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Responses of the picophytoplankton community to temperature fronts in the northeastern Arabian Sea during the northeast monsoon

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ABSTRACT

We investigated the responses of the picophytoplankton (< 3 µm) community to a temperature filament and front through high resolution spatial (~ 1 NM) sampling (November-23 to December-11, 2012) in the northeastern Arabian Sea (69°E, 18.85°N to 20.25°N). Samples were collected at discrete depths within the 100 m water column. *Synechococcus* dominated the picophytoplankton community numerically and in terms of biomass along the entire transect. To investigate the patterns of variability in picophytoplankton distribution, depending on the water mass characteristics, the entire transect was divided into four zones (1) south of filament (SFIL) with warm oligotrophic waters, (2) filament (FIL) with cooler and low saline waters, (3) north of filament (NFIL) with relatively cooler waters than the SFIL and (4) front (FRO) with relatively cooler and less saline waters than the FIL. Depth-integrated abundance and biomass of *Synechococcus* were relatively higher within the FIL and FRO whereas *Prochlorococcus* and picoeukaryotes were abundant in SFIL and NFIL. Redundancy analysis of environmental variables and picophytoplankton abundance showed that lower saline water mass within the mesoscale features harbored relatively higher *Synechococcus* abundance and biomass. Two *Synechococcus* ecotypes were distinguished based on the fluorescence intensity of the accessory pigment, phycoerythrin; the one with higher intensity (open ocean ecotype) dominating in the FIL and the other with lower intensity in the FRO (coastal ecotype). The relatively lower saline surface water mass at the FRO, probably a result of coastal advection, could have introduced the latter ecotype. Vertically, a positive correlation of *Prochlorococcus* with nutrients and *Synechococcus* with temperature corroborates their higher and lower abundance and biomass, respectively in the deeper waters. The positive correlation of *Synechococcus* with the total chlorophyll biomass indicates a similar response to environmental variables within the mesoscale features. This study shows that picophytoplankton contribution (16–24%) to the total phytoplankton carbon biomass in tropical mesoscale features is likely to have important consequences on the planktonic food web function.

1. Introduction

Picophytoplankton (Pico) are numerically abundant in the ocean and play a vital role in the planktonic community, especially in oligo- and mesotrophic regions of the ocean where they make a substantial contribution to carbon production, biomass and cycling of organic matter and nutrients (Rii et al., 2016). They are the dominant primary producers in the oligotrophic oceanic waters due to the small size that enables them to have a high ability of nutrient utilization and carbon fixation (Raven, 1998). These primary producers become more prominent in terms of biomass when physical conditions cannot sustain large standing stocks of large producers (Landry et al., 1997). In recent studies, the contribution of Pico to the global oceanic carbon flux is also highlighted to be more important than previously recognized, which can be proportional to their net production through direct ingestion and defecation of gelatinous macrograzers or aggregate formation mediated by faecal pellet transport of mesozooplankton consuming macrozooplankton (Richardson and Jackson, 2007). Pico comprises two prokaryotic groups, *Prochlorococcus* (*PRO*) and *Synechococcus* (*SYN*) and one eukaryotic group, picoeukaryotes (PEUK). *PRO* is the smallest known photosynthetic organism (0.7 µm), and is most abundant in tropical open-ocean waters with cell concentrations in the range of 10^5 cells mL^{-1}. The slightly larger (1 µm) *SYN* reaches similar concentrations in tropical and temperate oceans and frequently demonstrates patterns in distribution opposite to those of *PRO* (Partensky et al., 1999; Zubkov et al., 2000; Johnson et al., 2006). PEUK (0.8 to 2–3 µm) include taxonomically diverse populations with members scattered widely across many branches of the eukaryotic tree of life and are usually the least abundant amongst the Pico groups (Massana, 2011; Rii et al., 2016).

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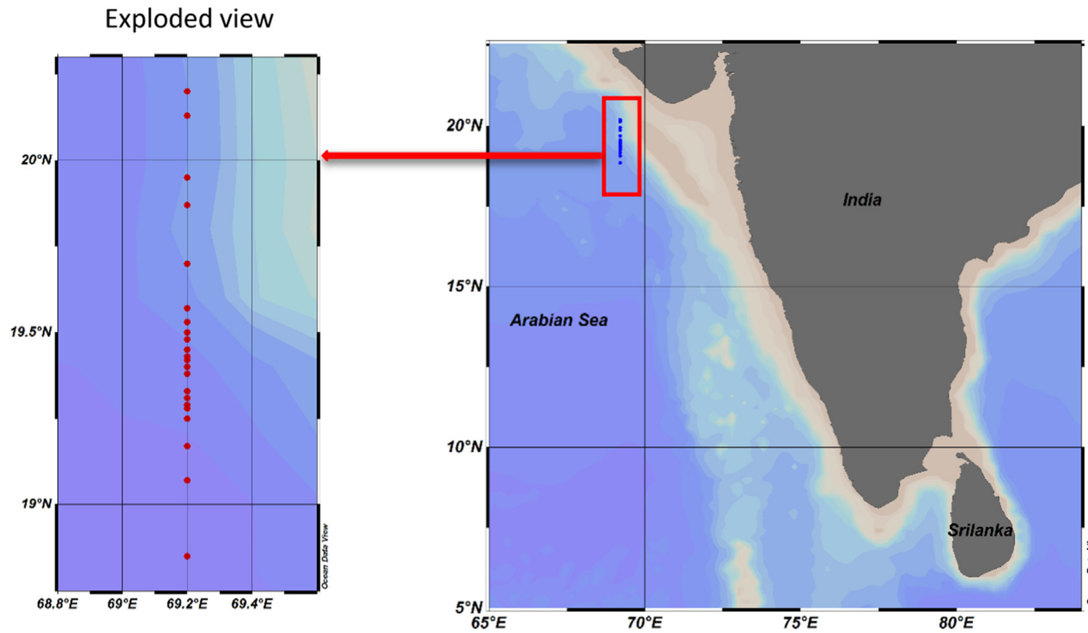

Fig. 1. Sampling station locations along the transect in the northeastern Arabian Sea.

Physical processes are a primary determinant of the dynamics of marine ecosystems (Lima and Olson, 2002; Mann and Lazier, 2005) which provide the environmental conditions and the physical structure within which biological processes occur. Mesoscale variability is particularly significant, influencing the distribution and rates of biological processes as well as community structure (Garçon et al., 2001). Fronts, eddies, plumes, and filaments are the main signatures of mesoscale activity at the sea surface and are primarily visible from satellite sea surface temperature (SST) images because the water masses involved in frontogenesis are generally of different temperatures (Demarcq and Dagorne, 2011). Oceanic fronts are complex fluid structures often characterized by sharp sea-surface gradients in density, temperature, and salinity. Distributed throughout the world's oceans, fronts occur at multiple spatial scales and have highly variable kinematics and flow fields (Fedorov, 1986). Filaments are elongated and weakly energetic structures that are ejected from the mesoscale turbulent structures such as eddies and fronts, reaching hundreds of kilometers in length and width smaller than 10 km (Rudnick, 2001). These episodic phenomena where vertical advection and exchange of momentum are intense, result in the injection of new nutrients to the euphotic zone leading to high biological productivity (Rudnick and Luyten, 1996; Taylor et al., 2012; Clayton et al., 2014). The resulting increased phytoplankton biomass can lead to the active aggregation of stronger swimming organisms searching for food [e.g. larvae, zooplankton and larger predators such as fish (Genin, 2004; Landaeta and Castro, 2006), seabirds and marine mammals (Bost et al., 2009)] thereby creating biological hotspots (Benoit-Bird et al., 2009). So these mesoscale features are indicators of many oceanographic processes and are sites of increased biological activity affecting all oceanic life forms.

The Arabian Sea is an intensely dynamic region of the world's oceans, driven by strong seasonal reversals in monsoon winds (Prasanna Kumar and Prasad, 1999). Upwelling influences the boundary and open ocean processes of Arabian Sea during summer and surface cooling and convective processes in winter that brings in high amount of nutrients into the upper ocean enhancing primary productivity, and ultimately the fisheries (Banse, 1968; Shetye et al., 1994; Madhupratap et al., 2001; Shankar et al., 2002). Relation of oceanic fronts with fishery resources has been documented by Laurs et al. (1984), Maul et al. (1984) and Solanki et al. (2008). SST and chlorophyll concentration images derived from satellite observations are used for forecasting potential fishing zones (Solanki et al., 2008). The waters of the Arabian Sea extending from the west coast of India down to 100 fathoms and lying between 18° N and 24° N latitude are of great importance from the point of view of the fishing industry, as they support some of the richest trawling grounds off the Indian Coast (Jayaraman and Gogate, 1957) especially during winter monsoon (Bhattathiri et al., 1996; Solanki et al., 2008).

Although Pico is known to be a significant contributor to phytoplankton biomass in the Arabian Sea (Brown et al., 1999), observations of patterns of their assemblages at the scale of these physical features are rare and still in its infancy, especially in the northeastern Arabian Sea (NEAS) (Madhupratap et al., 2001; Solanki et al., 2008). Across the sub-tropical front in the southwest Indian Ocean, $< 2\,\mu m$ cells contributed 56% to the total chlorophyll concentration (Fiala et al., 2004). In the California Current System, variable responses to frontal dynamics were observed wherein at some regions the larger phytoplankton increased with a reduction in Pico within the fronts (Taylor et al., 2012) and at other regions, phytoplankton biomass increased outside the fronts (Hood et al., 1991; Venrick, 2000). These observations imply that responses of the Pico vary across the globe. In this regard, it is essential to assess the Pico responses to better understand its role in the functioning of the microbial food web of tropical regions.

An interdisciplinary cruise was carried out in the NEAS between 18.85°N and 20.25°N along 69°E from 23 November to 11 December 2012, with the aim of understanding the ecosystem dynamics of the mesoscale features in the Indian EEZ. Vipin et al. (2015) detected a filament and front within this region, with relatively higher nutrient and phytoplankton pigment concentrations measured through high performance liquid chromatography (HPLC) than the surrounding waters (Roy et al., 2015). The present study was undertaken with the aim of investigating the response of Pico community structure/abundance/biomass to the prevailing hydrography and environmental conditions, horizontally and vertically across a transect encompassing a front and filament in the NEAS. We hypothesized that within the mesoscale features, the relatively lower temperature, salinity and higher nutrient concentrations induced by the upward mixing of the water column, will increase the abundance and carbon biomass of *SYN* but reduce that of *PRO*.