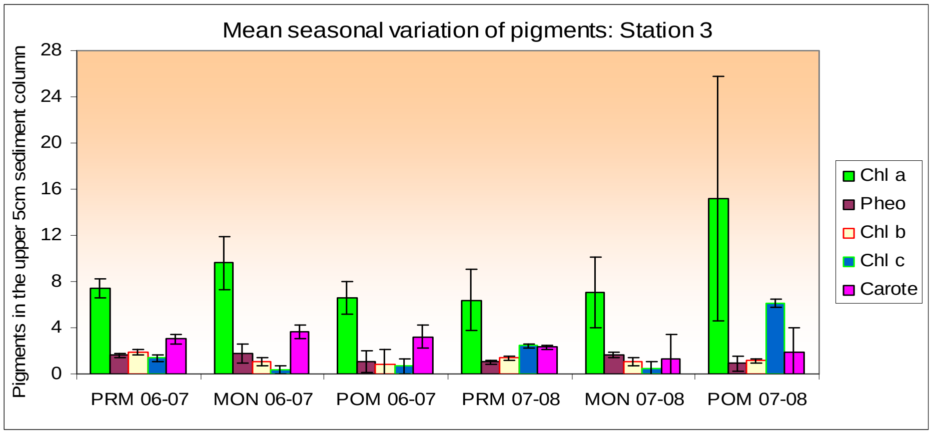


Fig. 96

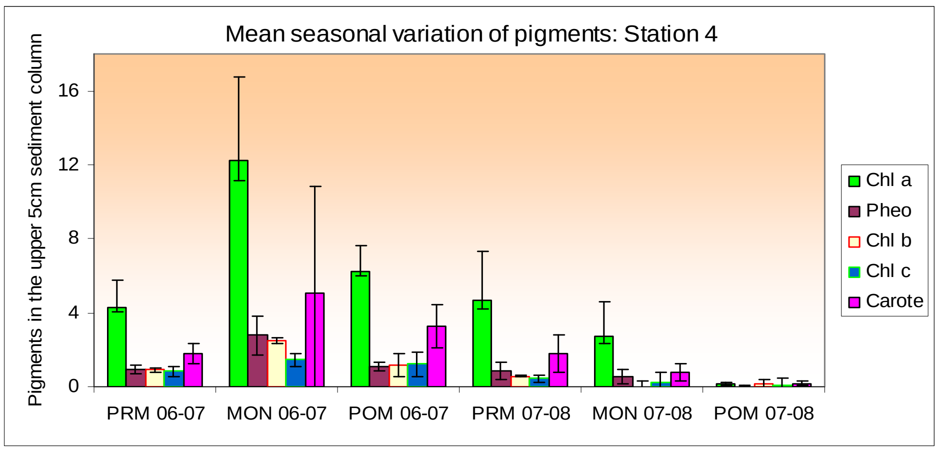


Fig. 97

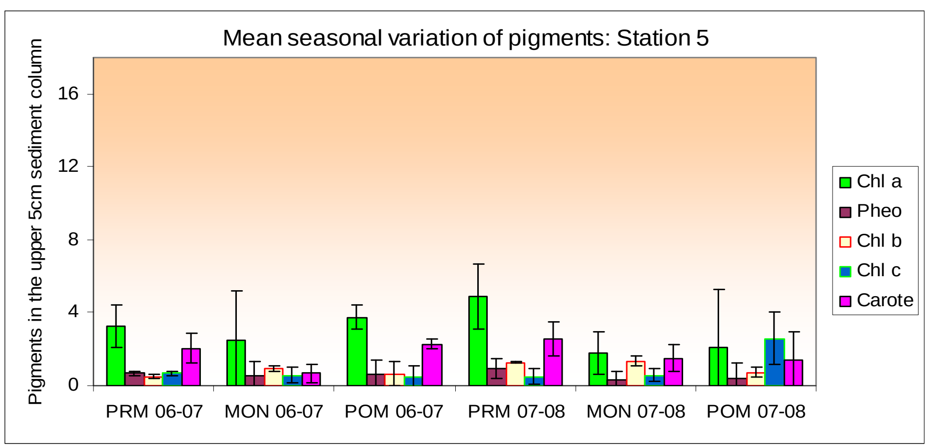


Fig. 98

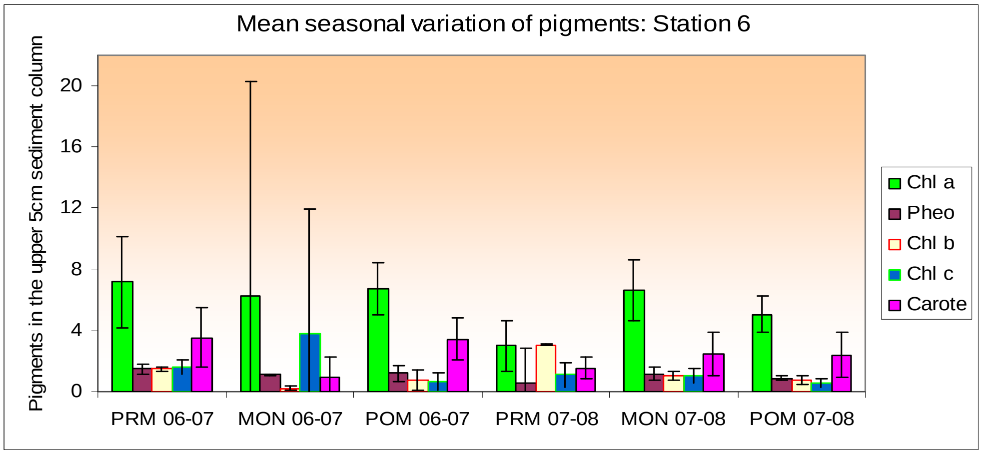
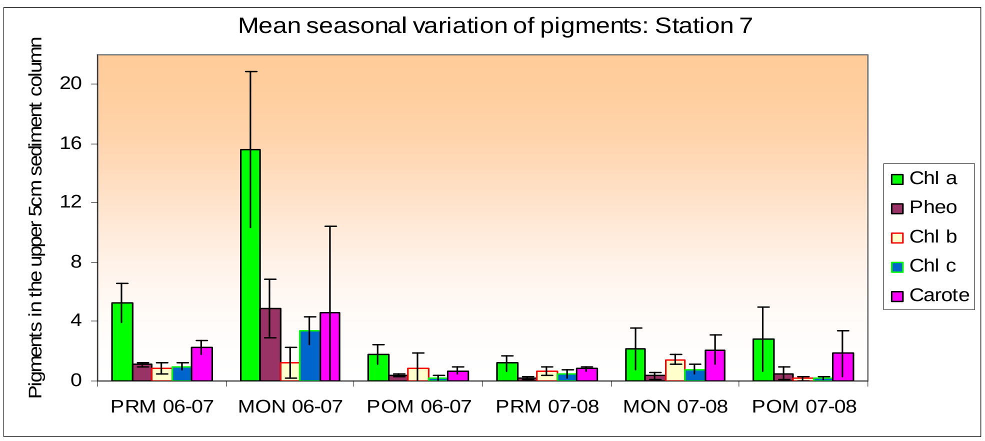
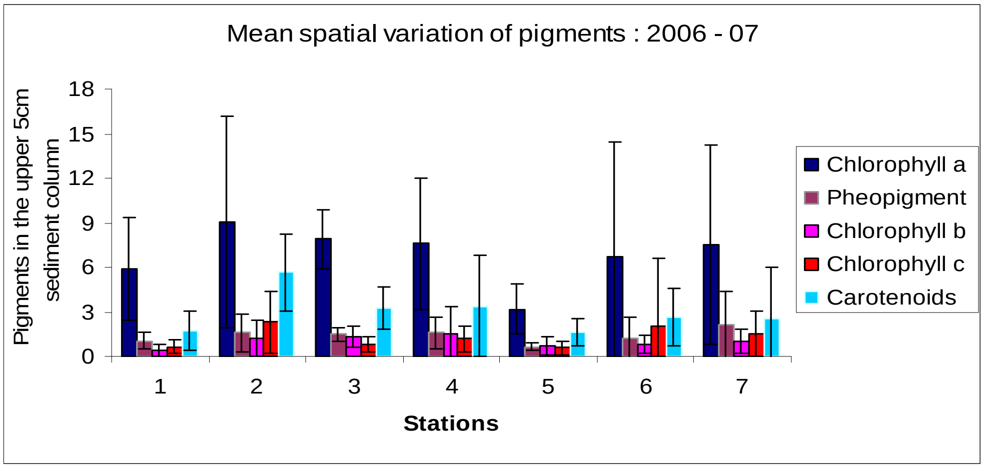


Fig. 99



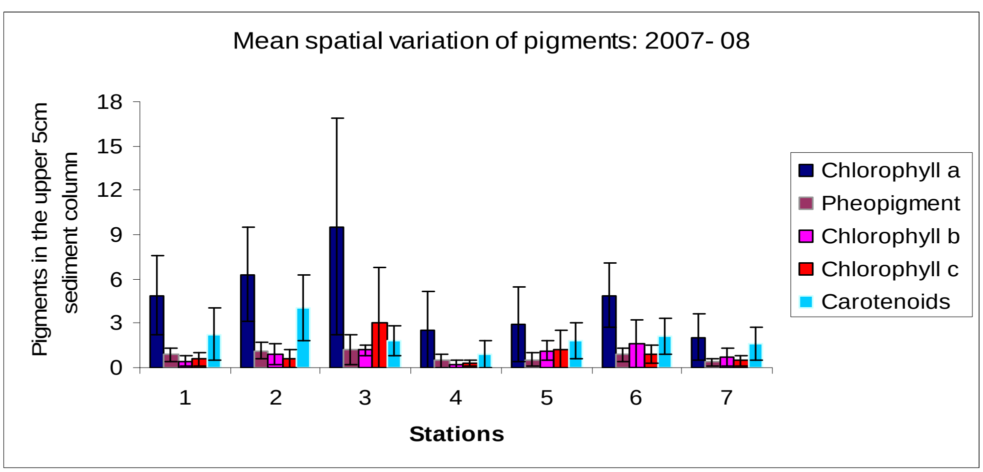
An overall mean of annual pigment variation in all the three seasons in the year 2006-07 and 2007-08 are shown in figs. 100 and 101. In 2006-07, the integrated 5cm column highest mean value of chlorophyll *a,* 9.03, observed in station 2, Kavanad and the lowest in station 5, Balathuruthu with 3.18. The pheopigment value in the 5cm sediment column ranging from 2.01 in station 7, Mahe to the lowest of 0.63 at station 5 Balathuruthu. The highest value of chlorophyll *b* was 1.52 recorded in Azheekode (station 4), and the lowest was recorded (0.39) from station 1 Vaadi. The range of chlorophyll *c* was 2.33 in station 2, Kavanad to 0.56, in station 4, Azheekode. Carotenoids was the highest at station 2, Kavanad with 5.68 to the lowest value of 1.65 in Balathuruthu in the 5cm sediment column (fig.100).

Fig.100



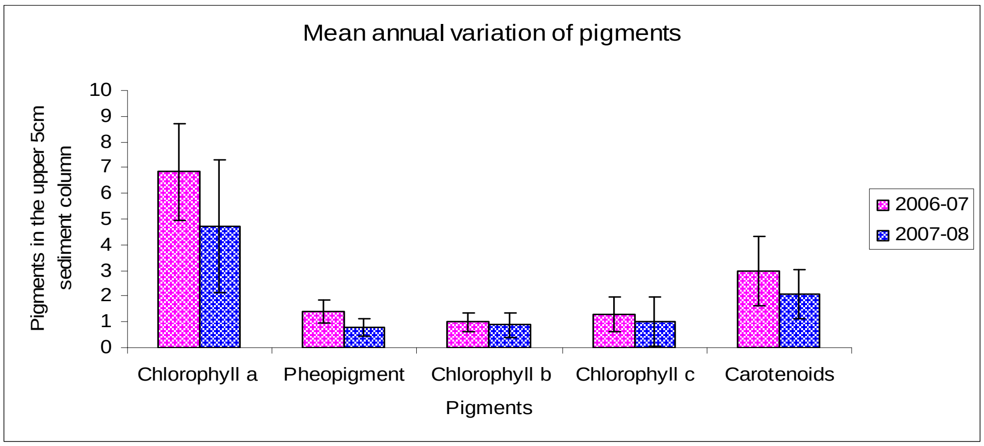
In 2007-08, chlorophyll *a* varied from 9.53 at station 2, Kavanad and with and lowest being 2.07 at station 7 Mahe in the 5cm sediment column. The pheopigment was found to be highest in station 2, Kavanad with 1.13 and the lowest being 0.36 at station 7, Mahe. Maximum chlorophyll *b* value of 1.17 found in station 3, Punnapra and the lowest value of 0.43 was recorded in station 1, Vaadi. Chlorophyll *c* was the maximum in station 3, with 3.01 and lowest in station 4, Azheekode with 0.25. Carotenoid pigment values varied from 4.01µgL^{-1} at station 2, to the lowest value of 0.92 at station 4 Azheekode in the 5cm sediment column (fig.101).

Fig. 101



Mean pigments value along the southwest coast of India during 2006-07 and 2007-08 is shown in fig. 102. All the pigments have highest values during 2006-07, compared to 2007-08 along the southwest coast of India.

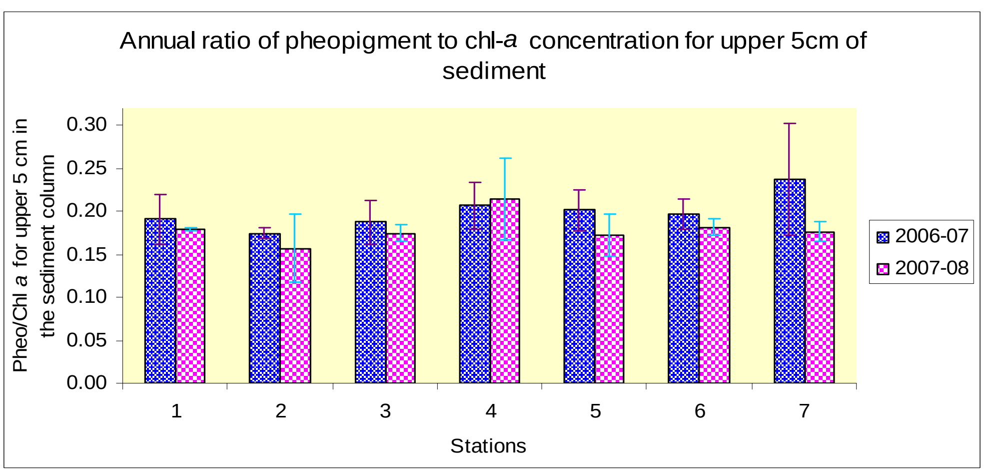
Fig. 102



4.3.3 Pheopigment to chlorophyll *a* ratio

The annual ratio of pheopigment to chlorophyll *a* concentration is shown in fig. 103. The ratio ranges from 0.17 to 0.24 during the year 2006-07 and 0.16 to 0.21 in the following year.

Fig. 103



4.3.4 Chlorophyll *a* and standing crop

Chlorophyll *a* and standing crop has shown a positive correlation during the pre monsoon and post monsoon 2006-07. However, in some seasons, it was not showed direct relationships, except in some stations (Figs, 104, 105, 106, 107, 108 & 109).

Fig. 104

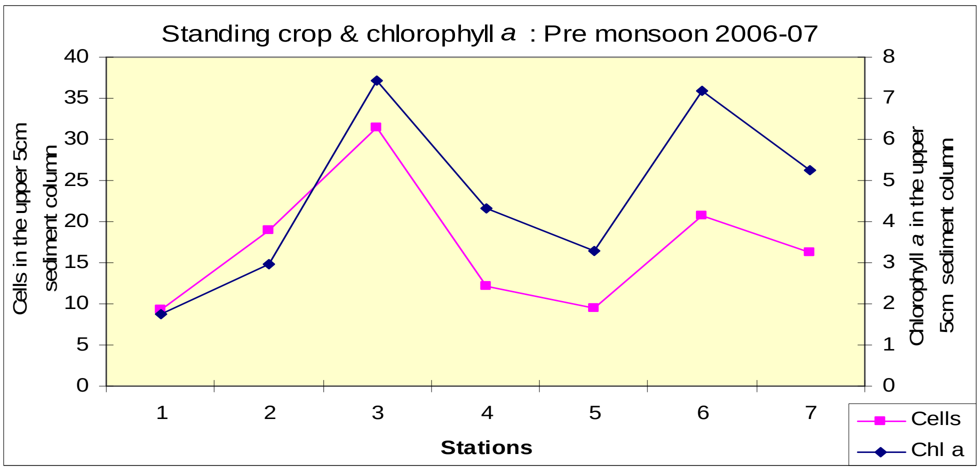


Fig. 105

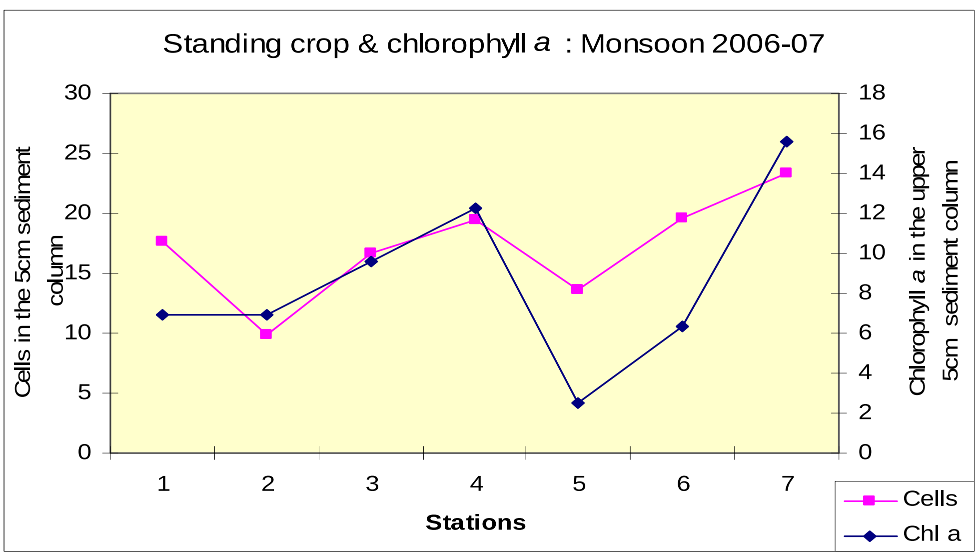


Fig. 106

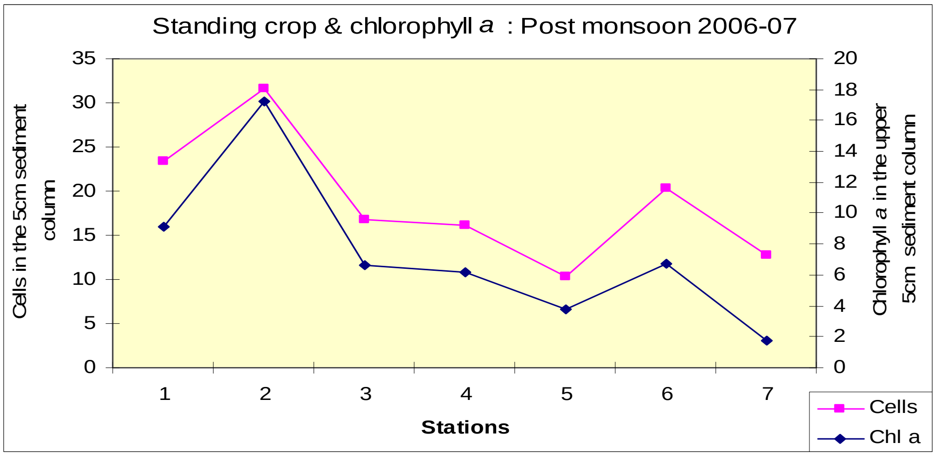


Fig. 107

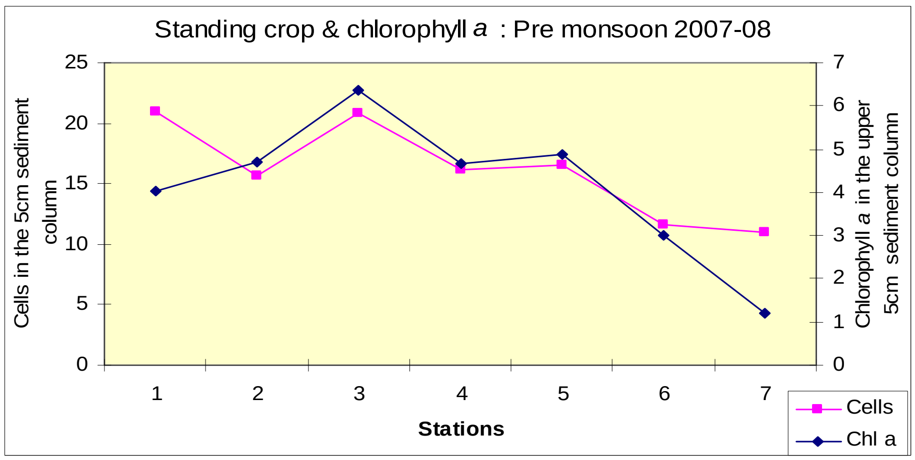


Fig. 108

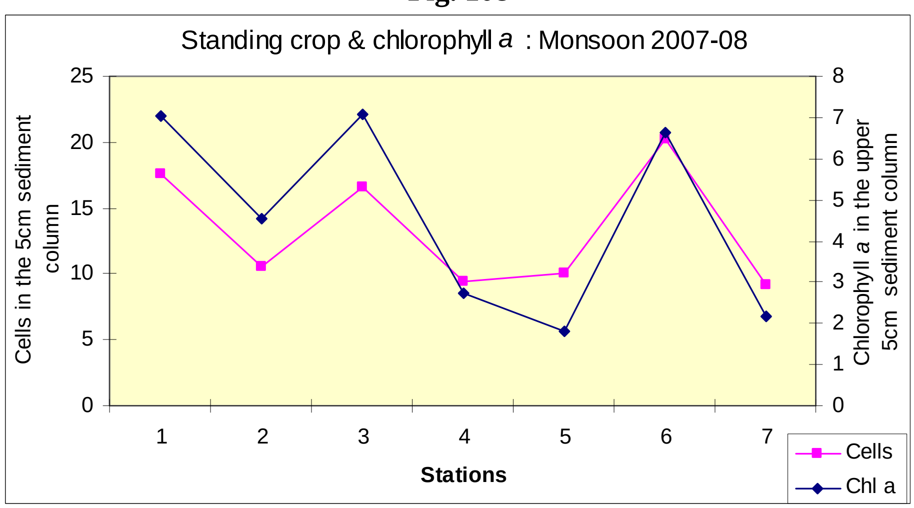
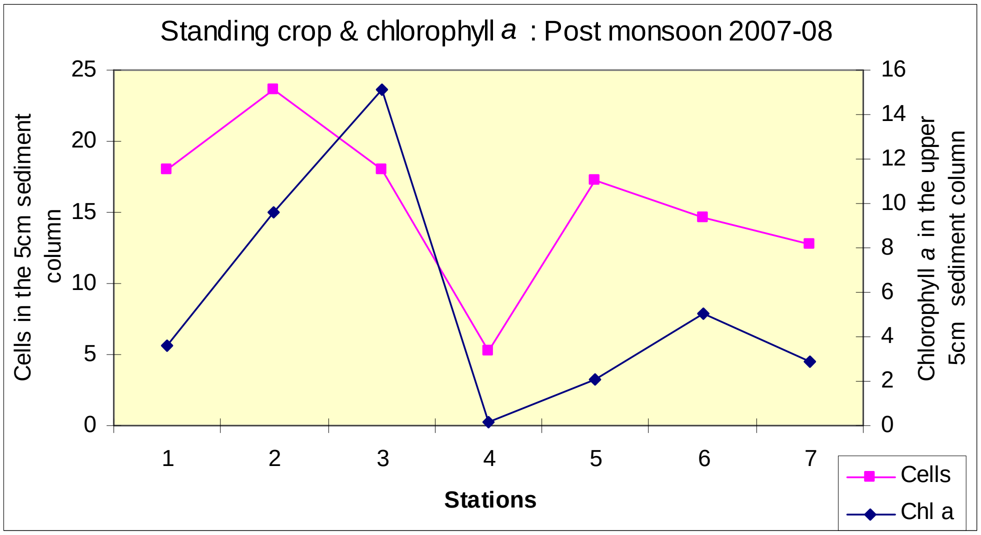


Fig.109



4.3.5 Sediment structure

The particle size of the sediment is shown in table 24. The clay silt and sand were found to have varied with stations and seasons. The lowest percentage of clay was observed in station 4, Azheekode during the post monsoon 2008 with only 0.34%. The highest was recorded as 59.66% at station 1, Vaadi during the same season. The silt was the lowest in Azheekode (station 4) with only 0.79% and the highest was 83.82% from station 6, Kodikkal during the post monsoon 2008. The sand particle was found to be less (1.4%) in Vaadi (station 1) during the post monsoon 2008 and the highest value of 98.88%, was recorded at Azheekode (table 24).

Table 24

Pre monsoon 2006-07

Stations	1	2	3	4	5	6	7
Clay %	3.34	15.47	21.97	27.31	12.21	19.37	7.36
Silt %	1.54	6.93	40.01	27.87	13.16	60.13	12.22
Sand %	95.12	77.60	38.02	44.82	74.64	20.50	80.42

Monsoon 2006-07

Stations	1	2	3	4	5	6	7
Clay %	15.55	12.40	19.22	11.05	3.67	19.56	18.33
Silt %	11.69	4.60	72.45	73.13	1.35	51.61	44.21
Sand %	72.76	83.01	8.33	15.82	94.98	28.83	37.46

Post monsoon 2006-07

Stations	1	2	3	4	5	6	7
Clay %	25.70	20.94	43.13	27.07	11.85	19.62	19.56
Silt %	44.55	49.43	47.28	43.89	30.77	63.85	37.55
Sand %	29.75	29.63	9.58	29.04	57.38	16.53	42.89

Pre monsoon 2007-08

Stations	1	2	3	4	5	6	7
Clay %	10.99	17.42	19.12	25.35	17.22	19.34	21.83
Silt %	42.43	43.40	74.36	27.48	40.05	32.56	31.92
Sand %	46.59	39.17	6.52	47.17	42.73	48.10	46.25

Monsoon 2007-08

Stations	1	2	3	4	5	6	7
Clay %	16.24	15.27	17.88	20.83	10.93	14.89	9.86
Silt %	82.07	50.59	72.78	60.54	33.21	59.99	31.34
Sand %	1.68	34.14	9.34	18.63	55.86	25.12	58.80

Post monsoon 2007-08

Stations	1	2	3	4	5	6	7
Clay %	59.66	19.58	14.30	0.34	21.80	7.13	19.06
Silt %	38.94	47.44	51.55	0.79	74.81	83.82	32.78
Sand %	1.40	32.98	34.15	98.88	3.39	9.05	48.17

4.3.6 Sediment composition and chlorophyll *a*.

The sediment silt percentage and chlorophyll a has shown a positive relationship. The mean seasonal chlorophyll a pigment in the upper 5cm sediment column is directly proportional to the silt percentage at all the stations. (Figs. 110, 111, 112, 113, 114 and 115). However, the percentage of clay and sand found to have no relationship with the pigments

Fig. 110

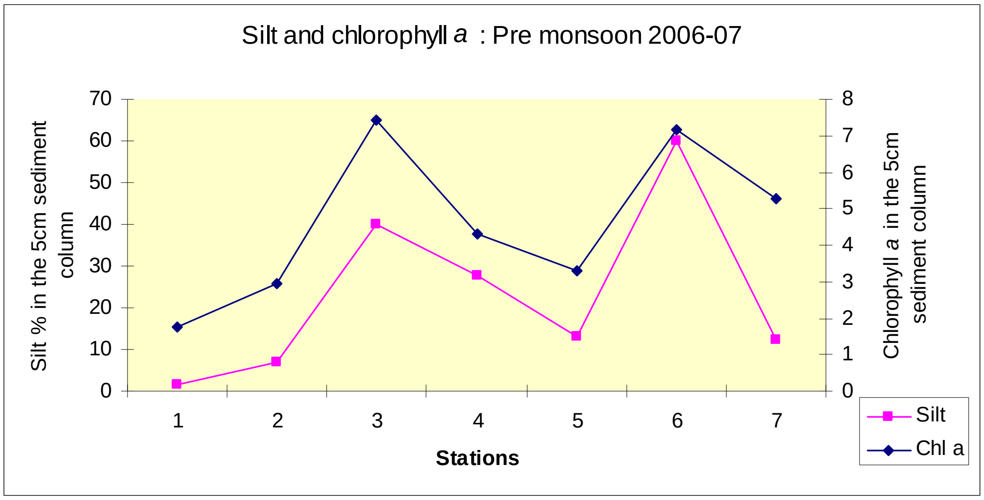


Fig. 111

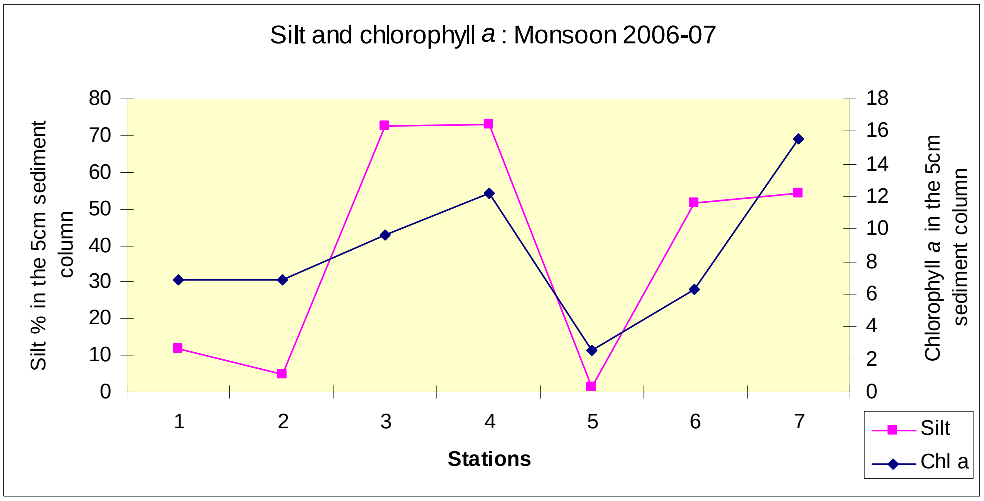


Fig. 112

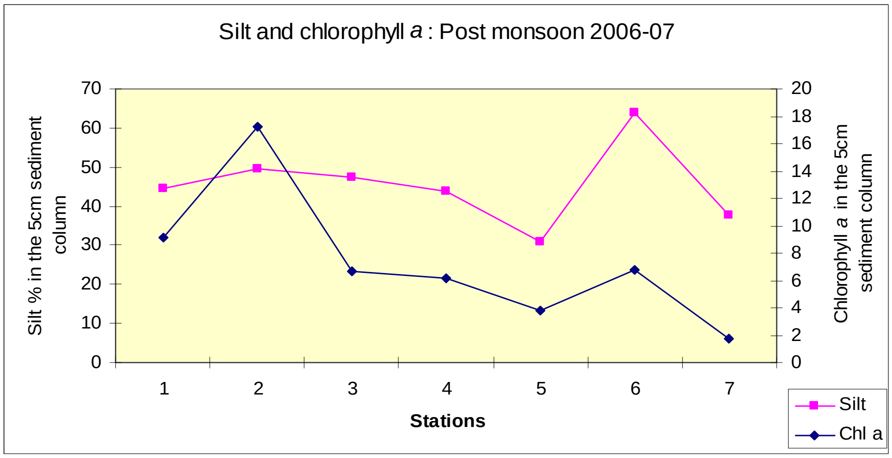


Fig.113

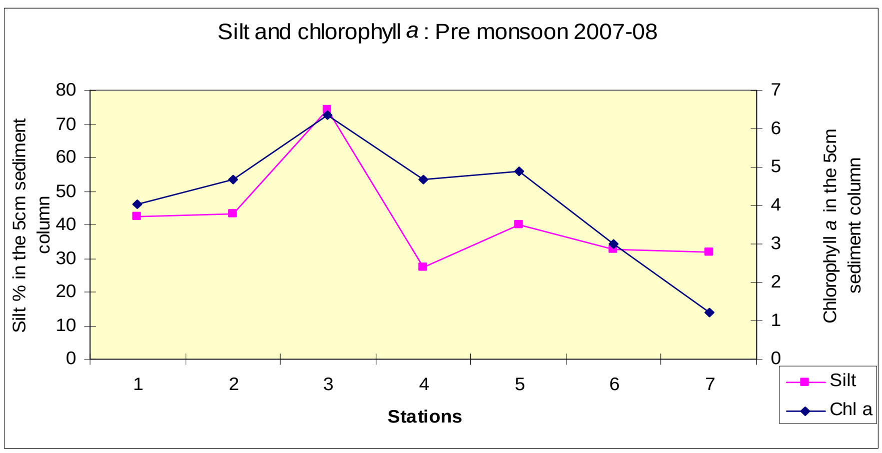


Fig.114

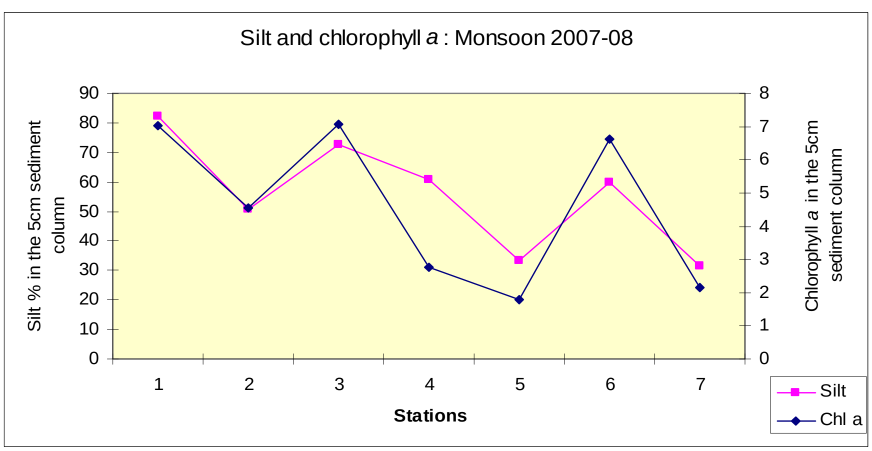
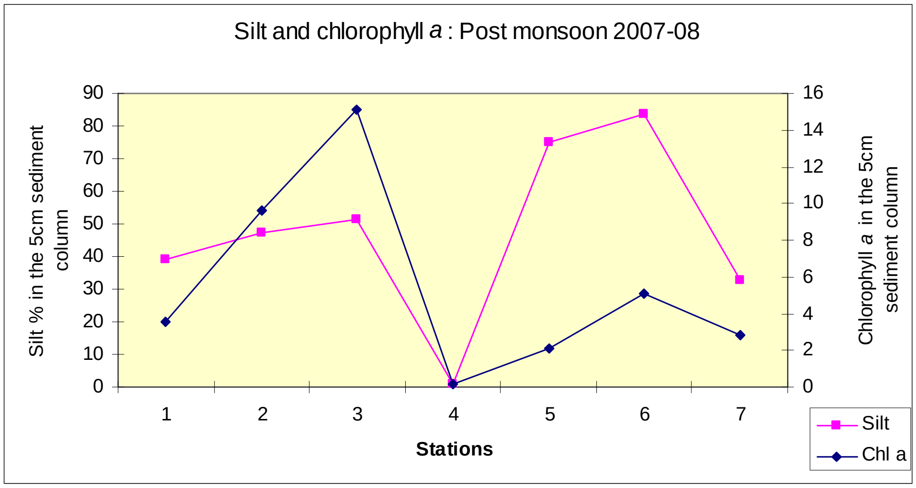


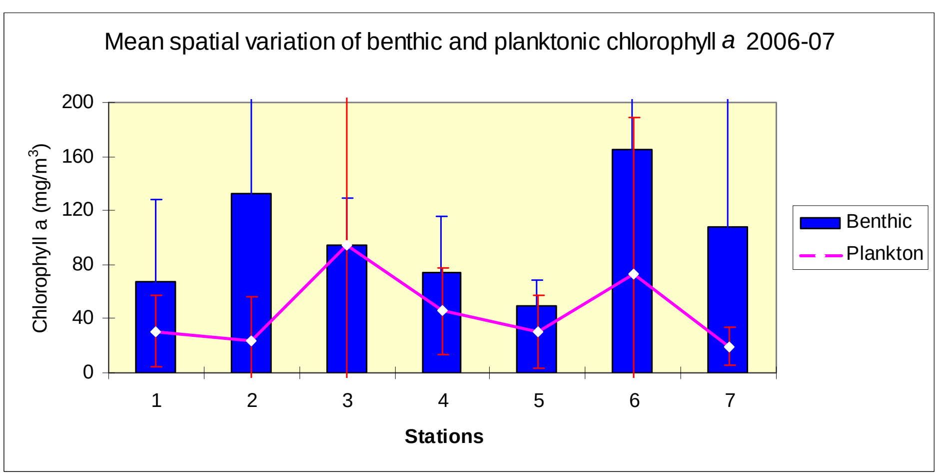
Fig.115



4.3.7 Spatio-temporal dynamics of planktonic and benthic microalgae

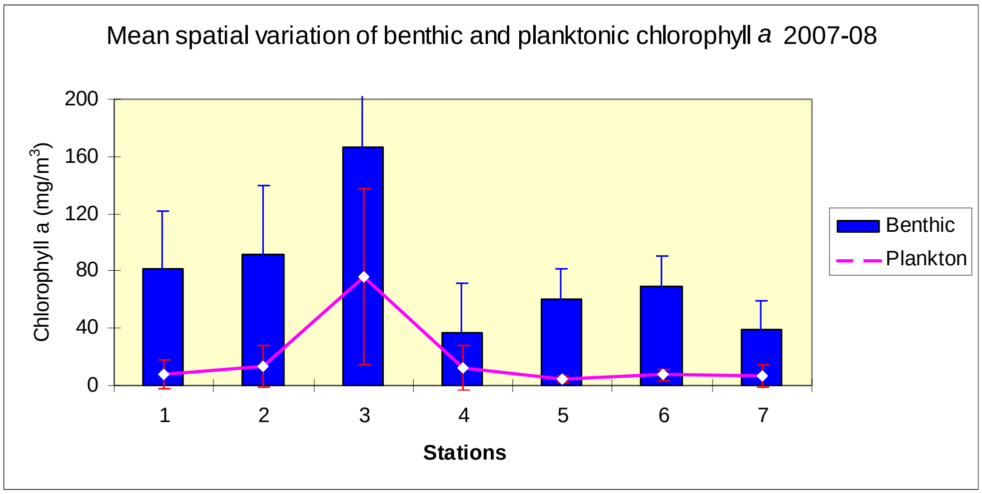
The surface water and the surface sediment stratum chlorophyll *a* were analyzed to study the dynamics of benthic and pelagic microalgae. The results showed that, the mean benthic microalgal biomass as chlorophyll *a*, was much higher than the planktonic in all the seven stations during 2006-07. The benthic chlorophyll *a* was ranged from 49.9mg/m^3 to 164mg/m^3 at stations 5 and 6 respectively. Similarly, the planktonic chlorophyll *a* varied from 19.4 (station 7) to 94. 05, at station 3 (fig.116).

Fig. 116



In the following year, the mean benthic chlorophyll *a* showed higher values than planktonic. The highest planktonic chlorophyll *a* (75.74mg/m^3) was found in station 3 and the lowest being 4.9mg/m^3 at station 5. Benthic microalgal chlorophyll *a* varied from 37.1mg/m^3 at station 4 to 166mg/m^3 in station 3 (fig. 117).

Fig. 117



The mean chlorophyll *a* values of benthic and pelagic microalgae showed conspicuous spatial and temporal variations. Both planktonic and microphytobenthic chlorophyll *a* biomass levels were generally much higher during the year 2007-08. Station 3 showed the maximum values in both the years.

4.3.8 Statistical analysis

The results of three way ANOVA shows that the pigments in stations, seasons and strata have significance. However, chlorophyll b didn't show any significant relationship to any of the season, strata and station. Chlorophyll c has significance only with the season and not significant with those of station and sediment strata (table 25)

Table 25

Chl a						
Source of Variation	DF	SS	MS	F	P	tabled value
Station	6	635.402	105.9	12.598	<0.001	2.175
Mud strata	4	690.153	172.538	20.525	<0.001	2.447
Season	5	559.081	111.816	13.301	<0.001	2.290
Residual	120	1008.77	8.406			
Total	209	5151.914	24.65			

Pheopigment						
Source of Variation	DF	SS	MS	F	P	tabled value
Station	6	13.067	2.178	7.744	<0.001	2.175
Mud strata	4	24.175	6.044	21.491	<0.001	2.447
Season	5	36.326	7.265	25.835	<0.001	2.290
Residual	120	33.747	0.281			
Total	209	224.773	1.075			

Chl b						
Source of Variation	DF	SS	MS	F	P	tabled value
Station	6	13.87	2.312	3.96	0.001	2.175
Mud strata	4	1.691	0.423	0.724	0.577	2.447
Season	5	2.712	0.542	0.929	0.465	2.290
Residual	120	70.047	0.584			
Total	209	190.519	0.912			

Chl c						
Source of Variation	DF	SS	MS	F	P	tabled value
Station	6	42.332	7.055	2.802	0.014	2.175
Mud strata	4	19.205	4.801	1.907	0.114	2.447
Season	5	64.276	12.855	5.106	<0.001	2.290
Residual	120	302.117	2.518			
Total	209	768.16	3.675			

Carotenoids						
Source of Variation	DF	SS	MS	F	P	tabled value
Station	6	200.319	33.386	13.292	<0.001	2.175
Mud strata	4	71.973	17.993	7.164	<0.001	2.447
Season	5	58.341	11.668	4.645	<0.001	2.290
Residual	120	301.41	2.512			
Total	209	1042.732	4.989			

One way ANOVA of the spatial distribution of pigments were also measured. It shows that, only chlorophyll a and carotenoids has shown the significance (table 26).

Table 26

ANOVA						
		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Chl *a*	Between Groups	635.402	6	105.900	4.760	.000
	Within Groups	4516.512	203	22.249		
	Total	5151.914	209			
Pheo	Between Groups	13.067	6	2.178	2.088	.056
	Within Groups	211.706	203	1.043		
	Total	224.773	209			
Chl *b*	Between Groups	13.870	6	2.312	2.657	.017
	Within Groups	176.649	203	.870		
	Total	190.519	209			
Chl *c*	Between Groups	42.332	6	7.055	1.973	.071
	Within Groups	725.828	203	3.576		
	Total	768.160	209			
Carotenoids	Between Groups	200.319	6	33.386	8.045	.000
	Within Groups	842.414	203	4.150		
	Total	1042.732	209			

Tabled value = 2.143

One way ANOVA of the vertical distribution in sediment strata show that, chlorophyll a, pheopigment and carotenoids have significance among themselves (table 27).

Table 27

ANOVA						
		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Chl *a*	Between Groups	690.153	4	172.538	7.927	.000
	Within Groups	4461.761	205	21.765		
	Total	5151.914	209			
Pheo	Between Groups	24.175	4	6.044	6.176	.000
	Within Groups	200.598	205	.979		
	Total	224.773	209			
Chl *b*	Between Groups	1.691	4	.423	.459	.766
	Within Groups	188.827	205	.921		
	Total	190.519	209			
Chl *c*	Between Groups	19.205	4	4.801	1.314	.266
	Within Groups	748.956	205	3.653		
	Total	768.160	209			
Carotenoids	Between Groups	71.973	4	17.993	3.800	.005
	Within Groups	970.759	205	4.735		
	Total	1042.732	209			

Tabled value = 2.416

Two way ANOVA of sediment characteristics, ie., percentage of clay, silt and sand didn't show any significant spatial and seasonal variation (table 28).

Table 28

Clay						
Source of Variation	**DF**	**SS**	**MS**	**F**	**P**	**Tabled value**
station	6	288.942	48.157	1.309	0.283	2.421
Season	5	101.77	20.354	0.553	0.735	2.534
Residual	30	1103.335	36.778			
Total	41	1494.048	36.44			

Silt						
Source of Variation	**DF**	**SS**	**MS**	**F**	**P**	**Tabled value**
station	6	5804.053	967.342	2.228	0.068	2.421
Season	5	3889.215	777.843	1.791	0.145	2.534
Residual	30	13027.75	434.258			
Total	41	22721.01	554.171			

Sand						
source of Variation	**DF**	**SS**	**MS**	**F**	**P**	**Tabled value**
station	6	7605.467	1267.578	2.115	0.081	2.421
Season	5	4856.304	971.261	1.62	0.185	2.534
Residual	30	17983.74	599.458			
Total	41	30445.51	742.573			

The correlation analysis shown that all the pigments have significant correlations (table. 29)

Table 29

Correlations						
		Chl *a*	**Pheo**	**Chl *b***	**Chl *c***	**Carotenoids**
Chl *a*	Pearson Correlation	1				
	Sig. (2-tailed)	.				
	N	210				
Pheo	Pearson Correlation	.854(**)	1			
	Sig. (2-tailed)	.000	.			
	N	210	210			
Chl *b*	Pearson Correlation	.293(**)	.286(**)	1		
	Sig. (2-tailed)	.000	.000	.		
	N	210	210	210		
Chl *c*	Pearson Correlation	.628(**)	.405(**)	.174(*)	1	
	Sig. (2-tailed)	.000	.000	.011	.	
	N	210	210	210	210	
Carotenoid	Pearson Correlation	.518(**)	.560(**)	.418(**)	.167(*)	1
	Sig. (2-tailed)	.000	.000	.000	.015	.
	N	210	210	210	210	210

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

The correlation analysis of sediment characteristics are shown in table. 30. Negative correlations were found between clay and sand and silt and sand.

Table 30

Correlations				
		Clay	**Silt**	**Sand**
Clay	**Pearson Correlation**	1		
	Sig. (2-tailed)	.		
	N	42		
Silt	**Pearson Correlation**	.535(**)	1	
	Sig. (2-tailed)	.000	.	
	N	42	42	
Sand	**Pearson Correlation**	-.683(**)	-.982(**)	1
	Sig. (2-tailed)	.000	.000	.
	N	42	42	42

** Correlation is significant at the 0.01 level (2-tailed).

4.4 Discussion

4.4.1 Standing crop

Both qualitative and quantitative analysis of microphytobenthos in the first year exhibited remarkable seasonal and spatial variation. The first station during the three seasons in 2006-07, recorded 20 species of microphytobenthos. Gradual increase in population and number of species was observed from pre monsoon to monsoon and post monsoon. It was found that at least three species *Gyrosigma spencerii,* in monsoon and *Diploneis notabilis* and *Nitzschia frustulum* during post monsoon were found distributed in all 5 strata. *Nitzschia spp.* are dominated in the benthic microalgal community (Cahoon *et al.*, 1993). It may be assumed that those species can survive well in the benthic environment even in buried condition signaling their potential heterotrophic characteristics. The distribution of species was moderately even (Mean Simpson index 0.15 $\pm$ 0.035), the species diversity was also moderate (Mean Shannon-Weiner index 2.043 $\pm$ 0.206).

During the second year of investigation, the number of species recorded in three seasons from the study area comprising seven stations was less than those of the previous year. Among the 17 species recorded, the cell abundance was more during the pre and post monsoon, while the lowest was during the monsoon. Species such as *Biddulphia mobiliensis, Cymbella marina, Navicula forcipata, Nitzschia frustulum* were found in the pre monsoon and *Diploneis notabilis, Navicula hennedyei* were observed in the entire 5cm sediment column in monsoon. All these diatoms including the centric *Biddulphia mobiliensis,* were collected from different benthic habitats worldwide. The centric diatom *Biddulphia mobiliensis* was a major constituent of planktonic microalgae and its distribution up to the 5^{th} stratum of sediment was quite interesting. *B. mobilensis* was found in the 0-15cm depth zone in the sediments of Goan coast (Mitbavkar and Anil, 2002, 2006). The distribution of species was almost even (Mean Simpson index 0.159 $\pm$ 0.047), the species diversity (Mean Shannon-Weiner index 1.969 $\pm$ 0.258) was low.

On evaluating the observations for six seasons impart clear understanding of the spatial distribution of microphytobenthos. Among the 30 species of diatoms recorded from station 1, none of the species were observed in all the seasons. *Navicula hennedyei*, and *Nitzschia frustulum* were observed in five seasons. The majority of diatom species present at station 1 were cosmopolitan and Facca *et al*., (2002a and b) reported that these were frequently recorded from Venice Lagoon. During 2007-08, the species diversity (Shannon-Weiner index) was less and eveness (Simpson index) was higher when compared to those of 2006-07.

At station 2, during 2006-07, 16 species of microphytobenthos were recorded from different strata of the 5cm phytozone. The highest number of cells was present in the post monsoon and the lowest in both pre monsoon and monsoon respectively. *Amphora coffeaeformis* was found in all the strata during all seasons indicating its almost enduring occurrence in benthic zone. *Amphora coffeaeformis* is one among the ASP producing diatoms (Richardson, 1997) and which was also declared as a facultative heterotroph (Hellebust and Lewin, 1977). Species such as *Gyrosigma spencerii, Navicula hennedyei* and *Pleurosigma angulatum* were observed in pre monsoon and *Caloneis permagna, Diploneis notabilis, Nitzschia panduriformis, Pleurosigma falx* were observed in post monsoon, in the entire strata of the sediment column. During monsoon, *Diploneis weissflogii* and *Nitzschia longissima* were recorded. In both pre and post monsoon abundance and species diversity were higher compared to those of monsoon. The distribution of species was more or less even (Mean Simpson index 0.163 $\pm$ 0.040) and the species diversity (Mean Shannon-Weiner index 1.897 $\pm$ 0.268) was quite normal.

In the year 2007-08, 14 species were recorded from all the seasons. Among these, a few species were found distributed in all the strata. They are, *Cymbella marina, Nitzschia panduriformis*, in the pre monsoon, *Amphora coffeaeformis, Pleurosigma aestuarii* in the monsoon and *Navicula forcipata* in post monsoon. No species was present in all the three seasons. The distribution of species was more or less even (Mean Simpson index 0.135 ± 0.029) and the species diversity (Mean Shannon-Weiner index 2.103 ± 0.214) was modest.

Sixteen species were recorded from station 2, during the period 2006-07 in different seasons. *Amphora coffeaeformis* was found distributed throughout the study period. Station 2, is shallow with a depth of 1.5m and the entire water column is euphotic irrespective of seasons. When the light is above optimum in the benthic zone or the penetration of light into the sediment sometimes may hider the active growth of some microphytobenthos due to its facultative heterotrophism. This would be the reason for decreased richness and diversity at station 2. Further more the distribution of various species in the entire strata of sediment indicates the facultative heterotrophic nature of microphytobenthos. The pennate diatoms recorded at station 2 was recognized as common benthic species (Cartaxana *et al*., 2006).

A total of 20 species were recorded from station 3, during the period 2006-07. During the pre monsoon, *Caloneis permagna, Navicula directa var. remota, Nitzschia frustulum, Pleurosigma aestuarii* and *Pleurosigma falx* and in the monsoon, species such as *Caloneis permagna, Gyrosigma nodiferum, Pleurosigma falx* and *Surirella fastuosa* were found distributed in all the sediment strata. None of the species was present in the entire strata during the post monsoon. *Pleurosigma falx* was recorded in all the seasons. There was a gradual decrease in the occurrence of species from pre monsoon to post monsoon. The species were evenly distributed (Mean Simpson index 0.105 ± 0.02) and the species diversity (Mean Shannon-Weiner index 2.350 ± 0.201) was slightly high.

In 2007-08, total number of species recorded was 20, as in the previous year. A few microphytobenthos were found in all the strata such as *Licmophora flabellata* and *Surirella fastuosa* in the pre monsoon, *Caloneis permagna, Surirella fastuosa Pleurosigma aestuari* during monsoon and, *Nitzschia longissima* and *Navicula directa var. remota* in post monsoon. *Ceratium symmetricum,* was recorded from the surface strata during monsoon. *Ceratium* was not a typical benthic species and its representation in the benthic zone was due to sinking characteristics of planktonic species. The distribution of species was relatively even (Mean Simpson index 0.121 ± 0.09) and the species diversity was almost high (Mean Shannon-Weiner index 2.232 ± 0.078).

During the 2 year period, 23 species were recorded from station 3. The dinoflagellate species *Ceratium symmetricum* was appeared along with diatoms. There was a bloom of *Ceratium spp.* occurred in the overlying water in the same period. Shannon-Weiner diversity index was decreased from 2006-07 to 2007-08, similarly, Simpson dominance index was increased a little. The species distribution was quite even during 2006-07 when compared to 2007-08.

In the year 2006-07 at station four, 24 species were observed in all the seasons. Among these, *Cymbella marina, Navicula elegans* and *Surirella flumiensis* were present in all the strata exclusively only during pre monsoon, monsoon and post monsoon respectively. *Navicula elegans* and *Nitzschia closterium* were found both in the pre monsoon and monsoon but not in post monsoon. Similarly, *Pleurosigma acuminatum* was seen in monsoon to post monsoon. *Amphora turgida* and *Pleurosigma falx* were present in pre monsoon and post monsoon and not in the monsoon. Dinoflagellate *Ceratium furca* was recorded from the top three strata of sediment during the post monsoon. The numerical abundance was high in the monsoon, when compared to other two seasons. The species distribution was even (Mean Simpson index 0.244 ± 0.215) and the species diversity (Mean Shannon-Weiner index 1.868 ± 0.589) was also moderate.

In the following year, 17 species were recorded and during the pre monsoon, *Gyrosigma hippocampus* and *Navicula forcipata* found in the entire strata where as in monsoon, *Achnanthes brevipes* was found in all the strata and none of the species was present in the entire strata during post monsoon. The diversity and the abundance were decreased from pre monsoon to post monsoon. No single species was found distributed throughout the seasons. The recorded species were evenly distributed (Mean Simpson index 0.210 ± 0.066), and the species diversity (Mean Shannon-Weiner index 1.677 ± 0.331) was also normal.

In station 4, at Azheekode, all together, twenty eight species were recorded from the entire six seasons. None of these species was present throughout the seasons *Ceratium furca* found in the surface strata during the pre monsoon of two years. Species diversity was decreased from 2006-07 to 2007-08 and the distribution was comparatively even during 2007-08.

At station 5, during the first year, 17 species were recorded, including 4 species from the class Cyanophyceae. In the pre monsoon, *Nitzschia closterium* and *Surirella fastuosa* were found in all the strata. *Surirella fastuosa* in monsoon and *Surirella flumiensis* and *Pleurosigma aestuarii* in the post monsoon were recorded in the entire strata. Cyanophycean species such as *Chroococcus turgidus Lyngbya aestuarii, Merismopdia elegans* and *Oscilllatoria chalybea* were distributed on the surface stratum during the monsoon. The highest species abundance was observed in the monsoon. The species distribution was relatively even (Mean Simpson index 0.184 ± 0.049) and the species diversity (Mean Shannon-Weiner index 1.658 ± 0.587) was normal.

During 2007-08, a total of 18 species were observed in three seasons. The following species were present in all the strata, *Amphora turgida* and *Gyrosigma nodiferum* in the pre monsoon, *Pleurosigma angulatum* and *Surirella flumiensis* in the monsoon and *Nitzschia panduriformis* and *Pleurosigma naviculaceum* in the post monsoon. *Lyngbya aestuarii* and *Oscilllatoria chalybea* are the two cyanophycean species which found in the surface stratum during the monsoon. Pre and post monsoon have high cell densities when compared to monsoon. The mean Simpson index was 0.145 ± 0.034 indicating an even distribution and the mean species diversity index (Shannon-Weiner) 2.037± 0.238) was slightly high and hence a moderate diversity was found in the microphytobenthos community composition.

Twenty six species including 4 cyanophycean species such as, *Merismopdia elegans, Chroococcus turgidus, Oscilllatoria chalybea* and *Lyngbya aestuarii,* were recorded. None of the species was present throughout the seasons. All the 4 species were found in the monsoon 2006-07 and only 2 species, viz., *Oscilllatoria chalybea* and *Lyngbya aestuarii* were present in the monsoon 2007-08. Station 5 is estuarine and in the monsoon it was in freshwater condition. Thajuddin and Subramanian (2005) reported that the cyanophycean species recorded in the present investigation were frequently occurring in the sediments from peninsular India. *Navicula spectabilis* was found in five seasons in the course of two years. The diversity and evenness of the community was higher during 2007-08 compared to those of 2006-07.

At station 6, seventeen species were observed in the period 2006-07. During the pre monsoon, *Gyrosigma nodiferum, Nitzschia closterium* and *Pleurosigma angulatum* were recorded from the entire sediment strata. Species such as *Pleurosigma acuminatum, P. aestuarii* and *P. falx* were found in the entire strata in the monsoon along with planktonic *Coscinodiscus asteromphalus* var. *centralis*. The same species produced bloom on the overlying water during the monsoon. There were many centric diatoms were recorded from intertidal sediments from Goa (Mitbavkar and Anil, 2002) however, *Coscinodiscus asteromphalus* var. *centralis* was not observed. The occurrence of the same in the sediment during monsoon might be due to the settlement of the species from the overlying waters (McIntyre *et al*., 1996). In the post monsoon, *Navicula hennedyei*, *Nitzschia panduriformis, Pleurosigma falx* and *Surirella flumiensis* were recorded from the all the strata of 5cm sediment column. *Navicula hennedyei* was documented throughout all the seasons. The numerical abundance of the species was the highest during the monsoon period. The distribution of species was quite even (Mean Simpson index 0.140 ± 0.043) and with slightly high species diversity (Mean Shannon-Weiner index 2.134 ± 0.263).

During 2007-08, 19 species were present in all the seasons. In the pre monsoon, species such as *Cymbella marina*, *Pleurosigma naviculaceum* and *Surirella fastuosa* were found in the all sediment strata. *Navicula inclementis,* *Pleurosigma aestuarii* and *P. angulatum* were found in the monsoon and *Nitzschia closterium*, *N. panduriformis* and *Surirella flumiensis* found in the post monsoon in all the strata. The abundance was high in the monsoon. . The species distribution of microphytobenthos was fairly even (Mean Simpson index 0.171 ± 0.030) and almost low species diversity (Mean Shannon-Weiner index 1.996 ± 0.218).

Twenty three species were recorded from all the six seasons in two years. Species such as *Cymbella marina, Gyrosigma nodiferum*, *Navicula hennedyei*, and *Pleurosigma acuminatum* were observed in five seasons. The dinoflagellate *Ceratium furca* was also recorded during the pre monsoon and monsoon periods in the year 2007-08. The species distribution was quite uneven and diversity was also less in 2007-08 compared to that of 2006-07.

In 2006-07, at station 7, fifteen species were recorded. Some of the biraphid pennate diatom species, such as *Pleurosigma aestuarii* during the pre monsoon, *Pleurosigma acuminatum, P. aestuarii* in the monsoon and *Surirella fastuosa* in the post monsoon, were recorded from all the segment of the sediment strata. besides these, *Nitzschia closterium* was observed from all the strata of the sediment in the three seasons. *Pleurosigma falx* was also found in three seasons but not in all the strata. The abundance of cells was gradually increased from pre monsoon to other seasons. The species were more or less evenly distributed (Mean Simpson index 0.192 ± 0.066) and the species diversity (Mean Shannon-Weiner index 1.826 ± 0.354) was slightly less.

In 2007-08, eighteen species were found in the three seasons. *Surirella ovalis* and *Pleurosigma acuminatum* were recorded from all the strata of 5cm sediment column in pre monsoon and monsoon respectively. In the post monsoon, *Amphora coffeaeformis* and *Surirella ovalis* were distributed in all the strata. *Pleurosigma falx* was found in all the three seasons in the surface strata. An increase in number of species was observed from pre monsoon onwards. The species distribution (Mean Simpson index 0.186 ± 0.060) was even and with a slightly less species diversity (Mean Shannon-Weiner index 1.885 ± 0.241).

All together, twenty two species, which includes, two Cyanophycean species during the monsoon and one dinoflagellate species (pre monsoon 2007-08) were recorded from various seasons during the period of 2 years. The biraphid pennate diatom, *Pleurosigma falx* was the found distributed in the entire seasons throughout the two year study period. There was no considerable variation in the species distribution and evenness during the two years, at station 7.

The highest mean annual abundance of standing crop in the upper 5cm sediment column of the sediment was found in station 3 (108 $\pm$ 42.44) and the lowest was in station 5 (61.67 $\pm$ 21.22) during 2006-07. The highest in 2007-08 was observed in station 1 with 94.33 $\pm$ 9.29 and the lowest was in station 4 (51.33 $\pm$ 27.75). Comparatively high abundance was seen in 2006-07 period except in station 1 and 5, where abundance was high in 2007-08. More over, the mean abundance of microphytobenthos in the southwest coast was high during 2006-07 (89.48 $\pm$ 15.89) than that in 2007-08 (75.67 $\pm$ 16.7).

During the two years of observations, from pre monsoon 2006-07 to post monsoon 2007-08, 55 species of microphytobenthos within 22 different genera were observed (Annexure 6), of which, class Bacillariophyceae was dominant with 48 species among 16 genera (88%), followed by Cyanophyceae with 4 genera and species (7%) and Dinophyceae with 3 (5%) species distributed in 2 genera. At Stellwagen Bank, USA, the dominance of diatoms was 97% (Cahoon *et al*., 1993) and it was 90% in Tagus estuary, Western Europe (Ribeiro *et al*., 2003). The concentration of diatoms was 68% in Bahia Blanca, Argentina (Parodi and Barria de Cao, 2003). The highest species diversity was found in station 1, with 30 species of microphytobenthos and the lowest was in station 2 with only 16 species. 54% of the total biomass was observed at the surface stratum and 87% was found in the upper 3cm depth.

Among the 55 species of microphytobenthos, species such as *Cocconeis littoralis* Subrahmanyan, *Cocconeis scutellum* Ehrenberg, *Cocconeis sigmoides* Subrahmanyan *Cymbella aspera* (Ehrenberg) Cleve, *Cymbella marina* Castracane, *Diploneis littoralis* (Donkin) Cleve, *Diploneis weissflogii* (A. Schmidt) Cleve and *Navicula directa var. remota* Grunow were found mostly in benthic zone. The rest were 'tychopelagic' (Cahoon and Laws, 1993), or 'tychoplanktonic' (Sylvestre *et al*., 2001).

The number of cells may be 2-5 folds higher in exposed benthic environment than that in the benthic zone covered by water (Perissinotto *et al*., 2003). Here in this study almost all station having a water depth of 3-5m and the transparency was approximately 1-2m. The species diversity was observed as quite normal and the abundance was very less compared to the exposed coasts and other shallow water ecosystems. The station 2 was shallower with a depth of less than 1.5m and was euphotic in all seasons. The lowest species diversity was found in station 2, when compared to other stations.

A study from the Goan coast reported that the diatom abundance was the lowest during the monsoons and the highest during the post-monsoons (Mitbavkar and Anil 2006). In the investigation, the post monsoon consistently recorded higher standing crop. The hike in cell numbers recorded in monsoon at some stations, is only apparent, which is due to the accumulation of algal blooms in the sediment. Microscopic examination of sediment have shown that benthic microalgae are dominated by pennate diatoms (>97% of total cells), including various species of *Nitzschia, Navicula* and *Amphora* (Cahoon *et al*., 1993, McIntyre *et al*., 1996). In all the stations, throughout the season, the biraphid pennate diatoms, such as *Pleurosigma angulatum, P falx, P aestuarii, Amphora coffeaeformis, A turgida, Nitzschia closterium*, *N. panduriformis, S fastuosa* and *S flumiensis* were found upto the final stratum of the sediment column. The pennate diatoms recorded during this study are typical benthic species (Vilbaste *et al*., 2000; Ribeiro *et al*., 2003). All the four species from the class Cyanophyceae were reported as benthic species earlier (Delgado, 1989; Parodi and Barria de Cao, 2003). The floral composition of microphytobenthos exhibited spatial variation in Cochin estuary (Sivadasan and Joesph, 1998). Such a variation was not observed in the present area of investigation where both marine and estuarine environment were included. Further more, the earlier study focused only on the surface stratum of the sediment and hence the buried microphytobenthos might not have included. The present investigation analyzed the vertical distribution of benthic flora and unraveled almost all the species present in this particular zone.

4.4.2 Pigments

The highest mean concentration of chlorophyll *a* in the entire 5cm sediment strata of the sediment was found during the post monsoon in 2006-07 at station 1 (9.083 $\pm$ 2.38), and the lowest was 1.765 $\pm$ 0.90 during the pre monsoon. Similarly, the highest value in 2007-08 was observed during the monsoon with (7.02 $\pm$ 3.37) and with a low value of (3.59 $\pm$ 1.91) in the post monsoon.

The range of pheopigment in the 5cm sediment column has not shown marked variation in 2006-07 and 2007-08. A high value of 1.56 $\pm$ 0.33, was found in 2006-07 during the post monsoon and the lowest was from pre monsoon in the same year in the 5cm sediment column (0.395 $\pm$ 0.22)

The mean chlorophyll *b* in the 5cm sediment column was the highest in the pre monsoon 2006-07 (0.242 $\pm$ 0.136) and the lowest recorded was (0.063 $\pm$ 0.054) during the same season in 2007-08. Chlorophyll *c* was the highest in the post monsoon, 0.957 $\pm$ 0.65, during the year 2006-07 and the lowest of 0.252 $\pm$ 0.18, found in the pre monsoon during 2007-08. The average carotenoid pigments showed the highest value of 3.32 $\pm$ 0.99 in the post monsoon in first year and the lowest concentration 0.766 $\pm$ 0.4, was observed in the pre monsoon of the same year.

The general distribution pattern of microphytobenthos ie., an inverse relationship of the biomass to the depth of the strata in the sediment, was not followed in station 1. The pigments values, in most cases, had shown an irregular pattern of distribution, however, the surface stratum having the highest value and the deepest stratum having the lowest values. In between there were no clear pattern. In station 1, the sampling area was located near the bar mouth and subjected to underwater currents. Due to the mixing of sediments, pigment concentration at least in the upper 5m present an irregular pattern.

In station 2, the highest mean value of chlorophyll *a* in the entire 5cm sediment column recorded during the post monsoon was 17.23 ± 5.44 in 2006-07 and the lowest of 2.96 ± 0.92, was observed in the pre monsoon of same year. Mean pheopigment value was the highest (3 ± 0.92) in the post monsoon and the lower concentration was 0.64 ± 0.13, found in the pre monsoon of the same year. Chlorophyll *b* was found to be the highest during the post monsoon of 2006-07 (2.52 ± 1.24) and the lowest mean concentration (0.41 ± 0.39) was recorded during the monsoon in 2007-08. The maximum average chlorophyll *c* (4.53 ± 1.93) was recorded during the monsoon in 2006-07 and the lowest from the monsoon of 2007-08 (0.1 ± 0.08), in the entire study period of two years. Similarly, highest mean value of (7.83 ± 1.83) carotenoid pigments was observed during the post monsoon in 2006-07 and the lowest average value was found in the pre monsoon in the same year (1.071 ± 0.62).

The value of chlorophyll *a,* decreases with increasing depth but not in all the season. The highest and the lowest values were recorded from the surface and bottom layers respectively. All the other pigments present an irregular pattern of distribution from top to bottom. Even though, the station 2 is in an estuary (Ashtamudy Estuary), the sampling area was very shallow (<1.5m) and ecologically disturbed area, hence the sediment may have relatively disturbed and loose in texture. This may be the probable reason for an uneven distribution of pigments.

At station 3, the highest mean value of chlorophyll *a* (15.14 ± 10.6) was recorded during the post monsoon 2007-08, the lowest (6.37 ± 2.66) was obtained from the pre monsoon in the same year in the 5cm sediment column. The mean pheopigment value was the highest in the monsoon 2006-07 (1.76 ± 0.36) a low value observed during the pre monsoon 2007-08 (1.03 ± 0.49). The mean chlorophyll *b* was the highest (1.88 ± 0.39) during the pre monsoon and the lowest

(0.88 ± 0.91) during the post monsoon 2006-07. Average chlorophyll *c* recorded the highest concentration of 6.14 ± 5.3, during the post monsoon in 2007-08 and the lowest (0.40 ± 0.11) during the monsoon in 2006-07. The carotenoid pigments concentration was the highest (3.61 ± 1.96) in the monsoon 2006-07 and the lowest was found in (1.37 ± 0.65) monsoon 2007-08.

The distribution pattern was uneven throughout the seasons and not followed as normal distribution. Station 3 is a permanent mud bank area of the west coast and the overlying water was shallow except in some seasons, however, the pattern of vertical distribution of pigments was quite irregular. In the present investigation, it is found that the percentage of silt and chlorophyll *a* having positive correlations. Evidently, the percentage of sediment silt was higher in almost all the seasons at station3 in the entire 5cm sediment column and the motile microphytobenthos frequently migrated from the top to bottom providing a irregular distribution of pigments.

At station 4, mean value of chlorophyll *a* in the 5cm sediment column was found to be the maximum (12.22 ± 4.55) during the monsoon 2006-07 and the lowest mean value was 0.12 ± 0.13 recorded during the post monsoon in 2007-08. The highest pheopigment value was observed in the monsoon 2006-07 (2.77 ± 1.06) and the lowest value was found during the post monsoon 2007-08 (0.034 ± 0.021). The highest mean concentration of chlorophyll *b* was 2.49 ± 2.98 and lowest (0.004 ± 0.005) during the monsoon 2006-07 and 2007-08 respectively. The highest mean concentration (1.45 ± 1.4) chlorophyll *c* was found during the monsoon in 2006-07 and the lowest value of 0.052 ± 0.07 during the post monsoon in 2007-08. Similarly, the highest concentration of mean carotenoid pigments (5.05 ± 5.7) and the lowest (0.08 ± 0.13) was found during monsoon 2006-07 and 2007-08 respectively.

The distribution of pigments in each sediment stratum was uneven in station 4. This station is also near the bar mouth and the sediment texture would change accordingly with strong currents. This would have the reason for uneven distribution of pigments in various strata starting from surface to bottom.

At station 5, the mean value of various pigments in the entire 5cm deep sediment showed that the highest chlorophyll *a* concentration (4.87 ± 1.8) was recorded during the pre monsoon and the lowest concentration was 1.79 ± 1.14, recorded during monsoon in the same year, 2007-08. The pheopigment value was found to be highest during pre monsoon (0.89 ± 0.29) and the lowest (0.33 ± 0.28) recorded during the monsoon in 2007-08. The chlorophyll *b* was highest (1.35 ± 0.42) during monsoon 2007-08 and lowest (0.5 ± 0.11) during the pre monsoon 2006-07. The highest value of chlorophyll *c* (1.13 ± 1.5) was found during the post monsoon in 2007-08 and the lowest value (0.37 ± 0.33) was recorded during the monsoon in 2006-07. The highest concentration of carotenoid pigments (2.54 ± 0.94) observed during the pre monsoon 2007-08 and the lowest (0.66 ± 0.5) was found during monsoon 2006-07.

The station 5 is situated in an estuary (Kadalundy Estuary). The depth of the sampling area was 1m. and was subjected to the tidal effects. The estuarine condition, particularly the shallow water benthic habitats would support a high biomass. However, the pigments values were found to be proportional.

At station 6, the maximum average concentration of chlorophyll *a* (7.16 ± 3.01) was found during the pre monsoon in 2006-07 and the lowest (2.99 ± 1.6) was, recorded during pre monsoon in 2007-08 in the sediment column. During the monsoon, in 2006-07, the highest chlorophyll *a* value of 31.2 ever recorded in the entire investigation was obtained from the surface stratum. The centric diatom, *Coscinodiscus asteromphalus* var *centralis,* formed a bloom in the overlying waters in the same season. The accumulation of the settled species in the benthic zone gave high chlorophyll *a* concentration. In the sub-surface strata the normal low chlorophyll values were obtained. The pheopigment value was the highest (1.51 ± 0.44) and the lowest (0.57 ± 0.27) observed during pre monsoon 2006-07 and 2007-08 respectively. The highest chlorophyll *b* was (1.51 ± 0.33) and lowest being 0.21 ±

0.07 during the pre monsoon and monsoon respectively in 2006-07. The highest value of chlorophyll *c* (3.69 ± 8.1) was found during the monsoon in 2006-07 and the lowest value (0.6 ± 0.29) was recorded during the post monsoon in 2007-08. The highest chlorophyll *c* (18.3µg/cm^3) value of the present study was recorded from the surface stratum during the monsoon 2006-07 and the probable reason was the preponderance of diatoms. The highest concentration of carotenoid pigments (3.53 ± 1.95) and the lowest (0.69 ± 1.48) were recorded from the pre monsoon and monsoon respectively in 2006-07 in the 5cm sediment column.

Station 6 was noted for an algal bloom during the monsoon 2006-07 and provided highest values of chlorophyll *a* and chlorophyll *c* in the surface strata. The distribution of pigments was uneven as in the other stations, irrespective of seasons.

At station 7, the highest mean value of chlorophyll *a* (15.58 ± 5.278) was found during the monsoon in 2006-07 and the lowest concentration of 1.19 ± 0.53 was recorded during pre monsoon of 2007-08 in the entire 5cm sediment column. The mean pheopigment value was found to be the highest (4.86 ± 1.95) during the monsoon in 2006-07 and the lowest being 0.22 ± 0.09, recorded during the pre monsoon in 2007-08. The highest mean concentration of chlorophyll *b* was (1.41 ± 0.32) and lowest (0.14 ± 0.11) during monsoon and post monsoon respectively in 2007-08. The highest value of chlorophyll *c* being 3.38 ± 0.93, and the lowest value (0.16 ± 0.17) recorded during the monsoon and post monsoon respectively in 2006-07. The highest value of carotenoid pigments (4.59 ± 5.7) observed during the monsoon 2006-07 and the lowest being 0.49 ± 0.38, found during the pre monsoon 2007-08.

Thus in station 7, due to the settlement of bloom species in the substratum, a moderately high chlorophyll *a* value and the highest carotenoid pigment value was recorded in the monsoon in 2006-07 from the surface stratum. Subsequently the highest value recorded from surface stratum and lower values have obtained from the subsurface strata.

In the southwest coast of India, the average integrated chlorophyll *a* of the 5cm sediment column was recorded during 2006-07 was 6.83 $\pm$ 0.46. Pheopigment (1.39 $\pm$ 0.38), chlorophyll *b* (0.98 $\pm$ 0.68), chlorophyll *c* (1.28 $\pm$ 1.36) and carotenoid pigments (2.98 $\pm$ 0.95), have highest values record during the 2006-07 period. Higher pigment values were recorded in 2006-07 compared to 2007-08. Comparatively higher values of pigments would have obtained during monsoon in 2006-07 particularly in station 6 and 7, were the contribution of bloomed species settles along with surface microalgae. This was supported by the findings of Perissinotto *et al*., (2002), that settled phytoplankton may increase the concentration of chlorophyll *a* in the sediment. The deposition of great amount of planktonic microalgae in the sediment increases the microphytobenthic biomass (Sundback and Jonsson, 1988; Migne *et al*., 2004). These values have contributed much to the mean of total pigments which have been recorded from other stations in 2006-07. In 2007-08, no bloom was observed except at station 3, where the bloom didn't settle to have a conspicuous hike in the total pigments.

Three-way ANOVA revealed significant effects of variables ie; station, sediment strata and season on chlorophyll *a* , pheopigment and carotenoid concentrations at <0.001 level of significance. However, chlorophyll *c* has significance with only the season and chlorophyll *b* not shown significance to any of the variables such as station, sediment depth and seasons. The correlation analysis of the pigments revealed that all of them have significant correlation with each other (significance at 0.01 and 0.05 levels). The strongest correlation (+0.854) was between chlorophyll *a* and pheopigment. One way ANOVA of the spatial distribution of pigments were also measured. Only chlorophyll *a* and carotenoids showed the significant difference.

The highest values of chlorophyll *a* were observed from the intertidal areas (Sundback and Jonsson, 1988; Lukatelich and McComb, 1986; Cahoon, 1999). Meanwhile, Urban-Malinga and Wiktor, (2003), reported that the highest values of chlorophyll *a* content was noted at the littoral zone compared to the exposed areas in the open bays of the southern Baltic Sea. The highest biomass of microphytobenthos was observed at a depth of 15m in Kattegat Bay (Sundback and Jonsson 1988). The pattern of microphytobenthos chlorophyll *a* concentration declined with increasing depth (Masini and McComb, 2001). Several exceptions to this pattern of distribution were observed during the present investigation.

Pigment patterns in the sediment were affected by the composition of microphytobenthic community (Van Leeuwe *et al*., 2008). The maximum concentration of pigments in the 5cm sediment was estimated to be chlorophyll *a.* Low values of pheopigments indicates a fairly actively growing community of microphytobenthos survives deep in the sediment. The dominant microphytobenthos observed during this study is diatoms, which lack chlorophyll *b*. however, the presence of chlorophyll *b* in the sediments indicated the presence of Chlorophytes, Prochlorophytes and/or Euglenophytes, but none were identified in these samples. This finding is in agreement with Cartaxana *et al*., (2006). In their study, considerable concentration of chlorophyll *b* was seen in the substrata without identifying any species belong 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). The pigments such as chlorophyll *c* and carotenoids offered a substantial contribution to the total pigments. Fucoxanthin is the most abundant pigment in carotenoids in sediments and is considered as good marker of the presence of diatoms (Barranguet, 1997). Qualitative analysis of microphytobenthos has showed that about 88% of the total are diatoms, along the southwest coast supports the above statement. Further more, relatively high ratios of chlorophylls *a*, *b*, and *c* to counts of cells identifiable by light microscopy, which were mostly diatoms, indicated the presence of substantial quantities of very small microalgae, likely to include other chlorophyll *b*-containing forms.

4.4.3 Pheopigment to chlorophyll *a* ratio

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). The annual ratio of pheopigment to chlorophyll *a* concentration ranges from 0.16 to 0.24. Thus the ratio suggests that a physiologically healthy microphytobenthic community was present along the southwest coast throughout the period of two years.

4.4.4 Chlorophyll *a* and standing crop

Chlorophyll *a* and standing crop has shown positive correlations during all the seasons. The correlation coefficient (r) was, 0.796, 0.692, 0.952, 0.782, 0.909 and 0.618 ($P = <0.01$) in various seasons starting from pre monsoon 2006-07 to post monsoon 2007-08 in the seven stations. The highest correlation coefficient was seen in the post monsoon 2006-07, which denotes the two characters i.e., chlorophyll *a* and standing crop was strongly correlated in this season. The rest of seasons also have shown moderate positive correlations. Sundback and Jonsson (1988), Gillespie *et al*., (2000) and Ribeiro *et al*., (2003), observed significant correlation between number of cells and chlorophyll *a* content. Standing crop and chlorophyll *a* found to be positively correlated only during the monsoon in Cochin estuary (Sivadasan and Joseph, 1997). However, Mitbavkar and Anil (2006) reported that the chlorophyll *a* concentrations failed to reveal any positive correlation with the diatom abundance at the sediment layers in the Goan coast.

4.4.5 Sediment structure

The relationship between benthic microalgal biomass and sediment grain size is very significant. (Cahoon *et al*.,1999). Cartaxana *et al*., (2006), reported that the muddy sediments provide significantly higher chlorophyll due to its higher water content. Staats *et al*., (2001) found that the presence of diatoms is dependent on sediment mud content. According to Perkins *et al*. (2003), chlorophyll *a* concentrations associated with sandy sediments are typically lower compared to muddy sediments, as wetter sediment areas are more favourable for the cells in terms of nutrient supply, gas exchange, and avoidance of desiccation. On the other hand, muddy sediments supported lower chlorophyll *a* level than sediments with fraction of sand content (Gillespie *et al*., 2000; Cahoon and Safi 2002) due to reduced interstitial space volumes or nutrient fluctuations. The biomass was more or less in the same order or magnitude in sandy and muddy locations (Spilmont *et al*., 2006). There are reports that cell abundance has increased with increasing percentage of fine sediment (Facca *et al*., 2002 a & b) since the mud substratum is more suitable for diatom growth than sand because mud particle are usually a source of organic compounds and nutrients. During this study, it is revealed that, percentage of silt plays an important role. The highest biomass as both cell abundance and chlorophyll *a* was recorded from the station 2 during the post monsoon 2006-07. Here the percentage of silt was about 50, where sand and clay have approximately 30 and 20 % each. Similarly, the lowest abundance and chlorophyll *a* was observed during the post monsoon 2007-08 in station 4, where the percentage of sand was about 98. It is evident that the biomass of microphytobenthos in the southwest coast is associated with neither sand nor mud. The cell abundance and biomass was moderately higher when the percentage of silt in the sediment was about 50. It is found that, a total dominance of silt% didn’t provide a higher biomass but the ratio of silt, sand and clay likely would be 50:25:25, offer a moderately high microphytobenthic biomass along the southwest coast of India. It is also proved in this study that, location-specific factors can alter the relationship between sediment composition and benthic microalgal biomass.

4.4.6 Sediment silt and chlorophyll *a.*

Chlorophyll *a* and percentage of silt have shown significant correlations. Percentage of silt in the sediment and chlorophyll *a* has positively correlated except in post monsoon 2006-07, where no significant correlation was found (p = >0.01). The correlation coefficient (r) in the other seasons are 0.873 in the pre monsoon 2006-07, 0.696 in the monsoon 2006-07, 0.680 in the pre monsoon 2007-08, 0.743 in the monsoon 2007-08 and 0.574 in the post monsoon 2007-08. All the correlations are significant at <0.01 levels.

Pearson correlation analysis of the sediment particles, ie., percentage of sand silt and clay have shown significant correlations at <0.01 level. Silt and clay has significant positive correlation and correlation between silt and sand and clay and sand having (-) relationships. The strongest negative correlation was between sand and silt (-0.982).

4.4.7 Spatio-temporal dynamics of planktonic and benthic microalgae

In all the stations, the mean benthic microalgal biomass, measured as sediment chlorophyll *a* substantially exceeded the planktonic. This is in agreement with Cahoon *et al*., 1990; Cahoon and Safi, 2002; Perissinotto *et al*., 2002 and 2003. The probable reason for the comparatively less planktonic chlorophyll would be the lack of significant contribution of re-suspended benthic microalgae to the pelagic zone. Or in other words, the diatom genera reported in plankton samples might be considered as ‘tychopelagic’ (Cahoon and Laws, 1993) or “tychoplanktonic”, (Sylvestre *et al*, 2001) and are functional to both benthic and pelagic habitats (Pinckney and Lee, 2008). This group includes centric and araphic pennate diatoms, and a more strongly attached flora including monoraphic and biraphic diatoms (Ribeiro *et al*., 2003; Parodi and Barria de Cao, 2003). The above mentioned groups were frequently observed during this study from various stations. These species are easily re-suspended by tidal currents and waves (Cahoon and Safi, 2002). The lower contribution of ‘tychopelagic’ or ‘tychoplanktonic’ species to the pelagic zone and high photosynthetic potential of typical benthic species were reasons for lower planktonic biomass than the benthic in the present study and in studies elsewhere (Cahoon and Safi, 2002; Perissinotto *et al*., 2002, 2003 and 2006).

In Galveston Bay, Texas, the benthic microalgal biomass was ranged from 0.39 to 11.7mg/m^2 (Pinckney and Lee, 2008). However, An and Joye, (2001), reported that benthic microalgal biomass in Trinity Bay ranged from 250-800mg/m^2, in the upper sediments. Thus the mean values of benthic chlorophyll *a* in the present study ranged in between the above two studies. The values in this study are more than 1-2 orders of magnitude higher than those reported in by Pinckney and Lee, (2008). The Pearson correlation analysis showed that statistically, planktonic and benthic chlorophyll *a* have given a significant positive correlation ($r = 0.58$) at <0.001 level. This indicates that both chlorophyll has a close relation and when one variable increases, the other also increases and vice versa.

The contribution of suspended microphytobenthos to the pelagic biomass in the Dollard (EMS estuary, the Netherlands) was about 60% (Cadee and Hegeman, 1974). However, nearly two decades later, 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. Comparatively lesser contribution of re-suspended microphytobenthos to the pelagic zone, swimming by motile forms, high grazing pressure in the water column are the reasons for low planktonic chlorophyll.

The strict separation of microalgae into benthic or pelagic species is misleading and problematic, at least for estuaries and coastal habitats due to the re-suspension and deposition processes effectively mix microalgae between sediment and water column (Pinckney and Lee, 2008). MacIntyre *et al*., (1996), report that, in shallow water ecosystems, the distinction among phytoplankton and phytobenthos is artificial, due to the exchange of living and non-living matter between sediment and water column. Under calm conditions, phytoplankton can swim to the bottom and incorporated as microphytobenthos and vice versa. However, Cahoon *et al*., (1990), Cahoon and Cooke (1992), Cahoon (1999) neglects the arguments of microphytobenthos as settled phytoplankton. The study in Onslow Bay states that, on visual observation, concentration of microalgal biomass at the top of sand ridges and not in the troughs, suggesting that these microalgae are firmly attached to the sediment. They also emphasize that, pennate diatoms in sediment samples also indicate that the benthic microalgae are distinct from the planktonic, which is dominated by the centric diatoms, dinoflagellates and coccolithophores. The domination of pennate diatoms over other groups in the benthic zone in the present study is in agreement with most of the benthic microalgal studies world wide and inevitably proved that microalgae inhabiting in this particular zone is specific.

Microalgae associated with the sediments in the deeper waters (3-7m) and in the pelagic zone, along the southwest coast exhibited both spatial and temporal variability in total biomass and community composition over the two year sampling period.

Diatoms are usually the dominant taxa among this taxonomically diversified group of microphytobenthos (MacIntyre *et al*., 1996, Miller *et al*., 1996, Cahoon, 1999). Light and Beardall, (1998), observed that the benthic microalgal biomass was significantly greater in the upper sediment stratum compared to the lower stratum and is in agreement with present study, where microphytobenthos have a significantly greater biomass associated with the surfacial sediment stratum (0–1cm) compared to the deeper sediment stratum (4–5 cm). However, greatest microphytobenthic biomass was not always found in the top layer of the sediment (Fielding *et al*., 1988) and it was observed that, on very few occasions, the second stratum of sediment showed high biomass than the surface stratum. 54% of the total biomass was observed at the surface stratum and 87% was found in the upper 3cm depth. A more or less similar result was found in some South African studies (Mundree *et al*., 2003), while it was 97% in the Bourgneuf Bay, France (Meleder *et al.,* 2007). In the present study about 88% of the total microphytobenthos are found to be diatoms. Both cell abundance and chlorophyll *a* show a significant decrease with the water depth.

Taxonomic analyses of benthic microfloral assemblages reveal that two somewhat distinct functional groupings are represented: an easily resuspended assemblage of loosely associated ("tychopelagic", Cahoon and Laws (1993), or "tychoplanktonic", Sylvestre *et al.*, 2001) species, including centric and araphic pennate diatoms, and a more strongly attached flora including monoraphic and biraphic diatoms (Ribeiro *et al*., 2003; Parodi and Barria de Cao 2003). Out of 55 microalgae, 8 diatom species, *Cocconeis littoralis* Subrahmanyan, *Cocconeis scutellum* Ehrenberg, *Cocconeis sigmoides* Subrahmanyan, *Cymbella aspera* (Ehrenberg) Cleve, *Cymbella marina* Castracane, *Diploneis littoralis* (Donkin) Cleve, *Diploneis weissflogii* (A. Schmidt) Cleve, *Navicula directa var. remota* Grunow, were mostly recorded from the benthic environment. The rest 47 species are considered as 'tychopelagic or tychoplanktonic', which include 40 diatoms (Annexure 7) 4 cyanophycean and 3 dinophycean species.

Viable diatom cells and a significant concentration of chlorophyll *a* were recorded from water depths upto 285m in Onslow Bay, in the US (Cahoon *et al*., 1990). However, photosynthetically active radiation (PAR) penetrates to depths usually <5mm in most substrates, hence most benthic microalgae are abundant in the top few millimeters of sediment (MacIntyre *et al.,* 1996). Though, viable benthic diatoms constitute a substantial part of the benthic microflora even at depths well below the euphotic zone (the depth of overlying water in the littoral zone is 7-35m) in Swedish west coast (Wulff *et al*., 2005). However, diatoms were present in the deep sediments of almost up to 30 cm. Very high sediment turnover rates by benthic macrofauna accounts for the presence of microalgae at depths of 30cm below the sediment surface (Steele and Baird, 1968; Fenchel and Straarup, 1971; Fielding *et al.,* 1988; Cahoon, 1999). Viable microalgal cells are often observed in substantial numbers down to depths of 10 cm or more in the sediment (Cahoon *et al*., 1994; Mitbavkar and Anil, 2002; Mundree *et al*., 2003) and in intertidal transects, diatoms were viable up to a depth of 15 cm (Mitbavkar and Anil, 2006). Benthic microalgae were found from the surface to 7cm deep in the sediments of Cochin estuary (Sivadasan and Joseph, 1998). However, in the present study, the depth of the 'phytozone' was 5cm.

The occurrence of photosynthetic microflora deep in the sediment has been attributed mainly to bioturbation by burrowing macrobenthos, deposit feeding, and physical hydrodynamic conditions, or to migration by motile species (MacIntyre *et al*., 1996; Pinckney and Zingmark, 1993; Barranguet *et al*. 1997; Easley *et al*., 2005). These microalgae have the capacity to survive at low irradiance and even in darkness without any damage to their photosynthetic potential (Wulff *et al*., 1997). Diatoms can retain photosynthetic capacity in dark, deeper sediments and can resume photosynthesis if resurfaced (Fielding *et al*., 1988). Benthic diatoms are not only able to survive but also grow under very low or nil light conditions (Vilbaste *et al*., 2000). Some species can even compensate for the low light levels by resorting temporarily to heterotrophic nutrition (Admiraal, 1984). *Amphora coffeaeformis* was the only species recorded in the present investigation which was considered as facultative heterotroph (Hellebust and Lewin, 1977).

In the littoral zone, the resuspension of the sediment along with the associated diatoms, by various physical factors disturbs the microphytobenthic community at the sediment surface. As a result, a substantial part of the biomass of these diatoms is found in deeper layers of the sediment. The resuspended material later gets deposited on the surface or within the deeper layers. Diatom genera dominant in the surface layers, particularly pennate forms were seen throughout the sediment column. Several reasons are attributed to the distribution of diatoms deep in the sediment column. Advection is an important factor, which can influence the distribution of diatoms to deeper layers. In sandy sediments, oscillatory wave motions will cause water exchange to a sediment depth of at least 20 cm (Mitbavkar and Anil, 2006).

Diatom movement is a well-known phenomenon and motile microphytobenthos, especially biraphid pennate diatoms move with speed of 1–25 µm s^{-1} (Round, 1971). Vertical migratory behavior in different sediment types has been related to physical factors (Mitbavkar and Anil, 2004). In the intertidal zone during emersion, motile microphytobenthos migrate upwards to the surface of the sediment and photosynthesize, but during flood tide they move down into the sediment or migrate vertically (Varela and Penas, 1985; Pinckney and Zingmark, 1991). Photosynthetically active microphytobenthic diatoms were found even after several months of incubation period in anaerobic and dark conditions and retained its photosynthetic activity when they receive radiant energy (Gargas and Gargas, 1982). Benthic diatom species survived more than 40 days in dark on sterilized sand (Admiraal, 1984). Chlorophyll *a* synthesis in the absence of light for diatoms capable of heterotrophic growth to thrive the unfavourable conditions, they can temporarily resort to heterotrophy (Hellebust and Lewin, 1977). Anyhow, viable cells were found in a depth of 5cm deep in the sediments of southwest coast during this study indicating the presence of plant life deep in the sediment.

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Chapter 5

Algal Blooms

Contents

5.1 Introduction

Planktonic microalgae can proliferate into enormous concentrations of upto millions of cells per litre when sufficient light and nutrients are available. Such sudden increase of microalgal cells are referred to as blooms. Most blooms are extremely beneficial to the marine ecosystem as a primary source of food for the larvae of commercially important marine organisms for virtually every other form of marine life. Of the many thousands of species of microalgae those that produce specific toxins hardly exceed a hundred. These occur in both salt and freshwaters and whilst most are planktonic some are benthic or float at the water surface (Fogg, 2002).

Abundance and fluctuations of bloom are commonly expressed in terms of community biomass, with chlorophyll amount usually the index of abundance against which total-community rate processes, such as productivity. This largely explains our biased understanding of blooms, based primarily on proximate, whole-community approaches, with neglect of the organismal approaches essential to elucidation of bloom events (Smayda, 1997a and b).

In most cases algal blooms are beneficial for aquaculture and fisheries operations. On the other hand, in some situations algal blooms can have a negative effect, causing severe economic losses to aquaculture, fisheries and tourism operations and having major environmental and human health impact (Hallegraeff, 1995).

International Council for Exploration of the Seas has defined algal blooms as ‘those which are noticeable, particularly to general public, directly or indirectly through their effects such as visible discolouration of the water, foam production, fish or invertebrate mortality or toxicity to humans’ (ICES, 1984). Several international agencies such as Intergovernmental Oceanographic Commission (IOC) of UNESCO, International Council for Exploration of the Seas (ICES), Scientific Committee for Oceanic Research (SCOR), European Union (EU), Asia Pacific Economic Cooperation Program (APEC), have established programmes or working groups focused specifically on HABs and their impacts

Algal blooms are completely natural phenomena and in the past two decades the public health and economic impacts of such events appear to have increased in frequency, intensity and geographic distribution (Daranas *et al*., 2001).

A very small number of the several thousand planktonic algae species known to exist are potentially harmful. These can cause fish kills, contaminate seafood with toxins, pose a direct risk to human health, or otherwise affect the ecosystems harmfully. These events are known as harmful algal blooms (HABs) and are sometimes incorrectly called red tides, which is a misnomer, as the term 'red tide' refers to only one particular form of potentially harmful event when planktonic algal densities become so high that the sea becomes discoloured. The term Harmful Algal Bloom is likewise not at all precise, as a bloom implies a massive proliferation of planktonic algal cells. Some species contain toxins so potent that only a small number need be present in order to contaminate shellfish seriously enough to render them unsuitable, even dangerous, for consumption by humans.

The concept of high abundance is implicit in the term `bloom', however, it has a dynamic and relative meaning: a bloom is a `significant population increase’ (Smayda, 1997a), which leads to a peak. The magnitude of this peak is specific for each species and may vary considerably in space and time, being dependent on environmental conditions. In this sense, a bloom does not imply a high biomass.

However, the impact of HABs depends on the concentration of the harmful species; even the most toxic species must have a minimum cell concentration to exert the harmful effect. In act, most harmful species are probably ubiquitous, and they become hazardous only when their concentration exceeds a certain threshold for a sufficiently long period.

Blooms of autotrophic algae and some heterotrophic protists are increasingly frequent in coastal waters around the world and are collectively grouped as harmful algal blooms. Aggregation of these organisms can discolor water giving rise to red, mahagony, brown or red tides, can float on the surface of scums, cover beaches with biomass or foam and deplete oxygen levels through excessive respiration or decomposition (Sellner *et al*., 2003).

The toxicity and other negative effects caused by harmful algae are not limited to a single algal class or to a few genera, but are distributed among several taxonomic groups and the high taxonomical diversity of harmful algae results in a variety of toxins (Anderson, 1997). Ecological requirements and bloom dynamics also vary considerably from one species to another and also noted that different populations of the same species may be toxic or not, exhibit different growth rates under the same conditions and show different life strategies (Satake *et al*., 1997).

About 300 planktonic algal species have been reported to produce “red tides,” including diatoms, dinoflagellates, silicoflagellates, prymnesiophytes, and raphidophytes (Sournia, 1995). Moreover, most red tide species do not produce harmful blooms. Only 60-80 species among the 300 taxa are actually harmful or toxic as a result of their biotoxins, physical damage, anoxia, irradiance reduction and nutritional unsuitability. The flagellate species alone contribute 90% of the HABs and among flagellates, dinoflagellates stand out as a particularly noxious group. They account for 75% (45-60 taxa) of all harmful algal bloom (HAB) species. Nano to larger sized; photoautotrophic, mixotrophic, or obligate heterotrophs; siliceous or non-siliceous species have diverse modes of inimical action (Smayda, 1997). About 40 of these species have the capacity to produce potent toxins that can find their way to humans through fish and shellfish (Sournia *et al*., 1991). In the last 15 years the number of identified species increased from about 20 to around 60 (Burkholder *et al*., 1992; Sournia, 1995).

Exceptional blooms as those with >100mg chl.m^3. Algal blooms of this magnitude are noteworthy. The maximal biomass levels of the annually recurrent blooms are usually far below this level and at a maximal population level of only 10^4cellsL^{-1}. A bloom may occur as an isolated community event or co-occur with other species, some of which may then reach population maxima several orders of magnitude higher (Smayda, 1997).

Algal blooms are attributed to two primary factors: natural processes such as circulation, upwelling relaxation, and river flow; and, anthropogenic loadings leading to eutrophication. The latter is generally assumed to be the primary cause of all blooms. It is usually acknowledged that occurrences of these phenomena are increasing throughout the world's oceans. The reasons for this obvious increase remain debated and include not only eutrophication but increased observation efforts in coastal zones of the world.

It can be classified into four major groups, based on the problems they cause. They are species which cause water discolouration, species non-toxic to humans but harmful to filter feeding invertebrates and fishes, species which produce toxins causing illness to humans through aerosols from bloom area to the coast and species produce potent toxins that can affect human through seafood (Hallegraeff, 1995). The first two is formed by the non-toxic species which discolour the water. However, under some conditions the growth is so high that it generates anoxic conditions resulting in indiscriminate killing of both fish and invertebrates. Oxygen depletion can be due to high respiration by the algae (at night or in dim light during the day) but more commonly is caused by bacterial respiration during decay of the bloom. Dinoflagellates that cause these problems are *Gonyaulax*, *Noctiluca*, *Scrippsiella* and Cyanophycean species like *Trichodesmium*. (Hallegraeff, 1995). The third group, some algal species can seriously damage fish gills, either mechanically or through production of hemolytic substances. While wild fish stocks have the freedom to avoid such problem areas, caged fish appear to be extremely vulnerable to such noxious algal blooms. A potent ichthyotoxins called prymnesin- 2 1 and prymnesin-1 2 have been isolated from *Prymnesium parvum* cultures (Yasumoto *et al*., 1996; Murata and Tasumoto, 2000). Other species fall in this group are diatoms like *Chaetoceros convolutus*, dinoflagellates like *Gymnodinium mikimotoi*, *prymnesiophytes Chrysochromulina polylepis*, *Prymnesium patelliferum* and raphidophytes *Heterosigma carterae* or *Chattonella antiqua* which killed 500 million US dollars' worth of caged yellowtail fish in the Seto Island Sea in 1972 (Okaichi, 1989).

The fourth group produces potent toxins which can find their way through the food chain to humans, causing a variety of gastrointestinal and neurological illnesses. They are as follows.

According to the symptoms observed in human intoxications by the secondary metabolites the so called toxins, produced by microalgae, it is likely to consider six illnesses caused by groups of marine toxins: Paralytic Shellfish Poisoning (PSP), Ciguatera Fish Poisoning (CFP), Diarrhetic Shellfish Poisoning (DSP), Neurotoxic Shellfish Poisoning (NSP), Amnesic Shellfish Poisoning (ASP) and Azaspiracid Poisoning (AZP).

Paralytic shellfish poisoning (PSP)

The causative organisms: *Alexandrium spp.*, *Gymnodinium catenatum, Pyrodinium bahamense.*

Toxins produced; Saxitoxins (STXs).

PSP is the longest-known and most infamous group of marine toxins. There are incidents referred to in the Bible that are attributed to PSP, and indeed many religious and tribal customs which evolved preached abstinence from eating certain seafood, habitually shellfish. Outbreaks of shellfish poisoning have occurred for centuries along both the east and west coastlines on the North American continent and this is manifested in North American Indian folklore. The first documented report of PSP in Canada appeared in 1798 and described the fatal poisoning of several crew members of Captain George Vancouver's expedition following consumption of contaminated mussels during their exploration of the British Columbia coastline in 1793 (Wright, 1995).

PSP induces muscular paralysis and in severe cases can lead to the death through paralysis of respiratory system. PSP is caused by about 18 different toxins which include saxitoxins, neosaxitoxins and gonyautoxins and is collectively called as 'PSP toxins'. The combination of the toxins found in contaminated shellfish seems to depend upon the type of toxin produced by the causative planktonic algae as well as the storage conditions and the metabolism of the compounds in the shellfish. Saxitoxin (STX) 5 was the first metabolite responsible for paralytic shellfish poisoning intoxication. These metabolites are also produced by the fresh-water, blue-green microalgae *Aphanizomenon flos-aquae* and *Anabaena circinalis*, (Shimizu, 1993). Recently it has been found that the origin of these toxins is purported to be bacterial, analogously with tetrodotoxin (TTX), (Kodama *et al*., 1990). Saxitoxins are specific and potent agents that block the sodium channels. Single point mutation studies of the sodium channels suggest that saxitoxins bind close to the extracellular side and/or in the pore wall of the channel in a region containing negatively charged groups (Narahashi, 2000).

Paralytic shellfish poisoning is a life-threatening poisoning syndrome. Symptoms are purely neurological and their onset is rapid. Within 30 minutes, a tingling or numbness around the lips, this gradually spreads to the face and neck, a prickly sensation in the fingertips, headache, fever, nausea, vomiting and diarrhea. The most severe cases result in respiratory arrest within 24 h of consumption of the toxic shellfish. There is no antidote at the moment, supportive therapy is the rule and survivors recover fully. These symptoms result primarily from the blockage of neuronal and muscular sodium channels, which prevents propagation of the action potential. For these reasons, PSP toxins are prevented by large-scale monitoring programmes, assessing toxin levels in shellfish (mussels, oysters, scallops, clams, etc.) and rapid closures of harvesting in suspect or demonstrated toxic areas (Shumway *et al*., 1995).

PSP is a world wide problem except in African and South American coasts. Shellfishes are the usual vectors of PSP to human consumers, however, crustaceans can also accumulate PSP toxins. Lobsters can accumulate toxins primarily in the hepatopancreas than in the meat. PSP toxins have been found in zooplankton and the guts of dead or diseased fish in the vicinity of blooms. Some PSP toxins have found in the muscles of affected fish and circumstantial evidence that PSP toxins may be implicated in mortalities of marine mammals.

Ciguatera fish poisoning (CFP)

Causative organisms: *Gambierdiscus toxicus, Prorocentrum lima., Ostreopsis siamensis., Coolia monitis., Thecadinium sp, Amphidinium carterae.,*

Toxins produced: Ciguatoxins (CTXs), Maitotoxin (MTX).

Ciguatera is a tropical fish-food poisoning syndrome well-known from coral reef areas in the Caribbean, Australia, and especially in French Polynesia. Ciguatera is a seafood poisoning that affects more than 50,000 people annually, caused by ingestion of coral reef fishes that have become toxic through diet. Ciguatera poisoning has been known for centuries in sub tropical and tropical waters. Captain Cook was stricken in New Caledonia in 1774 due to the infection of ciguatera poisoning. During 1960 to 1984, more than 24,000 incidents have been reported in Frech Polynesia alone (Hallegraeff, 1993).

There are two groups of compounds implicated in the poisoning. The principal group includes lipid-soluble toxins, the so-called ciguatoxins (CTXs) 28±37 and gambierol 38, both produced by the epiphytic/benthic dinoflagellate *Gambierdiscus toxicus* (Yasumoto and Murata, 1993), and the water soluble maitotoxin (MTX) 39 and palytoxin 40 are the other. Ciguatoxin 28, the main agent responsible for this poisoning was first isolated in 1980, but its structure was finally elucidated in 1989 together with its congener GT4B (CTX4B) 29, isolated in both cases from moray eels. Since then, more than twenty analogues have been found in fish and in the dinoflagellates. All the cited CTXs have been isolated from Pacific and Indian Ocean organisms, but the structures of two Caribbean CTXs, C-CTX-1 36 and its 56 epimer, C-CTX-2 37, have been reported (Lewis *et al*., 1998).

Ciguatoxins are very potent neurotoxins, which act by binding quasi-irreversibly to site 5 on sodium channels. Several effects are consequently observed at motor nerve terminals, such as hyper excitability of the membrane, spontaneous and repetitive neurotransmitter release, blockade of synaptic transmission, depletion of synaptic vesicles, and swelling of nerve terminals.

The toxins are transported through the food chain and human beings have been infected by the consumption of contaminated finfish. Ciguatera fish poisoning (CFP) generate gastrointestinal, neurological and cardiovascular disorders. Usually, in the initial stage, diarrhea, vomiting and abdominal pain occur, followed by neurological dysfunction including muscular aches, reversal of temperature sensation, dizziness, anxiety and a numbness and tingling of the mouth and digits. In the most severe cases, paralysis and death have been reported. The first symptoms usually appear within 2 to 6 h, and the complete syndrome develops within 24 h and lasts around one week, but it may persist for weeks or months. Recovery time is variable, may take weeks, months or years. Rapid treatment, preferably within 24 hours, with mannitol and calcium is reported to relieve some symptoms (Palafox *et al*., 1988).

Diarrhetic shellfish poisoning (DSP)

Causative organisms: *Dinophysis sp., Prorocentrum lima, P. maculosum, Protoceratium reticulatum, Coolia sp.*

Toxins produced: Okadaic acid, Dinophysis toxins, Yessotoxins and Pectenotoxins.

The first report to this phenomenon came from Northeast Japan in 1976 where it caused major problems for the scallop fishery (Yasumoto *et al*., 1978). The first dinoflagellate to be implicated was *Dinophysis fortii* (in Japan), soon followed by *D.*

acuminuta (in Europe), *D. acuta, D. norvegica* (in Scandinavia), *D. mitra, D. rotundata* and the benthic dinoflagellate *Prorocentrum lima*. The outbreaks were correlated with the appearance of the dinoflagellate *Dinophysis fortii*. Incident of DSP might have appeared earlier, but may be probably mistaken for being caused by bacterial gastrointestinal infections (Richardson, 1997). The toxin responsible was named Dinophysis toxin (DTX). The chemical structures of these toxins emerged following the isolation of a new polyether toxin named okadaic acid (OA) 41.

The symptoms are stomach pain, nausea, vomiting and diarrhea. There were no fatalities directly associated with DSP yet. Some of the toxins associated with DSP may promote the development of stomach tumours. Hence, prolonged or chronic exposure to DSP toxins may have long term negative effects on public health (Richardson, 1997). Unlike bacterial diarrhea, symptoms normally begin within 30 minutes to a few hours after eating contaminated shell fish. Okadaic acid the DTX toxins have been reported to cause injury to the intestinal mucosa (Garthwaite, 2000). No fatalities have been directly reported by the effect of DSP.

DSP events are cosmopolitan except in Africa and Antarctica. *Dinophysis spp.* cause diarrhetic shellfish poisoning (DSP) in tropical and temperate marine environments (Hallegraeff, 1993), producing serious economic damage to bivalve farming, with poisoning induced even at low abundance of 200 cellsL^{-1} (Yasumoto *et al*, 1978). Mixotrophic nutrition in have been reported by the presence of food vacuoles in *Dinophysis acuminata, D. norvegica, D. fortii*. Wide ranges of salinity and temperature were detected *Dinophysis spp* in and hence these have relatively negligible effect on the occurrence.

Neurotoxic shellfish poisoning (NSP)

Causative organisms: *Gymnodinium breve* (Syn. *Karenia brevis*)

Toxins produced: Brevetoxins.

NSP toxins are one of the most characteristic and spectacular classes of compounds produced by microalgae. The primary producer is a dinoflagellate

Karenia brevis (formerly known as *Gymnodinium breve*), which often forms blooms along the Florida coast and the Gulf of Mexico, leading to mass mortality of fish. Brevetoxin- B (BTX-B) 72 was the first toxin included in this group and also the first example of a polyether lipid soluble compound initially isolated from *Gymnodinium breve*. It produces nine potent polyether neurotoxins called PbTxs, designated as PbTx-1, PbTx-2.

A new type of toxin, hemibrevetoxin B 79, which has about a half-size skeleton of brevetoxins, has been discovered in the same dinoflagellate (Shimizu, 1993). NSP produces an intoxication syndrome nearly identical with that of ciguatera. In this syndrome, gastrointestinal and neurological symptoms predominate. Sea spray contaminated with the organisms irritates the eyes and nasal passages, leading to cough and asthma like symptoms (Garthwaite, 2000).

People who eat this shellfish suffer from neurotoxic shell fish poisoning (NSP), cause severe gastrointestinal and neurological symptoms. Anecdotal reports and limited references to human symptoms in the literature revealed acute respiratory irritations, including nonproductive cough and bronchoconstriction, burning of the eyes, nose, and throat as typical responses from exposure to areolized PbTx. *Karenia brevis* produce as many as nine potent polyether brevotoxins, designated as PbTx –1 to 9, and have been responsible for the killing of millions of fish, birds, mammals and other marine organisms during the red tide events

No deaths have been reported and the syndrome is less severe than ciguatera. Unlike ciguatera, recovery is generally complete in a few days. Although considerable knowledge exists about the biochemical and neurophysiologic activities of the brevotoxins, very little information is available about human health effects from environmental expousures such as aerosols. During onshore winds with breaking surf, brevotoxins become incorporated into marine aerosol by bubble-mediated transport

Amnesic shellfish poisoning (ASP)

Causative organisms: *Pseudonitzschia pungens f.multiseries, P. australis, P. pseudodelicatissima, P.seriata, Nitzschia actydrophila, Amphora coffeaeformis*.

Toxins produced: Domoic acid and its congeners.

In all the poisonings cited, the most recently discovered causative agents were the water soluble ASP toxins. In 1987, four victims died and a hundred acute cases occurred, after consuming toxic mussels from Prince Edward Island, Canada and domoic acid 80 was identified as the agent responsible for this intoxication (Wright, 1995). The diatom *Pseudonitzschia pungens f. multiseries* to be identified as the producer of the domoic acid, subsequently, it was isolated from several diatom species such as *P. pseudodelicatissima*, *Amphora coffeaeformis*, *Nitzschia actydrophila*, *P.australis* and *P. seriata* (Bates *et al*., 1989, Subba Rao *et al*., 1988, Martin *et al*., 1990, Maranda *et al*., 1990).

Symptoms include gastroenteritis, which usually develops within 24 h of the consumption of toxic shellfish. In severe cases, neurological symptoms also appear, usually within 48h. Dizziness, headache, disorientation, short term memory loss, respiratory difficulty and coma are also observed (Perl *et al*., 1990). Since memory loss was the most apparent, this intoxication was called ASP. Domoic acid 80 present in seafood is absorbed through the gastrointestinal mucosa, but the rate of absorption is very low.

Cyanophycean toxins

Several species and strains of cyanophyceae cause an often acute and potentially fatal condition from drinking water that contains high concentrations of toxic cells. Fatalities and severe illness of livestock (including birds), pets, wildlife and fish from heavy growths of waterblooms of blue-green algae are known to occur in almost all countries of the world. Most poisonings occur among terrestrial animals drinking algal infested freshwater supplies, but marine animals, especially maricultured fish, are also affected (Carmichael, 1992, Lambert *et al*., 1994).

The toxic strains within species of *Anabaena, Aphanizomenon, Cylindrospermopsis, Microcystis, Nodularia, Nostoc* and *Oscillatoria* are responsible for most toxic episodes, there are over 30 species of cyanophyceae that can be associated with toxic water blooms (Skulberg *et al*., 1993). Species and strains of *Anabaena*, *Aphanizomenon* and *Oscillatoria* can produce a potent postsynaptic cholinergic (nicotinic) agonist called anatoxin-a that causes a depolarizing neuromuscular blockade. Strains of *Anabaena flos-aquae* can produce an irreversible organophosphate anticholinesterase called anatoxin-a(s). Strains of *Anabaena circinalis, Aphanizomenon flosaquae* and *Lyngbya wollei* can produce the potent presynaptic sodium channel blockers called paralytic shellfish poisons (saxitoxins)

Hepatotoxic peptides like microcystins and nodularins can be produced by *Anabaena, Microcystis, Nodularia, Nostoc* and *Oscillatoria. Cylindrospermopsis* can produce a potent hepatotoxic alkaloid called cylindrospermopsin. Some genera, especially *Anabaena,* can produce both neuro and hepatotoxins. Neurotoxicosis, with death resulting in minutes to a few hours, from respiratory arrest may result from ingestion of the neurotoxic alkaloid producing cyanophyceae.

Poisoning usually does not occur unless there is a heavy water bloom that forms a dense surface scum. Factors contributing to heavy water blooms are nutrient rich eutrophic to hyper-eutrophic water experiencing warm, sunny weather. Agriculture practices and urban activities which lead to nutrient enrichment often contribute to water bloom formation.

Clinical signs of neurotoxicosis progress from muscle fasciculations, decreased movement, abdominal breathing, cyanosis, convulsion and death. When anatoxin-a is involved signs in avian species are similar but include opisthotonus. With smaller animals death is often preceded by leaping movements while in large ones collapse and sudden death occur. Animals, especially cattle and horses, that survive acute poisonings of either liver or neurotoxins may experience photosensitizations in areas exposed to light (nose, ears and back), that lead to hair loss followed by sloughing of the skin

Other algal blooms

Pfiesteria species are phagotrophic dinoflagellates that employ a feeding tube known as a peduncle to feed primarily on planktonic algae, such as unicellular Cryptomonads. The dinoflagellate, *Pfiesteria piscicida* was first discovered in an aquarium at North Carolina State University in 1988 where it was blamed for an incident of fish deaths. These deaths occurred shortly after the addition of Pamlico River water and where coincident with an increased abundance of small dinoflagellates (Miller and Belas, 2003). Interest in *Pfiesteria* was heightened in 1991 and 1992 when massive fish mortalities accompanied by open ulcerations on the bodies of the fish were reported from the estuaries of North Carolina. Further research revealed that these dinoflagellates produced a putative water-soluble toxin that causes ulcers, disorientaion and eventually death of fish and other marine animals. The symptoms included extremity paresthesias, circumoral paresthesias, arthralgia, myalgia, asthma, headache, nausea, abdominal pain, vomiting perspiration, tearing eye-ear irritation, dyspnea/respiratory problems, memory problems, emotional changes, and skin lesions. The 'Pfiesteria toxin' is a production of one or more bioactive substances with potency towards fish and other animals that does not involve bioaccumulation in the shellfish or finfish.

The eurythermal and euryhaline genus *Phaeocystis* is one of the most widespread marine haptophytes, with species sharing the ability to produce nearly monospecific blooms of gelatinous colonies in several coastal and oceanic waters. *Phaeocystis* is exceptional not only because of the high carbon biomass reached by its blooms (up to 10 mg C l^{-1}) but mainly because of its unique physiology which impacts food-web structures, hence global biogeochemical cycles and climate regulation (Lancelot *et al*., 1994). These colonies, constituted by thousands of cells embedded in a polysaccharidic matrix, are considered to be responsible for the success of *Phaeocystis* in marine systems and for the subsequent changes in ecological and biogeochemical properties. Phaeocystis plays a key role as an intermediary in the transfer of carbon as well as sulphur between ocean and atmosphere and vice versa. This makes Phaeocystis an ideal model organism to study the role of marine phytoplankters in global biogeochemical cycles and climate regulation. The high productivity associated with its blooms and its ubiquity makes *Phaeocystis* an important contributor to the ocean carbon cycle (Smith *et al*., 1991). *Phaeocystis* is basically non-toxic but its nuisance value is caused by very high biomass levels (Hallegraeff, 1995).

There is no precise correlation between algal concentrations and their potential harmful effects. Dinoflagellate species such *as Dinophysis and Alexandrium* can contaminate shellfish with toxins, even at very low cell concentrations. The prymnesiophyte *Chrysochromulina* produces only moderate biomass levels but has a very high toxic potency (Hallegraeff, 1995).

In recent decades, the increasing frequency, intensity and spreading of toxic and non-toxic planktonic algae blooms have been characterized as global epidemic (Hallegraeff *et al*., 1995). The main constrain in the study of these blooms is the lack of historical data and the restricted number of good long-term data series. Fish kills and human illness caused by toxic Dinoflagellates date back several hundred years and the apparent increase in bloom spreading may be false and due to past underreporting (Smayda, 1997b). At least 26 non-indegenous planktonic algae species have established persistent populations in the North Sea over the past 100 years.

Reasons for the increasing interest in HABs include not only public safety concerns associated with protecting human health, but, the adverse effects on living resources of many coastal systems, economic losses attributed to reduced tourism, recreation, or seafood related industries, and costs required to maintain public advisory services and monitoring programs for shellfish toxins, water quality, and plankton composition (Sellner, *et al*., 2003).

About 2000 cases of human poisoning are reported each year. However, this is probably an underestimation because many cases, particularly those involving gastrointestinal symptoms, are incorrectly diagnosed. Fatal episodes are estimated to exceed several hundred cases annually. In some areas affected by PSP, historical reports reveal that coastal populations were well aware of risks associated with eating sea-food in certain periods or under such conditions as a sea-water discoloration or phosphorescence (Hallegraeff, 1995).

Harmful algae usually affect fish and other invertebrates by producing toxins, but mucilage-producing or spine-bearing algae may cause mechanical clogging or lesions to the gills. A reduction in oxygen and production of hydrogen sulphide can also cause mass mortalities of huge proportions of commercially valuable species (Zingone and Enevoldsen, 2000).

The study on modern dinoflagellate cysts as well as planktonic cells has been very useful for understanding the mechanism implicated in the recurrence and geographic expansion of the harmful dinoflagellate blooms. Some dinoflagellates produce two different types of non-motile cells called as a temporary cyst and a resting cyst in their life cycle. The resting cysts can survive in harsh environmental condition and stay in certain periods of quiescence and dormancy, which induce simultaneous germination in response to better environmental change. Therefore, the resting cysts have an important ecological role as the source seedlings of the recurrent blooming and expansion of geographical distribution. Approximately 13–16% of living dinoflagellates produce resting cysts during their life cycle or there are more than 80 marine and 15 freshwater species of modern dinoflagellates are known to produce resting cysts. Many harmful dinoflagellate species causing harmful algal blooms (HABs), form cysts as a part of their life stages (Matsuoka and Fukuyo, 1995, 2000).

Resting cysts are dormant stages resulting from sexual fusion of gametes, produced in response to certain physicochemical conditions such as temperature and/or nutrient depletion. The organic nature of the cyst walls makes them resistant to degradation, thus providing good fossil records (Fensome *et al.*, 1993).

Flocculation and sedimentation with clay is one of the most promising control strategies to minimize the costs and environmental impacts of Harmful

Algal Blooms (Anderson, 1997). Over the past 25 years, clays have been investigated in several countries for removing harmful algae from the water column, in which South Korea Japan and Australia have been using this technique to control HABs.

Direct control of HABs is a sensitive issue. Controlling HABs through a human-introduced disturbance may pose more harm to the environment than the prevention. But short term negative impacts may be tolerable when compare to long-term economic and ecosystem impacts (Anderson 1997).

It is quite clear that the planktonic algal bloom will decline when the 'loss factors together exceed the increase factors'. Or in other words, the immediate reason of bloom decline is a decrease in the growth rate of bloom forming microalgal species brought about by light/nutrient limitation, grazing pressure, lysis or advection, for that particular species of the surrounding water column. Normally, flagellate blooms often to be degraded in the water column, while the diatom blooms often sink out. Even though, diatoms have different sinking rates, the sinking depends on the cell volume and physiological state of the particular species (Smetacek, 1985, Waite *et al*., 1992, Cushing, 1992,).

There are several reports that planktonic algal blooms are increasing world wide due to the anthropogenic activities. But due to the subjectivity in identifying HABs and the lack of relevant long-term comprehensive data sets, for most areas, difficult to address quantitatively the question of whether or not a real increase in such blooms has occurred. Our increasing interest in utilizing coastal waters for aquaculture is leading to an increased awareness of toxic algal species (Hallegraeff, 1995). It is clear that HABs occurred in pre-historic times, so anthropogenic activities or influence is certainly not a prerequisite for the occurrence of such algal blooms. But, a number of mechanisms by which anthropogenic activities, can theoretically affect, directly or indirectly to the occurrence of blooms, such as, eutrophication, pesticide influence and other aquaculture activities, distribution and transport of bloom forming species from one geographic regions through ballast water (Richardson, 1997).

Monitoring and surveillance of planktonic algal blooms along the South-west coast of India, both from the coastal/estuarine stations and open sea stations have been investigated in this study as a part of the MoES sponsored project on Harmful Algal Blooms (Harmful Algal Blooms in the Indian EEZ/ Monitoring and Surveillance of Algal Blooms, funded by Centre for Marine Living Resources & Ecology, Ministry of Earth Sciences, Govt. of India). Even though, no toxic algal blooms have been reported, however, an intensive bloom occurred during the study period. This was due to the proliferation of *Coscinodiscus asteromphalus* var. *centralis*, Ehrenberg, along the Calicut coast. A detailed investigation has been carried out on the taxonomy, enumeration, chlorophyll and ecology of algal blooms and identified a ‘fingerprint’ (complete data of the bloom event) which would provide a basis for predictive model related to the probable development of upcoming algal blooms.

5.2 Review of Literature

It is believed that the first written reference (back in 1000 years B.C.) to a harmful algal bloom appears in the Bible,"... all the waters that were in the river were turned to blood and the fish that was in the river died; and the river stank, and the Egyptians could not drink of the water of the river" (Exodus 7: 20-21). In this case, the event might have occurred as a result of non-toxic bloom-forming alga became so densely concentrated that it generated anoxic conditions resulting in indiscriminate kills of both fish and invertebrates. Oxygen depletion can be due to high respiration by the algae but more commonly is caused by bacterial respiration during decay of the bloom.

In the year 1793, one of the first recorded fatal cases of human poisoning had happened after eating shellfish contaminated with dinoflagellate toxins when Captain George Vancouver and his crew landed in British Columbia in an area now known as Poison Cove. He noted that for local Indian tribes it was taboo to eat shellfish when the seawater became phosphorescent due to dinoflagellate blooms (Dale and Yentsch, 1978).

The Harmful Algal Blooms (HAB) research has been first emerged as a discipline at the First International Conference on Toxic Dinoflagellate Blooms held in Boston, Massachusetts, in November 1974 (LoCicero, 1974). The major apprehension at that time was the massive New England red tide caused by the toxic dinoflagellate *Alexandrium* (*Gonyaulax*) *tamarense* in 1972. This successful meeting was followed by two further International Conferences on Toxic Dinoflagellate Blooms held in Miami, Florida, in 1978 and in St Andrews, Canada in 1985. The First International Symposium on Red Tides was held in 1987 at Takamatsu, Japan, which broadened its scope to include bloom events caused by other algal groups and this tradition of conferences were followed (Hallegraeff *et al.*, 1995).

In 1989, the fourth international conference on Harmful Marine Phytoplankton reached a consensus "that some human activities may be involved in increasing the intensity and global distribution of blooms and recommended that international research efforts be undertaken to evaluate the possibility of global expansion of algal blooms and man's involvement in this phenomenon". Afterward, a number of new international programmes were created to study and manage harmful algal blooms and their linkages to environmental changes in a manner consistent with the global nature of the phenomena involved. The establishment of a Harmful Algal Bloom programme by the Intergovernmental Oceanographic Commission (IOC) of UNESCO has been one such outcome.

The First Session of the IOC-FAO Intergovernmental Panel on Harmful Algal Blooms (Paris, 23 - 25 June 1992) therefore agreed to support the creation and free distribution to developing countries of a Manual on Harmful Marine Microalgae.

Hallegraeff, (1993) made a review on harmful algal blooms and their apparent global increase. This review is considered as one of the greatest literature work dealing with HABs.

In 1995, the manual on Harmful Marine Microalgae, was published by IOC-UNESCO. In the choice of the title of this Manual on "Harmful Marine Microalgae", Hallegraeff *et al*., 1995, decided to abandon the term "bloom" since some species such as *Chrysochromulina* and *Dinophysis* can cause serious problems even at moderate biomass levels. The term microalgae is used instead of "phytoplankton" in order to include problems caused by benthic species such as *Prorocentrum* and *Gambierdiscus*. This monumental work compiles widest information on the taxonomy, toxicology, and epidemiology of harmful algal blooms.

Wright in 1995, described a review on seafood toxins: present approaches and future options. The occurrence of new toxins and the rapid expansion of the shellfish aquaculture industry have put considerable pressure upon the scientific community to develop new methods of coping with these toxins, including more sensitive chemical or biochemical assays. The review discussed the possibilities and options for coping with these ubiquitous toxins.

Smayda, in 1997 clarified that the subjective, difference and arbitrary criteria are to be used to define blooms. Their presumed ecological consequences need to be replaced by a quantitatively based, ecological classification of the various types of phytoplankton blooms.

Zingone and Enevoldsen, in 2000, reviewed the effects of natural and man-induced environmental fluctuations on the frequency and apparent spreading harmful algal blooms. The article also highlighted the need for interdisciplinary research aimed at shedding light on basic mechanisms governing the occurrence and succession of microalgae in coastal seas.

In 2001, Marasigan, *et al*., reported the accumulation of a high level diarrhetic shellfishtoxins in the green mussel *Perna viridis* during a bloom of *Dinophysis caudata* and *Dinophysis miles* in Sapian Bay, in a Philippine island. The results shown that the green mussels accumulate high levels of DSP toxins when *D. caudata* and *D. miles* bloom at a high density.

The most well known taxonomist in the cotemporary Phycology, Grethe Hasle, in 2002 put a question that 'Are most of the domoic acid-producing species of the diatom genus *Pseudonitzschia* cosmopolites'. She made a conclusion that, nine *Pseudonitzschia* taxa known as potential domoic acid (DA) producers have been used to outline their geographical distribution. *Pseudonitzschia seriata* f. *seriata* as the only taxon was found in the North Atlantic Ocean exclusively. The records of *P*. *multistriata* were too few and the identification of *P*. *turgidula* from the North Atlantic too unreliable to provide an idea about their distribution. *Pseudo-nitzschia pungens* and the less frequently recorded *P*. *fraudulenta*, *P*. *multiseries* and *P*. *australis* appeared to be cosmopolites. The records of *P*. *delicatissima* and *P*. *pseudodelicatissima* also indicate a cosmopolitan distribution.

Usup *et al*., in 2002, carried out a study to determine the presence of paralytic shellfish poisoning (PSP) toxin-producing dinoflagellates in the coastal waters of Malaysian Peninsula. Five species of *Alexandrium* were ie., *Alexandrium affine*, *Alexandrium leei*, *Alexandrium minutum*, *Alexandrium tamarense* and *Alexandrium tamiyavanichii*.

Fleming *et al*., (2002) investigated the cyanobacterial toxins, surface drinking water in Florida. The monitoring survey aimed to reveal the organisms and microcystins in surface water drinking sources. A pilot ecological study was performed using a Geographic Information System (GIS) to evaluate the risk of primary hepatocellular carcinoma (HCC) and proximity to a surface water treatment plant at cancer diagnosis.

Yamamoto *et al*., in 2002, carried out a study on effects of winds, tides and river water runoff on the formation and disappearance of the *Alexandrium tamarense* bloom in Hiroshima Bay, Japan from March to June of 1992–1998. The north wind at the initial growth phase of *A. tamarense* appeared to have prevented bloom formation by dispersing the organism offshore and/or through turbulent mixing.

Fogg, in 2002, wrote a commentary on Harmful algae: a perspective which ahs been the ever first article of the journal Harmful Algae, which started the publication in 2002. Fogg described the role of planktonic as benthic microalgae and its capacity to produce toxins.

Godhe, *et al*., 2002, described the PCR detection of dinoflagellate cysts in field sediment samples from tropic and temperate environments. They described a method for cyst lysis, which include grinding with a pestle in a mortar under liquid nitrogen followed by microwave boiling.

Magana *et al*., in 2003, made a historical assessment of *Karenia brevis* in the western Gulf of Mexico. *K. brevis* commonly causes major fish kills, human respiratory distress, and significant economic disruption in the Gulf of Mexico.

Shumway *et al*., in 2003, put a question whether the marine birds are sporadic victims or under-reported events of harmful algal blooms. They present a summary of available data on seabird/toxic algal interactions and suggestions. A survey of available data on the impacts of toxic algae on seabirds revealed an array of responses ranging from reduced feeding activity, inability to lay eggs, and loss of motor coordination to death. Severe impacts on recruitment have been noted in some populations.

In 2003, Miller and Belas, in their minireview on *Pfiesteria piscicida* and *Pfiesteria shumwayae* are estuarine dinoflagellates thought to be responsible for massive fish deaths and associated human illnesses in the southeastern United States. These dinoflagellates are described as having a complex life cycle involving flagellated zoospores, cysts, and amoeboid stages.

Sellner *et al.*, 2003, written a review on ‘Harmful algal blooms: causes, impacts and detection’. Sellner very vastly described on the topic. Many efforts will provide resource managers with the tools needed to develop effective strategies for the management and mitigation of HABs and their frequently devastating impacts on the coastal environment

Kraberg and Montagnes (2004), made a website on all information about online resources in the taxonomy and ecology of harmful phytoplankton in collaboration with University of Liverpool (*http://www.liv.ac.uk/hab*). According to the authors, the production of such sites is not suggested to replace the conventional process of data dissemination. However, if designed appropriately, they can complement and enhance traditional resources equally benefit to researchers and environmental managers.

Jeffery *et al.*, 2004, made review on Amnesic shellfish poison. Amnesic shellfish poisoning (ASP) is caused by consumption of shellfish that have accumulated domoic acid, a neurotoxin produced by some strains of phytoplankton. The neurotoxic properties of domoic acid result in neuronal degeneration and necrosis in specific regions of the hippocampus. A serious outbreak of ASP occurred in Canada in 1987 and involved 150 reported cases, 19 hospitalisations and 4 deaths after consumption of contaminated mussels.

Emura *et al*., in 2004, carried out an investigation on evidence for the production of a novel proteinaceous hemolytic exotoxin by dinoflagellate *Alexandrium taylori*. The study demonstrated that *A. taylori* produces a proteinaceous hemolytic exotoxin which is toxic not only to *Artemia* but also to mammalian cultured cells. The hemolytic toxin may act on cell membrane through a specific target molecule.

Gastrich *et al*., (2004) conducted a 3 year study in Barnegat Bay in New Jersey (USA). The brown tide species, *Aureococcus anophagefferens* was enumerated and associated environmental factors were analyzed. The study indicated a potentially important impact of these harmful brown tide bloom events on shellfish resources and submerged aquatic vegetation.

Nguyen-Ngoc, (2004) carried out an autecological study of the potentially toxic dinoflagellate *Alexandrium affine* isolated from Vietnamese waters. Toxic dinoflagellate *Alexandrium affine* was isolated from Ha Long Bay of Vietnam. The specimen was cultured and maintained for morphological, physiological and toxicological studies.

Nuzzi, and Waters, (2004) made a study on long-term perspective on the dynamics of brown tide blooms in Long Island coastal bays in US. Brown tide, a bloom of the picoplankter *Aureococcus anophagefferens*, which is approximately 2.5 µm in diameter and at first it is appeared in eastern Long Island waters of US coast, in the late spring of 1985. Since then, it has recurred sporadically in various parts of USA, and only one other area of the world, Saldanha Bay, South Africa.

Wang *et al*., (2004) studied the surface sediments were collected from 10 locations to study the distribution of dinoflagellate resting cysts in Chinese coastal waters from July 2000 to May 2002. Sixty-one cyst morphotypes representing 14 genera were identified. Seventeen cyst types were new repots from Chinese coasts. Rich cyst assemblages were recorded in closed or semi-closed near shore harbors.

Kirkpatrick *et al*., (2004) made a review on Florida red tides. Toxic red tides have been observed in Florida since the 1840s. Since that time, multiple episodes with significant fish kills, as well as cases of NSP have been reported from the Gulf of Mexico (including the east coast of Mexico), the east coast of Florida, and up to the North Carolina coast; toxic blooms occur almost annually on the west coast of Florida.

Schoemann *et al*., in 2005, described a review on *Phaeocystis* blooms in the global ocean and their controlling Mechanisms. *Phaeocystis* is a genus of marine phytoplankton with a world-wide distribution. It has a polymorphic life cycle alternating free-living cells and colonies but develops massive blooms under the colony form in nutrient (major)-enriched areas (mostly nitrates) of the global ocean. Among the 6 species, only 3 (*P. pouchetii, P. antarctica, P. globosa*) have been reported as blooming species..

Cheng *et al*., (2005) studied the characterization of red tide aerosol on the Texas coast. Red tide events in the Gulf of Mexico are usually reported along the western coast of Florida.

Vilaa *et al*., (2005) made a comparative study on recurrent blooms of *Alexandrium minutum* in two Mediterranean coastal areas. In order to identify the factors determining the toxic blooms, the comparison the bloom conditions in two harbours were analysed.

Joyce *et al*., (2005) investigated the distribution and abundance of dinoflagellate cysts from surface sediments of Saldanha Bay, South Africa. The comparison of cyst assemblages in the adjacent coastal upwelling system as reflected in sediments.

Madigan *et al*., in 2005, investigated the bloom of the toxic dinoflagellate *Dinophysis acuminata* at Smoky Bay, on the west coast of South Australia (SA). Toxin concentrations were compared in shellfish samples, which were prepared in ways reflecting how the organisms may be consumed. Toxin concentrations varied between species and only the oyster sample was found to be above the Australian regulatory limit of 0.2 mg/kg (okadaic acid equivalent).

Watkinsona, *et al*., (2005) studied the ecophysiology of the marine cyanobacterium, *Lyngbya majuscula* (Oscillatoriaceae) in Moreton Bay, in Australia. The bloom at Deception Bay (Northern Moreton Bay) were studied in detail over the period January–March 2000.

Okolodkov, in 2005, studied on the global distributional patterns of toxic bloom dinoflagellates recorded from the Eurasian Arctic from about 500 literary sources. The global distributional patterns are presented for 14 toxic and potentially toxic dinoflagellate species such as, PSP, DSP, yessotoxin, azaspiracid and their analogues, ichthyotoxic and haemolytic compound producers are recorded from the Eurasian. The distributional patterns are based on materials collected during 28 expeditions to the Eurasian Arctic during the period from 1976 to 1999.

Henriksen, (2005) carried out an investigation on the abundance, biomass and characteristic pigments of *Nodularia spumigena* Mertens and the hepatotoxin nodularin produced by *N. spumigena* were analysed in water samples collected from the Baltic entrance area. Significant relationships were found between cell-bound concentrations of nodularin and the abundance and biomass of *N. spumigena* with a relationship of approximately 1 pg nodularin per *Nodularia*-cell. It is suggested that simple counts of *Nodularia* under the microscope may be used as a rapid on-site technique to estimate potential nodularin concentrations in recreational waters.

Hajdu *et al*., (2005) made a review on the morphology and occurrence *Prorocentrum minimum* (Dinophyceae) in the Baltic Sea. The invasion history is presented as well as new data on the spatial and inter-annual variability of this species and its relation to salinity, temperature, and nutrient concentrations. A short literature review of the morphological characters of the Baltic *P. minimum* is also included.

Effect of red tide caused by *Noctiluca* off south of Trivandrum on 29^{th} September 2004 was carried out by Sahayak *et al.* (2005). They found that there was a mass mortality of fishes along the Trivandrum coast.

In 2007, Mikhail, studied the monospecific bloom of raphidophyte *Chattonella antiqua* in Alexandria waters related to water quality and copepod grazing. Hernandez-Becerril *et al*., (2007), made a study on toxic and harmful marine phytoplankton and microalgae (HABs) in Mexican Coasts. In Mexico a number of human fatalities and important economic losses have occurred in the last 30 years because of these events. The most important toxin-producing species are the dinoflagellates *Gymnodinium catenatum* and *Pyrodinium bahamense* var. *compressum*, in the Mexican Pacific, and *Karenia brevis* in the Gulf of Mexico.

Sanilkumar *et al*., in 2009, reported the algal blooms along the coastal waters of southwest India during the period 2005-08 and prepared a probable ‘fingerprint’ of *Coscinodiscus asteromphalus* var. *centralis.*

5.3 Results

A conspicuous discolouration of surface water was found during the monsoon season (August) in 2006, along the northern part of Kerala, especially Off Kodikkal (11^0 28 43N and 75^0 36 10E) and in Mahe estuary (11^0 42 18N and 75^0 32 36E). It was due to the blooming of centric diatom *Coscinodiscus ehrenbergii* var. *centralis* along with pennate diatom, *Pleurosigma spp*. The entire bloom event lasted for a period of one week.

5.3.1 Standing crop

The abundance of standing crop during the bloom is shown in fig. 111 (in natural logarithm) and in table 31. Off Kodikkal the cell abundance varied from $7x10^6$ cellsL^{-1} on 23rd August to $13x10^3$ cellsL^{-1} on 27th August, with an average of $23x10^5$cellsL^{-1}. While in Mahe estuary, it ranged from $2x10^4$cellsL^{-1} 23rd August to $1x10^4$cellsL^{-1} on 27th August with an average of $17x10^3$ cellsL^{-1}.

Fig.111

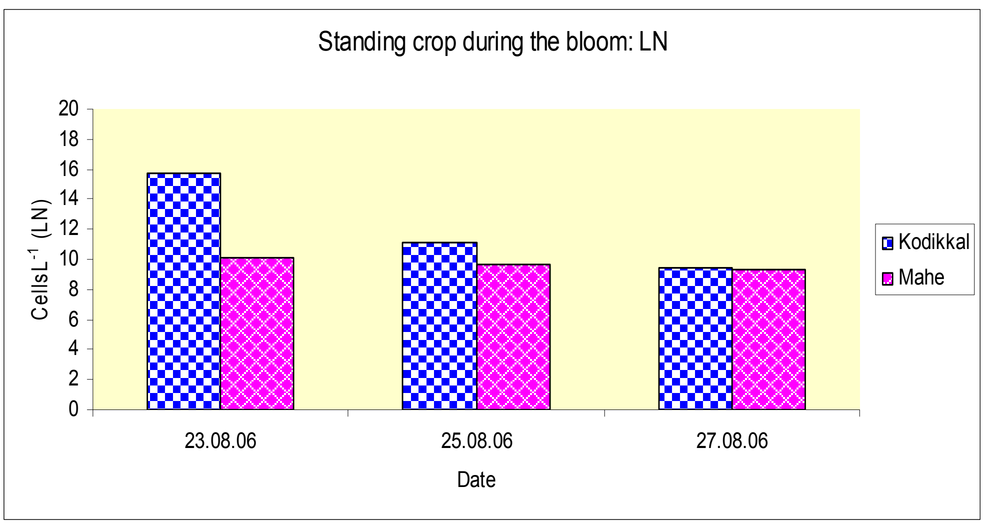


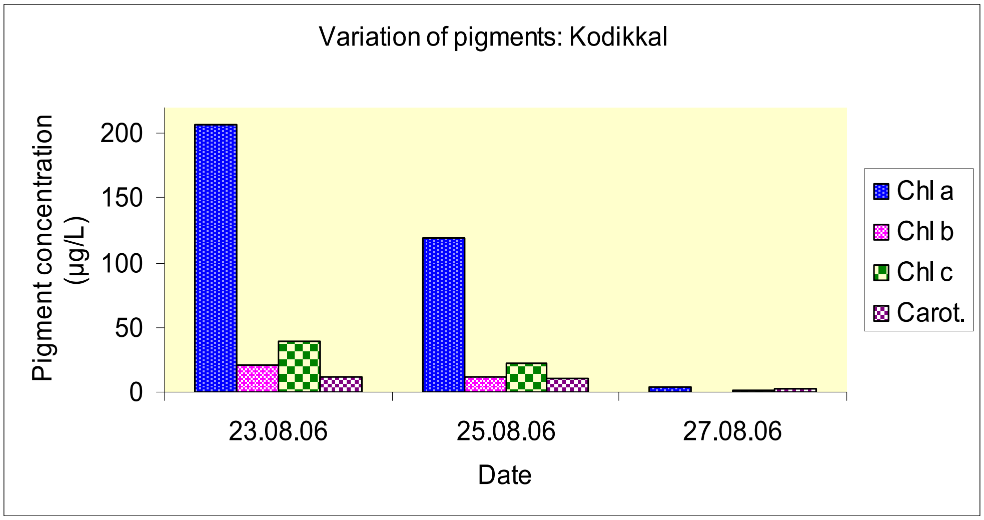
Table 31

		Stations					
	Class. Bacillariophyceae	**Kodikkal**			**Mahe**		
		23.08.06	25.08.06	26.08.06	24.08.06	26.05.06	27.08.06
1	*Biddulphia aurita*			108			
2	*Biddulphia mobilensis*	8					
3	*Coscinodiscus asteromphalus*	7000000	66000	12200	14000	9950	8870
4	*Coscinodiscus radiatus*			86			
5	*Cylindrotheca gracilis*			4		40	24
6	*Cymbella tumida*	10					
7	*Navicula arenaria*		24				
8	*Navicula elegans*						
9	*Navicula marina*			**22**			
10	*Nitzschia closterium*			5	9	20	16
11	*Nitzschia lorenziana*		28				
12	*Nitzschia paduriformis*			12		12	
13	*Navicula elegans*					14	
14	*Pleurosigma acuminatum*	1612	540		8000	4800	180
15	*Pleurosigma aestuarii*	10					12
16	*Pleurosigma angulatum*			54			34
17	*Pleurosigma falx*	29		540	1760	860	2451
18	*Pleurosigma intermedium*						
19	*Synedra ulna*			**5**			**8**
20	*Thalassionema nitzschioides*						
21	*Thalassiosira nordenskioldii*					20	
22	*Thalassiosira subtilis*						8
	Total	**7001669**	**66592**	**13036**	**23769**	**15716**	**11603**
	Class: Dinophyceae						
1	*Dinophysis tripos*					8	26
2	*Gymnodinium heterostriatum*			108			
3	*Pyrophacus horologium*			13			16
4	*Pyrophacus steinii*						20
	Total	**0**	**0**	**121**	**0**	**8**	**62**
	***Grand total**	**7001669**	**66592**	**13157**	**23769**	**15724**	**11665**
	***cells/lit.**						

5.3.2 Pigment composition

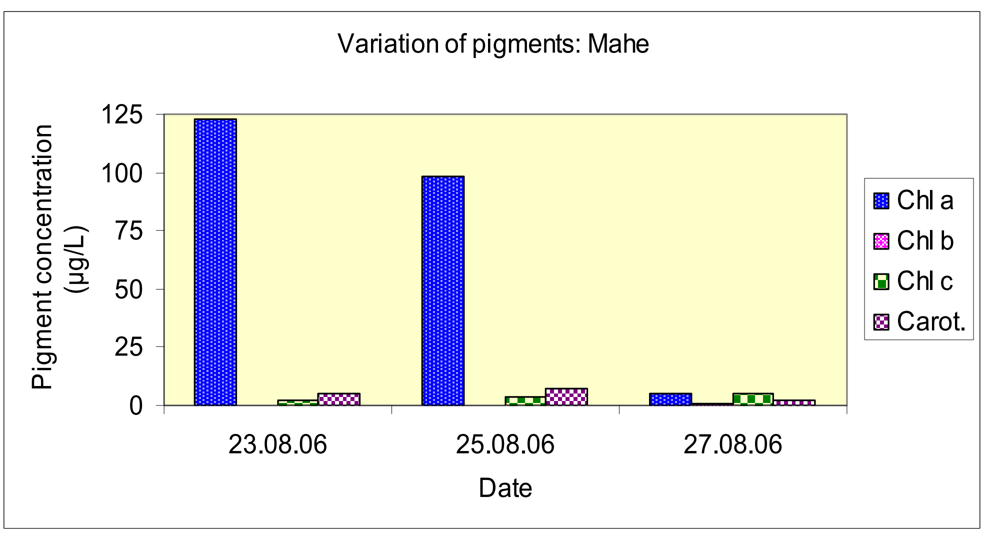
At Kodikkal, during the bloom chlorophyll *a* ranged from 206.5 to 3.29µgL^{-1}. The highest concentration of chlorophyll *b* was 20.4µgL^{-1} on the first day and lowest being 0.1µgL^{-1} on the final day. Concentration of 39.3 to 0.79µgL^{-1} was the variation of chlorophyll *c* and while carotenoid pigments varied from 11.9 on the first day to 2.1µgL^{-1} on the last day of bloom event (fig. 112).

Fig.112



During the bloom event at Mahe, the concentration of chlorophyll *a* varied from 123 µgL^{-1} on 23rd August to 5.2µgL^{-1} on 27th August. Chlorophyll *b* showed a variation of 0.53µgL^{-1} to 0.25µgL^{-1}. The highest concentration of chlorophyll *c* was 5.36 and lowest being 2.36µgL^{-1}. Carotenoid pigments ranged from 7.26 to 1.91µgL^{-1} from the initial day to the last day of collection (fig.118).

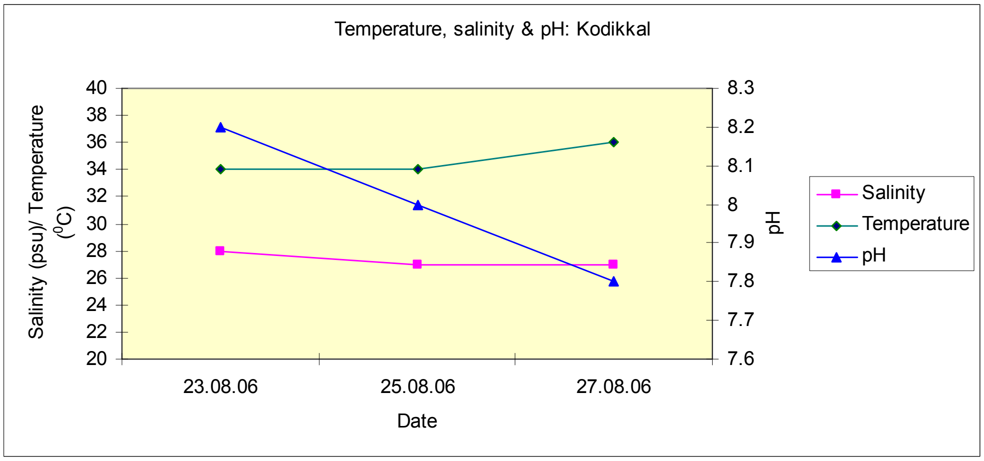
Fig. 118



5.3.3 Temperature, salinity and pH

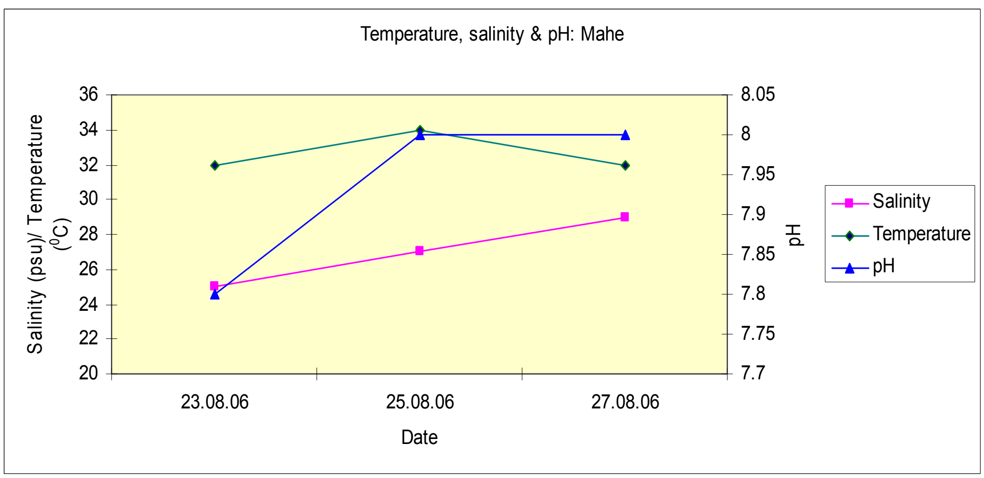
At Kodikkal, temperature varied from 34 to 36 ^{0}C, salinity was 28psu on the first day and increased to 28psu on the second and third day of collection, while pH ranged from 7.8 23rd August to 8.2 27th August (fig. 119).

Fig.119



At Mahe, during the bloom, temperature varied from 32 to 34^{0}C, salinity ranged from 25 to 29psu increased from day one to the third day and pH showed a variation from 7.8 on 23rd August to 8 on the 25th and 27th August (fig. 120).

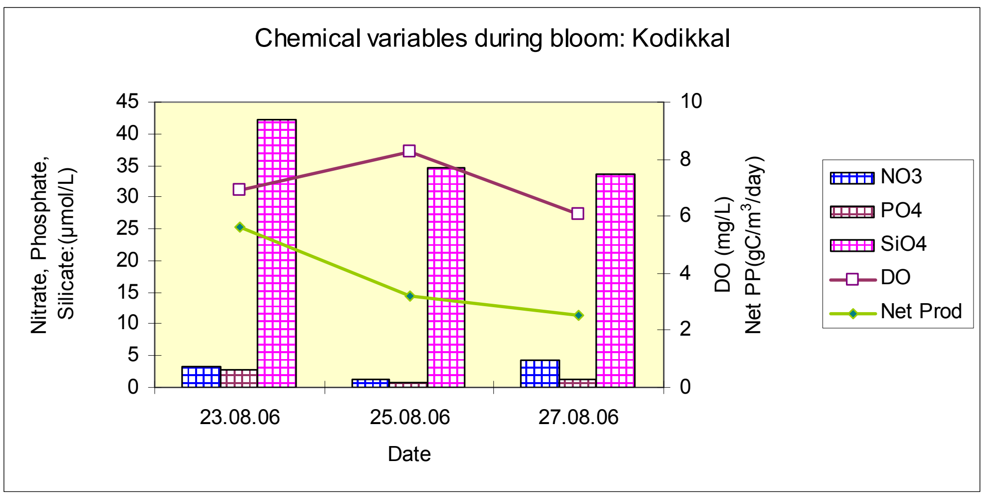
Fig.120



5.3.4 Nutrients, DO and primary productivity.

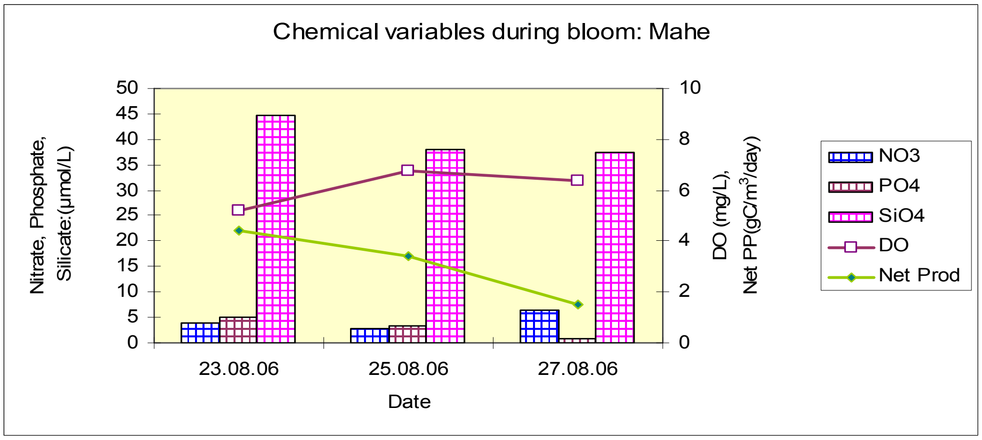
The concentration of nitrate varied from 4.2 on 23rd August to 1.2µmolL^{-1} on 27th August. Phosphate concentration varied from 2.8 to 0.7 and it was 42.2 to 33.6 µmolL^{-1} for silicate from the initial to the last day of collection. The concentration of nitrite was in below detectable ranges. Dissolved oxygen decreased from 8.2mgL^{-1} to 6.04mgL^{-1}, while the net primary production varied from 5.61 to 2.5gC/$m^3$$Day^{-1}$ from initial day to the last day during the bloom at Kodikkal (fig. 121).

Fig. 121



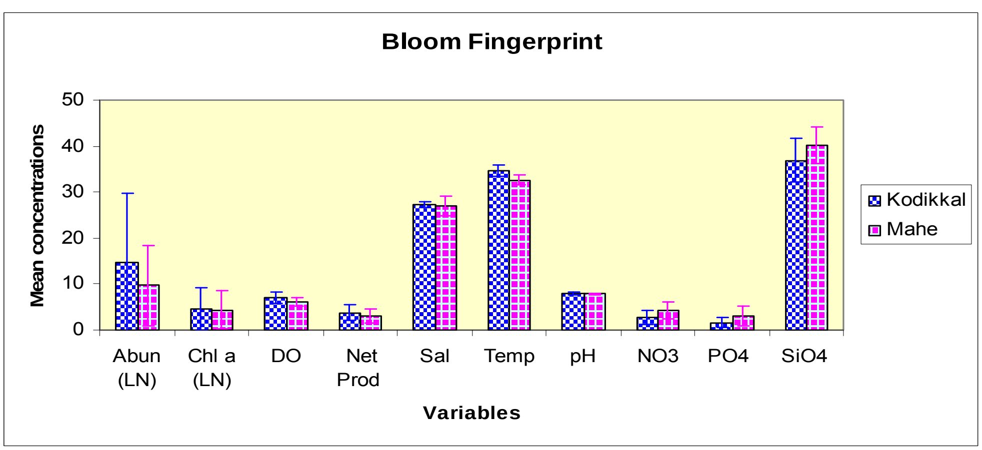
At Mahe estuary, the concentration of nitrate ranged from 6.38µmolL^{-1} to 2.8µmolL^{-1} from the initial to the final day of collection. It was 5.1 to 0.78µmolL^{-1} for phosphate and silicate values varied from 44.6 to 37.4µmolL^{-1}. The nitrite concentration was practically nil or in below detectable ranges. The variation of dissolved oxygen ranged from 6.7 to 5.2mgL^{-1}, and net primary production ranged from 4.4 gC/m^3 Day^{-1} to 1.5gC/m^3 Day^{-1} from the first to the last day of the bloom (fig. 122).

Fig. 122



The mean values of all the variables in two stations were plotted in fig.8. The abundance was 2360473 and 17053cells L^{-1}, chlorophyll *a* was 109.6 and 75.4µgL^{-1}, dissolved oxygen was 7.06 and 6.11mgL^{-1}, net primary production was 3.79 and 3.11gC/m^3 Day^{-1}, in Kodikkal and Mahe estuary respectively. The variation of mean salinity was 27 to 27.3psu, temperature was 34.67 and 32.67^{0}C and pH was 8 and 7.9 in respective stations of Kodikkal and Mahe. The concentrations of nutrients such as nitrate was 2.88 and 4.38µmolL^{-1}, phosphate, 1.6 and 3.06µmolL^{-1} and silicate was 36.8µmolL^{-1} and 40.08 µmolL^{-1}, recorded from Kodikkal and Mahe. The nitrite concentrations were recorded as in below detectable ranges in both stations. The corresponding LN values were used to plot the chlorophyll *a* and cell density (fig. 123).

Fig. 123



5.4 Discussion

The algal blooms or 'red tides' are common in Indian waters. Periodic blooms of planktonic algae such as, *Noctiluca scintilans, Trichodesmium erythraeum*, *Rhizosolenia sp*., have been reported. However, after 1981, events of harmful blooms from coastal Tamil Nadu, Karnataka, Maharashtra and Kerala were reported. In September 1997, an outbreak of PSP was reported in three villages of Kerala, resulting in the death of seven persons and hospitalization of over 500 (Bhat and Matondkar, 2004). The cyanophyte *Trichodesmium* and dinoflagellate *Noctiluca* species were most dominant members of the blooms reported. (Raghuprasad R., 1958; Katti *et al*., 1988; Sargunam *et al*., 1989; Nair *et al*., 1992; Naqvi *et al*., 1998; Eashwar *et al*., 2001; Sahayak *et al*., 2005; Sarangi *et al*., 2004; Mohanty *et al*., 2007; Padmakumar *et al*., 2008a,) A bloom of holococcolithophore (Ramaiah *et al*., 2005) is an exception. In spite of the above species, five types of cysts belonging to potentially toxic genera of *Alexandrium* and *Gymnodinium* were recorded from Mangalore coast (Godhe *et al*., 2000). A bloom of centric diatom *Coscinodiscus asteromphalus* var. *centralis* and *Microcystis aeruginosa* was also reported from the southwest coast of India (Padmakumar *et al*., 2007, 2008b).

The bloom of centric diatom, *Coscinodiscus asteromphalus* var. *centralis,* is the first report from Indian waters. In this study, at Kodikkal, on the first day of observation, the standing crop of *Coscinodiscus asteromphalus* var. *centralis* was alone found to be $7x10^6$cellsL^{-1}. The total standing crop was 7001669cellsL^{-1} distributed among 6 species. Next to *Coscinodiscus* was *Pleurosigma acuminatum,* contributing about 1612cellsL^{-1}. On the second day, standing crop was decreased to 66592 cellsL^{-1} distributed among 4 species. The dominant species, ie., *Coscinodiscus asteromphalus* var. *centralis* was found to be 66000cellsL^{-1}. *Pleurosigma acuminatum* also decreased to 540cellsL^{-1}. On the third day of bloom event the standing crop was 13036cellsL^{-1} distributed among 12 species. *Coscinodiscus asteromphalus* var. *centralis* attained a concentration of

12200cellsL^{-1}. A few of the species including *Pleurosigma falx* was also present in substantial concentrations. The composition of species has changed remarkly during the end of the bloom. The typical mono-specific bloom conditions were also recorded here, ie., during the initiation, the number of species was less and when bloom progressed, the species diversity again decreased and at last when it crashed, the composition was increased to 12 species, including two species of dinoflagellates. Except the dominant species, all most all the species were changed towards the end of the bloom.

The bloom extended towards north to Mahe estuary. The surface water was found to be slight brown. *Coscinodiscus asteromphalus* var. *centralis* was the dominant species along with pennate diatoms such as *Pleurosigma acuminatum* and *P. falx*. In Mahe estuary also three intermittent days of collection was made. In the first day on 23.08.06, only four species were observed, exclusively diatoms and among which, *Coscinodiscus asteromphalus* var. *centralis* was the dominant species (14,000cellsL^{-1}). The standing crop was 23769cellsL^{-1} including 8000cellsL^{-1} of *Pleurosigma acuminatum*, and 1760cellsL^{-1} of *P. falx*. On 25.08.06, the density of bloom decreased and diversity of species increased. The dinoflagellate *Dinophysis tripos* was also recorded among the nine. The total standing crop was 15724cellsL^{-1}, *Coscinodiscus asteromphalus* var. *centralis* (9950cellsL^{-}1) was the dominant species followed by *Pleurosigma acuminatum* (4800cellsL^{-1}) and *P. falx* (860cellsL^{-1}). During the third day of observation the density further decreased. Out of the eleven species recorded, three were dinoflagellates. The standing crop was 11665cellsL^{-1}, in which *Coscinodiscus asteromphalus* var. *centralis* was the dominanat species (860cellsL^{-1}). The number of *Pleurosigma falx* was found to be increased (2451cellsL^{-1}) from that of previous day.

In the event of microalgal bloom, the diversity decreased and the abundance of the dominant species increased. At the end of the bloom or bloom crash, the species diversity further increased and abundance decreased.

Pigment concentrations

Chlorophyll *a, b, c* and carotenoid concentrations during the bloom indicated the magnitude and composition of algal bloom. The presence of chlorophyll *b* indicated the presence of chlorophytes/ prochlorophytes/ euglenophytes, however, none of the species from these classes were recorded during the bloom. Due to the extreme minute size, they could not be counted with the help of a Sedgewick-Rafter counting cell. The significant hike of chlorophyll *c* and carotenoids were due to the presence of diatoms. The fluctuations in the pigment concentrations changed with the phases of the bloom. Initially the bloom was at its exponential phase as evident from the standing crop and chlorophyll. On the second day of collection, slight decrease in the standing crop and chlorophylls were observed indicating the transition of exponential phase to the stationery phase. Further decrease in the standing crop and pigments shows that the bloom was in the late stationary phase and enters into the death and decline phase.

Even though the recorded silicate values were in the range of 33.6 to 44.6µmolL^{-1} Silicate, utilized for the formation of siliceous frustules of diatoms, constitutes one of the most important nutrients regulating the phytoplankton growth and proliferation, and ultimately to its blooming (Kristiansen and Hoell, 2002). The individual values of silicate were shown decreasing from the initial to the final day. The N: P ratios (Redfield ratios) in two stations were quite low while Si:N ratios were moderately higher. It was assumed that the hike of Si:N ratio was one of the important factors which resulted in this bloom.

The Si:N ratios varied from 13:1 to 8:1 in Kodikkal and in Mahe, it ranged from 11:1 to 6:1 starting from the initial day to the end of the bloom event. So it is concluded that the high ratios of Si:N played a significant role in the formation of algal bloom. It is noted that the ratios were decreasing from the initial day to the last day in accordance with the decrease of chlorophyll *a* and standing crop.

At Kodikkal N:P ratio was 3:1 and in Mahe the ratio was 8:1 during the final day, where the cell number and pigments values were significantly decreased. Generally when N:P ratio is high, the standing crop should also be high, however, in this study, the higher N:P ratios in both stations were observed during the crash of the bloom. Arrigo (2005), reported that bloom forming phytoplankton optimally increase their allocation of resources toward production of growth machinery, reducing their N:P ratio to approximately 8. The very same ratio was obtained during the end of the bloom at Kodikkal.

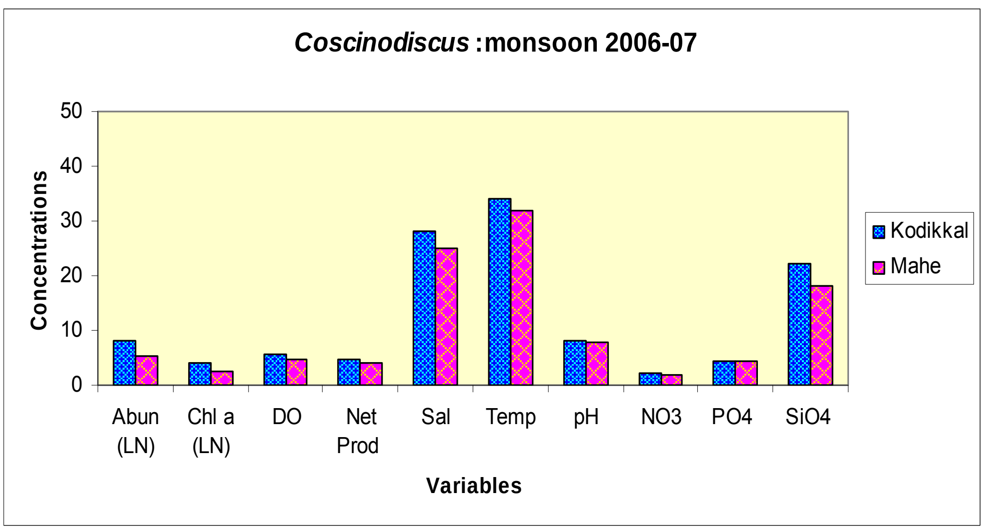
During the initial stages of the bloom dissolved oxygen and primary productivity were low. In the second collection, these attained the maximum. Dissolved oxygen and primary productivity were decreased towards the crash of the bloom. A very low level of dissolved oxygen concentrations as a consequence of excessive organic loading due to crash of the bloom in southern coast of Kerala Ramaiah *et al*., (2005).

The most remarkable comment in connection to planktonic microalgal blooms is not why they occur but rather what mechanisms control the species which occur at a given time and place (Richardson, 1997). Marine environment provides many different niches that can be exploited by different microalgal species and each species has its own specific combination of necessities to the external environment, such as light, micro and macro-nutrients. Hence, it may be possible to identify a ‘fingerprint’ of each bloom producing species describing its external requirements. So, matching the environmental condition at any given time to the ‘fingerprints’ of microalgal species potentially occurring in an area would provide a basis for predictive models pertaining to the probable development of algal blooms. The ‘fingerprint’ or the available data of the biological and physico-chemical variables recorded during the bloom of *Coscinodiscus asteromphalus* var. *centralis* Ehrenberg, was prepared in this study (fig. 123).

It is assumed that this ‘fingerprint’ definitely would help the upcoming bloom events and can correlate with this particular data. In practice, total description of the 'fingerprint' of each and every species enables to understand the factors that control planktonic algal succession is vital to the perceptive of why and where algal blooms occur.

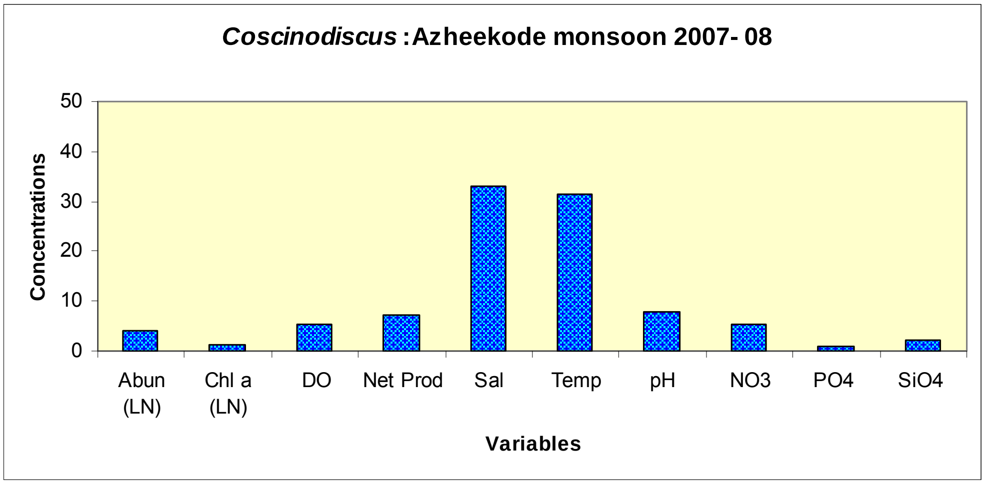
In the present investigation, the fingerprint of the bloom made up from available variables was evaluated by comparing the presence of the same species (*Coscinodiscus asteromphalus* var. *centralis*) from the entire sampling stations along the southwest coast. The occurrence of same species was recorded only two times, one before and another after the bloom. At first, as a part of the regular monitoring in the monsoon 2006-07, the same species were recorded from the same stations just one week before the bloom (Kodikkal and Mahe), however the concentrations of the standing crop, pigments and nutrients did not appear very close to that of the bloom (fig. 124).

Fig. 124



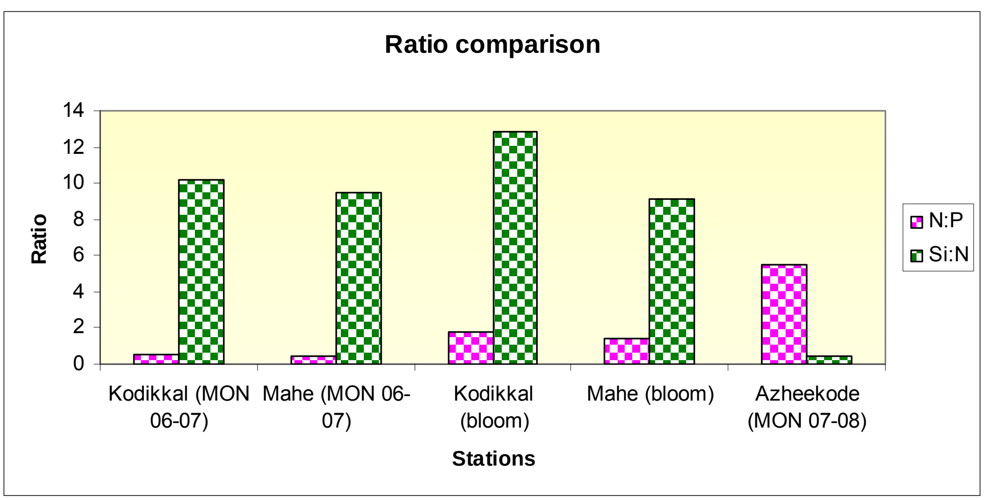
Similarly during the monsoon 2007-08, at Azheekode (Station no.4) the same species were recorded. The standing crop and chlorophyll *a* were low (56 cellsL^{-1}, and 3.6µgL^{-1}), along with other physico-chemical variables (fig. 125).

Fig. 125



The N:P and Si:N ratios were also given for a comparison. From these two observations, it is evident that the higher silicate concentrations along with higher Si:N ratio would probably played a major role of the initiation of bloom. It is also noted that the Si:N ratios during the monsoon at the two stations were closest to that of the bloom Si:N ratios. When bloom happened at Kodikkal, the Si:N ratio was 12.8:1 and at Mahe it was 9:1 (fig. 126).

Fig. 126



The same Si:N ratio was recorded at Mahe during the early monsoon collection which have been made just one week before the bloom and the standing crop was low when compared to the bloom. This ratio did not provide a huge hike in the standing crop. Hence it is clear that the origin of the bloom was at Kodikkal and due to the process of advection the cells were migrated towards the north Mahe estuary, about 40km away from Kodikkal. It is evident that microorganisms, particularly diatoms, passively dispersed between localities. Potential vectors for passive dispersal are water currents, animals and wind (Kristiansen, 1996). In which, water currents are an obvious dispersal mechanism between directly interconnected habitats, there are also studies indicating that wind and animals can carry smaller amounts of viable cells of at least the more resistant taxa over 10 to 100s of kilometer (Vanormelingen *et al*., 2008).

The increase of HAB records in coastal waters around the world has often been associated with nutrients derived from anthropogenic activities. However, there is limited evidence for a direct relationship between the spread of harmful events and eutrophication in the sea. High biomass blooms obviously require high nutrient levels. Nevertheless, a high nutrient supply may not necessarily favour harmful species; an abundance of multiple nutrient resources could stimulate the development of planktonic blooms.

During this study, in the southwest coast of India, eleven species of harmful microalgae were recorded among three taxonomic divisions, Cyanophyta, Bacillariophyta and Dinophyta. Among the eleven species, there was only one species from the class Cyanophyta (*Microcystis aeruginosa* Kutzing), two from Bacillariophyta (*Amphora coffeaeformis* (Agardh) Kutzing; *Pseudonitzschia seriata* (Cleve) Peragallo) and rest were from Dinophyta (*Coolia monotis* Meunier; *Dinophysis acuminata* Claparede and Lachmann; *Dinophysis caudata* Saville-Kent; *Dinophysis fortii* Pavillard; *Dinophysis miles* Cleve; *Dinophysistripos* Gourret; *Gonyalux monilatum* (Howell) Taylor and *Prorocentrum lima* Ehrenberg).

This is the first report of *Coscinodiscus asteromphalus var. centralis* Ehrenberg; bloom from Indian waters. The N:P ratios in two stations were quite low while Si:N ratios were comparatively higher. It is inferred that the high ratios of Si:N played a significant role in the formation of algal bloom (Sanilkumar *et al.*, 2009). An attempt has been made to prepare a 'fingerprint' of these bloom from the available data of the biological and physico-chemical variables recorded during the bloom of *Coscinodiscus asteromphalus var. centralis* Ehrenberg.

Chapter 6

Summary and Conclusion

Microalgae, both planktonic and benthic are ecologically very significant as the entire renewable resources in aquatic ecosystems are either directly or indirectly generated by virtue of their capacity of synthesizing organic matter. The magnitude and even the type of the fishery are influenced by the distribution, diversity and abundance of microalgal species which fluctuate with time and space.

Study on diversity of microalgae is of primary importance in aquatic ecology for assessing water quality, habitat integrity, habitat carrying capacity and trophic web stability. Direct microscopic observation, correct identification and accurate enumeration are essential to document species composition and biomass and are the only means to assess the morphological changes within the algal communities as a response to environmental variations. The biomass, distribution and species composition of microalgae change continuously with variations in physico-chemical variables such as temperature, light, nutrient availability, sediment characteristics, seasons and even with time of day.

For a realistic estimation of primary productivity and assessment of potential fishery resources in the aquatic environment, it is imperative to have an understanding on both planktonic and benthic microalgae. Hence the present investigation aims at ascertaining the distribution and abundance of these microalgae. Two algal blooms observed during the period of study are also investigated.

It is observed that the dominant species among phytoplankton are diatoms. Dinoflagellates, coccolithophorids, silicoflagellates, chlorophytes, and cyanophytes are also found distributed in comparatively lesser concentrations. Benthic forms comprise mainly of pennate diatoms and blue-green algae. The distribution and abundance of microalgae is influenced by various physico-chemical and biological factors. When the availability of those factors are at optimum level, microalgal blooms are formed as is observed along the Indian coast.

The role of benthic microalgae is very significant as evident from the fact that annual global productivity of microphytobenthos is approximately 500 million tons of carbon, as against about 3000 million tons of carbon by planktonic microalgae.

The study includes the seasonal and spatial variation of planktonic microalgae and microphytobenthos along the southwest coast of India (seven coastal and estuarine stations) for two years. It also includes the distribution of planktonic microalgae in selected regions in the open sea (samples collected onboard FORV Sagar Sampada). Two algal blooms, appeared along the Northern Kerala coast during this period were also investigated.

Physico-chemical variables such as temperature, salinity, pH, nitrate, nitrite, phosphate, silicate, dissolved oxygen and primary productivity influence the distribution, abundance and succession of microalgal species. The fluctuations of these factors for a period of two years from pre monsoon 2006-07 to post monsoon 2007-08 in the coastal and estuarine monitoring stations along the southwest coast are described. The spatial variations of standing crop, chlorophyll *a* and physico-chemical parameters collected from the open sea are also incorporated. Nitrate and silicate concentrations have shown marked variations.

Qualitative analysis of planktonic microalgae from the southwest coast of India includes 285 species from coastal and estuarine stations and 57 species collected from offshore waters during FORV Sagar Sampada cruises. Thirty one species were found common, both in coastal and offshore waters. Altogether, 311 species were found distributed among 89 genera in 7 classes/groups viz; cyanophyceae (9 genera), chlorophyceae (22 genera), bacillariophyceae (52 genera), dinophyceae (16 genera), chrysophyceae (1 genus), dictyochophyceae (1 genus) and coccolithophorids (1 genus).

Class bacllariophyceae was the dominant group with 185 species (59.4%), followed by dinophyceae with 64 species (20.57%), chlorophyceae with 43 species (13.8%), cyanophyceae with 14 species (4.5%), dictyochophyceae, coccolithophorids and chrysophyceae with comparatively less number of species. Pennate diatom *Navicula* was the most abundant species (22spp.) followed by *Chaetoceros* (12 spp), *Coscinodiscus* and *Pleurosigma* (11spp. each). In Dinophyceae, *Protoperidinium* was the dominant genus with 20 species followed by *Ceratium* with 14 and *Dinophysis* with 10 species.

Maximum standing crop and chlorophyll *a* were obtained when the mean N:P ratios were lower and Si:N ratios were higher. In the present investigation, the planktonic microalgal standing crop and chlorophyll *a* values are well supported by the higher Si:N ratios along the coastal and estuarine stations.

Benthic microalgae were found distributed at a depth of 5cm in the sediment column along the southwest coast of India. The vertical distribution of microphytobenthos has shown a significantly higher biomass associated with the surfacial sediment stratum (0–1cm). About 88% of the total microphytobenthos were found to be diatoms. Chlorophyll *a* and standing crop have shown positive correlations during all the seasons.

54% of the total biomass was observed at the surface stratum and 87% was found in the upper 3cm depth. Both cell abundance and chlorophyll *a* decreased with increase in the sediment depth. Microphytobenthos did not show any shift of major taxa, even in the monsoon. The cell abundance and biomass of microphytobenthos was higher when the ratio of percentage of silt, sand and clay was approximately 50:25:25.

Analysis of benthic microalgal assemblages reveals that there are two distinct functional groupings. One is mostly benthic species and the other is “tychopelagic” or“tychoplanktonic” which can be seen both in the benthic and pelagic habitats. Out of 55 microalgae, 8 species were mostly found in the benthic environment, viz; *Cocconeis littoralis* Subrahmanyan, *Cocconeis scutellum* Ehrenberg, *Cocconeis sigmoides* Subrahmanyan, *Cymbella aspera* (Ehrenberg) Cleve, *Cymbella marina* Castracane, *Diploneis littoralis* (Donkin) Cleve, *Diploneis weissflogii* (A. Schmidt) Cleve and *Navicula directa var. remota* Grunow and rest 47 species are tychopelagic" or "tychoplanktonic, including 40 species of diatoms, 4 species of blue-green algae and 3 species of dinoflagellates. Species such as *Amphora coffeaeformis (Agardh)* Kutzing, *Amphora turgida* Gregory, *Nitzschia closterium* (Ehrenberg) W. Smith, *Pleurosigma aestuarii* (Brebisson) W. Smith *Pleurosigma angulatum* (Queckett) W. Smith, *Pleurosigma falx* Mann and *Surirella fastuosa* Ehrenberg could be seen frequently in the deep strata.

The present investigation unraveled the magnitude and importance of microphytobenthos in littoral zone and estuaries along the southwest India. In all the stations, the mean benthic microalgal biomass substantially exceeded the planktonic biomass. The annual ratio of pheopigment to chlorophyll *a* suggests that a physiologically healthy microphytobenthic community with low grazing pressure was present along the southwest coast throughout the period of two years.

Blooms of centric diatom *Coscinodiscus asteromphalus* var. *centralis* Ehrenberg, were found during the monsoon season in 2006, along the northern part of Kerala, Off Kodikkal (11^0 28 $43^{'}$N and 75^0 36 $10^{'}$E) and in Mahe estuary (11^0 42 $18^{'}$N and 75^0 32 $36^{'}$E). This is the first report of *Coscinodiscus asteromphalus* var. *centralis* bloom from Indian waters. The N:P ratios in both the stations were quite low while Si:N ratios were comparatively higher. It is inferred that the high ratios of Si:N played a significant role in the formation of algal bloom.

Attempt has been made to prepare a 'fingerprint' of these blooms from the available data of the biological and physico-chemical variables recorded during the bloom of *Coscinodiscus asteromphalus* var. *centralis* Ehrenberg. This may be an effective tool for the prediction of algal blooms.

In all, three hundred and nineteen species of microalgae, 311 planktonic and 55 microphytobenthic species were recorded during the present investigation. Among these, 47 species were found in both benthic and pelagic habitats. (Annexure 8). They belong to seven taxonomic classes. In the class bacillariophyceae, pennate diatom *Navicula* was the most abundant species (22spp.). *Cheatoceros* (12 spp), *Cosciodiscus* and *Pleurosigma* (11spp. each) were also contributed well. In dinophyceae, *Protoperidinium* was dominant with 20 species followed by *Ceratium* (14spp) and *Dinophysis* with 10 species.

17 species of diatoms were found to be new record to Indian waters. The species include *Amphora angusta* Gregory, *A exigua* Gregory, *A turgida* Gregory, *Biddulphia regia* (Schultze) Ostenfeld, *Chaetoceros constrictus* Gran, *Cymbella tumida* Van Heurck, *Gyrosigma hippocampus* (Ehrenberg) Hassal, *G tenuissimum* (Smith) Griffith & Henfrey, *Navicula elegans* Smith, *N rhombica* Gregory, *Nitzschia constricta* (Gregory) Grunow, *N tryblionella* Hantzsch, *Pleurosigma intermedium* W.Smith, *Surirella striatula* Turpin, *Triceratium affine* Grunow, *Tropidonies longa* Cleve and *Thalassiosira australis* Peragallo.

During this study, eleven species of toxic microalgae were recorded among three taxonomic classes, Cyanophyta, Bacillariophyta and Dinophyta. They included *Microcystis aeruginosa* Kutzing), A*mphora coffeaeformis* (Agardh) Kutzing; *Pseudonitzschia seriata* (Cleve) Peragallo) *Coolia monotis* Meunier; *Dinophysis acuminata* Claparède and Lachmann; *Dinophysis caudata* Saville-Kent; *Dinophysis fortii* Pavillard; *Dinophysis miles* Cleve; *Dinophysis tripos* Gourret; *Gonyalux monilatum* (Howell) Taylor; and *Prorocentrum lima* Ehrenberg, indicating the possibility of potential threat of harmful blooms in the coastal environment of southwest India.

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TAXONOMIC DESCRIPTION OF DISTRIBUTIONAL RECORDS

CLASS BACILLARIOPHYCEAE

Order: Biddulphiales (Centrales)
Family: Coscinodiscaceae

Thalassiosira australis Peragallo

Tomas et al., 1997, p.63, pl. 9.

Cells cylindrical, usually in chains. Valve face flat or slightly concave. Valve mantle, high, steep, slightly slanting. Distance between cells in chains about half of pervalvar axis. Marginal ring of strutted processes can be faintly seen with LM analysis. Areolae 11-16, in 10µ.

Dimension: Diameter of the valve 23-56µ.
Distribution: commonly found in southern cold water region.

Family: Biddulphiaceae

Biddulphia regia (Schultze) Ostenfeld

Hendey 1964, p.104, pl.20, fig.2

Cells sometimes solitary, usually in chains, united by the spines of adjacent cell. Frustules weakly siliceous. Cells box-shaped with short horn-like processes at the corners. Valves elliptical, weakly concave, mantle deep. Valve surface faintly punctate, with two spines develop very close to the processes or horns. Processes small, with blunt, rounded ends. The spines interlock those with the neighbouring cells. The tips of the spines usually broaden a little, often split or furnished with small hooks. Chromatophores, numerous, rounded or irregular plate-like.

Dimension: Apical axis 100-200µ

Distribution: Planktonic, in North Sea, English Channel, Irish Sea. Recorded Off Punnapra (9^0 25 23'N & 76^0 19 41'E) during pre monsoon 2007-08.

Triceratium affine Grunow

Jin Dexiang et al., 1985, p.53, pl.12, fig.91.

Valve triangular with straight or slightly concave margins. Each angle ended with obtuse processes. Valve center slightly raised. Valve surface furnished with irregular areolae with a sub-radial arrangement, unparallel to each side. Areolae, mostly hexagonal, larger at the middle, decreases in size when come to the margin.

Dimension: Side length 84-160µ.

Distribution: Common in East China Sea, West Indies, Australia and US coasts. Recorded from Balathuruthu Estuary (11^0 07 50'N & 75^0 49 57'E) during pre monsoon 2007-08.

Family: Chaetoceraceae

Chaetoceros constrictus Gran

Cupp, 1943, p.122, fig. 76; Hendey, 1964, p.126, pl.9, fig. 2; Tomas., 1997, p.209, pl.43.

Chains short, straight, rectangular or oblong in girdle view. Valve surface elliptical, flat or weakly concave with a slight inflation in the central part. Corners of adjacent cell touching. Foramina narrow, symmetrically lanceolate, slightly narrowing at center. Valve mantle shallow. occur a conspicuous, deep constriction between valves and girdle band. Terminal setae distinct, short, turned towards the axis of the chain. Intercalary setae somewhat straight, deep constriction between valve and girdle band. Chromatophores two, plate-like bodies

Dimension: Apical axis 12-36μ.

Distribution: In North Sea, English Channel, Eastern Pacific. Recorded Off Azheekode (10^0 11 $02^{'}$N & 76^0 09 $22^{'}$E) during post monsoon 2007-08 and from Balathuruthu (11^0 07 $50^{'}$N & 75^0 49 $57^{'}$E) during post monsoon 2007-08.

Order: Bacillariales
Sub order: Naviculineae
Family: Naviculaceae

Tropidonies longa Cleve

Jin Dexiang et al., 1985, p.61, fig.125.

Frustules elongated, nearly rectangular, slightly constricted in the middle. Valves needle shaped. Each valve with a reduced keel, or a weak trace of keel can be seen, central part concave. Striae in parallel rows, numerous near the apices. Raphe straight, central area large, increasing horizontally into the rectangular space, not reaches the margin, axial area indistinct or absent. Terminal nodules very clear.

Dimension: Length 163-214μ, breadth 16-21μ

Distribution: Adriatic Sea, Norwegian coasts, South China Sea. Recorded Off Vaadi (8^0 52 $01^{'}$N & 76^0 34 $26^{'}$E) during the monsoon 2007-08 and Off Kodikkal (11^0 28 $43^{'}$N & 75^0 36 $10^{'}$E) during pre monsoon 2006-07.

Navicula elegans Smith

Hendey, 1964, p.215, pl. 34, fig. 1-4.

Valves elliptic-lanceolate, with produced sub-rostrate to sub-acute apices. Axial area narrow, straight, central area somewhat large, orbicular to sub-quadrate. Valve surface flat, with non-punctate striae. Striae radiate and curves in the centre and convergent at the apices. Raphe very clear. Polar nodules conspicuous.

Dimension: Length 60-120μ, breadth 25-30μ

Distribution: Common in British islands. Recorded Off Punnapra (9^0 25 $23^{'}$N & 76^0 19 $41^{'}$E) during monsoon 2006-07 and post monsoon 2007-08, also from Mahe Estuary (11^0 42 $18^{'}$N & 75^0 32 $36^{'}$E) during post monsoon 2006-07. *Navicula elegans* also recorded from the sediments Off Azheekode (10^0 11 $02^{'}$N & 76^0 09 $22^{'}$E).

Navicula rhombica Gregory

Hendey, 1964, p. 192, pl. 30, fig.3.

Valves weakly rhombic-lanceolate with sub-acute rounded apices. Axial area very narrow, widen when reach to the elliptical central area. Valve surface striate, striae radiate at the centre, weakly radiate or transverse at the apices. Striae very close together towards the apices. Polar nodules small and conspicuous. Chromatophores, two, large, plate-like lying on the girdle.

Dimension: Length 60-95µ, breadth 16-20µ.

Distribution: Common in European coasts. Recorded from Balathuruthu (11^0 07 $50^{'}$N & 75^0 49 $57^{'}$E) during the monsoon 2006-07.

Pleurosigma intermedium W.Smith

Hendey, 1974 p.244; Jin Dexiang et al., 1985, p.66, fig.139.

Syn: *Pleurosigma nubecula* W. Smith

Valves narrow lanceolate, with acute or sub-acute apices. Valves somewhat straight or slightly sigmoid, raphe almost straight, central. Axial area very narrow or absent, central area small elliptic. Central and polar nodules conspicuous, small and rounded. Valve surface striate.

Dimension: Length 126-194µ, breadth 10-16µ.

Distribution: Planktonic or benthic, recorded from Belgium, UK, Scandinavian coasts. Collected Off Vaadi (8^0 52 $01^{'}$N & 76^0 34 $26^{'}$E) during post monsoon 2006-07, Off Azheekode, (10^0 11 $02^{'}$N & 76^0 09 $22^{'}$E) during post monsoon 2007-08 and from Mahe estuary (11^0 42 $18^{'}$N & 75^0 32 $36^{'}$E) during post monsoon 2006-07.

Gyrosigma tenuissimum (Smith) Griffith & Henfrey

Hendey, 1964, p. 249; Jin Dexiang et al., 1985, p. 77, pl.24, fig.178.

Syn: *Pleurosigma tenuissimum* Wm. Smith.

Valves very narrow, linear-lanceolate with sigmod flexure towards the ends. Apices sub-acute or acute. Raphe central, the degree of curvature of raphe, similar, that to the valve. Central nodule, rounded, small. Valve surface striate, transverse striae more conspicuous than the longitudinal.

Dimension: Length 160-200µ, breadth 8-12µ

Distribution: British coasts, South China Sea. Recorded from Kavanad estuary (8^0 55 $55^{'}$N & 76^0 33 $37^{'}$E) during pre monsoon 2006-07, from Balathuruthu estuary, (11^0 07 $50^{'}$N & 75^0 49 $57^{'}$E) during monsoon and post monsoon 2006-07 and Off Kodikkal (11^0 28 $43^{'}$N & 75^0 36 $10^{'}$E) during post monsoon 2006-07.

Gyrosigma hippocampus (Ehrenberg) Hassal

Hendey, 1964, p. 249, pl.36, fig.5

Syn: *Navicula hippocampus* Ehrenberg; ***Pleurosigma hippocampus*** **(**Ehrenberg) Wm. Smith..

Valves lanceolate, sigmoid at the ends. Apices obtusely rounded, raphe centrally placed, sigmoid. Central nodule small, circular. Valve surface striate, longitudinal striae conspicuous. The longitudinal striae seen as curved when they pass around the central nodule.

Dimension: Length 142-180μ, breadth 22-26μ.

Distribution: Common species of British coasts. Recorded Off Azheekode, (10^0 11 02$'$N & 76^0 09 22$'$E) during pre monsoon 2007-08 and also collected from sediments Off Azheekode and Balathuruthu estuary, (11^0 07 50$'$N & 75^0 49 57$'$E).

Family Cymbellaceae

Cymbella tumida Van Heurck

Van Heurck, 1880, p. 64, pl. 1, fig.41; Hustedt, 1930, p.366; Jin Dexiang et al., 1985, p. 155, pl.45, figs. 481-82.

Valves bilaterally asymmetrical, dorsal margin convex and ventral margin straight or rather convex in the middle. Apices elongated, rostrate and truncate. Raphe arcuate. Axial area narrow, central area distinctly dilated. Ventral side with a free stigma, opposite to the central nodule. Striae radial.

Dimension: Length 50-89μ, breadth 18-21μ.

Distribution: Common freshwater species of Japan, Mangolia, Australia and China. Recorded from Kavanad estuary (8^0 55 55$'$N & 76^0 33 37$'$E) during pre monsoon 2006-07, and Off Kodikkal (11^0 28 43$'$N & 75^0 36 10$'$E) during the monsoon 2006-07.

Amphora angusta Gregory

Gregory, 1857, p. 510, pl. 12, fig. 66; A. Schmidt, 1878, pl. 25, figs.14-15; Simonsen, 1974, p.44; Jin Dexiang, 1985, p. 148, pl. 44, fig. 454.

Valves narrow, semi-navicular, with acute round apices. Dorsal margin convex, ventral margin straight with a narrow ventral side. Raphe straight, near the valve margin. Axial and central areas distinct, conspicuously broader on dorsal side and narrower on ventral side. Fine striae 17-19 in 10μ.

Dimension: Length 40-61μ, breadth 7-11μ.

Distribution: Cosmopolitan benthic species, marine, also in fossil; British and Chinese coasts. Recorded as planktonic and benthic Off Azheekode, (10^0 11 02$'$N & 76^0 09 22$'$E) during monsoon 2006-07, as planktonic Off Kodikkal (11^0 28 43$'$N & 75^0 36 10$'$E) during the pre monsoon 2006-07.

Amphora turgida Gregory

Gregory, 1857, p. 510, pl. 12, fig. 63; Hendey, 1964, p. 264.

Frustules small, broadly elliptical to orbicular. Valve almost hemi-cyclical, apices rostrated and curved to the dorsal side. Dorsal side broad, arcuate margin with a distinct longitudinal line crossing the transverse striae and ventrally straight. Raphe close to the ventral margin. Valve surface indistinctly striate.

Dimension: Length 17-36μ, breadth 7-9μ.

Distribution: Neritic; British coasts. Recorded Off Punnapra (9^0 25 23$'$N & 76^0 19 41$'$E) during monsoon 2006-07 and post monsoon 2006-07 and also collected from the sediments along the southwest coast of India during the present investigation.

Amphora exigua Gregory

Hendey, 1964, p. 266; Jin Dexiang, 1985, p. 153, pl. 45, fig. 474.

Frustules small linear elliptical, narrow with obtuse or truncate ends. Girdle complex, with usually eight divisions. Valves sub-lunate, with arcuate dorsal and straight ventral margin, apices rostrate-capitate. Raphe very close to the ventral margin, straight, slightly bent near the apices,

Dimension: Length 24-37μ, breadth 5-6μ.

Distribution: widespread in British coasts, West Indies, US coasts. Recorded from Mahe estuary (11^0 42 18'N & 75^0 32 36'E) during post monsoon 2006-07.

Sub order S**urirellineae**
Family **Bacillariaceae**

Nitzschia constricta (Gregory) Grunow

Grunow, 1880, p. 71; Jin Dexiang et al., 1985, p. 191, pl. 56, figs. 672-673

Cells shorter, panduriform. Valves linear elliptical, with a slight constriction in the middle, dividing the valve into two tongue-shaped segments, apices slightly produced broad cuneate. Margin with strongly marked keel. Longitudinal fold and keel puncta indistinct.

Dimension: Length 22-50μ, breadth 8μ.

Distribution: Marine benthic; Recorded from, France, England, Scotland, Germany, Taiwan and China. Recorded Off Azheekode, (10^0 11 02'N & 76^0 09 22'E) during post monsoon 2007-08.

Nitzschia tryblionella Hantzsch

Hendey, 1964, p. 276, pl. 44, figs. 2-3; Jin Dexiang et al., 1985, p. 194, pl. 57, fig. 687.

Syn:*Tryblionella gracilis* W. Smith; ***Tryblionella hantzschiana*** Grunow.

Valves navicular with acute apices. Valve surface with a distinct median broad, longitudinal fold strongly marked and restricted to the marginal zones of the valve. Keel marginal. Valve surface very finely striate, punctate, 30-35 in 10μ.

Dimension: Length 42μ, breadth 14μ.

Distribution: British coasts, European coasts and Chinese coasts. Recorded from Balathuruthu estuary, (11^0 07 50'N & 75^0 49 57'E) during post monsoon 2007-08. Frequently found in the sediments along southwest coast of India during the present study.

Family **Surirellaceae**

Surirella striatula Turpin

Hendey, 1964, p. 288, pl. 40, figs. 2-3

Cells solitary. Valves broadly ovate. Central area linear lanceolate bearing scattered punctae. Axial area linear lanceolate. Valve surface faintly striate. Marginal wings robust with 8-15 canaliculi to the centre of the valve. Size variable.

Dimension: Length 120-126μ, breadth 50-68μ.

Distribution: Brackish water; English Channel. Recorded as planktonic and benthic Off Azheekode, (10^0 11 02'N & 76^0 09 22'E) during pre monsoon and monsoon 2006-07 and as planktonic from Mahe estuary (11^0 42 18'N & 75^0 32 36'E) during pre monsoon 2007-08.

Annexure - 2

List of toxic microalgal species

1	*Amphora coffeaeformis (Agardh)* Kutzing.	7	*Dinophysis tripos* Gourret
2	*Coolia monotis* Meunier	8	*Gonyalux monilatum* (Howell) Taylor
3	*Dinophysis acuminata* Claparède and Lachmann	9	*Microcystis aeruginosa* Kutzing
4	*Dinophysis caudata* Saville-Kent	10	*Prorocentrum lima* Ehrenberg
5	*Dinophysis fortii* Pavillard	11	*Pseudonitzschia seriata* (Cleve) Peragallo
6	*Dinophysis miles* Cleve		

Annexure- 3

Microalgae from coastal and estuarine stations

	Class: Cyanophyceae	14	*Euastrum ansatum*
1	*Aphanocapsa littoralis*	15	*Euastrum didelta*
2	*Aphanocapsa pulchra*	16	*Gleobotrys limnetica*
3	*Chamaesiphon sideriphilus*	17	*Kirchneriella lunaris*
4	*Chroococcus turgidus*	18	*Micrasterias americana*
5	*Gloeothece rupestris*	19	*Micrasterias foliacea*
6	*Lyngbya aestuarii*	20	*Onychonema laeve*
7	*Lyngbya majuscula*	21	*Pediastrum biradiatum*
8	*Merismopedia glauca*	22	*Pediastrum tetras*
9	*Microcystis aeruginosa*	23	*Phacus suecicus*
10	*Microcystis pulverea*	24	*Scenedesmus armatus*
11	*Oscillatoria brevis*	25	*Scenedesmus dimorphus*
12	*Oscilllatoria chalybea*	26	*Scenedesmus quadricauda*
13	*Oscillatoria formosa*	27	*Selenastrum gracile*
14	*Phormidium valderianum*	28	*Sphaerozosma aubertianum*
	Class: Chlorophyceae	29	*Sphaerozosma granulatum*
1	*Ankistrodesmus spiralis*	30	*Sphaerozosma sp*
2	*Arthrodesmus convergens*	31	*Spondylosium moniliforme*
3	*Chlorosarcina minor*	32	*Staurastrum asteroideum.*
4	*Closterium cynthia*	33	*Staurastrum chaetoceras*
5	*Closterium kutzingii*	34	*Staurastrum cuspidatum*
6	*Closterium sp*	35	*Staurastrum glabrum*
7	*Coelastrum cambricum*	36	*Staurastrum gracile*
8	*Coelastrum sphaericum*	37	*Staurastrum leptocladium*
9	*Cosmarium portianum*	38	*Tetraedron hastatum*
10	*Cosmarium quadrum*	39	*Tetraedron trigonum*
11	*Cosmarium reneforme*	40	*Ulothrix zonata*
12	*Cosmarium sp* Ralfs	41	*Xanthidium antilopaeum*
13	*Dimorphococcus lunatus*	42	*Xanthidium cristatum*

Class: Bacillariophyceae			
1	*Achnanthes coarctata var. parallela*	48	*Coscinodiscus centralis*
2	*Achnanthes brevipes*	49	*Coscinodiscus curvatulus*
3	*Achnanthes hauckiana*	50	*Coscinodiscus eccentricus*
4	*Achnanthes longipes*	51	*Coscinodiscus granii*
5	*Amphiprora alata*	52	*Coscinodiscus lineatus*
6	*Amphiprora gigantea var. sulcata*	53	*Coscinodiscus marginatus*
7	*Amphora angusta*	54	*Coscinodiscus nitidus*
8	*Amphora coffeaeformis*	55	*Coscinodiscus radiatus*
9	*Amphora exigua*	56	*Coscinodiscus rothii*
10	*Amphora turgida*	57	*Coscinodiscus subtlis*
11	*Asterionella japonica*	58	*Cyclotella striata*
12	*Asteromphalus flabellatus*	59	*Cylindrotheca gracilis*
13	*Aulacodiscus orbiculatus*	60	*Cymbella hustedtii*
14	*Bacillaria paradoxa*	61	*Cymbella tumida*
15	*Bacteriastrum comosum*	62	*Diploneis bombus*
16	*Bacteriastrum hyalinum*	63	*Diploneis dydima*
17	*Bacteriastrum varians*	64	*Diploneis elliptica*
18	*Biddulphia aurita*	65	*Diploneis notabilis*
19	*Biddulphia heteroceros*	66	*Diploneis ovalis*
20	*Biddulphia longicruris*	67	*Diploneis smithii*
21	*Biddulphia mobilensis*	68	*Diploneis splendida*
22	*Biddulphia regia*	69	*Ditylum brightwelli*
23	*Biddulphia reticulata*	70	*Ditylum sol*
24	*Biddulphia rhombus*	71	*Eucampia cornuta*
25	*Biddulphia sinensis*	72	*Eucampia zodiacus*
26	*Caloneis brevis*	73	*Fragilaria oceanica*
27	*Caloneis madraspatensis*	74	*Grammatophora marina*
28	*Calonies permagna*	75	*Grammatophora serpentina*
29	*Caloneis westii*	76	*Grammatophora undulata*
30	*Campylodiscus ecclesianus*	77	*Guinardia flaccida*
31	*Campylodiscus hodgsonii*	78	*Gyrosigma balticum*
32	*Cerataulina bicornis*	79	*Gyrosigma fasciola*
33	*Cerataulus turgidus*	80	*Gyrosigma hippocampus*
34	*Chaetoceros affinis*	81	*Gyrosigma nodiferum*
35	*Chaetoceros breve*	82	*Gyrosigma spencerii*
36	*Chaetoceros constrictus*	83	*Gyrosigma tenuissimum*
37	*Chaetoceros curvisetus*	84	*Hantzschia amphioxys*
38	*Chaetoceros decipiens*	85	*Hantzschia marina*
39	*Chaetoceros didymus*	86	*Lauderia annulata*
40	*Chaetoceros lorenzianus*	87	*Leptocylindrus danicus*
41	*Chaetoceros socialis*	88	*Leptocylindrus minimus*
42	*Chaetoceros teres*	89	*Licmophora flabellata*
43	*Cheatoceros danicus*	90	*Licmophora juergensii*
44	*Cocconeis placentula var. euglypta*	91	*Mastogloia braunii*
45	*Corethron criophilum*	92	*Mastogloia cochinensis*
46	*Corethron inerme*	93	*Mastogloia dolosa*
47	*Coscinodiscus asteromphalus*	94	*Mastogloia exigua*

95	*Mastogloia lanceolata*	136	*Pleurosigma attenuatum*
96	*Melosira numuloides*	137	*Pleurosigma elongatum*
97	*Melosira sulcata*	138	*Pleurosigma falx*
98	*Navicula bicapitata*	139	*Pleurosigma intermedium*
99	*Navicula cincta*	140	*Pleurosigma naviculaceum*
100	*Navicula digito-radiata*	141	*Pleurosigma normanii*
101	*Navicula distans*	142	*Pleurosigma strigosum*
102	*Navicula elegans*	143	*Podosira montagnei*
103	*Navicula forcipata*	144	*Proboscia alata*
104	*Navicula granulata*	145	*Pseudonitzschia seriata*
105	*Navicula halophila*	146	*Rhaphoneis amphiceros*
106	*Navicula hasta*	147	*Rhizosolenia borealis*
107	*Navicula henneidyi*	148	*Rhizosolenia castracanei*
108	*Navicula humerosa*	149	*Rhizosolenia hebetata*
109	*Navicula inclementis*	150	*Rhizosolenia imbricata*
110	*Navicula longa*	151	*Rhizosolenia robusta*
111	*Navicula lyra*	152	*Rhizosolenia setigera*
112	*Navicula maculosa*	153	*Rhizosolenia stolterfothii*
113	*Navicula marina*	154	*Rhozosolenia styliformis*
114	*Navicula mutica*	155	*Skeletonema costatum*
115	*Navicula perigrina*	156	*Stephanopyxis turris*
116	*Navicula pygmoea*	157	*Surirella fastuosa*
117	*Navicula rhombica*	158	*Surirella flumiensis*
118	*Navicula spectabilis*	159	*Surirella neumeyeri*
119	*Navicula tuscula*	160	*Surirella ovalis*
120	*Nitzschia closterium*	161	*Surirella striatula*
121	*Nitzschia constricta*	162	*Synedra ulna*
122	*Nitzschia frustulum*	163	*Thalassionema bacillare*
123	*Nitzschia longissima*	164	*Thalassionema frauenfeldii*
124	*Nitzschia lorenziana*	165	*Thalassionema nitzschioides*
125	*Nitzschia paduriformis*	166	*Thalassiosira coramandeliana*
126	*Nitzschia paduriformis*var *minor*	167	*Thalassiosira decipiens*
127	*Nitzschia paleacea*	168	*Thalassiosira nordenskioldii*
128	*Nitzschia sigma*	169	*Thalassiosira subtilis*
129	*Nitzschia tribionella*	170	*Trachyneis aspera*
130	*Paralia sulcata*	171	*Triceratium affine*
131	*Planktoniella sol*	172	*Triceratium dubium*
132	*Pleurosigma acuminatum*	173	*Triceratium favus*
133	*Pleurosigma aestuarii*	174	*Tropidoneis longa*
134	*Pleurosigma angulatum*	175	*Tropidonies leptidoptera*
135	*Pleurosigma angulatum var. strigosum*		
Class: Dinophyceae			
1	*Alexandrium affine*	7	*Ceratium gibberum*
2	*Alexandrium sp.*	8	*Ceratium horridium*
3	*Ceartium pentagonum*	9	*Ceratium kofoidii*
4	*Ceratium concilians*	10	*Ceratium symmetricum*
5	*Ceratium furca*	11	*Ceratium trichoceros*
6	*Ceratium fusus*	12	*Ceratium tripos*

13	*Ceratium vultur*	31	*Prorocentrum micans*
14	*Coolia monotis*	32	*Protoperidinium assymmetricum*
15	*Diniphysis caudata*	33	*Protoperidinium brochii*
16	*Diniphysis caudata* f *acutiformis*	34	*Protoperidinium compressum*
17	*Dinophysis acuminata*	35	*Protoperidinium granii*
18	*Dinophysis odiosa*	36	*Protoperidinium leonis*
19	*Dinophysis miles*	37	*Protoperidinium mediterraneum*
20	*Dinophysis ovum*	38	*Protoperidinium minor*
21	*Dinophysis fortii*	39	*Protoperidinium oblongum*
22	*Dinophysis tripos*	40	*Protoperidinium obovatum*
23	*Diplopsalis lenticula*	41	*Protoperidinium oceanicum*
24	*Goniodoma sphaericum*	42	*Protoperidinium pellucidum*
25	*Gonyalux moniliana*	43	*Protoperidinium steinii*
26	*Noctiluca miliaris*	44	*Protopridinium conicum*
27	*Prorocentrum arcuatum*	45	*Protperidimuim cerasus*
28	*Prorocentrum compressum*	46	*Protperidimuim minutum*
29	*Prorocentrum gracile*	47	*Pyrophacus horologium*
30	*Prorocentrum lima*	48	*Pyrophacus steinii*
Dictyochophyceae			
1	*Dictyocha crux* Ehrenberg	3	*Dictyocha octonaria* (Ehr.) Hovass
2	*Dictyocha fibula* Ehrenberg		
Class: Chrysophyceae			
1	*Dinobryon belgica* Meunier		
Coccolithophores			
1	*Syracosphaera sp* Lohmann		

Annexure - 4

Microalgae from FORV Sagar Sampada cruises

Class: Bacillariophyceae			
1	*Achnanthes coarctata*	14	*Navicula distans*
2	*Asterionella japonica*	15	*Navicula hsata*
3	*Biddulphia mobilensis*	16	*Navicula marina*
4	*Campylodiscus iyengarii*	17	*Nitzschia paleacea*
5	*Chaetoceros diversus*	18	*Planktoniella sol*
6	*Chaetoceros pseudocurvisatus*	19	*Proboscia alata*
7	*Coscinodiscus curvatulus*	20	*Pseudosoleinia calcar avis*
8	*Coscinodiscus marginatus*	21	*Rhizosolenia bergonii*
9	*Coscinodiscus radiatus*	22	*Rhizosolenia hebetata*
10	*Cyclotella meneghiniana*	23	*Synedra ulna*
11	*Cyclotella stylorum*	24	*Thalassiosira australis*
12	*Ditylum sol*	25	*Thalassiosira eccentrica*
13	*Eucampia zodiacus*	26	*Thalassiosira simensonii*
		27	*Thalassiosira subtilis*

Class: Dinophyceae			
1	*Alexandrium sp*	16	*Gymnodinium heterostriatum*
2	*Ceratium arietinum*	17	*Gymnodinium sp.*
3	*Ceratium candelabrum* var. *depressum*	18	*Noctiluca miliaris*
4	*Ceratium contortum*	19	*Ornithocercus magnificus*
5	*Ceratium furca*	20	*Ornithocercus steinii*
6	*Ceratium fusus*	21	*Prorocentrum micans*
7	*Ceratium pentagonum*	22	*Protoperidinium brevipes*
8	*Ceratium trichoceros*	23	*Protoperidinium depressum*
9	*Ceratium tripos*	24	*Protoperidinium murrayi*
10	*Corythodinium tesselatum*	25	*Protoperidinium oceanicum*
11	*Dinophysis caudata*	26	*Protoperidinium ovatum*
12	*Dinophysis fortii*	27	*Protoperidinium pellucidum*
13	*Dinophysis hastata*	28	*Protoperidinium pyriforme*
14	*Diplopeltopsis minor*	29	*Pyrophacus horologium*
15	*Diplopsalis lenticula*	30	*Pyrophacus steinii*

Annexure - 5

Planktonic microalgae from all the stations

Class: Cyanophyceae			
1	*Aphanocapsa littoralis*	8	*Merismopedia glauca*
2	*Aphanocapsa pulchra*	9	*Microcystis aeruginosa*
3	*Chamaesiphon sideriphilus*	10	*Microcystis pulverea*
4	*Chroococcus turgidus*	11	*Oscillatoria brevis*
5	*Gloeothece rupestris*	12	*Oscilllatoria chalybea*
6	*Lyngbya aestuarii*	13	*Oscillatoria formosa*
7	*Lyngbya majuscula*	14	*Phormidium valderianum*
Class: Chlorophyceae			
1	*Ankistrodesmus spiralis*	17	*Kirchneriella lunaris*
2	*Arthrodesmus convergens*	18	*Micrasterias americana*
3	*Chlorosarcina minor*	19	*Micrasterias foliacea*
4	*Closterium cynthia*	20	*Onychonema laeve*
5	*Closterium kutzingii*	21	*Pediastrum biradiatum*
6	*Closterium sp*	22	*Pediastrum tetras*
7	*Coelastrum cambricum*	23	*Phacus suecicus*
8	*Coelastrum sphaericum*	24	*Scenedesmus armatus*
9	*Cosmarium portianum*	25	*Scenedesmus dimorphus*
10	*Cosmarium quadrum*	26	*Scenedesmus quadricauda*
11	*Cosmarium reneforme*	27	*Selenastrum gracile*
12	*Cosmarium sp* Ralfs	28	*Sphaerozosma aubertianum*
13	*Dimorphococcus lunatus*	29	*Sphaerozosma granulatum*
14	*Euastrum ansatum*	30	*Sphaerozosma sp*
15	*Euastrum didelta*	31	*Spondylosium moniliforme*
16	*Gleobotrys limnetica*	32	*Staurastrum asteroideum.*

33	*Staurastrum chaetoceras*	39	*Tetraedron trigonum*
34	*Staurastrum cuspidatum*	40	*Ulothrix zonata*
35	*Staurastrum glabrum*	41	*Xanthidium antilopaeum*
36	*Staurastrum gracile*	42	*Xanthidium cristatum*
37	*Staurastrum leptocladium*	43	*Xanthidium sp*
38	*Tetraedron hastatum*		
Class: Bacillariophyceae			
1	*Achnanthes coarctata var. parallela*	42	*Chaetoceros lorenzianus*
2	*Achnanthes brevipes*	43	*Chaetoceros pseudocurvisatus*
3	*Achnanthes hauckiana*	44	*Chaetoceros socialis*
4	*Achnanthes longipes*	45	*Chaetoceros teres*
5	*Amphiprora alata*	46	*Cheatoceros danicus*
6	*Amphiprora gigantea var. sulcata*	47	*Cocconeis placentula var. euglypta*
7	*Amphora angusta*	48	*Corethron criophilum*
8	*Amphora coffeaeformis*	49	*Corethron inerme*
9	*Amphora exigua*	50	*Coscinodiscus asteromphalus*
10	*Amphora turgida*	51	*Coscinodiscus centralis*
11	*Asterionella japonica*	52	*Coscinodiscus curvatulus*
12	*Asteromphalus flabellatus*	53	*Coscinodiscus eccentricus*
13	*Aulacodiscus orbiculatus*	54	*Coscinodiscus granii*
14	*Bacillaria paradoxa*	55	*Coscinodiscus lineatus*
15	*Bacteriastrum comosum*	56	*Coscinodiscus marginatus*
16	*Bacteriastrum hyalinum*	57	*Coscinodiscus nitidus*
17	*Bacteriastrum varians*	58	*Coscinodiscus radiatus*
18	*Biddulphia aurita*	59	*Coscinodiscus rothii*
19	*Biddulphia heteroceros*	60	*Coscinodiscus subtlis*
20	*Biddulphia longicruris*	61	*Cyclotella meneghiniana*
21	*Biddulphia mobilensis*	62	*Cyclotella striata*
22	*Biddulphia regia*	63	*Cyclotella stylorum*
23	*Biddulphia reticulata*	64	*Cylindrotheca gracilis*
24	*Biddulphia rhombus*	65	*Cymbella hustedtii*
25	*Biddulphia sinensis*	66	*Cymbella tumida*
26	*Caloneis brevis*	67	*Diploneis bombus*
27	*Caloneis madraspatensis*	68	*Diploneis dydima*
28	*Caloneis westii*	69	*Diploneis elliptica*
29	*Calonies permagna*	70	*Diploneis notabilis*
30	*Campylodiscus ecclesianus*	71	*Diploneis ovalis*
31	*Campylodiscus hodgsonii*	72	*Diploneis smithii*
32	*Campylodiscus iyengarii*	73	*Diploneis splendida*
33	*Cerataulina bicornis*	74	*Ditylum brightwelli*
34	*Cerataulus turgidus*	75	*Ditylum sol*
35	*Chaetoceros affinis*	76	*Eucampia cornuta*
36	*Chaetoceros breve*	77	*Eucampia zodiacus*
37	*Chaetoceros constrictus*	78	*Fragilaria oceanica*
38	*Chaetoceros curvisetus*	79	*Grammatophora marina*
39	*Chaetoceros decipiens*	80	*Grammatophora serpentina*
40	*Chaetoceros didymus*	81	*Grammatophora undulata*
41	*Chaetoceros diversus*	82	*Guinardia flaccida*

83	*Gyrosigma balticum*	130	*Nitzschia paduriformis*
84	*Gyrosigma fasciola*	131	*Nitzschia paduriformis*var *minor*
85	*Gyrosigma hippocampus*	132	*Nitzschia paleacea*
86	*Gyrosigma nodiferum*	133	*Nitzschia sigma*
87	*Gyrosigma spencerii*	134	*Nitzschia tribionella*
88	*Gyrosigma tenuissimum*	135	*Paralia sulcata*
89	*Hantzschia amphioxys*	136	*Planktoniella sol*
90	*Hantzschia marina*	137	*Pleurosigma acuminatum*
91	*Lauderia annulata*	138	*Pleurosigma aestuarii*
92	*Leptocylindrus danicus*	139	*Pleurosigma angulatum*
93	*Leptocylindrus minimus*	140	*Pleurosigma angulatum var. strigosum*
94	*Licmophora flabellata*	141	*Pleurosigma attenuatum*
95	*Licmophora juergensii*	142	*Pleurosigma elongatum*
96	*Mastogloia braunii*	143	*Pleurosigma falx*
97	*Mastogloia cochinensis*	144	*Pleurosigma intermedium*
98	*Mastogloia dolosa*	145	*Pleurosigma naviculaceum*
99	*Mastogloia exigua*	146	*Pleurosigma normanii*
100	*Mastogloia lanceolata*	147	*Pleurosigma strigosum*
101	*Melosira numuloides*	148	*Podosira montagnei*
102	*Melosira sulcata*	149	*Proboscia alata*
103	*Navicula bicapitata*	150	*Pseudonitzschia seriata*
104	*Navicula cincta*	151	*Pseudosoleinia calcar avis*
105	*Navicula digito-radiata*	152	*Rhaphoneis amphiceros*
106	*Navicula distans*	153	*Rhizosolenia bergonii*
107	*Navicula elegans*	154	*Rhizosolenia borealis*
108	*Navicula forcipata*	155	*Rhizosolenia castracanei*
109	*Navicula granulata*	156	*Rhizosolenia hebetata*
110	*Navicula halophila*	157	*Rhizosolenia imbricata*
111	*Navicula hasta*	158	*Rhizosolenia robusta*
112	*Navicula henneidyi*	159	*Rhizosolenia setigera*
113	*Navicula humerosa*	160	*Rhizosolenia stolterfothii*
114	*Navicula inclementis*	161	*Rhozosolenia styliformis*
115	*Navicula longa*	162	*Skeletonema costatum*
116	*Navicula lyra*	163	*Stephanopyxis turris*
117	*Navicula maculosa*	164	*Surirella fastuosa*
118	*Navicula marina*	165	*Surirella flumiensis*
119	*Navicula mutica*	166	*Surirella neumeyeri*
120	*Navicula perigrina*	167	*Surirella ovalis*
121	*Navicula pygmoea*	168	*Surirella striatula*
122	*Navicula rhombica*	169	*Synedra ulna*
123	*Navicula spectabilis*	170	*Thalassionema bacillare*
124	*Navicula tuscula*	171	*Thalassionema frauenfeldii*
125	*Nitzschia closterium*	172	*Thalassionema nitzschioides*
126	*Nitzschia constricta*	173	*Thalassiosira australis*
127	*Nitzschia frustulum*	174	*Thalassiosira coramandeliana*
128	*Nitzschia longissima*	175	*Thalassiosira decipiens*
129	*Nitzschia lorenziana*	176	*Thalassiosira eccentrica*

177	*Thalassiosira nordenskioldii*	182	*Triceratium dubium*
178	*Thalassiosira simensonii*	183	*Triceratium favus*
179	*Thalassiosira subtilis*	184	*Tropidoneis longa*
180	*Trachyneis aspera*	185	*Tropidonies sp*
181	*Triceratium affine*		
Class: Dinophyceae			
1	*Alexandrium affine*	29	*Diplopeltopsis minor*
2	*Alexandrium sp.*	30	*Diplopsalis lenticula*
3	*Ceratium arietinum*	31	*Goniodoma sphaericum*
4	*Ceratium candelabrum* var. *depressum*	32	*Gonyalux moniliana*
5	*Ceratium concilians*	33	*Gymnodinium heterostriatum*
6	*Ceratium contortum*	34	*Gymnodinium sp.*
7	*Ceratium furca*	35	*Noctiluca miliaris*
8	*Ceratium fusus*	36	*Ornithocercus magnificus*
9	*Ceratium gibberum*	37	*Ornithocercus steinii*
10	*Ceratium horridium*	38	*Prorocentrum arcuatum*
11	*Ceratium kofoidii*	39	*Prorocentrum compressum*
12	*Ceratium pentagonum*	40	*Prorocentrum gracile*
13	*Ceratium symmetricum*	41	*Prorocentrum lima*
14	*Ceratium trichoceros*	42	*Prorocentrum micans*
15	*Ceratium tripos*	43	*Protoperidinium assymmetricum*
16	*Ceratium vultur*	44	*Protoperidinium brevipes*
17	*Coolia monotis*	45	*Protoperidinium brochii*
18	*Corythodinium tesselatum*	46	*Protoperidinium compressum*
19	*Diniphysis caudata*	47	*Protoperidinium depressum*
20	*Diniphysis caudata* f *acutiformis*	48	*Protoperidinium granii*
21	*Dinophysis acuminata*	49	*Protoperidinium leonis*
22	*Dinophysis fortii*	50	*Protoperidinium mediterraneum*
23	*Dinophysis hastata*	51	*Protoperidinium minor*
24	*Dinophysis miles*	52	*Protoperidinium murrayi*
25	*Dinophysis odiosa*	53	*Protoperidinium oblongum*
26	*Dinophysis ovum*	54	*Protoperidinium obovatum*
27	*Dinophysis sp*	55	*Protoperidinium oceanicum*
28	*Dinophysis tripos*	56	*Protoperidinium ovatum*
29	*Diplopeltopsis minor*	57	*Protoperidinium pellucidum*
30	*Diplopsalis lenticula*	58	*Protoperidinium pyriforme*
24	*Dinophysis miles*	59	*Protoperidinium steinii*
25	*Dinophysis odiosa*	60	*Protopridinium conicum*
26	*Dinophysis ovum*	61	*Protperidimuim cerasus*
27	*Dinophysis sp*	62	*Protperidimuim minutum*
28	*Dinophysis tripos*	63	*Pyrophacus horologium*
		64	*Pyrophacus steinii*

Dictyochophyceae			
1	*Dictyocha crux* Ehrenberg	3	*Dictyocha octonaria* (Ehr.) Hovass.
2	*Dictyocha fibula* Ehrenberg		
Class: Chrysophyceae			
1	*Dinobryon belgica* Meunier		
	Coccolithophores		
1	*Syracosphaera sp* Lohmann		

Annexure - 6

List of microphytobenthos

Class: Cyanophyceae			
1	*Chroococcus turgidus*	3	*Merismopdia elegans*
2	*Lyngbya aestuarii*	4	*Oscilllatoria chalybea*
Class: Bacillariophyceae			
1	*Achnanthes brevipes*	25	*Navicula directa var. remota*
2	*Achnanthes coarctata var. parallela*	26	*Navicula elegans*
3	*Amphora angusta*	27	*Navicula forcipata*
4	*Amphora coffeaeformis*	28	*Navicula hennedyei*
5	*Amphora turgida*	29	*Navicula humerosa*
6	*Aulacodiscus orbiculatus*	30	*Navicula inclementis*
7	*Biddulphia mobiliensis*	31	*Navicula monilifera*
8	*Caloneis permagna*	32	*Navicula spectabilis*
9	*Cocconeis littoralis*	33	*Nitzschia closterium*
10	*Cocconeis placentula*	34	*Nitzschia frustulum*
11	*Cocconeis scutellum*	35	*Nitzschia longissima*
12	*Cocconeis sigmoides*	36	*Nitzschia panduriformis*
13	*Coscinodiscus asteromphalus*	37	*Nitzschia tribionella*
14	*Coscinodiscus marginatus*	38	*Nitzschia sigma*
15	*Cymbella aspera*	39	*Pleurosigma acuminatum*
16	*Cymbella marina*	40	*Pleurosigma aestuarii*
17	*Diploneis littoralis*	41	*Pleurosigma angulatum*
18	*Diploneis notabilis*	42	*Pleurosigma falx*
19	*Diploneis weissflogii*	43	*Pleurosigma naviculaceum*
20	*Gyrosigma hippocampus*	44	*Surirella fastuosa*
21	*Gyrosigma nodiferum*	45	*Surirella flumiensis*
22	*Gyrosigma spencerii*	46	*Surirella ovalis*
23	*Licmophora flabellata*	47	*Surirella striatula*
24	*Navicula cincta*	48	*Thalassiosira coramandeliana*
Class: Dinophyceae			
1	*Ceratium furca*	3	*Protperidimuim cerasus*
2	*Ceratium symmetricum*		

Annexure - 7

Tycho-pelagic diatoms

Class: Cyanophyceae			
1	*Achnanthes brevipes*	22	*Navicula inclementis*
2	*Achnanthes coarctata var. parallela*	23	*Navicula monilifera*
3	*Amphora angusta*	24	*Navicula spectabilis*
4	*Amphora coffeaeformis*	25	*Nitzschia closterium*
5	*Amphora turgida*	26	*Nitzschia frustulum*
6	*Aulacodiscus orbiculatus*	27	*Nitzschia longissima*
7	*Biddulphia mobiliensis*	28	*Nitzschia panduriformis*
8	*Caloneis permagna*	29	*Nitzschia tribionella*
9	*Cocconeis placentula*	30	*Nitzschia sigma*
10	*Coscinodiscus asteromphalus*	31	*Pleurosigma acuminatum*
11	*Coscinodiscus marginatus*	32	*Pleurosigma aestuarii*
12	*Diploneis notabilis*	33	*Pleurosigma angulatum*
13	*Gyrosigma hippocampus*	34	*Pleurosigma falx*
14	*Gyrosigma nodiferum*	35	*Pleurosigma naviculaceum*
15	*Gyrosigma spencerii*	36	*Surirella fastuosa*
16	*Licmophora flabellata*	37	*Surirella flumiensis*
17	*Navicula cincta*	38	*Surirella ovalis*
19	*Navicula elegans*	39	*Surirella striatula*
20	*Navicula hennedyei*	40	*Thalassiosira coramandeliana*
21	*Navicula humerosa*		

Annexure - 8

List of microalgae (Benthic & Planktonic)

Class: Cyanophyceae			
1	*Aphanocapsa littoralis* Hansg	8	*Merismopedia glauca* Ehrenberg
2	*Aphanocapsa pulchra* (Kutz.) Raben.	9	*Microcystis aeruginosa* Kutzing
3	*Chamaesiphon sideriphilus* Starmach	10	*Microcystis pulverea* (Wood) Forti
4	*Chroococcus turgidus* Kutzing	11	*Oscillatoria brevis* (Kutzing) Gomont
5	*Gloeothece rupestris* (Lyngbye) Born.	12	*Oscilllatoria chalybea*
6	*Lyngbya aestuarii*	13	*Oscillatoria formosa* Bory
7	*Lyngbya majuscula* Harvey	14	*Phormidium valderianum* Gomont
Class: Chlorophyceae			
1	*Ankistrodesmus spiralis* Turner Lemm	8	*Coelastrum sphaericum* Naegeli
2	*Arthrodesmus convergens* Ehrenberg	9	*Cosmarium portianum* Archer
3	*Chlorosarcina minor* Gerneck	10	*Cosmarium quadrum* Ralfs
4	*Closterium cynthia* Denot	11	*Cosmarium reneforme* (Ralfs) Archer
5	*Closterium kutzingii Brebisson*	12	*Cosmarium sp* Ralfs
6	*Closterium sp* Ralfs	13	*Dimorphococcus lunatus* A. Braun
7	*Coelastrum cambricum* Archer	14	*Euastrum ansatum* Ehrenberg

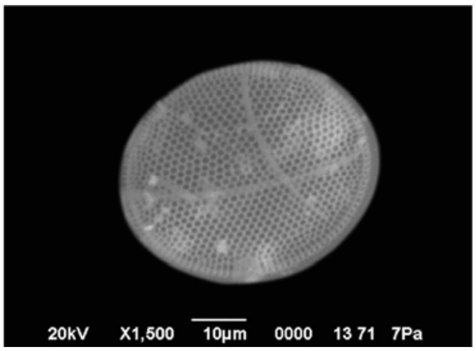
15	*Bacteriastrum comosum* Pavillard	30	*Sphaerozosma sp*
16	*Bacteriastrum hyalinum* Lauder	31	*Spondylosium moniliforme* Lundell
17	*Bacteriastrum varians* Lauder	32	*Staurastrum asteroideum.* J. Rzicka
18	*Biddulphia aurita* (Lyngbye) Brebisson.	33	*Staurastrum chaetoceras* (Shr.) Smith
19	*Biddulphia heteroceros* Grunow	34	*Staurastrum cuspidatum* Brebisson
20	*Biddulphia longicruris* Greville	35	*Staurastrum glabrum* (Ehr.) Ralfs
21	*Biddulphia mobiliensis* (Bailey) Grunow ex van Heurck.	36	*Staurastrum gracile* Ralfs
22	*Biddulphia pulchella*	37	*Staurastrum leptocladium* Nordstedt
23	*Phacus suecicus* Lemmermann	38	*Tetraedron hastatum* (Rein) Hansgirg
24	*Scenedesmus armatus* (Chodat) Smith	39	*Tetraedron trigonum* (Naeg.) Hans
25	*Scenedesmus dimorphus* (Tur.) Kutz.	40	*Ulothrix zonata* **(Web Mohr)** Kutzing
26	*Scenedesmus quadricauda* (Tur.) Breb	41	*Xanthidium antilopaeum* (Breb.) Kutz.
27	*Selenastrum gracile* Reinsch	42	*Xanthidium cristatum* Brebisson
28	*Sphaerozosma aubertianum* W. West	43	*Xanthidium sp* Ehrenberg Ex Ralfs
29	*Sphaerozosma granulatum* Roy Bisst		
Class: Chrysophyceae			
1	*Dinobryon belgica* Meunier		
Coccolithophores			
1	*Syracosphaera sp* Lohmann		
Class. Bacillariophyceae			
1	*Achnanthes brevipes* Agardh.	26	*Caloneis brevis* (Gregory) Cleve
2	*Achnanthes coarctata var. parallela* Venkataraman.	27	*Caloneis madraspatensis* Sub.
3	*Achnanthes hauckiana* Grunow	28	*Caloneis westii* (Smith) Hendey
4	*Achnanthes longipes* Agardh.	29	*Calonies permagna* (Bailey) Cleve
5	*Amphiprora alata* (Ehrenberg) Kutzing.	30	*Campylodiscus ecclesianus* Greville
6	*Amphiprora gigantea var. sulcata* Cleve.	31	*Campylodiscus hodgsonii* Smith
7	*Amphora angusta* Gregory	32	*Campylodiscus iyengarii* Sub.
8	*Amphora coffeaeformis* (Agar.) Kutzing.	33	*Cerataulina bicornis* (Ehre.) *Hasle.*
9	*Amphora exigua Gregory*	34	*Cerataulus turgidus* Ehrenberg
10	*Amphora turgida* Gregory	35	*Chaetoceros affinis* Lauder
11	*Asterionella japonica* Cleve	36	*Chaetoceros brevis* Schutt
12	*Asteromphalus flabellatus* (Breb.) Grev.	37	*Chaetoceros constrictus* Gran
13	*Aulacodiscus orbiculatus* Sub.	38	*Chaetoceros curvisetus* Cleve
14	*Bacillaria paradoxa* Gmeline	39	*Chaetoceros decipiens* Cleve
15	*Bacteriastrum comosum* Pavillard	40	*Chaetoceros didymus* Ehrenberg
16	*Bacteriastrum hyalinum* Lauder	41	*Chaetoceros diversus* Cleve
17	*Bacteriastrum varians* Lauder	42	*Chaetoceros lorezianus* Grunow
18	*Biddulphia aurita* (Lyngbye) Brebisson.	43	*Chaetoceros pseudocurvisatus* Mang.
19	*Biddulphia heteroceros* Grunow	44	*Chaetoceros socialis* Lauder
20	*Biddulphia longicruris* Greville	45	*Chaetoceros teres* Cleve
21	*Biddulphia mobiliensis* (Bailey) Grunow ex van Heurck.	46	*Cheatoceros danicus* Cleve
22	*Biddulphia pulchella*	47	*Cocconeis littoralis* Subrahmanyan
23	*Biddulphia regia* (Schultze) Ostenfeld	48	*Cocconeis placentula* Ehrenberg
24	*Biddulphia rhombus* (Ehr) W.Smith.	49	*Cocconeis placentula* var. *euglypta* Cl.
25	*Biddulphia sinensis* Greville	50	*Cocconeis scutellum* Ehrenberg

51	*Cocconeis sigmoides Subrahmanyan*	96	*Gyrosigma tenuissimum* (Sm.) GrHen.
52	*Corethron criophilum* Castracane	97	*Hantzschia amphioxys* Ehrenberg
53	*Corethron inerme* Karsten	98	*Hantzschia marina* (Donkin) Grunow
54	*Coscinodiscus asteromphalus*var.*centralis* Ehrenberg	99	*Lauderia annulata* Cleve
55	*Coscinodiscus centralis*Ehrenberg	100	*Leptocylindrus danicus* Cleve
56	*Coscinodiscus curvatulus* Grun Schmidt	101	*Leptocylindrus minimus* Gran
57	*Coscinodiscus eccentricus* Ehrenberg	102	*Licmophora flabellata* (Grev.) Agardh
58	*Coscinodiscus granii* var. *aralensis* (Ostenfeldt) Hustedt	103	*Licmophora juergensii* Agardh
59	*Coscinodiscus lineatus* Grunow	104	*Mastogloia braunii* Grunow
60	*Coscinodiscus marginatus* Ehrenberg	105	*Mastogloia cochinensis* Gopinathan
61	*Coscinodiscus nitidus* Gregory	106	*Mastogloia dolosa* Venkataraman
62	*Coscinodiscus radiatus* Ehrenberg	107	*Mastogloia exigua* Lewis
63	*Coscinodiscus rothii* (Ehr.) Grunow	108	*Mastogloia lanceolata* Thwaites
64	*Coscinodiscus subtlis* Ehrenberg	109	*Melosira numuloides* (Dill.) Agardh
65	*Cyclotella meneghiniana* Kutzing	110	*Melosira sulcata* (Ehrenberg) Kutzing
66	*Cyclotella striata* (Kutzing) Grunow	111	*Navicula bicapitata* Lagerstedt
67	*Cyclotella stylorum* Brightwell	112	*Navicula cinta* (Ehr.) Van Heurck
68	*Cylindrotheca gracilis* (Breb.) Grunow	113	*Navicula digito-radiata* (Greg.) Ralfs
69	*Cymbella aspera* (Ehrenberg) Cleve	114	*Navicula directa var. remota* Grunow
70	*Cymbella hustedtii* Krasske	115	*Navicula distans* W.Smith
71	*Cymbella marina* Castracane	116	*Navicula elegans* W. Smith
72	*Cymbella tumida* Van Heurck	117	*Navicula forcipata* Greville
73	*Diploneis bombus* Ehrenberg	118	*Navicula granulata* Bailey
74	*Diploneis dydima*(Ehrenberg) Cleve	119	*Navicula halophila* (Grunow) Cleve
75	*Diploneis elliptica* (Kutzing) Cleve	120	*Navicula hasta* Pantocsek
76	*Diploneis littoralis* (Donkin) Cleve	121	*Navicula hennedyii* Cleve
77	*Diploneis notabilis*(Greville) Cleve	122	*Navicula humerosa* (Brebi. W. Smith
78	*Diploneis ovalis*Cleve	123	*Navicula inclementis* Brockmann
79	*Diploneis smithii* (Brebisson) Cleve	124	*Navicula longa* (Gregory) Ralfs
80	*Diploneis splendida* (Gregory) Cleve	125	*Navicula lyra* Ehrenberg
81	*Diploneis weissflogii* (Schmidt) Cleve	126	*Navicula maculosa* Donkin
82	*Ditylum brightwelli* (West) Grunow	127	*Navicula marina* (Ralfs) Pritchard
83	*Ditylum sol* (Grunow) De Toni	128	*Navicula mutica* Kutzing
84	*Eucampia cornuta* (Cleve) Grunow	129	*Navicula peregrina* (Her.) Kutzing
85	*Eucampia zodiacus*Ehrenberg	130	*Navicula pygmoea* Kutzing
86	*Fragilaria oceanica* Cleve	131	*Navicula rhombica*
87	*Grammatophora marina*(Lyn.) Kutz.	132	*Navicula spectabilis* Gregory
88	*Grammatophora serpentina*(Ralfs in Pritchard) Ehrenberg	133	*Navicula tuscula*
89	*Grammatophora undulata* Ehrenberg	134	*Nitzschia closterium* (Ehr.) W. Smith
90	*Guinardia flaccida* (Castr.) Peragallo	135	*Nitzschia constricta* (Greg.) Grunow
91	*Gyrosigma balticum* (Ehr.) Rabenhors	136	*Nitzschia frustulum* (Kut.) Grunow
92	*Gyrosigma fasciola* (Ehr.) Griffith Henf.	137	*Nitzschia longissima* (Breb.) Ralfs
93	*Gyrosigma hippocampus* (Ehr.) Hass.	138	*Nitzschia lorenziana* Grunow
94	*Gyrosigma nodiferum* (Grun) G.West	139	*Nitzschia paduriformis* Gregory
95	*Gyrosigma spencerii* W. Smith	140	*Nitzschia paleacea* Grunow

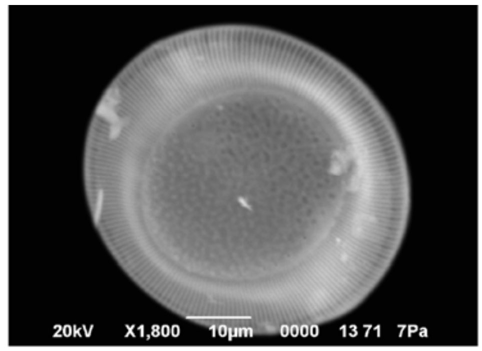
141	*Nitzschia sigma* (Kutzing) W.Smith	164	*Rhizosolenia hebetata* Bailey
142	*Nitzschia tryblionella* Hantzsch	165	*Rhizosolenia imbricata* Brightwell
143	*Paralia sulcata* (Ehrenberg) Cleve	166	*Rhizosolenia robusta* Nor. Pritchard
144	*Planktoniella sol* (Wallich) Schutt	167	*Rhizosolenia setigera* Brightwell
145	*Pleurosigma acuminatum* (Kutz.) Grun.	168	*Rhizosolenia stolterfothii* Peragallo
146	*Pleurosigma aestuarii* (Breb.) Smith	169	*Rhozosolenia styliformis* Brightwell
147	*Pleurosigma angulatum* (Que.) Smith	170	*Skeletonema costatum* (Grev.) Cleve
148	*Pleurosigma angulatum* var. *quadratum* (W. Smith) Van Heurck	171	*Stephanopyxis turris* (Greville) Ralfs
149	*Pleurosigma attenuatum* (Kutz.) Smith	172	*Surirella fastuosa* Ehrenberg
150	*Pleurosigma elongatum* W.Smith	173	*Surirella flumiensis* Grunow
151	*Pleurosigma falx* Mann	174	*Surirella neumeyeri* Janish
152	*Pleurosigma intermedium* W. Smith	175	*Surirella ovalis* Brebisson
153	*Pleurosigma naviculaceum* Brebisson	176	*Surirella striatula Turpin*
154	*Pleurosigma normanii* Ralfs	177	*Synedra ulna* Ehremberg
155	*Pleurosigma strigosum* W. Smith	178	*Thalassionema bacillare* Kolbe
156	*Podosira montagnei* Kutzing	179	*Thalassionema frauenfeldii* (Grun.) Hal.
157	*Proboscia alata* (Brightwell) Sundstrom	180	*Thalassionema nitzschioides* (Grun.) H.
158	*Pseudonitzschia seriata* (Cleve) Pera.	181	*Thalassiosira australis* Peragallo
159	*Pseudosolenia calcar-avis* Schultze	189	*Triceratium affine* Grunow
160	*Rhaphoneis amphiceros* Ehrenberg	190	*Triceratium dubium* Brightwell
161	*Rhizosolenia bergonii* Peragallo	191	*Triceratium favus* Ehrenberg
162	*Rhizosolenia borealis* Sundström	192	*Tropidonies lepidoptera* (Greg.) Cleve
163	*Rhizosolenia castracanei* Peragallo	193	*Tropidonies longa* Cleve
Class: Dinophyceae			
1	*Alexandrium affine* (Inoue & Fukuyo) Balech	20	*Dinophysis fortii* Pavillard
2	*Alexandrium sp* Halim	21	*Dinophysis acuminata* Clap & Lach.
3	*Ceartium pentagonum* Gourret	22	*Dinophysis caudata f. acutiformis* Kofoid & Skogsberg
4	*Ceratium arietinum* Cleve	23	*Dinophysis caudata* Saville-Kent
5	*Ceratium candelabrum* var. *depressum*	24	*Dinophysis hastata* Stein
6	*Ceratium concilians* Jorgensen	25	*Dinophysis miles* Cleve
7	*Ceratium contortum* (Gourret) Cleve	26	*Dinophysis odiosa* (Pavil.) Tai & Sko.
8	*Ceratium furca* (Ehr.) Clap & Lach.	27	*Dinophysis ovum* Schutt
9	*Ceratium fusus* (Ehr.) Dujardin	28	*Dinophysis tripos* Gourret
10	*Ceratium gibberum* Gourret	29	*Diplopeltopsis minor* Pavillard
11	*Ceratium horridium* (Cleve) Gran	30	*Diplopsalis lenticula* Bergh
12	*Ceratium kofoidii* Jorgensen	31	*Goniodoma sphaericum* Murray & Whitting
13	*Ceratium pentagonum*	32	*Gonyalux monilatum* (Howell) Taylor
14	*Ceratium symmetricum* Pavillard	33	*Gymnodinium sp.* Stein
15	*Ceratium trichoceros* (Ehrenberg) Kofoid	34	*Gymnodinium heterostriatum* Kofoid & Swezy
16	*Ceratium tripos* (Muller) Nitzsch	35	*Noctiluca miliaris* Suriray
17	*Ceratium vultur* Cleve	36	*Ornithocercus magnificus* Stein
18	*Coolia monotis* Meunier	37	*Ornithocercus steinii* Schutt
19	*Corythodinium tesselatum* (Stein)	38	*Prorocentrum arcuatum* Issel

39	*Prorocentrum compressum* Bailey	52	*Protoperidinium leonis* Pavillard
40	*Prorocentrum gracile* Schütt	53	*Protoperidinium mediterraneum* Kof.
41	*Prorocentrum lima* Ehrenberg	54	*Protoperidinium minor*
42	*Prorocentrum micans* Ehrenberg	55	*Protoperidinium murrayi* Kofoid
43	*Protoperidimuim cerasus* Paulsen	56	*Protoperidinium oblongum* Aurivillius
44	*Protoperidimuim minutum* Kofoid	57	*Protoperidinium obovatum* Wood
45	*Protoperidinium asymmetricum* Bal.	58	*Protoperidinium oceanicum* Van.
46	*Protoperidinium brevipes* Paulsen	59	*Protoperidinium ovatum* Pouchet
47	*Protoperidinium brochii* Kof. et Swezy	60	*Protoperidinium pellucidum* Schütt
48	*Protoperidinium compressum* Abe	61	*Protoperidinium pyriforme* Paulsen
49	*Protoperidinium conicum* Gran	62	*Protoperidinium steinii* Jørgensen
50	*Protoperidinium depressum* Baily	63	*Pyrophacus horologium* Stein
51	*Protoperidinium granii* Ostenfeld	64	*Pyrophacus steinii* (Sch.) Wall & Dale
Dictyochophyceae			
1	*Dictyocha crux* Ehrenberg	3	*Dictyocha octonaria* (Ehrenberg) Hovasse
2	*Dictyocha fibula* Ehrenberg		

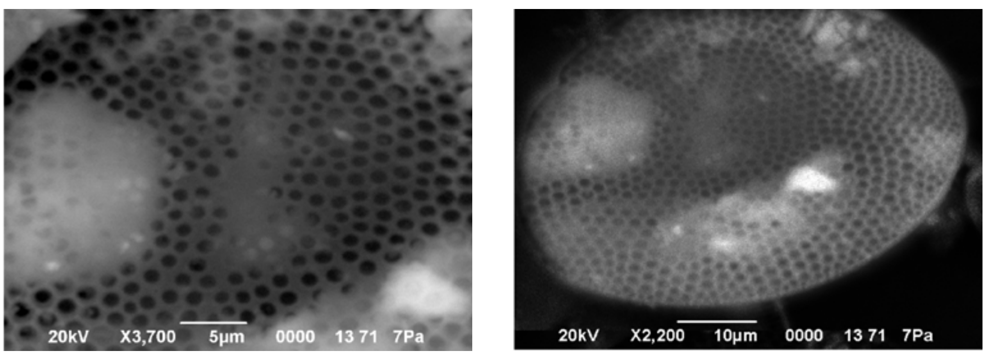
PLATE -1
Scaning Electron Micrographs



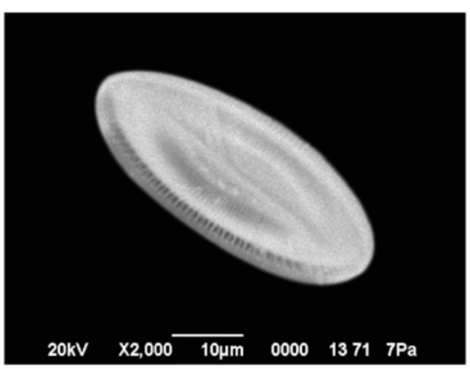
Thalassiosira sp Cleve



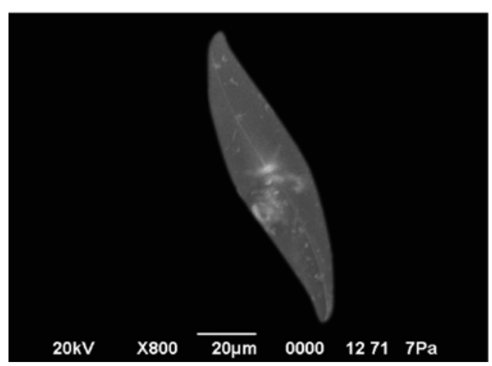
Cyclotella striata (Kutz) Grunow



Coscinodiscus asteromphalus var.centralis Ehrenberg



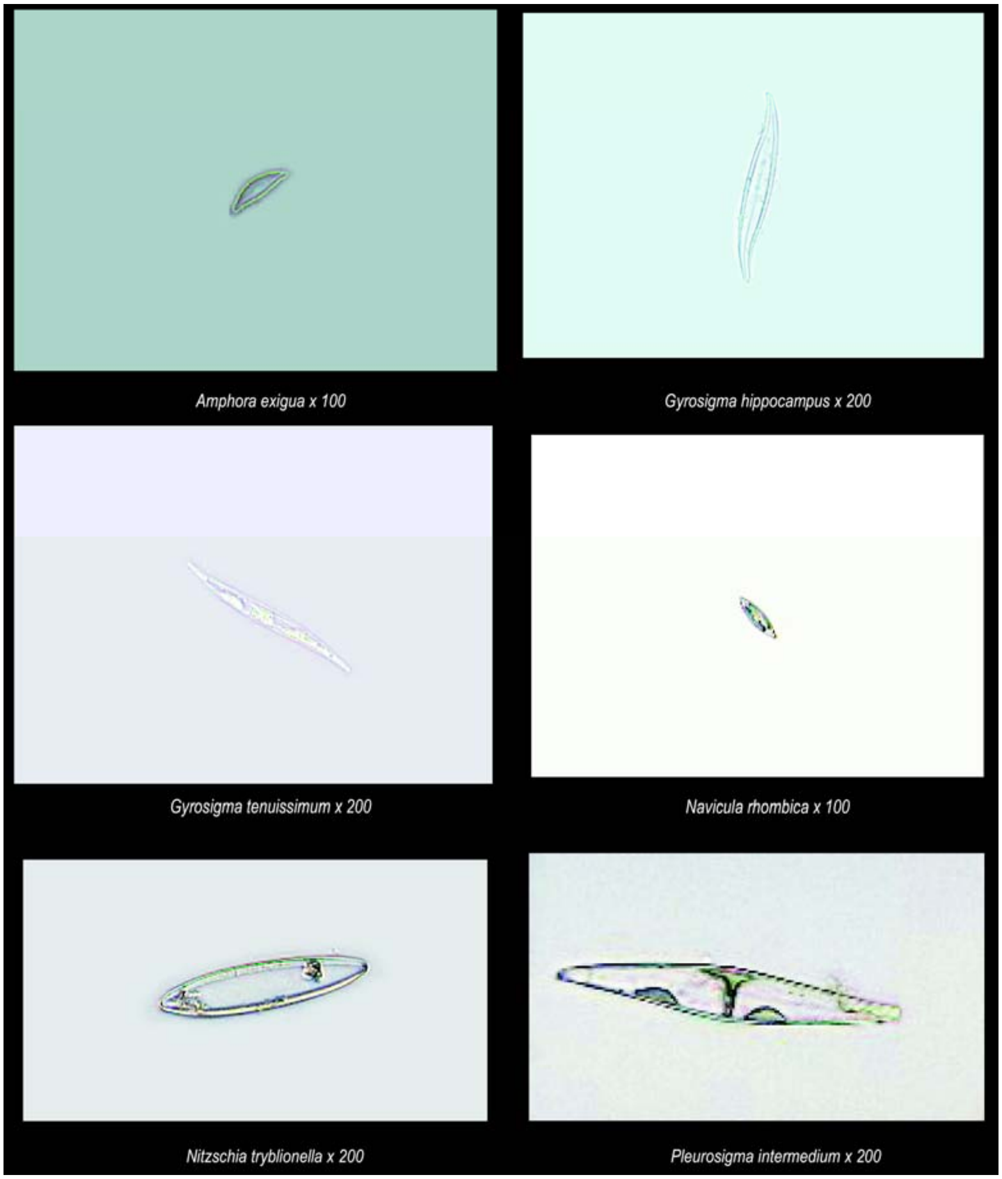
Mastogloea sp. Thwaites



Pleurosigma aestuarii (Breb.) Smith

PHOTOMICROGRAPHS (LM)

PLATE -2
Distributional Records



Amphora exigua x 100

Gyrosigma hippocampus x 200

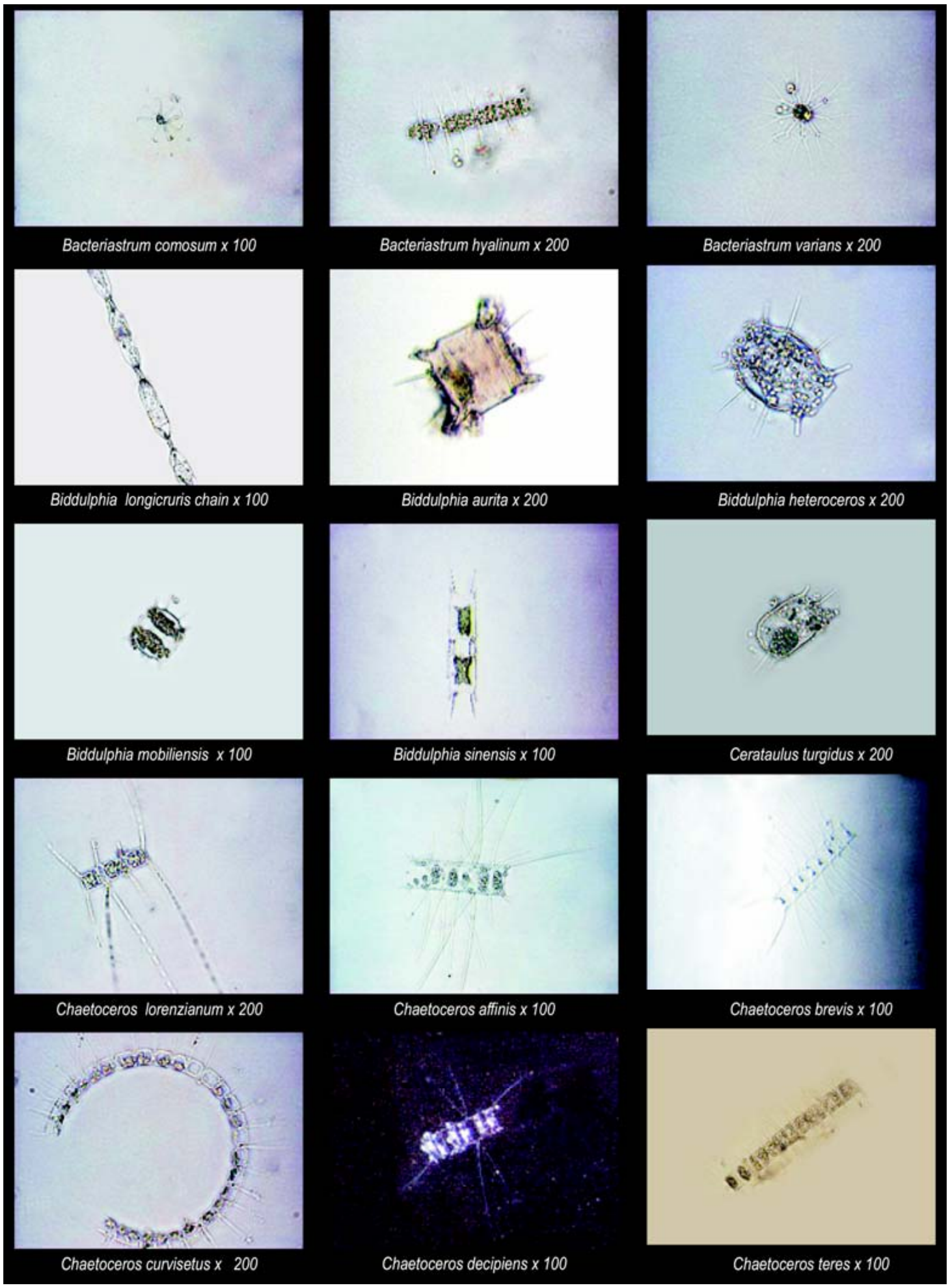
Gyrosigma tenuissimum x 200

Navicula rhombica x 100

Nitzschia tryblionella x 200

Pleurosigma intermedium x 200

PLATE - 3
CLASS : Bacillariophyceae (Centric Diatoms)



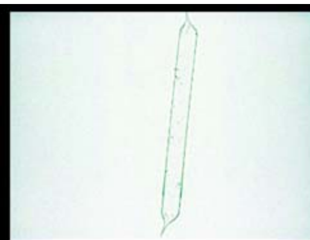
Bacteriastrum comosum x 100
Bacteriastrum hyalinum x 200
Bacteriastrum varians x 200
Biddulphia longicruris chain x 100
Biddulphia aurita x 200
Biddulphia heteroceros x 200
Biddulphia mobiliensis x 100
Biddulphia sinensis x 100
Cerataulus turgidus x 200
Chaetoceros lorenzianum x 200
Chaetoceros affinis x 100
Chaetoceros brevis x 100
Chaetoceros curvisetus x 200
Chaetoceros decipiens x 100
Chaetoceros teres x 100

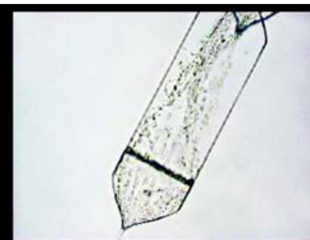
Continued…….

Corethron enerme x 200
Coscinodiscus curvatulus x 200
Coscinodiscus marginatus x 200
Coscinodiscus radiatus x 100
Coscinodiscus rothii x100
Coscinodiscus subtilis x 200
Cyclotella striata x 200
Ditylum brightwellii x 200
Ditylum sol x 100
Eucampia sp x 100
Guinardia flaccida x 200
Lauderia annulata x 200
Melosira nummuloides x 200
Planktoniella sol x 200
Podosira montagnei x 200

Continued…….


Proboscia alata x100

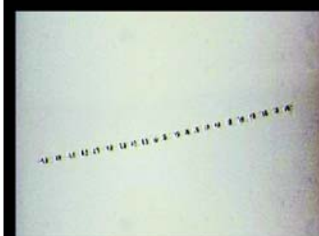

Rhizosolenia calcaravis x 100

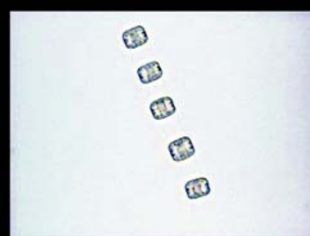

Rhizosolenia castracanei x 100


Rhizosolenia robusta x 100


Rhizosolenia setigera x 100


Rhizosolenia stolterfothii x 200


Skeletonema costatum x 100

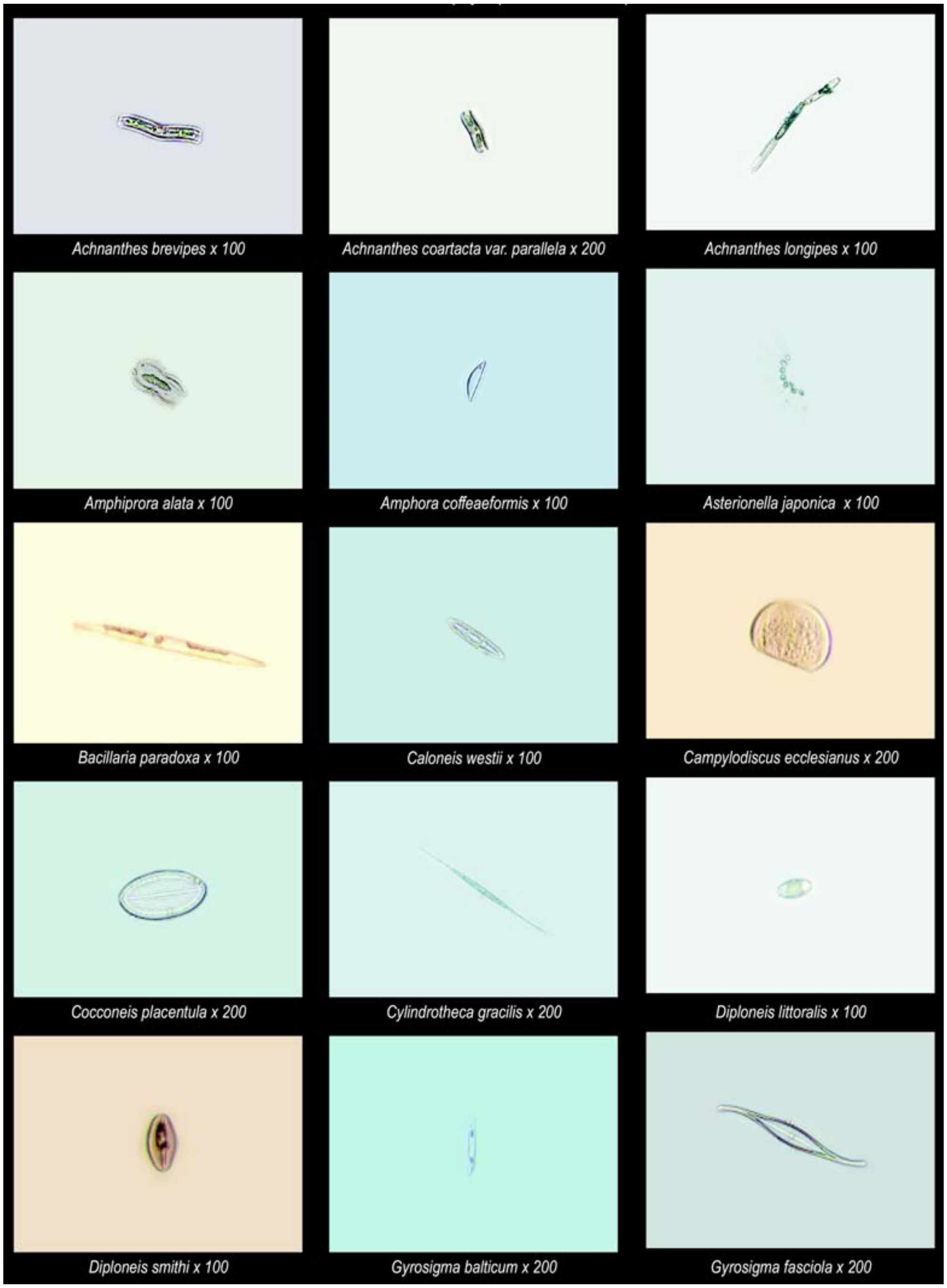

Thalassiosira nordenskioldii x 200


Triceratium affine x 100


Triceratium reticulatum x 200

PLATE - 4

CLASS: Bacillariophyceae (Pennate Diatoms)



Achnanthes brevipes x 100

Achnanthes coartacta var. *parallela* x 200

Achnanthes longipes x 100

Amphiprora alata x 100

Amphora coffeaeformis x 100

Asterionella japonica x 100

Bacillaria paradoxa x 100

Caloneis westii x 100

Campylodiscus ecclesianus x 200

Cocconeis placentula x 200

Cylindrotheca gracilis x 200

Diploneis littoralis x 100

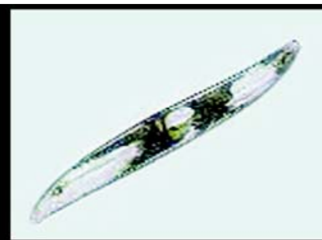
Diploneis smithi x 100

Gyrosigma balticum x 200

Gyrosigma fasciola x 200

Continued…….

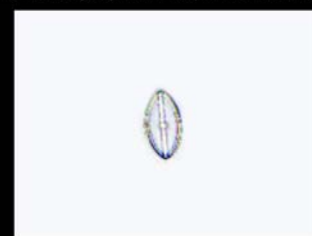

Gyrosigma nodiferum x 200


Gyrosigma spencerii x 200


Licmophora juergensii x 200 (Valve & Girdle view

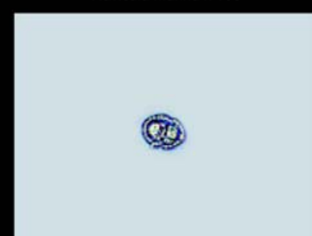

Licmophora juergensii x 200 (with stalk)

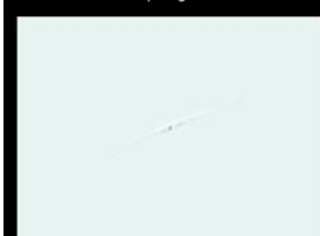

Mastogloia braunii x 200

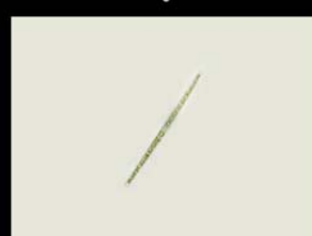

Navicula marina x 100


Navicula peregrina x 100


Nitzchia sigma x 200


Nitzschia panduriformis var minor x 200


Nitzschia closterium x 200


Nitzschia frustulum x 200

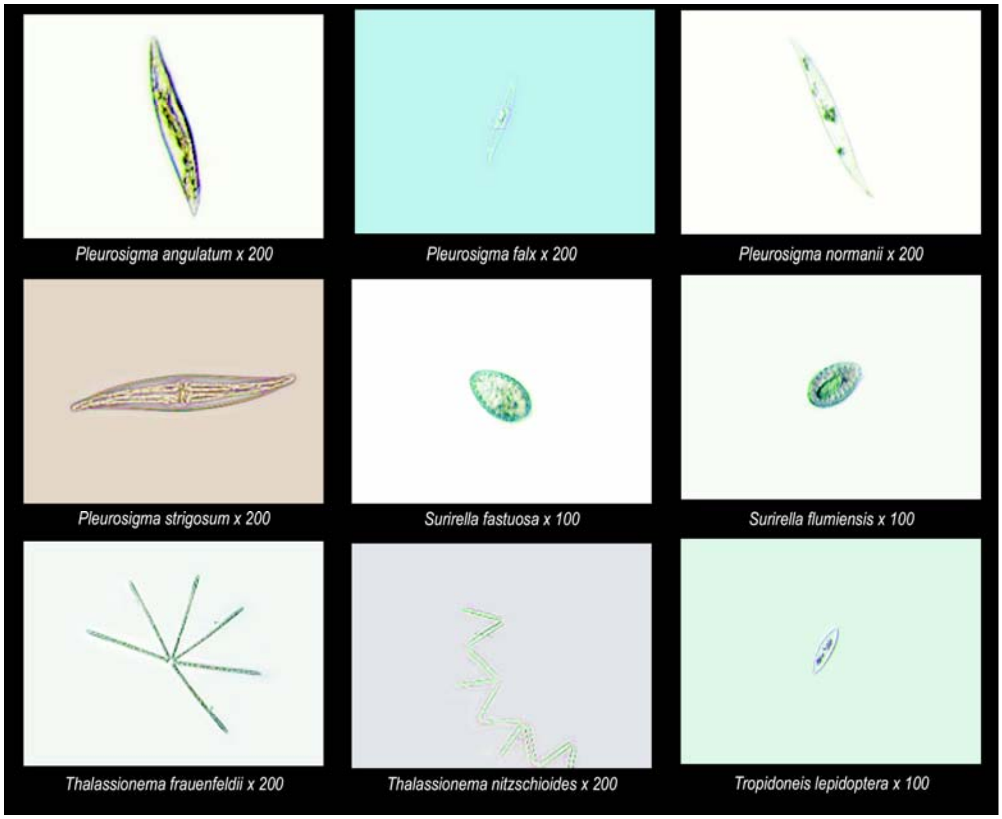

Nitzschia longissima x 100


Nitzschia longissima x 100


Pleurosigma acuminatum x 100


Pleurosigma aestuarii x 100

Continued…….



Pleurosigma angulatum x 200

Pleurosigma falx x 200

Pleurosigma normanii x 200

Pleurosigma strigosum x 200

Surirella fastuosa x 100

Surirella flumiensis x 100

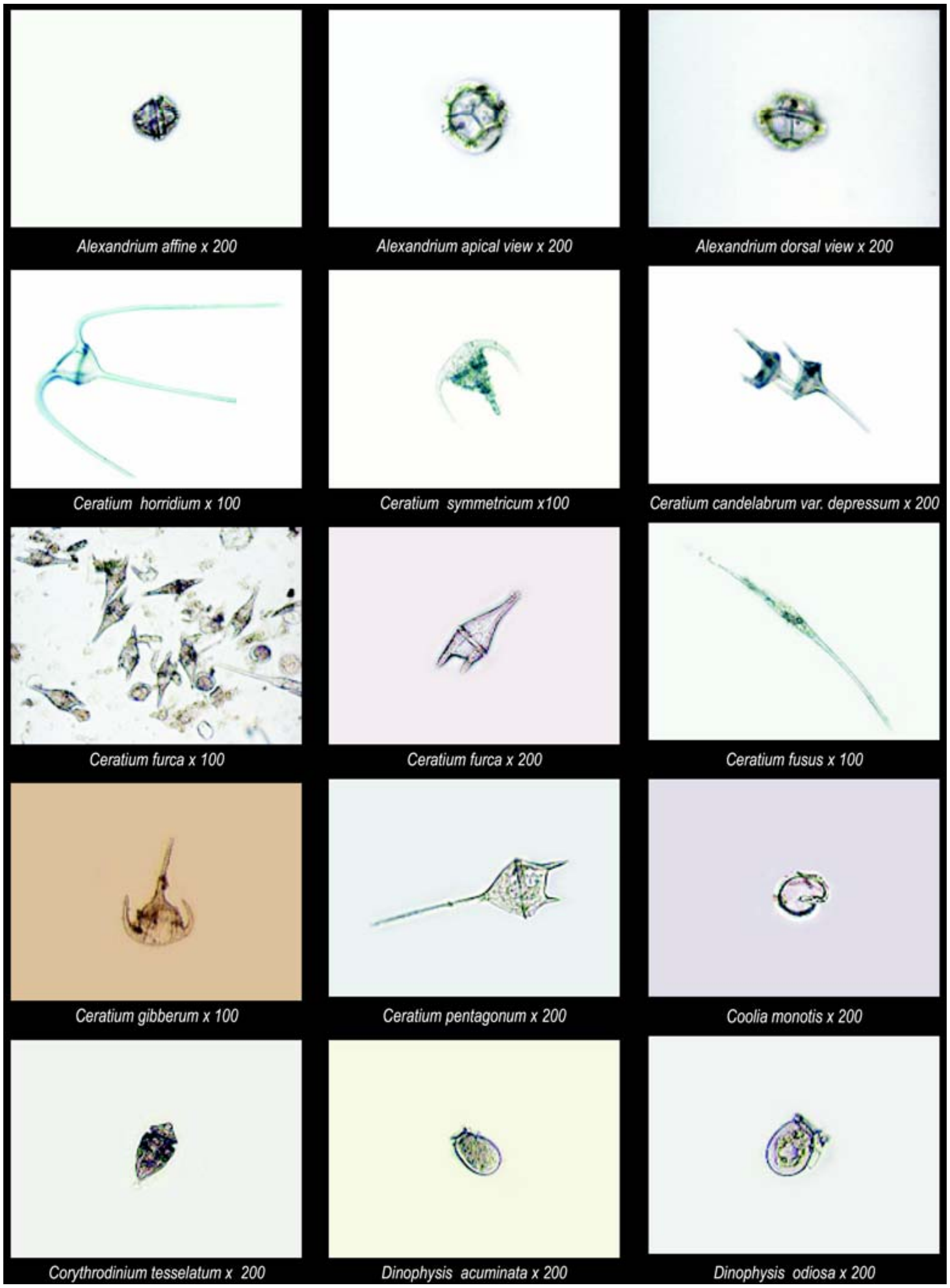
Thalassionema frauenfeldii x 200

Thalassionema nitzschioides x 200

Tropidoneis lepidoptera x 100

PLATE - 5

CLASS : Dinophyceae



Alexandrium affine x 200

Alexandrium apical view x 200

Alexandrium dorsal view x 200

Ceratium horridium x 100

Ceratium symmetricum x100

Ceratium candelabrum var. depressum x 200

Ceratium furca x 100

Ceratium furca x 200

Ceratium fusus x 100

Ceratium gibberum x 100

Ceratium pentagonum x 200

Coolia monotis x 200

Corythrodinium tesselatum x 200

Dinophysis acuminata x 200

Dinophysis odiosa x 200

Continued…….

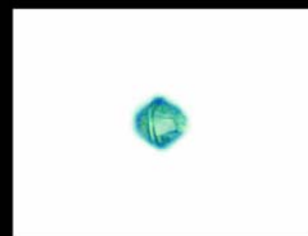
Dinophysis caudata x 200

Dinophysis hastata x 200

Dinophysis miles x 200

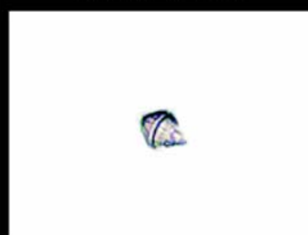
Dinophysis tripos x 200

Diplopsalis lenticula x200



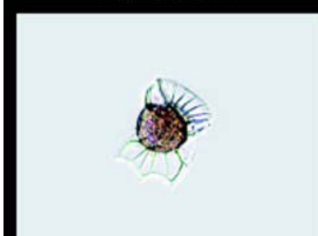
Goniodoma sphaericum x 200

Gonyalux moniliana

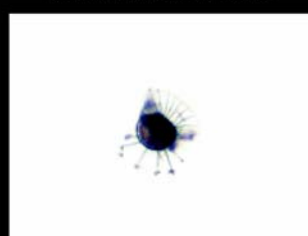


Gymnodinium heterostriatum x 200

Noctiluca miliaris x 50

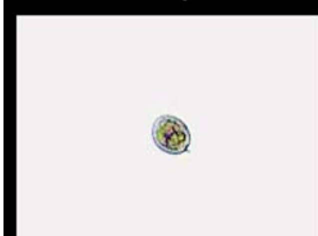


Ornithocercus magnificus x 200



Ornithocercus steinii x 100

Prorocentrum arcuatum x 200

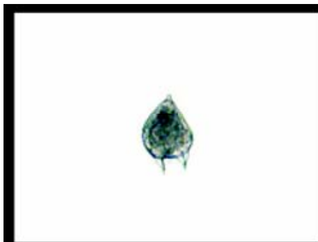


Prorocentrum compressum x 200

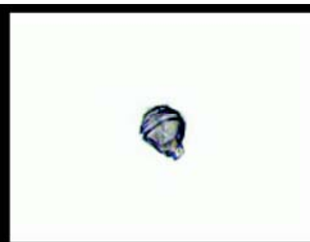
Prorocentrum gracile x 100

Prorocentrum micans x200

Continued…….

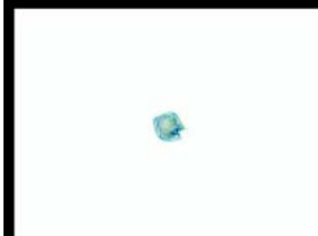


Protoperidinium brevipes dorsal view x 100



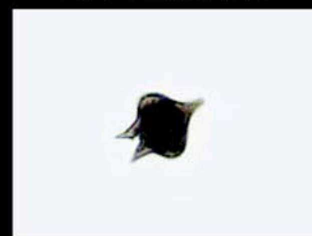
Protoperidinium brochii x 200

Protoperidinium cerasus x 200

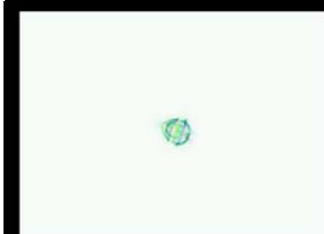


Protoperidinium conicum x 100

Protoperidinium leonis x 200



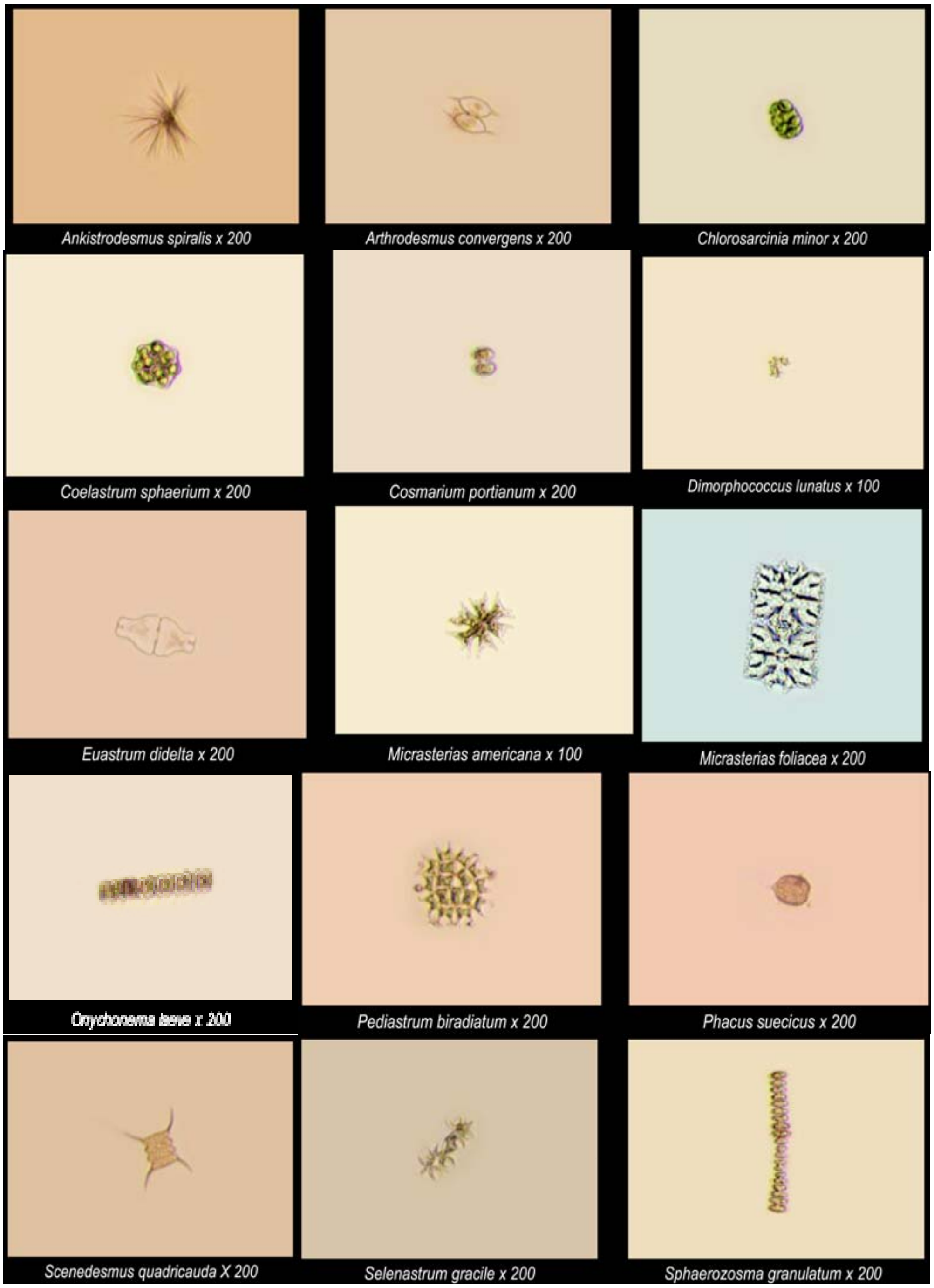
Protoperidinium oceanicum x 100



Protoperidinium ovatum x 100

PLATE - 6

CLASS : Chlorophyceae



Ankistrodesmus spiralis x 200

Arthrodesmus convergens x 200

Chlorosarcinia minor x 200

Coelastrum sphaerium x 200

Cosmarium portianum x 200

Dimorphococcus lunatus x 100

Euastrum didelta x 200

Micrasterias americana x 100

Micrasterias foliacea x 200

Onychonema laeve x 200

Pediastrum biradiatum x 200

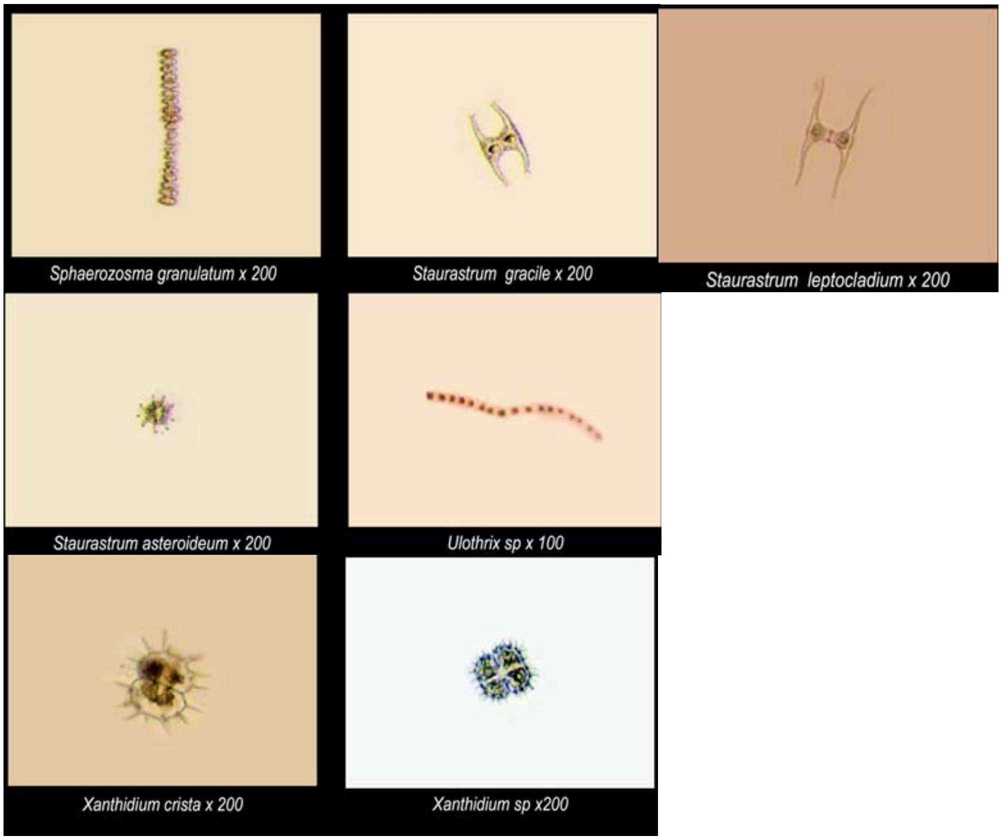
Phacus suecicus x 200

Scenedesmus quadricauda X 200

Selenastrum gracile x 200

Sphaerozosma granulatum x 200

Continued…….



Sphaerozosma granulatum x 200

Staurastrum gracile x 200

Staurastrum leptocladium x 200

Staurastrum asteroideum x 200

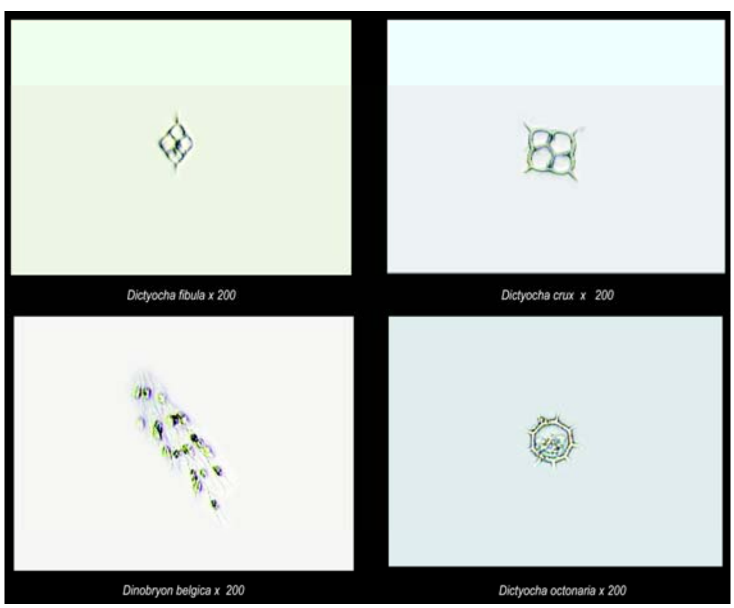
Ulothrix sp x 100

Xanthidium crista x 200

Xanthidium sp x200

PLATE - 7

CLASS : Dictyochophyceae & Chrysophyceae



Dictyocha fibula x 200

Dictyocha crux x 200

Dinobryon belgica x 200

Dictyocha octonaria x 200

ANNEXURE