On the occurrence of *Trichodesmium erythraeum* (Ehr.) bloom in the coastal waters of Kalpakkam, east coast of India

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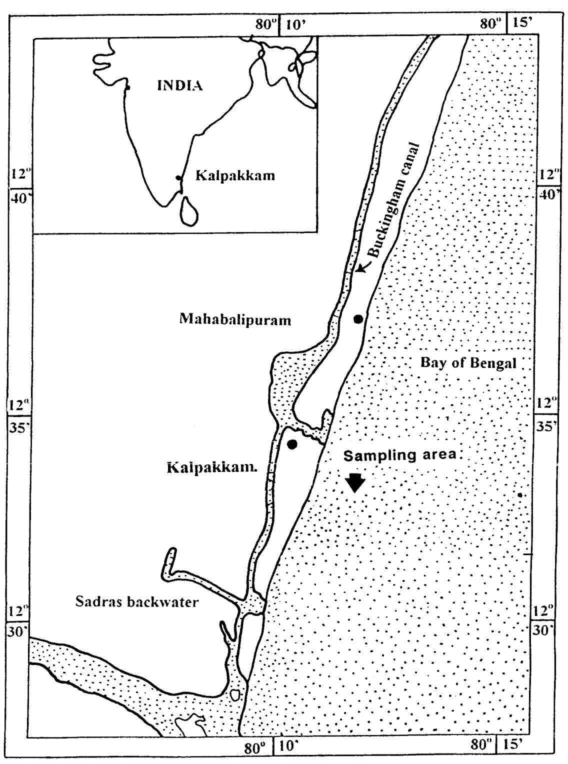
Abstract: A prominent discolouration of the coastal waters by the blue-green alga *Trichodesmium erythraeum* was encountered in the east coast of Kalpakkam on 16th March 2007. The bloom persisted only for one day exhibiting visible alteration in physico-chemical properties and phytoplankton community structure of the coastal waters. The *Trichodesmium* cell density was 4.14 x 10^6 cells l^{-1}, sharing 74.19 % of the total cell count (5.57 x 10^6 cells l^{-1}). Only 24 species of phytoplankton were encountered on the day of bloom as compared to the highest number of 44 species in a single observation during pre- and post-bloom periods (1st March to 29th March). Concentration of chlorophyll-*a* and phaeopigments increased to about 20 times on the day of bloom compared to the pre-bloom values. An abrupt increase in ammonia, total nitrogen and phosphate was noticed on the day of bloom. The impact of this bloom on coastal water quality is reported.

Keywords: *Trichodesmium erythraeum*, algae, bloom, marine cyanobacterium, east coast, India.

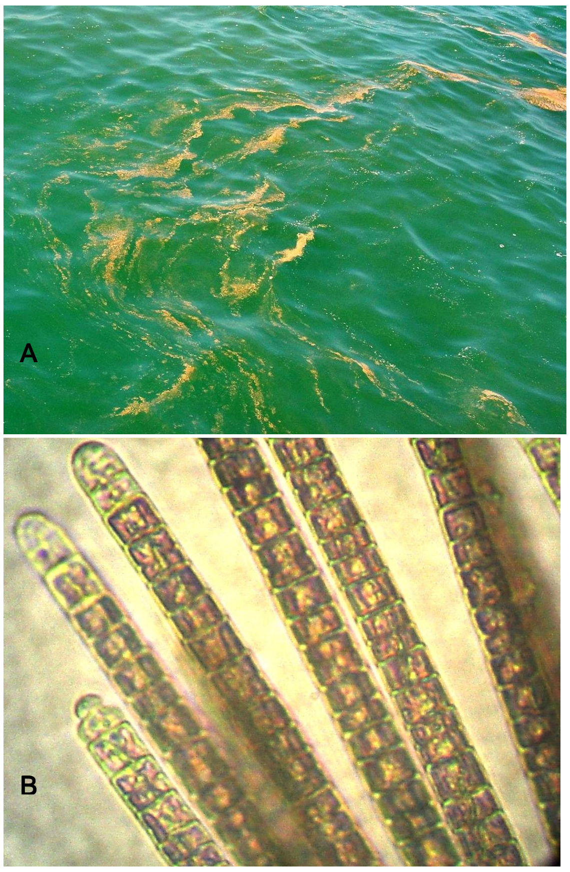
Fig.1. Study area showing the sampling location



Introduction

Trichodesmium erythraeum, a marine cyanobacterium is an important nitrogen-fixer in the sea. It is one of the common bloom-forming species found in tropical and sub-tropical waters, particularly in the eastern tropical Pacific and Arabian Sea, contributing >30% of the algal blooms. Estimated global nitrogen fixation by *Trichodesmium* bloom (~42 Tg N yr^{-1}) and during nonbloom conditions (~20 Tg N yr^{-1}) suggests that it is likely to be the dominant organism in the global ocean nitrogen budget (Westberry & Siegel, 2006; Capone *et al.*, 1997). Reports in literature showed frequent occurrence of *Trichodesmium* blooms in Indian waters, more frequently in the west coast (Prabhu *et al.*, 1965; Qasim, 1970; Devassy *et al.*, 1978; Devassy *et al.*, 1987; Shetty *et al.*, 1988; Koya & Kaladharan, 1997; Sarangi *et al.*, 2004; Krishnan *et al.*, 2007) as compared to east coast (Ramamurthy *et al*, 1972; Adhakary & Sahu, 1992; Santhanam *et al.*, 1994; Jyothibabu *et al.*, 2003). Equipped with buoyancy regulating gas vesicles and nitrogen fixation enzymes, *Trichodesmium* is regarded as an organism well adapted to stratified, oligotrophic conditions (Capone *et al.*, 1997). Thus, *Trichodesmium* abundance should be high in boundary currents and decrease towards the coast where nitrogenous nutrients become more available. In the present study, the bloom was sighted in the east coast of India and to our knowledge it is a first time report. In the east coast of India, phytoplankton blooms are common during February to May when the prevailing hydrobiological conditions are relatively stable (Devassy *et al.*, 1979; Perumal *et al.*, 1999; Jyothibabu *et al.*, 2003). During spring inter monsoon, eddies and recirculation zones from the coastal regions of Bay of Bengal due to the western Bay of Bengal current (WBC) found to enhance phytoplankton growth (Gomes, *et al.*, 2000; Prasanna Kumar *et al.*, 2004). During a regular coastal water monitoring program, a prominent discolouration of the surface water was noticed in the coastal waters of Kalpakkam (12° 33' N Lat. and 80° 11' E Long) (Fig.1) on 16th March 2007. The bloom was very dense and created yellowish-green coloured streaks (Fig.2A) of about 4 to 5m width and extended to several meters. The phytoplankton responsible for discolouration was identified as *Trichodesmium* *erythraeum* (Fig.2B). Although, bloom of *Noctiluca scintillans* (Sargunam *et al.*, 1989) and

Fig.2. A photographic view of phytoplankton bloom on 16 March 2007 by Trichodesmium erythraeum in the coastal waters of Kalpakkam, east coast of India (A) and the photomicrograph of the Trichodesmium filament (x 2400) (B)



Asterionella glacialis (Satpathy & Nair, 1996) in the coastal waters of the Kalpakkam has been reported, there has been no report of 'green tide' formation by *Trichodesmium erythraeum*. One of the interesting features of this bloom was that it was sighted only for one day, which drastically declined on the next day with a negligible *Trichodesmium* cell density. A perusal of available literature did not reveal such a sudden appearance and decline in bloom forming organisms in general and *Trichodesmium* in particular. The three different phases of a typical phytoplankton bloom such as, the exponential phase (log phase), peak and senescent phase (lag phase) could not be seen during this observation. Interestingly, the bloom was sighted just after the southwest to northeast monsoon transition during which the current direction changes from equatorward to poleward in Bay of Bengal. This prompted us to closely monitor the coastal waters with respect to chemical and biological characteristics during the post bloom period. Although, the data collected during our regular work were not concerned directly with an investigation into the causes of the bloom, the interest stimulated from the studies of various physicochemical and biological characteristics of the coastal water justifies the purpose of this report. The impact of this bloom on coastal water quality is reported in this paper.

Material and methods

Surface water samples were collected (between 9 to 10 AM) regularly from 1st March-29th March using a clean polythene bottle and analyzed for various physicochemical parameters. Winkler's titrimetric method (Grasshoff *et al.*, 1983) was followed for the estimation of DO. Salinity measurements were carried out by Knudsen's method (Grasshoff *et al.*, 1983). Turbidity of the water samples was measured by turbidity meter (CyberScan IR TB 100) having 0.01 NTU resolution. Suspended particulate matter (SPM) was estimated following standard procedure (Grasshoff *et al.*, 1983). pH measurement was carried out by a pH meter (CyberScan PCD 5500) with a resolution of 0.01. Dissolved nutrients such as, nitrite, nitrate, ammonia, silicate and phosphate along with TN and TP were estimated following the methods of Parsons *et al.*(1984) and Grasshoff *et al.*(1983), using the filtered samples passed through 0.45µ Millipore filter paper. Photosynthetic pigments such as chlorophyll-*a, b, c* and phaeophytin were measured spectrophotometrically (Parsons *et al.*, 1984). For all the spectrophotometric analyses, a double beam UV-Visible Spectrophotometer (Chemito Spectrascan UV 2600) was used. The phytoplankton density was estimated using Utermohl's sedimentation technique (Vollenweider, 1974) and counted using Sedgwick Rafter counting chamber with the aid of an inverted microscope. The identification of phytoplankton was done by following standard taxonomic monographs for diatoms (Desikachary, 1987), dinoflagellates (Subramanian, 1968; 1971) and green and blue-green algae (Cyanobacteria) (Fristch, 1935).

Results and discussions

A. Hydrography

Temperature has long been recognized as a major factor that controls *Trichodesmium* abundance (Marumo & Nagasawa, 1976; Carpenter, 1983). Generally bloom of this filamentous alga occurred during hot weather season (Ramamurthy *et al.*, 1972), as cyanobacteria require relatively high temperature for its optimum growth compared to other phytoplankton (Suvapepant, 1992; Sellner, 1997). The surface seawater temperature during this period ranged from 28.1 to 30.3 ^{0}C (Fig. 3A). Similar observations during the appearance of *Trichodesmium* bloom have been reported during March (Qasim, 1970; Ramamurthy *et al.*, 1972;

Santhanam *et al.*, 1994, Desa *et al.*, 2005) and spring inter monsoon (Madhu *et al.*, 2006) in the coastal waters of India with temperature ~29 ^{0}C. The observed salinity values ranged from 31.58 to 33.54 psu, during the study period. Stable salinity condition close to typical value of 32 psu and above is known to support the growth and abundance of *Trichodesmium* as this cyanobacterium is a stenohaline form with optimum growth at >33 psu and can't survive in low salinities (Ramamurthy *et al.*, 1972; Krishnan *et al.*, 2007; Santhanam *et al.*, 1994). pH did not show any significant variation (8.1-8.3) and also it did not show any correlation to the bloom appearance. Marginal increase in DO during the bloom compared to the pre-bloom concentrations was noticed. It ranged from 5.7 to 7.1 mg l^{-1}. Higher DO values during bloom and post-bloom could be due to photosynthetic release of oxygen by the highly dense algal biomass. Similar increase of DO content during *Trichodesmium* bloom has also been reported (Capone *et al.*, 1997). Turbidity and SPM values showed an irregular trend of variation during the study period; however, turbidity was relatively high on the day of bloom and on the next day compared to the pre-bloom observations. Unexpectedly, SPM value was relatively low (31.6 mg l^{-1}) on the day of bloom and increased in the next two days to 41.8 mg l^{-1} and 39.2 mg l^{-1}, respectively.

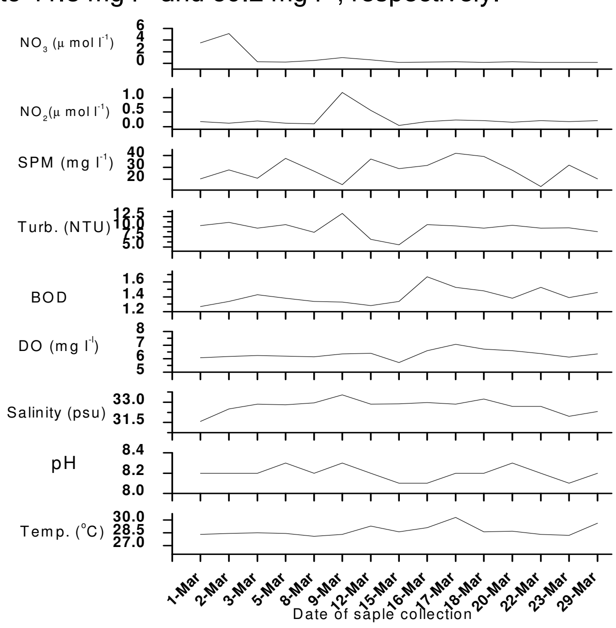


Fig.3A. Variation in physico-chemical properties of the coastal water during the Trichodesmium bloom

B. Nutrients

Phosphate constitutes the most important inorganic nutrient that can limit the phytoplankton production in tropical coastal marine ecosystems (Cole & Salford, 1989) and thereby the overall ecological processes. Apart from the physical and chemical processes, phosphate concentration in coastal waters mainly depends upon phytoplankton uptake and replenishment by microbial decomposition of organic matter. In the present study, an abrupt increase in phosphate content was encountered on the bloom day as compared to pre- and post-bloom periods. Phosphate values ranged from BDL during the pre-bloom to 2.56 µmol l^{-1} on the bloom day (Fig. 3B). The peak coincided with the day of highest

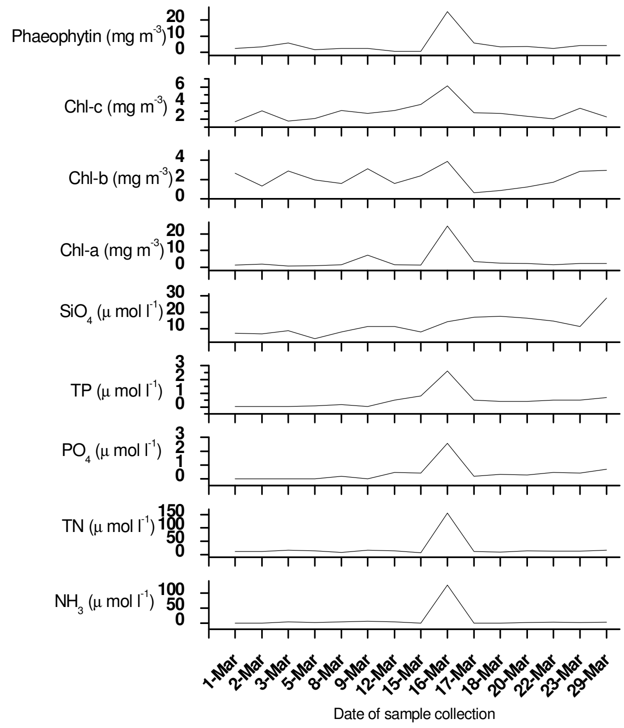


Fig.3B. Variation in physico-chemical properties and photosynthetic pigments of the coastal water during the Trichodesmium bloom

cell density observation. This increase in phosphate level during the bloom period could be due to the decomposition of plankton, resulting in release of phosphate. Moreover, bacterial liberation of phosphate from dead organisms has also been reported to be responsible for enhanced levels of phosphate during blooms (Rao, 1969). Usually seawater serves as the main source of phosphate in estuarine and coastal waters except those receives fresh water contaminated with phosphate. Very low levels of phosphate during pre- and post-bloom periods could be due to its rapid uptake by phytoplankton. The relatively high phosphate levels on the day of bloom could also be attributed to the drifting of phosphate rich oceanic water from the central Indian Ocean into the coastal water during current reversal (La Fond, 1957 & Potemra *et al.*, 1991). Others have also reported similar increase in phosphate content during the occurrence of bloom of *Trichodesmium* (Santhanam *et al.*, 1994; Pant & Devassy, 1976), *Noctiluca*

(Raghuprasad & Jayaraman, 1954; Dharani *et al.*, 2004; Sahayak *et al.*, 2005) and *Asterionrlla* (Satpathy & Nair, 1996) in coastal waters. The present highest value of phosphate is much higher than that of the March 2006, which ranged from 0.14 to 0.46 µmol l^{-1} (unpublished data). TP concentrations also showed similar trend as that

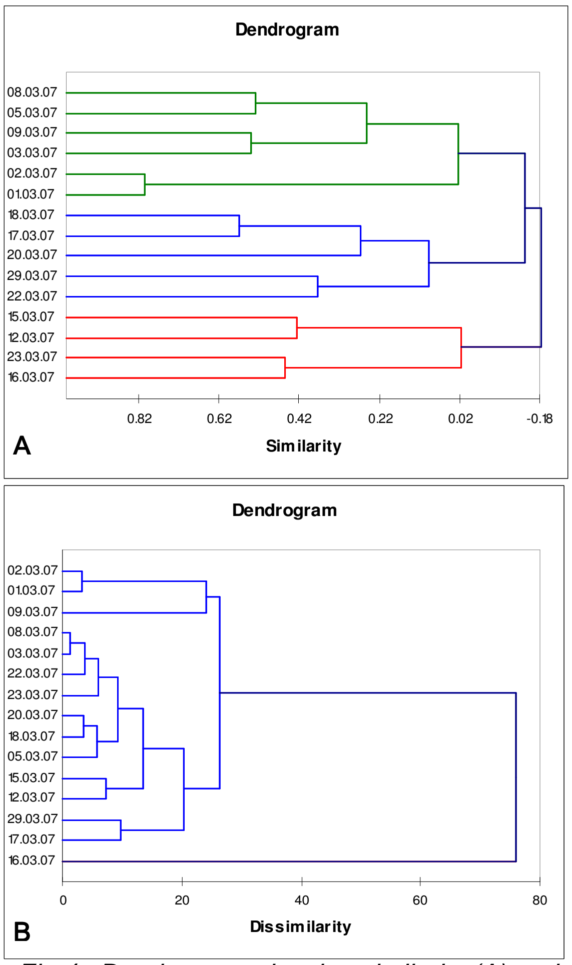
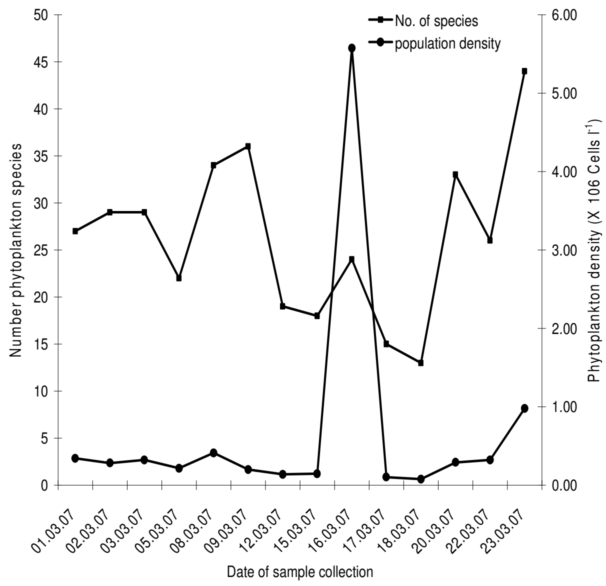


Fig.4. Dendrogram showing similarity (A) and dissimilarity (B) clusters

of phosphate and ranged from 0.05 to 2.60 µmol l^{-1}. Silicate, utilized for the formation of the siliceous frustules of diatoms, constitutes one of the most important nutrients regulating the phytoplankton growth and proliferation and ultimately to its blooming. Its values ranged from 4.13 to 28.58 µmol l^{-1} with lowest and highest values being observed during pre- and post bloom periods respectively. The marginal increase in silicate concentration on the bloom day, compared to pre-bloom, could be due to its un-utilization by the cyanobacteria bloom. Observations similar to this have also been reported by several authors during the appearance of non-diatom blooms (Sargunam *et al.*, 1989; Dharani *et al.*, 2004; Raghuprasad & Jayaramana, 1954). The post bloom increase in silicate values could be attributed to the relatively low cell density of phytoplankton as compared to the pre-bloom cell density. Similar to that of phosphate, the post bloom silicate values are relatively high than the last year values (range 5.78 to 12.53 µmol l^{-1}) (unpublished data) for the same time period. Nitrate, considered to be the most stable nitrogenous nutrient responsible for the metabolism and growth of phytoplankters, is readily assimilated by phytoplankters in aquatic medium leading to its large-scale variations (De Souza, 1983; Zepp, 1997). Nitrate concentrations varied between 0.13 and 5.10 µmol l^{-1}, the highest value being observed during the pre-bloom period and the lowest just before the bloom. The nitrite values ranged from 0.04 to 1.17 µmol l^{-1}. Similar reduction of nitrate concentration during *Trichodesmium* bloom has been reported by Santhanam *et al.* (1994) and Jyothibabu *et al.* (2003). Insignificant variation in concentration of nitrite was noticed during the period of study. On the contrary, ammonia value was unexpectedly higher on the day of bloom compared to the pre- and post bloom observations. It ranged from BDL to 126.72 µmol l^{-1}. This could be ascribed to the diazotrophic nature of *Trichodesmium*, which depicts the ability to produce ammonium from dinitrogen through the process of nitrogen fixation (Chang *et al.*, 2000). A comparison of the present values of ammonia with that of the previous year data (range BDL to 0.61µmol l^{-1}) for the same period revealed an unusual increase during this study. As a result of the above process, the TN was also very high (155.21 µmol l^{-1}) on the day of bloom. Qasim (1970), Devassy (1987) and Nair *et al.* (1992) have also reported an increased ammonia content of the seawater during *Trichodesmium* bloom where they depicted that the bloom remain largely ungrazed and decompose resulting in elevated ammonia levels.

The similarity cluster analysis carried out based on the physico-chemical and biological parameters of individual dates formed three clusters showing three different periods (Fig. 4A). The cluster 1 consisted of six observations during the pre-bloom period. Similarly in cluster 3 five post-bloom observations were included. The cluster 2 which included totally four observations comprised of the 2 pre-bloom observations, the day of bloom and one post- bloom observation. Though it was difficult to notice the existence of different periods with respect to individual parameters, there existed three different periods with different environmental conditions when all the parameters were taken into account. Eventhough the bloom was sighted for one day, the prevalence of such three different periods could be due to the similarity of environmental conditions between individual observations, which in turns depends upon the various oceanographic processes in coastal waters and particularly on the transitional current reversal observed during the study. Interestingly, only two clusters were formed in dissimilarity cluster analysis (Fig. 4B). The bloom day alone formed one class and all the pre- and post-bloom observations formed the other. This showed that the day of bloom was distinctly different from other days in terms of the physico-chemical and biological aspects as discussed earlier.

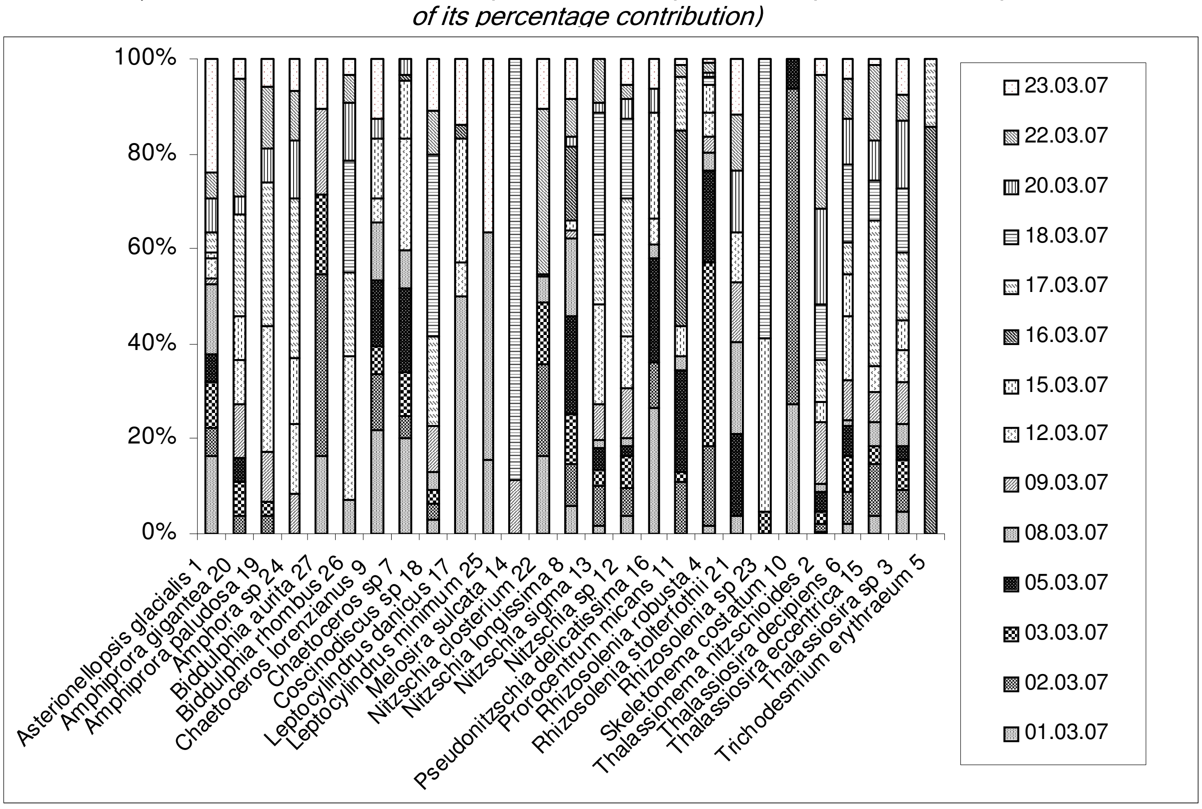
Fig. 5. Variation in phytoplankton population density and number of species during the study period



C. Phytoplankton community structure

In total 99 species of phytoplankton were identified which comprised of 89 diatoms (36 pennate and 53 centric), 9 dinoflagellates and the cyanobacteria *Trichodesmium erythraeum*. The population density of phytoplankters varied in between 7.84 x 10^4 and 5.57 x 10^6 cells l^{-1} (Fig. 5) showing a two order increase on the day of bloom. Highest cell density was observed on the day of bloom, whereas, the lowest was observed on the post bloom period. Surprisingly, *Trichodesmium* was found only on the day of bloom and the next day. Its contribution to the population density was 74.19 % (4.14 x 10^6 cells l^{-1}) and 12.50 % (0.13 x 10^6 cells l^{-1}) on the day of bloom and the next day respectively. It is well known that *Trichodesmium* is more abundant in subsurface layers as compared to surface water (Chang *et al.*, 2000). In order to examine the presence of *Trichodesmium* in the subsurface layers, bottom samples (max. water column depth of the sampling location 7-8 m) were collected in the post bloom period but its presence could not be found out. Thus, it is surprising to see that *Trichodesmium* abundance went through a dramatic change in such a short period. The observed cell density was marginally higher than the earlier reported value of 3.38 x 10^6 cells l^{-1} by Ramamurthy *et al.* (1972) and comparable to the value reported by Krishnan *et al.* (2007) (4.80 x 10^6 cells l^{-1}) but significantly lower than the value

Fig.6. Percentage contribution of the dominant species of phytoplankton on different dates of observation (Numbers in the end of each species name represent the position of the species in terms of its percentage contribution)

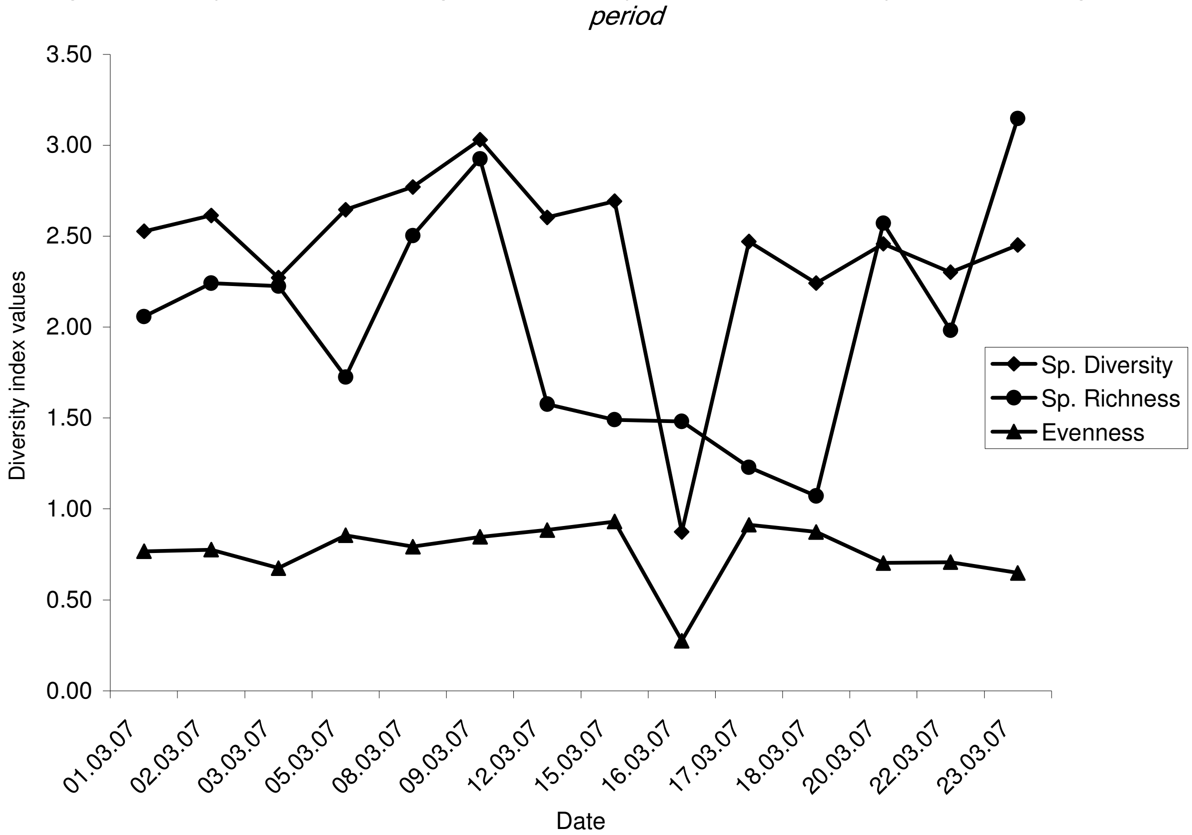


reported by Santhanam *et al.* (1994) which was 17.5 x 10^6 cells l^{-1}. Community structure of phytoplankton showed that the number of species on a single observation varied between species numbering 13 (on the day of lowest cell count) and 44, both values encountered during the post bloom period. Relatively less number of species (24) was found on the day of bloom as compared to the pre-bloom (max. 36 species) and post-bloom (max. 44 species) period. Similar results have been reported (Mishra *et al.*, 2006) wherein less number of phytoplankton species were encountered, however, during the appearance of non-*Trichodesmium* bloom. In the present study, based on the numerical abundance 27 species were considered as important contributing 54.17 to 96.39 % of the population density (Fig. 6). Out of these 27 species *Asterionella glacialis, Nitzschia sigma, Nitzschia sp., Rhizosolenia robusta, Thalassionema nitzschioides, Thalassiosira decipience, Thalassiosira eccentrica* and *Thalassiosira* sp. were almost present throughout the study. One of the interesting observations is the percentage contribution of dinoflagellates to the total phytoplankton density on the day of bloom. They accounted for ~15 % of the standing stock on the day of bloom which was the highest value as compared to the pre- and post-bloom observations. The dinoflagellate *Procentrum* sp. was found only on the day of bloom and was absent on all the other observations. This could be due to the inflow of offshore water into the coastal region as the dinoflagellate population in offshore areas is considered to be high. A distinct variation in diversity indices, particularly species diversity and evenness, was noticed on the day of bloom (Fig.7). Relatively high diversity and richness index values during the pre- and post-bloom periods showed that the phytoplankton community was floristically rich during these periods. The significant decrease in diversity and evenness values on the day of bloom could be attributed to the dominance of *Trichodesmium* and the presence of very less number of phytoplankton species.

D. Photosynthetic pigments

Chlorophyll, which constitutes the chief photosynthetic pigment of phytoplankton, is an index that could provide the primary production potential upon which the biodiversity, biomass and carrying capacity of that system depends. During the present study, photosynthetic pigments such as Chlorophyll-*a, b* & *c* and Phaeophytin showed wide range of variation (Fig.8). Highest value of all these pigments was encountered on the day of blooming. Concentration of chlorophyll-*a* and phaeopigments increased almost 20 times on the day of bloom compared to the pre-bloom values. In general, concentration of all these pigments remained higher during the post bloom period as

Fig.7. Diversity indices of showing variation in phytoplankton community structure during the study period



compared to the pre-bloom period. Similar observations of unusually high pigment concentrations have been reported by Ramamurthy *et al*. (1972) and Pant & Devassy (1976) during *Trichodesmium* bloom and Mishra *et al*. (2006) and Mishra and Panigrahy (1996) during *Asterionella* bloom.

Conclusion

Trichodesmium erythraeum bloom is common along the southwest coast of India but rarely reported from the east coast. The species has been identified as toxic and reported to contain neurotoxin commonly associated with paralytic shellfish poisoning (PSP) (Bhat & Verlencar, 2006). However, perusal of over 30 reports published on various aspects of *Trichodesmium* bloom in Indian waters showed that the cause for fish mortality whenever occurred is mostly attributed to asphyxiation and gill damage by the filaments of the alga. During the present study, no such mortality of fish and other organisms was noticed on the bloom day possibly due to its one-day appearance. In the hindsight it is worthwhile to mention that the very high ammonia value observed on the day of bloom, had it continued for a few more days could have resulted in serious repercussion. As it is known that a concentration of <0.1 mg l^{-1} of ammonia is toxic for the fish community. One of the prominent features of this bloom was the discoloration of the coastal waters with formation of yellowish-green patches. Although planktonic blooms have been observed at this coast on a few occasions, the present one was unique having the following features: i) first report on the appearance of *Trichodesmium erythraeum* bloom and its photographic evidence from this location, ii) the bloom sighted for only one day, iii) bloom appearance exhibited visible alteration in physico-chemical properties and phytoplankton dynamics of the coastal waters on the day of its appearance and iv) most interestingly the bloom appeared in coastal waters (~0.5- 1 km from the shore) in contrast to the all other reports known to the authors, which showed its appearance in offshore waters (> 30 km). Observation of such high values of ammonia, silicate, phosphate and chlorophyll associated with this bloom not only surprise the environmental scientists but it also underlined increasingly recognized need for continuous monitoring of the coastal waters to understand the triggering mechanism behind such events better. Let us agree that 'Nothing in sea falls haphazard; if we cannot predict, it is because we do not know the cause, or how the cause works' Henry Bigelow, 1929.

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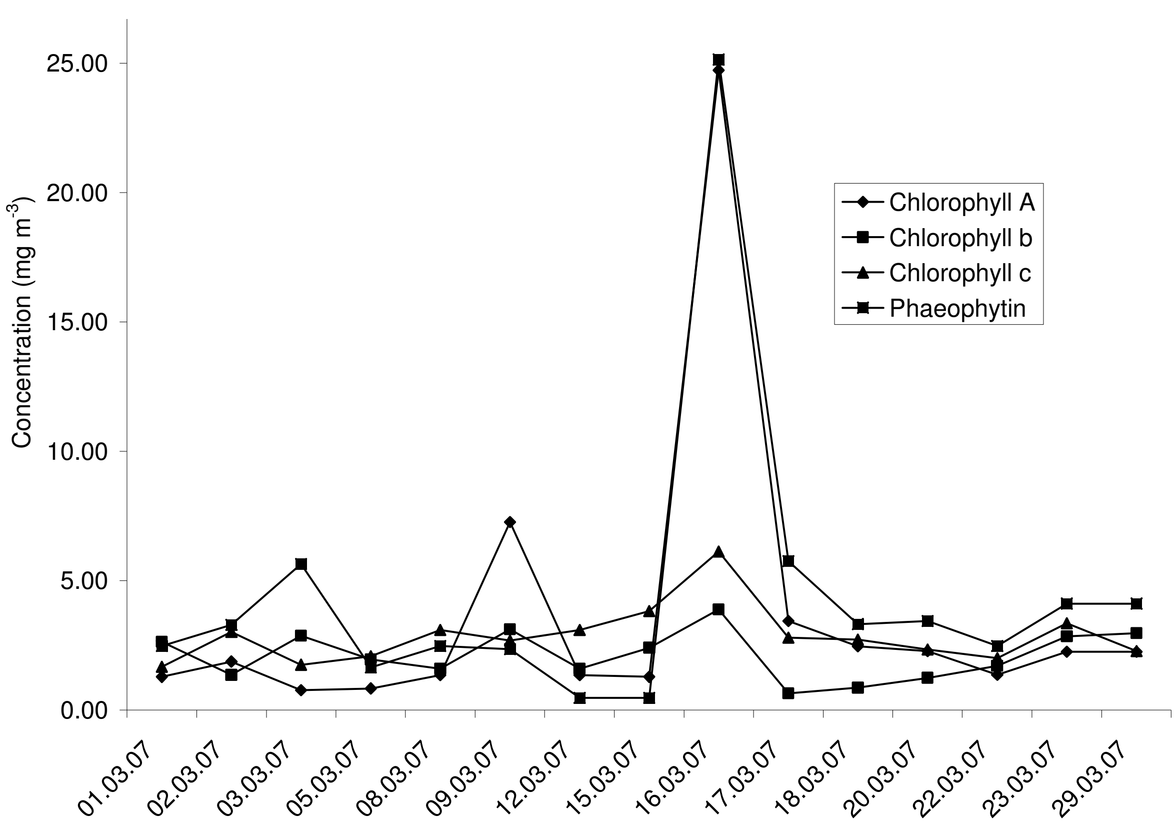
Fig. 8. Variation in photosynthetic pigments during the study period



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