Satellite and ship studies of phytoplankton in the Northeastern Arabian during 2000 – 2006 period

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ABSTRACT

Sequence of the images from IRS P4 / OCM satellite and extensive shipboard sampling programme are used to understand the seasonal variation of phytoplankton abundance and types in the Northeastern (NE) Arabian Sea and Lakshadweep Sea. An appreciable degree of spatial and temporal variability is observed in chlorophyll *a* distribution from November to April months, as well as coastal and offshore stations, indicating marked seasonality in phytoplankton distribution in NE Arabian Sea. During November month (fall intermonsoon) average chlorophyll *a* (Chl *a*) by fluorometer was (0.799 mgm⁻³) and by OCM it was 0.584 mgm⁻³. The higher chlorophyll *a* observed was due to *Trichodesmium* (cyanobacteria) blooms. During December the average chlorophyll *a* was 0.34 mgm⁻³ also due to *Trichodesmium* filaments in water column. During January onwards winter cooling led to increase in nutrients which enhanced chlorophyll *a* value to 0.64 mgm⁻³ due to growth of flagellates (as seen by high chlorophyll *b* besides chlorophyll *a*) in water column. February, March and April supported moderately high chlorophyll value (0.3 to 0.5 mgm⁻³) due to growth of prasinophytes (as seen by pigment prasinoxanthin) and blooms of the *Noctiluca miliaris*. Time series monitoring of *Noctiluca* bloom was also conducted using OCM based chlorophyll images in NE Arabian Sea. During February chlorophyll *a* retrieved by OCM was 0.3 to 0.9 mgm⁻³. Pigment analysis of water samples indicated the equal important of accessory pigment like zeaxanthin, prasinoxanthin, β -carotene. The relevance of these pigments estimated by HPLC like zeaxanthin (cyanobacteria), fucoxanthin (diatoms), peridinin (dinoflagellates) is presented and discussed. Similarly, exercise is conducted in Lakshadweep waters where *Trichodesmium* related peak in chlorophyll *a* was observed during March onwards in OCM data. The average chlorophyll *a* in NE Arabian Sea at surface during November was (0.726 mgm⁻³), December (0.34 mgm⁻³), January (0.723 mgm⁻³), February (0.344 mgm⁻³), March (0.963 mgm⁻³) and April 0.665 mgm⁻³. Similar trend was observed in primary productivity estimates. The attempt is made to work out seasonality in the productivity of the Arabian Sea using OCM derived chlorophyll and relation of enhancement in productivity due to development of winter blooms in the Arabian Sea. The environmental conditions (temperature, wind, nutrients and mixed layer depth) affecting these blooms responsible for year to year variation in bloom biomass and productivity is also presented in detail.

Keywords: HPLC, phytoplankton, ocean colour monitor, Arabian Sea, chlorophyll

1. INTRODUCTION

The reversal of monsoon winds brings about changes in circulation pattern of the Arabian Sea ^{1,2,3} have shown that this reversal winds can induce seasonality in the abundance of phytoplankton in the Arabian Sea and winter blooms⁴. The seasonality of phytoplankton is also connected to coastal

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processes related to monsoons^{5,6}. During southwest monsoon (June-September), west coast of India experience upwelling of nutrient rich water. During this period there is a southwardly movement of surface currents and shallowing of isotherms along the coast. Towards the end of the SW monsoon offshore component of wind stress recedes so is upwelling. During NE monsoon (November-March), the surface currents reverse their direction and move northwards along the coast carrying warm, low saline, low nutrient waters from equatorial region. During this time thermoclines are located in deeper part of water column. In the region north of 15°N this northward flowing current turns westwards off the coast of Saurashtra. These environmental changes decide the phytoplankton seasonality in the Arabian Sea along the west coast of India. Since the early 1940s the method of choice for studying phytoplankton diversity has been⁷⁻¹⁴. Although the data sets obtained have provided valuable insights into the diversity of phytoplankton, such information has been limited to regions very close to the coast.

In addition to microscopy, photosynthetic and non-photosynthetic pigment distributions was used to identify the presence of different algal groups¹⁵⁻¹⁷. Accessory pigments can provide class-specific differentiation, allowing for the recognition of major taxonomic groups of marine phytoplankton¹⁵. Over the last twenty years, the development of high performance liquid chromatography (HPLC) has greatly advanced our understanding of phytoplankton pigment composition and functionality in response to ecosystem changes^{15,18}. In the western and central Arabian Sea for example, HPLC-analyzed pigments helped provide new information as well as a better understanding of changes in phytoplankton populations associated with the seasonal cycle of the monsoons^{19,20,21}.

During this study a wide and varied sampling strategy offshore as well as close to the coast ensured a comprehensive investigation on the seasonality of phytoplankton during the SW monsoon (June-August) when upwelling occurs along the west coast of India⁵, during the NE monsoon (November – February) when winter cooling takes place²²⁻²⁵ and during the inter-monsoon (March-May) when the water column becomes highly stratified and devoid of nutrients²⁶. Chlorophyll and primary productivity studies are also conducted during this study. Besides shipboard data IRS-P4 (OCM) data from the Arabian Sea is also collected for strengthening the idea of phytoplankton seasonality in the Arabian Sea

2. METHODOLOGY

Data on phytoplankton taxonomy, pigments and primary productivity is collected from NE Arabian Sea during Nov-April months. Station positions during various cruises is presented in Fig. 1.

2.1 Physico-chemical study: Temperature and salinity data was collected by using CTD. Nutrients like PO₄-P and NO₃-N are analysed by using standard methods²⁷.

2.2 Biological studies: Water was collected within the euphotic zone with 5L Niskin sampling bottles mounted onto a Sea Bird Electronics® CTD Rosette and processes in ship laboratory for pigments, primary productivity and taxonomy of the phytoplankton. The depth of the euphotic zone was established using a Secchi Disc.

2.2.1 Chl *a* by Fluorometer

Phytoplankton Chl *a* concentration was determined by filtering 1000 ml of seawater in 10 ml of 90 % acetone, sonicated and held in the dark in a freezer overnight. Chl *a* concentration was determined with a Turner designs 10-000R fluorometer (UNESCO, 1994). The fluorometer was periodically calibrated with a spectrophotometer according to UNESCO, 1994.

2.2.2 Pigments by HPLC method

For pigment estimations, samples between 1 and 2.5 litre were filtered through GF/F filters, frozen in liquid nitrogen at sea and then transported to the shore lab for analysis by HPLC^{15,17}. Prior to the HPLC analysis, the filters were immersed in 90 % acetone, extracted under cold and dark conditions overnight, sonicated and finally filtered through 0.2 µm, 13 mm PTFE filters to rid the sample of particulate debris. Aliquots of 1 ml of the pigment extract was then mixed with 0.3 ml of distilled water in a 2 ml amber vial and allowed to equilibrate for 5 minutes prior to injection into an HPLC (Agilent® 1100 series) equipped with a diode array detector. The mobile phase was a gradient mixture of 3 solvents: Solvent A (80:20, v:v; methanol : 0.5M ammonium acetate aq., pH=7.2; 0.01 % BHT, w:v), Solvent B (87.5:12.5,v:v; acetonitrile : water; 0.01 % BHT, w:v) and Solvent C (ethyl acetate). Pigments were separated in a C-18 reverse-phase column using the eluent gradient program of Wright, et al. (1991) as adapted by Bidigare and Charles (2002). Chl,

carotenoids and xanthophylls were detected by their absorbance peaks at 436 nm and identified by comparison with the retention times of standard pigments obtained from DHI[®] Water and Environment, Denmark, and Sigma Aldrich Chemicals[®] USA.

2.2.3 Primary Productivity

Water samples were collected and estimated by ¹⁴C technique and insitu incubations where activity was determined with a Wallac Scintillation counter (model no. 1409). All counts were quench corrected²⁸.

2.2.4 Phytoplankton Taxonomy

For identification and enumeration of phytoplankton, 1000 ml of seawater samples was fixed with 3 % Lugol's iodine²⁹ and then stored in 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. Replicates of 1ml sample concentrates were transferred to a Sedgwick-Rafter and counted using an Olympus Inverted microscope (Model IX 50) at 200 X magnification. Identifications were based on standard taxonomic keys³⁰. The results are expressed as numbers of cells except for *Trichodesmium* which are expressed as number of trichomes.

2.3 OCM data

2.3.1 Estimation of chlorophyll from Oceansat I/ OCM

As a part of processing of OCM data to generate chlorophyll images water leaving radiances were retrieved through removal of atmospheric effects from the satellite radiance values in the first step³¹. The atmospheric correction scheme makes use of long wavelengths for estimating aerosol optical thickness. Subsequently, bio-optical algorithm was applied to the corrected water leaving radiance data^{32,33}. O'Reilly's OC-2 algorithm was used for generating chlorophyll images from OCM data.

3. RESULTS AND DISCUSSION

Phytoplankton counts at surface and column as well as group level information at surface is presented in Table 1. During November cyanobacteria constituted major phytoplankton population (69.21 %). The average surface counts were high $15.831 \times 10^4 \text{L}^{-1}$ so was column counts of phytoplankton during November ($180.69 \times 10^6 \text{m}^{-2}$). The high counts of *Trichodesmium* were also recorded in column during December although surface counts were low. January and February counts were moderately high in water column was mainly due to *Noctiluca* bloom in the water column. The high phytoplankton counts during March and April was again high due to *Trichodesmium* bloom. During April as high as 80 % phytoplankton were composed of the *Trichodesmium* spp. specially *Trichodesmium erythraeum*. The Chl *a* estimated during various months is presented in Table 2. Chl *a* was high during November (due to cyanobacteria), February (due to *Noctiluca*) and April to May due to *Trichodesmium erythraeum*. Similar trend was observed in the column Chl *a*. The high value was due to *Trichodesmium erythraeum* bloom during Nov, *Noctiluca* bloom during February and *T. erythraeum* blooms during April and May (plates) which is discussed below.

3.1 Fall Intermonsoon season (November)

During November high Chl *a* at surface (0.726 mgm^{-3}) and column (43.812 mgm^{-2}) is due to *Trichodesmium thiebautii* bloom. The bloom of *T. thiebautii* during November was also seen under ocean colour image of November. The productivity of area was comparatively low at surface ($8.46 \text{ mgCm}^{-3}\text{d}^{-1}$) as well as column ($21.139 \text{ mgCm}^{-3}\text{d}^{-1}$) and is mainly due to shortage of nitrogen nutrients as indicated by *Trichodesmium* growth in the environment. The presence of *Trichodesmium* was also noticed in the pigment analysis. During November zeaxanthin and β-carotene level in particulate matter is high. The environmental conditions during November favoured the *Trichodesmium* growth. NE Arabian Sea, wind was low and PAR was high. This combined with low nitrate level was responsible for growth of the *Trichodesmium* during November (fall intermonsoon) in the Arabian Sea.

3.2 NE Monsoon (December to February)

The NE monsoon season is responsible for the churning of the water column through nutrients like NO_3 and PO_4 level was high during NE monsoon, unstability of water column was responsible for maintaining Chl *a* to moderately high level. Chl *a* during December was 0.34mgm^{-3} , January 0.723mgm^{-3} and February 0.344mgm^{-3} . During January increase in Chl *a* was due to high counts of dinoflagellates in water column. This peak in dinoflagellates has helped to promote growth of the *Noctiluca miliaris* during January and February. Similar trend of the Chl *a* was also observed by OCM images (Fig. 3). The column Chl *a* values were maximum during January (44.524mgm^{-2}) compared to December and February (Table 1). The rate of primary productivity was high during December and January but low during February (Table 2). The *Noctiluca miliaris* is the heterotrophic dinoflagellates and same productivity recorded was due to symbiotic algae (prasinophytes) inside *Noctiluca miliaris* cells.

3.3 Spring Intermonsoon (March to April)

The hike in Chl *a* (surface and column) was recorded during March-April, due to blooms of the *T. erythraeum*. This has increased primary productivity at surface as well as in column. During this period (spring intermonsoon) water temperature was high, nutrients were low which help to develop *T. erythraeum* bloom in the NE Arabian Sea. The chemotaxonomic studies during January revealed the presence of peridinin indicating the growth of dinoflagellates prior to *Noctiluca*. During *Noctiluca* bloom Chl *b* at high level so was prasinoxanthin due to symbiotic prasinophytes. During spring intermonsoon the high levels of the zeaxanthin and β -carotene was indicative of the *Trichodesmium* in the NE Arabian Sea specially during April. In the May, zeaxanthin was 11.77 %, β -carotene was 8 % due to extensive bloom of the *Trichodesmium* in the Arabian Sea specially in coastal region.

4. CONCLUSIONS

In Nov/Dec, depletion of nutrients upwelled during SW monsoon coincided with development of blooms of *T. thiebautii* at surface in Nov and at subsurface in Dec. This was confirmed by elevated zeaxanthin and β -carotene measured. Low Chl *a* concentrations and low phytoplankton counts were seen in Dec, a situation that was mirrored in the ocean colour images. In Jan, blooms comprising of a mixture of several species of dinoflagellates were observed which contributed to the high Chl *a* seen in the ocean color data and to the high concentrations of peridinin measured by HPLC. This mixed dinoflagellate bloom was followed by an intense *N. miliaris* bloom in Feb. The elevated levels of Chl *b* and Chl *c* were derived from the *N. miliaris* bloom. High levels of prasinoxanthin were due to the symbiotic prasinophyte *Pedinomonas noctilucae* that the *N. miliaris* harbors as an endosymbiont. *T. erythraeum* blooms were seen in association with the *N. miliaris* bloom as well as during the post *N. miliaris* bloom stage in Mar-April. May was marked by an intense *T.* bloom which was associated with flagellates as the associated phytoplankton.

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Table 1 Chlorophyll *a* at surface and column

Months	Surface Chl <i>a</i> (mgm⁻³)			Column Chl <i>a</i> (mgm⁻²)		
	Min	Max	Aver	Min	Max	Aver
Nov (n=13)	0.173	5.344	0.726	8.621	146.426	43.812
Dec (n=14)	0.190	0.510	0.340	18.39	27.24	22.140
Jan (n=25)	0.173	2.6	0.723	1.743	322.525	44.529
Feb (n=10)	0.132	0.960	0.344	3.292	49.383	17.366
March (n=13)	0.169	2.741	0.963	1.605	338.975	62.842
April (n=35)	0.074	5.905	0.665	3.337	64.126	14.001

Table 2 Primary productivity at surface and column

Months	Surface PP (mgCm⁻³d⁻¹)			Column PP (mgCm⁻² d⁻¹)		
	Min	Max	Aver	Min	Max	Aver
Nov (n=13)	0.953	20.457	8.460	7.808	42.267	21.139
Dec (n=12)	55.85	706.66	314.68	1299	15442.57	7343.33
Jan (n=13)	0.907	2572.194	226.098	182.195	26906.72	3356.701
Feb (n=6)	1.724	12.528	5.406	93.168	389.543	219.096
March (n=10)	1.056	19.775	9.093	93.033	872.025	436.578
April (n=24)	5.441	3489.104	367.982	100.131	17414.98	2711.610

Table 3 Dominant phytoplankton species in the NE Arabian Sea

Months	Dominant phytoplankton species					
	Surface			Column		
Nov	<i>Trichodesmium thiebautii</i>	<i>Nitzschia closterium</i>	<i>Ampphora hyalina</i>	<i>Chaetoceros socialis</i>	<i>Melosira moniliformis</i>	<i>Chaetoceros danicus</i>
Dec	<i>Gymnodinium gracile</i>	<i>Prorocentrum minimus</i>	<i>Rhizosolenia alata</i>	<i>Trichodesmium thiebautii</i>	<i>Nitzschia longissima</i>	<i>Actinoptychus senarius</i>
Jan	<i>Gymnodinium breve</i>	<i>Gonyaulax schilleri</i>	<i>Amphidinium carteari</i>	<i>Amphidinium carteari</i>	<i>Coscinodiscus radiatus</i>	<i>Gyrodinium spirale</i>
Feb	<i>Noctiluca miliaris</i>	<i>Navicula sp. I</i>	<i>Nitzschia closterium</i>	<i>Noctiluca miliaris</i>	<i>Rhizosolenia shrubsolei</i>	<i>Coscinodiscus oculus</i>
March	<i>Trichodesmium erythraeum</i>	<i>Noctiluca miliaris</i>	<i>Hemiaulus sinensis</i>	<i>Rhizosolenia shrubsolei</i>	<i>Pyrophacus horologium</i>	<i>Cocconeis scutellum</i>
April	<i>Trichodesmium erythraeum</i>	<i>Coscinodiscus marginatus</i>	<i>Peridinium elegans</i>	<i>Navicula delicatula</i>	<i>Trichodesmium erythraeum</i>	<i>Rhizosolenia stolterfothii</i>

Fig. 1 Sampling stations in the Arabian Sea

Fig 2 Distribution of pigments during different months. Chl a – chlorophyll a; Chl b – chlorophyll b; Chl c- chlorophyll c; fuco – fucoxanthin ; β-car- β-carotene; per-peridinin

Fig. 3 Chlorophyll *a* from OCM in the NE Arabian Sea during different months