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Ecology and trophic preference of picoplankton and nanoplankton in the Gulf of Mannar and the Palk Bay, southeast coast of India

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ABSTRACT

The Gulf of Mannar (GoM) and the Palk Bay (PB) are two least studied marine environments located between India and Sri Lanka. The environmental and smaller plankton (0.2–20 μm) data from 30 locations in the GoM and PB during the northeast monsoon (November–February) are presented in this paper. Coastal currents during the study period was from the east to west and as a result, the PB had Bay of Bengal (BoB) waters, which was low saline (av. 28.98 ± 1.34) as compared to the GoM (av. 31.96 ± 0.58). The BoB waters caused significantly higher turbidity in the PB (av. 7.84 ± 13.59 NTU) as compared to the GoM (av. 1.76 ± 1.38 NTU). Multivariate analyses of hydrographical parameters demarcated two separate clusters in the study area clearly segregating the GoM and PB. This was mainly due to the physical barriers (Rameswaram Island, Ramsethu and Mannar Island) that inhibit the mixing of waters between the GoM and PB. The fluorescence microscopy and flow cytometry data showed a high abundance of picoeukaryotes, heterotrophic bacteria and autotrophic nanoplankton in the GoM whereas, *Synechococcus* and heterotrophic nanoplankton were higher in the PB. The picoplankton and nanoplankton carbon biomass was higher in the GoM (av. 62.2 mgC m^{-3}) as compared to the PB (av. 47.6 mgC m^{-3}). The carbon biomass in the GoM and PB was mainly contributed by nanoplankton (>70%) signifying their trophic preference in the study area. The carbon contribution of different plankton components in the GoM was autotrophic nanoplankton > heterotrophic bacteria > heterotrophic nanoplankton > *Synechococcus* > picoeukaryotes. On the other hand, heterotrophic nanoplankton was the second most dominant component in the PB followed by heterotrophic bacteria, *Synechococcus* and picoeukaryotes. The redundancy analysis (RDA) showed that picoeukaryotes, heterotrophic bacteria and autotrophic nanoplankton are positively correlated with salinity and nitrate, whereas *Synechococcus* and heterotrophic nanoplankton are positively correlated with turbidity, phosphate and dissolved oxygen. The data presented in this paper forms the first information on the relative trophic preference of various fractions of smaller plankton in Indian coastal waters.

1. Introduction

In recent decades, studies based on fluorescent microscopy and flow cytometry provided enough evidences to believe that smaller plankton (<20 μm) are abundant in estuarine and marine environments (Brown et al., 2002; Burkill et al., 1993; Garrison et al., 2000; Landry et al., 1996; Li and Wood, 1988; Li et al., 1983, 1992; Veldhuis et al., 1993). Various smaller plankton components function as primary producers, grazers as well as mineralizers thereby, they act as an integral part of the microbial plankton food web and biogeochemical processes (Brown et al., 2002; Landry et al., 1996; Veldhuis et al., 1993). These smaller plankton components consist of both prokaryotes and eukaryotes and are distributed from polar to tropical seas (Burkill et al., 1993; Campbell et al., 1997; Veldhuis et al., 1993).

The picoautotrophs in marine environment consist of prokaryotes *Prochlorococcus*, *Synechococcus* and eukaryotic plankton (Partensky et al., 1996). The smallest autotrophic picoplankton *Prochlorococcus* (0.6–0.8 μm) abundantly occurs in oligotrophic open oceans (Li, 1994, 1995; Vaulot et al., 1995). The other prokaryote *Synechococcus*, larger in size (0.8–1.5 μm), abundantly occurs in the upper well lit layers of the coastal waters (Mitbavkar and Anil, 2011; Partensky et al., 1996). Chlorophyll *a* and *b* are the predominant photosynthetic pigments in *Prochlorococcus* whereas, phycoerythrin dominates in *Synechococcus*. Eukaryotic picophytoplankton, composed of algae *Prasinophyceae*, *Pelagophyceae* and *Bolidophyceae*, contains chlorophyll *a* and abundantly occurs in the estuarine and coastal environments (Courties et al., 1994; Mitbavkar and Anil, 2011). The heterotrophic bacteria are the most abundant pico-heterotrophs in marine waters, which contribute significantly to the particulate organic carbon pool in the ocean (Ducklow, 1986; Ducklow et al., 2001). They sometimes consume even half of the marine organic production and subsequently transfer

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it to microzooplankton (Cho and Azam, 1988; Ducklow, 1986; Lugioyo et al., 2007).

Autotrophic nanoplankton contributes majority of the phytoplankton biomass and primary production in marine and estuarine environments (Detmer and Bathmann, 1997; Hickel, 1998; Madhu et al., 2010; Tarran et al., 2001; Zhang and Zhang, 2007). They are mainly composed of smaller algae and flagellates, which form the main source of the dissolved organic matter (Lugioyo et al., 2007). Heterotrophic nanoflagellates are the dominant consumers of picoplankton and they play a key role in energy flow and material cycling from picoplankton to higher trophic levels (Fenchel, 1982a,b; Reckermann and Veldhuis, 1997; Sanders et al., 1992, 2000; Tong, 1997). Heterotrophic nanoplankton consists of flagellates, small ciliates and heterotrophic dinoflagellates, which form an important component of the secondary producers in marine ecosystems (Brown et al., 2002; Reckermann and Veldhuis, 1997; Sherr and Sherr, 2007).

Studies carried out in the central and western Arabian Sea (AS), as part of the international JGOFS programme, reported a high abundance of picoautotrophs ($>10^7$ cells L^{-1}) in the surface mixed layer (Burkill et al., 1993; Campbell et al., 1997). Later, Roy et al. (2006) presented HPLC pigment data from the southwest coast of India giving more evidence of picoautotrophs as an ecologically important plankton component. However, as of now, there is no published data available on the abundance and relative trophic preference of smaller plankton in Indian Seas. Recent brief appraisal by Mitbavkar and Anil (2011) has presented the natural variation of picoplankton in some selected locations along the Indian coast. Lack of information on pico and nanoplankton is more severe in the case of the BoB and the available information from the region is limited only to the discussion shared by some researchers (Jyothibabu et al., 2008a; Mitbavkar and Anil, 2011; Naik et al., 2011). The oligotrophy caused by nutrient and light limitation is considered to be favorable for the dominance of smaller phytoplankton in the BoB (Jyothibabu et al., 2008a; Mitbavkar and Anil, 2011; Naik et al., 2011).

The AS and the BoB have contrasting hydrographic characteristics, which are mainly governed by excess evaporation over precipitation in the former region and the large freshwater flux in the latter. Though the GoM and PB are interconnected, we hypothesized that there could be noticeable differences in the distribution of picoplankton and nanoplankton in these regions. In order to evaluate this hypothesis, we quantified the picoplankton and nanoplankton community in the GoM and the PB during the northeast monsoon (January 2011) based on fluorescence microscopy and flow cytometry. The hydrographical parameters were also measured to understand the environmental setting in the GoM and the PB and its link to the distribution of smaller plankton. In this study, we mainly focused on (a) the hydrographical features relevant to the plankton distribution in the GoM and the PB and (b) distribution, abundance, carbon biomass and trophic preference of various smaller fractions of plankton in the GoM and the PB.

2. Sampling and methods

2.1. The study area

The GoM is located between the southern tip of India and the northwest coast of Sri Lanka (Fig. 1). It is a large and relatively deep gulf of the AS. On the other hand, the PB is an enclosed shallow basin, which connects the Indian mainland to the Mannar Island of Sri Lanka. The coastal currents along the Indian subcontinent have been studied by many researchers (Rao et al., 2011; Shankar et al., 2002; Shetye, 1998; Vinayachandran et al., 2005). Based on these studies, a schematic representation of the coastal currents around India during the northeast monsoon is depicted in Fig. 1b. There are two seasonally reversing coastal currents that exchange waters between the AS and BoB. The coastal currents along the east coast of India (East India Coastal Current — EICC) bring low saline BoB water into the AS during the northeast monsoon period. In contrast, the coastal current along the west coast of India (West India Coastal Currents — WICC) brings high saline AS waters into the BoB during the summer monsoon period. With the GoM and the PB having located between the AS and the BoB, their overall surface currents are driven by the seasonal reversal of WICC and EICC (Rao et al., 2011).

The PB is a large reservoir of suspended sediments brought from the BoB during the northeast monsoon period (Fig. 2a). Sediments are also brought by Rivers such as Vaigai, Vaishali, and Valryar (Chandramohan et al., 2001). The high level of sediments under the influence of a weak wave action cause deposition of sediments in the PB causing the emergence of sand banks (Chandramohan et al., 2001). The gross sediment transport into the PB is estimated to be around 0.448×10^6 m^3. The GoM receives sediments from the PB and also from rivers such as Thamiraparani, Vembar and Vaippar. However, the annual sediment flux in the PB is several orders of magnitude higher than the GoM (Rao et al., 2008; Sanilkumar et al., 2002).

The waters of the GoM are intermediate between the oceanic waters of the Arabian Sea and the coastal conditions of the PB (Rao et al., 2008). The Rameswaram (Pamban) island, submerged island chain Ramsethu (Adam's Bridge) and Mannar Island act as physical barriers between the GoM and the PB (Fig. 2b). As a result, the BoB waters significantly influence the hydrography of the PB and the AS waters influence the GoM (Murty and Varma, 1964). The resultant ecological regimes in the GoM and PB are expected to have a noticeable influence on the distribution of biological variables. The GoM is commonly known as the 'Paradise of Marine Biologists', which is a legally protected Marine Biosphere Reserve (Rao et al., 2008).

In recent decades, the GoM and PB were extensively studied for their economically important and vulnerable biological resources (Alagarswami et al., 1987; Kaliaperumal and Kalimuthu, 1993; Kaliaperumal et al., 1992, 1998; Pragasam and Dev, 1987; Rao et al., 2008 and references therein). On the other hand, it is surprising to note that as of now there is no comprehensive data available on various plankton components in the GoM and the PB. The fragmented information available is from the historical qualitative methods such as the net plankton and settling volume (Prasad, 1954, 1956, 1958; Prasad et al., 1952). The lack of quantitative information on the plankton community in the GoM and the PB force the contemporary researchers to depend on historical data to explain the current environmental setting in these regions (Rao et al., 2008). In this context, the present study is relevant as it provides advanced quantitative information on plankton components with respect to the unique hydrographical conditions in the GoM and PB.

The field sampling was carried out in January 2011 in 30 locations, 15 each in the GoM and the PB. The locations were distributed along 10 transects (5 each in the GoM and the PB), oriented perpendicular to the Indian coastline. Each transect consists of 3 locations; coastal, middle and inshore located with an approximate distance of 20 km. In each location, water samples were collected from the surface and bottom waters using 5 L Niskin samplers. Due to the difference in bathymetry of the study area, there has been a difference in bottom sampling depths in various locations (Table 1). This difference in the bottom sampling depths can introduce a certain level of error in interpretations when the bottom parameters are compared between the GoM and the PB. In order to minimize this error factor, a comparison of bottom parameters between the GoM and PB locations is avoided throughout this paper. However, it is important to note that the surface and bottom sampling depths in both the GoM and PB are actually represented within the surface mixed layer (within upper 15 m). Therefore, most of the hydrographical parameters except turbidity and dissolved oxygen show only slight differences between the surface and bottom waters (Table 2).

2.2. Climate and physicochemical parameters

In order to understand the general climatic features in the study area, air temperature recorded by an AWS installed at Mandapam