

## Long-term patterns of net phytoplankton and hydrography in coastal SE Arabian Sea: What can be inferred from genus level data?



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### ABSTRACT

Based on 21 years of phytoplankton and environmental monitoring data from the surface water of coastal southeast Arabian Sea, we demonstrate a shift in phytoplankton community towards higher sample genus richness and diatom abundance during the two decades of observations. Analyses were based on 587 water samples collected between 1990 and 2010 and additionally revealed marked long-term changes in sea surface temperature (SST), sea surface salinity (SSS) and turbidity (Secchi depth). The abundances of dinoflagellate genera were positively correlated to SST, particularly during and after the 1997–1998 El Niño Southern Oscillation event. Several diatom genera increased in abundances with decreasing turbidity around and after 1995–2000, mainly the large celled genera *Coscinodiscus* spp, *Odontella* spp and *Ditylum* spp. In 1996–2000, sample genus richness increased from mean of 8–14, and decreased to 11 thereafter. The increase in sample genus richness was linked to the more frequent presence of most taxa during 1996–2000. Increasing Secchi depth and abundance of frequently encountered large-celled diatoms concurrent with decreasing abundances of *Trichodesmium* spp might signal the alleviation of the nitrogen limitation in the region, favouring diatoms.

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## 1. Introduction

Marine ecosystems are undergoing rapid change in response to natural processes, human activities, and climate change, most notably the increase in the sea surface temperature and nutrient loadings to coastal waters (Barnett et al., 2005). Although estuaries and upwelling zones constitute only a minor part of the global ocean spatially, these areas are characterized by the highest rates of primary productivity (Field et al., 1998). Phytoplankton comprise an extremely diverse, polyphyletic group of microscopic photosynthetic protists and cyanobacteria. Due to their small size, short generation times, and large population numbers, phytoplankton are sentinels of marine ecosystem change, including a whole suite of environmental stressors. Of the very high taxonomic diversity

inherent to net phytoplankton in general, diatoms, dinoflagellates and cyanobacteria are the three characteristic phylogenetic and functional groups that frequently dominate coastal phytoplankton assemblages. These three groups exhibit unique and often contrasting adaptive ecologies, explaining their niche partitioning on the turbulence-nutrient matrix of habitats and onshore-offshore gradients. Generally, diatoms are successful competitors in turbulent or tide-affected nutrient rich water (Margalef, 1978; Odebrecht et al., 2014), while dinoflagellates have diverse habitat preferences and are capable of forming usually mono-specific blooms throughout onshore-offshore gradient of decreasing nutrients, reduced mixing and deepened euphotic zone (Smayda and Reynolds, 2003). Diazotrophic cyanobacteria thrive during hot weather amid high insolation in nitrogen depleted water (Sellner, 1997). Phytoplankton indicators are ecologically and biogeochemically relevant proxies since phytoplankton conduct a large proportion of primary production within coastal ecosystems and hence carbon and nutrient cycling. The phytoplankton

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community is characterised by large variations in time and space, where the presence of certain functional groups is associated with contrasting environmental regimes (Barton et al., 2013).

The existence of long-term biological time series is one of the primary prerequisites in studies of climate change and anthropogenic effects on the ecosystems (Ducklow et al., 2009; McClain, 2009; Boyce et al., 2010). Especially acute is the scarcity of long-term biological data series from marine realm, due to the relatively higher cost of data collection (Edwards et al., 2010). While there are some studies from the temperate waters (e.g. Richardson and Schoeman, 2004; Edwards et al., 2010) and from the subtropics (e.g. Hawaii Ocean Time series; Karl and Lukas, 1996), we are not aware of any studies that would be based on decadal biological time-series from the tropics and the effects of climate variability on coastal marine tropical ecosystems remain largely unknown.

Hydrographic conditions in the study area – the coastal southeast Arabian Sea – are controlled by the semi-annual reversal of the monsoon winds. The northeast winter monsoon prevails from November to March and provides continuous mixing (Schott and McCreary, 2001). Following this, during March–May, the sea is calm, surface insolation is intense, sea surface temperature increases with subsequent development of thermal stratification, evaporation increases sea surface salinity, and the concentration of bioavailable nitrogen is relatively low in the surface water (Gandhi et al., 2011). *Trichodesmium* spp, a N<sub>2</sub>-fixing filamentous cyanobacterium, thrives under these warm oligotrophic conditions, and bloom formation is frequently observed in the central and eastern Arabian Sea (Gandhi et al., 2011). The southwest (SW) summer monsoon occurs from June through to September. During this period the wind shows a steep rise in along-shore components, and a weaker rise in cross-shore components. This wind induced divergence causes Ekman transport of surface water away from the coast and a shoaling of the thermocline (Muraleedharan and Kumar, 1996). The coastal upwelling supplies cooler nutrient-rich waters to the photic zone and promotes elevated primary production. During October and November, the upwelling strength of the SW monsoon is reduced, marked by gradually decreasing nutrient levels (Prakash and Ramesh, 2007). A peak in zooplankton biomass occurs during October and November, fuelled by the preceding summer monsoon upwelling and diatom blooms (Krishnakumar and Bhat, 2008; George et al., 2012).

We analysed long-term trends in the phytoplankton community composition of the coastal south-eastern (SE) Arabian Sea (SW coast of India) collected between 1990 and 2010, to detect the temporal changes in the abundances of different phytoplankton genera or changes in phytoplankton genus richness, and identify the oceanographic variables best associated to the variation in phytoplankton community composition. Phytoplankton abundances were determined as cell numbers at genus level, therefore special consideration is given to the choice of methods best suited in detecting long term shifts in this type of data.

## 2. Material and methods

### 2.1. Data

Water samples for environmental variables and phytoplankton counts were collected during the monitoring program conducted between 1990 and 2010. Sampling occurred at four fixed stations along an inshore-offshore transect off the coast of Chitrapur, Karnataka state, India: 1) 12°57'07.33" N, 74°46'48.34" E, 2) 12°57'00.48" N, 74°46'09.63" E, 3) 12°56'38.16" N, 74°45'26.46" E, 4) 12°56'47.50" N, 74°44'45.85" E, station depths 4, 8, 12 and 15 m, respectively (Fig. 1). Data were collected from surface water (<2 m) at all stations once a month from October to May. Water samples

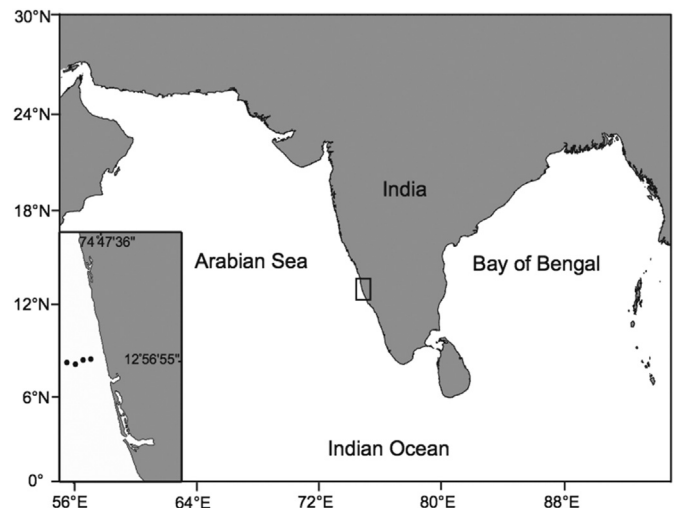


Fig. 1. Map of the sampling area offshore from Chitrapur on the Indian SW coast. The insert at bottom left corner (depicted by the box at the large map) zooms into the area to show the locations of four fixed sampling stations.

were collected with a Niskin water sampler (Aquatrap 2.5 L, Partex Products), and immediately transferred into dark containers. Sea surface temperature (SST) was recorded on board using a standard thermometer, and Secchi depth was measured. Data on sea surface salinity (SSS) and inorganic nutrients (nitrite, nitrate, silicate, phosphate) were obtained following Strickland and Parsons (1972). A Heron-Tranter net equipped with a flow meter, a mouth area of 0.25 m<sup>2</sup> and a mesh size of 60 μm was used for collection of phytoplankton. The net was lowered to 2 m above the sediment surface and slowly pulled to the surface. Concentrated phytoplankton samples (250 ml) were preserved in 1% acid Lugol's solution. The concentrated phytoplankton sample was thoroughly mixed, 1 ml sample was placed onto gridded Sedgewick-Rafter cell (Wildlife supply company, USA), where all cells were counted. For each sample, counting was done in triplicates, and averaged to get the final abundances. Phytoplankton cells were identified to the genus level and quantified at 100, 200 and 400× magnification (Nikon Diaphot-TMD). For the analysis, counts of morphologically similar phytoplankton genera were summed together, i.e., *Thalassiothrix* spp and *Thalassionema* spp, and *Cyclotella* spp and *Planktoniella* spp. Apparent benthic genera that were most likely resuspended from the sediment were excluded from analysis. Analysis was carried out on 33 phytoplankton taxa (23 diatom genera, 9 dinoflagellate genera, and 1 cyanobacteria) in 587 samples.

### 2.2. Statistical analyses

All analyses were done in the R framework for statistical computing (R Development Core Team 2013). Constrained redundancy analysis (RDA, R library *vegan*, Oksanen et al., 2012) was used to visualize the general co-variability of genus abundances and abiotic variables (SST, SSS, Secchi depth) with each other and time (variable 'year'). Species abundances were standardized using the logarithmic transformation [ $\log(x + 1)$ ] as suggested by Anderson et al. (2006). Scaling of the RDA biplot was set to '2' to retain the correct angles (correlations) between variables. Although all major dissolved nutrients (nitrite, nitrate, ammonium, phosphate, silicate) were measured simultaneously with phytoplankton sampling, we only use those data to assess any long-term trends in nutrient availability, but not in RDA, since correlations between the phytoplankton abundances and ambient nutrient concentrations

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