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Ecological Insights from Phytoplankton Diversity Off Veraval, Gujarat Coast, India

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ABSTRACT

Phytoplankton species are sensitive to environmental and seasonal variability. This property of phytoplankton can be used to predict and study fluctuations in the ecological health of the system. In this study, phytoplankton diversity and its direct interactions with abiotic components of the ecosystem were studied to evaluate the health and stability of the coastal waters of Veraval, Gujarat coast, India. Results showed that diatoms dominated the ecosystem with a strong seasonal pattern of community succession. Waters were well churned and turbidity hindered penetration of light into deeper layers during the fall and winter monsoon season whereas stratification during spring inter-monsoon governed the distribution of different phytoplankton groups in the water column. These seasonal shifts resulted in a sincere pattern of annually re-occurring seasonal succession and formation of bloom events in the region. Apart from general phytoplankton diversity and its seasonal succession, the study intended to understand the forces governing the diversity and ecological system as a whole. To meet this objective, percent light intensities of chlorophyll-a, at various depths and temperatures were studied in relation to phytoplankton density. The correlation did not stand well for stations having active bloom formation showing that chlorophyll-a cannot be used as a proxy of phytoplankton biomass during bloom conditions. Thus excluding the points corresponding to active bloom conditions, second order polynomial equations were developed explaining the changes in chlorophyll-a concentration with variations in phytoplankton cell counts for study seasons. It was observed that most phytoplankton cells preferred upper well-lit layers of the water column with 100% light intensity followed by depths with 50% and 1% light intensities respectively. Study on temporal dynamics of the phytoplankton community in relation to temperature showed that the winter monsoon was characterized by a temperature range of 21.9 °C to 29 °C where *Navicula distans* was the most abundant phytoplankton species. *Skeletonema costatum* was the most abundant species at 27.2 °C during fall inter-monsoon. Spring inter monsoon had an abundance of *Navicula distans* at both 28.35 °C and 28.9 °C.

***Key words** : Phytoplankton ecology, Phytoplankton diversity*

Introduction

Phytoplankton community assemblage is the most basic component of a marine ecosystem. Studies on phytoplankton succession started in 1922 (Birge and Juday) since then many authors have studied and described phytoplankton succession and its ecological implications (Green and Vascotto 1978; Mukai and Takimoto 1985; Bijumon *et al.,* 2000; Motwani *et al.,* 2014). Still natural communities, their interactions and ecology remains ambiguous and keep ecologists pondering over them (Werner and Peacor, 2003). Interplay and variations in physical and chemical components of the environment form a suitable habitat for the organisms. For unicellular and short-lived organisms such as phytoplankton, these environmental variations greatly drive the organization of the community (Green and Vascotto, 1978).

Coastal and shelf regions of Veraval, Gujarat coast, form an essential part of the north-eastern Arabian Sea that represents a human-dominated ecosystem. Veraval is the biggest shipping and fishing port in the state (Bhagirathan *et al.,* 2014) having low bathymetry (Rao *et al.,* 1979) and high tidal influences. Such typical characteristics of the region make it unique in itself and phytoplankton being one of the most sensitive organisms to changes in environmental fluctuations (Mukai and Takimoto, 1985), the study of phytoplankton diversity and its direct interactions with the abiotic components of the system can serve as a means of evaluating ecosystem health.

Phytoplankton species composition, community structure and biodiversity for coastal and shelf regions of Gujarat are understudied even though Gujarat has the longest coastline (1214.7 kms) (Sanil Kumar *et al*., 2006). Although phytoplankton diversity in the Arabian Sea has been studied extensively since the time of JGOFS expeditions, by many researchers (Tiwari and Nair, 1998; Redekar and Wagh, 2000a and c; Bijumon *et al.,* 2000; Gopinathan *et al.,* 2001; Ramalingam *et al.,* 2008; and Shivaprasad *et al.,* 2012, Motwani *et. al.,* 2014) the work presented in this study is first of its type for coastal waters off Veraval, Gujarat. This study is a preliminary approach to understand the role of annual and seasonal fluctuations in phytoplankton community structure thereby facilitating to understand the ecosystem health and its prediction through variations in phytoplankton communities and associated physical components of the system.

Materials and Methods

Seasonal sampling was conducted from October 2010 to March 2017. Sampling seasons were categorized into fall inter-monsoon (October-November), winter-monsoon (December-March) and spring inter-monsoon (April-May) seasons. Figure 1 shows the geographical distribution of the sampling sites (stations) for annual and monthly coastal campaigns. To understand the effects of ecological components (pigment content, light and temperature) on phytoplankton diversity, abundance of various phytoplankton species and its seasonal succession were studied as biotic factors of the ecosystem. Secondly relation of these biotic factors with abiotic factors such as pigment content (chlorophyll-a in this case), percent light intensity at a given depth with respect to surface and temperature were studied. Based on these relationships a conceptual understanding of the complex coastal waters off Veraval was developed.

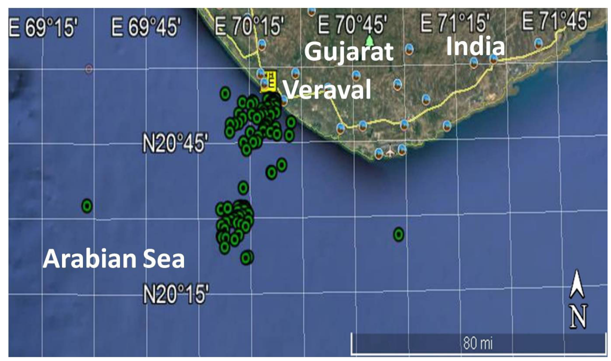

Fig. 1. Geographic location of sampling points off Veraval Coast (represented by green points)

Phytoplankton abundance was studied using classical microscopic technique (Tomas, 1997). Chlorophyll-a absorption was measured using UV-VIS spectrophotometer (Shimadzu UV-1800) and quantified following Jeffrey and Humphrey's (1975) equation. Percent light intensities at various sampling depths were measured using Satlantic® under water hyper-spectral radiometer.

Results

Biotic components of the ecosystem

Phytoplankton diversity

Coastal waters off Veraval showed a sincere pattern of seasonal succession in phytoplankton species composition. Although diatoms dominated in all the seasons studied (Figure 2), the dominance of a particular species in a given season was observed. In general, coastal waters of Veraval favoured growth of diatoms that contributed to 79.81% of the total phytoplankton density. Among all diatoms, *Pseudonitzschia delicatissima* occurred with highest density and contributed to 20.26%. Percent density of dinoflagellates was 1.89% whereas other algae (including chlorophytes and cyanophytes) contributed to 18.29% of total phytoplankton density. The major contributor to total dinoflagellates was *Prorocentrum balticum* with 0.37 % and *Trichodesmium erythrium* was the major cyanophyte (considered under 'other algae') which contributed to 8.17 %.

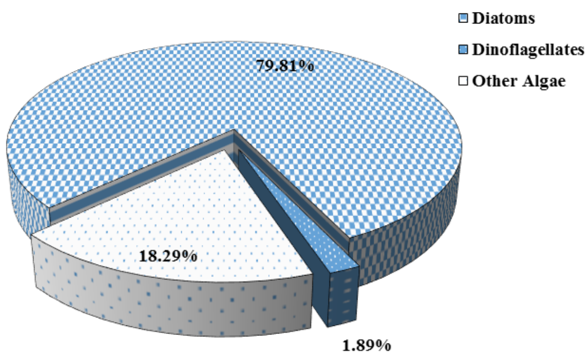

Fig. 2. Percent contributions of major phytoplankton species

On classifying phytoplankton abundance temporally into fall inter, winter and spring inter monsoon seasons, it was observed that percent density of diatoms was 97.68 during the fall inter monsoon season and *Asterionellopsis glaciallis* was the major species contributing to 39.81 % of total diatoms of the season. Table 1 summarizes the contribution of different phytoplankton groups during various seasons studied. Summing up the results, it was observed that phytoplankton diversity was at its maxima in the winter monsoon season while it decreases in inter-monsoon periods.

Trichodesmium erythrium formed bloom during spring inter monsoon seasons. Spring inter monsoon season is characterised by typically stratified water. *T. erythrium*is (blue-green alga/ Cyanophyte), is ecologically considered a diazotroph or nitrogen fixer. Bloom formation by this phytoplankton in spring inter monsoon season is a recurring phenomenon. Also, pointing out that the waters are nitrogen deficit and stratified in the early spring inter-monsoon season.

A. glaciallis dominated in the fall inter-monsoon season. This *A. glaciallis* dominance shifted to the dominance of *P. delicatissima* in the winter monsoon season. With changes in seasonal conditions from winter to spring inter monsoon season, phytoplankton densities changed from dominance of *P. delicatissima* to *T. erythrium* with extra-ordinarily outcompeting cells of *T. erythrium* (Table 1). Over the decade, this sincerity in seasonal patterns repeated every year. Annual convective mixing due to winter cooling effects whereas stratification of the water column during the inter monsoons (especially in spring inter monsoon season) (Motwani *et al.*, 2015) can be considered as driving forces for the seasonal patterns observed in the study. Availability of nutrients and light is greatly affected by the convective mixing and stratification in the column thereby influencing the phytoplankton community structure across the seasons.

Although factors governing diversity and distribution of phytoplankton community structure are complicated, light, temperature and availability of nutrients have a key role in regulating phytoplankton densities. As there is no influx of nutrients by riverine runoff in the coastal waters of Veraval, high doses of inorganic pollutants from fishing and shipping activities, vertical mixing and high tidal ampli-

Table 1. Contribution of different phytoplankton groups in different seasons

Seasons	Phytoplankton groups contribution	%	Dominant species	% contribution by dominant species
Fall inter monsoon	Diatoms	97.68	*A. glaciallis*	39.81
	Dinoflagellates	1.75	*Scrippsiellatrochoidea*	0.32
	Other algae	0.55	*T.erythrium*	0.37
Winter monsoon	Diatoms	88.72	*P.delicatissima*	25.12
	Dinoflagellates	1.46	*P.balticum*	0.42
	Other algae	9.81	*T. erythrium*	4.54
Spring inter monsoon	Diatoms	48.31	*Nitzschialongissima*	18.53
	Dinoflagellates	2.29	*P. balticum*	0.63
	Other algae	49.38	*T. erythrium*	46.36

tudes serve as a source of nutrients for the region. According to Wetzel, 2001, light and temperature are two inseparable components that affect the distribution of phytoplankton. Coastal waters of Veraval represent a typical tropical condition where the availability of light is generally never limiting for the growth of phytoplankton (Raitsos *et al.,* 2013) with exception of highly turbid regions where the light penetration in the water column is limited.

Except spring inter monsoon season, overall dominance of diatoms reflects that the aquatic system is physically unstable, having low salinity and high amount of nutrient supply (possibly silica) due to re-suspension (Smetacek, 1985; 1988; Fernandes and Brandini, 2004). Unstable and mixed water types prevent the cells from sinking thus making them available for zooplankton (eg: copepods) (Lopes *et al.,* 1998). Evidently, in a diatom-dominated unstable system, the cells have higher probabilities of entering the food chain and contributing to energy transfer to higher trophic levels rather than acting as a direct sink of organic matter (carbon).

Surface chlorophyll-a in relation to average phytoplankton abundance at the surface

To understand the factors governing variations in phytoplankton diversity, its relation with chlorophyll-a was evaluated for surface waters. Chlorophyll-a is a well-established proxy for phytoplankton biomass but its relation (Figure 3(a)) with overall phytoplankton cell count was not good (R^2=3.16). This was because the points corresponding to the stations where the bloom was observed became outliers. Thus points corresponding to bloom stations were removed and data were temporally classified into seasons. Recalculated results showed a good correlation between phytoplankton counts and chlorophyll-a concentrations for all the seasons (Figure 3 b, c & d). From the above results, it can be inferred that chlorophyll-a can be used as a proxy for phytoplankton only in non-bloom conditions. The correlation of chlorophyll-a and cell counts showed a positive second order polynomial curve. A positive correlation of phytoplankton cells with chlorophyll-a concentration implies that chlorophyll concentration increased when phytoplankton cells increase. The rate of increase of chlorophyll content with an increase in phytoplankton density is governed by seasonal variations in the abiotic factors. Thus different models (shown in Figure 3) were formed for different seasons.

Actively growing cells always tend to have higher chlorophyll concentrations to meet their

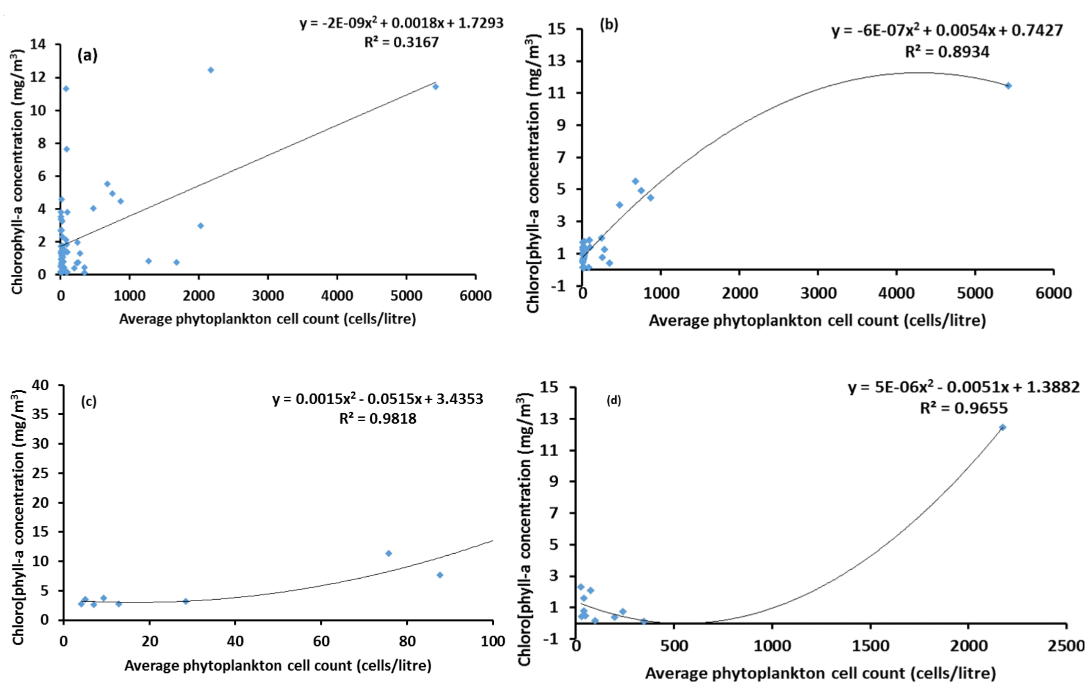

Fig. 3(a). Correlation of phytoplankton cell count with chlorophyll-a concentration; (b) for wintermonsoon season; (c) for fall inter monsoon season; (d) for spring inter monsoon season physiological needs. Variations in seasonal conditions primarily alter the availability of nutrients and temperature. Based on the response of phytoplankton species to seasonal alterations, they can be classified as, first, the tolerant species. These are the ones that can adapt to the changed conditions. Such species outcompete others and either dominate or form blooms. This adaptation is not straightforwardly related to the increase in chlorophyll concentration. Thus in most cases, chlorophyll-a concentration does not act as a proxy for phytoplankton biomass.

Second, the sensitive species. These are the ones that cannot adopt and either reduce their growth rates or turn completely dormant.

Abiotic components of the ecosystem

Phytoplankton diversity with respect to percent light in the water column

In this study, it was observed (Figure 4) that diatoms, dinoflagellates and all other algae had preferential distribution in the vertical column of water, where most phytoplankton occupied the well-lit upper layer of water with 100% light availability. Secondary preference was to occupy the depths with 50% light intensities where availability of light and nutrients was better optimised than the depths with 1% light level. Turbid waters did not allow penetration of light in the lower depths thus phytoplankton diversity decreased at lower depths (with 50% and 1% light intensities). According to Harris, (1986), phytoplankton communities can be preserved and perpetuated in stable systems. In case of the coastal waters off Veraval, the nutrients are well mixed due to re-suspension of the particulate matter. Such physically disturbed (unstable) systems are turbid and can affect the penetration of light into the deeper layers thus influencing the translocation of the phytoplankton communities along the vertical column of water (Leland, 2003; Walks and Cyr, 2004 and Rejas *et al.*, 2005).

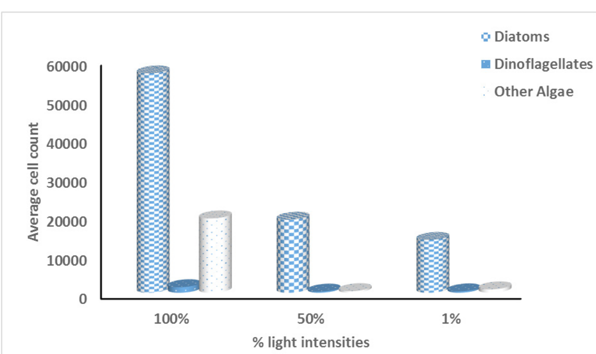

Fig. 4. Distribution of phytoplankton groups along the vertical column of water with respect to percent light intensities

Surface temperature in relation to average phytoplankton abundance at surface

The influence of temperature on phytoplankton abundance was better understood by pooling the data seasonally (Figure 5). Variations in phytoplankton density with changes in temperature showed a sincere seasonal pattern. Each season marked a range of temperatures where average phytoplankton abundance was maximum and a specific temperature where a specific species outcompeted others. Winter monsoon was characterized by a temperature range of 21.9 °C to 29 °C (Figure 5(b)). *Navicula distans* was the most abundant phytoplankton species with maximum abundance at 24.8 °C. *Skeletonema costatum* and *Asterionellopsis glacialis* were the most abundant species at 27.2°C and 26.1°C respectively during fall inter monsoon species. Fall inter monsoon was characterized by a temperature range of 25.5°C to 27.9°C (Figure 5(c)). Similarly, spring inter monsoon is characterized by a narrow temperature range of 28 °C to 29 °C (Figure 5(d)) and abundance of *Navicula distans* at both 28.35 °C and 28.9 °C was observed.

A. glacialis can form bloom at temperatures around 26 °C. *S. costatum* was considered a cold water species by Fernandes and Brandini, 2004. The maximum abundance of *S. costatum* at around 27 °C contradicts the consideration of Fernandes and Brandini in coastal waters of Veraval, Gujarat Coast, India, showing that it can flourish at higher temperatures as well. *N. distans* outcompetes the average phytoplankton abundance during both winter as well as spring inter monsoon season. This brings out that *S. costatum* and *N. distans* are highly tolerant species that can flourish at wider ranges of temperatures. *N. distans* comes out to be the most tolerant species with respect to temperatures and stratification in the water column.

Discussion

Primary observational results provided insights of associated ecosystem conditions of the region. Diatoms formed the major group contributing to phytoplankton diversity in all the seasons studied indicating that the waters were well mixed and represented a turbulent system. Seasonal shifts from the dominance of *A. glaciallis* in the fall inter monsoon, the dominance of *P. delicatissima* during winter, and the dominance of *T. erythrium* in the early spring, were observed to follow a sincere pattern over the entire study period. The dominance of diatoms during fall inter and winter monsoon indicated a physically unstable system with a high nutrient supply while the spring inter monsoon season was characterised by stratified water. In diatom dominated unstable systems where water is well churned, phytoplankton cells are more prone to remain suspended and enter the food chain rather than acting as a direct sink for organic matter.

A species grows and multiplies in favourable conditions. It is also a fact that no species continues to dominate a region forever because environmental factors keep changing seasonally. Seasonal alterations in abiotic factors of the environment turn one or the other factor unfavourable or limiting even if all the other unchanged factors continue to remain favourable (Odum, 1971). In this study, when vertical distribution of phytoplankton cells was studied, light acted as a limiting factor at depths with 50% and 1% light intensities. Increase in phytoplankton abundance did not ensure a consistent increase in chlorophyll-a concentration within the cells. Availability of nutrients and temperature check upon the growth and multiplication of cells as also on the chlorophyll-a concentrations within them. In this ecological fight for growth, multiplication and survival, *N. distans* turned out to be the most tolerant species with a wide range of tolerance for temperature as well as the availability of nutrients.

Based on the observations of diversity, coastal waters off Veraval can be considered eutrophic in almost all seasons, but seasonal blooms and a strong pattern of seasonal shift in species composition makes the region complicated. Many ecological laws such as 'seasonal succession', 'law of resource competition', 'law of limiting factor', 'laws governing species dominance, ecological diversity and formation of blooms' in sync with geographical phenomena such as 'convictive mixing during winter monsoon' and 'stratification during spring inter monsoon' all act synergistically to balance the ecosystem health of the region. The results are important for future ecosystem modelling and remote sensing based studies where wind can act as an additional input variable.

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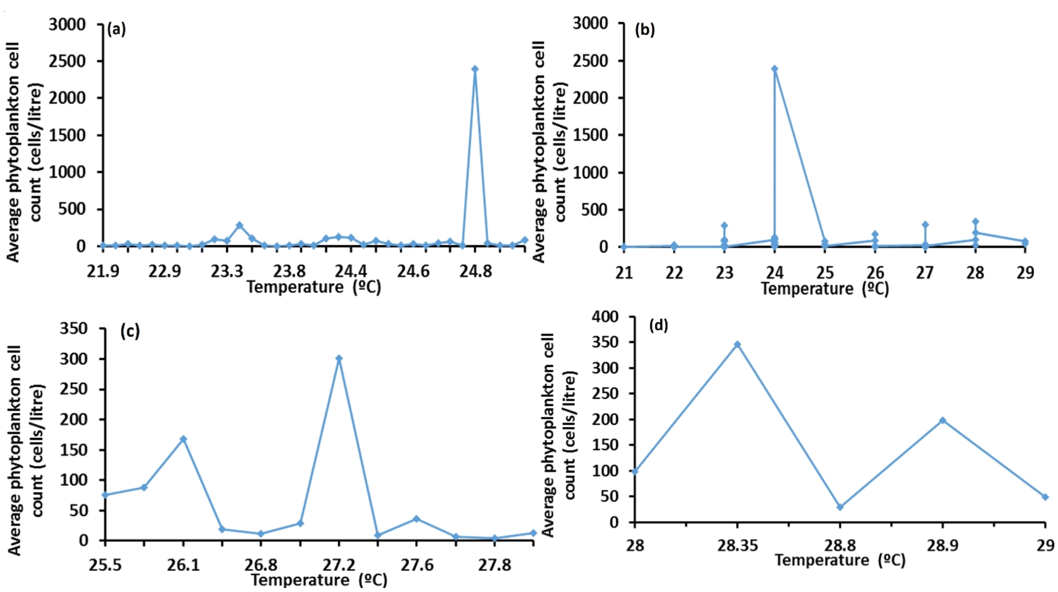

Fig. 5(a). Correlation of phytoplankton cell count with Temperature; (b) for winter monsoon season; (c) for fall inter monsoon season; (d) for spring inter monsoon season

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