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DISTRIBUTION AND ABUNDANCE OF PHYTOPLANKTON IN VEMBANAD ESTUARY, A RAMSAR SITE ON SOUTH WEST COAST INDIA

S.Bijoy Nandan [*1], K.Sajeevan [2]
[*1] Department of Marine Biology, Microbiology & Biochemistry, School of Marine Sciences, Cochin University of Science & Technology, Cochin 682016, India
[2] Centre for Marine Sciences and Technology, M.S. University, Rajakkamangalam, Tirunelveli, Tamil Nadu, India

Abstract:
The phytoplankton abundance and distribution from the Vembanad estuary, south west coast of India was studied for a period of two years from March, 2011 to February, 2013. A total of 73 genera of phytoplankton were recorded and Bacillariophyceae formed the dominant group in all seasons of the study. The constant addition of nutrients particularly, nitrate and phosphate based fertilizers used in the Kuttanad paddy fields enhanced the phytoplankton production in the estuary. During 2011-2012 and 2012-2013 period, phytoplankton biomass varied from 2 to 46 ml/m3 (av. 11.09 ml/m3) and 1 to 26 ml/m3 (av. 5.78 ml/m3) respectively. Phytoplankton biomass, distribution and species composition showed variations in contrast to the prevailing water temperature, light intensity (Secchi disc visibility), nutrient availability, grazing pressure, tide and water movements, and seasonal pattern and even with time of day. The salinity regime of the water body also influenced the phytoplankton distribution in the study locations. Phytoplankton production showed a higher value in the northern as compared to the southern zone. Thus, the mesohaline condition prevailing in the northern zone of the estuary supported higher abundance and diversity of phytoplankton species which in turn contributed to higher production rate.

Keywords: *Distribution; Phytoplankton; Vembanad Estury.*

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1. Introduction

In any water body the most important link in food chain is plankton. Phytoplanktons are the primary producers of the pelagic marine ecosystems and some of the phytoplankton species may also reflect the ecological changes in the environment. Marine phytoplankton constitutes 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). Planktonic primary production provides the base upon which the aquatic food chains culminating in the natural fish populations,

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get exploited by man are founded, at the same time generating some 70% of the world's atmospheric oxygen supply (Reynolds, 1984). 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.

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, that has become a serious environmental problem in the world. Increased nitrogen loading has been associated with eutrophication affecting the 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 (Smith et al., 1999).The distribution of phytoplankton biomass is largely associated to nutrient availability at large, medium and small spatial scales by biophysical processes like the light environment, water column stratification/turbulence, temperature and grazing (Platt, 1972).Changes in the phytoplankton community representing an ecological succession also occur associated to such environmental gradients 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. In this context, this contribution elaborates the distribution and abundance of phytoplankton in the Vembanad estuary in relation to the prevailing water quality conditions.

2. Materials and Methods

2.1. Study Area

The Vembanad estuarine system (09˚00' -10˚40'N and 76˚00'-77˚30'E) spreads across three districts of Kerala – Ernakulam, Kottayam and Alappuzha – has a total surface area of 36,500 ha.The Thanneermukkom Barrage (TMB) was built in 1976 as a part of Kuttanad Development Scheme to prevent salinity intrusion in the dry season and retain a freshwater condition into the Kuttanad region so as to make it possible for the Paddy (*Punja*) cultivation. It has been relatively successful in ensuring freshwater conditions in Kuttanad and enabling cropping additional areas during dry seasons. The estuary has two permanent openings into the Arabian Sea - at Cochin and Azhikode. The Cochin gut is 450m wide at the same time Azhikode gut is 100 m (325 ft) wide and fairly deep (Fig. 1).

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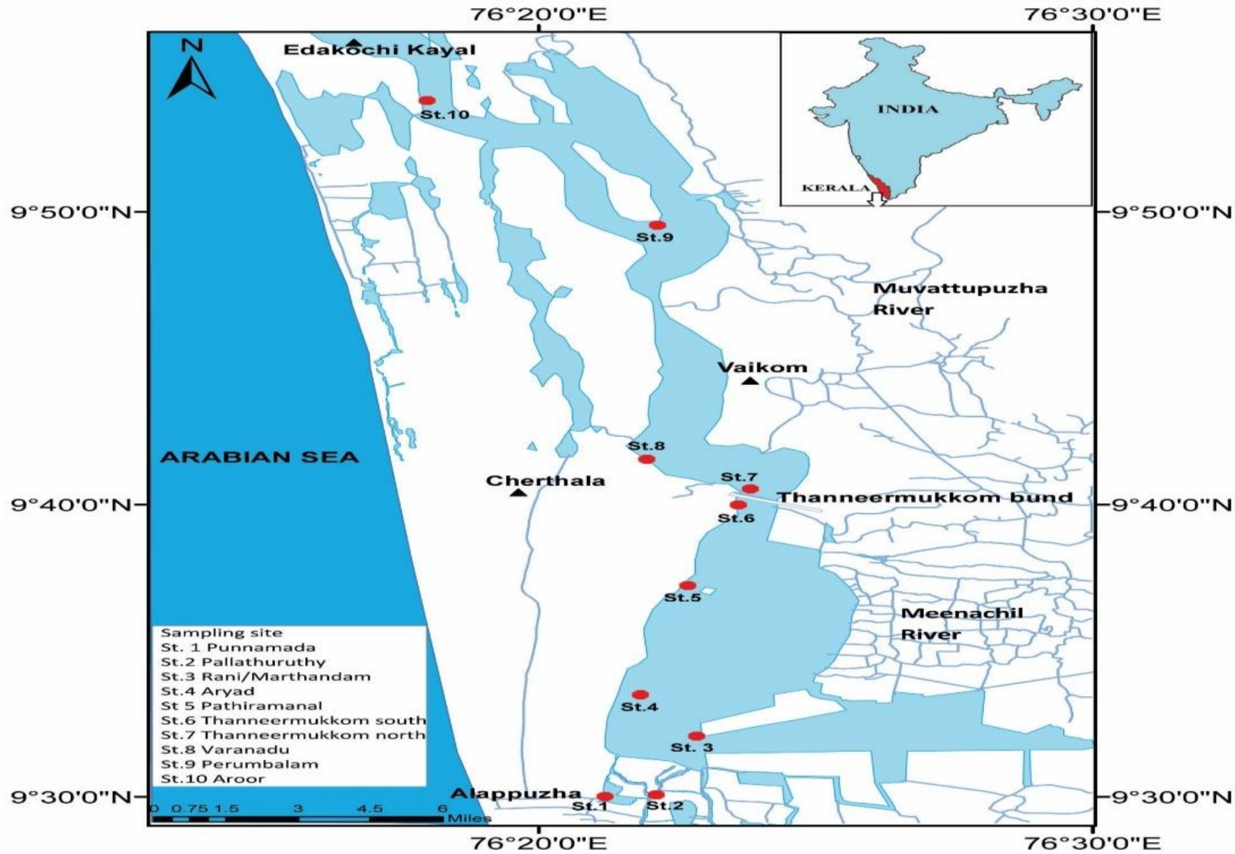

Figure 1: Map of Vembanad estuarine system indicating the study stations during 2011-13 period

2.2. Field Sampling and Analysis

Field sampling was undertaken for 24 months from March 2011 to February 2013 on a monthly basis for the collection and analysis of phytoplankton from the selected study stations in Vembanad estuarine system. The exact sampling locations were fixed by using Global Positioning System (GPS) based on its ecological importance and was statistically tested, with six stations on southern side and four onnorthern side of the TMB, extending from south, to the north of the estuary The study stations, St.1 Punnamada, St.2 Pallathuruthy, St.3 Rani/Marthandam, St.4 Aryad, St.5 Pathiramanal, St.6 Thanneermukkom South, St.7 Thanneermukkom North, St.8 Varanadu, St.9 Perumbalam and St.10 Aroor. The observations were made into three distinct periods, viz. premonsoon (PRM - February to May), monsoon (MN - June to September) and postmonsoon (PMN - October to January).The depth of the estuary ranged between1.4 to 8.5m with an average of 3.93 ± 1.93m.

The water samples were collected using a standard Niskin sampler (General Oceanics) of 5L capacity. Preservation and transportation of the water samples to the laboratory for analysis were based on standard methods (APHA, 2005).Samples for micro phytoplankton were collected by filtering 50 liter of sub surface water through 20μm sieve (Tait; 1998). Replicate samples were collected simultaneously and samples were preserved using 3% formalin and Lugol's iodine. Prior to the preservation the live sample was analyzed and microphotographs were taken. The biomass of plankton was determined based on the displacement method and was expressed as

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ml/m^3 (Davis, 1955) and samples were concentrated to 15ml for further studies (Tait, 1998). Standing crop was estimated by enumeration in Sedgewick-Rafter counting cell. For counting the requisite volume, the sample was transferred into a Sedgewick- Rafter counting cell. From the average values obtained the total count of each taxonomic group per m^3, population density and percentage abundance were computed. The enumeration and identification of plankton was done using a binocular microscope- Leica DM 500 (Subramanyan, 1946). Water quality assessment using phytoplankton was done using Palmers index (Palmer, 1969). The total number of microphytoplankton cells present was calculated per litre using the formula (Santhanam et al., 1989).

$$N = n \times v / V$$

Where,
N = Total number of microphytoplankton cells present per litre
n = Number of microphytoplankton cells in one ml
v = volume of plankton sample preserved in ml
V = Total volume of water filtered in litre

2.3. Data Analysis Tools

Two-way analysis of variance (ANOVA) was used to calculate the variation in different physico-chemical and biological parameters using statistical software SPSS version 16. Statistical analysis was carried out using the Plymouth Routines in Multivariate Ecological Research (PRIMER v6) software (Clarke and Gorley, 2006).In the present study, the data were analyzed for diversity index (H') using the following Shannon-Wiener's formula (1949), the Species richness (S) was calculated by Margalef index (1958).The equitability (J') evenness index was computed using the following formula of Pielou (1966).In the present study, to ascertain the relationship between biological and in particular to find out the influence of distribution of organisms, environmental variables, the BIO-ENV procedure (Clarke and Ainsworth, 1993) was employed. The basic principle behind this is to measure the agreement between the rank correlations of the biological (Bray-Curtis similarity) and environmental (Euclidean distance) matrices. A weighted Spearman rank correlation coefficient ($\rho\omega$) was used to determine the harmonic rank correlation between the biological matrix and all possible combinations of the environmental variables.

3. Results and Discussion

Seasonal average values of major physico-chemical parameters are given in Table 1. The lowest temperature of 28Cº was observed in Station 1, Station 2, Station3 and Station 4 and maximum of 33Cº in Station 9 and Station 10. The pre monsoon season (31.03 ± 1.14 Cº) showed the maximum temperature as compared to post monsoon (31.4 ± 0.68 Cº) and monsoon (30.25 ± 1 Cº). The average minimum temperature of 29.2 ± 0.95 Cº was recorded during February 2012 and maximum 32.05 ± 0.64 Cº during April 2012. The ANOVA of temperature showed that variation between seasons was significant ($F= 11.08, p < 0.01$). The transparency value ranged between 0.25m (March, 2012, Station 3) to 2.25m (December 2012, Station 6) with an average of 1.74m. The pH varied from 6.25 (August 2012, Station 1) to 10.02 (March 2012, Station 4).

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The mean pH of the estuarine system during the study period was 7.06 ± 0.56. The lowest mean value was recorded in August 2012 (6.37 ± 0.98), while highest in February 2012 (8.39 ± 0.66). Generally alkaline condition was observed in the northern sector of the estuary. On an average, pH of the study stations in the southern sector was 7.06, whereas that of the northern sector was 7.2. Compared to pre monsoon and post monsoon, a relatively low alkaline condition was observed during monsoon (6.72 ± 0.24). The ANOVA of pH showed that the variation between seasons were significant (F= 17.24, $p < 0.01$). The dissolved oxygen ranged from 4mg/l, recorded during November 2012 at station 1 and 2 to 9.6 mg/l, recorded during June at Station 2 and 8 with mean value of 6.8 ± 1.2 mg/l. When compared to stations of southern sector (6.78 ± 0.28 mg/l), higher dissolved oxygen values were observed in stations of northern sector (6.92 ± 0.14 mg/l). Maximum dissolved oxygen concentration was observed during monsoon (7.6 ± 1.3 mg/l) followed by pre monsoon (6.8 ± 1.1 mg/l) and post monsoon period (6.1 ± 0.87 mg/l). The ANOVA showed that seasonal variation of dissolved oxygen was significant (F= 16.57, $p < 0.01$).The maximum salinity of 33 ppt was observed in Station 10 and minimum 0.1 ppt in Station 2. The average salinity of 1.37 ± 2.1ppt was observed during the monsoon and followed by pre monsoon (7.58 ± 8.2 ppt) and post monsoon (7.89 ± 1.15 ppt) periods.

A total of 73 genera of phytoplankton were recorded during the study. Bacillariophyceae, Chlorophyceae, Cyanophyceae, Euglenophyceae, Zygnemophyceae, Chrysophyceae, Conjugatophyceae, Fragilariophyceae, Terbouxiphyceae, Dinophyceae were the major phytoplankton groups observed. Bacillariophyceae, Cyanophyceaeand Chlorophyceaewere represented primary by Coscinodiscussp., Melosirasp.,Campylodiscussp., Ulotrixsp., Oedogoniumsp., Spirulinasp; and Microsporasp., Pediastrumsp. etc. During the present study Bacillariophyceae(diatoms) formed the dominant group in all seasons. The annual mean percentage abundance of major phytoplankton genera is given in Fig. 2. Reports suggest that diatoms formed the most abundant group (>90%) in all the stations of Cochin estuary (Madhu et al., 2010).He found that optimum nutrients and light intensity during PRM enhanced the abundance of nanoplankton (Diatoms) community in Cochin estuary and during PM the low light availability and higher turbidity reduces the nanoplankton growth and abundance.

In the present study mean percentage abundance of Bacillariophyceae increased from 31.8% during PRM to 63% and 93.45% during MN and PM respectively. The density of Cyanophyceae was maximum during premonsoon (39.6%), while a sharp decrease was observed during MN (16.4%) followed by PM (1.5%).The heavy rain fall associated with low salinity and temperature might have influenced the distribution of Cyanophyceae. The percentage abundance of Chlorophyceae was found to be higher during PRM (29%) and decreased during MN (17.3%) and PM (5.2%). According to Dayala et al., (2013), the major phytoplankton group in Cochin estuary were diatoms>Dinoflagellates>Blue green algae>Green algae and its density was maximum during PRM.The mean standing crop of Bacillariophyceae was maximum in St.3 (205980 ind/m^3) and minimum in St.10 (23250 ind/m^3).Similar to Bacillariophyceae, Chlorophyceae were found to be higher in St.3 (18990 ind/m^3) and minimum in St.10 (2670 ind/m^3).Station 3, Rani- Marthandam was influenced by agricultural activities mainly by the location of the paddy fields in the surrounding area. The constant addition of nutrients particularly by nitrate and phosphate fertilizers used in the paddy fields enhances the phytoplankton production. According to Williams and Tonnessen, (2000), the increased nitrate and phosphorus concentrationleadsto increase in the phytoplankton levels. This is because they

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are both basic necessities for phytoplankton growth and development. Cyanophyceae was maximum in St.4 (14010 ind/m^3) and minimum in St. 10 (2490 ind/m^3). In the present study Ulotrix sp.was dominant group during PRM (25.3%) and MN (18.3%). During postmonsoon, the Melosira sp.dominated over the other groups and contributed 44%.It was reported that excessive growth of algal genera, Melosira indicate nutrient enrichment of aquatic bodies (Zargar and Ghosh, 2006). The genera like Euglena, Oscillatoria, Scenedesmus, Nitzchia and Navicula are generally found in organically polluted waters (Panigrahi et al., 2001). During 2011-2012 period phytoplankton biomass varied from 2 to 46 ml/m^3 with an average value of 11.09 ml/m^3. The maximum of 46 ml/m^3 was observed in St.3 during March 2011. Mean value of phytoplankton biomass was maximum in St.3 (15.5 ml/m^3) and minimum 8 ml/m^3 in St.8 and monthly maximum average value (26.6 ml/m^3) was observed during March 2011 and minimum (4.6 ml/m^3) during November 2011. During 2012-2013 period, the phytoplankton biomass varied from 1 to 26 ml/m^3 with an average value of 5.78 ml/m^3. The minimum average (3.71 ml/m^3) was observed in St. 5 and maximum was in St.1 and St.10 (7.25 ml/m^3). Monthly variation showed that maximum average value (12 ml/m^3) was observed during March 2012 and minimum (2.15 ml/m^3) during January 2013.

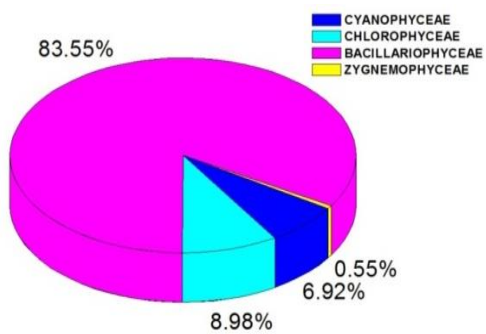

Figure 2: Annual mean percentage abundance of phytoplankton observed in Vembanad

Estuarine system during 2011-2013

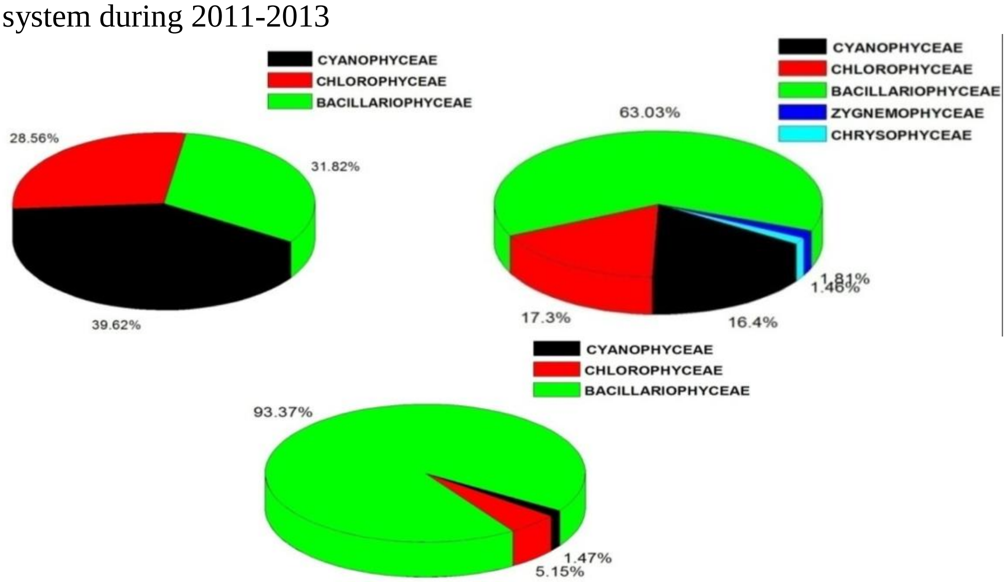

Figure 3: Seasonal mean percentage abundance of phytoplankton during a) premonsoon, b) monsoon, c) postmonsoon in Vembanad estuarine system during 2011-2013

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Nair et al., (1975) reported that in Alappuzha region the average number of phytoplankton were higher with the presence of Ceratulina, Chaetoceros and Skeletonema. The migration of euryhaline species of Chaetoceros and Skeletonemawas also reported here. It was also reported that the fresh and brackish water form of phytoplankton dominate in southern region mainly due to the establishment of stable optimum environmental conditions. During monsoon the fresh water species such as Pledorina, Pediastrum, Scenedesmus, Zygnema, Oscillatoria, Cosmarium, Desmidium and Staurastrum contributed maximum in the south (Nair et al., 1975) and during post monsoon *Cerataulinabergonii*wasdominant in south (Joseph and Pillai, 1975). During the present study,Oscilatoria, Ulotrix sp., Melosira, Microcysts sp., Dinobryon sp. were the major dominant phytoplankton groups. Joseph and Pillai, (1975) reported that,Chaetoceros sp. which is adapted to higher salinity were dominant during premonsoon and its bloom occurred in south when salinity was 15 to 24ppt. In the present observation, the abundance of Chaetoceros sp. was negligible in the southern part of TMB. The average salinity in the southern part of estuary was 2.45 ppt. that influenced the distribution of phytoplankton in the estuarine system. The dominant species such as Pediastrum sp., Ulotrix sp., Melosira sp., Microcysts sp. and Coscinodiscus sp., were recorded during the present study but not recorded from the previous studies by Joseph and Pillai, (1975). Pediastrum sp., disappeared when salinity reaches upto 6-7ppt (Schernewski and Schiewer, 2002), showing its stenohaline nature. Other species of the genera Melosira, Campylodiscus, Coscinodiscuswere observed in the present study that was euryhaline in nature.In the estuarine waters of Mangalore, Madhavi et al., (2014) observed salinity tolerance of 0.03 to 35.3 ppt for Melosira, Campylodiscus and Coscinodiscus. Thus, a comparison was attempted to study the phytoplankton composition during the prebarrage and post barrage phase of TMB (Table 1).During monsoon season, Cyanophyceaewas dominant in southern stations which may be due to the nutrient rich flood water that occurred during monsoon season. Major activities in the floodwater include photosynthesis and respiration, and photo-dependent biological N_2 fixation by free-living and symbiotic cyanobacteria.

Table 1: Variation in major groups of phytoplankton in Vembanad estuary,before and after commissioning of the TMBduring 2011-13 period

Joseph &Pillai, 1975	**Anon, 2001**	**Present Study**
Chaetoceros sp.	Spirogyra sp.	Pediastrum sp.
Ceratium sp.	Microspora sp.	Ulotrix sp.
Synechococcus	Botryococcus sp.	Oscilatoria sp.
Nitzschia sp.	Anabena sp.	Melosira sp.
Surirella sp.	Lyngbya sp.	Campylodiscus sp.
Gyrosigma sp.	Desmidium sp.	Microcysts sp.
Synedra sp.	Micrasterias sp.	Coscinodiscus sp.
Thalassiosira sp.	Stuarastrum sp.	
Merismopedia sp.		
Fragilaria sp.		

In the present study Margalefrichness index (d) values varied between 0.64 and 1.3. The minimum value was noticed in st.3 and maximum in St.1. Pielou's evenness index (J') was found to vary from a minimum value of 0.19 in St.6 to a maximum of 0.62 in St.9. Shannon Wiener index varied from 0.63 to 1.59 with minimum value in St.6 and maximum in St.9. Dash, (1996),

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reported that the higher value of Shannon index (H') signifies the planktonic diversity. Bajpai, (1997) reported that the low diversity of the species would be due to the disturbance in the system. Adesalu and Nwankwo, (2008), reported that the low value of Shannon index of phytoplankton population in rainy season is due to dilution of area. While a great diversity indicates mature settlements, the low diversity index shows a weak internal structure of populations. Hendley, (1977) used the Shannon index as pollution index in diatom communities and puts forward the following scale: of 0–1 for high pollution, of 1–2 for moderate pollution, of 2–3 for small pollution, and of 3- 4 for incipient pollution. Wu, (1984), used phytoplankton as bio indicator for water quality in Taipei, Taiwan where diversity index of phytoplanktonic community was correlated in some cases with the degree of pollution. This was also similar with the results obtained in the Changjiang estuary, China (Gao and Song, 2005). Shannon diversity index of phytoplankton greater than 3 indicates the suitability of water for growth and sustenance of phytoplankton (Tahami et al., 2012).The diversity index from this study also revealed that the water of the estuary is not good for growth and sustenance of phytoplankton. It may undergo severe disturbance due to water quality deterioration.

Distribution patterns of phytoplankton were strongly correlated with environmental factors (Lepisto et al., 2004). The relationship between phytoplankton diversity and environmental factors has great importance in assessment of pollution status (Buric et al., 2007) and identification of the main factors controlling phytoplankton in a particular water body that was essential for choosing an appropriate method for maintenance of desired ecosystem state (Peretyatko et al., 2007). Its distribution is influenced by several mechanisms other than local conditions and resource availability (e.g. dispersal, species strategies and biological interactions), the environmental variability that may comprise much of the explanation for local community structure (Vanormelingen et al., 2008). The BIOENV analysis identified the rank correlations between environmental factors and phytoplankton abundance data.The single environmental variable which best correlated with the phytoplankton patterns was PO_4-P (ρ = 0.642). The BIOENV analysis (Table 2and Fig. 4.)revealed that phytoplankton community pattern was best explained by factors such as PO_4-P (ρ= 0.454) followed by N-NO_3 (ρ = 0.365), salinity (ρ = 0.340), temperature (ρ= 0. 206) and N/P ratio (ρ = 0.114). According to Rothenberger et al., (2009) phytoplankton assemblages were strongly related to temperature and total nitrogen and total phosphorus ratios, with expected seasonal changes in species composition in Neuse river estuary, North Carolina. Temperature showed the highest affinity to phytoplankton distribution (ρ= 0.37).

Table 2: Results of the BioEnv analysis for the relationship between phytoplankton community and environmental variables

Sl. No	**Variables**	**Variables selected**	**Best correlation values (Rho)**
1	pH	5	0.642
2	Temp.	2, 5, 8	0.640
3	Salinity	1, 2, 5, 8	0.618
4	DO	1, 5	0.613
5	Phosphate	1, 2, 5, 9	0.608
6	Silicate	1-3, 5, 8	0.598
7	Nitrate	2, 3, 5, 8	0.594
10	Biomass	1, 2, 5, 8, 9	0.591

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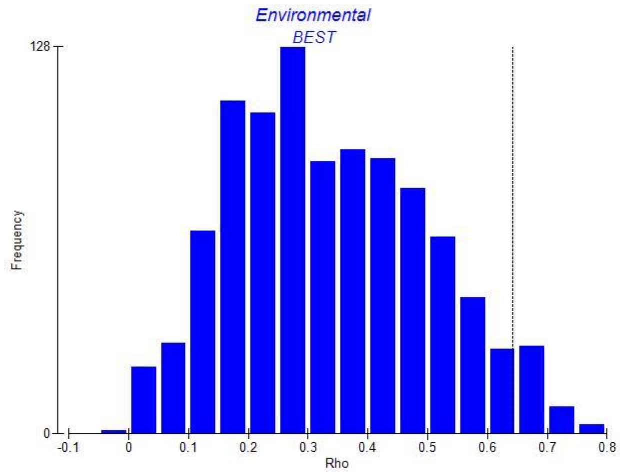


Figure 4: Bio Env analysis for the relationship between phytoplankton community and environmental variables

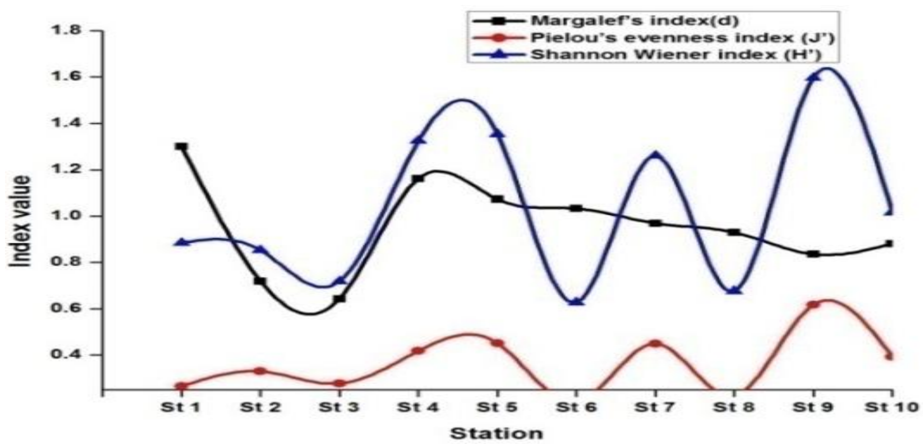
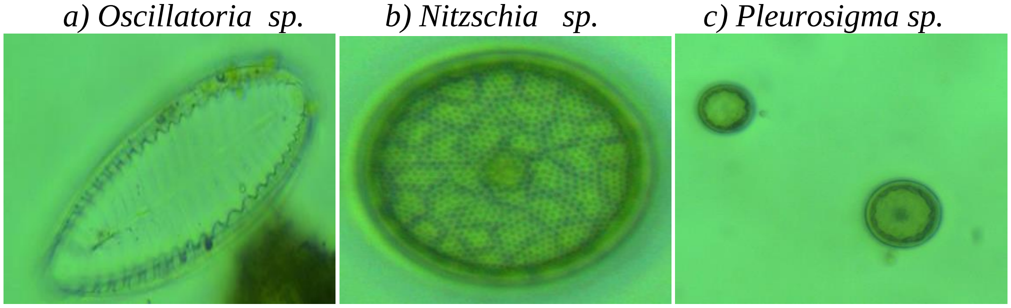


Figure 5: Phytoplankton diversity indices of Vembanad estuarine system during 2011-2013.

a) Oscillatoria sp. *b) Nitzschia sp.* *c) Pleurosigma sp.*



d) Surinella sp. *e) Coscinodiscus sp.* *f) Coscinodiscus sp.*

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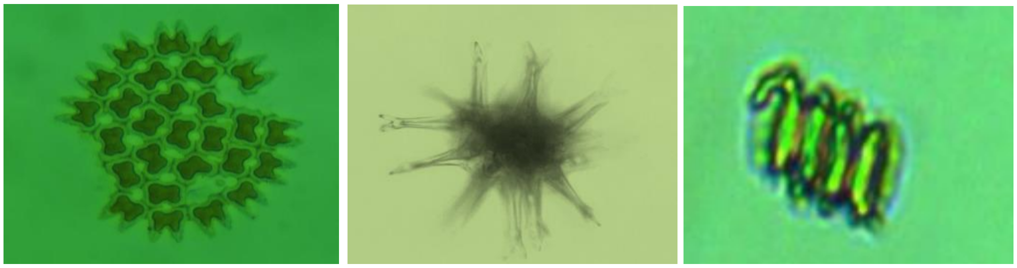
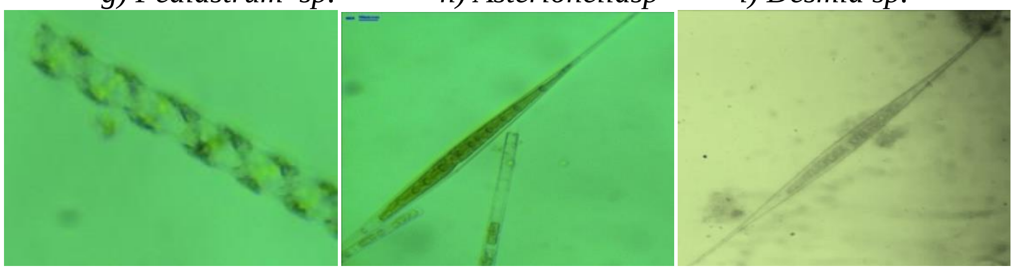


g) Pediastrum sp. *h) Asterionellasp* *i) Desmid sp.*



i) Spirogy ra sp. *j) Closteriopsis sp.* *k) Closteriopsis sp.*

Plate 1: Images of major phytoplankton observed in Vembanad estuarine system during 2011-2013 periods

Algal pollution indices were developed for use in rating water samples for high or low organic pollution (Palmer, 1969). Based on the Palmer's index in Vembanad estuary pollution tolerant genera were represented by Chlorella, Closterium, Cyclotella, Euglena, Gomphonema, Melosira, Navicula, Nitzschia, Oscillatoria and Scenedesmus. For obtaining the index, the pollution index factors of the algae present were observed. A Palmer index score of 20 or more for a sample is taken as evidence of high organic pollution, while a score of 15 to 19 is taken as probable evidence of high organic pollution (Palmer, 1969)(Table 4). So, from the present study the index value (index value 27) represented higher organic pollution in Vembanad estuarine system. Bioindicators are taxa or groups of organisms that show signs that they are affected with environmental pressure because of human activities or the destruction of biotic system (McGeoch, 1998). Since a biotic community is the outcome of the integration and interaction of different physical, chemical and geo-morphological characteristics of any water body, biological assessment is a useful alternative in assessing those systems (Stevenson and Pan, 1999). Due to the short life span and quick response to pollutant algae are used for rapid bioindicator of water quality (Sonnemanet al., 2001).The pollution from the houseboats is affecting the environment and ecosystem of the Vembanad estuary mainly by sewage from toilets, oil from engines, plastic wastes and food wastes etc. (SafooraBeevi and Devadas, 2014) enhance the organic load into the water column. The rise in the houseboat industry, which now has more than 1000 boats, has led to trigger the organic pollution of the system. The major source of pollution in Vembanad estuary is the solid wastes and sewage wastes. Sewage discharge from hanging toilets is a feature observed especially along the banks of Vembanad estuary. The agricultural fertilizers from the Kuttanad region may also be increasing the pollution load in the estuary.

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Table 3: Algal genus pollution index in Vembanad estuarine system

Sl. No.	**Algal Genus**	**Pollution Index**
1	Chlorella	3
2	Closterium	1
3	Cyclotella	1
4	Euglena	5
5	Gomphonema	1
6	Melosira	1
7	Navicula	3
8	Nitzschia	3
9	Oscillatoria	5
10	Scenedesmus	4
Total		27

Table 4: Pollution index score for phytoplankton based on Palmer (1969)

Pollution Index Score20 or more	Indicate high organic pollution
Pollution Index Score 15 to 19	Indicate probable organic pollution
Pollution Index Score15	Indicate less organic pollution

4. Summary and Conclusion

In the present observation a total of 73 genera of phytoplankton were observed. Diatoms were the major group in the study period. Coscinodiscus sp., Melosira sp., Campylodiscussp., Ulotrix sp., Oedogonium sp., Spirulina sp; and Microspora sp., Pediastrum sp. were the abundant forms of phytoplankton. During postmonsoon, the Melosira groups dominate over the other groups and contributed 44%. Shannon diversity was high (1.59) in station 10, situated on the northern zone of Thanneermukkom barrage and a minimum value of 0.63 was in station 6 located on the southern zone of barrage. Margalef's index (d) ranged from 0.643 to 1.3 with minimum value in station 3 and maximum in station 1. BIOENV analysis revealed that environmental parameters have strong correlation with phytoplankton assemblage structure. Phosphorus, temperature, pH and net primary productivity were the variables best explained the phytoplankton spatial assemblages in the estuary (ρ = 0.642). Phytoplankton composition during the prebarrage and post barrage phase revealed that several groups of phytoplankton were disappearing during the study period.

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*Corresponding author.
E-mail address: bijoynandan@ yahoo.co.in