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Baseline

Intra-annual variations in phytoplankton biomass and its composition in the tropical estuary: Influence of river discharge

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ABSTRACT

To examine the influence of river discharge on phytoplankton composition, time-series observations were conducted at upper, middle and lower Godavari estuary during 2009. The salinity variations in the estuary were depended on freshwater discharge and tidal exchange. River discharge brought a significant amount of nutrients, however it did not induce phytoplankton bloom due to severe light limitation driven by high turbidity. Enhanced phytoplankton biomass and abundance were associated with water column stratification during moderate discharge period, suggesting that water column stability is more important than nutrients to promote phytoplankton blooms. The contribution of diatoms to the total phytoplankton abundance increased with decrease in salinity and vice versa for blue-green algae. The relationship of phytoplankton abundance with salinity and nutrients suggests that low salinity and high N:P ratio favored growth of blue-green algae, whereas high salinity and low N:P/N:Si favored diatoms. This study suggested that discharge brought modification in phytoplankton composition.

Estuaries, the transition zone between land and sea, are among the most productive marine ecosystems in the world (Badarudeen et al., 1996; Gameiro et al., 2004). They receive land driven nutrients through rivers and modify them before delivering to the adjacent ocean (Ketchum, 1967). Phytoplankton constitutes the base of the food chain (Ananthan et al., 2008) and determines the organic carbon production in an estuary (Cloern, 1996). Among various abiotic factors in estuaries, fresh water discharge and tidal activities mainly control growth and abundance of inhabiting phytoplankton population (Cloern, 1996; Sin et al., 1999). Most of the estuaries are also known to severely light limited (Pennock, 1985; Lehman, 1992; Cole et al., 1992; Irigoien and Castel, 1997; Sarma et al., 2009). Land driven nutrients support rich phytoplankton production in estuaries (Crouzet et al., 1999; Neill, 2005). However, it has been noticed that while nitrogen is limiting in the coastal waters, phosphorous is more limiting in fresh and estuarine waters due to biological uptake and chemical precipitation (Fisher et al., 1992; Neill, 2005). In contrast, inorganic ammonium (NH_4^+) plays a significant role in the phytoplankton growth in polluted water (Crouzet et al., 1999). Even the river is not polluted, changes in river discharges are known to affect the salinity, nutrient load, and stratification as a resulting modification of estuarine and coastal biogeochemical processes, however, and the evidences are rather sparse (van Bennekom, 1981; Admiraal et al., 1990).

Phytoplankton biomass accumulation and bloom formation in estuaries depends not only on their productivity, but also biotic factors such as grazing and abiotic factors such as washout, resuspension and deposition (Underwood and Kromkamp, 1999). Net increase in phytoplankton is only possible when net gain (through reproduction and recruitment) exceeds the losses due to death and grazing. As low river inputs usually associated with long water residence times that allow accumulation of phytoplankton and development of blooms (Gameiro et al., 2004). Phytoplankton communities consist of several taxonomic groups and the occurrence of various groups is depended on several physico-chemical characteristics of the water column (Roy et al., 2006). Seasonal variations in primary production are depend on the nutrient availability, light conditions and temperature (Jouenne et al., 2007). The species composition, biomass, relative abundance and their spatial and temporal distribution of this aquatic biota are an expression of the environmental health or biological integrity of a particular water body (Ekwu and Sikoki, 2006). In order to understand the variability in marine ecosystem, it is necessary to quantify the phytoplankton biomass as well as community composition and examine the controlling factors on diversity of phytoplankton composition in the system.

Monsoonal estuaries are unique compared to other estuaries with

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reference to freshwater discharge pattern (Vijith et al., 2009; Sarma et al., 2009, 2012b). Discharge into the monsoonal estuaries is concentrated during short-span of time and entire estuary filled with freshwater with no vertical gradients in salinity. In contrast, monsoonal estuaries contain relatively high saline water with moderate stratification during no discharge period and high stratification is noticed during moderate discharge periods (Acharyya et al., 2012). Therefore, monsoonal estuaries experience wide range of salinity and stratification patterns within an annual cycle. Hence, all these changes determine the phytoplankton biomass and community composition in the monsoonal estuaries. Several studies have been conducted in the recent years in the Godavari estuary (Sarma et al., 2009, 2010, 2011, 2012; Acharyya et al., 2012) and also various estuaries in India about phytoplankton diversity, for instance, Cochin Back Waters (Madhu et al., 2007), Mahanadhi (Naik et al., 2009), Hooghly estuary (De et al., 1991) and Mandovi estuary (Pednekar et al., 2011). Decrease in biomass and abundance was found during the peak discharge period and increased during dry and moderate discharge periods in the Mahanadi and Hooghly estuaries. However, limited integrated studies have been conducted on phytoplankton composition and their relations to the environmental properties in the Indian estuaries. The purpose of this study is to investigate the taxonomic composition of estuarine phytoplankton assemblages and examine the influence of hydrographic properties on them in the largest monsoonal estuary, the Godavari, India.

The Godavari estuarine system is situated around 16°15′ N and 82° 5′ E covering 330 km^2. The Godavari is one of the largest rivers in India with a basin of 3.1×10^5 km^2 and 25 tributaries and an annual discharge of 105 km^3 (Rao et al., 1975). Among the 60 largest rivers in the world, Godavari River ranks 34th and 32nd in terms of catchment area and water discharge respectively (Ludwig, 1996; Gaillardet et al., 1999). Average annual rainfall in the Godavari river basin is 1512 mm y^{-1}, indicating dry basin climate. According to Central Pollution Control Board (CPCB, 1995), > 75% of rainfall occurs during summer monsoon period (June–September) and it is the sole source of water in the Godavari River. This is the largest peninsular river, which traverses about 1480 km before opening into the Bay of Bengal. Godavari River serves freshwater for local agricultural activities and domestic use. Near the town Rajahmundry at Dowaleiswaram, the river flow to the estuary is controlled by a dam. After emerging from the dam, Godavari divides into two major distributaries. The eastward flowing major tributary is Gautami-Godavari, while the other flowing southwards is Vasistha-Godavari. The latter has relatively minor flow compared to the former tributary; hence, the sampling was conducted in the Gautami-Godavari. To understand phytoplankton composition, diversity and controlling factors in the Godavari estuary, three stations have been selected representing freshwater zone (upper estuary), brackish water zone (middle estuary) and seawater zone (lower estuary) (Fig. 1). Samples were collected at monthly interval from January to December 2009 covering various discharge periods.

Temperature, salinity was measured using a portable Conductivity–Temperature–Depth profiler (CTD; SBE-19 plus, Sea- Bird Electronics, USA). Surface water samples were collected using a 5 L Niskin bottle for chlorophyll-*a* (Chl-*a*), nutrients and Suspended Particulate Matter (SPM). Nutrients samples were analyzed following the standard spectrophotometric procedures (Grasshoff et al., 1983). The accuracies of nitrate + nitrite (NO_3 + NO_2), ammonium, phosphate and silicate were ± 0.2, 0.2, 0.1 and 0.2 μM, respectively. Nearly 150–500 ml of the water sample was filtered through glass fiber filter (GF/F; 0.7 μm; Whatman) and Chl-*a* retained on the filter was extracted with *N,N*-dimethyl formamide at 4° C in dark for 24 h and fluorescence was measured using spectrofluorophotometer (Eclipse Varian Instruments, UK) following Suzuki and Ishimaru (1990). The signal frequency band (Fb) was recorded in the excitation and emission wavelength of 445 nm and 665 nm respectively. The analytical precision for Chl-*a* analysis was ± 4%. All these analyses were completed within 12 h of sampling at the shore-based laboratory established on the bank of the river. Discharge data were obtained from the Dam authorities at Dowleiswaram.

In order to determine phytoplankton composition, one liter 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, 1993; Tomas, 1996; Baker, 2012).

Diversity, dominance, evenness and richness of the data were under taken using software Primer 5.2.8 (Clarke and Warwick, 1994).

Phytoplankton diversity (H') was calculated using the following equation.

Shannon and Wiener Index H' = -SUM (Pi x Log (Pi)) (Shannon and Weaver, 1998).

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

Dominance of phytoplankton was calculated using the following equation.

Index of dominance = SUM (Pi^2) (Simpson, 1949).

Richness was calculated using the following equation.

Margalef Index D' = S – 1 / log N (Margalef, 1957).

Where S = number of species and N = number of individuals.

Evenness was calculated using the following equation (Pielou, 1966).

Evenness index J' = H'/ Log S (Pielou, 1966).

H = Shannon Index of general diversity; S = Number of species.

Seasonal and spatial variations in phytoplankton were examined by hierarchical cluster analysis using the Bray-Curtis similarity index as an estimate of similarity among months and stations using Primer 5.2.8 software. Canonical Correspondence Analysis (CCA) was used to assess associations between phytoplankton and environmental variables (using past3 software). The matrix with biotic data was constructed only with species abundant in at least one sample. 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. Grapher (version 3) was used for the 2 dimensional graphical representations of the data.

The monthly mean river discharge into the Godavari estuary varied from near zero during No Discharge Period (hereafter called as NDP) (January to May) to < 120 $m^3 s^{-1}$ during Moderate Discharge Period (MDP) (June, October–December) and > 500 $m^3 s^{-1}$ during Peak Discharge Period (PDP) (July to September; Fig. 2). The water temperature during the study period varied between 25.9 and 32.4° C in the estuary and minimum was observed during the winter while maximum in summer (Fig. 2). The salinity in the upper estuary ranged from 0.05 to 16.9 whereas 0.1 to 30.9 and 0.1 to 33.4 in the middle and lower estuary respectively (Fig. 2). SPM varied between 22.0 and 145 mg. l^{-1} and maximum was observed with PDP (Fig. 2).

Ammonium concentrations in the entire estuary ranged between 0.16 and 2.98 μM with relatively high concentration in the upper estuary and decreased towards lower estuary. Relatively higher concentrations were noticed during NDP and PDP (Fig. 3). The peak in nitrate, phosphate and silicate concentrations was associated with initial pulse of discharge and relatively higher in the upper and decreased towards lower estuary. Significant increase in nitrate concentrations was observed associated with PDP up to 115.1 μM in the upper estuary while it was ~20–40 μM in the middle and lower estuary (Fig. 3). The mean concentration of Dissolved Inorganic Nitrogen (DIN) (Nitrate + Nitrite + Ammonium), Dissolved Inorganic Phosphate (DIP) and Dissolved Inorganic Silicate (DISi) were comparatively higher in the upper