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Baseline

Loricate ciliates as an indicator of eutrophication status in the estuarine and coastal waters

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ABSTRACT

Owing to the environmental sensitivity of ciliate species, the monitoring and assessment of these communities can indicate the health of the aquatic environment. Sampling for loricate ciliates was carried out during different seasons at three different locations in the estuarine and coastal waters of Kochi, Southwest coast of India. The loricate ciliate community comprising of 27 species belonging to 10 genera revealed significant differences among the three sampling locations. The maximum numerical abundance and less species diversity of loricate ciliates were recorded at the estuarine locations whereas the minimum abundance and more species diversity were encountered in the coastal waters. Multivariate statistical analyses revealed that *Tintinnopsis beroidea* and *Tintinnopsis uruguayensis* were correlated positively with nutrients in the estuarine environment, which receives large amount of anthropogenic inputs. Thus, we propose that these two loricate ciliates may be considered as a potential bioindicator of eutrophication status in marine ecosystems.

The monitoring of bio-indicators are an ideal tool to assess the impact of pollutants on the environment before the impacts are noticeable (Van Gestel and Van Brummelen, 1996). It is progressively being recognized in recent years that ciliates have numerous advantages in evaluation of marine ecosystems (Xu et al., 2009; Tan et al., 2010; Jiang et al., 2011). They are a significant component of microzooplankton communities and represent a crucial link between the microbial fraction and the larger grazers (Pierce and Turner, 1992). It is reported that some ciliates can tolerate extreme levels of environmental conditions (Xu et al., 2011a, 2011b). Recently, planktonic ciliates have been used as indicators for water quality and health status of aquatic ecosystems because of their rapid response to environmental changes (Feng et al., 2015; Jiang et al., 2011, 2013; Xu et al., 2009, 2016).

Assuming that ciliates reflect the water quality of an area, we focused our study on the loricate ciliate communities of the estuarine and the adjacent coastal waters of Kochi. The Kochi estuary is the most productive estuary along the southwest coast of India which receives runoff from six rivers (Periyar, Muvattupuzha, Pamba, Manimala, Meenachil, and Achancoil), joins the southeastern Arabian sea through two barmouths (Jyothibabu et al., 2006; Revichandran et al., 2012). The six rivers have become discharge trenches for the industrial and domestic wastes which are important sources of nutrients entering the Arabian Sea (Balachandran et al., 2003). It is important to notice that over the past five decades Kochi estuary has undergone major changes leading to alterations in the population and structure of the trophic webs which has transformed the estuary from an autotrophic to a highly heterotrophic system (Menon et al., 2000; Thottathil et al., 2008; Gupta et al., 2009). Recent investigations have reported that the Kochi waters suffer from eutrophication due to the high anthropogenic nutrient loading (Bhavya et al., 2016). In this context, it is significant to carry out an investigation of the loricate ciliate populations of this complex ecosystem. Under our ongoing project on "Ecosystem Modelling", we monitored spatially and temporally the loricate ciliate assemblages in the estuarine and coastal waters of Kochi to understand the relationships between water quality parameters and their assemblages and finally to verify the hypothesis if loricate ciliates could be used as an bioindicator for water quality.

Surface water sampling for loricate ciliates was carried out seasonally (summer inter-monsoon (SIM), summer monsoon (SM) and fall inter-monsoon (FIM)) in 2015 at three locations (A, B and C), during the spring and neap tide as shown in Fig. 1. Location A and B, located at the barmouths (approx. depth 4.5 m) are highly eutrophic sites. Location C, located at 10 m depth in the coastal waters is a moderately eutrophic site. Surface water samples were collected and analyzed for the various physical-chemical and biological parameters (sea surface temperature (SST), salinity, pH, dissolved oxygen, nitrite, nitrate, ammonia, phosphate, silicate, dissolved organic carbon and chlorophyll-a) following standard protocols (Carrit and Carpenter, 1966; Grasshoff,

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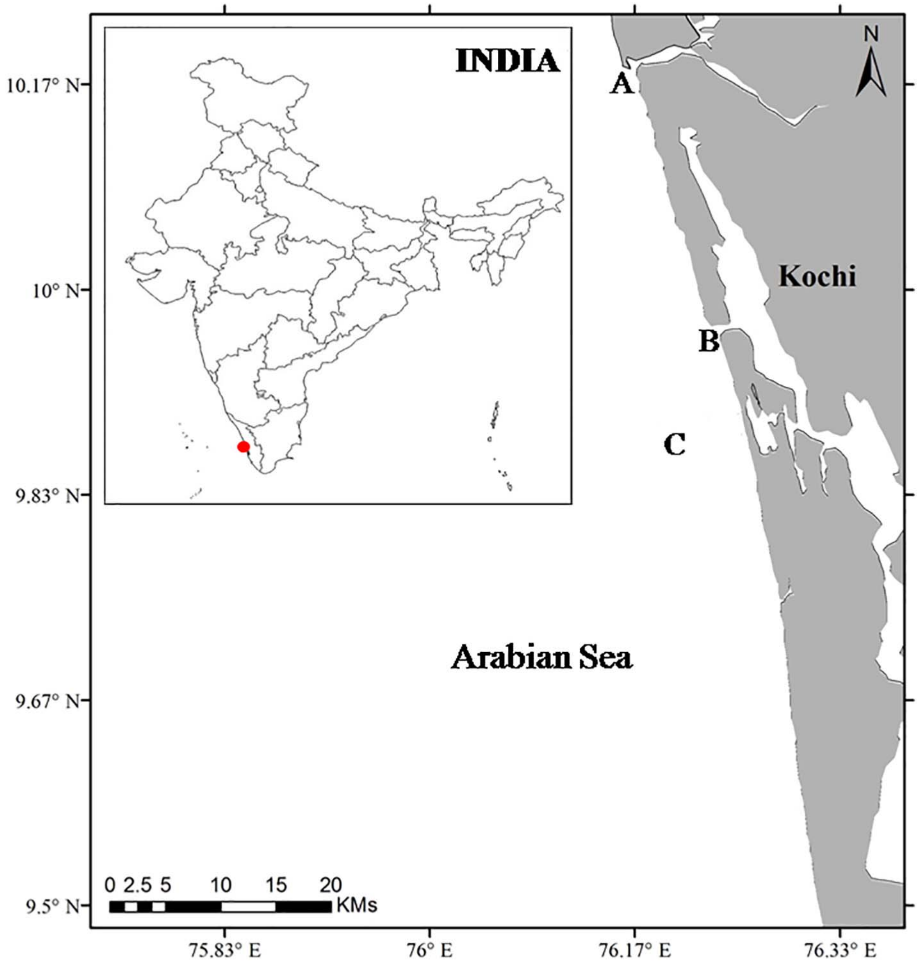

Fig. 1. Map showing the sampling locations (A, B and C) in the estuarine and coastal waters of Kochi, Southwest coast of India. A & B are estuarine locations which are highly eutrophic sites whereas C is a coastal location at 10 m depth which is a moderately eutrophic site.

1999; Spyres et al., 2000). The identification of loricate ciliates was done following published references (Hada, 1938; Corliss, 1979).

To elucidate the community structure of loricate ciliates, the diversity indices [viz., Shannon-Weiner species diversity index (H′), Margalef's species richness (d) and Pielou's Evenness index (J')] were calculated. Cluster analysis and non-metric multidimensional scaling (NMDS) was done by Bray-Curtis similarity index to investigate the similarity between locations using the PRIMER (v 6.0) statistical software. The relationships between loricate ciliate communities and environmental variables were examined by canonical correspondence analysis (CCA) from the log transformed data ($\log_{10}$ (X + 1), X = abundance of loricate ciliates) using the PAST (v 3.16) software.

The summarized physico-chemical and biological variables at the three sampling locations (A, B and C) are shown in Table 1. Most of the variables showed clear seasonal differences. The SST ranged between 24.56 and 32.20 °C, reaching the highest in the SIM (av. 31.99 ± 0.24) and the lowest in the SM (av. 25.70 ± 0.79). Lower temperature in the surface waters during the SM was due to the intense rainfall and upwelling phenomenon. The temperature was slightly higher in the spring phase than the neap phase during the SIM and FIM except for the SM. The pH was moderately alkaline (pH 7.13–8.27) during the study period, showing maximum during the SIM (8.24 ± 0.04) and minimum during the SM (av. 7.21 ± 0.08). The spatial variation of pH did not show much variation for the tidal phases during either season. Salinity showed spatial and temporal variations, ranging from 1.15 to 35.34 with high salinity during the SIM (av. 33.84 ± 0.27 and 34.0 ± 0.11 in spring and neap phases, respectively) at location C. Low salinity was observed during the SM (av. 3.24 ± 1.76 and 3.15 ± 0.35 in spring and neap phases, respectively) at location B. A clear drop in salinity was noticed at the estuarine locations (site A and B) as compared to the coastal location (C) as a result of the heavy freshwater influx during the SM. The maximum average value of dissolved oxygen (DO) was recorded during the SIM (av. 7.97 ± 0.60 in neap phase) and the minimum during the FIM (av. 3.01 ± 0.20) in neap phase. Concentration of DO ranged from 2.60 to 8.83 mg l^{-1}, with higher concentrations at the estuarine locations during all the seasons. The higher levels of DO at the estuarine locations (A and B) might be due to the high algal biomass in this nutrient rich system (Jyothibabu et al., 2006, 2008). The nutrient concentrations were higher during the SM and FIM, except for NO_2 and PO_4 in the estuarine locations. The dissolved inorganic nitrogen (DIN) which is the sum of all the inorganic nitrogenous species, ranged from av. 1.7 μM to 22.87 μM, reaching maximum during the SM at the estuarine location (A) and lowest during the SIM at the coastal location (C) in neap phase. The SiO_4 levels were higher during the SM at location B (87.09 ± 6.65 μM) followed by location A (87.05 ± 8.60 μM) during the FIM and lowest during the SIM at the coastal location C (2.7 ± 0.76 μM). The PO_4 concentrations in the estuarine locations were higher and ranged between 0.69 μM and 2.64 μM. Irrespective of the seasons, the concentrations of all the nutrients in spring and neap phase were higher at the estuarine locations as compared to the coastal location, which is mainly due to the discharge of untreated industrial and domestic sewage effluents and agricultural wastes by the various rivers into the Kochi estuary (Qasim, 2003 Balachandran et al., 2005). The elevated nutrient concentrations at the estuarine locations might have promoted the intensive growth of primary producers (Jyothibabu et al., 2006), and hence the