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Variability of phytoplankton in the coastal waters of Visakhapatnam, Central east coast of India (Bay of Bengal) with special reference to environmental parameters

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Abstract

In the present study, seasonal distribution of species composition, cell abundance of phytoplankton and statistical data of hydrography and nutrients in the coastal waters along the Visakhapatnam coast were analysed. This survey carried out in 4 stations (Fishing harbor, Lawsens bay, Rushi hills and Bheeminipatnam) during premonsoon and post monsoon in 2011. Totally 110 species of phytoplankton were identified. Maximum phytoplankton population was recorded in pre monsoon at Fishing harbor and minimum were observed at Rushi hills during post monsoon. The diversity indices were calculated for the four study sites. The hydrographical parameters such as temperature, pH, salinity and dissolved oxygen along with the nutrient content of NO_2, NO_3,NH_3,PO_4 and SiO_4were carried out in both surface and bottom waters during the study period. Hydrographical parameters were correlated with nutrients by Pearson Correlation Matrix, showed Chl *a* is negatively correlated with temperature, pH, salinity, ammonia and positive correlation with dissolved oxygen, nitrites, nitrates, phosphates and silicates.

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Introduction

Biological communities give consideration to the entire ecological integrity, consolidate the effects of different stressors and provide a broad measure for their aggregate impact (Lohse *et al*., 2009; Sigua and Tweedale, 2003). Therefore, aquatic assemblages, generally including phytoplanktonic assemblages, have been commonly used as bioindicators for water quality monitoring to directly assess marine, coastal and estuary ecosystem health in relation to the water pollution (Zettler *et al*.,2009; Nayar *et al*.,2005).

Phytoplankton is an assemblage of heterogeneous microscopic algal forms of aquatic systems whose movement is more or less dependent upon water currents (Kudelaand Peterson, 2009). Phytoplankton commences the marine food chain, being served as food to primary consumers like zooplankton, shellfish and finfish (Sridhar *et al*., 2006; Saravanakumar *et al*., 2008).

The free-living phytoplankton serves as feed and caters for the energy needs of planktonivorous organisms and is the key factor capable of determining the fishery potential of the region (Bhanuprakash *et al*., 2014). As phytoplankton assemblages are at the base of the food web, changes in phytoplankton biomass, species composition and pattern of primary production have implications for the whole community (Ahlgren *et al*., 2005).

Phytoplanktons are important in an environmental impact study in as much as they are extremely responsive to change in the environment and thus indicate environmental changes and fluctuations that may occur (Jyothi and Rao, 2013). Marine phytoplankton communities usually comprise several taxonomic groups, and contribute to primary production and interaction between tropic levels (Roy *et al.,* 2006).

The distribution of phytoplankton is not always stable and varies spatially and temporally. Further, the environmental conditions such as topography, water movement, salinity, oxygen, temperature and nutrients characterizing particular water mass also determine the composition of its biota. Thus the nature and distribution of flora and fauna in an aquatic system are mainly controlled by the fluctuations in the physical and chemical parameters of the water body (Damotharan *et al* ., 2010).

Earlier works in Bay of Bengal were mainly focussed on the taxonomic identification of different phytoplankton genera and very restricted to the specific regions of Bay of Bengal, while the studies on regional and seasonal distribution of phytoplankton were meager.

Phytoplankton ecology at different parts of Bay of Bengal coast was well documented over a period of time (Edward and Ayyakkannu, 1991; Gouda and Panigrahy, 1996; Saravanane *et al*., 2000; Panigrahi *et al*., 2004, Nagamani *et al*., 2011).

Despite these facts of phytoplankton assemblages of near shore waters of the Bay of Bengal is in isolation and not holistic. The present study was made to obtain the qualitative and quantitative distribution of phytoplankton with seasonal variation to physicochemical parameters in coastal waters along the Visakhapatnam coast. This information would be helpful in the ecological monitoring of this ecosystem.

Materials and methods

Site description

Visakhapatnam lies between the latitudes 17° 14’ 30” and 17° 45 ’ N and the longitudes 83° 16’25” and 83° ’ 21’ 30” E on the central east coast of India. For the present study, four sampling stations were chosen to collect surface water and phytoplankton samples at Fishing harbor area, Lawsons Bay area, Rushi hill area and Bheeminipatnam area during April (Premonsoon season) and September (monsoon season).

Location of sampling stations along the coast of Visakhapatnam was shown in the figure no. 1.

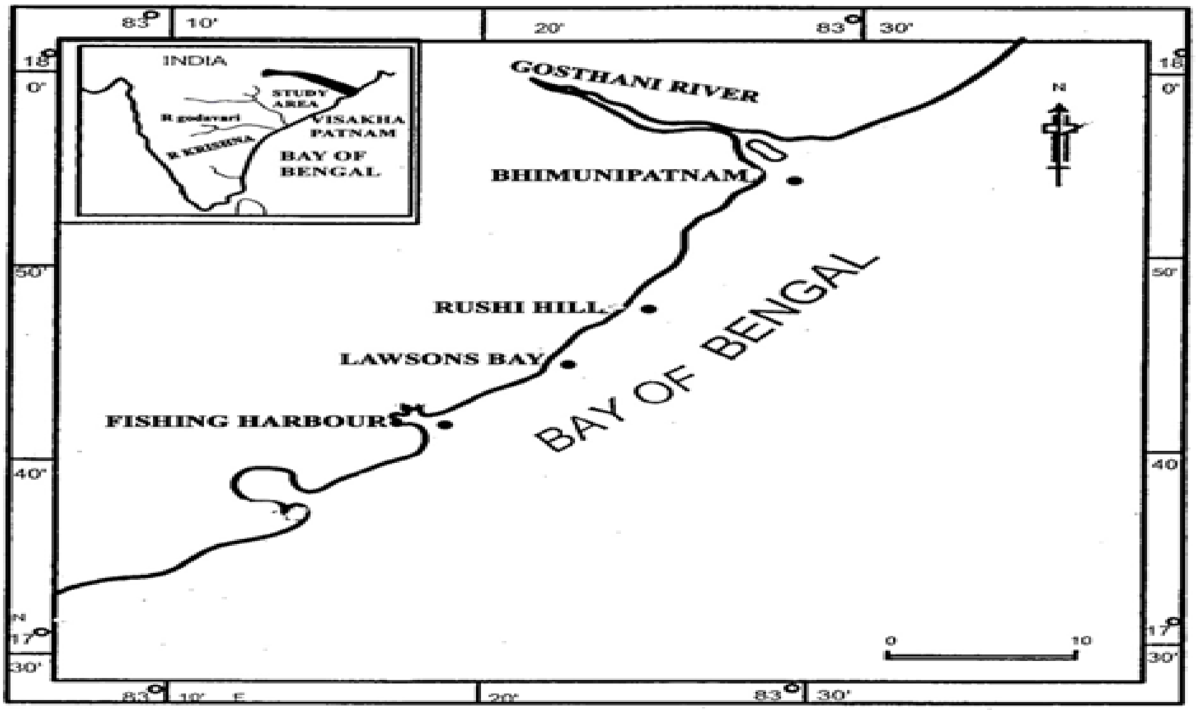

Fig. 1. Station locations along the visakhapatnam coast.

Collection of Water Samples

Surface water samples for the determination of the environmental variables were collected in pre-cleaned polythene bottles from the four sites of each sampling station seasonally (Apremonsoon season; April, 2011) and monsoon season (September, 2011) and stored in a refrigerator prior to their analysis.

Hydrographic variable analysis

Surface water temperature was measured using a mercury-in-glass thermometer. pH and salinity were analyzed with the help of a Systronics water analyzer. The chlorophyll-a contents was analyzed by the acetone extraction method (Jeffrey and Humphrey, 1975). The turbidity of the water samples was measured using a nephelometer. Dissolved oxygen was determined by Winkler's titrimetric method (Strickland and Parsons, 1972). The dissolved nutrients such as nitrate, phosphate and silicate contents were estimated by following the procedure outlined by standard methods (Strickland and Parsons, 1972; Grasshoff *et al.*, 1983; APHA, 1992).

Collection, Preservation and Analysis of Phytoplankton Samples

Phytoplankton samples were collected by horizontal towing of plankton net (mesh size 60 µm and 0.25 diameter) in the surface water (1 m depth) quantitatively into a wide mouth 1 litre polyethylene bottle, and then preserved with 4 % formaldehyde. Then plankton samples were centrifuged at 1500-2000 rpm for 10-12 min. The phytoplanktons settled were diluted to a desirable concentration in such a way that they could be easily counted individually under compound binocular microscope and phytoplanktons were measured and multiplied with the dilution factors, using Sedgwick Rafter cell (APHA,2005) as was described by Welch (1948), Smith (1950). Standard manuals and publications were used to aid identification of the species (Desikachary, 1959; Desikachary, 1989; Tomas, 1997) the counts were converted to cells l^{-1}.

Statistical analysis

The results were calculated as the mean value of the triplicate tests with the standard deviation. The correlation matrix (Pearson's correlation coefficients) was carried out by SPSS statistical software (Version 16.0 for Windows).

The total number of species (S) the total number of individuals (N) and the diversity indices such as Shannon weiver (H) index (Shannon and Weaver ,1949), Simpson (d) index (Simpson, 1949) and Jaccards (J) index (Jaccard, 1902) were calculated.

Results

A total of 110 microalgae were identified during the course of this study. A total of 16409312 cells were identified at fishing harbour with maximum abundance of the species *Rizosolinia alata* (866666cells/m3). 14905676 cells were found at Lawson,s Bay with *Coscinodiscus eccentricus* (500000 cells/m3) as the abundant form. 10720987cells/m3cells were reported at Rushi hills and the *Navicula* sp. (833333cells/m3) showed abundance.11653218 cells/m3were observed at Bheemunipatnamand the abundant form was *Skeletonema coastatum* (466666 cells/m3). Detailed list of phytoplankton is presented in Table 1 and 2.

Table 1. Station wise distribution of phytoplankton abundance in the surface waters along the Visakhapatnam coast during the dry period, 2011.

Year/	March 2011							
Area	FiishingHarbour		Lawsons' Bay		Rushi Hills		Bheemunipatnam	
Species Composition	Total	%	Total	%	Total	%	Total	%
Cyclotela comta	300000	1.83	300000	2.01	0	0.00	250000	2.15
Cyclotela sp.	0	0.00	0	0.00	333333	3.11	0	0.00
Lauderia annulata	216666	1.32	133333	0.89	133333	1.24	100000	0.86
Planktonella sol	250000	1.52	216000	1.45	216000	2.01	300000	2.57
Porociragracilis	100000	0.61	0	0.00	0	0.00	0	0.00
Skeletonemacostatum	583000	3.55	333333	2.24	0	0.00	466666	4.00
Thalassiosiraangulata	500000	3.05	216666	1.45	300000	2.80	166666	1.43
Thalassiosiradecipines	416666	2.54	200000	1.34	83333	0.78	200000	1.72
T. eccentricus	416666	2.54	0	0.00	0	0.00	100000	0.86
Melosiramoniliformis	0	0.00	0	0.00	183333	1.71	200000	1.72
Leptocylindricus sp.	83333	0.51	50000	0.34	33333	0.31	133333	1.14
Corethroncriophilum	216666	1.32	0	0.00	133333	1.24	0	0.00
Corethronhystrix	100000	0.61	0	0.00	200000	1.87	200000	1.72
Coscinodiscus radiates	350000	2.13	200000	1.34	500000	4.66	200000	1.72
Coscinodiscus centralis	450000	2.74	233357	1.57	200000	1.87	233237	2.00
Coscinodiscus sp.	233333	1.42	0	0.00	133333	1.24	200000	1.72
Coscinodiscus eccentricus	83333	0.51	500000	3.35	500000	4.66	300000	2.57
Asterompha lusheptactis	500000	3.05	383333	25.69	0	0.00	0	0.00
Asteromphalus sp.	0	0.00	0	0.00	133333	1.24	133333	1.14
Hemidiscus cuneiformis	266666	1.63	133333	0.89	50000	0.47	83333	0.72
Rizosoliniaalata	866666	5.28	333333	2.24	500000	4.66	466666	4.00
Rizosolenia crassinopina	0	0.00	0	0.00	300000	2.80	333333	2.86
Rizosolenia setegera	66666	0.41	0	0.00	0	0.00	133333	1.14
*Rizosolenia*sp.	0	0.00	0	0.00	0	0.00	150000	1.29
Guinaridia sp.	66666	0.41	50000	0.34	83333	0.78	50000	0.43
Eucampiazoodiacus	0	0.00	133333	0.89	50000	0.47	83333	0.72
Climacodium sp.	100000	0.61	0	0.00	0	0.00	0	0.00
Bacteristrum sp.	183333	1.12	66666	0.45	100000	0.93	150000	1.29
Chaetoceros pelagicus	383333	2.34	300000	2.01	200000	1.87	316666	1.29
Chaetoceros affinis	66666	0.41	400000	2.68	38333	0.36	83333	0.72
Chaetoceros sp.	23333	0.14	400000	2.68	100000	0.93	0	0.00
Ditylumbrightwelli	200000	1.22	66666	0.45	0	0.00	0	0.00
Ditylum sol	150000	0.91	100000	0.67	133333	1.24	66666	0.57
Triceratium sp.	33333	0.20	33333	0.22	0	0.00	83333	0.72
Buddulphia sinenses	133333	0.81	200000	1.34	0	0.00	233333	2.00
Buddulphia mobiliensis	100000	0.61	0	0.00	200000	1.87	100000	0.86
Buddulphia sp.	133333	0.81	200000	1.34	0	0.00	233333	2.00
Asterionellopsis japanica	483333	2.95	266666	1.79	50000	0.47	466666	4.00
Synedra sp.	233333	1.42	100000	0.67	316666	2.95	100000	0.86
Licmophora sp.	100000	0.61	0	0.00	0	0.00	200000	1.72
Grammatophora sp.	33333	0.20	50000	0.34	0	0.00	33333	0.29
Climacospenia moniligera	200000	1.22	0	0.00	50000	0.47	0	0.00
Climacospenia alongata	0	0.00	233333	1.57	0	0.00	216666	1.86
Thalassionema nitzschioids	416666	2.54	333333	2.24	366666	3.42	466666	4.00

Thalassiothrix longissima	300000	1.83	366666	2.46	500000	4.66	383333	3.29
Navicula sigma	100000	0.61	66666	0.45	133333	1.24	0	0.00
Navicula longa	266666	1.63	133333	0.89	166666	1.55	183333	1.57
Naviculahennedyii	216666	1.32	0	0.00	83333	0.78	116666	1.00
Navicula sp.	0	0.00	0	0.00	833333	7.77	0	0.00
Pinnularia sp.	100000	0.61	133333	0.89	83333	0.78	100000	0.86
Pleurosigma directum	200000	1.22	0	0.00	0	0.00	100000	0.86
Pleurosigma normanii	100000	0.61	266666	1.79	200000	1.87	150000	1.72
Gyrosigma balticum	200000	1.22	200000	1.34	200000	1.87	50000	1.29
Gyrosigma sp.	100000	0.61	0	0.00	50000	0.47	50000	0.43
Amphiprora sp.	0	0.00	66666	0.45	0	0.00	166666	1.43
Amphora sp.	0	0.00	133333	0.89	0	0.00	86666	0.74
Cymbella sp.	66666	0.41	0	0.00	0	0.00	50000	0.43
Bacillaria parodoxa	100000	0.61	166666	1.12	66666	0.62	200000	1.72
Surerella gemma	0	0.00	60000	0.40	33333	0.31	116666	1.00
Nitzschia longissima	300000	1.83	333333	2.24	133333	1.24	133333	1.14
Nitzschia closterium	300000	1.83	200000	1.34	83333	0.78	200000	1.72
Prorocentrum scuteiuoros	200000	1.22	200000	1.34	0	0.00	50000	0.43
Prorocentrum micon	28333		200000		133333		266666	
Exuvialla sp.	216666	1.32	200000	1.34	50000	0.47	50000	0.43
Amphisolenia bodenta	86666	0.53	0	0.00	0	0.00	66666	0.57
Dinophysisc audata	250000	1.52	133333	0.89	66666	0.62	200000	1.72
Dinophysis sp.	200000	1.22	0	0.00	0	0.00	133333	1.14
Histoneiescarenata	200000	1.22	0	0.00	0	0.00	100000	0.86
Ornithoceros quadratus	233333	1.42	0	0.00	0	0.00	66666	0.57
Noctilucasp	150000	0.91	0	0.00	66666	0.62	0	0.00
Ceratium trichoceros	300000	1.83	200000	1.34	266666	2.49	0	0.00
Ceratium furca	266666	1.63	333333	2.24	233333	2.18	200000	1.72
Ceratium tripos	133333	0.81	200000	1.34	300000	2.80	200000	1.72
Ceratium gibberum	133333	0.81	250000	1.68	300000	2.80	200000	1.72
Ceratium fusus	183333	1.12	216666	1.45	200000	1.87	0	0.00
Gonyaulax sp.	250000	1.52	133333	0.89	0	0.00	66666	0.57
Pyrophacus horologicum	50000	0.30	66666	0.45	0	0.00	50000	0.43
Peridinium eccentroceros	0	0.00	0	0.00	0	0.00	166666	1.43
Peridinium sp.	416666	2.54	200000	1.34	100000	0.93	133333	1.14
Protoperidinium pentagonum	266666	1.63	133333	0.89	0	0.00	0	0.00
Protoperidinium dipression	300000	1.83	133333	0.89	83333	0.78	0	0.00
Protoperidinium oceanicum	0	0.00	200000	1.34	50000	0.47	0	0.00
Protoperidinium conicum	66666	0.41	0	0.00	100000	0.93	50000	0.43
Protoperidinium brave	50000	0.30	100000	0.67	100000	0.93	166666	1.43
*Oxytoxum*sp.	266666	1.63	133333	0.89	100000	0.93	166666	1.43
*Gymnodium*sp.	100000	0.61	83000	0.56	50000	0.47	66666	0.57
Euglena sp.	83333	0.51	0	0.00	50000	0.47	0	0.00
Trichodesmium erythraca	33333	0.20	33333	0.22	0	0.00	33333	0.29
Spirulina sp.	133333	0.81	50000	0.34	166666	1.55	83333	0.72
Oscillatoria sp.	200000	1.22	133333	0.89	100000	0.93	66666	0.57
*Microsysts*sp.	33000	0.20	0	0.00	0	0.00	0	0.00
Scenedesmus quadri	83333	0.51	0	0.00	33333	0.31	0	0.00
Pediastrum sp	66666	0.41	0	0.00	33333	0.31	0	0.00
Cocconeis sp.	66666	0.41	33333	0.22	83333	0.78	33333	0.29
Total	16409312	100	14905676	100	10720987	100	11653218	100

The total number of species (S), The total number of individuals (N), The diversity indices such as Shannon weiver index (H''), Simpson index (d) and Jaccards index (J) were presented in Table-3.

In the course of this study, the mean water temperature went through a seasonal cycle characterized by 30.09°C in surface water and 28.93 in bottom water.

It was determined that in spring and summer, sudden temperature changes took place between the depths of 15 and 30 m, and that this change was not felt much due to vertical circulation in autumn and winter. No significant variation in pH was observed during the present study, as it was 7.67 on average in surface water and 7.82 in bottom water. Average salinity values in surface water was 31.37psu and 32.15 psu in bottom waters.

Salinity was increased from the surface to the bottom, reaching its highest value at a depth of 30 m. After 20 m, a sudden increase in salinity was remarkable in spring and summer, indicating the presence of a halocline layer. In autumn and winter, it was determined that an intermediate layer did not form with respect to vertical salinity change, and that salinity showed a similar distribution at all depths.

Table 2. Station wise distribution of phytoplankton abundance in the surface waters along theVisakhapatnam coast during the wet period,2011.

Month/	September 2011							
Station Name	Fishing Harbour		Lawsons' Bay		Rushi Hills		Bheemunipatnam	
Species Composition	Total Nos.	%	Total Nos.	%	Total Nos.	%	Total Nos.	%
Cyclotela comta	133333	1.01	250000	2.52	133333	1.30	333333	2.74
Lauderia annulata	100000	0.75	0	0.00	0	0.00	0	0.00
Lauderia borealis			100000		83333		133333	
Planktonella sol	166666	1.26	233333	2.35	166666	1.62	166666	1.37
Porocira gracilis	0	0.00	33333	0.34	0	0.00	133333	1.10
Skeletonema costatum	466666	3.52	233333	2.35	366666	3.57	433333	3.57
Thalassiosira angulata	533333	4.02	0	0.00	383333	3.73	383333	3.16
Thalassiosira eccentricus	200000	1.51	333333	3.36	0	0.00	0	0.00
Thalassiosira gracilis	0	0.00	300000	3.02	133333	1.30	0	0.00
Melosira moniliformis	0	0.00	0	0.00	183333	1.78	200000	1.65
Leptocylindricus sp.	33333	0.25	50000	0.50	50000	0.49	133333	1.10
Lauderia borealis	0	0.00	100000	1.01	83333	0.81	133333	1.10
Corethron criophilum	216666	1.63	33333	0.34	133333	1.30	0	0.00
Corethron hystrix	66666	0.50	33333	0.34	33333	0.32	133333	1.10
Coscinodiscus radiates	200000	1.51	0	0.00	200000	1.94	433333	3.57
Coscinodiscus centralis	333333	2.51	0	0.00	416666	4.05	0	0.00
Coscinodiscussp.	333333	2.51	133333	1.34	0	0.00	0	0.00
Coscinodiscus eccentricus	300000	2.26	0	0.00	0	0.00	0	0.00
Asteromphalus heptactis	0	0.00	383333	3.86	400000	3.89	466666	3.84
Asteromphalussp.	83333	0.63	0	0.00	0	0.00	433333	3.57
Aulacodiacussp.	0	0.00	0	0.00	0	0.00	83333	0.69
Hemidiscusc uneiformis	233333	1.76	200000	2.01	0	0.00	0	0.00
Rizosolinia alata	366666	2.76	416666	4.19	233333	2.27	266666	2.19
Rizosolenia crassinopina	50000	0.38	0	0.00	416666	4.05	466666	3.84
Rizosolenia setegera	0	0.00	0	0.00	100000	0.97	166666	1.37
Rizosolenia styliformis	416666	3.14	0	0.00	0	0.00	200000	1.65
Rizosolenia sp.	0	0.00	0	0.00	266666	2.59	133333	1.10
Guinaridia sp.	0	0.00	133333	1.34	0	0.00	0	0.00
Eucampia sp.	133333	1.01	66666	0.67	183333	1.78	33333	0.27
Climacodium sp.	0	0.00	0	0.00	0	0.00	50000	0.41
Bacteristrum delecatulum	50000	0.38	0	0.00	0	0.00	50000	0.41
Bacteristrum furcatum	33333	0.25	66666	0.67	50000	0.49	50000	0.41
Bacteristrum sp.	100000	0.75	150000	1.51	66666	0.65	133333	1.10
Chaetoceros pelagicus	333333	2.51	0	0.00	0	0.00	0	0.00
Chaetoceros sp.	333333	2.51	466666	4.70	333333	3.24	400000	3.29
Ditylum brightwelli	150000	1.13	100000	1.01	150000	1.46	100000	0.82
Ditylum sp.	66666	0.50	133333	1.34	0	0.00	0	0.00
Lithodesmium sp.	216666	1.63	200000	2.01	0	0.00	66666	0.55

Triceratium sp.	133333	1.01	33333	0.34	66666	0.65	133333	1.10
Buddulphia sinenses	166666	1.26	166666	1.68	166666	1.62	183333	1.51
Buddulphia mobiliensis	66666	0.50	0	0.00	183333	1.78	150000	1.23
Asterionellopsis japanica	483333	3.64	266666	2.68	0	0.00	466666	3.84
Synedra sp.	233333	1.76	66666	0.67	316666	3.08	166666	1.37
Licmophora sp.	33333	0.25	83333	0.84	66666	0.65	0	0.00
Rabdonema sp.	83333	0.63	0	0.00	0	0.00	33333	0.27
Grammatophora sp.	133333	1.01	0	0.00	50000	0.49	66666	0.55
Climacospenia moniligera	133333	1.01	0	0.00	50000	0.49	33333	0.27
Climacospenia alongata	100000	0.75	66666	0.67	0	0.00	66666	0.55
Frazillariao ceanica	33333	0.25	83333	0.84	0	0.00	50000	0.41
Raphoneis discardes	66666	0.50	0	0.00	33333	0.32	166666	1.37
Thalassionema nitzschioids	333333	2.51	416666	4.19	283333	2.76	300000	2.47
Thalassiothrix longissima	200000	1.51	233333	2.35	300000	2.92	150000	1.23
Thalassiothrix frauenifeld	133333	1.01	166666	1.68	50000	4.86	233333	1.92
Navicula sigma	0	0.00	0	0.00	0	0.00	133333	1.10
Navicula longa	133333	1.01	100000	1.34	0	1.94	0	1.65
Naviculahennedyii	133333	1.01	133333	1.34	200000	1.94	200000	1.65
Cylendrotheca compressa	50000	0.38	0	0.00	0	0.00	0	0.00
Cylendrotheca decipines	0	0.00	0	0.00	50000	0.49	0	0.00
Cylendrotheca closterium	50000	0.38	0	0.00	0	0.00	0	0.00
Pinnularia alpine	0	0.00	0	0.00	0	0.00	33333	0.27
Pleurosigma directum	133333	1.01	0	0.00	0	0.00	0	0.00
Pleurosigma formosum	0.00	0.00	0.00	0.00	0.00	0.00	133333	
Pleurosigma normanii	133333	1.01	266666	2.68	0	0.00	200000	1.65
Gyrosigma sp.	0	0.00	0	0.00	100000	0.97	0	0.00
Diploneis sp.	50000	0.38	66666	0.67	0	0.00	133333	1.10
Amphiprora sp.	133333	1.01	33333	0.34	66666	0.65	50000	0.41
Amphora sp.	50000	0.38	133333	1.34	100000	0.97	200000	1.65
Cymbella sp.	150000	1.13	0	0.00	0	0.00	133333	0.00
Bacillaria parodoxa	66666	0.50	0	0.00	0	0.00	0	0.00
Surerella gemma	0	0.00	133333	1.34	83333	0.81	0	0.00
Nitzschia longissima	200000	1.51	166666	1.68	233333	2.27	250000	2.06
Nitzschia closterium	100000	0.75	100000	1.01	133333	1.30	200000	1.65
Nitzschia serita	50000	0.38	0	0.00	0	0.00	0	0.00
Amphisolenia bodenta	33333	0.25	0	0.00	0	0.00	33333	0.27
Amhisolenia tripos	66666	0.50	100000	1.01	166666	1.62	33333	0.27
Dinophysis caudata	100000	0.75	166666	1.68	33333	0.32	133333	1.10
Dinophysis sp.	66666	0.50	100000	1.01	0	0.00	0	0.00
Dinophysis tripos	66666		100000		0		0	
Histoneies carenata	133333	1.01	33333	0.34	0	0.00	66666	0.55
Histoneies sp.	33333	0.25	0	0.00	0	0.00	66666	0.55
Ornithoceros quadratus	200000	1.51	66666	0.67	0	0.00	66666	0.55
Noctiluca sp.	150000	1.13	0	0.00	133333	1.30	66666	0.55
Procentrum micans	133333	1.01	100000	1.01	66666	0.65	266666	2.19
Procentrum sp.	33333	0.25	183333	1.85	166666	1.62	266666	2.19
Ceratium trichoceros	300000	2.26	200000	2.01	266666	2.59	0	0.00
Ceratium furca	266666	2.01	333333	3.36	233333	2.27	200000	1.65
Ceratium tripos	133333	1.01	200000	2.01	300000	2.92	200000	1.65

Ceratium gibberum	133333	1.01	250000	2.52	300000	2.92	200000	1.65
Ceratium fusus	183333	1.38	216666	2.18	200000	1.94	266666	2.19
Ceratium sp	200000	1.51	166666	1.68	0	0.00	0	0.00
Gonyaulax sp.	66666	0.50	100000	1.01	33333	0.32	66666	0.55
Pyrophacus horologicum	50000	0.38	33333	0.34	33333	0.32	50000	0.41
Peridinium pentagonum	50000	0.38	150000	1.51	133333	1.30	166666	1.37
Peridinium sp.	150000	1.13	133333	1.34	266666	2.59	0	0.00
Protoperidinium dipression	66666	0.50	166666	1.68	0	0.00	0	0.00
Protoperidinium oceanicum	0	0.00	100000	1.01	0	0.00	133333	1.10
Protoperidinium conicum	66666	0.50	0	0.00	0	0.00	0	0.00
Oxytoxum sublatum	0	0.00	66666	0.67	33333	0.32	33333	0.27
Oxytoxum sp.	216666	1.63	133333	1.34	100000	0.97	116666	0.96
Pyrocystis sp	33333	0.25	0	0.00	50000	0.49	50000	0.41
Gymnodium sp.	66666	0.50	0	0.00	66666	0.65	166666	1.37
Euglena sp.	83333	0.63	66666	0.67	0	0.00	50000	0.41
Coccolithopora	33333	0.25	0	0.00	0	0.00	0	0.00
Trichodesmium erythraca	133333	1.01	33333	0.34	0	0.00	0	0.00
Trichodesmium favus	133333	1.01	33333	0.34	0	0.00	66666	0.55
Spirulina sp.	100000	0.75	0	0.00	0	0.00	0	0.00
Oscillatoria sp.	266666	2.01	0	0.00	0	0.00	0	0.00
Microsysts sp.	83333	0.63	0	0.00	0	0.00	0	0.00
Ankistrodesmus sp.	83333	0.63	0	0.00	33333	0.32	0	0.00
Total	13266639	100	9933311	100	10283314	100	12149976	100

Average DO values of surface and bottom waters were 5.00mg.l^{-1}.The amount of oxygen at the depth of 30 m was found to be very low. Throughout the year when the research was conducted, the average amounts of nitrate , nitrite, phosphate and silicate in surface water were 0.63 µm, 11.73 µm,4.14 µm,1.02 µm and 20.42 µm and in bottom were 0.43 µm,6.22 µm,4.56 µm,0.64 µm and 11.62 µm respectively (Table.4; Fig.3&4). Compared with the surface, the N:P ratio is considerably higher in deep waters, and this is in reverse proportion to DO content. In this study, phytoplankton biomass (Chl *a*) of surface water was 4.45 mg.m^{3}and of bottom was 2.82 mg.m^3.

Table 3. Species diversity of phytoplankton in four study stations during 2011.

	March				October			
	FH	LB	RK	BHPM	FH	LB	RK	BHPM
S	80	62	63	73	89	65	61	73
N	16409312	14905676	10720987	11653218	13266639	9933311	10283314	12149976
d	4.7552	3.6931	3.8301	4.425	5.3656	3.9723	3.7161	4.4137
J	0.9463	0.8477	0.9255	0.9553	0.9458	0.9489	0.9418	0.9439
H'	4.15	3.5	3.83	4.1	4.25	3.96	3.87	4.05

The lowest values of Chl- *a* were observed in October-December with the decline in cell number. Pearson correlation coefficient between hydrological and nutrient parameters was evaluated (Fig. 2) which shows Chl- *a* is negatively correlated with temperature, pH, salinity, ammonia and positive correlation with Dissolved oxygen, nitrites, nitrates, phosphates and silicates.

Discussion

This study has made it possible to determine a number of phytoplanktonic members of algae. It was observed that the number of phytoplankton species increased especially in late spring and during the whole period of summer, and that Bacillariophyceae dominated more in winter and early spring. It has been reported that, during summer, the phytoplankton community is dominated by diatoms in eutrophic and semi-enclosed areas (Caroppo and Cardellicchio, 1995).

Table 4. Statistical data on the hydrography and nutrient parameters in the coastalsurface waters of Visakhapatnam during 2011

Parameter	Min.	Max.	Average	S.D (±)
Temp (°C)	27.20	31.50	30.09	1.49
pH	7.11	8.16	7.67	0.27
Salinity (psu)	27.20	33.60	31.37	1.99
D.O. ($mg.l^{-1}$)	3.84	6.10	5.00	0.76
Chl-a ($mg.m^3$)	3.15	5.52	4.45	0.53
Nitrite (µM)	0.11	1.55	0.63	0.41
Nitrate (µM)	4.44	23.32	11.73	5.94
Ammonia (µM)	1.5	7.34	4.14	1.93
Phosphate (µM)	0.19	2.00	1.02	0.55
Silicate (µM)	12.03	40.00	20.42	7.91

The diatoms were dominant species in the neritic region of the oligotrophic waters of the Levant Basin, and the most abundant diatoms belonged to the genera Chaetoceros,

Coscinodiscus and Rhizosolenia (Azov, 1986). of the premonsoon and post monsoon peaks noted in the bay, those belonging to the former period occurred in March and May, and that belonging to the latter period was observed in September. It was in confirmation of this finding that the Chl a value was higher during these periods. Over the year, the amount of Chl a varied decreasing in proportion to the decline of cell numbers between October and December (Neslihan, 2003).

Table 5. Inter-correlations between hydrography and nutrient parameters in the Visakhapatnam Coastal surface waters during study period (2011).

Environmental parameters	Temp.	pH	Salinity	D.O.	NO_2	NO_3	NH_4	PO_4	SiO_4
pH	0.19								
Salinity	0.33	0.74					N=16		
D.O.	-0.50	0.13	0.24				P = <0.05		
NO_2	0.04	-0.53	-0.27	-0.13					
NO_3	-0.27	-0.74	-0.71	0.02	0.45				
NH_4	-0.37	-0.32	-0.38	-0.02	0.36	0.36			
PO_4	-0.06	-0.62	-0.33	0.03	0.87	0.44	0.58		
SiO_4	-0.13	-0.65	-0.77	-0.19	0.25	0.91	0.32	0.23	
Chl-a	-0.31	-0.43	-0.07	0.18	0.37	0.48	-0.09	0.26	0.17

Simpson's index (d) which varied from 0 to 1, gives the probability that two individuals drawn at random from a population belong to the same species.

The higher values of Shannon's Index (H′), indicated the greater species diversity which means large food chain.

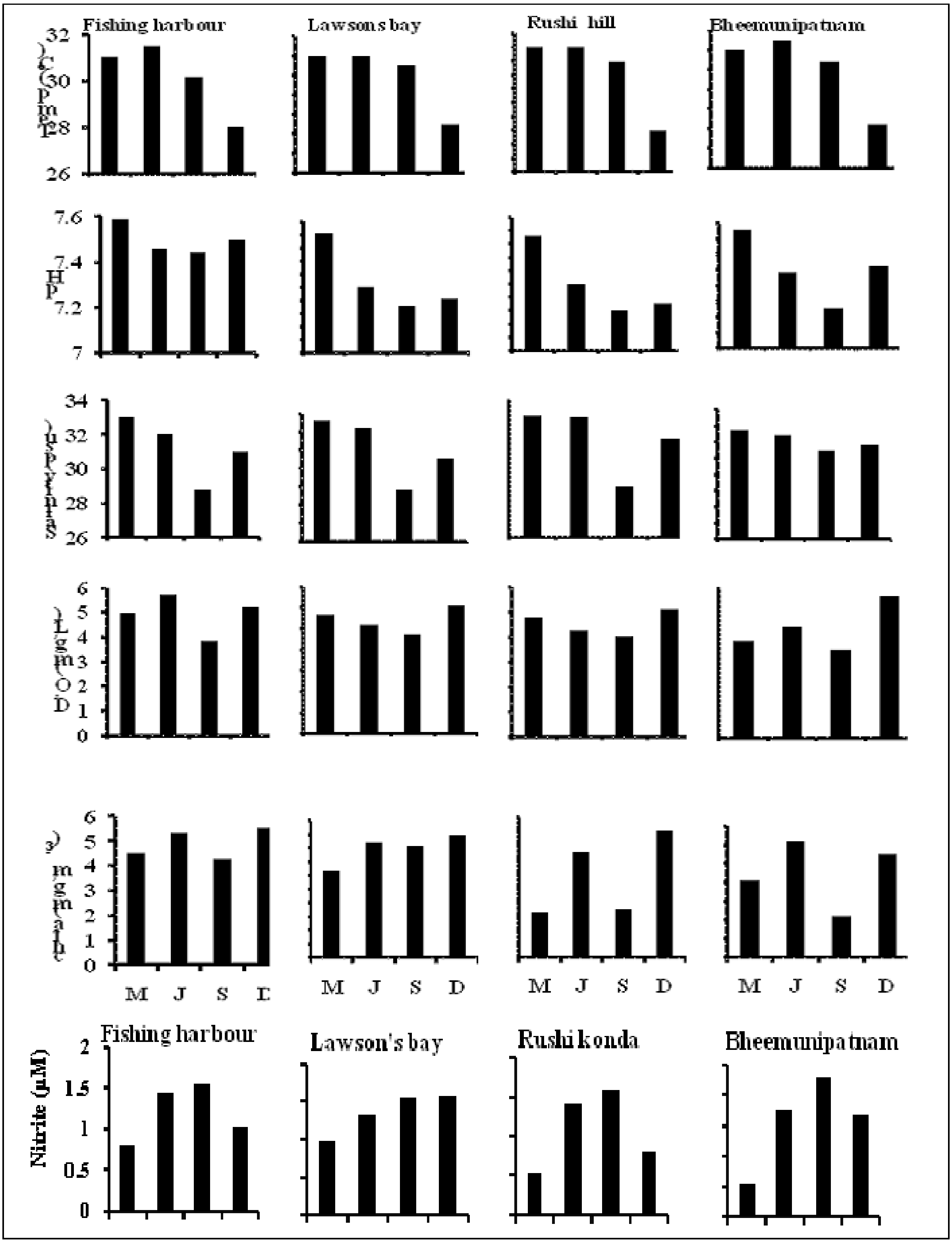

Fig. 2. Spatial and seasonal distribution of hydrographical parameters in the coastal waters (surface) of Visakhapatnam during 2011.

The Jaccard's index value showed greater similarity of phytoplankton species in the study sites. It was found in this research that the values of temperature, salinity and DO changed according to the months and depths; however, the variations between the four stations were not very significant. There will be a flux in spatial temperature due to variable prevailing wind intensity and wave action (Reddy *et al.*,1993). It was obvious that vertical mixing was responsible for the slight increase in salinity between the depths of 15 and 20 m. During winter and spring, the salinity of the surface water in the Sea was slightly higher due to the circulation caused by the winds (Beşiktepe *et al.*, 1995). The fluctuation in salinity is due to mixing of agricultural and domestic wastes, land drainage, industrial effluents into the coast results in decreased biological activity (Govindaraju *et al.*, 2011).

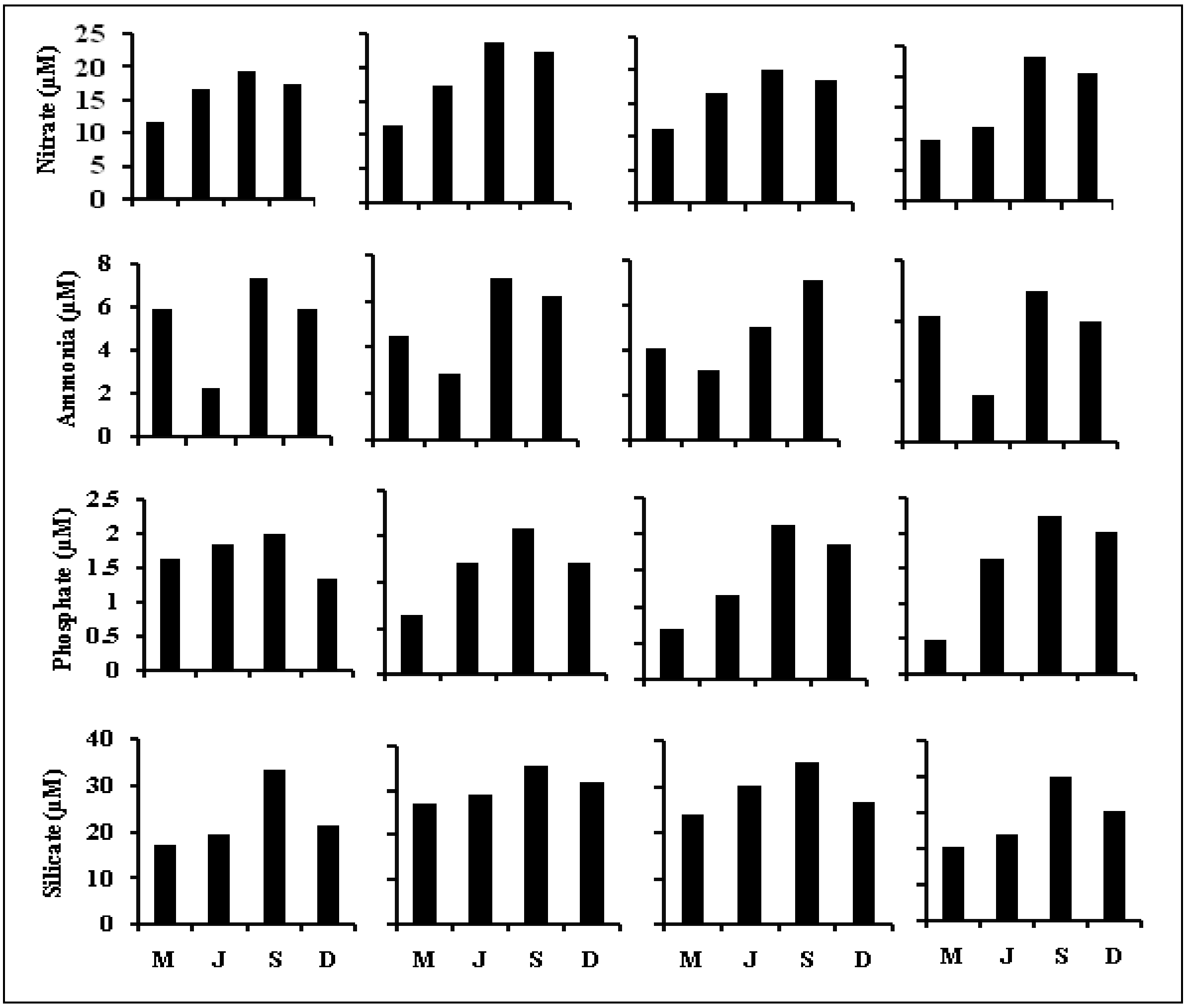

Fig. 3. Spatial and seasonal distribution of nutrient parameters and chl-a in the coastal waters (surface) of Visakhapatnam during 2011.

In this study, it was determined that the surface water, which is in direct contact with the atmosphere, constantly involved higher DO than deep water. Quite lower values of DO were observed at lower layers throughout the year, especially between April and December.

Of note, the amount of DO at such depths was higher in cold seasons. At a depth of 30 m, characterized by lower DO, there were fewer species with low cell numbers. Vertical stratification in spring and summer does not allow the surface water to mix with the deep water.

The amount of oxygen at the depth of 30 m was found to be very low. This was due to excessive oxygen consumption during the decomposition of detritus, which is produced as a consequence of primary production in the upper layer and biochemical reactions occurring in the deeper layer (Neslihan, 2003).

The effects of eutrophication caused by increased light availability and vertical stability are evident during late spring and summer. This is when peaks of phytoplankton abundance and production have been recorded. During this study, none of the species reached a level of a million per litre. Of the nutrient elements detected in Visakhapatnam coast, nitrate, nitrite, phosphate and silicate increased slightly towards the winter months. However, there was not a significant difference between the amounts of those nutrients with respect to the stations and time of year. The higher concentration of nitrate level values is due to the organic materials received in the stream which depend on the level of tide (Ashok *et al.*, 2008). It was found that deep waters originating from this Sea possessed higher values of nutrients compared with upper waters and that, throughout the year (Koray,1994).

The water in the coast was poor in nutrients, become rich in nitrate and orthophosphate as a result of the decomposition of particulate organic material in the depths. It was also noticed that consumption takes place more slowly in these deep waters compared with the upper layers. It is because of the decomposition of organic material that there are low levels of oxygen in these deep waters rich in nutrients. Nutrient availability, which in open waters is mainly controlled by water column structure, is in coastal waters strongly influenced by terrestrial inputs (Zingone *et al.*, 1990). Consequently, anthropic factors may play an important role in determining the trophic and structural characteristics of phytoplankton communities in coastal areas. The phosphate concentration is 2.25 $\mu g\ l^{-1}$ in coastal waters with initial eutrophication, and can rise to 4.5 $\mu g\ l^{-1}$ in highly eutrophic systems (Uslu and Saner, 1998). An increase in pollutants in this bay may be a factor that will elevate future eutrophication. The findings of this study do not imply eutrophication in Visakhapatnam coast, therefore, the upper layer of this Sea is considered as oligotrophic. This study has shown that a number of phytoplankton species live in this Sea and they contribute to the biological diversity of the Visakhapatnam coast.

References

Ahlgren G, Van Nieuwerburgh L, Wanstrand I, Pedersen M, Snoeijs P. 2005. Imbalance of fatty acids in the base of the Baltic Sea food web–amesocosm study. Canadian Journal of Fisheries and Aquatic Sciences **62,** 2240–2253.

APHA. 2005. Standard methods for the examination of water and waste waters, 21st Ed. Washington, DC. USA.

APHA. 1992. Standard Methods for the Examination of Water and Waste Water. American Public Health Association, Washington, DC. 522p.

Azov Y. 1986. Seasonal patterns of phytoplankton productivity and abundance in nearshore oligotrophic waters of the Levant Basin (Mediterranean). Journal Of Plankton Research **8,** 41–53.

Besiktepe ST, Sur HI, Ozsoy E, Abdul Latif MA, Oguz T, Unluata U. 1995. The circulation and hydrography of the Marmara Sea. Progress in Oceanography **34,** 285–334.

BhanuPrakash M, Jyothi K, Rao GMN. 2014. Seasonal variations of phytoplankton community structure in relation to Physico-chemical factors in Lake Kolleru, Andhra Pradesh, India. Journal of Algal Biomass Utilization **5 (3),** 1 – 7.

Caroppo C. Cardellicchio N. 1995. Preliminary study on phytoplankton communities of Mar Piccolo in Taranto (Jonian Sea). Oebalia **21,** 61–76.

Damotharan P, VengadehPerumal N, Arumugam M, Vijayalakshmi S, Balasubramnian T. 2010. Seasonal variation of physicochemical characteristics in point Calimere coastal waters (South East Coast of India). Middle-East Journal of Scientific Research **6(4),** 333-339.

Desikachary TV. 1989. Atlas of Diatoms. Madras Science Foundation, Madras. 809.

Desikachary TV. 1959. Cyanophyta. Indian Council of Agricultural Research, New Delhi. 686.

Edward JKP, Ayyakkannu K. 1991.Studies on the ecology of plankton Community of Kollidam estuary, South-east coast of India, I. Phytoplankton Mahasagar-Bulletin of National Institute of Oceanography **24,** 89–97.

Grasshoff K, Ehrharrot M, Kremling, K. 1983.Methods for Seawater Analysis. Verlag. Chemic. Weinheim, 419.

Govindaraju M, Kumar P, Selvaraj M, Rajina C. 2011. Study on Physico-Chemical Parameters along the Coastal Waters around Kudankulam Nuclear Power Plant. International Journal of Oceans and Oceanography **5(1),** 73-83.

Gouda R, Panigrahy RC. 1996. Ecology of phytoplankton in coastal waters off Gopalpur, east coast of India. Indian Journal of Marine Sciences 2, 13–18.

Jaccard P. 1902. Lois de distribution florale. Bulletin de la Socíété Vaudoise des Sciences Naturelles **38,** 67-130.

Jeffrey SW, Humphrey GF. 1975. New spectrophotometric equations for determining chlorophylls a, b, c1 and c2 in higher plants, algae and natural phytoplankton. Biochem Physiol Pflanzen **167,** 191-194.

Jyothi K, Rao GMN. 2013. Seasonal Distribution of Phytoplankton in Riwada Reservoir, Visakhapatnam, Andhra Pradesh, India. Notulae Scientia Biologicae **5(3),** 290-295.

Koray T. 1994. Phytoplankton species succession, diversity and nutrients in neritic waters of the Aegean Sea (Bay of Izmir). Turkish Journal of Botany **19,** 531–544.

Kudela RM, Peterson TD. 2009. Influence of a buoyant river plume on phytoplankton nutrient dynamics: what controls standing stocks and productivity? Journal of Geophysical. Research **114,** 15.

Lohse KA, Brooks PD, McIntosh JC, Meixner T, Huxman TE.2009. Interactions Between Biogeochemistry and Hydrologic Systems. Annual Review of Environment and Resources **34,** 65-96.

Nagamani PV, Rajesh Shikhakolli, Prakash Chauhan. 2011. Phytoplankton Variability in the Bay of Bengal During Winter Monsoon Using Oceansat-1 Ocean Colour Monitor Data. Journal of the Indian Society of the Remote Sensing **39(1),** 117-126.

Nayar S, Goh BPL, Chou LM. 2005. Settlement of marine periphytic algae in a tropical estuary. Estuarine Coastal and Shelf Science **64(2-3),** 241-248.

Neslihan Balkis. 2003. Seasonal variations in the phytoplankton and nutrient dynamics in the neritic water of Buyukçekmece Bay, Sea of Marmara. Journal of Plankton Research **25(7),** 703-717.

Panigrahi SN, Acharya BC, Das SN. 2004. Distribution of diatoms and dinoflagellatesin tropical waters of Orissa and West Bengal with emphasis on neritic assemblages. Proceedings of National Seminar, New Frontiers in Marine Bioscience Research 535–543p.

Reddy V, Mavrovouniotis M, Liebman M. 1993. Petri net representations in metabolic pathways. In L. Hunter, editor, Proceedings of the first international conference on intelligent systems for molecular biology. MIT Press.

Saravanakumar A, Rajkumar M, Thivakaran GA. 2008. Abundance and seasonal variations of zooplankton in the arid and zone mangrove of Gulf of Kachchh Gujarat. Journal of Environmental Biology **29,** 71–274.

Saravanane N, Nandakumar K, Durairaj G. 2000. Plankton as indicators of coastal water bodies during south-west to north-east monsoon transition at Kalpakkam. Current Science **78(2),** 173–176.

Sigua GC, Tweedale WA. 2003. Watershed scale assessment of nitrogen and phosphorus loadings in the Indian River Lagoon basin, Florida. Journal of Environmental Management **67(4),** 363-372.

Shannon CE, Weaver W. 1949. The mathematical theory of communication. University of Illinois Pres, Urbana.

Simpson EH. 1949. Measurement of diversity. Nature 163-688.

Sridhar R, Thangaradjou T, Senthil Kumar S. 2006. Water quality and phytoplankton characteristics in the Palk Bay, southeast coast of India. Journal of Environmental Biology **27,** 561–566.

Smith GM. 1950. The fresh-water algae of the United States, IInd Ed. McGraw-Hill book com. Inc. New York.

Strickland JDH, Parsons TRA. 1972. Practical Handbook of Seawater Analysis.2nd ed. Fisheries Research Board of Canada, Ottawa. 310p.

Tomas C. 1997. Identifying Marine Phytoplankton. Academic Press, San Diego. 856p.

Uslu, O Saner E. 1998. Izmir’de atıksu yonetimi ve korfezde kirlenme kontrolü. Buyukşehirlerde atıksu yonetimi ve deniz kirlenmesi kontrolu sempozyumu. ISKI, 93–107p.

Welch PS. 1948. Limnology methods, Mc Graw Hill Book Co. Inc. New York.

Zettler ML, Bochert R, Pollehne F. 2009. Macrozoobenthos diversity in an oxygen minimum zone off northern Namibia. Marine Biology **156(9),** 1949-1961.

Zingone A, Montresor M, Marino D. 1990. Summer phytoplankton physiognomy in coastal waters of the Gulf of Naples. Marine Ecology **11,** 157–172.