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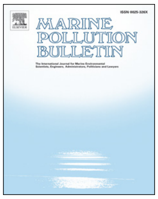

Baseline

Influence of river discharge on abundance and composition of phytoplankton in the western coastal Bay of Bengal during peak discharge period

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ABSTRACT

To understand the influence of river discharge on phytoplankton composition along western coastal Bay of Bengal (BoB), surface water samples were collected during peak discharge period. River discharge from the Ganges influences northwest (NW) coastal BoB whereas peninsular rivers (Godavari and Krishna) discharge to the southwest (SW) coastal Bay. River discharge from the Ganges is an order of magnitude higher than peninsular river resulting in low saline, less suspended matter and lower nutrients concentrations in the NW and contrasting to that was observed in the SW. ~50%of the phytoplankton were composed of *Thalassiosira* spp., *Nitzschia* spp., *Microcystis* spp., *Amphiprora* spp. and *Thalassionema* spp. in the SW whereas *Thalassiosira* spp., *Nitzschia* spp., *Chaetoceros* spp., *Merismopedia* spp. and *Peridinium* spp. in the NW. Significant variability in phytoplankton composition was observed from coast to offshore. Our study revealed that river discharge and associated physico-chemical characteristics governed the phytoplankton community along western coastal BoB.

Continental shelf zones are usually active regions of biological production (Holligan and de Boois, 1993) and they play a significant role in the net absorption of atmospheric CO_2. They provide at least 25% of global primary productivity (15–30% of the oceanic primary production), 90–95% of the world's marine fish catch, 80% of global carbonate production (Middleton and Thomas, 1992). Coastal region receives nutrients from various sources such as coastal upwelling, fresh water runoff, rainfall, cyclones/depressions, sewage from industrial and domestic sectors (Sarma et al., 2013). River runoff brings significant amount of nutrients to coastal regions and they are closely related to terrestrial ecosystem processes and human activities (Wang et al., 2015). Consequently, alterations may occur in phytoplankton composition and primary production in marine aquatic ecosystem. Phytoplankton is an important indicator of marine primary productivity, eutrophication status and fishery resources, and it determines pelagic food web. Phytoplankton organisms account for only 1–2% of the total global biomass, they are responsible for producing 30–60% of the global annual fixation of carbon on earth, thus they provide the necessary energy for consumers and ultimately, to human beings (Helbling and Villafane, 2009).

Phytoplankton abundance and community structure are highly sensitive to physicochemical variability of the ambient waters (Bandyopadhyay et al., 2017). Phytoplankton production is directly influenced by the combination of salinity, light, nutrients, temperature and microelements, whereas, dispersal, accumulation and isolation of plankton communities depend on regional circulation pattern (Sournia, 1978). Salinity stratification, driven by either heavy precipitation or river discharge, controls the vertical mixing that lead to decrease in nutrient supply to mixed layer but increases the stability of water column (Varkey et al., 1996; Prasanna Kumar et al., 2002). The composition of phytoplankton and their biomass is rather controlled by both physical processes and composition of nutrients in the photic zone (Dugdale and Goering, 1967; Ryther and Dunstan, 1971; Smayda, 1980). River plumes are generally turbid and rich in nutrients and stimulate phytoplankton growth (Lunven et al., 2005). Besides nutrient concentrations, nutrient ratios also determine phytoplankton composition in coastal waters. Based on these ratios, it is also possible to examine the limiting nutrient for phytoplankton growth (Hecky and Kilham, 1988; Dortch and Whitledge, 1992). For instance, if N:P is < 10 and N:Si < 1 indicates, nitrogen is a limiting nutrient where as if N:Si > 1 and Si:P < 3 denotes Si is a limiting nutrient (Parsons et al., 1961; Harrison et al., 1977; Healey and Hendzel, 1979; Brzezinski,

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1985; Levasseur and Therriault, 1987;). Therefore, holistic study of physical, chemical and biological processes together results in better understanding of the controlling processes on phytoplankton composition.

The Bay of Bengal (BoB) of which located on Northeastern Indian Ocean, receives significant amount of freshwater from the major rivers, such as Ganges, Brahmaputra, Godavari, Cauvery etc. (Schott and McCreary Jr, 2001; Shankar et al., 2002; Sarma et al., 2012, 2013). The excessive fresh water runoff into BoB ($1.652 \times 10^{12}\,m^3\ y^{-1}$) (Subramanian, 1993) leads to strong salinity stratification in the coastal BoB (Varkey et al., 1996). During southwest monsoon period (June--September), coastal BoB receives excessive precipitation over evaporation and river discharge peaks resulting in occurrence of seasonally the lowest salinity and the highest suspended load (Milliman and Meade, 1983; Ittekkot et al., 1991; Milliman and Syvitski, 1992; Unger et al., 2003). Sarma et al. (2012, 2013) observed relatively higher concentrations of nutrients in the southwestern region, where peninsular rivers discharge, compared to northwestern region where glacial river discharges. Sarma et al. (2013) found that N:P ratios during November to May were > 10 whereas < 1 of Si:N and contrasting to that observed during other period when coastal BoB receives freshwater from various rivers. This suggests that river discharge modifies nutrients stoichiometry in the coastal Bay that may modify coastal phytoplankton composition. The objective of the present work is to examine the influence of river discharge on phytoplankton composition in the coastal waters, phytoplankton samples were collected along the western coastal BoB at various discharge during peak discharge period.

The BoB is a unique region in terms of its geographical setting, as it is semi enclosed and opened to the Indian Ocean in the south, and semi-annual reversal in circulation due to monsoon. During the southwest (summer) monsoon season, winds blow from the southwest direction and from the northeast direction during northeast (winter) monsoon. East Indian coastal current (EICC) flows from the south to north during February to September, and flows from the north to south during October–January (Schott and McCreary Jr, 2001). The BoB receives significant amount of freshwater and suspended load from various rivers leading to strong stratification (Varkey et al., 1996). The northwestern (NW) coastal BoB receives discharge mainly from glacial river (Ganges) whereas peninsular rivers, such as Godavari, Krishna, discharge in the southwestern (SW) coastal BoB. Samples were collected both north and south of riverine outflow of major rivers, such as Godavari (GN, GS where N and S represents north and south of mouth of river), Krishna (KN, KS), Mahanadi (MS, MN) and minor rivers such as Vamsadhara (VD), and Hyadri (HD). In addition to this, samples were also collected at off Visakhapatnam (V) where no direct river discharge occurs (Fig. 1).

Samples were collected during southwest monsoon period (peak river discharge period) on board ORV Sagar Nidhi (#SN 42) during 23rd July to 10th August 2010 along the western coastal BoB. Forty five stations were occupied in nine transects (five stations along each transect). Water samples were collected using a Seabird Conductivity-Temperature-Depth (CTD)-rosette system fitted with 5 L Niskin bottles. Analysis for nutrients (nitrate, ammonium, phosphate and silicate) and dissolved oxygen (DO) were completed shortly after collection of the samples. DO was estimated by potentiometric method following Carritt (1966) using Tritrinado 835 Metrohm autotitrator. Nutrients were analyzed following standard procedures (Grassoff et al., 1983) using an auto analyzer. The analytical precision, expressed as standard deviation, was ± 0.07% RSD for DO whereas for nitrate + nitrite, ammonium, phosphate and silicate were ± 0.02, 0.02, 0.01 and 0.02 μM respectively. A 2 to 5 L of water sample was filtered through GF/F filter (Whatman) and phytoplankton biomass retained on filter was extracted with N, N Dimethyl formamide (DMF) for Chlorophyll-a (Chl-*a*) at 4 °C in dark for 12 h, and then analyzed spectrofluorometrically (Varian Eclipse Fluorescence spectrophotometer, USA) following Suzuki and Ishimaru (1990). The analytical precision for Chl-*a* analysis was ± 4%. The suspended particulate matter (SPM) was measured based on weight difference of the matter retained on 0.22 μm pore size polycarbonate filters after passing 1 L of sample.

In order to determine phytoplankton composition, 1 L of surface water sample was collected in a polythene bottle and fixed with 0.5% lugols iodine solution (Throndsen, 1978). Before identification, water samples were allowed to settle for 24 h and the supernatant was decanted and sample concentrated to 10 mL. About 0.1 mL of concentrated sample were taken in a common glass slide and observed under BX51 OLYMPUS microscope (Olympus, Japan). Phytoplankton cell counts were observed under 400× magnification. Phytoplankton was identified following procedures given by earlier investigations (Santra and Pal, 1989; Hasle et al., 1996; Baker et al., 2012). Phytoplankton diversity (H′) was calculated using the following equation (Shannan and Weaver, 1963)

$$\text{Shannon and Wiener Index } H' = -\text{SUM}\,(\text{Pi} \times \text{Log}\,(\text{Pi}))$$

Pi is n/N where n is individual number of phytoplankton and N is total number of individuals of all phytoplankton in a sample.

Spatial variations in phytoplankton were examined by hierarchical cluster analysis using the Bray-Curtis similarity index as an estimate of similarity among stations using Primer 7 software. Similarity percentage programme (SIMPER) was then used to identify the species contributing to intra-group similarity and those species responsible for dissimilarity between groups. Correlation coefficient (Spearman) among physicochemical and biological parameters was computed using the statistical software (Statistica 5.0) to understand the relation between environmental properties and phytoplankton composition.

The river discharge into the BoB peaks during summer monsoon (June to September) from all major rivers (UNESCO, 1965). The SW coastal BoB receives discharge from monsoonal rivers, such as Godavari ($1050\,m^3\,s^{-1}$) and Krishna ($823\,m^3\,s^{-1}$) whereas NW coastal BoB receives major discharge from the Ganges ($> 14{,}000\,m^3\,s^{-1}$) and minor flow from monsoonal rivers, such as Mahanadi ($683\,m^3\,s^{-1}$), Vamsadhara ($111\,m^3\,s^{-1}$) and Hyadri ($1600\,m^3\,s^{-1}$) (Sarma et al., 2012).

The influence of temperature, salinity and nutrients in the coastal BoB was explained in detail in Sarma et al. (2013), however, it is explained in brief here. The surface salinity ranged between 21.0 and 34.1 in the coastal BoB (Table 1) with low mean salinity in the NW (~25 ± 3 psu) compared to SW coastal BoB (> 31 ± 1 psu) (Fig. 2). Such low saline water in the NW region (VD, HD, MS and MN transects) was resulted from high fresh water discharge from Ganges river ($> 14{,}000\,m^3\,s^{-1}$). The salinity difference between surface and 50 m depth was up to 13 psu in the NW which was < 0.5 in the SW region (Sarma et al., 2013). The occurrence of low saline water over a large area of the northern bay was reported earlier (Krishna and Sastry, 1985; Shetye et al., 1991; Conkright et al., 1994). The upsloping of high salinity and low temperature contours from ~50 m was observed in the southwest (SW) coastal BoB (KS, KN, GS and GN transects) due to coastal upwelling (Sarma et al., 2013). The surface water temperature was ~27 °C in the SW region which is ~3 °C cooler than that of NW region due to occurrence of coastal upwelling in the former region (Fig. 2).

The SPM in the surface waters varied between 4.3 and 42.7 mg/l (Table 1) with relatively higher concentrations in the SW (23.1 mg/l) compared to NW region (11.6 mg/l) (Fig. 2). Despite river Ganges contributes ~0.2% of SPM to the world ocean sediment; low concentrations were observed in the NW region due to dominant transport of SPM towards east and south from the mouth of the Ganges. Based on the clay mineral distribution, Rao et al. (1988) suggested that the Ganges river derived sediment does not reach up to the shelf off the peninsular rivers as the major outflow of the Ganges river is eastward (Varkey et al., 1996). The enhanced SPM in the SW region was also contributed by resuspension of sediments during upwelling due to narrow shelf (Sarma et al., 2013).

Discharge is a significant source of nutrients to the coastal BoB