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ORIGINAL ARTICLE

Diurnal hypotheses of phytoplankton in Ennore Coast, Southeast coast of India

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ABSTRACT
To understand the effects of diurnal variation in phytoplankton community in tropical coastal waters, samples were collected for 2 days term with each 3hr interval at Ennore. For this investigation hydrological parameters were compared with community structure of phytoplankton including chlorophyll 'a' (Chl-a) content. About 42 species of phytoplankton belonging to 15 families (Ceratiaceae, Coscinodiscaceae, Triceratiaceae, Chaetocerotaceae, Peridiniaceae, Thalassionemataceae, Rhizosoleniaceae, Fragilariaceae, Biddulphiaceae, Thalassiosiraceae, Protoperidiniaceae, Skeletonemaceae, Lithodesmiaceae, Pleurosigmataceae, Phormidiaceae) were accounted. Among these, the diatoms were the dominant group of phytoplankton. The current investigation shows that the phytoplankton diversity is dependent on diurnal variations in the nutrient load. Further investigations are required to understand the importance of other factors that contribute to phytoplankton community structure.
Keywords: Diurnal variations, hydrological, phytoplankton, density, diversity

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INTRODUCTION

The total life of the world depends on water and hence the physicochemical parameters of water are very much essential to understand the relationship between its different tropic levels and food webs. The increasing population, urbanization, and industrial sources have given rise to environmental stress and pollution all over the world [1]. Industrialization and urbanization of the coastal region often lead to a decrease in coastal resource and destruction of natural defence structures [2]. The release of industrial and agricultural wastes and anthropogenic activities are the preliminary sources for higher nutrient supplements to the nearby aquatic ecosystems. The progressing of large industries in nearby areas has become a threat to the health of estuarine and coastal water environment [3]. One of the abundant environmental distresses is eutrophication contributing to algal blooms, which leads to complications in the aquatic ecosystem such as decline in DO concentrations. The environmental conditions such as topography, water current and stratification, temperature, DO, salinity and nutrients emphasizing specific water condition also decide the community structure and distribution of its diversity [4]. The shoreline and estuarine water bodies exhibit extensive seasonal fluctuation based on the native circumstances such as tidal incursion, rainfall, different biotic and abiotic stress and the quantum of fresh water influx disturbing the food web of the different coastal environment [5].The natural distribution of the flora and fauna in the aquatic system are mainly controlled by the fluctuation of the physical and chemical characteristics of the water body [6 – 8] [6, 7, 8]. In recent decades, many investigation reports have been documented [9, 2] and these contaminants might be transported widely through the atmosphere and eventually pollute all over the world. The physicochemical parameters of Bay of Bengal have been reported by many workers [10, 11, 12, 13, 14] [10 – 14]. The abundance of larvae, juveniles, adults fish can however, be influenced by the physical condition of salinity, temperature, pH and turbidity that vary in time, largely due to seasonal variation in freshwater input [15, 16]. Higher salinity would cause a

profound impact on an animal such as plankton, fungi, fish, shrimp and crab and their larvae. The following authors have contributed to the knowledge of physicochemical parameters of waters in different estuaries [17, 18, 19] [17 – 19].
Phytoplankton acts as better source of energy for the higher nutritious levels in aquatic ecosystems [20, 21, 22] [20 – 22]. Phytoplankton assemblages have additionally been utilized as markers to water quality [23, 24, 25] [23 – 25], contaminations and human interference in the marine surrounding. The knowledge regarding their dynamics is essential for developing predictive ecosystem models as well as ecological assessment. The knowledge about their dynamics is being for development foreboding ecosystem fashion as well as ecologic assessment. Plankton has small and short life span organisms.
Many aquatic organisms exhibit diurnal rhythms in their activities which are influenced by factors such as light, temperature, food and size. Subsurface illumination for the 24-hour period has been found to be the most essential stimulus. It is with this respect that [26] disclosed that plankton (phytoplankton) growth and distribution depend on the carrying capacity of the environment and on the nutrients concentration both intracellular and extracellular. Physicochemical parameters also affect plankton distribution, sequential occurrence and species diversity [27]. These therefore cause seasonal variation in phytoplankton populations. The environmental variables such as temperature, pH and phosphate play a decisive role in altering the phytoplankton density.
The present study aimed to assess the diurnal variation of phytoplankton with relation to the various physicochemical parameters at Ennore, southeast coast of India.

MATERIAL AND METHODS

Study area description
Ennore coast (13° 12' 23.4864'' N, 80° 19' 38.0100'' E) receives considerable quantity of untreated domestic sewage from Royapuram and adjutant areas, and industrial effluents discharged from Manali Industrial Belt, which houses many refineries and petro-chemical industries. The periodic dredging activities in Ennore region result in changes in the landscape, sediment transport and dust pollution to the coastal environment. The southern arm of the Ennore creek is well developed with industries, utilities, suburban residential areas and fishing hamlets. Northern section of the creek is linked to the Pulicate Lake and has two major developments North Chennai Thermal Power Station (NCTPS) and Ennore satellite port has chocked the mouth of the Ennore creek. The Buckingham canal is polluted with industrial effluents and cooling waters, municipal sewage waters and local urban activities, ultimately it enters into Bay through Ennore estuary waters.

Hydrological Parameters

ST	DAY	TIME	WT	pH	SAL	ALK	DO	BOD	NO2	NO3	NH3	TN	IP	TP	SIO3
Code		(24hrs)	° C		PSU	Ppm	mg/l	mg/l	µmol/l	µmol/l	µmol/l	µmol/l	µmol/l	µmol/l	µmol/l
0 hrs	Day1	0:00	27	7.9	33	116	5.42	0.81	22.22	4.91	4.41	39.12	6.92	1.12	19.82
3 hrs	Day1	3:00	28	8	34	122	3.88	1.05	52.92	52.16	7.25	112.34	12.82	4.95	52.13
6 hrs	Day1	6:00	28	8.1	34	132	4.36	0.09	69.77	81.98	10.56	186.13	5.18	5.22	47.04
9 hrs	Day1	9:00	26	8.1	34	114	6.14	0.26	0.43	7.44	4.53	13.51	0.44	0.48	7.71
12 hrs	Day1	12:00	29	8.1	34	117	5.98	0.33	4.41	25.95	7.65	42.63	1.59	1.62	21.21
15 hrs	Day1	15:00	27	8	34	119	3.72	1.18	48.43	66.73	9.34	132.13	5.85	6.01	22.49
18 hrs	Day1	18:00	29	8	34	131	5.49	0.07	47.43	67.06	8.98	129.13	4.16	4.32	17.33
21 hrs	Day1	21:00	27	8.1	34	97	6.14	0.03	6.53	10.73	6.04	29.13	1.51	1.60	10.42
24 hrs	Day2	0:00	30	8.1	34	99	5.66	0.92	2.22	4.73	4.47	12.43	4.96	5.11	20.89
27 hrs	Day2	3:00	28	8.1	34	99	3.88	1.15	46.92	55.17	8.25	120.25	5.85	5.94	62.19
30 hrs	Day2	6:00	28	8.1	34	128	1.78	0.22	47.73	103.95	7.48	163.46	16.38	17.10	22.65
33 hrs	Day2	9:00	26	8.1	33	98	6.30	0.07	1.08	8.35	0.67	11.02	1.86	1.94	8.66
36 hrs	Day2	12:00	30	7.9	33	97	5.82	0.29	2.67	145.22	4.79	160.28	2.57	2.61	16.96
39 hrs	Day2	15:00	30	7.7	33	10	5.49	1.83	2.63	129.84	7.89	148.02	4.07	4.31	24.88
42 hrs	Day2	18:00	29	7.9	34	131	1.94	0.19	48.59	56.71	10.72	122.51	16.16	18.12	62.67
45 hrs	Day2	21:00	27	8	33	126	3.72	0.31	6.15	5.86	5.49	25.30	6.23	4.11	11.35
48 hrs	Day2	0:00	28	8.1	34	114	5.68	0.92	34.25	44.21	4.37	95.03	1.12	1.03	30.79

Table1: Hydrological Parameters

The samples were collected from Ennore coast (13º14’2.0”N 80º19’54.0”E). Water samples for physicochemical and biological analysis were collected at 3 hrs interval for 48hrs (across 2 days), i.e. 3, 6, 9, 12,15,18,21, and 24 hrs. The sampling was conducted on 30th and 31st January 2017 (Winter or Post-monsoon) at of Ennore coastal waters, southeast coast of India. The salinity, pH and temperature of water samples were measured with the use of Hand Refractometer (Erma Company, Japan), digital pH pen and mercury thermometer. Dissolved oxygen was determined by modified Winkler’s method [28]. All the collected samples were immediately preserved to refrigerated conditions at 4ºC then transferred to lab and stored refrigerator until further analysis. The preserved water samples were filtered through

Whattman GF/C filter paper and analysed for the organic matters and nutrients. Unfiltered samples were used for the determination of ammonia, total nitrogen and total phosphorus. Nitrate, Nitrite, Ammonia, Inorganic Phosphate and Reactive Silicate contents in the samples were analysed by calorimetric method described by [29].

Estimation of Chlorophyll

Chlorophyll extraction was done by filtering the samples through Whattman GF/C filter papers (mesh size 47 mm) with 90 % acetone. The optical density methodology which is described by Delorenzo (2012) using UV–vis spectrophotometer (UV-1800, Shimadzu, Japan) were followed to estimate chlorophyll [30].

Phytoplankton assessment

The samples were collected from by following the method of Mayalagu et al., [31] by using the plankton net made up of bolting silk (with No. 25 mesh size 48 μm). The collected samples were preserved in 4 % neutralized formalin and used for identification purpose. The morphological identification of marine phytoplankton was done by using Optical Light Microscope (Nikon – Phase contrast microscope). The phytoplankton density was estimated using Sedgwick Rafter Counting Chamber [32] and Identification was done by the following standard taxonomical keys and literatures [33, 34, 35, 36, 37] [33 – 37].

RESULTS

Hydrological Parameters

The fluctuations in hydrological parameters of the coastal waters during the period of study have been given in Table 1. Surface water temperature variations were significant at all the sampling periods. The surface water temperature ranged between 26°C and 30°C. pH value had a range from 7.7 to 8.1. The oxygen demand of both Dissolved (DO) and Biological (BOD) are ranged from 1.78 to 6.30 mg/L and 0.03 to 1.83 mg/L respectively. The lowest DO was observed at 30 hrs (Day2 at 6.00 am) similarly highest was 33 hrs (Day2 9.0 am), BOD minimum was showing at 12hrs (Day1 at 12.00noon) whereas maximum was 39 hrs (Day2 at 3.00 pm). The diurnal concentrations of nutrients such as NO_2, NO_3, NH_3, TN, IP, TP and SiO_4 ranged from 0.432 to 69.773 μmol L^{-1}, 4.731 to 145.216 μmol L^{-1}, 0.669 to 10.717 μmol L^{-1}, 11.024 to 186.127 μmol L^{-1}, 0.443 to 16.384 μmol L^{-1}, 0.481 to 18.124 μmol L^{-1} and 7.708 to 62.673 μmol L^{-1}respectively.

Diurnal Fluctuation of Chlorophyll

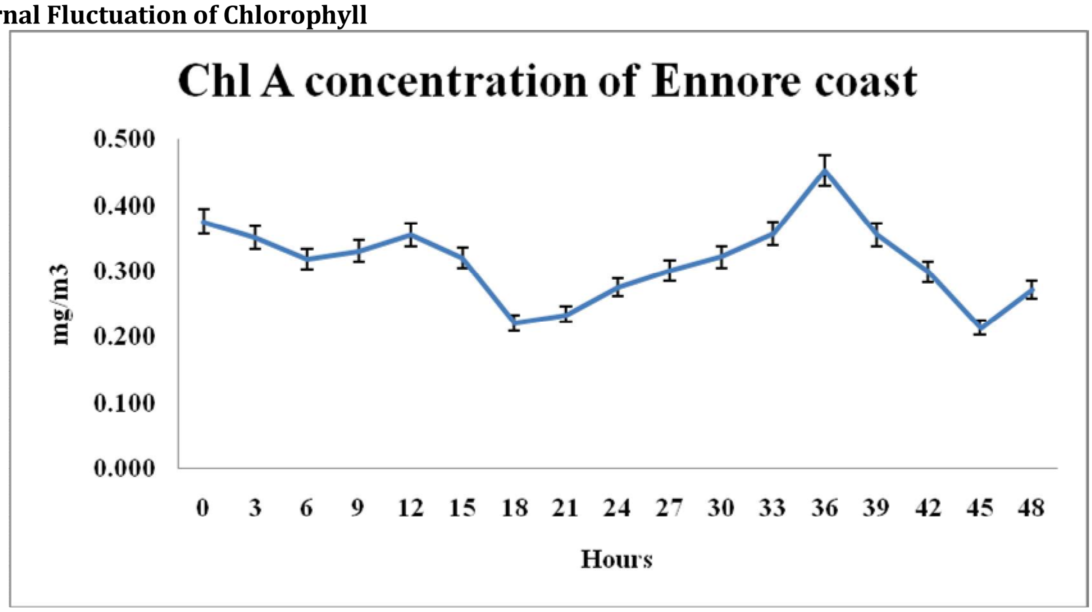

Fig 1: Diurnal variation of Chlorophyll A at ENN coast

The ENN coast surface water Chl A was least during 36 hrs (Day2 at 12.00 pm) 0.453 mg/m^3 while highest was during at 18 hrs (Day1 at 6.00 pm) 0.221 mg/m^3.

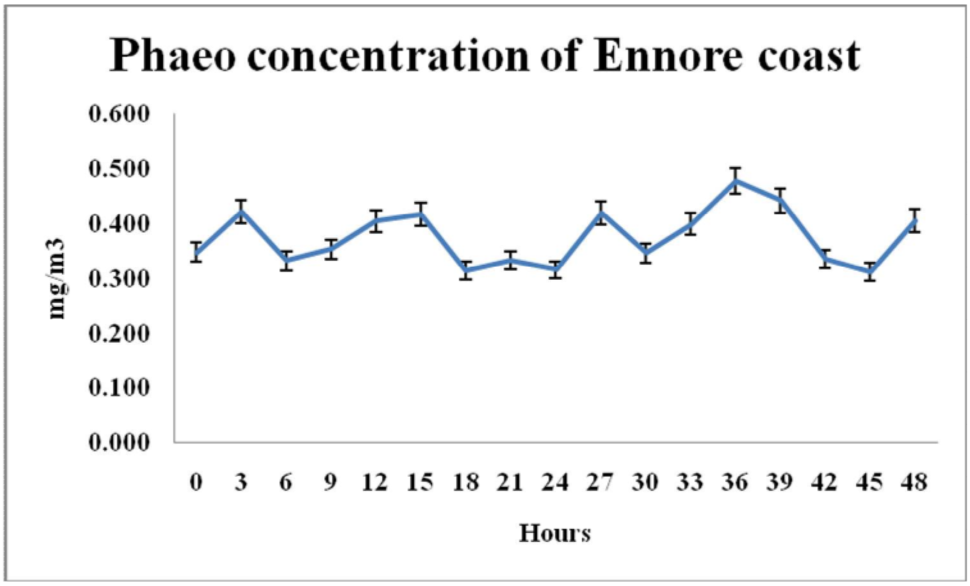

Fig 2: Diurnal variation of Phaeopigment at ENN coast

The concentration of phaeopigment was always lower than the corresponding level of Chlorophyll ‘a’ suggesting that the water of the coastal and hot spot areas are conducive to the growth of phytoplankton. The ENN coast water Phaeo showed maximum concentration during 36 hrs (Day 2 at 12.00 pm) 0.478 mg/m^3 while minimum was during 18 hrs (Day1 at 6.00 pm) 0.315mg/m^3.

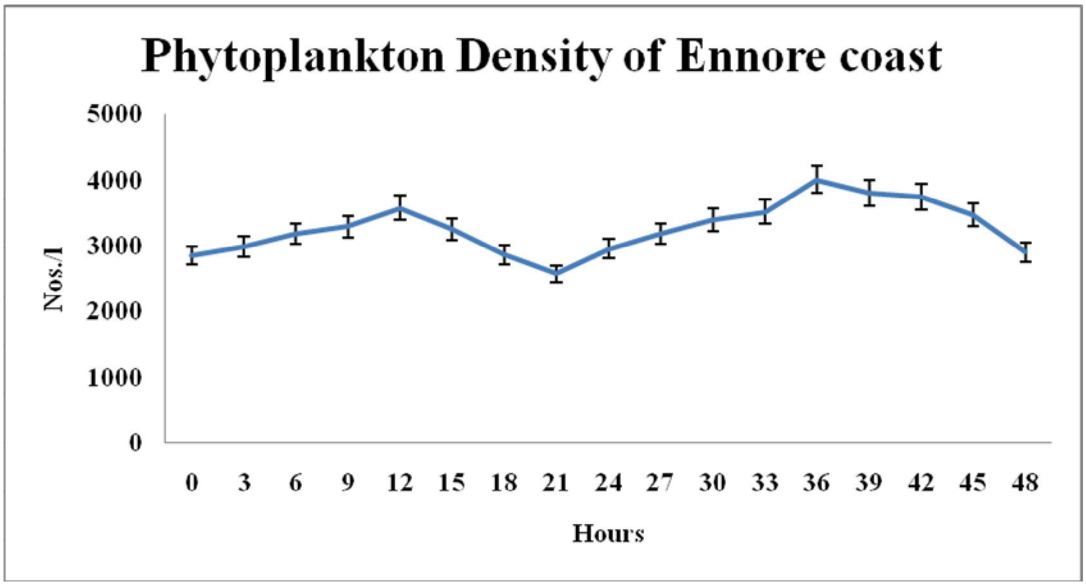

Fig 3: Diurnal variation of Phytoplankton density at ENN coast

In general, the distribution and abundance of phytoplankton in tropical water, varied remarkably due to the seasonal environment fluctuations, and these variations are well pronounced in the sheltered system of estuarine and coastal waters. The percentage contribution of each family of phytoplankton in the order of:

Ceratiaceae>Coscinodiscaceae>Triceratiaceae>Chaetocerotaceae>Peridiniaceae>Thalassionemataceae>Rhizosoleniaceae>Fragilariaceae>Biddulphiaceae>Thalassiosiraceae>Protoperidiniaceae>Skeletonemaceae>Lithodesmiaceae>Pleurosigmataceae>Phormidiaceae.

Phytoplankton density maximum were observed during at mid-day time (36 hrs. Day2 at 12.00 pm) 4012 Nos/L, while minimum was during at mid-night time (24 hrs. Day2 at 12.00 am) 2578 Nos/L.

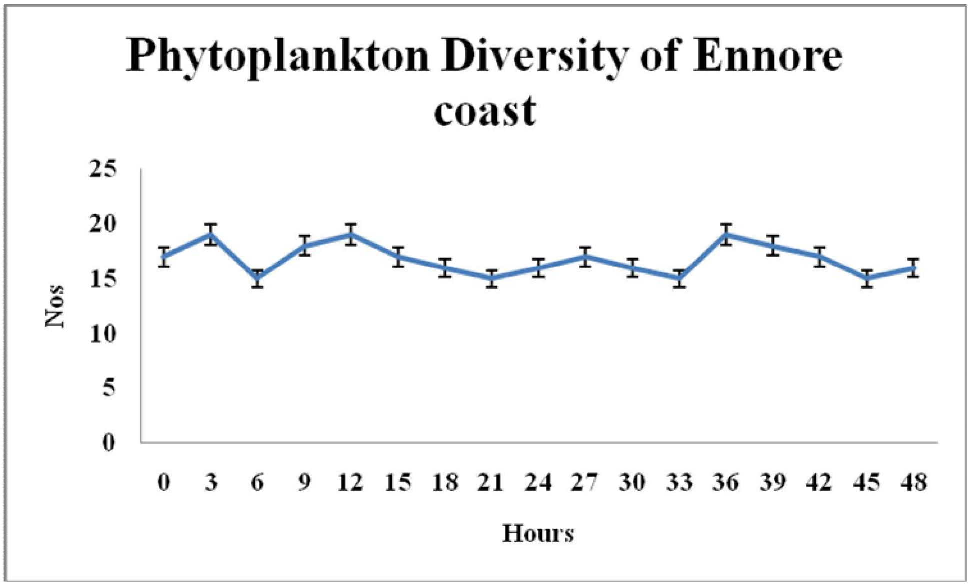

Fig 4: Diurnal variation of Phytoplankton diversity at ENN coast

Phytoplankton diversity maximum were recorded during at noon time (12 hrs.& 36hrs, Day1 and 2 at 12.00 pm respectively) while minimum was during 6 hrs.,21hrs., (Day1 6am and 9 pm) and 33 hrs (Day2 9 am).

Species Name	Family	0 hrs	3 hrs	6 hrs	9 hrs	12 hrs	15 hrs	18 hrs	21 hrs	24 hrs	27 hrs	30 hrs	33 hrs	36 hrs	39 hrs	42 hrs	45 hrs	48 hrs
Asterionella glacialis	Fragilariaceae	-	-	-	+	-	-	+	-	-	-	-	-	-	-	-	-	-
Astrionella sp.		+	+	+	-	+	+	-	+	+	-	-	-	+	+	+	+	+
Biddulphia reticulate	Biddulphiaceae	-	-	-	-	+	-	-	+	-	-	-	-	-	-	+	-	-
Biddulphia sp.		+	+	-	+	+	+	+	-	+	+	+	+	+	+	+	+	+
Ceratium furca	Ceratiaceae	-	-	+	+	-	-	+	-	-	-	-	-	-	-	-	-	-
Ceratium fusus		+	+	-	-	-	-	-	-	+	+	+	+	+	+	-	-	+
Ceratium lineatum		-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ceratium longipes		+	+	+	-	+	+	-	-	+	+	+	-	-	-	+	-	+
Ceratium macroceros		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Ceratium trichoceros		+	-	+	+	+	+	+	-	+	-	-	-	-	-	+	-	-
Ceratium tripos		-	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+
Chaetoceros affinis	Chaetocerotaceae	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-
Chaetoceros currvisetus		-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-
Chaetoceros indicus		-	-	+	+	-	-	+	-	-	-	-	-	-	-	-	-	-
Chaetoceros sp.		-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-
Coscinodiscus centralis	Coscinodiscaceae	-	+	-	-	-	-	-	+	-	+	+	+	-	-	-	+	-
Coscinodiscus ecentricus		-	+	-	-	-	-	-	-	-	+	-	-	-	+	+	-	-
Coscinodiscus gigas		-	+	-	-	-	-	-	-	-	+	+	+	+	-	-	-	-
Coscinodiscus granii		-	+	-	-	-	-	-	-	-	+	+	+	+	-	-	-	-
Coscinodiscus radiates		+	-	+	+	+	+	+	+	+	-	+	+	+	+	+	+	+
Coscinodiscus sp.		+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	-	+
Coscinodiscus thori		+	+	-	+	-	-	-	-	+	+	-	-	-	-	-	-	+
Ditylum brightwelli	Lithodesmiaceae	+	+	-	-	-	-	-	-	+	-	+	-	+	+	+	-	+
Gyrosigma sp.	Pleurosigmataceae	+	-	+	-	+	+	-	+	+	-	-	-	-	-	-	+	+
Odontella mobiliensis	Triceratiaceae	-	-	-	-	+	+	-	+	-	-	-	+	+	+	+	+	-

Odontella sinensis		-	-	-	+	-	-	+	-	-	-	-	-	-	-	-	-	-
Peridinium claudicans	Peridiniaceae	-	-	-	-	+	-	-	-	-	-	-	-	-	-	+	-	-
Peridinium divergens		-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	+	-
Peridinium sp.		-	+	+	+	+	+	+	+	-	+	+	+	+	+	-	+	-
Planktoniella sol	Thalassiosiraceae	+	+	-	-	-	-	-	+	-	-	-	-	-	-	-	+	-
Pleurosigma normani		-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-
Protoperidinium depressum	Protoperidiniaceae	-	-	-	+	-	-	+	+	-	-	-	-	-	-	-	+	-
Protoperidinium oceanicum		-	-	-	-	-	-	-	-	-	-	-	-	+	+	+	-	-
Rhizosolenia sp.	Rhizosoleniaceae	+	+	-	-	+	+	-	-	+	+	+	+	+	+	-	-	+
Rhizosolenia styliformis		-	-	-	+	+	-	+	-	-	-	-	-	+	+	+	-	-
Skeletonema costatum	Skeletonemaceae	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Thalassiothrix frauenfeldii	Thalassionemataceae	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Thalassiothrix nitzschioides		+	-	+	+	+	+	+	-	+	-	-	-	-	-	-	-	+
Triceratium favus	Triceratiaceae	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-
Triceratium reticulatum		-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	+	-
Triceratium sp.		+	+	-	-	-	-	-	-	+	+	+	-	+	-	-	-	+
Trichodesmium erythaeum	Phormidiaceae	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

Table 2: Diurnal variation of Phytoplankton species composition at ENN coast

DISCUSSION

Nutrients

Water parameters play an essential role in the structuring the fish species in mangrove swamp, estuaries, and coastal areas. Salinity and temperature are important hydrological parameters influencing the occurrence, density, and growth of larvae of fish and shellfish in coastal areas [38, 39], and water depth can also influence fish distribution. The basis was predominantly influenced by the seasonal reversal of the monsoon resulting in the input of large quantity of freshwater from major rivers. Further, winds and stratification influence phytoplankton productivity in the bay [40].The temperature fluctuation is also one of the factors in the coastal and estuarine system, which may affect the physicochemical characteristics and also influence the distribution and abundance of flora and fauna [41 – 43] [41, 42, 43]. Hydrogen ion concentration is another important factor in the aquatic ecosystem. The variation of pH of the water was less pronounced throughout the study period. Thus, pH is used in the measurement of alkalinity, CO_2 and many other acid - base equilibrium [44]. Dissolved oxygen (DO) is one of the most important abiotic parameters influencing the life in the estuarine environment. Dissolved oxygen concentrations were above 5mg/l which was adequate enough to support aquatic life [45]. This is because of the oxygen is consumed more by the aquatic animals due to effluent stress. Normally high DO is encountered in polluted. Further, depletion of dissolved oxygen to the level of anaerobic is the most critical manifestation of pollution [46]. Salinity is one of the significant factors which influence the abundance and distribution of the organisms in the coast estuarine environment. Total alkalinity is the total concentration of bases in water usually bicarbonates and carbonates [47]. Safari et al., reported the total alkalinity depends on the concentration of the substance which would raise the pH of the water [48]. High levels of alkalinity indicate the presence of strongly alkaline industrial wastewater and sewage in the estuary. The degradation of plants, living organism and organic waste in the estuary might also be one of the reasons for the increase in carbonate and bicarbonate levels, shows an increase in alkalinity value (10.0 to 132.0 ppm) [49]. The higher concentration of nitrate could be attributed due to the variation in phytoplankton, excretion, and oxidation of ammonia and reduction of nitrate and by recycling of nitrogen and also due to bacterial decomposition of planktonic detritus present in the environment [50, 51]. Further, the increased nitrates (145.22 µmol/l) level was due to freshwater inflow, mangrove leaves (litterfall) decomposition and terrestrial runoff during the monsoon season [52, 42]. The variation of physicochemical parameters mainly depends on monsoon rains and also other sources of freshwater. The fluctuations in physicochemical parameters influence the biological activity and productivity of aquatic organisms. Water is the basic need for the life sustaining medicine for the propagation of aquatic organisms

especially larvae and juveniles. The continuous discharge of effluents to the estuarine ecosystem may directly or indirectly influence the organisms.
In general, surface water temperature is influenced by the solar radiation intensity. And the observed spatial variation in temperature (26 to 30 ºC)could be due to the viable intensity of prevailing currents and the consequent mixing of water [53].This range is good for growth of aquatic organisms like phyto and zoo planktons reported by many authors [54, 55]. Increased pH (8.1) values noted may be due to the discharge of domestic waste water, sewage and industrial effluent etc. The dissolved oxygen in water depends upon the partial pressure of gas in the air close to water, rate of photosynthesis and oxygen holding capacity of water [44]. The salinity is the major physical parameter and acts as a limiting factor, which impacts the planktonic communities' distribution [56, 57]. The riverine waters will enter into brackish ecosystem like mangrove, backwaters and estuaries by tidal variations or by rainfalls cause variations into the salinity [58]. Nutrients are primary parameters of the mangrove environment for the diversion of phytoplankton. Distribution of nutrients is due to the season, tidal conditions and freshwater flow from land sources. An increasing of nitrate and inorganic phosphate observed during monsoon season might be more freshwater influx into the estuary and domestic inputs [59, 60]. The recorded least amount during non-monsoonalperiod may be due to high photosynthetic activity of phytoplankton and also due to the dominance ofmarine water intrusion with negligible amount of nitrate [61, 62, 63] [61 – 63]. High amount of silicate and sulphate was observed in post monsoon and summer maybe due to heavy influx of fresh water derived from land drainage carrying silicate leached out from rock sand also from the bottom [60]. Due to the seasonal environmental fluctuations, the distribution and abundance of phytoplankton in tropical waters, varied remarkably. These variations are well pronounced in the sheltered system of coastal mangrove waters. This study recorded 42 species of phytoplankton species belonging to diverse 15 groups among Ceratiaceae, Coscinodiscsceae and Triceratiaceae (Table 2). The present findings show that there are certain members of species in the Chlorophyceae and Cyanophyceae which are dominant to organic pollution and resist the stress caused by pollutants. Abundance of such taxa in the polluted habitats suggests their possible use a "indicator organism". Therefore, the results of this investigation suggest that the Ennore estuarine region is heavily contaminated by rapid urbanization and industrialization to release untreated industrial effluents and domestic sewages to this ecosystem. However urgently need the regular biological monitoring of water and fish for safety in seafood consumption from Ennore area. So avoid such kind of problem in the Ennore ecosystem to practicing safe disposal mechanism of industrial effluents and domestic sewages. Generally, surface water temperature was influenced by the intensity of solar radiation, evaporation and insulation and the recorded low temperature during monsoon could be due to strong sea breeze and cloudy sky [52, 50].
The salinity was the main physical parameter that can be attributed to the plankton diversity which acts as a limiting factor and influences the distribution of planktonic community [56, 57].
The fluctuations in pH values can be related with 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 [64, 65]. The observed high pH values in summer can be attributed to the influence of seawater inundation and the high density of phytoplankton [61, 66].
Variations in dissolved oxygen may be due to temperature and salinity which affects the dissolution of oxygen [67] and also high level of pollution in water.
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., and Thillai Rajasekar et al., [68, 69].

Phytoplankton density and diversity

Plankton biodiversity is a fundamental research area in the aquatic ecological studies and it is used for the variety of marine ecological problems, such as protection of biodiversity, bionetwork roles and services. Therefore, the phytoplankton is involving the various ecological processes with influence the species diversity [70, 71]. Biomass production of phytoplankton in different size ranges are important factors regulating the productivity of higher tropic-level organisms. Phytoplankton production contributes about 95% of total production in the marine environment [72]. The phytoplankton distribution is not always consistent and varies spatially and temporally. Among all nutrients, availability plays a key role in determining the phytoplankton population density [73, 74]. The qualitative and quantitative studies of phytoplankton have been utilized to assess the quality of water [75, 76]. Several phytoplankton species are reported as a bio-indicators [77, 78, 79] [77 – 79] and water pollution studies [80]. Phytoplankton ecology at different parts of Bay of Bengal coast was well documented over a period of time [81, 82, 83] [81 – 83]. Increasing pressure on coastal areas due to urbanization, industrialization and intensive aquaculture in this area poses a threat to this ecosystem. A regular monitoring of water bodies with required number of parameters not only prevents outbreak of diseases and occurrence of other hazards but also checks the water from further deterioration. The management of any aquatic ecosystem is a means of conservation of fresh water habitat with an aim to maintain the water quality or to rehabilitate the Physicochemical and biological settling of water [84].

The phytoplankton community structure and species succession have been regulated by temperature, salinity and trophic conditions [85, 86, 87, 88, 89, 90] [85 – 90]. Other environmental determinants have been reported to below light intensity, high nutrient availability [91, 92, 93, 94] [91 – 94], zooplankton grazing [95] and a strong tidal mixing of the water column [96]. The salinity gradient also played a major role in determining the distribution of communities of phytoplankton. The salinity variations also influence the species distribution and communities as it depends on monsoon and tidal patterns. Such conditions produce higher primary productivity because of competition among the various phytoplankton communities [97].The phytoplankton community presented lower diversity and abundances during night time. A reduction of light energy could be the major reason for extreme decline of algal biomass [98, 99]. Finally, the results support the view that temporal variation, even in the coastal waters, located in a region of high seasonal weather variation, enhances the global phytoplankton diversity and explains in part, the coexistence of a much larger number of species in a specific environment [100]. The developments of mixed assemblages of coastal water species varied monthly throughout the study period and varied predominantly during the monsoon periods, when heavy rainfalls regulated the increasing amount of nutrient runoff from domestic sewage into the coastal waters leads to nutrient content accumulation and influencing primary productivity. This explains the cause behind high values recorded for nutrients especially nitrate and silicate at both stations. Along with nutrient axis, the phytoplankton assemblage dominated by sensitive and clean water species was replaced by nutrient tolerant phytoplankton taxa, indicating that algal growth was affected mainly by nutrient status. The major coastal water inhabitants in the two stations, as in the other coastal waters, were diatoms and dinoflagellates, which were positively correlated with the salinity factor. It is also possible that the community goes through a period of rapid change as a response to environmental conditions, and then remains fairly constant for a long time without major shifts in species composition as long as conditions remain stable [101]. Very minor fluctuations such as wind strength influence to the plankton structures in the water bodies during daily weather changes. This short variation can preclude the establishment of a well-defined succession variation in the plankton communities as stated by the general theory of plankton succession [100, 102]. Diatoms and dinoflagellates have strong relationship with environmental parameters such as light and temperature.

The balance between nutrient delivery and adjective losses associated with river flow is a potent driver of the spatiotemporal patterns of estuarine phytoplankton productivity and biomass [103, 104], and the NRE exemplifies this. Whether phytoplankton biomass exhibits a positive or negative relationship with increasing flushing time is determined by the balance between intrinsic growth and in situ losses (losses other than advection such as grazing, sedimentation, infection etc.) [105]. Under flushing time conditions shorter than this threshold, nutrients are replete and the accumulation of biomass of the dominant phytoplankton classes proceeds at the expense of uptake of riverine derived nutrients within the upstream regions. Maximum phytoplankton biomass occurs at approximately the same flushing time as depletion of the riverine inorganic N load within the NRE, as indicated by the depletion of the nitrate pool [106]. Phytoplankton prefers the utilization of ammonium to nitrate [107]. So, it is assumed that the small pool of riverine ammonium is utilized prior to nitrate and that the ammonium that is present once nitrate is depleted is due to internal regeneration within the estuary. The mechanisms of reduced biomass at longer flushing times are not fully resolved but both bottom-up and top-down biological pressures and dilution with low biomass ocean waters are likely [108].

Diurnal variation

Phytoplanktons showed upward movements during noon time and downward movement after sunset. Among Ceratiaceae (*Ceratium macroceros* and *Ceratium tripos*), Coscinodiscaceae (*Coscinodiscus radiates* and *Coscinodiscus* sp.), Skeletonemaceae (*Skeletonema costatum*), and Phormidiaceae (*Trichodesmium erythaeum*) are predominantly present in each condition (timimg, hrs). Upward movement of these phytoplanktons could be attributed to the presence of gas vacuoles which helped these planktons in floating on the surface of water. Bacillariophyceae, *Ceratium macroceros* and Skeletonemaceae, *Skeletonema costatum* showed its abundance at 09.00 hrs, 12.00 hrs, and 15.00 hrs. Whereas, *Ceratium tripos*, Coscinodiscaceae, *Coscinodiscus radiates* and Phormidiaceae, *Trichodesmium erythaeum* showed its abundance at 12.00 hrs, and remaining hrs showed down migration during the study. The rapid cell division during early morning could be the probable factor responsible for the abundance of diatoms [109]. *Thalassionema nitzschioides* and *Ceratium trichoceros* (411 and 388 individual L^{-1}) showed its abundance at 06.00 hrs, whereas *Skeletonema Costatum* (1199 and 1398 individuals L^{-1}) after its peak at 09.00 hrs, and 12.00 hrs, showed downfall during the say. Green algae showed a clear picture of diurnal variation with a remarkable preference to the bright hours of the day. During present studies, distribution of certain species of plankton during day showed positive phototactic behaviour and during night showed negative phototactic behaviour. However, evening and morning abundance of certain species could be attributed to be an effect of endogenous rhythm [109, 110].

Biodiversity is commonly estimated with richness and evenness. The environmental heterogeneity in estuaries makes an essential contribution to plankton species diversity and numerical variability [111]. Diversity has interrelation with several ecological regulations [112]. Biotic and abiotic factors like species competition, predation, heterogeneity, habitat harshness and size control diversity of particular ecosystem but to what extent it is controlled is still questionable [112].

CONCLUSION

The present investigation summarizes the diurnal fluctuations in physicochemical parameters and phytoplankton diversity at Ennore coastal waters. Ennore waters are highly subjective to larger riverine freshwater inundation as the Ennore estuary debouches into the Bay of Bengal. Introduction of the high organic load during tidal variations plays a substantial role in phytoplankton succession which helps the phytoplankton to avail the nutrients and proliferate. Totally, 42 species were identified, belonging to 15 different families, among which the most dominant species belonged to Ceratiaceae and Coscinodiscaceae. Based on nutrient availability, the phytoplankton community structure showed diurnal variations. Thus, the overall study gives a good outline of the diurnal dynamic relationship between phytoplankton and environmental parameters.This study indicates that the rapid growth of a few species led to the low diversity indices. Phytoplankton diversity is influenced by nutrient inflow however there may be several other factors which may also influence the diversity of the phytoplankton which needs to be investigated further.

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