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Nutrient stoichiometry and freshwater flow in shaping of phytoplankton population in a tropical monsoonal estuary (Kundalika Estuary)

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ABSTRACT

The present study aimed to understand the role of freshwater flow and physico-chemical parameters in influencing the phytoplankton community shift and thereby helping in balancing the ecosystem. The Kundalika estuary (KE) is a semi-diurnal tropical monsoonal estuary. Strong upstream currents during monsoon as assessed through a 2D numerical model influenced the succession of marine, estuarine and freshwater phytoplankton species depending on the extent of freshwater influx and its distribution in the estuary. Nitrogen and phosphorus played a pivotal role in regulating the phytoplankton growth and their proliferation. Distribution of different phytoplankton species in accordance to salinity and nutrient content was clearly observed. Among the four major classes (Diatoms, Dinoflagellates, Chlorophytes and Phytoflagellates) occurring in the KE, diatoms occupied a wide salinity range. Large-scale shifts in phytoplankton biomass and composition were associated with river run-off during monsoon. Phytoflagellates and Chlorophytes restricted their abundance to relatively high nitrogen level zones. Canonical Correspondence Analysis (CCA) between environmental variables and dominant taxa of phytoplankton indicated the influence of salinity on phytoplankton distribution in the estuarine precinct. Thus the freshwater influx in the KE played a major role on phytoplankton species diversity and its bloom potential.

1. Introduction

Estuaries are transitional zones between the freshwater fronts and the coastal sea with strong gradients in environmental variables such as salinity and nutrients (Lohrenz et al., 1990). The spatial distribution of salinity in an estuary is a useful indicator of the system physical condition as it represents the net effect of numerous complex processes, such as freshwater inflow, tidal range and degree of turbulence (Eaton, 2007) which in turn have a very large impact on the biology including the composition of phytoplankton especially the stenohaline types as they suffer osmotic stress upon salinity changes (Lionard et al., 2005).

Another potentially important factor that can regulate an estuarine phytoplankton community and biomass is nutrients - especially Nitrogen (N) and Phosphorus (P) which enter estuaries through land runoff, domestic waste and industrial effluents (Paerl, 1988; Nixon, 1995; Spatharis et al., 2007) and are frequently referred as key factors in regulating the phytoplankton growth and its assemblages (Rhee, 1978; Domingues et al., 2011; Ganguly et al., 2013). Natural as well as anthropogenic activities influence the N:P ratio which under other favourable environmental variables can trigger an algal bloom with single species dominance thereby hampering the ecosystem balance (Hallegraeff, 1993).

Phytoplankton growth, distribution and diversity are also affected by changing hydrodynamic conditions of estuaries. Thus for example, river freshwater discharge directly controls phytoplankton via flushing and the advection of cells from the estuary to the ocean and vice versa. When the N:P ratio is favourable, bloom development requires the net growth of phytoplankton cells to be faster than the hydraulic residence time (Alpine and Cloern, 1992). Increased flushing may prevent the accumulation of nutrients as well as biomass despite a high growth rate thereby preventing phytoplankton blooms. Suspended solids which are an outcome of

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land runoff or re-suspension of bottom sediments also play a prominent role in the functioning of phytoplankton through depressed photosynthesis (Cloern, 1987; Oliver et al., 2010; Shen et al., 2011).

Estuaries in the Indian sub-continent under the influence of the Indian Summer Monsoon (ISM) during the month June to September (Vijith et al., 2009) receive high river runoff facilitating dilution and flushing of contaminants out of the estuary thereby cleansing these water bodies on an annual cycle (VishnuRadhan et al., 2015). The Kundalika Estuary (KE) on the west coast of India is one among them which is a semi-diurnal estuary with a permanent opening to the Arabian Sea permitting constant mixing of fresh- and sea-water through efficient tidal exchanges (Dinesh Kumar et al., 2001).

Along the Indian west coast, the monsoonal effect on phytoplankton has been studied in the Mandovi-Zuari estuarine system (M-Z estuary) (Patil and Anil, 2011, 2015; Parab et al., 2013) and Cochin Estuary (CE) (Madhu et al., 2007) and reported the occurrence of monsoonal phytoplankton bloom due to decrease in salinity and high nutrient flux through land run-off in these estuaries. Apart from the movement and mixing of contaminants by Dinesh Kumar et al., 2001 and the physico-chemical characteristics by Jadhavar et al., (2013), no other study in the KE is available in the published literature with information on phytoplankton assemblages largely lacking. Here we report the distribution of phytoplankton and changes in their composition with seasonal variations in the river discharge, changing salinity quantified using 2D numerical model and nutrient stoichiometry.

2. Materials and methods

2.1. Study area

Kundalika (Lat. 18°27″ to 18°29″ N and Long. 72°43″ to 73°10″ E) is one of the major rivers along the central west coast of India that originates in the Sahyadris at an altitude of 820 m near Hirdewadi and meets the Arabian Sea near Revdanda port in Raigad District of Maharashtra. (Fig. 1a). Revdanda port is an important fish landing centre of this coast and provides shelter for many fishing boats. An industrial cluster developed on the bank of Kundalika River at Dhatav-Roha which is towards the south houses about 40 chemical units manufacturing diversified products and bulk chemicals (MPCB, 2009). These industries release their wastewater into the river through some point sources in the inner estuary. The estuary is also the recipient of domestic wastewater - largely untreated through various point sources from Roha city which is developing as well as extending (MPCB, 2009). These anthropogenic releases and other activities such as shipping and fishing would eventually lead to changes in the ecosystem functioning of the KE.

This region experiences a tropical warm, humid climate throughout the year with temperature range between 25 and 31 °C. The Kundalika is a tide dominated estuary which is semi-diurnal in nature except during the periods of high monsoonal river discharge when the estuary is freshwater dominated. Though the tidal range is generally more than 2 m, the limit of tidal flooding is ~30 km (Dinesh Kumar et al., 2001) due to steep bed gradient of the shallow estuary with the maximum depth of 10 m (Fig. 1b). Seasons in KE have been classified on the basis of rainfall received during Indian Summer Monsoon (ISM). The monsoon season (wet season) with high rainfall during June to September (min-max 154.2–1418.6 mm, av. 711.6 ± 460.5 mm) and river discharge (Fig. 2) is followed by the postmonsoon season - the inter-phase of wet and dry season and then the premonsoon season (dry season) with least rainfall and river discharge. It is therefore expected that under monsoonal influence, the wastewater released into the estuary is quickly transported to the sea by prevailing high flushing rate and turbulence and the estuary is freed of accumulated contaminants on an annual cycle.

During the present study, six stations (K1 to K6) were sampled along the estuary with stations K1 and K2 located in the coastal water and at the mouth of the estuary respectively. Stations K3 and K4 were in the middle estuary and stations K5 and K6 were situated in the upper estuary in the vicinity of the effluent discharge location of the industrial estates. The distance between two consecutive stations was approx. 5 km (Fig. 1a).

2.2. Methodology

The sampling was conducted at six locations covering from coastal to freshwater region of KE during March (Premonsoon), September (Monsoon) and December (Postmonsoon) of 2014. Annual rainfall data for the region was obtained from Indian Meteorological Department (IMD), Pune and river discharge from Central Water Commission (CWC), Nasik. To define monsoonal estuary in the Indian context, two parameters were introduced viz., $\eta_R = Ra/Ve$; where Ra is the volume of total annual run-off (m^3) and Ve is the volume (m^3) with respect to mean sea level in the estuary. While $\eta_T =$ Maximum monthly run-off/Average monthly run-off by which were used to determine the flushing characteristics (Vijith et al., 2009). In order to assess the monsoonal influence on the physico-chemical and biological parameters in the KE, the currents (combined effect of tidal and riverine flow) were generated using 2D numerical model, TIDAL. In-situ observations of tide and current were made in the estuary by a seaguard tide gauge and RCM11 (Norway) current meter recorder respectively from 29/11/2014 to 11/12/2014, which were used to calibrate and validate the model. Atmospheric forcing due to wind stress was neglected in the study. The average river discharge rates of 0 m^3s^{-1}, 1.2 m^3 s^{-1} and 0.7 m^3 s^{-1} were given as model inputs for premonsoon, monsoon and postmonsoon respectively.

Surface and near bottom water samples were collected using 5L capacity Niskin water sampler (Germany). Temperature was measured by hand held thermometer with an accuracy of ±0.1 °C. Salinity was determined by Mohr titration (Grasshoff et al., 1983). Total Suspended Sediments (TSS, mg l^{-1}) was determined gravimetrically by filtering the sample through a Millipore membrane filter (pore size, 0.45 μm) and after drying at 70 °C for 6–8 h (APHA, 2005). Dissolved Oxygen (DO) was fixed immediately after collection and measured by the Winkler method (Grasshoff et al., 1983). Nutrient nitrite (NO_2), nitrate (NO_3), phosphate (PO_4) were analyzed within 6 h of collection by following Strickland and Parsons, 1972 and Grasshoff et al., 1983. Measurement of ammonia (NH_4) as the sum of ionized ammonia (NH_4^+-N) and unionized ammonia (NH_3-N) was carried out following protocols of Grasshoff et al., (1983); USEPA, 1985; Batley and Simpson 2009.

For the estimation of Chlorophyll *a*, 500 ml of water sample was filtered through GF/F filters (0.7 μM) and extracted with 90% acetone for 24 h in the dark at 4 °C. The measurement of chlorophyll *a* was carried out by using a Turner Trilogy fluorometer (Model 7200) following the standard procedure (UNESCO, 1994).

For qualitative and quantitative studies of phytoplankton taxonomy, 500 ml of water sample was fixed with Lugol's iodine (1%; w/v, acidic solution prepared using acetic acid glacial). Samples were allowed to settle for 48 h in dark and were concentrated to 5–10 ml by carefully siphoning the top layer of the sample with silicon tubing, one end of which was covered with 10 μm Nitex mesh. Using a Sedgwick Rafter (UK) chamber, 1 ml of each concentrate was counted under compound microscope (400 X magnifications) and identified up to possible lowest taxonomic level based on the standard taxonomic keys (Subrahmanyan, 1946; Desikachary and Prema, 1987; Desikachary, 1989; Tomas, 1997).