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Hydrographic, seasonal diversity, distribution and abundance of phytoplankton in coastal waters off Cochin - south-eastern Arabian Sea

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Phytoplanktons are the key primary producers in the ocean; their growth mainly depends on various physico-chemical parameters. In this study, a total of 73 species of phytoplanktons from 48 genera were identified from Cochin coastal waters. Diatoms dominated the phytoplankton community followed by dinoflagellates. *Asterionellopsis glacialis, Chaetoceros decipiens* and *Chaetoceros curvisetum* were the major diatoms noticed during the study period. The results revealed relatively high species diversity in the pre-monsoon season when compared to monsoon and post-monsoon seasons. The hierarchical multidimensional scaling of phytoplankton communities using PRIMER 6 revealed maximum similarity between the species from stations 1 and 2 during monsoon season. The canonical correspondence analysis was done using PAST version 2.17c. The results showed that post-monsoon stations were characterized by high dissolved oxygen, low temperature, phosphate, ammonia and silicate. Phytoplanktons, such as *Rhizosolenia sp., Thalasionema sp., Navicula sp.* were found to be strongly linked to these parameters. A bloom of *Skeletonema costatum* was also observed during the study period.

[**Keywords:** Phytoplankton, Coastal water, Monsoon, South-eastern Arabian Sea]

Introduction

Cochin coastal waters are one of the most studied areas of Arabian Sea as it is influenced by increasing industrial development and rapid urbanization. Increase in anthropogenic activities such as urbanization, tourism and marine transportation are the main reasons that contribute to significant changes in coastal water quality[1]. A number of investigators[2,3,4] studied the hydrographic characters of Arabian Sea as an attempt to understand the factors affecting the marine biodiversity. The major environmental factors that influence the life of marine organisms are: Salinity, dissolved oxygen, turbidity, pH, and temperature. The south-west monsoon provides a large amount of freshwater influx along with huge quantities of suspended matter to the west coast of India; and this may change the chemical and physical properties of marine environment resulting in seasonal changes in phytoplankton community[5,6]. The phytoplankton growth mainly depends on the spectral composition of light, irradiance, salinity, temperature, the concentration of nutrients and several other biotic and abiotic factors[7, 8].

Currently, the researchers focus mainly on the effects of global changes in physico-chemical parameters, their relationships with the phytoplankton community structure, and stoichiometry[9,10]. Being the major primary producer, the health of phytoplankton community is very important for all other organisms of the marine ecosystem. The phytoplankton cells have an average ratio of C, N and P which is approximately 106:16:1. This Redfield ratio explains the relationship between primary production and dissolved nutrient concentration in an aquatic ecosystem[11,12,13]. The vertical stratification, physical parameters and dependent biological reactions also have an effect on future phytoplankton productivity[14,15]. The present study is an attempt to understand the seasonal changes of physico-chemical parameters, phytoplankton abundance and changes in community structure of phytoplankton in Cochin coastal waters.

Materials and Methods

Study area

The present study was carried out in the coastal waters of Cochin, along the south-west coast of India Figure 1. The coastal waters of Cochin form a multi-dimensional system where the dynamic processes are rarely in equilibrium. Compared to the Cochin open

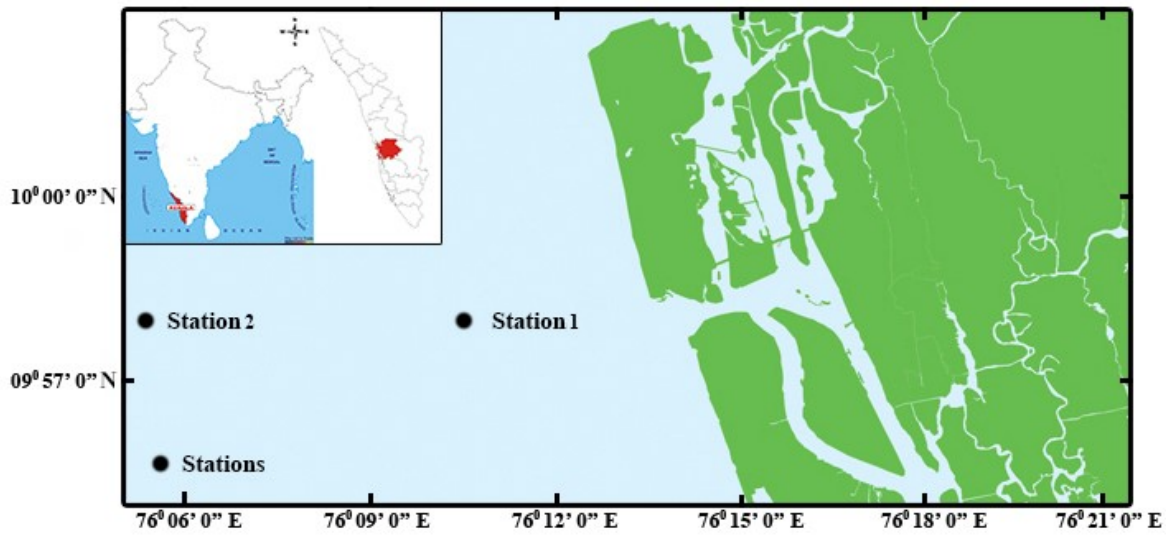

Fig. 1 — Map showing study area

ocean systems, the coastal waters exhibit spatial and temporal environmental gradient on micro- or macro-scale[16].

The study was conducted for two years ranging from post-monsoon 2013 to monsoon 2015, and the samples were collected seasonally on board a seaworthy fishing boat hired for sampling. Surface and sub-surface water samples were collected from two stations based on depths, 10 m (9°58'457"N and 76°09'749"E) and 30 m (9°58'229"N and 76° 03'750" E). A sub-surface water sample of 10 m station was collected from a depth of 8 m and that of 30 m station was collected from 27 m. Water samples from surface and sub-surface were collected using Niskin water sampler and were preserved in an ice box for further analysis.

Analysis of physico-chemical parameters

The physico-chemical parameters such as temperature, pH and salinity were measured on board. The temperature was measured using a mercury bulb thermometer with an accuracy of ±0.01 °C and the salinity was measured using a hand-held refractometer (Atago, S/Mill – E, Japan). The dissolved oxygen (DO) was determined by modified Winkler's method[17] and the nutrient parameter such as ammonia was measured as per modified standard protocol[18]. The concentration of nitrite, nitrate, phosphate and silicate were measured as per standard procedure[19].

Analysis of phytoplankton

For the collection of phytoplankton, 15 l of surface water was filtered through phytoplankton net (20 µm) and samples were preserved in Lugol's Iodine. Siphoning procedure was used to concentrate the sample, and planktons per ml were counted using Sedgewick-Rafter counting cell. Species level identification was carried out using a light microscope (Leica DM 2000 LED) and characterized as per standard identification manuals[20,21,22,23,24,25,26,27,28].

Statistical analysis

The results were subjected to hierarchical multidimensional scaling (MDS) analyses to identify the similarity of phytoplankton communities between stations. This was calculated as Bray-Curtis similarity index using PRIMER version 6[29]. The canonical correspondence analysis (CCA) was done using Paleontological Statistics Software package for education and data analysis (PAST) version 2.17c.

Results and Discussion

The physico-chemical parameters and phytoplankton abundance of Cochin coastal waters were compared to reveal the factors affecting phytoplankton community structure. The observed physico-chemical parameters of Cochin coastal surface and sub-surface waters are shown in Table 1. The temperature varied between 24.67 and 31.3 ºC showing a variability of about ~6.6 ºC. During study

Table 1 — Physico chemical parameters of study area

Seasons	Station	S/ SS	Temperature (ºC)	Salinity (‰)	pH	DO (mg L^{-1})	Nitrate	Nitrite	Ammonia	DIP	Silicate
							(μmol L^{-1})				
Post-monsoon 2013	Stn 1	S	27.30	29.50	8.34	8.80	3.34	0.04	1.46	0.29	11.27
		SS	26.80	31.00	7.96	6.40	1.87	1.33	2.53	0.53	6.45
	Stn 2	S	27.40	32.00	8.06	7.20	1.10	0.17	0.17	0.19	2.61
		SS	27.20	30.00	7.80	6.40	1.17	0.12	0.11	0.24	3.94
Pre-monsoon 2014	Stn 1	S	28.20	30.00	7.58	4.96	0.20	0.18	0.41	0.55	8.40
		SS	27.50	35.00	7.34	3.76	2.75	1.09	1.23	1.81	8.45
	Stn 2	S	28.50	35.50	7.83	7.56	0.09	0.06	0.85	0.25	3.48
		SS	27.60	35.00	8.19	6.69	0.05	0.20	1.29	0.28	4.62
Monsoon 2014	Stn 1	S	28.50	23.10	7.20	7.20	0.48	0.07	10.00	0.39	11.86
		SS	28.20	30.90	7.00	7.20	0.26	0.15	6.98	0.55	7.87
	Stn 2	S	27.90	34.00	7.50	6.80	0.91	0.15	7.14	0.83	11.51
		SS	28.10	34.00	7.40	4.80	0.95	0.28	3.95	1.46	11.37
Post-monsoon 2014	Stn 1	S	29.21	33.88	7.00	4.53	0.20	0.18	0.41	0.55	4.21
		SS	29.06	34.39	6.90	3.67	2.75	1.09	1.23	1.81	6.01
	Stn 2	S	29.06	30.95	7.10	4.50	0.09	0.06	0.85	0.25	2.78
		SS	28.98	34.77	7.00	4.43	0.05	0.20	1.29	0.28	2.67
Pre-monsoon 2015	Stn 1	S	31.30	31.70	8.12	6.40	2.25	0.30	0.62	0.50	3.51
		SS	31.20	33.40	8.01	4.80	2.40	0.20	0.87	0.84	1.73
	Stn 2	S	30.87	33.75	8.20	4.50	1.04	0.11	0.14	0.43	2.44
		SS	27.74	35.01	7.95	3.16	2.69	1.04	0.66	0.64	5.22
Monsoon 2015	Stn 1	S	25.49	29.94	7.60	8.20	1.86	1.11	6.24	0.70	8.29
		SS	24.67	33.83	7.60	6.00	2.16	0.89	9.61	0.84	7.60
	Stn 2	S	28.62	26.12	7.60	4.86	0.14	0.11	1.53	0.09	2.61
		SS	25.65	35.23	7.60	1.34	16.35	1.18	1.54	1.60	11.60

S - Surface, SS - Subsurface

period, the highest temperature was observed in surface water of pre-monsoon season and lowest from sub-surface water in monsoon season. The comparison of our observation with the previous studies showed that there were no significant variations in surface and sub-surface waters off Cochin[30,31,32,33].

Salinity is one of the important factors which influence the chemical and physical properties of coastal waters. Surface salinity was found to be lower than the sub-surface waters and ranged between 23.1 ‰ and 35.5 ‰. This may be because of fresh water influx through Cochin Barmouth to surface water and northerly coastal current which brings low saline water to the surface[16]. These findings were in strong agreement with the earlier studies[34,35]. Relatively high salinity was observed in surface waters during pre-monsoon season and low during monsoon season.

The surface water pH remained alkaline throughout the study period. Seasonal pH variations showed that monsoon has low pH values. Sub-surface water showed low pH when compared to the surface waters. Another major factor which affects the community structure of the aquatic organisms is DO. In the present study, the DO varied between 1.34 mg $L^{-1}$and 8.8 mg L^{-1}. Even though the surface layers are receiving a large amount of fresh water in monsoon season, the lowest concentration of sub-surface DO was observed in the same season. This may be because of the absence of vertical mixing due to density stratification and oxidation of organic matter[36]. The DO concentration showed negative correlation with the salinity; minimum DO coincides with the maximum values of salinity.

There are some other inorganic substances which help to support the life in ocean system. Among the nitrogenous nutrients, nitrate, nitrite and ammonia are the major nutrients that play a major role in phytoplankton growth and abundance[10]. The concentration of nutrients in the surface layers is an

important factor that affects the productivity of a region[16]. During the study period, various nutrients (nitrite, nitrate, phosphate, silicate and ammonia) were analysed. The nitrite concentration ranged between 0.04 and 1.33 µmol L^{-1}. The nitrate values varied from 0.05 to 16.35 µmol L^{-1}. The phosphate concentration ranged from 0.09 to 1.81 µmol L^{-1}. The concentration of phosphate in coastal water varies with the interaction between the water column and the sediment, and it is also influenced by the monsoon rainfall[37,38,39]. High concentration of nitrate and phosphate may be due to the addition of nitrogenous nutrients mainly by fresh water and terrestrial runoff during pre-monsoon showers[40,41]. High concentration of silicate was recorded during monsoon and low concentration during pre-monsoon periods. The concentration of silicate varied from 1.73 to 11.86 µmol L^{-1} and concentration of ammonia varied between 0.11 and 10 µmol L^{-1}. Higher values of silicate during monsoon season may be because of the addition of silica materials by land runoff caused by flooding[42].

The distribution and succession of phytoplanktons are influenced by physical parameters, seasonal variations in rainfall and its subsequent effect on the spatial distribution of salinity[43]. The effects of environmental factors on population dynamics of phytoplankton have been studied earlier[44,45,46,47,48]. The present study results showed that diatoms dominate the phytoplankton community followed by dinoflagellates in all stations of Cochin coastal waters. This study enumerated six classes of phytoplankton, identified as Bacillariophyceae, Mediophyceae, Coscinodisco-phyceae, Dinophyceae, Cyanophyceae, and Chlorophyceae. Nearly 99% of phytoplankton identified during this study was coming under diatom and Chlorophyceae was the least dominant class. Maximum species diversity was observed in the post-monsoon season compared to other seasons. *Asterionellopsis glacialis, Chaetoceros decipiens, Chaetoceros curvisetum, Coscinodiscus* sp., *Cyclotella* sp., *Ditylum brightwelli, Odontella mobiliensis, Odontella sinensis, Leptocylindrus danicus, Rhizosolenia* sp., and *Skeletonema costatum* were the major diatoms identified and *Ceratium furca* and *Prorocentrum* sp. were the major dinoflagellates.

During the seasonal studies of phytoplankton, the *Skeletonema costatum* bloom was observed in early pre-monsoon season; water salinity and temperature were 30 ‰ and 28.2 °C, respectively; where as the optimum salinity and temperature of bloom was reported as 18~35 ‰ and 19~32 °C, respectively[49]. During the bloom, the concentration of NH_4-N (0.41 µmol L^{-1}), NO_3-N (0.20 µmol L^{-1}), PO_4-P (0.55 µmol L^{-1}) and SiO_3-Si (8.4 µmol L^{-1}) of surface water declined gradually from normal concentrations. The bloom was in a dying stage while sampling, the observed pH was 7.58 and the DO of bloom station was 4.96 mg L^{-1}. For the phytoplankton *Skeletonema costatum*, the growth was most stimulated by high nitrate and optimum phosphate concentration present at station during this season[50,8]. The previous studies reported that the *Skeletonema* sp. bloom was observed in low saline waters of west coast of India[5,51] and the occurrence of lower temperature also considered as a major factor in blooming[52]. The increased silicate concentration is due to the presence of siliceous frustules of diatoms[53]. During summer monsoon through river runoff and coastal upwelling, the coastal waters are enriched with nutrients that concomitantly trigger plankton production[54].

Community structure analysis of phytoplankton showed that diversity, richness, evenness and dominance were high in pre-monsoon followed by post-monsoon and monsoon seasons (Fig. 2). The indices were calculated excluding the bloom. The dilution of water during monsoon season and zooplankton grazing might affect the phytoplankton density and richness[55]. Evenness index of phytoplankton

showed that there are no significant variations in values. The species evenness was more or less the same in all the stations during the study period. The concentration of silicate showed a negative relationship with the phytoplankton richness in summer seasons. It might be due to the increase in phytoplankton especially diatoms and increase in uptake of silicate by the phytoplankton for biological activity[56].

In the MDS plot analysis of phytoplankton abundance, the stations and sampling periods were shown to be clearly distinct at 0.12 stress level. The Bray-Curtis similarity showed the lowest similarity of 17.21% between station 2 of pre-monsoon season during 2015 and all other stations from Cochin. Stations 1 and 2 showed maximum similarity during monsoon season (84.6%) followed by pre-monsoon 2015 (81%) and post-monsoon 2014 (61.31%). From Figure 3, there is no significant difference in faunal assemblage in two stations of pre-monsoon and monsoon 2015.

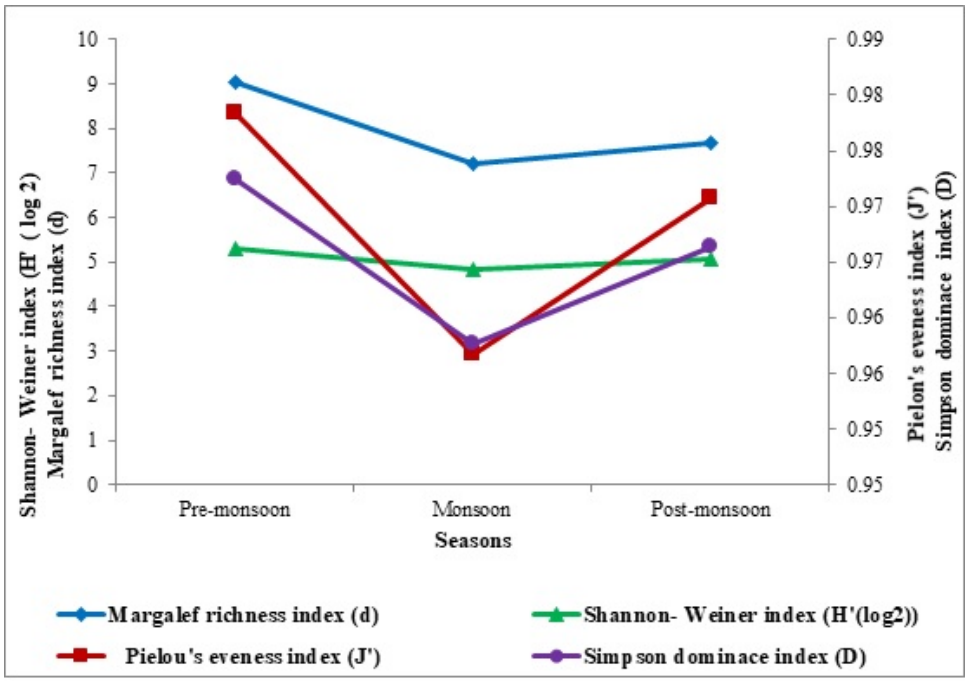

Fig. 2 — Seasonal community structure of phytoplankton during study period.

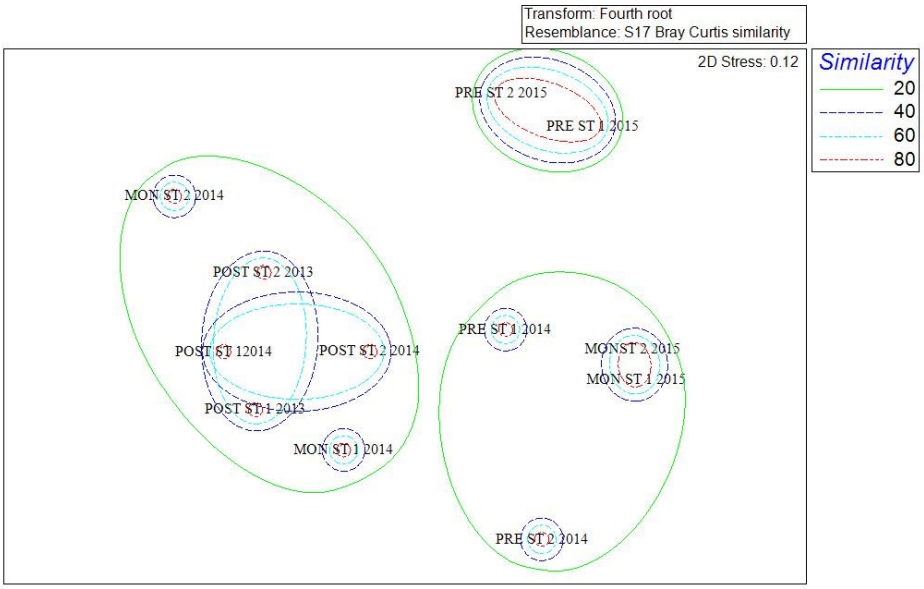

Fig. 3 — MDS plot displaying the clustering of stations based on species similarity.

However, comparing the results of two stations in pre-monsoon and monsoon during 2014, the phytoplankton assemblage similarity was nearly 20%. From the plot, it could be further summarised that post-monsoon seasons showed similarity in faunal assemblage.

Based on CCA shown in figure 4, post-monsoon stations are characterized by high DO, low temperature, phosphate, ammonia, and silicate. Phytoplanktons such as *Rhizosolenia* sp., *Thalasionema* sp., *Navicula* sp., which were well distributed at these stations, were found to be strongly linked to these parameters. Pre-monsoon stations are characterized by low DO, high temperature, phosphate, ammonia, and silicate. *Nitzschia* sp., *Coscinodiscus radiatus, Gyrosigma* sp.,

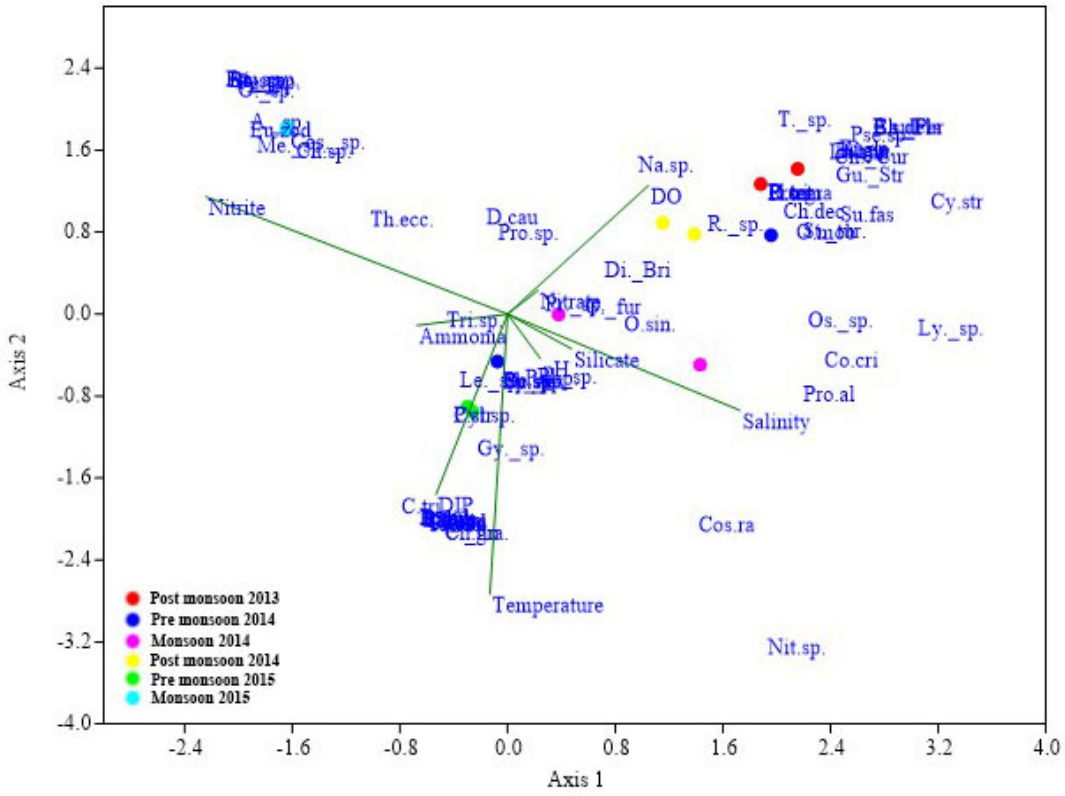

Fig. 4 — Canonical Correspondence Analysis (CCA) showing scatter plot.

Leptocylindrus sp., *Triceratium* sp. showed high correlation with these conditions. The monsoon 2014 stations were strongly influenced by high concentrations of salinity and silicate comparatively, and phytoplankton species such as *Coscinodiscus* sp., *Proboscia alata*, *Corethron criophilum* and *Lyngbya* sp. which were well distributed at these stations showed high correlation with these conditions.

Conclusion

The present study identified 73 species of phytoplanktons from 48 genera. A bloom of *Skeletonema costatum* was identified in pre-monsoon season during 2014. Spatio-temporal analysis of phytoplankton community composition showed that Class: Mediophyceae dominated all other classes. The statistical analysis of community structure showed that diversity, evenness, richness and dominance of phytoplankton were the highest in pre-monsoon season and minimum in monsoon season. *Skeletonema costatum, Chaetoceros* sp., *Chaetoceros constrictus, Chaetoceros curvisetus, Coscinodiscus* sp., *Rhizosolenia hebetata, Asterionellopsis glacialis, Pseudo-nitzschia* sp., and *Biddulphia* sp. were the major species observed during the study period. The community analysis showed that diversity, richness, evenness and dominance were high in pre-monsoon season and low in monsoon season.

The study was conducted to determine the phytoplankton abundance and the environmental factors that influence the growth of phytoplankton in Cochin coastal waters and to identify the major changes in phytoplankton species during the seasonal changes. Comparing our results with the earlier studies showed that the major factors that mostly influence the phytoplankton distribution were: Temperature, salinity, dissolved oxygen, silicate, inorganic phosphate and nitrate. The community structure studies showed that pre-monsoon is the most favourable season for phytoplankton production in Cochin coastal waters.

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References

1 Menon N.N., Balchand A.N., and Menon N.R., Hydrobiology of the Cochin backwater system—a review, *Hydrobiologia,* 430 (2000) 149–183. doi:10.1023/A: 1004033400255.

2 Naqvi S.W. A., Moffett J.W., Gauns M.U., Narvekar P. V., Pratihary A.K., Naik H., Shenoy D.M., Jayakumar, D. A., Goepfert, T. J., Patra, P.K., Al-Azri, A. and Ahmed S.I., The Arabian Sea as a high-nutrient, low-chlorophyll region during the late Southwest Monsoon, *Biogeosciences,* 7 (2010) 2091-2100.

3 Robin R.S., Vishnu Vardhan Kanuri, Pradipta R. Muduli, Jaikumar, M., Karthikeyan, P., Suresh Kumar, C., Saravana Kumar, C., Influence of Coastal and Backwaters Coupling on sustenance of High Nutrients and Organic Production along the Southeast Arabian Sea, *Marine Science*, 3(3) (2013) 79-90.

4 Gupta G.V.M., Sudheesh V., Sudharma, K.V., Saravanane N., Dhanya V., Dhanya K. R., Lakshmi G., Sudhakar M. and Naqvi S.W.A., Evolution to decay of upwelling and associated biogeochemistry over the southeastern Arabian Sea shelf, *J. Geophys. Res. Biogeosci.*, 121(2015) 159-175.

5 Subrahmanyan R., Studies on the phytoplankton of the West coast of India. Part 1. Proc. Indian Acad. Sci., 50B (1959) 113-187.

6 Qasim S.Z., Wellershaus S., Battathiri P.M.A. and Abidi, S.A.H., Organic production in a tropical estuary, *Proc. Indian Acad. Sci.,* 69 B (2) (1969) 51-94.

7 Townsend D.W., Sources and cycling of nitrogen in the Gulf of Maine, *J. Marine Syst.*, 16 (1998) 283-295.

8 Vasudevan S., Arulmoorthy M.P., Balachandar K., Harikumar S., and Ashok V., Extensive bloom of phytoplankton *Skeletonema costatum* in Vellar Estuary , Parangipettai , Tamilnadu , Southeast Coast of India, *Int. J. Cur. Tr. Res.*, 3(2) (2014) 154-157.

9 Asha Devi C.R., Jyothibabu R., Sabu P., Josia Jacob, Habeebrehman H., Prabhakaran M.P., Jayalakshmi K.J. and Achuthankutty C.T., Seasonal variations and trophic ecology of microzooplankton in the southeastern Arabian Sea, *Cont Shelf Res.,* 30 (2010) 1070-1084.

10 Sahu Gouri Satpathy K.K., Mohanty A.K. and Sarkar S.K., Variations in Community Structure of Phytoplankton in Relation to Physicochemical Properties of Coastal Waters, Southeast Coast of India, Indian J. Appl. Res., 41(June) (2012) 223-41.

11 Forsberg C., Ryding S.O.A., Forsberg and Claesson A., Research on recovery of polluted lakes. 1. Improved water quality in Lake Boren and Lake Ekoln after nutrient reduction, *Verh. Internat. Verein. Limnol.,* 20 (1978) 825-832.

12 Smith S.V., Phosphorus versus nitrogen limitation in the marine environment, *Limnol. Oceanogr.,* 29 (1984) 1149-1160.

13 Kirkkala T., Helminen H., and Erkkilä A., Variability of nutrient limitation in the Archipelago Sea, SW Finland, *Hydrobiologia,* 363 (1998) 117-126.

14 Henson S.A., Sarmiento J.L., Dunne J.P., Bopp L., Lima I., Doney S.C., John J., and Beaulieu C., Detection of anthropogenic climate change in satellite records of ocean chlorophyll and productivity, Biogeosciences, 7 (2) (2010) 621–640. doi:10.5194/bg-7-621-2010.

15 Steinacher M., Joos F., Frölicher T.L., Bopp L., Cadule P., Cocco V., Doney S.C., Gehlen M., Lindsay K., Moore J.K., Schneider B., and Segschneider J., Projected 21st century decrease in marine productivity: a multi-model analysis, Biogeosciences, **7** (3) (2010) 979-1005. doi:10.5194/bg-7-979-2010.

16 Balachandran K. K., *Chemical oceanographic studies of the coastal waters of Cochin*, Ph.D Thesis. Cochin University of Science and Technology, Cochin, 2001.

17 Strickland J.D.H., and Parsons T.R., *A Practical Handbook of Seawater Analysis*, (Fisheries Research Board of Canada, Ottawa) 1972, pp. 311.

18 Parsons, T.R., Maita Y., and Lalli C.M., *A Manual of Chemical and Biological Methods for Seawater Analysis,* (Pergamon Press, Oxford) 1984 pp. 173.

19 Grasshoff K., Ehrhardt M., and Krembling K., *Methods of Seawater Analysis,* (New York: Verlag Chem., Weinheim) 1983 pp. 419.

20 Allen W.E., and Cupp E.F., Plankton diatoms of the Java Seas, *Ann. Jord. Bot. Buitenz.,* 44 (1935) 101-174.

21 Venkataraman G., A systematic account of some south Indian diatoms, *Proc. Indian. Acad. Sci.*, 10 (1939) 293-368.

22 Cupp E.E., Marine plankton diatoms of the west coast of North America, *Univ. of California press*, California, 221 (1943).

23 Hustedt F, Marine littoral diatoms of Beufort, North Carolina. Duke Univ. *Mar. Sta. Bull.,* 6 (1955) 1-67.

24 Hendey N.I., *An introductory account of the smaller algae of the coastal waters. Part V. Bacillariophyceae (Diatoms)*, (Ottokoeltz Science Publishers, Koenigstein, Germany) 1964 pp. 317.

25 Simonsen R., *The Diatom Plankton of the Indian Ocean Expedition of "R.V. Meteor"1964-1965*. (Gebruder Borntraeger, Berlin, Stuttgart) 1974 pp.66.

26 Gopinathan C.P., A systematic account of the littoral diatoms of the southwest coast of India. *J. Mar. biol. Ass. India.*, 26 (1984) 1-31.

27 Desikachary T.V. and Sreelatha, P.M., *Oamaru Diatoms. J. Cramer*, Berlin, 1989, pp. 330

28 Tomas C.R. (Ed.), *Identifying Marine Phytoplankton* (Academic Press, California) 1997 pp. 858

29 Clarke K.R., and Warwick, R.M., Changes in marine communities: an approach to statistical analysis and interpretation. Plymouth, UK' *Plymouth Marine Laboratory,* 144 (1994).

30 Nair A S K, *An interim report on the study of mud bank off the Kerala coast, India. Technical Report, Centre for Earth Science Studies, Trivandrum, India*. 1983, pp. 21.

31 Rao D.S., Regunanthan, A., Mathew, K.J., Gopinathan, C.P. and Murthy, A.V.S., Mud of the mudbank: Its distribution and physical and chemical characteristics, *CMFRI Bulletin,* 31 (1984) 21-25.

32 Damodaran R., Studies on the benthos of the mudbank regions of Kerala Coast, *Bull. Dept. Marine Sciences, University of Cochin*, 6 (1973) 1-126.

33 Balachandran V.K., Rajagopalan M.S., and Pillai V.K., Chlorophyll A., and pheo-pigments indices of biological productivity in the inshore surface waters off Cochin, *Indian J. Fish.,* 36 (3) (1989) 227-237.

34 Ramamirtham C.P., and Patil M.R., Hydrography of the west coast of India during the pre-monsoon period of the year 1962- part 2: In and offshore waters of the Konkan and Malabar Coast, *J. mar. biol. Ass. India*, 7 (1965) 150-168.

35 Rivonker C.U., Verlencar X.N., and Reddy M.P.M., Physico-chemical characteristics of fishing grounds of Mangalore, West coast of India, *Indian J. Mar. Sci*., 1 (1990) 17-27.

36 Naqvi S.W.A., and Jayakumar D.A., Ocean biogeochemistry and atmospheric composition, Significance of the Arabian Sea, *Curr. Sci.,* 78 (3) (2000) 289-299.

37 Jitts H.R., The adsorption of phosphate by estuarine bottom deposits, *Aust. J. Mar. Fresh Water Research,* 10 (1959) 7-21.

38 Pomeroy L.R., Smith E.E., and Grant C.M., The exchange of phosphate between estuarine water and sediments, *Limnol. Oceanogr.,* 10 (1965) 167-172.

39 Nixon S.W., *Remineralization and nutrient cycling in coastal marine ecosystems. In: Nutrient Enrichment in estuaries. (Eds: Neilson and L.E. Cronin)*, (Humana Press, Clifton, New Jersey) 1981 pp. 111-138.

40 Govindasamy C., Kannan L., and Azariah J., Seasonal variation in physico-chemical parameters properties and primary production in the coastal water biotopes of Coromandel Coast, India., *J. Environ. Biol.*, 21(2000) 1-7.

41 Segar K., and Hariharan V., Seasonal distribution of nitrate, nitrite, ammonia and plankton in 'effluent' discharge area off Mangalore, west coast of India, *Indian J. Mar. Sci.,* 18 (1989) 170-173.

42 Rajasegar M., Physico-chemical characteristics of the Vellar estuary in relation to shrimp farming, *Jour. Environ. Biol.,* 24 (2003) 95-101.

43 Twomey L. and John, J., Effects of rainfall and salt-edge movement on phytoplankton sucession in the Swan-Canning Estuary, Western Australia, *Hydrobiol. Proc.,* 15 (2001) 2655-2669.

44 Alam M.G.M., Jahan N., Thalib L., Wei B., and Maekawa T., Effects of environmental factors on the seasonal change of phytoplankton populations in a closed fresh water pond, *Environ. Int.,* 27(5) (2001) 363-371.

45 Roslin A.S., and Lazarus, S., Seasonal variations of environmental parameters in the Arockiapuram coast, *Seaweed Res.,* 23(1-2) (2001) 89-99.

46 Shastri Yogesh and Pendse D.C., Hydrobiological study of Dahikhura reservoir, *J. Environ. Biolo.*, 22 (2001) 67-70.

47 Turk D., McPhaden M.J., Busalacchi A.J., and Lewis M.R., Remotely sensed biological production in the equatorial Pacific, *Science*, 293 (2001) 471-474.

48 Seo Jung Kwan., Yu Jae Jeung., Jay Jung., Yang Seng Yang and Chung Ik Kyo, Phytoplankton community dynamics and evaluation of Trophic state in the Lake Unmoon, *Algae*, 18(22) (2003) 135-143.

49 Yan T., Zhou, M., and Qian P, Combined effects of temperature, irradiance and salinity on growth of diatom *Skeletonema costatum. Chinese J. Oceanol. Limnol.,* 20(3) (2002) 237-243.

50 Minu P., Shaju S.S., Muhamed Ashraf P., and Meenakumari B., Phytoplankton community characteristics in the coastal waters of the southeastern Arabian Sea, *Acta Oceanol. Sin.,* 33(12) (2014) 170–179. doi:10.1007/s13131-014-0571-x.

51 Gopinathan C.P., Seasonal abundance of phytoplankton in the Cochin backwaters, *J. Mar. Biol. Assoc. India*., 14 (1974) 568-577.

52 Padmakumar K.B., Thomas L.C., Salini T.C., John E., Menon N.R. and Sanjeevan V.N., Monospecific bloom of noxious raphidophyte *Chattonella marina* in the coastal waters of South–West coast of India, *Int. J. Biosci.,* 1 (2011) 57-69.

53 Kristiansen S., and Hoell E.E., The importance of silicon for marine production, *Hydrobiologia*, 484 (2002) 21-31.

54 Nair S.R.S., Devassy V.P., and Madhupratap M., Blooms of phytoplankton along the west coast of India associated with nutrient enrichment and the response of zooplankton, *Sci. Total Environ.,* (1992) 819-828.

55 Lande V.W., and Sangolkar L.N., Abundance and diversity of phytoplankton in the coastal waters of Kakinada, *Phykos.,* 41(1-2) (2002) 43-50.

56 Gouda R., and Panigrahy R.C., Studies on the phytoplankton of Rushikulya estuary, east coast of India. In: Aquatic Sciences in India (Eds.: Brijgopal and V. Asthana). Indian Association for Limnology and Oceanography, New Delhi, (1991)pp.173-187.