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Diversity and Distribution of Phytoplankton at Verem (Mandovi Estuary) Goa

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Abstract

To understand diversity, distribution and the effect of environmental factors on phytoplankton, samples were collected fortnightly at Verem station in the Mandovi estuary during monsoon and non-monsoon period from June 2008 to May 2009. Study examined taxonomic composition, abundance and spatial distribution of phytoplankton. Highest biomass was reported during the non-monsoon season ranged between 1.09-5.62 mg m^{-3} average of 2.43 mg m^{-3} and phytoplankton cell density ranged from 0.05-7.00 X 10^4/L an average of 0.57 X 10^4/L. Altogether, 125 species of phytoplankton were reported during monsoon and 93 species during non-monsoon period. The highest numbers of species (125) consists of diatoms, dinoflagellates and other algae accounting for 90, 31 and 4 species respectively. Diatoms were the major taxonomic group accounting for between 78 and 82% of the total population. Diversity index (H') and evenness (J) were 4.20 and 0.78 in the monsoon season, and 3.81 and 0.73 in non-monsoon. The CCA analysis showed that the environmental parameters like salinity, nutrients and rainfall has greater influence on the distribution of phytoplankton species. It can be confirmed from this findings that monsoon acts as a major player in the temporal distribution of phytoplankton. Salinity and nutrients are the governing factors in the growth of the phytoplankton.

***Key Words*: Estuary; Monsoons; Rainfall; Chlorophyll a; Phytoplankton; Diversity.**

Introduction

Estuaries with their associated river systems form an integral part of the inshore waters. In spite of the extreme conditions, estuaries are fertile and excellent nursery grounds for variety of commercially important fishes and prawns. In India we have many estuaries which are located along the east and west coasts. Mandovi is a tropical estuary located along the west coast of India between 15° 21' and 15 °31'N and 73° 45'and 73°49'E. Together with the Zuari estuary and the Cumbarjua canal, it forms the major estuarine system of the State of Goa. They are monsoonal estuaries where freshwater runoff is greatest during the southwest monsoon (SWM, summer), when most estuaries along the west coast of India become freshwater dominated (Vijith *et al.*, 2009). A unique feature of these estuaries along the west coast of India is the phenomenal tides that they are subjected to (Shetye *et al.,* 2007). Though, partially landlocked, they are exposed to constant flushing and flooding by the semidiurnal tides, which considerably affect the environmental features of the area. In recent years, it has been observed that the banks of these estuaries are exploited by the people greatly to carry out recreational and anthropogenic activities. Hence, monitoring health of this estuarine system is essential. The main objective of the present work was to see the seasonal variability in distribution of phytoplankton biomass and species composition in response to environmental factors. The influence of South-West monsoon on the growth and abundance of different phytoplankton species is also revived.

Materials and Methods

Sampling site and sampling protocols

Sampling in the Mandovi River commenced well before the predicted start of the South West Monsoon (SWM) of 2007. Surface water samples were collected fortnightly from Verem station (Lat- 15 ^{o} 30' 09.2"N Long- 73 ^{o} 48' 44.8"E) roughly 2 km upstream of the mouth of the Mandovi estuary (Fig. 1.). Collection period started from 1st June 2008 to the 31st May 2009 see the abstract encompassing the monsoon and non-monsoon seasons. Rainfall data was collected from the Indian Meteorological Department of Goa. Salinity was measured with a 'Salinometer"' (Atago S/Mill®, Japan, Salinity range 0 ~ 100 psu, resolution 1 psu between 10 and 20^{o}C). Nutrients were estimated using the method outlined in Strickland and Parsons (1972) and restricted to the period to early monsoon (June).

Fig. 1. Map showing sampling station Verem in Mandovi estuary.

Chlorophyll *a* and Phytoplankton Taxonomy: Chlorophyll *a* (Chl *a*) was measured by filtering water samples of known volume on to 47 mm glass fiber filters (Whatman® GF/F), which were then extracted overnight in 10 ml of 90% acetone under cold and dark conditions. Chl *a* extracts were then filtered through PTFE (0.2µm) filters for removal of GF/F filter debris and was estimated in duplicate using HPLC (Agilent® 1100 series) and were separated in a C-18 reverse-phase column using the eluent gradient program of Wright, *et al.* (1991) as described by Parab *et al.,* (2006). Samples for phytoplankton taxonomy and cell counts were collected in 500 ml opaque plastic bottles, fixed with a few drops of Lugol's iodine, preserved in 3% buffered formaldehyde and then stored under dark and cool conditions until the time of analysis. Prior to microscopic analysis, samples were concentrated to 5-10 ml by carefully siphoning the top layer with a tube covered with a 10 µm Nytex filter on one end. Sample concentrates were then carefully transferred to a 1 ml capacity Sedgwick-Rafter and counted. Phytoplankton cell identifications were based on standard taxonomic keys (Thomas, 1997) and cell counts were carried out in duplicate.

Statistical methods for data analysis: Statistical data analysis: Data processing was done using PRIMER version 5.2.8 (Clarke and Warwick, 1994) where Species diversity (H') was calculated according to (Shannon and Weaver, 1963). Evenness was calculated using Pielou's (J').

Results

Physico-chemical parameters: Seasonal variations in environmental parameters are presented in Fig. 2. Highest nutrients concentration was observed during monsoon period. This is influenced by the land runoff during monsoon season, leading to flushing of nutrients into the estuary.

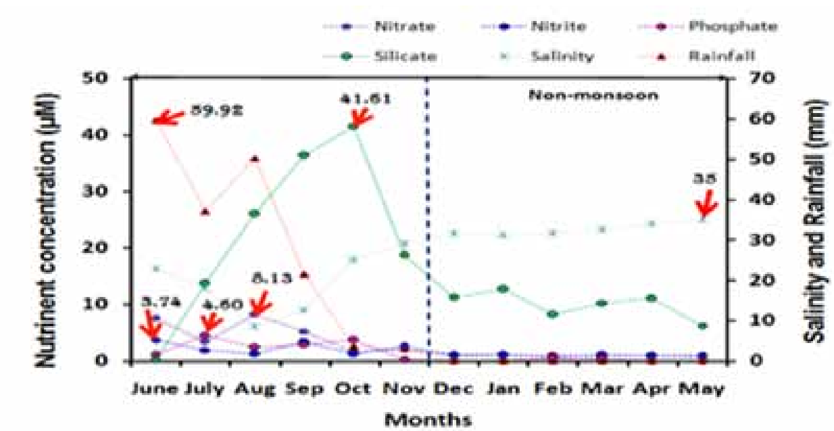

Fig. 2. Seasonal variations in physico-chemical factors at Verem station in Mandovi estuary.

Nitrate: Highest concentration was reported in August 8.13 µM
Nitrite: Highest value was observed in June 3.74 µM
Phosphate: Found in July 4.60 µM

Silicate: Present in high concentration throughout the study period with highest value 41.61 µM in October.

Salinity: Followed opposite pattern with highest of 35 PSU observed in May.

Correlation Analysis between the environmental parameters: The linear correlation coefficients between the physico-chemical variables of monthly data are given in Table 1. Nitrate, nitrite, phosphate and silicate are positively correlated to each other whereas rainfall negatively correlated with salinity.

Table 1. Summarization of correlation analysis between environmental factors.

	Nitrate	**Nitrite**	**Phosphate**	**Silicate**	**Salinity**	**Rain fall**
Nitrate	1.00					
Nitrite	0.66	1.00				
Phosphate	0.43	0.30	1.00			
Silicate	0.18	0.12	0.62	1.00		
Salinity	-0.85	-0.50	-0.74	-0.55	1.00	
Rainfall	0.94	0.62	0.49	-0.02	-0.77	1.00

Phytoplankton Biomass (Chl a) and Cell density: Highest phytoplankton biomass was reported during monsoon period (October 2008), presented in Fig. 3. Total phytoplankton cell density was high during non-monsoon period (May 2009).

Diversity and species evenness

The results showed in Table 2. Average diversity index (*H'*) and evenness (*J*) was 4.20 and 0.78 respectively was highest in monsoon. In non-monsoon diversity varied from 1.58-4.85 and monsoon showed variation in the range of 3.51-5.13. This may be attributed to changes in species composition reflecting the species' preference for different salinity ranges and also in part by phytoplankton from fresh water source.

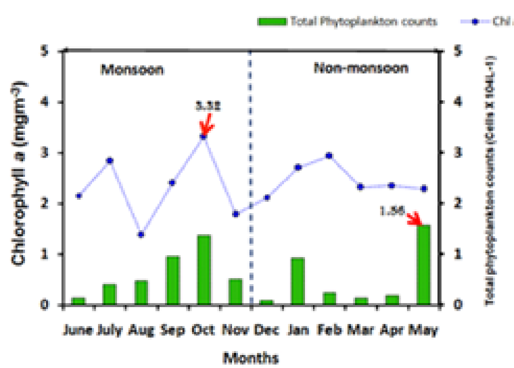

Fig. 3. Monthly variations in Chl a and phytoplankton cell density at Verem station during 2008-2009 in Mandovi estuary.

Table 2. Summary of diversity and evenness of phytoplankton (2008-2009).

Monsoon	Diversity index (*H*′)	4.20 (Average)	3.51-5.13
	Evenness (*J*)	0.78 (Average)	0.68-0.91
Non-monsoon	Diversity index (*H*′)	3.81 (Average)	1.58-4.85
	Evenness (*J*)	0.73 (Average)	0.30-0.96

Phytoplankton composition: The total genera and species recorded during the monsoon and non-monsoon phase of this study are presented in Fig. 4. Total genera (54) and species (125) were high during monsoon period.

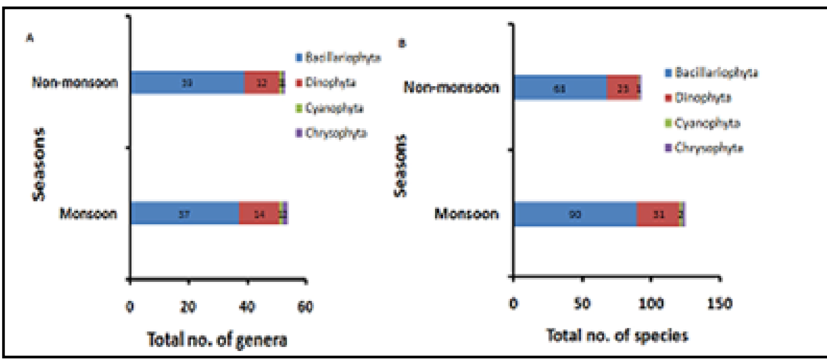

Fig. 4. Seasonal distribution of phytoplankton genera and species A) No. of Genera during monsoon and non-monsoon and B) No. of species during monsoon and non-monsoon at Verem station during 2008-2009 in Mandovi estuary.

Bacillariophyta were the major taxonomic group accounting for between 78% and 82% of the total population over the sampling period (Fig. 5). The highest % of diatoms (82%) was recorded during the non-monsoon period, whereas the minimum of 78% was observed during the monsoon period. As a group diatoms were unaffected by the low saline conditions during the peak monsoon period. Dinoflagellates, the second largest taxonomic group, varied from 15% -

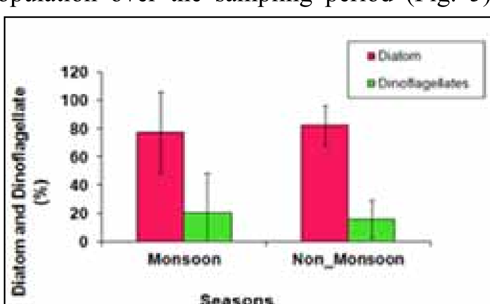

Fig. 5. Seasonal distribution of percentages of diatom and dinoflagellate at Verem station in Mandovi estuary.

20% and displayed a definite seasonality (Fig. 5), with the highest percentage being recorded during the monsoon period. The lowest percentage (15%) of dinoflagellates was observed during the non-monsoon phase. Other algae such as Silicoflagllates, green algae and cyanobacteria constituted a small percentage of the population 2 % during both the periods.

Temporal distribution of dominant species

Mesohaline toxic species of *Gymnodinium breve* and euryhaline potentially harmful species of *Skeletonema costatum* were found to be dominating during the monsoon season where salinity was in the range of 15-25 PSU. Euryhaline and eurythermal species of *Actinocyclus octonarious* was found to proliferate in estuarine conditions during non-monsoon period. *Detonula pimula* was found to grow during non-monsoon period. As represent the K-type growth strategy, able to grow in stressful conditions and develop the ability to harvest more light. This distribution represents succession in the phytoplankton community Fig. 6.

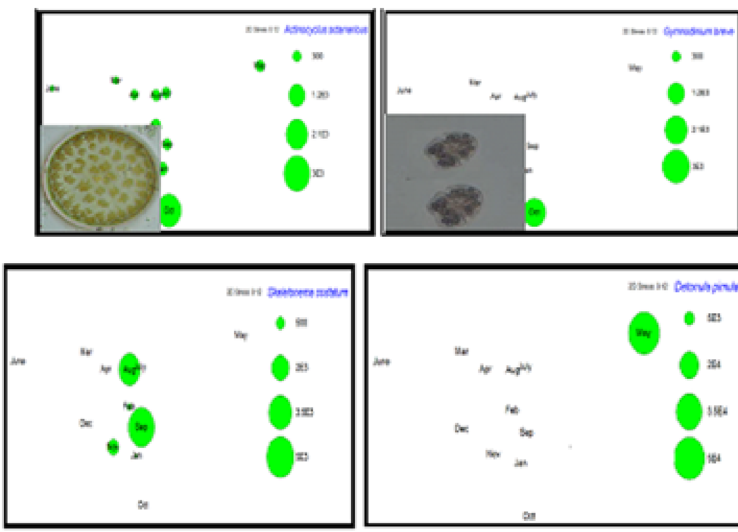

Fig. 6. Temporal distribution of phytoplankton species at Verem station in Mandovi estuary.

The relationships between phytoplankton and some physico-chemical parameters

First three axes explained 85.8% of relation between phytoplankton species and environmental parameters. *Nitzschia longissimum, Skeletonema costatum* showed strong correlation with silicate and rainfall. *Detonula pimula* and *Ditylum brightwelii* growth was influenced by nitrate and phosphate. Nitrate, phosphate and salinity influenced the growth of dinoflagellates *Gymnodinium breve* and *Scripsiella trachoidea* (Fig. 7).

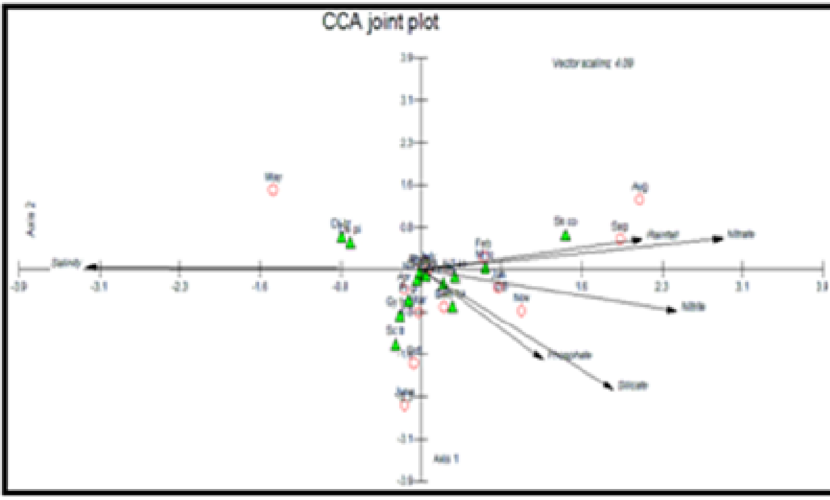

Fig. 7. CCA conjoint biplot

Discussion

Present study which was carried out in the Mandovi estuary during the year 2008-2009 examines lots of changes in the phytoplankton structure with respect to salinity, nutrients and rainfall pattern. This year being the normal monsoonal year (Fig. 2.) and where breaks between rainy spells can last for several days at a stretch. Our observations can therefore be considered as baseline data for future studies aimed at understanding the consequences of climate-mediated changes in rainfall patterns predicted for the Indian subcontinent (Goswami *et al.,* 2006).

During the peak of the monsoon, when the estuary was at its freshest, phytoplankton biomass was lower side, but surprisingly the community was made up of the largest number of species where species evenness is driven by the influence of the fresh water flow in to the estuary. Large increase in biomass observed in the non-monsoon period, where salinity levels in the estuary ranged between 0-30 PSU and cell numbers were high during non-monsoon period. The phytoplankton biomass (Chl *a* >3 mg m^{-3}) and counts (>1 x 10^4 cells L^{-1}) recorded during present study is highest in nature due to effect of the high rainfall which lead to the lots of fresh water discharge along with high nutrients, also the mixing action of fresh water with estuary water leading to the dilution of Mandovi estuary (Shetye *et al.,* 2007; Vijith *et* *al.,* 2009, De Sousa *et al*., 1981). However, diversity and evenness of species during monsoon was also found high (Table 2).

Present study in the Mandovi estuary, reported nitrate concentration in the monsoon period varied from 0.21 to 3.46 µM (Fig. 2.) in comparison with previous reports by De Sousa, (1983) found nitrate values of the order of 6.5 to 9.8 µM whereas Sankaranarayanan and Qasim, (1969) found the order of 25-35 µM during the monsoon in the Cochin backwaters. However, seasonal distribution of nutrients in the Mandovi estuary seems to be different from that of the Cochin backwater as earlier marked by Bhattathiri *et al.,* (1976). Inverse relationship of nitrate-salinity is established in Mandovi estuary (Table 1). This might be the consequence of freshening of the estuary due to rainfall and runoff also led to a gradual increase in nitrate concentrations following the abrupt reduction in salinity. Although there are no reports of nitrate or any other nutrients being limiting for phytoplankton in the Mandovi estuary, we hypothesize that both the reduction in salinity and the absence of nutrient limitation, contributed to a surge in phytoplankton cell numbers. The growth of phytoplankton during monsoon is particularly important since fish population from costal water take shelter in estuary during monsoon especially for breeding purpose. The nitrate is added to system with pre-monsoon shower (atmosphere dust) and subsequently monsoon drainage. The added nitrate at the monsoon stage is clearly seen which was quickly utilized by phytoplankton. It is also observed that particularly diatoms are first one to use and grow during this monsoon phase (Desouza, 1983).

The high total phytoplankton counts, total diatom and other algae during monsoon includes lots of fresh and brackish water forms of Chlorophytes, Crysophytes, silicohytes and Cyanophytes, which has been brought into the mouth of the estuary by heavy fresh water discharge during the heavy rainfall period. This is in comparison to Devassy and Goes (1988) reported very low phytoplankton biomass in the monsoon period. In non-monsoon the phytoplankton biomass was very low, probably because of the decease of fresh water flushes from the Mandovi estuary (Shetye *et al*., 2007; Vijith *et al.,* 2009) and increase in the salinity level (Devassy and Bhattathiri*.,* 1974) leading to the negative correlation of total phytoplankton counts with salinity.

Hundred and twenty five species of phytoplankton were recorded during monsoon season which is higher in comparison with previous study by (Devassy and Goes, 1988). Around 70% euryhaline, 20% brackish water and 10% fresh water species were reported in the present study. Phytoplankton exhibit strong positive correlation with diatoms as diatoms to be the dominant phytoplankton population. In the present study during the monsoon 56 genera with 180 species of diatom were reported (Fig. 4A and B.). However dinoflagellates which are another group of organisms remained unaffected in Mandovi estuary. Altogether 50% mixotrophic, 30% autotrophic and 20% heterotrophic forms of dinoflagellates were reported. It is clear, therefore, that the Mandovi estuary is an experimental ecosystem especially during monsoon period which results in a drastic change in the hydrographic conditions which are instrumental in the complete transformation of the phytoplankton population with size and structure (Qasim, 1980.). The flow pattern of fresh water and tidal variations also extensively influence the assemblages and dispersal of phytoplankton communities.

The one year observation on phytoplankton in the present study reveals the fact that these phytoplankton species can grow at wide range of salinity during monsoon and non-monsoon periods in the Mandovi estuary. These results are in agreement with Qasim, 1980 and Devassy and Goes, 1988. The organisms which can grow at lower salinity <5psu and moderate salinity 15-20psu in Mandovi estuary besides normal flora known to grow at 35psu salinity (Prabhu Matondkar *et al*., 2007). Subrahmanyan (1959) remarked that a fall in temperature from optimum levels (32 to 25 ^{0}C), a slight lowering of salinity (35 to 32 PSU) and a plentiful supply of nutrients during the early monsoon period (Madhu *et al.,* 2010) lead to intense phytoplankton blooms. Thus, the reduction in salinity by itself is not a precondition for the formation of phytoplankton blooms, but rather due to the adaptability of certain phytoplankton to moderate changes in salinity brought about by the south-west monsoon showers coupled with a large input of nutrients (Fig. 2.). In the present study centric diatom like *Actinoptichus senarius* and coastal neritic species *Fragilaria oceanica* found to grow in the early showers of rainfall in nutrient rich water. In the whole study period its growth was restricted to early monsoon only with salinity of 0-24 PSU. Later this was replaced by typical monsoonal species of centric diatom genus *Cocsinodiscus granii*, *Cocsinodiscus radiatus* and *Thalassiossira essentricus*. They are present from the month of June to November during which the salinity is averaging between 5-29 PSU. As the monsoon progresses and lots of stratifications in salinity, in the mid of monsoon period diatoms were replaced by dinoflagellates. Autotrophic dinoflagellate *Gymnodinium splendens* was found during progression of monsoon i.e. September- October. It is reported as red tide forming species (Fiedler, 1982). It is also a pollution indicator brackish water type species (Hallegraeff *et al*., 2003). The highest abundance of 1,122 CellsL^{-1} were observed in the month of September were salinity was ranging between 0-12psu. *Scrippsciella trachoidea* which is mixotrophic in nature made its presence during same period (1,212 CellsL^{-1}). The euryhaline species *Navicula maculosa*, *Skeletonema costatum*, *Cylindrotheca cloterium* and *Thalassiothrix frauenfeldii* made their appearance throughout the year in both monsoon and non-monsoon seasons during which the salinity varied between 0-35psu.

Though the composition of dominant species varied with different years and with increasing salinity *Skeletonema costatum* was always prominent in tropical as well as temperate waters (Devassy and Goes, 1988, Marshall and Alden, 1990; Huang *et al.,* 2004; Madhu, 2007). In the present study *Skeletonema costatum* showed high abundance of 599-3421 CellsL^{-1} in the monsoon period. It is reported as a harmful species produces the mucilaginous substance which intern causes clogging in gills of fishes by Hallegraeff *et al*., 2003. Gopinathan (1974) reported the dominance of *Skeletonema costatum* which contributed 68.8%, immediately after or following a break in the monsoon in the Cochin backwater. Towards the end of the summer period i.e. during March to May with a gradual increase in salinity and return of favorable conditions, massive counts of marine coastal water species like *Streptotheca tamesis, Pluerosigma angulatum, Bacillaria paxillifer, Chaetoceros curvisetum* and *Chaetoceros lascinious* were reported in the Mandovi estuary. *Bacillaria paxillifer*, coastal water species as a bloom forming species during post-monsoon season in Parangipettai coast. Pollution indicating species like *Streptotheca tamesis* (Naik *et al.,* 2009) was also found to grow during post-monsoon period. Whereas during the earlier studies by Devassy and Goes, 1988 observed the massive blooms of *Ceratium furca* and *Nitzschia closterium* at the end of the monsoon. During this period, the coastal environment tended to reflect the effect of the process of upwelling; viz. increased nutrient levels and enhanced plankton production. The transect study which was carried out along the Mandovi estuary presented *Skeletonema costatum* as dominant form in every layer of the water. This euryhaline species can also grow quickly in eutrophic conditions (Huang *et al.,* 2004 and Ganapati and Raman*,* 1979).

In conclusion, phytoplankton communities in the present study were influenced by the annual riverine runoff and the associated changes in the physico-chemical parameters. The phytoplankton community showed gradual temporal shifts along the salinity and nutrients gradients, i.e. oligohaline species during the low salinity monsoon period, mesohaline species (15–25 psu), and euryhaline species, which are present throughout the study period. Bacillariophyta dominated the phytoplankton population with ≥70% of the total number of genera and species. Toxic bloom-forming phytoplankton species that have not been encountered here earlier, like *Gymnodinium breve*, were observed during the present study.

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