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Phytoplankton diversity in Pichavaram mangrove waters from south-east coast of India

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Abstract: *The results of an investigation carried out during September 2002 to August 2003 on hydrography, composition and community structure of phytoplankton including chlorophyll 'a' (Chl-a) content and primary productivity (PP) of the Pichavaram mangrove (South-east coast of India) are reported. Atmospheric and surface water temperatures varied from 30.0 to 34.8°C and from 29.7 to 34.2°C respectively while the light extinction coefficient values (LEC) (K) ranged between 3.2 and 14.9. Salinity values varied from 9.6 to 35.4‰ and the pH ranged between 7.2 and 8.6. Variation in dissolved oxygen content was from 3.2 to 6.5 ml* l^{-1}*. The ranges of inorganic nutrients viz., nitrate, nitrite, phosphate and silicate were: 7-36.23, 0.31-5.46, 0.28-3.70 and 12.26-56.64* μM *respectively. Chlorophyll 'a' content ranged between 0.20 and 105.60* $\mu g\ l^{-1}$ *and the ranges of gross and net primary productivities (PP) were: 16.54-826.8 and 11.52-610.2 mg C* $m^{-3}\ hr^{-1}$ *respectively. Presently a total of 94 species of phytoplankton were identified. Among these, the diatoms formed predominant group. Population density of phytoplankton varied from 400 to 3,21,000 cells*$^{-1}$*. While the peak diversity (5.23 bits / ind.) of the phytoplankton was observed during summer season, the maximum population density was found during summer season coinciding with the stable hydrographical conditions.*

Key words: *Nutrients, Primary production, Phytoplankton, Pichavaram, Mangroves*
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Introduction

Mangroves are economically important ecosystems for fisheries in tropical regions (Kawabata *et al*., 1993). Mangrove ecosystem acts as a buffer zone between land and sea (Bardarudeen *et al*., 1996). Phytoplankton is one of the initial biological components from which the energy is transferred to higher organisms through food chain (Rajesh *et al*., 2002; Ananthan *et al*., 2004; Tiwari and Chauhan, 2006; Sridhar *et al.,* 2006; Mathivanan *et al.,* 2007; Tas and Gonulal, 2007; Shashi Shekher *et al.,* 2008; Saravanakumar *et al.,* 2008). Fertility and healthiness of mangrove environment is reflected through productivity of the phytoplankton and zooplankton as primary and secondary producers. Phytoplankton species undergoes spatio-temporal changes in their distribution due to the differential effect of hydrographical factors on individual species. They serve as bio-indicators with reference to water quality and thus serve as a tool for assessing the health of the aquatic ecosystems. Further, the measurement of primary productivity of aquatic ecosystem is required to forecast fishery potential of an area. The rate of gross primary productivity is important for assessing the fisheries yield (Gouda and Panigrahy, 1996).

Larval retention and high productivity in mangrove-lined estuaries have generally been attributed to the abundant planktonic-food supply in comparison to adjacent marine areas (Robertson *et al*., 1992). Organic materials derived from decaying mangrove leaves are also used as primary food source, which sustain larval and juvenile stocks. Influence of physical and chemical variables on planktonic communities in mangrove waters are more pronounced than the near shore coastal environment, resulting in seasonal changes of planktonic species composition and densities (Kannan and Vasantha, 1992). Thus, planktonic communities and their periodic shift in abundance and composition is an important biotic factor in the mangrove ecosystem. Some studies on the annual distribution patterns of phytoplankton have been made earlier in the Pichavaram mangroves (Krishnamurthy and Jeyaseelan, 1983; Mani *et al*., 1986; Kannan and Vasantha, 1992; Mani, 1992; Kathiresan, 2000). During the past one decade more number of shrimp farms has been built around the Pichavaram mangroves and it resulted in discharge of (more quantity) waste water into surrounding water bodies. In the present paper an attempt has been made to study the spatial and temporal variations of phytoplankton diversity and primary productivity in Pichavaram mangrove waters in relation to the hydrography of the area during September 2002 to August 2003.

Materials and Methods

The mangrove forest at Pichavaram (Lat. 11° 29' N: Long. 79° 46' E) is located along south-east coast of India, about 250 km south of Chennai city and 10 km south of Parangipettai in the state Tamil Nadu (Fig. 1). It is one of the typical mangrove swamps of the Vellar-Coleroon estuarine complex, covering an area of ca. 1100 ha and consisting of 51 islets ranging in size from 10 m^2 to 2 km^2 (Kathiresan, 2000; Godhantaraman, 2002). Of the total area, 50% is covered by the forest, 40% by the waterways and the remaining 10% by the sand and mud flats (Godhantaraman, 2002). It is highly productive with about 8 tones of organic plant detritus ha/year (Rajendran and Kathiresan, 2004). The channels in the mangroves are lined by a luxuriant vegetation of small salt marsh plants, trees, shrubs and thickets totaling about 30 species, of which ca. 20 are woody plants.

Three different sampling sites were chosen and the distance between the stations was about 1 km (Fig. 1). Station 1, received neritic water from the adjacent Bay of Bengal through a mouth called 'Chinnavaikal' (marine zone) with a depth of about 2 m,

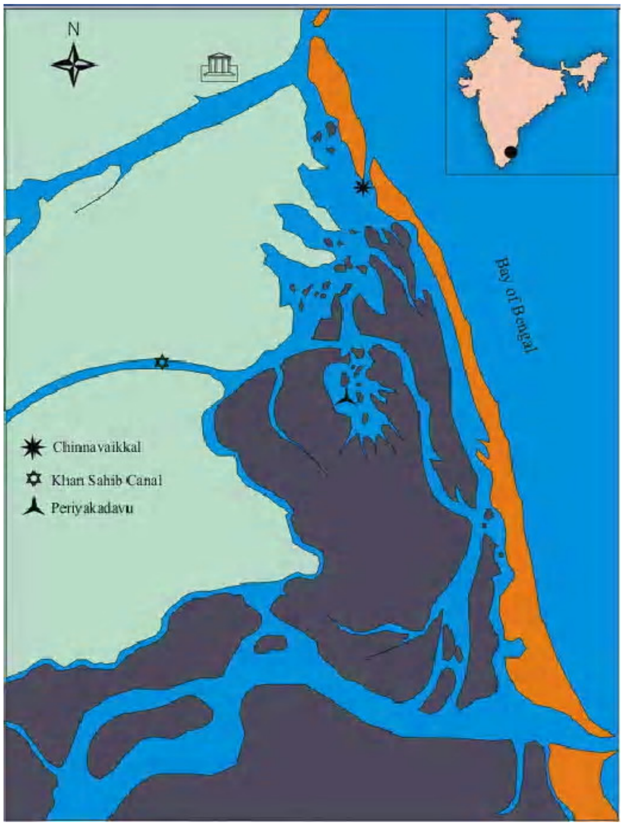

Fig. 1: Map showing the study sites of Pichavaram mangrove water

recent Tsunami closed this mouth; Station 2, Periyakadavu, is located in the interior area and characterized by brackish water conditions. The tidal amplitude would ranges from 0.50 to 1.00 m. The banks of the waterway in this area are lined by dense mangrove vegetation and Station 3 situated just opposite to the tourist jetty which received freshwater from an irrigation channel and from the paddy fields (0.75 m depth) ('Khan Sahib Canal'), as well from the main channel of the Coleroon River (Fresh water zone). The tides are semi-diurnal and vary in amplitude from about 15 to 100 cm in different regions during different seasons, reaching a maximum during monsoon and post-monsoon and a minimum during summer. The rise and fall of the tidal waters is through a direct connection with the sea at the Chinnavaikkal mouth and also through the two adjacent estuaries. The depth of the waterways ranges from 0.3 to 3 m (Kathiresan, 2000).

Seasonal collections were made to record the physico-chemical and phytoplankton characteristics of the Pichavaram mangrove waters. Rainfall data were obtained from the local meteorological unit (Govt. of India) located at Marine Biological Centre, Parangipettai. In this tropical region, based on the meteorological events, the year is divisible into four climatic seasons: monsoon (October 2002 to December 2002); post-monsoon (January 2003 to March 2003); summer (April 2003 to June 2003) and pre-monsoon (July, August 2003 to September 2002).

Atmospheric and surface water temperatures were measured using standard mercury filled centigrade thermometer. Salinity was measured with the help of a hand refractometer (Atago, Japan) and the pH was measured using a Elico pH meter (Model LC-120). Dissolved oxygen was estimated by the modified Winkler's method, described by Strickland and Parsons (1972). Light penetration in the water column was measured with the help of Secchi disc and the light extinction co-efficient (LEC) was calculated using the formulae of Pool and Atkins (1929).

For the analysis of nutrients, surface water samples were collected in clean polythene bottles and kept in an ice box and transported immediately to the laboratory. The water samples were filtered using a Millipore filtering system (MFS) and the nutrients were analyzed by adopting the standard methods described by Strickland and Parsons (1972). Phytoplankton samples were collected from the surface water by horizontal towing a conical net (0.35 m mouth diameter), made up of bolting silk (cloth No. 30; mesh size 48 μm) for thirty minutes. The collected samples were preserved in 5% neutralized formalin and used for qualitative analysis and were identified using the standard works. For the quantitative analysis of phytoplankton, the settling method described by Sukhanova (1978) was adopted. Numerical plankton analysis was carried out using Utermohl's inverted plankton microscope. Biodiversity indices such as species diversity, evenness and richness were calculated following the standard formulae (Shannon and Weaver, 1949; Pielou, 1966; Gleason, 1922).

Chlorophyll 'a' concentration was estimated by the method of Strickland and Parsons (1972). Primary production was estimated by adopting the light and dark bottle technique and the productivity has been expressed as $mgCm^{-3}hr^{-1}$. Simple correlation (r) was made for the statistical interpretation of the physico-chemical and plankton characteristics.

Results and Discussion

Monthly rainfall ranged between 10 mm (pre-monsoon season) to 362 mm (monsoon season) (Fig. 2a). No rainfall was recorded during January to April and in June. The variations in physico-chemical parameters are mainly responsible for the marked variation in phytoplanktonic abundance and distribution. Hence, rainfall is the most important cyclic phenomena. These hydrographical parameters in Pichavaram mangroves showed a distinct pattern of variation all around the study period. During monsoon rainfall, the mangrove ecosystem received heavy freshwater inflow from the land drainage and showed abrupt changes in all the analyzed physico-chemical parameters. The peak values of rainfall were recorded during the monsoon month of October 2002. The rainfall in India is largely influenced by two monsoons *viz.*, south-west monsoon on the west coast, northern and north-eastern India and by the north-east monsoon on the south-east coast, the Pichavaram mangrove ecosystem is largely influenced by north-east monsoon (Perumal, 1993). On the other hand tidal rhythm, water current and evaporation in summer produced only little variation in those parameters or more less stable in the absence of rainfall. Maruthanayagam and

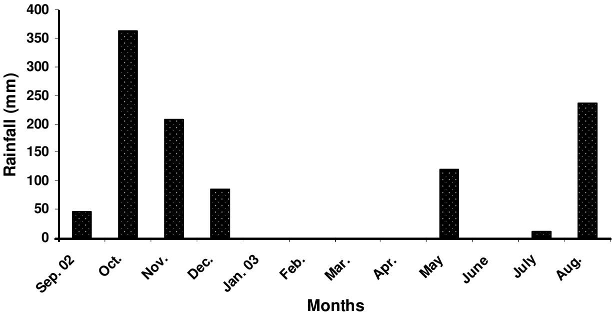

Fig. 2a: Monthly variations in rainfall recorded from Pichavaram mangroves

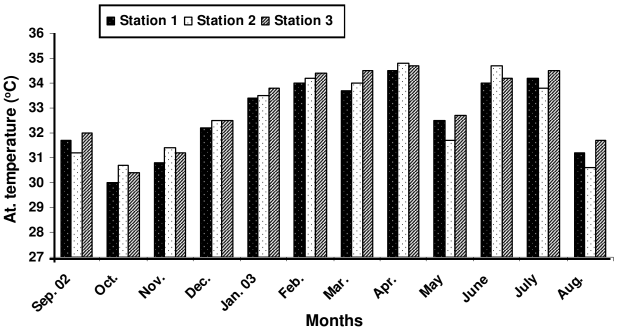

Fig. 2b: Monthly variations in atmospheric temperature recorded from stations 1, 2 and 3

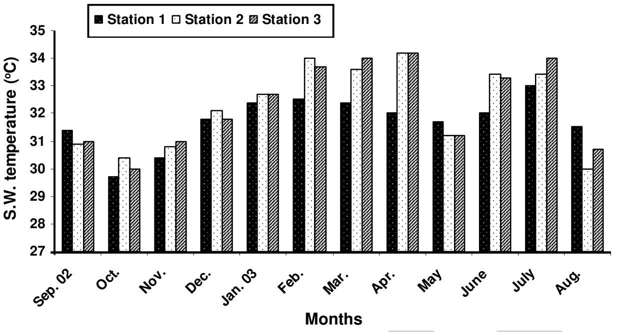

Fig. 2c: Monthly variations in surface water temperature recorded from stations 1, 2 and 3

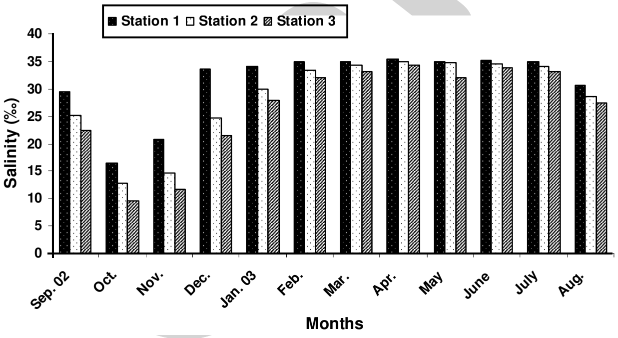

Fig. 2d: Monthly variations in salinity recorded from stations 1, 2 and 3

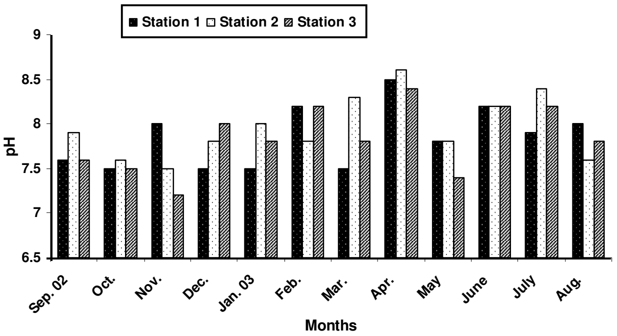

Fig. 2e: Monthly variations in pH recorded from stations 1, 2 and 3

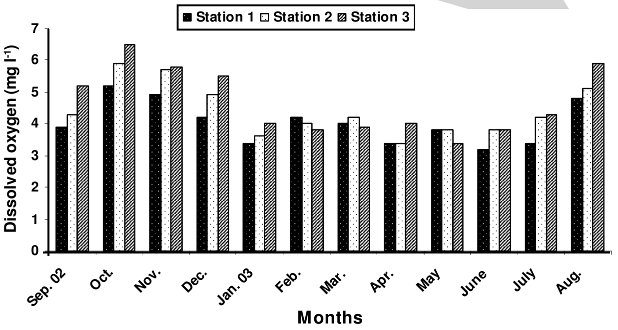

Fig. 2f: Monthly variations in dissolved oxygen recorded from stations 1, 2 and 3

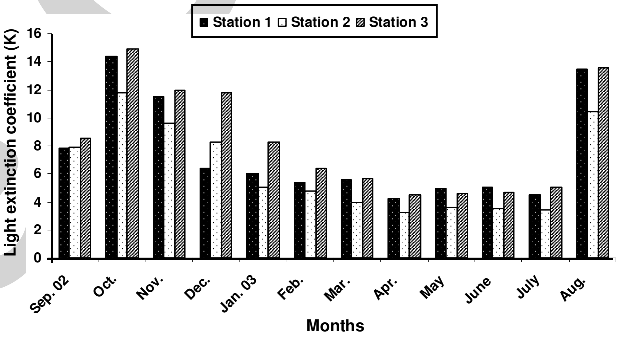

Fig. 2g: Monthly variations in light extinction coefficient recorded from stations 1, 2 and 3

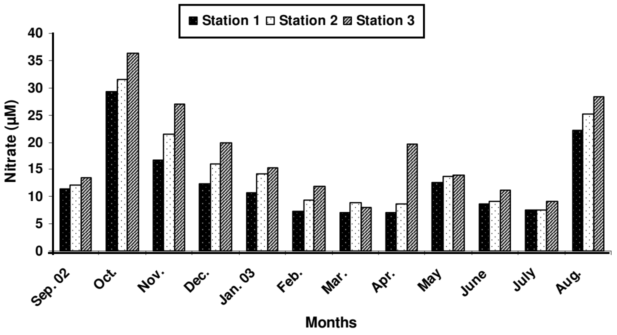

Fig. 3a: Monthly variations in nitrate recorded from stations 1, 2 and 3

Subramanian (1999) have also reported the bulk of rainfall in the south-east coast of India during north-east monsoon season.

Atmospheric and surface water temperature varied from 30 to 34.8°C and 29.7 to 34.2°C respectively during monsoon and summer seasons (Fig. 2b,c). The surface water temperature showed an increasing trend from December 2002 to April 2003. Generally, surface water temperature is influenced by the intensity of solar radiation, evaporation and insolation and the recorded low temperature during monsoon could be due to strong sea breeze and cloudy sky (Karuppasamy and Perumal, 2000; Govindasamy *et al*., 2000). The observed spatial variation in temperature could be due to the viable intensity of prevailing currents and the consequent mixing of water (Reddi *et al*., 1993). Statistical analysis showed a positive correlation (r =0.8910 at Station 1, r=0.9831 at Station 2 and r=0.9709 at Station 3) between air and surface temperature for all the three stations.

The light extinction co-efficient values ranged between 3.2 K (summer) and 14.9 K (monsoon) (Fig. 2g). Light extinction co-efficient at all the three stations were high during the monsoon season due to the low intensity of solar radiation and higher concentration of dissolved organic matter and suspended sediments. Further, turbulent freshwater discharge and bottom sediment could also be the important factors in governing light penetration (Sampathkumar and Kannan, 1998). Low light extinction co-efficient was observed during summer season, which it could be due to the higher solar penetration, clean water condition and low runoff (Kannan and Kannan, 1996). Further LEC showed a positive correlation with rainfall.

Salinity showed wide variations in the ranges of 9.6 to 35.4‰ (Fig. 2d). The salinity is the main physical parameter that can be attributed to the plankton diversity act as a limiting factor which influences the distribution of planktonic community (Kouwenberg, 1994; Ramaiah and Nair, 1997; Chandramohan and Sreenivas, 1998; Balasubramanian and Kannan, 2005; Sridhar *et al*., 2006). Generally, changes in the salinity of the brackish water habitats such as estuaries, backwaters and mangrove are due to the influx of freshwater from land run off, caused by monsoon or by tidal variations. This is further evidenced by the negative correlation (r= -0.8550 at Station 1, r=-0.7936 at Station 2 and r=-0.7869 at Station 3) obtained between salinity and rainfall. Salinity showed a significant positive correlation with temperature. Presently recorded high summer values could be attributed to the high degree of

Table - 1: List of phytoplankton species recorded at Pichavaram mangrove waters (September 2002 - August 2003)

Bacillariophyceae (Diatoms)
Amphora coffeaeformis (Ag) Kutz
Asterionellopsis japonica Cl. and Moller
A. glacialis Castracane
Bacillaria paxillifer (Muller) Hendey
Bacteriastrum comosum Pavillard
B. delicatulum Cleve
B. hyalinum Lauder
Bellerochea malleus (Brightwell) Van Heurck
Odontella heteroceros Grunow
O. mobiliensis (Bailey) Grunow
O. sinensis (Greville) Grunow
Cerataulina bergonii Peragallo
C. orientalis Schiller
Chaetoceros affinis Lauder
C. curvisetus Cleve
C. diversus Cleve
C. lorenzianus Grunow
C. peruvianus Brightwell
Climacosphenia elongata Bailey
Coscinodiscus centralis Ehrenberg
C. gigas Ehrenberg
C. lineatus Ehrenberg
C. sublineatus Grunow
C. marginatus Ehrenberg
C. jonesianus (Greville) Ostenfeld
C. oculus – iridis Ehrenberg
C. perforatus Ehrenberg
C. excentricus Ehrenberg
Cyclotella striata (Kuetzing) Grunow
Diploneis sp.
D. bombus Ehrenberg
Ditylum brightwellii (West) Grunow
Eucampia zoodiacus Ehrenberg
Grammatophora marina (Lyngbye) Kuetz.
G. sphaerophorum Ehrenberg
Guinardia flaccida (Castracane) Peragallo
Gyrosigma balticum (Ehrenberg) Rabenhorst
G. disortum (W. Smith) Cleve
Hemidiscus hardmannianus H.Peragallo
Leptocylindrus danicus *Cleve*
Navicula granulata Berb. and Her.
N. cincta (Ehrenberg) Kuetz.
Nitzschia acuta Cleve
N. closterium (Ehrenberg) Smith
N. longissima *(Brebission) Ralfs*
N. seriata Cleve
N. sigma (Kuetzing) W. Smith
N. sigmoidea (Nitz) W. Smith
Planktoniella sol (Wallich) Schutt
Pleurosigma angulatum (Kuetz.) W. Smith
P. elongatum W. Smith
P. normanii Ralfs
Pleurosigma sp.
Raphidonema sp.
Rhizosolenia alata (Cleve) Grunow
R. hebetata Bail
R. robusta Norman
R. crassispina Schroeder
R. cylindrus Cleve
R. imbricata (Cleve) Schroeder
R. setigera Brightwell
R. stolterfothii H. Peragallo
R. styliformis Brightwell
Schroederella delicatula (Peragallo) Pavillard
Skeletonema costatum (Grev.) Cleve
Stephanophyxis palmeriana (Grev.) Grunow
Surirella sp.
Synedra ulna (Kuetz) Ehrenberg
Thalassionema nitzschioides (Grunow) Meresch
Thalassiosira subtilis (Ostenfeld) Gran
Thalassiothrix frauenfeldii (Grunow) Hallegraeff
Triceratium favus Ehrenberg
T. reticulatum Ehrenberg

Dinophyceae (Dinoflagellates)
Ceratium breve (Ost. Schm.) Sch.
C. furca (Ehrenberg) Claparede and Lachmann
C. fusus (Ehrenberg) Dujardin
C. extensum (Paul.) Balch
C. macroceros (Ehrenberg) Cleve
C. tripos (O.F.Muller) Nitzsch
Dinophysis caudata Saville-Kent
Noctiluca scintillans Sch. (Macarthey) Ehrenberg
Prorocentrum micans Ehrenberg
Peridinium excentricum Paulsem. Balech
Protoperidinium conicum (Gran) Belech
P. oceanicum (Van Hoffer) Balech
P. pentagonum (Gran) Balech
P. depressum Bailey
Pyrocystis fusiformis W. Thompson

Chrysophyceae (Silicoflagellate)
Distephanus speculum (Her.) Haeckel

Cyanophyceae (Blue-greens)
Anabena sp.
Oscillatoria sp.
Trichodesmium erythraeum Ehrenberg

Chlorophyceae (Greens)
Chlorella sp.
Ulothrix sp.

evaporation and also due to neritic water dominance from sea (Subramanian and Mahadevan, 1999; Senthilkumar *et al*., 2002). During the monsoon season, the heavy rainfall and the resultant freshwater inflow from the land in turn moderately reduced the salinity. Thus the variations in salinity in the study sites were mainly influenced by the rainfall and entry of freshwater as reported earlier by Vijayalaksmi *et al.* (1993) in the Gulf of Kachchh; Saisastry and Chandramohan (1990) in the Godavari estuary, and Mitra *et al.* (1990) in the Bay of Bengal.

The dissolved oxygen values were high (6.5 ml l^{-1}) during the monsoon (October) and low (3.2 ml l^{-1}) during the summer (June) season (Fig. 2f). Season-wise observation of dissolved oxygen showed an inverse trend against temperature and salinity. It is well known that the temperature and salinity affect the dissolution of oxygen (Vijayakumar *et al*., 2000). In the present investigation, higher values of dissolved oxygen were recorded during monsoon months at all the stations. Relatively lower values were found during summer, which could be mainly due to reduced agitation in the coastal and estuarine waters. Higher dissolved oxygen concentration observed during the monsoon season might be due to the cumulative effect of higher wind velocity coupled with heavy rainfall and the resultant freshwater mixing. Das *et al*. (1997) and Saravanakumar *et al.* (2007) mainly attributed seasonal variation of dissolved oxygen to freshwater influx and ferruginous impact of sediments. Further, significant inverse relationship between rainfall and nutrients indicated that freshwater input constituted the main source of the nutrients in the mangroves.

The pH varied from 7.2 to 8.6 during monsoon and summer season (Fig. 2e). Hydrogen ion concentration (pH) in surface waters remained alkaline throughout the study period at all the stations with maximum value during the summer seasons and minimum values during monsoon. Generally, fluctuations in pH values during different seasons of the year can be attributed to factors like removal of CO_2 by photosynthesis through bicarbonate degradation, dilution of seawater by freshwater influx, reduction of salinity and temperature and decomposition of organic matter as stated by (Upadhyay, 1988; Rajasegar, 2003; Paramasivam and Kannan, 2005). The observed high summer pH values which might be due to the influence of seawater inundation and the high density of phytoplankton (Das *et al*., 1997; Subramanian and Mahadevan, 1999). The statistical analysis also revealed that salinity had highly significant negative correlation with rainfall.

Concentrations of nutrients *viz.* nitrate (7 to 36.23 μM), nitrite (0.31 to 5.46 μM), phosphate (0.28 to 3.83 μM) and reactive silicate (12.26 to 56.64 μM) also varied independently (Fig. 3a-d). Nutrients are considered as one of the most important parameters in the mangrove environment influencing the distribution of phytoplankton. Distribution of nutrients is mainly based on the season, tidal conditions and freshwater flow from land sources. High concentration of inorganic phosphate observed during monsoon season might possibly be due to intrusion of upwelling seawater into the creek that increased the level of phosphate (Nair *et al*., 1984).

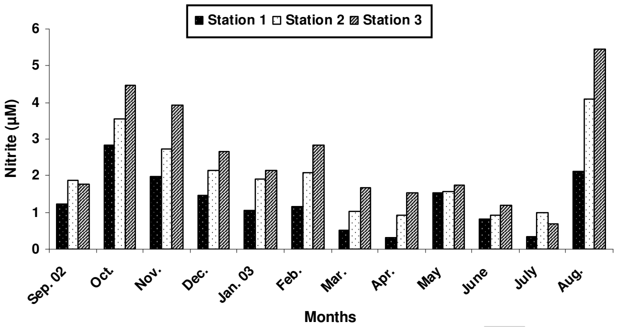

Fig. 3b: Monthly variations in nitrite recorded from stations 1, 2 and 3

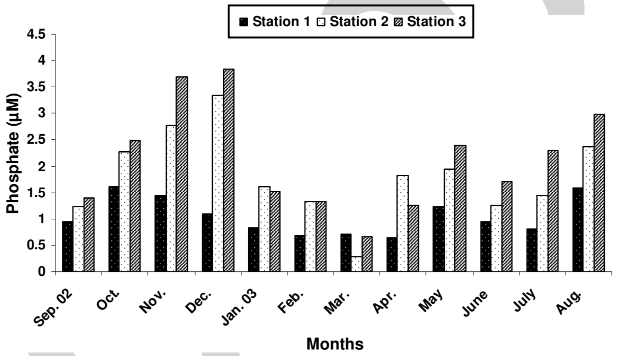

Fig. 3c: Monthly variations in phosphate recorded from stations 1, 2 and 3

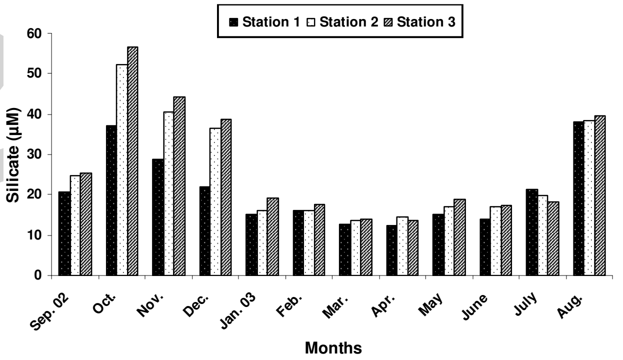

Fig. 3d: Monthly variations in silicate from stations 1, 2 and 3

The low values were observed during post monsoon and summer seasons due to decreased runoff and due to the utilization by phytoplankton (Ramakrishnan *et al*., 1999). Further, regeneration and release of total phosphorus from bottom mud into the water column by turbulence and mixing also attributed to the higher monsoonal values (Chandran and Ramamoorthy, 1984). The recorded highest phosphate values during monsoon season could be attributed to the heavy rainfall, land runoff, nutrients-rich discharges from shrimp farms, its autochthonous origin and alkali metal phosphates input from weathering rocks liberation (Gowda *et al*., 2001). In addition, anthropogenic activities of fertilizers applied to the agricultural fields and alkyl phosphates used in households as detergents can be other sources for higher amount of inorganic

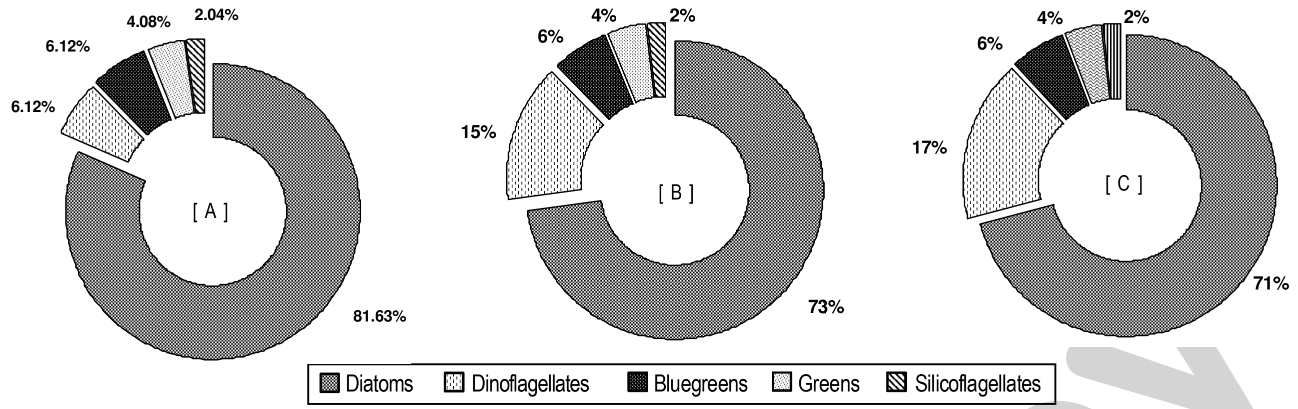

Fig. 4: Percentage composition of phytoplankton recorded from (A) Station 1, (B) Station 2, (C) Station 3

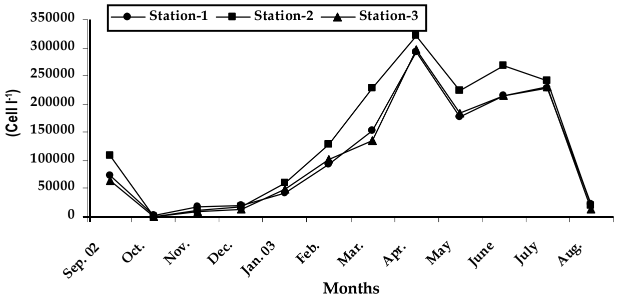

Fig. 5a: Monthly variations in phytoplankton population density from stations 1, 2 and 3

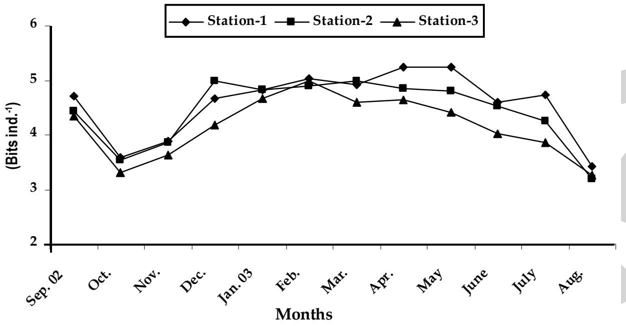

Fig. 5b: Monthly variations in species diversity from stations 1, 2 and 3

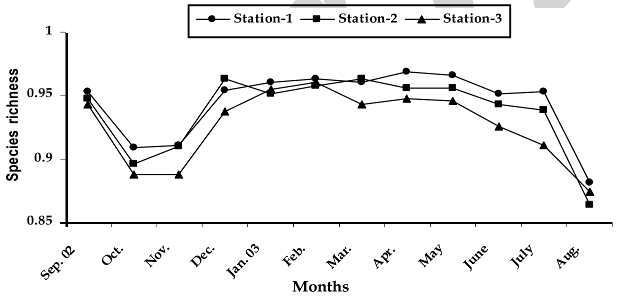

Fig. 5c: Monthly variations in species richness recorded from stations 1, 2 and 3

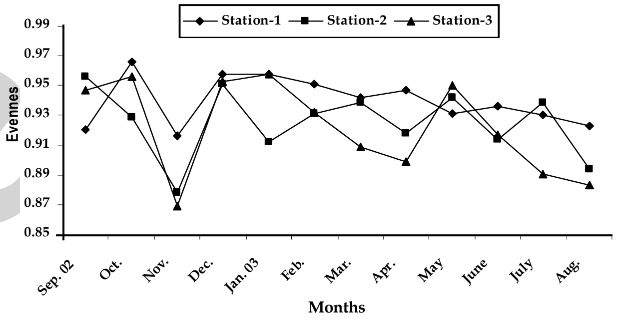

Fig. 5d: Monthly variations in species evenness recorded from stations 1, 2 and 3

nitrate and phosphate during the season (Das *et al*., 1997; Senthilkumar *et al*., 2002).

Maximum values of nitrate concentration were recorded during monsoon season at all the stations, which may be due to the anthropogenic inputs and organic matter from the catchment area during ebb tide (Mishra *et al*., 1993). Another possible way of nitrate input might be through oxidation of ammonia a form of nitrogen to nitrite and consequently to nitrite (Rajasegar, 2003). The recorded low values during non-monsoonal period may be due to its utilizations by phytoplankton as evidenced by high photosynthetic activity and also due to the dominance of marine water intrusion with negligible amount of nitrate (Gouda and Panigrahy, 1995; Das *et al*., 1997).

The recorded higher value of nitrite during monsoon season could be due to variation in phytoplankton fixation, oxidation of ammonia, reduction of nitrate and by recycling of nitrogen besides bacterial decomposition of planktonic detritus present in the environment (Govindasamy *et al*., 2000) also due to denitrification and air-sea interaction (Choudhury and Panigrahy, 1991). The recorded low value during pre-monsoon and summer season may be due to high salinity (Mani and Krishnamurthy, 1989; Murugan and Ayyakkannu, 1991).

The silicate content was higher than the other nutrients (NO_3, NO_2 and PO_4), and the recorded higher monsoonal values may be due to heavy influx of freshwater derived from land drainage carrying silicate leached out from rocks and also from the bottom sediment (Mishra *et al*., 1993). The recorded low value of summer could be attributed to uptake of silicate by phytoplankton for their biological activity (Mishra *et al*., 1993).

Presently recorded high summer productivity could be attributed to the neritic element domination, high light intensity, clear water condition and availability of nutrients, as reported earlier by Gopinathan *et al*. (1994) and Thillai Rajasekar *et al*. (2005). The values of gross and net primary productivity varied from 16.54-826.8 and 11.52- 610.2 mg $\text{Cm}^{-3}\text{hr}^{-1}$ during monsoon and summer seasons (Fig. 6a,b). The bimodal type of primary productivity was recorded presently. The primary peak was observed during the summer and secondary peak during premonsoon seasons. During the above seasons the salinity and other hydrological parameters were in stable condition and this could have promoted the phytoplankton production (Nayer and Gowda, 1999; Rajesh *et al*., 2002).

The recorded low primary productivity can be related to the wash of off the phytoplankton to the neritic region by the monsoonal flood or the reduction of salinity, which could have affected the phytoplankton population (Rajasegar *et al*., 2000; Gowda *et al*., 2001; Thillai Rajasekar *et al*., 2005).

Both gross and net productivity were low in the northeast monsoon season (October - December). Net productivity was positively correlated with salinity. The high productivity during summer and southwest monsoon season may be due to increased radiation (Mani, 1992). The increase in respiration in the samples collected from northeast monsoon season may be due to the mixing of land drainage, which carries a lot of organic substances, resulting in the possibility of biological oxidation (Subramanian and Mehadevan, 1999). In addition, the low values of primary productivity recorded during monsoon season could be due to the cloudy weather and allochthonous constituent downpour drain also caused low value of primary predominants (Rajasegar *et al*., 2000).

The chlorophyll *a* concentration range were: 0.24-69.82 ($\mu g\ l^{-1}$) (St. 1); 0.20-105.60 ($\mu g\ l^{-1}$) (St. 2) and 0.20 to 94.80 ($\mu g\ l^{-1}$) (St. 3) (Fig. 7). A higher value of chlorophyll a was recorded during summer, the low value was observed during monsoon. The reduction in Chlorophyll *a* values during northeast monsoon season may be due to freshwater discharges from the rivers (dilution), causing turbidity and less availability of light (Kawabata *et al*., 1993; Godhantaraman, 2002; Thillai Rajasekar *et al*., 2005).

In general, the distribution and abundance of phytoplankton in tropical waters, varied remarkably due to the seasonal environmental fluctuations, and these variations are well pronounced in the sheltered system of coastal mangrove waters. In the present study, diatoms formed the dominant group followed by dinoflagellates, blue greens, greens and silicoflagellates at all the 3 stations. Percentage composition of each group of phytoplankton was in the following order: Diatoms > Dino flagellates > Blue greens > Greens > Silicoflagellates.

This study recorded 94 species of phytoplankton species belonging to diverse groups such as Bacillariophyceae (73), Dinophyceae (15), Cyanophyceae (3), Chlorophyceae (2) and Chrysophyceae (1) (Table 1). The percentage wise compositions of phytoplankton were dominantly occupied by diatoms followed by others (Fig. 4). Phytoplankton species composition was comparatively more in Station 1 than in Stations 2 and 3. Generally, diatoms were found to be dominant in mangrove waters, which could be due to the fact that diatoms can tolerate the widely changing hydrographical conditions (Mani, 1992; Kannan and Vasantha, 1992; Rajasegar *et al*., 2000; Gowda *et al*., 2001; Senthilkumar *et al*., 2002).

Presently observed high population density and species diversity during post monsoon and summer might be due to the predominance of diatoms *viz. Pleurosigma normanii*, *P. elongatum, Cocconeis disculoidus*, *Rhizosolenia alata F. gracillima, Thalassiothrix frauenfeldii, Odontella mobiliensis, O. sinensis, Chaetoceros decipiens, C. lorenzianus, Chaetoceros affinis, Asterionellpsis japonica, A. gacialis, Ceratium tripos, C. breve, R. imbricata, R. stolterfothii, Thalasiosira subtilis, Skeletonema costatum, Nitzschia longissima, N. closterlum, Thalassionema nitzschioides* and *Navicula wawrikae.* The phytoplankton abundance during summer season could be attributed to the increased salinity, pH, high temperature and high intensity of light penetration during the season (Mani and Krishnamurthy, 1989).

The abundance of phytoplankton was lowest during monsoon months, when the water column was remarkably stratified to a large extent because of heavy rainfall, high turbidity caused by run-off, reduced salinity, decreased temperature and pH, overcast sky and cool conditions. However, during this season, freshwater algal forms like *Anabena* sp. *Spirogyra* sp. and *Volvox* sp. were noticed. These phytoplankton counts were high during southwest monsoon season as reported in some of the studies in Bay of Bengal (Marichamy *et al*., 1985). Similar observations were earlier made by Patterson Edward and Ayyakkannu (1991), Gouda and Panigrahy (1996), Rajasegar *et al*. (2000). This is further supported by Ei-Gindy and Dorghan (1992) that phytoplankton and their growth depend on several environmental factors, which are variable in different seasons and regions. This kind of cyclic change in the species composition of phytoplankton was a characteristic feature of the Pichavaram coastal mangroves (Mani 1992).

The ranges of phytoplankton population density were: 1400-2,92,000 cells l^{-1} (St. 1); 750 -3,21,000 cells l^{-1} (St. 2) and 400-2,97,000 cells l^{-1} (St. 3) (Fig. 5a). The maximum density was recorded during summer and minimum during monsoon. The observed high density during the summer could also be attributed to more stable hydrographical conditions prevailed during that period. Station 2 showed comparatively high population density due to high nutrient concentrations and optimal salinity than at Stations 1 and 3 (Gouda and Panigrahy, 1996; Rajasegar *et al*., 2000). Further, the density showed a negative correlation with nutrients, which might be due to the utilization of nutrients by phytoplankton. It was noticed that the density value coincided with the values of species richness. The

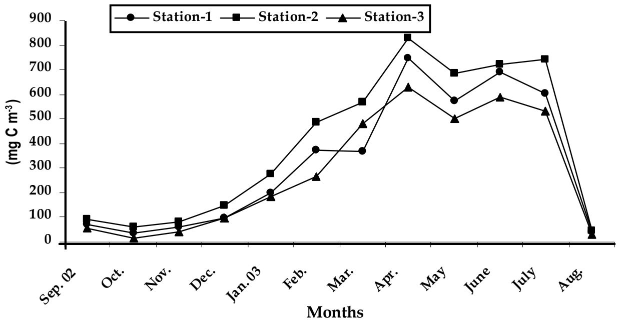

Fig. 6a: Monthly variations in gross primary production recorded from stations 1, 2 and 3

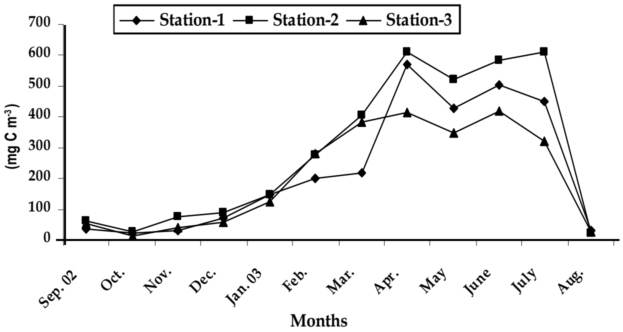

Fig. 6b: Monthly variations in net primary production recorded from stations 1, 2 and 3

population density was found to be higher in summer season at all the stations but the species diversity values were observed to be higher only in post monsoon and summer seasons and it may be due to the occurrence of allochthonous species during the season (Senthilkumar *et al*., 2002; Thillai Rajasegar *et al*., 2005).

The ranges of species diversity, richness and evenness at stations 1, 2 and 3 were: 3.20-5.23, 0.86-0.96 and 0.86-0.96 respectively (Fig. 5b-d). The least values of biodiversity indices were recorded during monsoon season, but were higher during other periods. A total of 94 species of phytoplankton identified in Pichavaram mangrove waters are often common and contributed significantly to the total abundance of phytoplankton, as reported in many coastal waters (Kannan and Vasantha, 1992; Gowda *et al*., 2001; Senthilkumar *et al*., 2002). Species such as *N. closterium*, *T. frauenfeldii*, *C. disculoidus*, *T. nitzschioides*, *R. alata*, *R. stolterfothii* and *A. glacialis* were noticed during the entire study period, implying their euryhaline and eurythermal nature. Most phytoplankton species occurred on a remarkable seasonal basis. Species from the genera, *Odontella*, *Coscinodiscus*, *Nitzschia*, *Thalassionema*, *Thalassiothrix*, *Rhizosolenia*, *Asterionellopsis*, *Navicula*, *Planktoniella*, *Pleurosigma*, *Skeletonema*, *Ceratium*, *Prorocentrum* and *Trichodesmium* were noticed at high numbers during all seasons except monsoon season in all the three stations, indicating their thermophilic nature. A few phytoplankton species (*P. elongatum*) was particularly abundant during monsoon season, indicating that these species are adapted to low temperature conditions. Thus, the seasonal occurrence of phytoplankton species may be closely associated with the species-specific environmental conditions that required to encystment or excystment. The occurrence of species from the genera: *Bacteriastrum*, *Cerataulina*, *Chaetoceros*, *Rhizosolenia*, *Ceratium*, *Protoperidinium* in Chinnavaikkal was conspicuous. The observed higher number and variety of phytoplankton species in the Station 1 might be influenced by the tidal ingression of species belonging to the adjacent sea, *i.e.*, Bay of Bengal, and these migration activities are limited in the mangroves due to the distance from the sea. Phytoplankton populations also respond to temperature and salinity variation. Thus, communities may show marked seasonal variation (Mani, 1992). In earlier studies at Pichavaram mangroves, there were 82 species of phytoplankton, which included 67 species of diatoms, 12 species of dinoflagellates and 3 species of blue-green algae were observed. The diatom forms the bulk, with 75% of the census, followed by the dinoflagellates with 15% (Kannan and Vasantha, 1992). Natural phytoplankton communities were dominated by *N. closterium*, *Pleurosigma* species, *T. nitzschioides* and *T. frauenfeldii* (Mani, 1992). Thirty one species were bloom formers with a predominance of *Rhizosolenia alata f. gracillima*, attaining a maximum bloom concentration of $2881X10^{7}\mu m^{2} l^{-1}$ (Mani *et al*., 1986). Unlike the estuary, the mangrove harbours many species of epiphytic diatoms attached to the submerged roots of vegetation, particularly woody species of *Rhizophora* (Krishnamurthy and Jeyaseelan, 1983). Phytoplankton biomass, productivity and size are closely tied diversity and abundance of higher trophic levels. The mangrove water had significantly richer nannophytoplankton than the estuary. Phytoplankton may make only small contributions to total productivity in estuarine mangrove waters, they may be critical to supporting higher trophic levels (Robertson and Blabber, 1992). This may be particularly true because of the high nutritional quality of phytoplankton relative to mangrove detritus. Phytoplankton are responsible for 5-10µm size contributed 33-51% of total chlorophyll *a* and 20-22% of the total gross production in the Vellar estuarine system of South India (Kawabata *et al*., 1993). Robertson and Blabber (1992) stated that phytoplankton productivity is significantly lower in estuarine mangrove areas than it is in lagoons or open embayments fringed by mangroves. Selvam *et al*. (1992) found phytoplankton productivity to be four times higher in mangrove waters than in adjacent marine waters in south India. In the present study, 88 phytoplankton species (73 species diatoms, 15 dinoflagellates) occur in all the stations. *C. disculoidus*, *A. gracialis*, *Pleurosigma* spp. *N. closterium*, *T. nitzschioides* and *T. faruenfeldii* are most abundant. 36 species of the bloom forming phytoplankton species were seasonally dominant. Thillai Rajasekar *et al*. (2005) observed the number of phytoplankton species increased consistently towards the outer region of the Bay of Bengal, where the salinity was high.

The observed species richness from all the stations is similar to that of phytoplankton population density and the maximum richness values were recorded during the post-monsoon and summer seasons and low richness during pre-monsoon season, as reported earlier by Rajasegar *et al*. (2000), in Vellar estuary. Further, Mani (1992) also reported a summer peak of phytoplankton production from Pichavaram mangroves, which he ascribed to the high salinity values. Presently, this is supported by the positive correlation

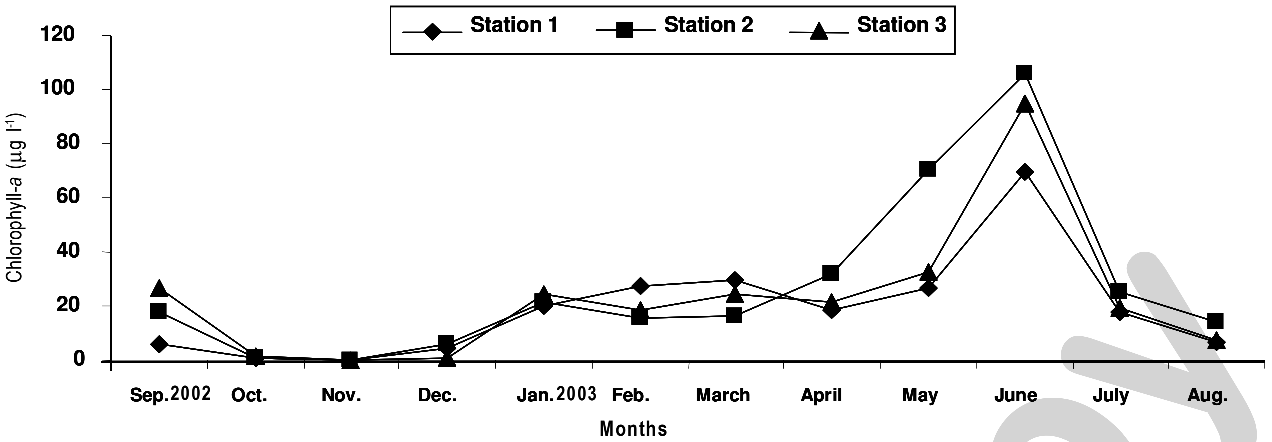

Fig. 7: Monthly variations in Chlorophyll *a* recorded from stations 1, 2 and 3

obtained between salinity and species richness (r=0.6911 at Station 1, r=0.5379 at Station 2 and r=0.5592 at Station 3). From the above, it is concluded that the Pichavaram mangroves is more fertile with rich phytoplankton productivity.

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