Dissolved organic nutrients in the Pichavaram mangrove waters of east coast of India

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Spatial and temporal analytical measurements of organic nutrients were made in the Pichavaram mangrove ecosystem (south east coast of India) to understand the dissolved organic nutrient dynamics. Monthly measurements of physical parameters and dissolved organic nutrients were made at several locations at daytime during low tides. High concentrations of DOC and DON were found in monsoon and DOP in summer. The distribution and dynamics of dissolved organic matter have been regulated by the monsoonal fresh water discharge from the adjacent sources. However, the microbial mineralization induced by summer temperature regulates the nutrient biogeochemical processes and also control the biological productivity. In general, the mangrove ecosystem supplies considerable loads of nutrients to the oceans than the river systems and regulate the global nutrient biogeochemical cycles.

Key words: Mangrove, DOC, DON, DOP, Outwelling, Pichavaram

1. Introduction
Mangrove forests are the highly productive ecosystems of the tropical environments.1 Mangroves, the backbone of the tropical ocean coastlines, are far more important to the global ocean's biosphere than previously thought. A team of researchers has noted that the woody coastline-dwelling plants provide more than 10% of essential dissolved organic carbon (DOC) that is supplied to the global ocean from land. Robertson et al.2 reported considerable fraction up to half of the primary productivity could be transported from the mangrove creeks to the adjacent ocean. This regulates the biogeochemical cycling of nutrients and trophic food web.3 The coastal upwelling is the natural mechanism which brought nutrient rich deep water to the surface and increases the primary production and affects the global biochemical nutrient cycles. However, no substantial information is available from all over the globe and this process is confined to few regions. Some mangroves act as both source and sinks for nutrients (Australian Hinchinbrook mangroves4), some supply nutrients to adjacent sea (Rookery Bay mangroves, Florida5) and some takes up nutrients (Terminos Lagoon mangroves, Mexico6). Detailed information about the dynamics of dissolved organic nutrients is available from various Australian, North American and South American mangroves.7 The information on the dissolved organic nutrient dynamics from the Indian mangroves is very scarce. According to Dittmar and Lara7, mangrove environments supply large amounts of nutrients to the oceans than the river systems. However, a comprehensive study has not been done on any Indian mangrove to characterize the importance of Indian mangrove nutrients to the global biogeochemical cycles. Hence, a detailed annual study has been conducted on the Pichavaram mangrove of south east coast of India to understand the dynamics of dissolved organic nutrients.

2. Materials and Methods
2.1 Study Area
The Pichavaram mangrove forest (11° 25’ N and 79° 47’ E) is a shallow lagoon and is in between the Vellar and the Coleroon estuarine complexes with total area of 1100 ha (Fig. 1). It has 51 islets, ranging in size from 10 m² separated by intricate waterways, that connect the Vellar estuary in north and the Coleroon estuary in south.8 The Coleroon estuary part is largely dominated by mangroves, while the Vellar

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Fig. 1—Map of the Pichavaram mangrove (southeast Coast of India) with sampling locations

estuary is dominated by mud flats. Tidal neritic water enters the Pichavaram mangrove through a small direct connection with the sea at Chinnavaikkal and estuarine waters through the two adjacent river systems. *Avicennia marina* is the dominant mangrove species followed by *Rhizophora apiculata*, *R. mucronata*, *Bruguiera cylindrica* and *Exocoecaria agallocha*. In comparison to other mangroves of India, tides in the Pichavaram mangroves were semi-diurnal and vary in amplitude from 0.15 to 1 m$^3$ and the tidal amplitude of the Pichavaram is very low, MSL is about 0.34 m, MHHW is about 0.67 m and MLHW is about 0.03 m. Mangrove soils are composed of fine sand (45%), with a mixture of clay (25%), silt (15%) and coarse (15%) sand.

2.2 Methodology

Since the water column is vertically mixed, only one large i.e. 500ml of surface water sample was collected from each location using pre-washed polyethylene bottles from the mangrove environment from July 2003 to June 2004. Each water sample was
divided into two parts: one aliquot was used to measure temperature, dissolved oxygen (DO) and salinity by using Thermometer, Thermo Orion DO Probe (080510) and a hand-held Refractometer and the second aliquot (250 ml) was filtered with Whatman 0.47µm GC/F filter paper for nutrient analysis. Water aliquots for dissolved organic nitrogen (DON) and dissolved organic phosphorus (DOP) were poisoned with HgCl$_2$ to a sample concentration of 100 mg l$^{-1}$ and kept frozen in polyethylenebottles. Samples for the determination of dissolved organic carbon (DOC) were adjusted after filtration to pH=2 with 1 N HCl and kept frozen in precombusted sealed ampoules.

DON was determined by wet oxidation using persulphate as oxidizing reagent.\textsuperscript{11} DOP was calculated as the difference between total dissolved phosphorus (TDP) and reactive soluble phosphorus (SRP). TDP was determined with hot persulphate oxidation method\textsuperscript{12} and SRP was analysed by ascorbic acid reduction method.\textsuperscript{13} DOC was measured by high-temperature catalytic oxidation with a Shimadzu TOC analyzer.\textsuperscript{14} Duplicate sub-samples of each aliquot were analysed. Analytical precision was ±5% for all nutrients.

Temporal and spatial variations in nutrient concentrations relation to salinity were examined using regression models using SPSS.\textsuperscript{11} Level of significance was P = 0.05.

3. Results and Discussion

The lagoonal Pichavaram mangrove ecosystem entails the exclusively native process within the catchment sector could cause strong influence over the inorganic and organic nutrient dynamics. The concentration levels of dissolved organic nutrients and the physical driving parameters of the Pichavaram water are given in Table 1. Inter-seasonal variability in temperature and salinity mimics the evapotraspiration and freshwater discharge patterns for this coastal ecosystem with highest temperature and salinity in pre-monsoon and summer and lowest water temperature and salinity in monsoon.\textsuperscript{9} The levels of DO in the mangrove water are a function of the biological respiration. In summer, due to high temperature, biological activities rates would be doubled, resulting in the consumption of a substantial amount of DO. Where as in monsoon, the rapid circulation of water would facilitate the dissolution of atmospheric oxygen in the water column, thus increase the DO levels. High salinity controls the biological activities by reducing the availability of nutrients. High temperature increases salinity of water by evaporation and reduces DO levels due to increased rates in the biological function of the ecosystem (Fig. 2). Thus, it is clear that the eco-physiology of Pichavaram is largely controlled by the seasonal factors.

Highest levels of DOC and DON were observed in post-monsoon and DOP in summer. The spatial and temporal variability in the nutrient distribution of the Pichavaram is driven by both internal and external factors. Monthly variations in these three parameters are shown in Figure 2. Seasonal variations in nutrient levels may also be due to partly influence by seasonal patterns in mangrove litter fall and decomposition rates.\textsuperscript{16} High temperature favors the microbial mineralization in summer, thus considerable levels of DOC, DON and DOP were found in post-monsoon and summer (Table 1 and Fig. 3). However, rapid increase in DOP levels in summer than DOC and DOP may be because of both in-situ microbial processes and ex-situ sources. High nutrient inputs from adjacent agricultural fields and aquaculture ponds\textsuperscript{17} are likely responsible for the high levels of nutrients. Alongi et al.\textsuperscript{18} measured microbial nutrient mineralization rates in this mangrove sediments to the depth of 1 m implying high rates of nutrients regeneration and lateral transport via groundwater. Prasad et al.\textsuperscript{19} reported that in this ecosystem inorganic nutrient dynamics is driven by the seasonal factors and it is further aggravated by the increasing anthropogenic activities.

Spatial variability in organic nutrients for monsoon and summer is shown in Figure 4. Slight to moderate seasonal variability among the seasons has been observed among three different regions of the Pichavaram. On an over all scale, the dissolved organic nutrients levels in the interior mangrove zone were higher followed by the Vellar and Coleroon estuarine zones. This may be because of intensive microbial mineralization processes in the interior mangrove soils,\textsuperscript{18} this probably tends to supply nutrients from the reserved bed sources. Random variabiity has been observed between the two seasons for the mangrove zone. However, this scenario is different for the two estuaries i.e. in the Vellar estuary all the three nutrients were in higher concentrations in
Table 1—Mean nutrient concentration (±SD) in the Pichavaram waters.

<table>
<thead>
<tr>
<th>Season</th>
<th>Temp (°C)</th>
<th>DO (mg/l)</th>
<th>Salinity (%)</th>
<th>DOC (µM)</th>
<th>DON (µM)</th>
<th>DOP (µM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-monsoon</td>
<td>29.9 (1.75)</td>
<td>5.63 (0.54)</td>
<td>46.7 (7.74)</td>
<td>51.59 (20)</td>
<td>46.32 (12.43)</td>
<td>0.39 (0.12)</td>
</tr>
<tr>
<td>Monsoon</td>
<td>25.9 (1.65)</td>
<td>5.93 (0.59)</td>
<td>22.0 (3.14)</td>
<td>70.23 (19.31)</td>
<td>52.77 (13)</td>
<td>0.83 (0.14)</td>
</tr>
<tr>
<td>Post-monsoon</td>
<td>28.0 (1.98)</td>
<td>4.73 (1.29)</td>
<td>25.0 (6.38)</td>
<td>87.05 (16.28)</td>
<td>62.23 (18.42)</td>
<td>5.94 (2.31)</td>
</tr>
<tr>
<td>Summer</td>
<td>29.4 (1.57)</td>
<td>3.75 (0.79)</td>
<td>48.1 (8.18)</td>
<td>70.88 (18.61)</td>
<td>51.72 (14.2)</td>
<td>6.24 (1.94)</td>
</tr>
</tbody>
</table>

Fig. 2—Monthly variability in salinity and DO in the mangrove water.

Fig. 3—Monthly variability in the concentrations (µM) of dissolved organic nutrients in the mangrove water.

Monsoon than the summer; for the Coleroon, this trend is opposite. This indicates that these two zones are actively influenced by not only native biogeochemical processes but also by the external processes i.e. inputs from anthropogenic activities, runoff from agricultural fields etc.

Mixing plots between nutrients vs. salinity (Fig. 5) showed apparently random variations throughout the year and slight or no significant concentration variability relative to conservative mixing along the mangrove. Moderate to strong variations in organic nutrients were found in monsoon and summer. In monsoon, the freshwater discharge from adjoining streams supplies both organic and inorganic compounds from land to the mangrove and whereas in summer i.e. allochthonous sources, high temperature driven microbial activities degrade the complex organic compounds i.e. autochthonous material which in turn supplied to the water column. Further, in summer organic nutrients have significant relationship with salinity (DOC $r^2 = 0.75$, p<0.05; DON $r^2 = 0.63$, p<0.05 and DOP $r^2 = 0.69$, p<0.05), this explains the oceanic supply of organic nutrients from the Bay of Bengal to the mangrove system. In pre-monsoon and post-monsoon, the mixing pattern seems to be constant through out the mangrove and this may be due to conservative utilization of nutrients for the biological productivity. Generally, the outwelling of nutrients from the mangrove is higher than the input to the ocean by the freshwater sources. Thus the mangrove ecosystems control the marine biogeochemical processes in the tropics. Further research is required to trace the nutrient sources for the biological productivity by using stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotopes and molecular lignin phenols. Mangroves cover <0.1% of the continents, but they probably account for >10% of the DOC globally transported from the continents to the ocean. Hence mangroves, rather than rivers, support the marine biological productivity.
Acknowledgements

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Fig. 5—Mixing diagrams (concentration vs. salinity) for DOC, DON and DOP for the study period (Index: solid squares-Pre-monsoon; open squares-Monsoon; solid circles-Post-monsoon; open circles-Summer).