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Phytoplankton community characteristics in the coastal waters of the southeastern Arabian Sea

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Abstract

Remote sensing applications are important in the fisheries sector and efforts were on to improve the predictions of potential fishing zones using ocean color. The present study was aimed to investigate the phytoplankton dynamics and their absorption properties in the coastal waters of the southeastern Arabian Sea in different seasons during the year 2010 to 2011. The region exhibited 73 genera of phytoplankton from 19 orders and 41 families. The numerical abundance of phytoplankton varied from 14.235×10^3 to 55.075×10^6 cells/L. Centric diatoms dominated in the region and the largest family identified was Thalassiosiraceae with main genera as *Skeletonema* spp., *Planktionella* spp. and *Thalassiosira* spp. Annual variations in abundance of phytoplankton showed a typical one-peak cycle, with the highest recorded during premonsoon season and the lowest during monsoon season. The species diversity index of phytoplankton exhibited low diversity during monsoon season. Phytoplankton with pigments Chlorophyll *a*, Chlorophyll *b*, Chlorophyll *c*, peridinin, diadinoxanthin, fucoxanthin, β-carotene and phycoerythrobilin dominated in these waters. The knowledge on phytoplankton dynamics in coastal waters of the southeastern Arabian Sea forms a key parameter in bio-optical models of pigments and productivity and for the interpretation of remotely sensed ocean color data.

Key words: phytoplankton, diversity, community structure, ocean color, southeastern Arabian Sea

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1 Introduction

The chlorophyll concentration, considered as an indicator of phytoplankton biomass, determines the optically active constituents altering the underwater light field. Hence *in-situ* measurements of phytoplankton and their optical characteristics in the coastal areas can provide the database required to develop bio-optical algorithms useful in retrieving chlorophyll from space (Carder et al., 1991; Tassan, 1994; Le et al., 2011). Chlorophyll *a* (Chl *a*) is the major pigment in phytoplankton which absorbs blue and red light in the visible spectrum and results in the blue-green color of ocean. Also the regional, seasonal and inter-annual variations of the ocean color products and its retrieval depend on the types of dominant phytoplankton that contribute to the ocean color. Hence understanding the variations in phytoplankton community structure helps to know its own inherent optical properties and dynamics of complex coastal waters in which they inhabit, thereby to get a clear idea about the water leaving signal reaching the sensor (IOCCG report No.9). Phytoplankton taxonomic studies provide basic information on the phytoplankton species which can be used in pigment marker studies. The contribution of various marker pigments is used for the development of algorithms to determine the contribution of these pigments to the total Chl *a* concentration.

Few studies have been carried out in the coastal waters off Kochi, in the eastern Arabian Sea to know the phytoplankton community characteristics, even though the Kochi backwaters and Arabian Sea were investigated in detail. Previous studies in the area were mainly focused on physical and chemical characteristics of phytoplankton blooms (Padmakumar et al., 2010, 2012). A latest study on identification of the major phytoplankton confirmed nanoplankton as the major contributor to the total Chl *a* and primary production in the region. Nanoplankton is found to have maximum photosynthetic efficiency in coastal waters (Madhu et al., 2010). The present study examines the phytoplankton community structure, its diversity and the variation in absorption properties in relation to its diversity index.

2 Methodology

The study area is situated between 9°54′28″N, 76°12′47″E and 10°02′37″N, 76°09′15″E which is in the eastern coast of Arabian Sea. The area being in the tropics experiences an annual rainfall of 4 000 mm per year and is subjected to seasonally reversing monsoonal wind system, which drives the near surface currents and affects the development of mixed layer, thereby the nutrient availability in the upper water column which favours the phytoplankton growth. Based on these diverse features and prevailing monsoon, three distinct seasons exists in this region-

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premonsoon (February to May), monsoon (June to September) and postmonsoon (October to January).

Surface water samples were taken once in every month from eight sampling sites during June 2010 to May 2011. Sampling was done using a commercial purse seiner. Samples collected using Niskin water sampler were stored in clean dark polyethylene bottles, kept in cold and transported to the laboratory where further analysis was carried out. Station 1 is in the nearby estuarine area where increased nutrient rich fresh water influx occurs to the adjacent coastal waters during monsoon season. Station 4 is represented by the area where mixing of marine and fresh water occurs. Other stations were on the northern and southern parts of an inlet to the Kochi estuary as shown in Fig. 1.

For phytoplankton species identification, water samples were collected separately and preserved in formaldehyde (4%, v/v) solution. Total phytoplankton density was calculated as cells/L (Utermöhl, 1958). The method did not include small size fractionization of phytoplankton. Identification was carried out according to Cupp (1943), Subrahmanyan (1959) and Tomas (1997). Changes in phytoplankton dynamics examined using Shannon-Wiener diversity index (*H*) (Zar, 1984). Species richness indicated by the number of species and evenness by Pielou's evenness index.

During the study period, the hydrographic parameters affecting the phytoplankton were investigated. Turbidity was measured using Nephelometer (NTU), water temperature (degree Celsius) with thermometer and pH with pH meter. Concentrations of nutrients like nitrite, phosphate and silicate were measured using spectrophotometer according to standard protocols (Grasshoff et al., 1983). For Chl *a* analysis, water samples were filtered through 47 mm GF/F filters. The filter paper is transferred to a glass screw capped tube containing 20 mL of 90% (v/v) acetone for chlorophyll extraction and is measured using Turner Design 10AU Fluorometer (Strickland and Parsons, 1972). For measuring phytoplankton absorption, 0.2 to 2 L of seawater were filtered through 25 mm Whatman GF/F filters with low pressure and measured using Shimadzu UV-2450 attached with integrating sphere (Mitchell and Kahru, 1998). The absorption was measured from 400 to 750 nm with a resolution of 1 nm before and after rinsing the filters with hot methanol. The particulate (a_p (l)) and detritus (a_d (l)) absorption were determined using the equation

$$a_{ph}(\lambda) = a_p(\lambda) - a_d(\lambda),$$

$$a_p(\lambda) = \frac{2.303 OD_s(\lambda)}{V/S},$$

$$a_d(\lambda) = \frac{2.303 OD_s(\lambda)}{V/S},$$

$$OD_s(\lambda) = 0.378 OD_f(\lambda) + 0.523\left[OD_f(\lambda)\right]^2,$$

where OD_s is the optical density of total suspended particulate matter or detritus matter, *V* is the filtration volume (m^3) and *S* is the filtration area (m^2). The coefficients 0.406 8 and 0.368 are the path-length correction factors caused by multiple scattering in the glass fiber filter. Phytoplankton absorption, a_{ph}(l), was determined by the difference between the total particulate material absorption, $a_p(\lambda)$ and non-pigmented detritus material absorption, $a_d(\lambda)$. A fourth derivative analysis of $a_{ph}(\lambda)$ was calculated by applying a four point fourth degree polynomial smoothing and then differentiating using the Savitzky-Golay method (Savitzky and Golay, 1964). The procedure was carried out using Microcal Origin 6.0 Scientific analysis software. Peaks in the fourth derivative curves were selected using the peak finder tool in the software.

3 Results

3.1 *Hydrographic parameters*

The pH, turbidity, temperature and salinity of the water

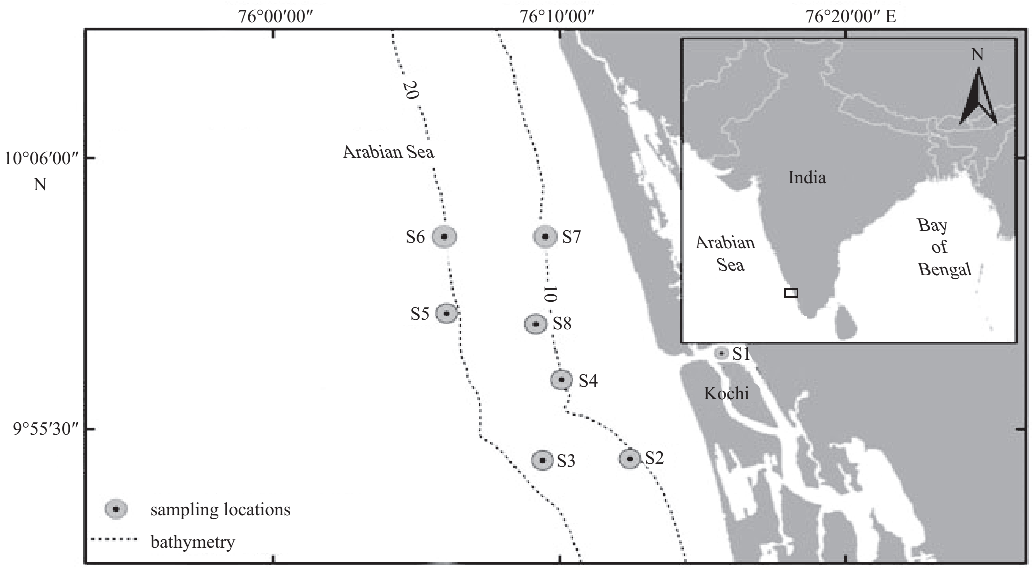

Fig.1. Map showing the study area. Station 1 (S1) is in the nearby estuarine area, Sta. 4 (S4) is represented by the area where mixing of marine and fresh water occurs. Stations S2, S3, S5, S6, S7 and S8 occur on the northern and southern parts of an inlet to the Cochin Estuary. S1, S2, S7 and S8 have 10 m depth while S3, S5 and S6 have 20 m bathymetry.

samples collected from the study area varied from 7.14 to 8.79, 0.75 to 21.6 NTU, 26.5 to 31°C and 6.50 to 35.09 respectively. Nitrite, phosphate and Chl *a* ranged between 0.005–9.105 μmol/L, 0.211–4.486 μmol/L and 0.019–83.6 mg/m^3 respectively. Monsoon season recorded minimum salinity (6.50–33.40) while turbidity (1.96–20.20 NTU), nitrite (0.070–9.105 μmol/L) and phosphate (0.674–4.591 μmol/L) concentrations were measured maximum during the season.

3.2 *Phytoplankton composition*

The composition of different phytoplankton species were shown in Table 1. A total of 73 genera of phytoplankton from 19 orders and 41 families were identified. Main orders identified were Biddulphiales with 11 family and 23 genera, Bacillariales with 5 family and 15 genera and Gonyaulacales with 5 family and 6 genera. The largest community identified was Thalassiosiraceae with 5 genera, Fragilariaceae and Gymnodiniaceae with 4 genera each. The principal species of the family Thalassiosiraceae were *Skeletonema* spp., *Planktionella* spp. and *Thalassiosira* spp.

Station wise analysis showed that Sta. S4 with 10 m depth (46 genera) recorded the highest phytoplankton species richness index followed by Sta. S8 (10 m depth, 45 genera). The estuarine Sta. S1 (10 m, estuarine region) recorded lowest species richness with only 39 genera. Seasonal changes in species richness of phytoplankton were also observed. Monsoon season recorded 43 genera of phytoplankton whereas postmonsoon recorded 48 genera. High species richness with highest numerical abundance was observed during premonsoon season with 57 species. As a tropical coastal region, the dominant ecotype of phytoplankton was at estuarine region (Sta. S1) with higher abundance during premonsoon season followed by postmonsoon and monsoon seasons, and the second dominant ecotypes were at Sta. S6 (20 m) and Sta. S8 (10 m) during premonsoon season. Low numerical density was exhibited in all the stations during monsoon. Even though postmonsoon recorded high species richness, numerical abundance of phytoplankton in this region during the season was comparatively low.

3.3 *Seasonal variation and spatial distribution of phytoplankton abundance*

The cell abundance of phytoplankton varied from 14.23×10^3 to 55.07×10^6 cells/L (Fig. 2). The predominant abundance all over the year was by centric diatoms which ranged from 27.84×10^3 to 25.10×10^5 cells/L. The lowest density of centric diatoms was recorded during monsoon season in Sta. S1 with the density of 27.84×10^3 cells/L, and the highest peak (25.10×10^5 cells/L) during premonsoon season in the same station. During monsoon season, in Sta. S1, nitrite concentration was 0.65 μmol/L and phosphate concentration was 2.45 μmol/L while during premonsoon season it were 0.25 and 1.57 μmol/L respectively.

Pennate diatoms ranged from 48.95×10^2 to 21.47×10^5 cells/L. Spatial analysis recognized the lowest numerical abundance of pennate diatoms in Sta. S1 during monsoon season and highest in Sta. S8 during premonsoon. Dinoflagellate abundance ranged from 44.10×10^2 to 44.92×10^4 cells/L. Lowest abundance of dinoflagellate was recorded during monsoon season in Sta. S1 and highest during premonsoon season in Sta. S8. Phytoflagellates ranged from 2.23×10^2 to 5.05×10^4 cells/L and it exhibited lowest numerical density during monsoon season in Sta. S5. The highest abundance of phytoflagellate was recorded during premonsoon season in Sta. S7. Monsoon season showed lowest abundance and premonsoon season showed highest abundance of blue-green algae which ranged from 33×10^3 to 3.80×10^6 cells/L. Lowest abundance of blue green algae were seen in Sta. S4 and highest in Sta. S6.

Centric diatoms were identified as the dominant groups, but their percentage contribution during premonsoon was lower than that of other seasons (Table 2). Centric diatoms contributed to an average of 59.09% during monsoon season whereas during postmonsoon and premonsoon seasons, the average percentage composition was 47.64% and 38.96% respectively. In contrast pennate diatoms showed high percentage composition during postmonsoon season (31.25%) and least during monsoon season (14.87%). Dinoflagellates had higher abundance during monsoon season (average of 24.63%) and lowest during premonsoon season (average of 7.69%). Station S7 exhibited highest percentage of dinoflagellates (75.35%) during monsoon season whereas Sta. S2 exhibited lowest percentage (3.58%) during premonsoon season. Phytoflagellates and blue-green algae were minor contributors

Table 1. List of phytoplankton species identified during the study

Diatoms:

Centric diatoms: *Skeletonema costatum*, *Cyclotella*, *Lauderia annulata*, *Planktionella* spp., *Thalassiosira subtilis*, *Melosira*, *Leptocylindrus danicus*, *Corethron* spp., *Coscinodiscus* spp., *Hemidiscus*, *Azpeitia*, *Asteromphalus*, ***Rhizosolenia* spp.:** *R. setigera*, *R. delicatula*, *R. imbricate*, *R. styliformis*, *R. stolterfothii*, *R. alata*, *Guinardia*, *Eucampia* spp., *Hemiaulus*, ***Bacteriastrum* spp.:** *B. hyalinum*, *B. delicatulam*, *B. furcatum*, ***Chaetoceros* spp.:** *C. decipiens*, *C. curvisetus*, *Triceratium*, *Ditylum brightwelltii*, *Streptotheca*, *Odontella*, ***Biddulphia* spp.:** *B. sinensis*, *B. mobiliensis*, *B. aurita*, *Climacosphenia*, *Licmophora*, *Cyclophora*

Pennate diatoms: ***Pleurosigma* spp.:** *P. elongatum*, *P. directum*, *Amphiprora*, *Navicula* spp., *Striatella*, *Pseudoeunotia*, *Asterionella japonica*, *Fragilaria*, *Thalassiothrix*, *Synedra*, *Thalassionema* spp., *Phaeodactylum*, *Nanoneis*, *Pseudonitzschia* spp., *Cylindrotheca closterium*, ***Nitzschia* spp.:** *N. longissima*, *N. seriata*, *N. sigma*

Dinoflagellates:

***Prorocentrum* spp.:** *P. micans*, *P. lima*, *Mesoporos*, ***Dinophysis* spp.:** *D. caudata*, *D. acuminate*, *D. fortii*, *D. tripos*, *Gymnodinium*, *Gyrodinium*, *Chochlodinium*, *Katodinium*, *Pyrocystis*, *Pyrophacus*, *Alaxandrium*, ***Ceratium* spp.:** *C. fusus*, *C. tripos*, *C. furca*, *C. inflatum*, *C. horridum*, *Gonyaulax*, *Lingulodinium*, *Peridinium*, *Preperidinium*, ***Protoperidinium* sp.:** *P. ovatum*, *P. leonis*, *Scripisella*, *Noctiluca*

Green algae: *Agmenellum*, *Oscillatoria*, *Lyngbya*, *Anabaena*, *Nostoc*, *Staurastrum*

Blue green algae: *Trichodesmium erythraeum*

Phyto flagellates: *Euglena*, *Pediastrum* spp., *Senedesmus*, *Actinastrum*, *Dictyocha*

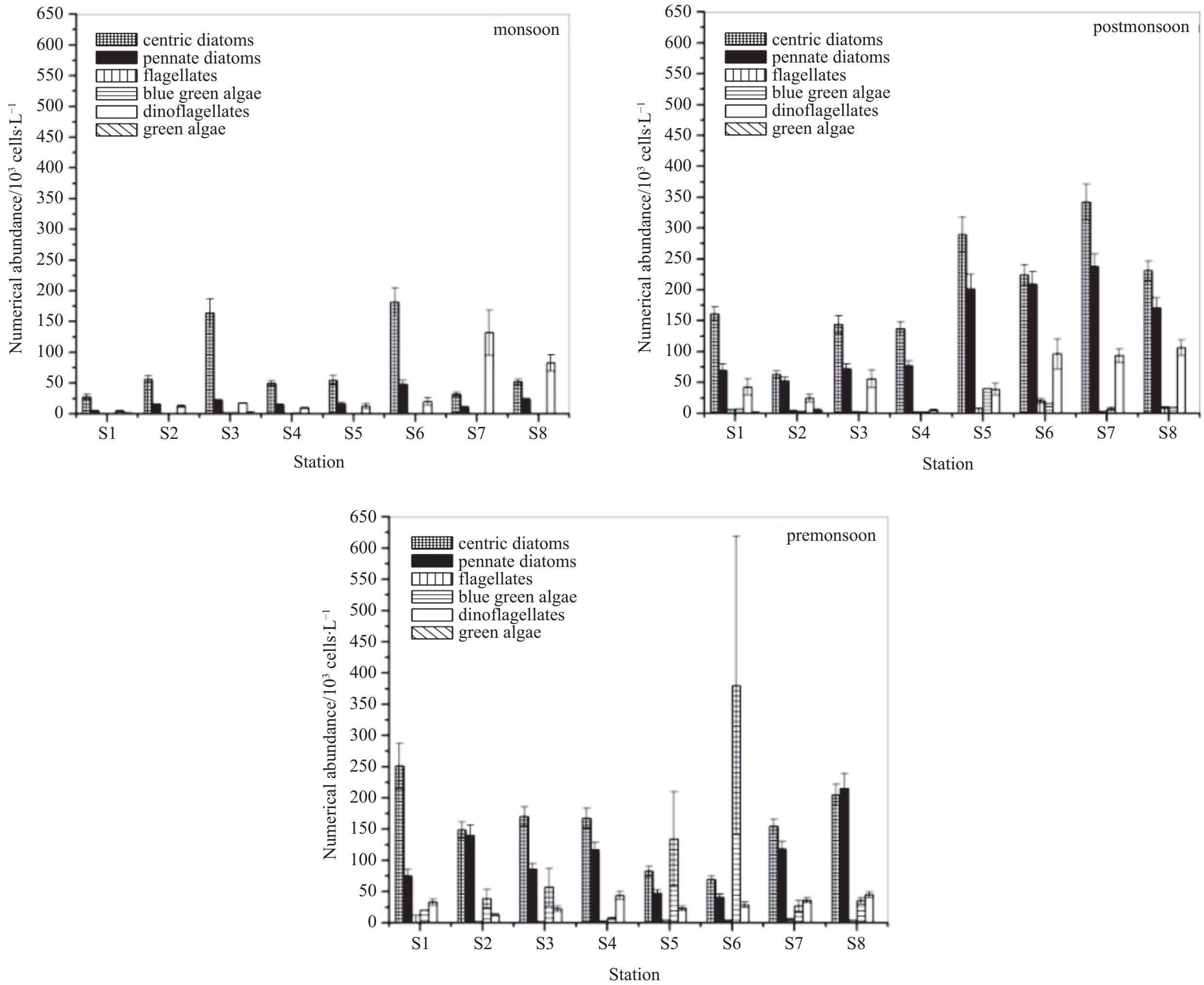

Fig.2. Spatial and temporal analysis of numerical abundance of phytoplankton species in the study area. *X* axis represented by stations and *Y* axis by numerical abundance expressed in cells/L.

Table 2. Percentage composition of phytoplankton communities in the study area during the three seasons

Phytoplankton	Monsoon Order/Family/ Genera (percentage composition)	Postmonsoon Order/Family/ Genera (percentage composition)	Premonsoon Order/Family/ Genera (percentage composition)
Centric diatoms	3/13/21 (59.089%)	1/11/20 (47.646%)	1/11/23 (38.962%)
Pennate diatoms	1/4/9 (14.874%)	1/4/12 (31.256%)	1/5/14 (26.422%)
Dinoflagellates	5/8/9 (24.639%)	5/8/9 (1.569%)	7/11/12 (0.690%)
Phytoflagellates	1//1 (0.392%)	3/3/3 (2.295%)	2/2/2 (20.686%)
Blue green algae	1/1/1 (0.343 %)	1/1/1 (13.304%)	3/3/3 (7.692%)
Other communities	1/2/2 (0.499%)	2/2/2 (0.401%)	1/1/1 (0.009)

to the entire phytoplankton community in the region (⩽1%) during monsoon and postmonsoon seasons. In case of phytoflagellates, highest percentage was observed in Sta. S6 during postmonsoon season and in case of blue green algae, it was in the same station during premonsoon season (71%). The occurrence and highest contribution of blue green algae during premonsoon season was attributed to the presence of *Trichodesmium erythraeum* bloom prevailed during the season.

3.4 *Dominant species*

The study revealed the composition of dominant species of phytoplankton as complex and centric diatoms as the most common constituent. Some species existed throughout the year. During monsoon low temperature and comparatively low salinity of coastal waters, due to mixing of fresh water, led to the rapid growth of both freshwater and marine species.

Cyclotella spp., *Striatella* spp., *Pseudoeunotia* spp., *Frag-*

ilaria spp., *Euglena* spp., *Alexandrium* spp. and green algae were not seen during monsoon season whereas it occurred in the other two seasons. Phytoplankton such as *Climacosphenia*, *Licmophora*, *Gyrosigma* and *Pediastrum* were seen only during monsoon season. *Gonyaulax* spp. was not seen during the postmonsoon season while *Staurastrum* spp. occurred only during postmonsoon season. Phytoplankton species such as *Azpeitia* spp., *Streptotheca* spp., *Odontella* spp., *Amphiprora* spp., *Synedra* spp., *Nanoneis* spp., *Agmenellum* spp., and *Noctiluca* spp. were identified during premonsoon season only but *Senedesmus* spp. observed during other two seasons was not identified in premonsoon.

3.5 *Species diversity and evenness*

Species diversity is the number of different species in a particular area, which is an important index in characterizing the community structure and community importance in ecosystem. The results showed that the Shannon-Wiener diversity index (*H* index) was relatively high during the three seasons (Fig. 3). The species diversity during postmonsoon season was high and reached up to 4.59 followed by premonsoon and monsoon season. The maximum index obtained is 4.08 (S4) during monsoon, 4.59 (S8) during postmonsoon and 4.52 (S5) during premonsoon. The minimum diversity index observed during monsoon season is 2.62 (S7), and 4.03 (S5), 2.30 (S6) during postmonsoon and premonsoon season respectively.

Station wise analysis of Shannon-Weiner diversity indices showed that Sta. S8 had highest diversity during all the seasons. In Stas S1 and S6, diversity index during monsoon season was higher than postmonsoon season. In Sta. S4 diversity index seemed to be unchanged in all the seasons whereas in Sta. S7, monsoon season showed lower diversity index and during postmonsoon and premonsoon season the diversity remained the same. Station S5 exhibited the same diversity index during monsoon and premonsoon season. Other two Stas S2 and S3 showed the lowest values during monsoon season followed by premonsoon and the highest values during postmonsoon season.

Evenness, a measure of the relative abundance of the different species constituting the richness of an area, is an indicator of whether the community structure is developed and stable. The Pielou's evenness index exhibited high in all the stations except S4 during postmonsoon season followed by monsoon (except in Stas S3 and S7) and premonsoon seasons (Fig. 4). In Sta. S4 high evenness was observed during the monsoon season followed by postmonsoon and premonsoon seasons respectively. Stations S3 and S7 exhibited high evenness during postmonsoon season followed by premonsoon while monsoon season showed the least evenness.

3.6 *Phytoplankton absorption spectral characteristics*

Absorption by phytoplankton (a_{ph}) from stations with high and low Shannon-Weiner index was shown in Fig. 5. Contribution by different phytoplankton species has varied the spectral absorption at blue and red wavelengths. The absorption coefficient value varied in the blue and red part of the region in all the seasons and with high and low phytoplankton diversity. During monsoon season, when the diversity was high, maximum absorption, measured at 440 nm was 0.760 m^{-1}, while it was 0.689 m^{-1} when the diversity was low and the wavelength shifted to 430 nm. Postmonsoon season showed lower absorption coefficient compared to monsoon season and the difference in a_{ph} values at blue and red region was clear in the stations with high and low diversity index. The absorption coefficients value was 0.508 m^{-1} at 436 nm during high diversity and 0.397 m^{-1} at 439 nm during low diversity. Compared to monsoon and postmonsoon, the lowest a_{ph} values were observed during the premonsoon season. During premonsoon the absorption was comparatively low and it was 0.150 m^{-1} at 437 nm and 0.047 m^{-1} at 436 nm during high and low phytoplankton diversity. The phytoplankton absorption peak showed a shift from the usual 440 nm towards shorter wave length.

A fourth derivative analysis was also performed to identify the pigment peak contributions other than Chl *a*. The fourth derivative analysis identified peaks at 438–441 nm and 674–677

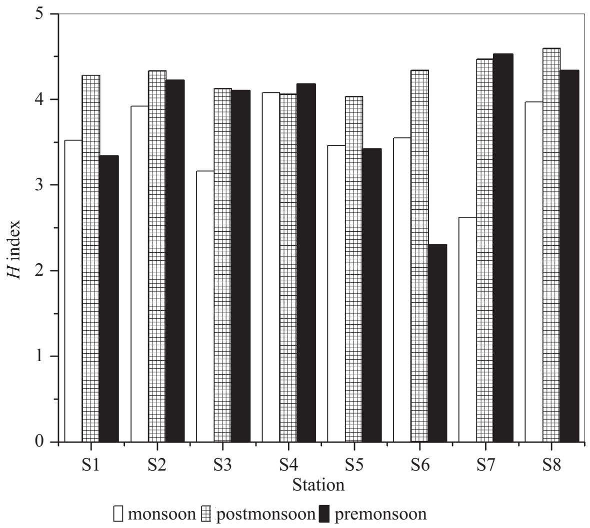

Fig.3. Spatial and temporal analysis of Shannon-Weiner species diversity index (*H* index) of phytoplankton in eight stations during three seasons.

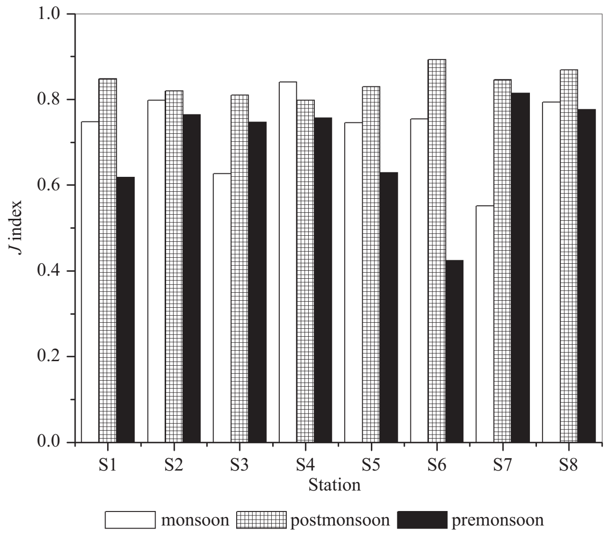

Fig.4. Spatial and temporal analysis of Pielou's evenness index (*J*) of eight stations during three seasons.

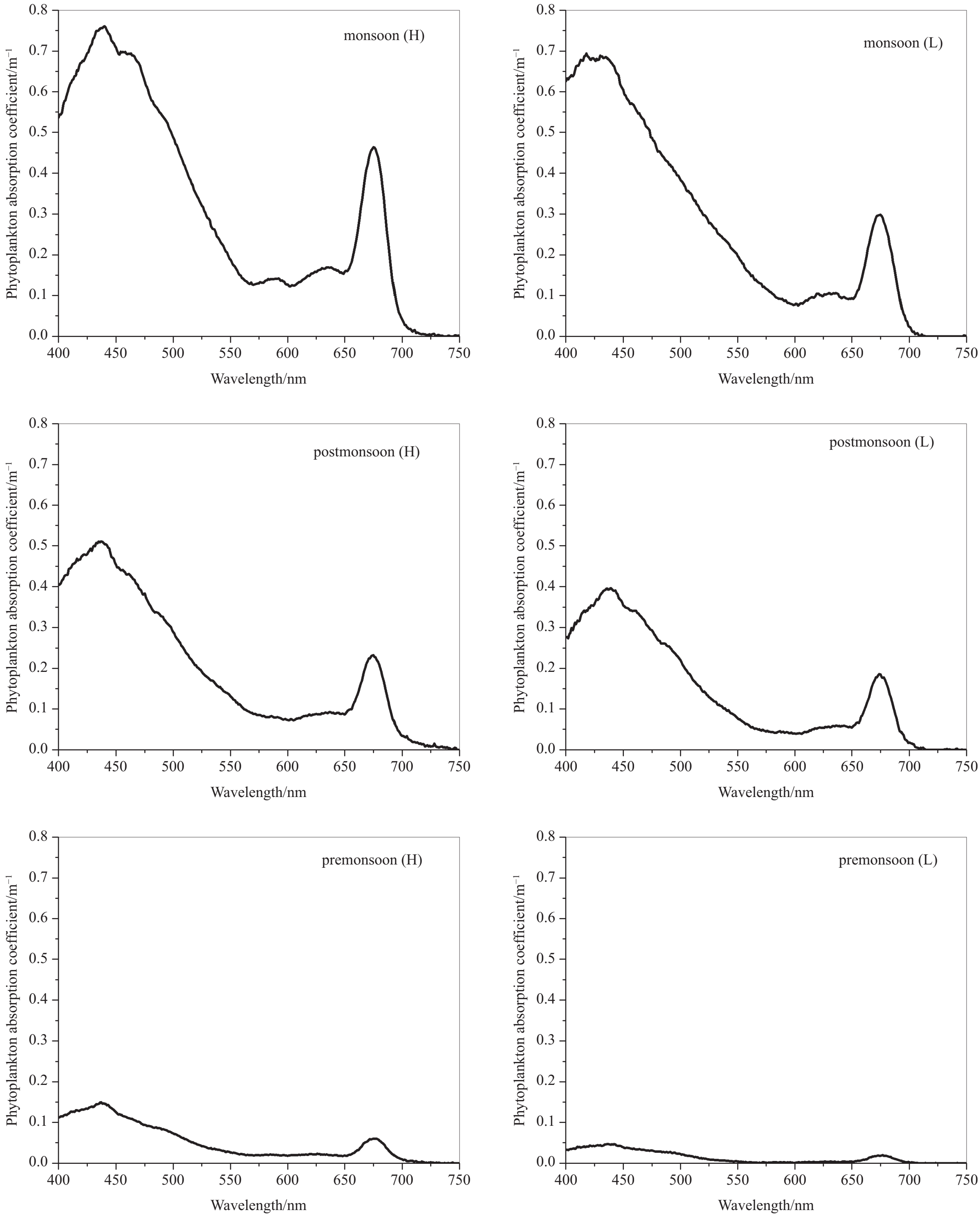

Fig.5. Phytoplankton absorption spectra from the stations with highest (H) and lowest (L) Shannon-Weiner diversity index during the three seasons (monsoon, postmonsoon and premonsoon). *X* axis represented by wavelength ranging from 400–750 nm and *Y* axis by phytoplankton absorption coefficient expressed as m^{-1}.

nm for Chl *a*, 465–467, 639–641 nm for Chl *c*, 491–497 nm for phycourobilin and 541–546 nm for phycoerythrobilin. Peaks at 584–592 nm was identified for Chl *b*. The results of derivative analysis showed that these waters are dominated by phytoplankton containing pigments such as Chl *a*, Chl *b* and Chl *c*, peridinin, diadinoxanthin, fucoxanthin, *β*-carotene and phycoerythrobilin (Fig. 6). Pigment phycoerythrobilin was present during monsoon and postmonsoon seasons when the *H* index

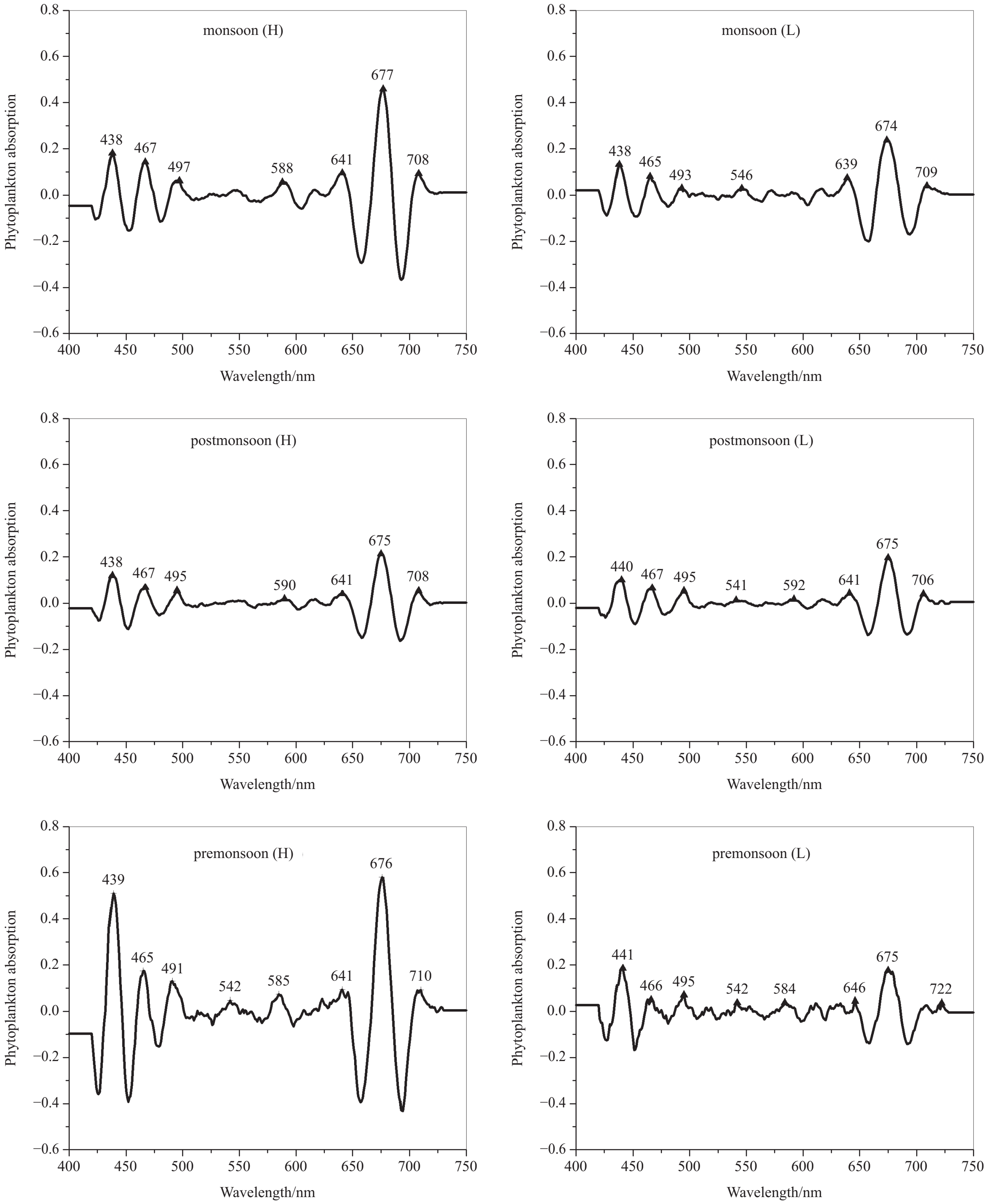

Fig.6. Fourth derivative analysis of phytoplankton absorption spectra from the stations exhibited with highest (H) and lowest (L) Shannon-Weiner diversity index during three seasons (monsoon, postmonsoon and premonsoon). *X* axis represented by wavelength ranging from 400–750 nm and *Y* axis by phytoplankton absorption coefficient after performing 41 point Savitsky–Golay polynomial smoothing and differentiation.

was low, while premonsoon season showed the pigment during both high and low phytoplankton diversity index (Table 3).

4 Discussion

The study area being influenced by the monsoon, forces hydrographic changes to occur thereby alter the phytoplank-

Table 3. Summary of photosynthetic pigment absorption maxima determined by fourth derivative analysis in this study

Wave lengths (nm) of absorption in seasons in high (H) or low (L) concentrations						Pigment group	Reference
Monsoon		Postmonsoon		Premonsoon			
High	Low	High	Low	High	Low		
438	438	438	440	439	441	chlorophyll *a*	Prezelin and Alberte (1978); Prezlin and Boczar (1986); Aguirre-Gomez et al. (2001)
467	465	467	467	465	466	chlorophyll *c* Peridinin	Millie et al. (1995); Millie et al. (1997); Goericke and Repeta (1993)
497	493	495	495	491	495	phycourobilin	Millie et al. (1995); Millie et al. (1997); Louchard et al. (2003)
—	546	—	541	542	542	phycoerythrobilin	Ong et al. (1984)
588	—	590	592	585	584	chlorophyll *b*	Millie et al. (1997)
641	639	641	641	641	646	chlorophyll *c*	Millie et al. (1995); Millie et al. (1997)
677	674	675	675	676	675	chlorophyll *a*	Prezelin and Alberte (1978); Aguirre-Gomez et al. (2001)

ton community structure. The study identified the estuarine region as the dominant ecotype of phytoplankton because of its high phytoplankton abundance during premonsoon season. The premonsoon season was characterized by tides and inflow of saltwater from adjacent sea to the estuary where mixing of seawater with fresh water occurs. The high temperature with high light intensity is also characterized in the season. Large amounts of nutrients by the river discharge along with mixing of seawater and fresh water with high temperature and light intensity seemed to have favoured the growth of phytoplankton in this area. Hence it evolved as a dominant ecotype.

Low numerical density of phytoplankton was exhibited during the monsoon season and may be influenced by the low pH and temperature prevailed in the area. Nutrients like nitrite and silicate was high but phosphate concentration was low. The present study showed some variations in the dominant species, the sequence of dominance and cell abundance when compared with the previous studies carried out in the region. Matondkar et al. (2006) reported dominance of green algae and *Noctiluca* during premonsoon season and *Trichodesmium* and flagellates during post monsoon seasons in the northeastern Arabian Sea. Dominance of *Trichodesmium* and *Noctiluca* were reported during premonsoon season and diatoms and coccolithophores during monsoon season along the eastern Arabian Sea by Parab et al. (2006) and Martin et al. (2013). They also reported the dominance of dinoflagellates and picobacteria soon after the monsoon season.

Throughout the study period centric diatoms dominated in the area. They are known for their fast growth responses to nutrient enrichments (Harrison and Davis, 1979; Sanders et al., 1987; Kuosa et al., 1997) and dominate often in natural eutrophic waters. Kochi coastal waters are considered to be among one of the highly productive regions in the world because of its high eutrophication due to upwelling and wind driven mixing of waters (Rao et al., 1992; Gopinathan et al., 2001). Pennate diatoms generally have lower growth rates than the centric species (Grover, 1989; Sommer, 1989). But in monsoon season centric diatoms seemed to be low in their numerical abundance along with a decrease in dinoflagellate abundance. The reason for this can be related to the low light prevailed in the region due to monsoon clouds (Pinker and Laszlo, 1992; Banse and English, 2000). Cyanobacterial dominance during premonsoon season was accounted with low nitrogen concentrations (Hobro, 1979; Niemi, 1973; Rinne et al., 1981; Kononen and Niemi, 1984; Niemisto et al., 1989). For the phytoplankton *Skeletonem*a, which was the dominant phytoplankton during the study, the growth was most stimulated by high nitrate and optimum phosphate concentration which were present during the study period.

The results of the fourth derivative analysis identified pigments contributing to the phytoplankton absorption. These studies provide an insight to the presence of diverse phytoplankton species in the region. Shifting of absorption to shorter wavelengths during different seasons and diversity variation may be due to the influence of high amount of non algal particles by the decomposition of chlorophyll or the superimposition of some other pigments peak on to the spectrum (Bricaud and Stramski, 1990; Morel and Ahn, 1990; Babin et al., 1993). Peridinin is the biomarker pigment of dinoflagellates. Phycoerythrobilin, a subtype of the pigment phycobiliprotiens are the light harvesting pigment found in cyanobacteria, rhodophytes and cryptophytes. Fucoxanthin and diadinoxanthin are carotenoid pigments found in diatoms, prymnesiophytes, raphidophytes, and chrysophytes (Hsiu-Ping et al., 2002). The pigment β carotene is found in cyanobacteria. As the derivative analysis were performed for the phytoplankton absorption spectra from stations with the highest and lowest Shannon-Weiner diversity index, this attempt provides only minimal insight to the influence of other pigments on the shift in the absorption peak at blue region of the spectra. A detailed examination of the detritus absorption spectra also has to be done in order to understand the exact reason for the unusual shift in the blue region of the spectra.

5 Conclusions

The present study determined 73 phytoplankton genera from 19 orders and 41 families. Biddulphiales evolved as the dominant order and the dominant family was Thalassiosiraceae. The dominant phytoplankton identified were *Skeletonema* spp. during the entire study period. In terms of abundance and diversity, diatoms formed the major groups compared to other taxonomic groups. Spatio-temporal analysis of phytoplankton community composition in the Kochi coastal waters identified dominance of diatoms, but a shift to dinoflagellates and cyanobacteria was observed in certain stations during the study. Spatial analysis revealed highest species richness index in station where mixing of marine and fresh water occurs and the lowest in the estuarine region. Temporal analysis exhibited the lowest species richness during the monsoon season and the highest during premonsoon season. Shannon-Weiner diversity index analysis showed the highest diversity during post monsoon and the lowest during monsoon season.

During the study period, the composition of dominant species was not complex and there occurred succession of species. Compared with the previous studies, some dominant species, the sequence of dominance, and cell abundance had changed. Lower species diversity during monsoon highlights the instability of phytoplankton community in the region. Phytoplankton containing pigments such as Chl *a*, Chl *b*, Chl *c*, peridinin, diadinoxanthin, fucoxanthin, β carotene and phycoerythrobilin identified from the results of derivative analysis are seemed to dominate in these waters. A detailed examination of detritus absorption spectra along with the fourth derivative analysis is suggested for further applications.

Diatoms are normally associated with high production rates and elevated organic matter export. The alteration of dominance between the groups from diatoms to dinoflagellate and cyanobacteria, in different seasons can result in significant changes in the light absorption by phytoplankton pigments in the region. This inturn affects the ocean color estimation used for various applications. Thus the data on the phytoplankton numerical abundance and diversity along with its absorption properties in the present study will provide insight to community dynamics and to the phytoplankton pigment composition of this water mass. This can also be used to indicate that major differences in phytoplankton absorption spectra, which forms the basis of ocean color remote sensing, with respect to seasons in the area.

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