

Comparison between phytoplankton bio-diversity and various indices for winter monsoon and inter monsoon periods in north-eastern Arabian Sea

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Phytoplankton samples of north-eastern Arabian Sea were collected during ocean colour satellite validation cruises from 2003-2007. Phytoplankton community organization and distribution was analyzed using various diversity indices like Shannon Diversity Index, Simpson Diversity Index, Margalef Diversity Index, McIntosh Diversity Index, Pielou Evenness Index and dominance index. Results showed that *Navicula*, *Thalassiothrix* and *Rhizosolenia* were most abundant among the diatoms. *Trichodesmium*, a cyanobacteria, dominated the shallow coastal waters. Resultant indices were correlated with phytoplankton cell counts and it was found that Shannons index better represents the diversity than other indices. Cell counts were also correlated with *in situ* chlorophyll-a values, which showed that this correlation does not stand good for the bloom conditions.

[**Keywords:** Phytoplankton diversity, diversity indices]

Introduction

Although 70% of the Earth's surface is occupied by the oceans, our knowledge of biodiversity patterns in marine phytoplankton is very limited in comparison to that of the biodiversity of plants on the land¹. It is well established that diversity enhances productivity and stability in communities of higher organisms; however, knowledge of such relationships between unicellular organisms like phytoplankton, which contribute to about 50% to the global primary productivity, is still lacking².

A diversity index is a measure of species diversity within a community that consists of co-occurring populations of several (two or more) different species. It includes two components: richness and evenness. Richness is the measure of the number of different species within a sample showing that more the types of species in a community, the higher is the diversity or greater is the richness. Evenness is the measure of relative abundance of the different species with in a community.

Present study is an attempt to analyze phytoplankton community structure (evenness and richness) using various diversity indices like Shannon Diversity Index, Simpsons Diversity Index, Margalef Diversity Index, McIntosh Diversity Index, Pielou

Evenness Index and dominance index. The use of these indices is well established in ecological literature however choice of a suitable index depends on how well the richness and evenness is represented by each index.

Materials and Methods

The Site selected for this study was Northern and Eastern section of Arabian Sea, occupying an area 6.225×10^6 km Sq. and extends from 0° to 25°N and 50° to 80°E³. It is bordered by Oman at the west, Iran at the North-West and the India at the east. Periyar, Bharathapuzha and Pamba rivers from Kerala; Kali, Netravati and Sharavati rivers from Karnataka, Tiracol, Chapora, Baga, Mandovi and Zuari rivers from Goa; Shastri, Gad, Vashishti, Savitri, Patalganga, Ulhas and Vaitarna rivers from Maharashtra; Tapti, Narmada, Mahi and Sabarmati rivers from Gujarat and Indus from Pakistan bring fresh water into Arabian Sea⁴. Phytoplankton samples of North Eastern Arabian Sea were collected during ship cruises organized for ocean colour satellite validation from 2003-2007 as shown in figure 1. The details of samples collected and analyzed for various cruises are summarized in table 1.

The water samples were collected from various sampling stations, which were decided on the basis of percent light intensity/penetration with reference to the surface irradiance in the water column. Satlantic under water Hyper-spectral radiometer was used to measure the light levels at the sampling sites. For microscopic identification and cell counts 500 mL of sea water was fixed with 1% lugol's Iodine and preserved in 3% buffered formaldehyde solution and stored under dark and cool conditions till analysis. Samples were concentrated approximately to 5-10 mL by siphoning the top layer of the sample carefully with a tube, 1 mL of sample were transferred to a Sedgwick-Rafter slide and identified and counted using an Olympus Inverted Microscope (Model IX 50) at 200% magnification. Standard taxonomic keys⁵ were used for identification. The cruises were temporally categorized into

winter-monsoon (Dec-March) and inter-monsoon (April-May) to better understand the seasonal variation in phytoplankton type and concentration.

The species diversity indices such as Shannon Diversity Index, Simpson Diversity Index, Margalef Diversity Index, McIntosh Diversity Index, Pielou Evenness Index and dominance index were computed. Surface diversity (at 0 m depth) was evaluated for FORV-212 and FORV-22 whereas surface as well as depth wise (vertical profile) evaluation of diversity was carried out for FORV-244 and FORV-253. For analyzing the community structure of phytoplankton in the North-Eastern Arabian Sea these indices were calculated as follows:

Shannon Diversity Index:

This index is applied to biological systems very commonly for calculating diversity. It was derived from a mathematical formula by Shannon in 1948⁶.

$$H' = -\sum [(ni / N) \times \ln (ni / N)]$$

H': Shannon Diversity Index

ni: Number of individuals belonging to i species

N: Total number of individuals

Simpson Diversity Index:

This diversity index is derived by Simpson in 1949^{7,6}. Simpson index values (Δ) are between 0 – 1. But while calculating, final result is subtracted from 1 to correct the inverse proportion.

$$1 - \Delta = [\sum ni (ni - 1)] / N(N-1)$$

Δ : Simpson Diversity Index

ni: Number of individuals belonging to i species

N: Total number of individuals

Margalef Diversity Index:

It has no limit value and shows a variation depending upon the number of species. Thus, it is used for comparison between various sites⁸.

$$d = (S-1) / \ln N$$

d: Margalef Diversity Index

S: Total number of species

N: Total number of individuals

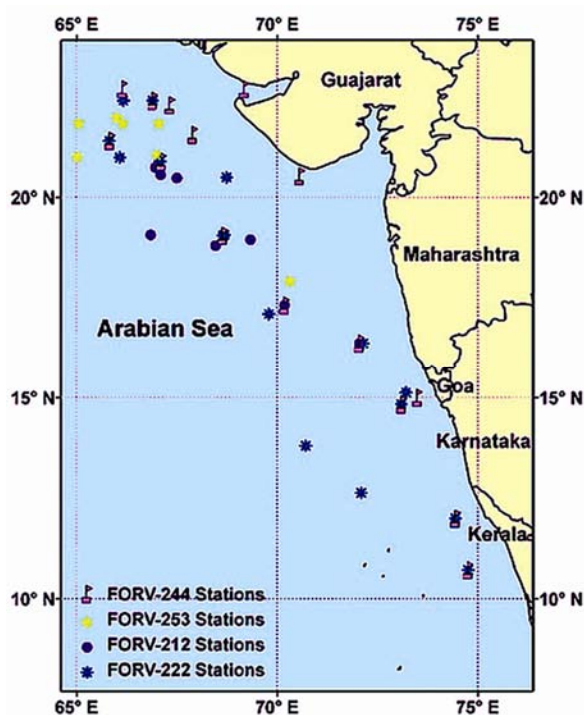


Fig. I—Map of stations at FORV-244, FORV-253, FORV-212 and FORV-222

Table I—Details of the cruise, season, sampling stations and depths

Cruise Id	Period of Study/ season	No. of stations analysed	Sampling Depths
FORV-212	27 th February to 5 th March 2003, Winter-Monsoon	5	100% light level (Surface) only.
FORV-222	21 th February to 11 th March 2004, Winter-Monsoon	3	100% light level (Surface) only.
FORV-244	15 th April to 28 th April 2006, Inter-Monsoon	15	100% light level (Surface), to 1 % light level.
FORV-253	28 th February to 11 th March 2007, Winter-Monsoon	8	100% light level (Surface), to 1 % light level.

McIntosh Diversity Index:

It was suggested by McIntosh in 1967. The value ranges between 0 – 1. The closer is the value to 1; the more homogeneous is the distribution of phytoplankton⁹.

$$Mc = [N - \sqrt{(\sum ni^2)}] / [N - \sqrt{N}]$$

Mc: McIntosh Diversity Index

ni: Number of individuals belonging to i species

N: Total number of individuals

Pielou Evenness Index:

It was derived from Shannon index by Pielou in 1966. The ratio of Shannon index to the maximum value gives the Pielou Evenness Index result. The values range between 0 – 1. The closer is the value to 1; the more even is the distribution of phytoplankton¹⁰.

$$J' = H' / H'max$$

J': Pielou evenness index

H': The observed value of Shannon index

H'max: lnS

S: Total number of species

Dominance Index:

Dominance index ranges from 0 to 1. 0 represents that all taxa are equally distributed and 1 means one taxon dominates the community completely⁷.

$$D = \sum ((n_i/n)^2)$$

n_i: Number of individuals of taxon i.

Results and Discussions*Phytoplankton Richness*

The phytoplankton community structure of the Arabian Sea was highly diverse with 274 species identified. Diatoms (Bacillariophyceae) exhibited the greatest diversity with 142 species followed by dinoflagellates (Dinophyceae) 129 species; other Algae (Cyanophyceae) with 3 species. Diatoms and dinoflagellates were the most diverse groups. Out of 142 species of diatoms 28% was contributed by three genera: *Chaetoceros* (18 species), *Navicula*

(12 species), *Rhizosolenia* (11 species). Of the 129 species of dinoflagellates, 30% were represented by two genera: *Ceratium* (21 species) and *Protoperdinium* (17 species). As a whole, a pronounced prevalence of diatoms was typical for the phytoplankton community in the Arabian Sea during the period of analysis. On an average, diatoms contributed 52% to the total species diversity as shown in figure 2. Their prevalence was at a maximum (70.2%) during the winter-monsoon period, in February and March, and reduced to 65% during the Inter-monsoon period (April to May). Dinoflagellates contributed only 47% to the total species diversity, with 25.4% during the winter-monsoon period, and reduced to 19.24% during the Inter-monsoon period. The remaining 1% was contributed by other algae. 2 Species of *Trichodesmium* represented this category.

Temporal variation in phytoplankton concentration at surface

Total phytoplankton cells observed at the surface (0 m depth) of the Arabian Sea ranged from (11 cells/lit to 10440 cells/lit) during 2003 to 2007. This shows that the waters of Arabian Sea are highly productive. Their concentrations in winter monsoon and inter monsoon periods is summarized in table 2 and figures 3 and 4 illustrate their group wise concentration in the two periods. More than half (60%) of the total diatoms was contributed by *Rhizosolenia alata* (10779 cells/lit), *Rhizosolenia shrubsolei* (6552 cells/lit), *Navicula* sp. (4500

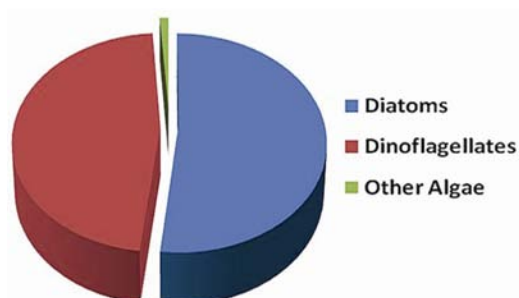


Fig II—Richness of various Phytoplankton groupss

Table II—Phytoplankton cell concentration and percent contribution, in winter monsoon and inter monsoon periods and their group wise concentration and percent contribution in the two periods

Total cell Concentration (116525 cells/lit)					
Winter monsoon period (60867 cells/lit) 52%			Inter monsoon period (55658 cells/lit) 48%		
Diatoms	Dinoflagellates	Other Algae	Diatoms	Dinoflagellates	Other Algae
(42568cells/lit) 70%	(15407cells/lit) 25%	(2892cells/lit) 5%	(36170cells/lit) 65%	(10714cells/lit) 19%	(8774cells/lit) 16%

cells/lit) and *Rhizosolenia hebatata* (3710 cells/lit). *Noctiluca scintillans* (10440 cells/lit) alone contributed to 68% of the total dinoflagellates in the winter monsoon period. *Trichodesmium erythraeum* (6316 cells/lit) was the greatest contributor (72%) among other algae (Cyanophyceae), in the inter monsoon period. Among dinoflagellates observed in the inter monsoon period, 21% was formed by *Scripsiella trachoides* (2220 cells/lit) and 14% was formed by *Prorocentrum minimus* (1462 cells/lit). Among diatoms that occurred in the inter monsoon period, *Navicula* sp. (5782 cells/lit); *Thalassiothrix frauenfeldii* (2504 cells/lit) and *Rhizosolenia fragilissima* (2220 cells/lit) were the major ones.

Spatial variation in phytoplankton concentration at surface

To study the spatial distribution of phytoplankton Arabian Sea was categorized as Coastal (< 50 m depth), shelf (50-200 m depth), slope (200-500 m depth) and Open Ocean (>500 m depth). *Noctiluca scintillans* formed massive blooms in the open ocean of northern Arabian Sea covering a large area from 17°19.40'N and 70°11.95'E to 20°28.72'N and 67°30.51'E during winter monsoon period as shown in figure 5. Whereas *Trichodesmium erythraeum* formed bloom in the coastal waters at 20°31.87'N and 70°34.77'E during inter monsoon period as shown in figure 6.

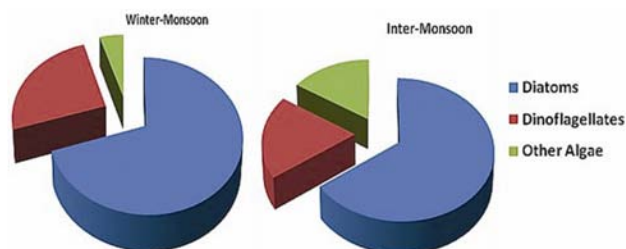
Phytoplankton Concentration and its relation with light and chlorophyll

Phytoplankton concentration in cell/lit was found to be directly proportional/linearly related to the chlorophyll concentration. Vertical distribution of phytoplankton cells was related to chlorophyll concentrations at surface, Deep Chlorophyll maxima (DCM) and 1% light level depth (euphotic depth). This correlation stands well in the inter monsoon period with $r^2 = 0.968$ at surface, $r^2 = 0.895$ at DCM and $r^2 = 0.807$ at 1% light level as shown in figure 7. Phytoplankton concentration does not show a very good correlation with chlorophyll, in the winter monsoon period. It has $r^2 = 0.195$ at surface, $r^2 = 0.546$ at DCM and $r^2 = 0.063$ at 1% light level as shown in figure 8. This is because *Noctiluca scintillans* formed bloom at the surface in the winter monsoon period. Though the number of cells/lit was found to be high in this period but chlorophyll concentration remained comparatively

low. *Trichodesmium erythraeum* also formed bloom in the inter monsoon period, but this bloom was restricted to the coastal waters only and coastal waters have a well mixed vertical profile with respect to phytoplankton cells, chlorophyll and light. So the bloom condition did not influence the correlation between cells and chlorophyll very significantly.

Range of diversity indices

The results of diversity calculation show that the coastal waters have more diversity than the open ocean waters. Also diversity of the open ocean is greatly affected by the *Noctiluca scintillans* bloom in



Fig—III and IV: Percent contribution of diatoms, dinoflagellates and other algae in winter and inter monsoon periods

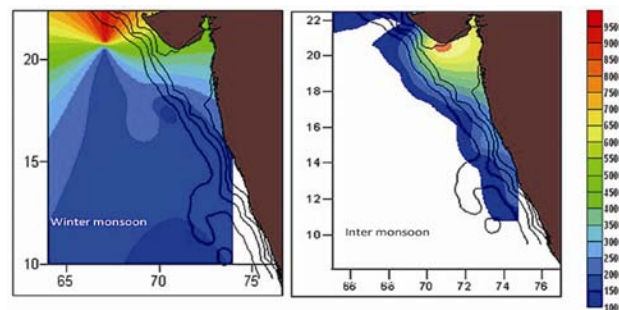


Fig V and VI: Spatial distribution of phytoplankton cells over the Arabian Sea during winter and inter monsoon periods. The colour bar shows cell concentration (cells/lit); green to red colour in the map shows the region covered by the bloom.

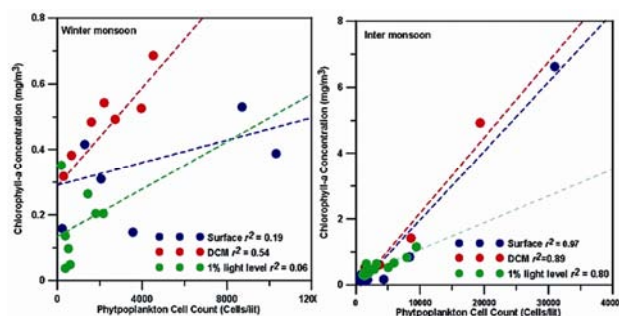


Fig VII and VIII: Correlation between phytoplankton cell counts and Chlorophyll-a at surface, DCM and 1% during winter and inter monsoon periods. The dotted lines are the linear fits applied to the data points.

Table III—Range of diversity indices in all the cruises

Diversity index	Minimum value	Maximum value
H'	0.098 (FORV-222, station 10)	3.28 (FORV-244, station 15)
Δ	1.45 (FORV-253, station 4)	20.91 (FORV-244 station 15)
d	0.44 (FORV-222, station 10)	4.64 (FORV-244 station 15)
Mc	0.17 (FORV-253, station 4)	0.78 (FORV-244 station 15)
J'	0.08 (FORV-253, station 4)	0.43 (FORV-244, station 10)
D	0.01 (FORV-222, station 7)	0.69 (FORV-253 station 4)

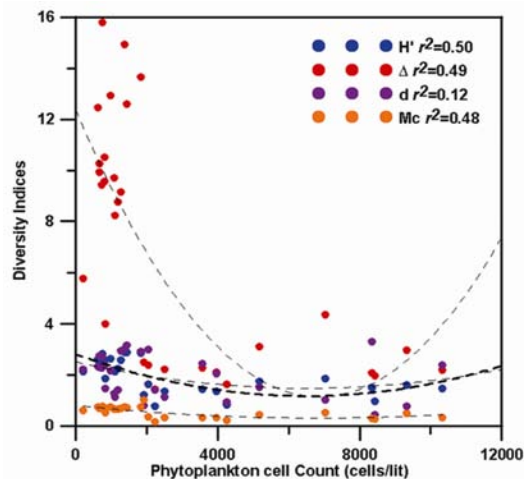


Fig 9—Correlation between phytoplankton cell counts and various Diversity indices

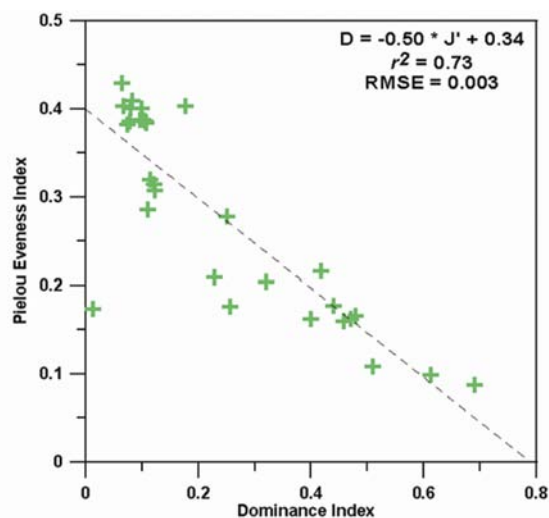


Fig 10—Correlation between Dominance Index and Pielou Evenness Index

the winter monsoon period. The minimum and maximum values of various diversity indices are tabulated in table 3.

Comparison between various diversity indices

The diversity indices were calculated using the cell counts obtained from the samples collected during the cruise. All the diversity indices represent the phytoplankton diversity over the Arabian Sea. To determine which index best represents the diversity, the diversity indices (Shannon index, Simpson's index, Margalef index and McIntosh index) were correlated with the phytoplankton cell concentration. The results of this correlation, as shown in figure 9, clearly indicate that the Shannon index has better correlation with the cell counts. Thus it best represents the phytoplankton diversity as compared to other indices. If one or two species dominate the phytoplankton community, the phytoplankton distribution will be uneven. Such an inverse relation between dominance and evenness was computed and their negative correlation has $r^2=0.73$ and $RMSE=0.003$ as shown in figure 10.

Analyses of these six indices show that none of these could formulate the richness component of diversity. In particular, the most preferred index among the other diversity indices, the Shannon index, cannot express the evenness component. Even other scaling diversity indices failed to formulate both the richness aspect and the evenness aspect of diversity.

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