

Distribution of particulate carbohydrate species in the Bay of Bengal

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Suspended particulate matter (SPM) of surface seawaters was collected during December 2003 to October 2004 at 10 stations in the Bay of Bengal, and analyzed for particulate organic carbon (POC), total particulate nitrogen (TPN), total particulate carbohydrate (TPCHO) and total particulate uronic acids (TPURA). The concentrations of POC, TPCHO and TPURA varied from 4.80 to 29.12, 0.85 to 4.24, 0.09 to 0.91 $\mu\text{M C}$, respectively. The TPCHO-C and TPURA-C accounted for 6.6–32.5% and 0.87–3.65% of POC. The trends observed for the distribution of these compounds were generally similar to those recorded for the distribution of chlorophyll *a* (Chl *a*). The C/N ratios varied from 3.2 to 22.3 with most of the values being < 10 . This suggests that the organic matter was mostly derived from phytoplankton and bacteria. Relatively low C/N ratios and high TPCHO yield imply that freshly derived organic matter was present during SWM and FIM. Our data suggest that the quality and quantity of organic matter varied spatially and seasonally.

1. Introduction

Carbohydrates are the most important constituents produced by phytoplankton during the process of photosynthesis. Typically, carbohydrates comprise more than 40 wt% of bacteria and 75 wt% of vascular plants (Moers and Larter 1993), 20–40 wt% of plankton (Parsons *et al* 1984b), 13% of sinking particulate organic carbon (Tanoue and Handa 1987), ~ 3 –35% of suspended particulate organic carbon (Khodse *et al* 2007), 10–85% in seawater dissolved organic carbon (DOC) (Pakulski and Benner 1994) and sediment pore water DOC (Burdige *et al* 2000), and 3–26% of sedimentary organic carbon (Khodse *et al* 2008). These compounds are useful substrates for heterotrophic organisms. It appears that the concentration and composition of carbohydrates are influenced by several factors including nutrient levels, composition of organisms, growth phase, etc. Carbohydrates are classified as structural and storage

components of both marine and terrestrial organisms. The storage carbohydrates are utilized preferentially. This results in the accumulation of relatively less degradable structural carbohydrates in the degraded organic matter.

In addition to neutral carbohydrates, many marine micro-organisms, terrestrial plants, algae and other organisms produce uronic acids or acidic carbohydrates (Bergamaschi *et al* 1999; Hung *et al* 2003). They are also present in dissolved organic matter, particulate matter, and marine sediments (Bergamaschi *et al* 1999; Hung *et al* 2003; Khodse *et al* 2007, 2008). Although present in small amounts, they are involved in many marine processes such as the production of humic substances and mucilaginous aggregates, biofilm formation and bacterial adhesion and detoxification of toxic chemicals and removal of metal ions (Decho 1990).

There are many studies describing the physical, chemical and biological characteristics of the

Keywords. Suspended particulate matter; chlorophyll *a*; particulate organic carbon; C/N ratio; particulate carbohydrates; particulate uronic acids; organic matter, Bay of Bengal.

Table 1. Details of sample, location, station depth, season and date of sampling in the Bay of Bengal.

Station no.	Latitude	Longitude	Depth (m)	Date of sampling			
				WM	SPIM	SWM	FIM
1	13.02'N	80.54'E	2655	22/12/2003	17/04/2004	24/07/2004	13/10/2004
2	12.14'N	83.03'E	3275	23/12/2003	18/04/2004	25/07/2004	13/10/2004
3	12.25'N	85.00'E	3277	23/12/2003	18/04/2004	25/07/2004	13/10/2004
4	11.49'N	89.05'E	3151	24/12/2003	19/04/2004	26/07/2004	14/10/2004
5	11.25'N	91.54'E	1470	24/12/2003	20/04/2004	27/07/2004	14/10/2004
6	14.04'N	92.56'E	650	01/01/2004	–	05/08/2004	17/10/2004
7	15.57'N	91.37'E	2300	01/01/2004	–	05/08/2004	17/10/2004
8	18.59'N	89.30'E	1500	02/01/2004	–	06/08/2004	18/10/2004
9	20.04'N	89.03'E	1344	02/01/2004	–	06/08/2004	18/10/2004
10	20.35'N	88.40'E	145	02/01/2004	–	07/08/2004	18/10/2004

Bay of Bengal (Madhupratap *et al* 2003; Prasanna Kumar *et al* 2004, 2007; Sardesai *et al* 2007; Paul *et al* 2007, 2008; Fernandes *et al* 2008). However, there is only one study that deals with the seasonal variation in the characterization of suspended particulate organic matter of the Bay of Bengal (Khodse *et al* 2007). Studies on the distribution of suspended particulate organic matter provide useful information on the dynamics, nature and fate of organic matter in marine environment. Therefore, in this paper, we assess the seasonal variations in the distribution of particulate organic carbon (POC), total particulate nitrogen (TPN), particulate carbohydrates (TPCHO), and particulate uronic acids (TPURA) along the Chennai to Andaman and Andaman to Kolkata transects in the Bay of Bengal.

2. Materials and methods

2.1 Description of the study area

Bay of Bengal (BOB) is a semi-enclosed tropical basin located in the northern Indian Ocean. It is bounded by the Indian Peninsula and Sri Lanka on the west and by the Andaman–Nicobar Islands and Burma on the east. The Bay is influenced by reversing monsoons that cause seasonal changes in circulation and weather. Its unique characteristic is the major rivers Ganges, Brahmaputra, Godavari, Krishna, Mahanadi, Pennar and Cauvery drain into the Bay large quantities of fresh water ($1.6 \times 10^{12} \text{ m}^3 \text{ yr}^{-1}$) (Subramanian 1993). These rivers introduce $2.0 \times 10^{15} \text{ g}$ of suspended particulate matter into the Bay (Rao 1985). River discharge is expected to add nutrients to the upper layers and increase the biological productivity of the Bay. However, warm sea surface temperature

and low salinity lead to strong stratification that prevents transport of nutrients into surface waters. Moreover, the weak winds are unable to break the thermocline. Upwelling has been observed along the western boundary of the Bay (Shetye *et al* 1991). Cyclones are frequent in the Bay, and can pump nutrients into the surface waters. This results in localized algal blooms (Vinaychandran and Mathew 2003). Phytoplankton biomass measured as Chl *a* showed small variation, and diatoms such as *Thalassiothrix* sp, *Rizosolenia* sp, and *Nitzschia* are generally abundant (Paul *et al* 2007). The average primary production was $9.3 \text{ mg C m}^{-3} \text{ day}^{-1}$ and $20 \text{ mg C m}^{-3} \text{ day}^{-1}$ in the central Bay and the western Bay (Fernandes *et al* 2008). Surface primary production was higher during southwest monsoon (SWM) ($11\text{--}13 \text{ mg C m}^{-3} \text{ d}^{-1}$) followed by winter monsoon (WM) ($5.5\text{--}3.1 \text{ mg C m}^{-3} \text{ d}^{-1}$) and spring inter monsoon (SPIM) ($5\text{--}4.4 \text{ mg C m}^{-3} \text{ d}^{-1}$) (Jyothibabu *et al* 2008). Bacteria were abundant and varied from 0.04 to $1.0 \times 10^9 \text{ cells l}^{-1}$ (Gauns *et al* 2005). Prasanna Kumar *et al* (2004, 2007) suggested the importance of cold core eddies in enhancing the biological productivity of the Bay. According to Gauns *et al* (2005) Chl *a*, primary production, phytoplankton and zooplankton abundance are several fold lower in the Bay as compared to the Arabian Sea. Many factors including cloud cover, large sediment load, narrow shelf, stratification, etc., are considered to be responsible for the low production in the Bay (Madhupratap *et al* 2003; Paul *et al* 2007; Fernandes *et al* 2008).

2.2 Experimental methods

At five selected stations along Chennai to Andaman, and from Andaman to Kolkata routes,

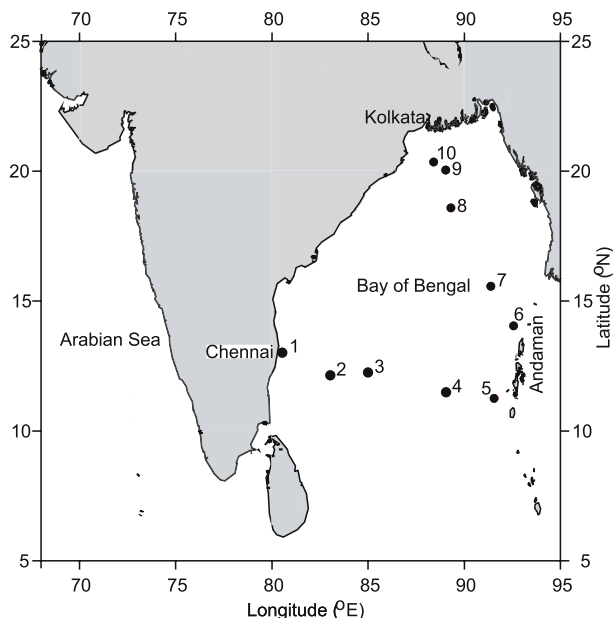


Figure 1. Map showing the location of sampling stations in the Bay of Bengal.

suspended particulate matter (SPM) of surface water was sampled (table 1, figure 1) during winter monsoon (WM), spring inter monsoon (SPIM), southwest monsoon (SWM) and fall inter monsoon (FIM). A clean plastic bucket was used to collect surface seawater. Immediately after collection, a known amount of water sample (4l) was filtered through pre-combusted (450°C, 4 h) glass fiber filter (47 mm GF/F, 0.7 μ m pore size). The SPM collected on the GF/F filter was dried at room temperature and transferred into clean vials and stored at -20°C until analysis. The SPM was analyzed for POC, TPN, TPCHO and TPURA.

2.3 Analytical methods

Sea surface temperature (SST) data were obtained from Expendable Bathythermograph (XBT). SST data for SWM were collected from http://dsrs.atmos.umd.edu/DATA/SODA_1.4.3. Sea surface salinity (SSS) was analyzed using auto-analyzer. Weekly data on Chl *a* abundance during the period December 2003 to October 2004 were derived from SeaWiFS (<http://reason.gsfc.nasa.gov/OPS/Giovanni/ocean.seawifs.shtml>). POC was analyzed spectrophotometrically by the wet oxidation of carbon with acid dichromate (Parsons *et al* 1984a). TPN was estimated following the method of Raimbault and Gerd (1991). TPCHO was analyzed by the phenol-sulfuric acid method (Dubois *et al* 1956), and the TPURA was estimated by the hydroxydiphenyl method (Filisetti-Cozzi and Carpita 1991) as described in Khodse *et al* (2007). Analytical variability of these methods was $< 10\%$.

3. Results and discussion

3.1 General hydrography

The distribution of sea surface temperature (SST) and sea surface salinity (SSS) along Chennai–Andaman and Andaman–Kolkata are given in table 2. SST along the Chennai–Andaman transect shows marginal variation during WM, SWM and FIM. However, during SPIM, SST showed an increase from 29.7°C off Chennai to 31.4°C towards Andaman Sea. Along the Andaman–Kolkata transect, SST showed opposite trend during SWM and FIM. On the other hand, under the influence of winter cooling, SST showed continuous decrease from Andaman (28.0°C) towards Kolkata (25.9°C) during WM (Shetye *et al* 1993; Varkey *et al* 1996). The SSS showed small changes along the Chennai–Andaman transect (table 2), whereas the SSS generally decreased from station 6 to station 10 along the Andaman–Kolkata transect in SWM and FIM. During the WM, SSS varied from 30.5 to 32.5 along the Andaman–Kolkata transect. It may be noted that under the influence of river runoff and precipitation over the Bay of Bengal, during FIM SSS showed a dramatic decrease from 31.5 at station 6 in the Andaman Sea to 26.7 at station 9 off Kolkata.

3.2 POC, TPN C/N ratio and Chl *a*

The POC and TPN showed seasonal and spatial variation and ranged between $4.80\ \mu\text{M C}$ and $29.12\ \mu\text{M C}$, and 0.31 and $1.52\ \mu\text{M N}$, respectively. Concentrations of POC and TPN observed during this study are comparable with those previously recorded for the Bay (Nandakumar *et al* 1987; Bhosle *et al* 1988; Kumar *et al* 2004; Fernandes *et al* 2006; Khodse *et al* 2007). The distribution of POC and TPN along these two transects compares well with the seasonal distribution of Chl *a* derived from SeaWiFS (figure 2). The concentrations of POC were generally high during the WM followed by SWM, FIM and SPIM (table 2). TPN also showed small spatial variations, and concentrations were high in SWM and FIM and low in SPIM (table 2). During WM, high concentration ($29.12\ \mu\text{M C}$) of POC was recorded at station 1. Concentrations decreased from station 1 to station 4 along the Chennai–Andaman transect. Similarly, along the Andaman–Kolkata transect, with the exception of station 8, POC concentration showed small variations. During all the seasons pumping of nutrients in near surface waters by eddies has been observed (Prasanna Kumar, personal communication). Moreover, during WM (11–16 December 2003) cyclone was observed in western Bay of Bengal (Kotal *et al* 2008). These

Table 2. Distribution of temperature, salinity, particulate organic carbon (POC), particulate nitrogen (TPN), C/N ratio, total particulate carbohydrates (TPCHO), particulate uronic acids (TPURA) and TPURA/TPCHO ratio in suspended particulate matter of the surface seawater collected at various locations of the Bay of Bengal.

Station no.	Temperature (°C)	Salinity	POC ($\mu\text{M C}$)	TPN ($\mu\text{M N}$)	C/N ratio	TPCHO ($\mu\text{M C}$)	TPURA ($\mu\text{M C}$)	TPURA/TPCHO ratio
Winter monsoon (WM)								
1	28.6	33.5	29.12 \pm 0.17	–	–	4.24 \pm 0.25	0.91 \pm 0.11	0.23
2	28.4	33.4	12.07 \pm 0.84	–	–	1.13 \pm 0.08	0.40 \pm 0.04	0.38
3	28.5	33.2	12.93 \pm 0.30	–	–	0.85 \pm 0.05	0.28 \pm 0.03	0.36
4	28.2	33.5	11.26 \pm 0.47	–	–	1.14 \pm 0.08	0.15 \pm 0.02	0.14
5	28.3	32.6	13.14 \pm 0.11	–	–	1.46 \pm 0.03	0.23 \pm 0.02	0.17
6	28.0	32.4	10.99 \pm 0.52	–	–	1.64 \pm 0.05	0.19 \pm 0.00	0.12
7	27.5	30.3	13.53 \pm 0.29	–	–	2.10 \pm 0.14	0.27 \pm 0.03	0.14
8	26.5	32.5	17.76 \pm 0.25	–	–	1.71 \pm 0.03	0.28 \pm 0.02	0.18
9	25.5	32.5	12.00 \pm 0.11	–	–	1.46 \pm 0.04	0.27 \pm 0.02	0.20
10	25.9	30.5	12.63 \pm 0.12	–	–	1.79 \pm 0.04	0.33 \pm 0.02	0.20
Spring inter monsoon (SPIM)								
1	29.7	35.0	4.80 \pm 0.60	0.44	9.4	1.56 \pm 0.02	0.19 \pm 0.01	0.13
2	30.1	34.1	6.54 \pm 0.84	0.50	11.2	1.16 \pm 0.00	0.13 \pm 0.02	0.12
3	30.3	32.3	6.35 \pm 0.39	0.53	10.4	1.18 \pm 0.07	0.11 \pm 0.01	0.10
4	30.0	32.4	7.23 \pm 0.63	0.31	19.8	1.02 \pm 0.08	0.09 \pm 0.01	0.09
5	31.4	32.5	6.29 \pm 0.28	0.47	11.4	1.16 \pm 0.05	0.11 \pm 0.01	0.10
Southwest monsoon (SWM)								
1	30.0	33.0	7.68 \pm 1.15	0.70	9.4	1.28 \pm 0.12	0.21 \pm 0.01	0.17
2	29.5	33.0	8.79 \pm 0.60	0.89	8.5	1.17 \pm 0.13	0.19 \pm 0.02	0.17
3	29.3	32.6	11.60 \pm 0.36	0.86	11.5	0.91 \pm 0.12	0.11 \pm 0.01	0.13
4	28.9	32.9	7.47 \pm 0.80	1.01	6.3	1.58 \pm 0.12	0.14 \pm 0.02	0.10
5	28.8	33.1	6.16 \pm 0.60	0.99	5.3	1.02 \pm 0.05	0.10 \pm 0.01	0.09
6	29.3	32.6	11.4 \pm 1.15	1.14	8.5	1.76 \pm 0.15	0.16 \pm 0.01	0.10
7	29.4	32.3	9.70 \pm 1.44	1.52	5.5	1.55 \pm 0.20	0.20 \pm 0.01	0.14
8	29.9	31.6	14.24 \pm 0.80	1.34	9.1	2.23 \pm 0.31	0.19 \pm 0.02	0.09
9	30.4	31.6	12.55 \pm 1.71	0.48	22.3	1.13 \pm 0.10	0.14 \pm 0.00	0.13
10	30.3	31.5	11.81 \pm 1.00	1.25	8.1	1.85 \pm 0.12	0.15 \pm 0.01	0.09
Fall inter monsoon (FIM)								
1	29.5	33.7	13.00 \pm 0.42	0.55	20.0	2.43 \pm 0.35	0.14 \pm 0.01	0.06
2	29.3	33.8	9.38 \pm 0.58	0.68	11.8	0.91 \pm 0.12	0.19 \pm 0.02	0.22
3	28.7	31.9	8.29 \pm 1.15	0.55	13.0	1.11 \pm 0.15	0.14 \pm 0.02	0.13
4	28.9	33.3	6.51 \pm 0.61	1.39	4.0	1.02 \pm 0.05	0.11 \pm 0.01	0.12
5	29.1	32.8	8.11 \pm 0.74	0.61	11.4	1.44 \pm 0.18	0.11 \pm 0.01	0.08
6	29.3	31.5	12.68 \pm 1.18	1.16	9.4	2.51 \pm 0.25	0.14 \pm 0.02	0.06
7	29.1	31.2	9.44 \pm 1.20	1.42	5.7	1.82 \pm 0.04	0.15 \pm 0.02	0.09
8	28.8	30.6	7.93 \pm 1.10	1.26	5.4	2.00 \pm 0.26	0.28 \pm 0.01	0.15
9	28.8	26.7	5.69 \pm 0.70	1.52	3.2	1.03 \pm 0.11	0.23 \pm 0.01	0.24
10	28.8	28.0	7.62 \pm 0.90	1.29	5.1	1.21 \pm 0.05	0.15 \pm 0.01	0.14

– = no data; \pm = represent SD of three different samples. Temperature data for the SWM was obtained from the site <http://dsrs.atmos.umd.edu/DATA/SODA-1.4.3/>.

cyclonic circulation features can bring the nutrients to the surface. Availability of nutrients in near surface waters enhances biological production. This was evident from the SeaWiFS data showing high abundance of Chl *a* at station 1 in the southern Bay

and relatively low concentrations at other stations (figure 2).

During SWM, concentrations of POC and TPN were higher at station 10 (11.81 $\mu\text{M C}$, 1.25 $\mu\text{M N}$) in northern Bay as compared to station 1

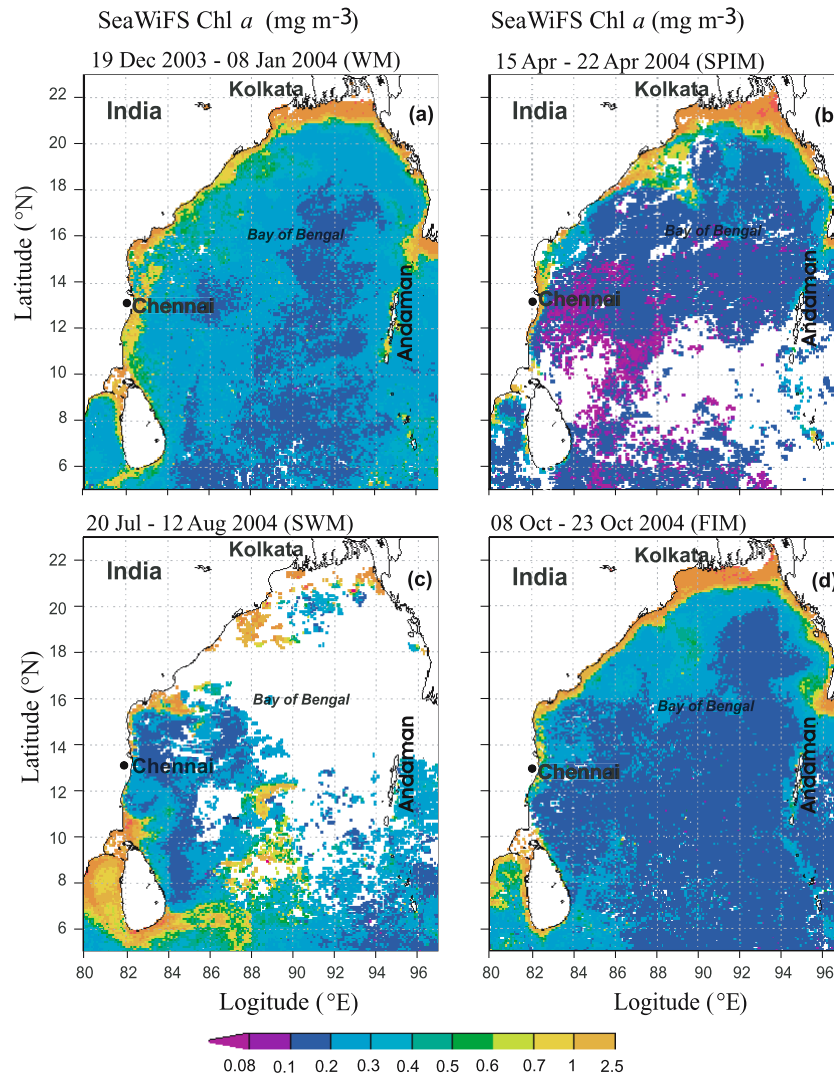


Figure 2. Seasonal variations of weekly SeaWiFS Chl *a* concentrations (mg m^{-3}) during winter monsoon (WM) (a), spring inter monsoon (SPIM) (b), southwest monsoon (SWM) (c) and fall inter monsoon (FIM) (d) in the Bay of Bengal. Chl *a* concentration derived from <http://reason.gsfc.nasa.gov/OPS/Giovanni/ocean.aqua.shtml>.

($7.68 \mu\text{M C}$, $0.70 \mu\text{M N}$) in the southern Bay. The excess precipitation over evaporation and river run-off freshen up the upper water layers, especially of the northern region of the Bay. River discharge adds nutrients to the upper layers and thus expected to increase biological productivity of the Bay. However, during the SWM, the upper ocean layer is highly stratified. Prasanna Kumar *et al* (2004, 2007) identified cold core eddies during SWM in the Bay of Bengal, and proposed eddy pumping as possible mechanisms of vertical transfer of nutrients across the halocline to the oligotrophic euphotic zone during SWM. This would induce rapid biological uptake, and in turn enhance biological production. Therefore, organic matter production due to nutrient addition by eddy pumping and the inputs of organic matter from rivers may be responsible for the higher

concentration of POC and TPN at station 10 during the SWM.

On the other hand, during the FIM, some increase in nitrate and silicate due to fresh water run-off in the north was detected (Prasanna Kumar *et al* 2007; Sardesai *et al* 2007). During this period, four cyclonic eddies were observed. The availability of nutrients and improved light condition due to low SPM enhances biological productivity in the north while it was more than double in the south (Prasanna Kumar *et al* 2007). This was evident from the distribution of POC at station 1 ($13.0 \mu\text{M C}$) in southern Bay and at station 10 ($7.62 \mu\text{M C}$) in the northern Bay. During SPIM, only the Chennai–Andaman transect was operated. During this period, the POC concentrations were relatively lower than those recorded at these locations during SWM and FIM. During the SPIM

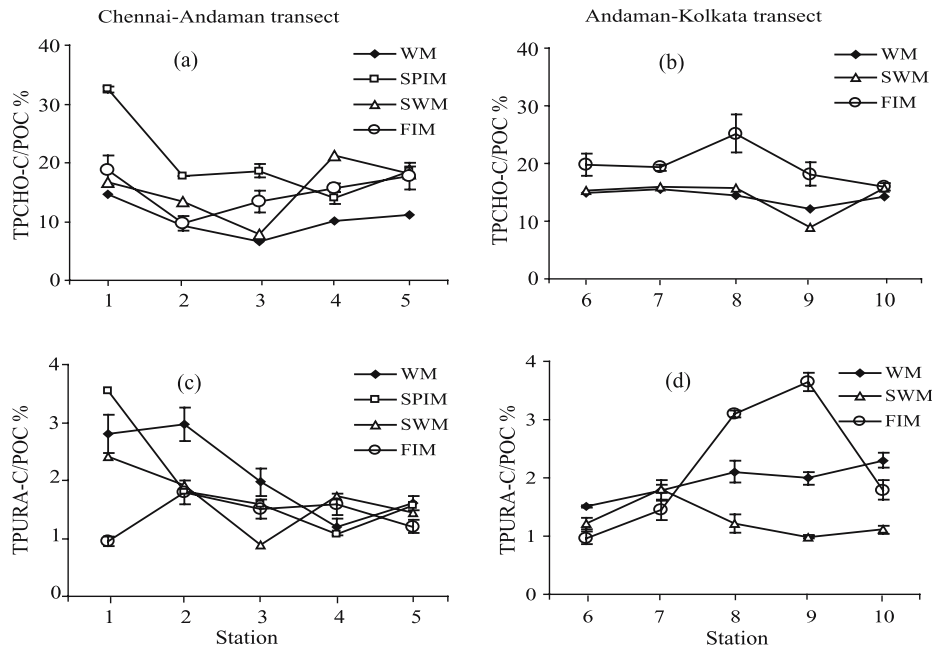


Figure 3. Seasonal and spatial variation of %TPCHO-C/POC, and %TPURA-C/POC of the suspended particulate matter at various stations of the Bay of Bengal.

period, the physical forcing is weak (Prasanna Kumar *et al* 2007; Sardessai *et al* 2007), and probably because of this, the POC production was relatively low during this period.

The C/N ratio is a useful tool to assess the nature of organic matter. The C/N ratio varied from 3 to 22 (table 2, figure 4d). With the exception of a few values, the C/N ratio was < 10 for most of the stations. Moreover, the C/N ratio was generally low during SWM for the stations sampled on the Chennai to Andaman transect. Interestingly, the C/N ratio was lowest for the stations sampled along the Andaman to Kolkata transect during the FIM. Average C/N ratio was high for the SPIM (12.4 ± 4.2) and relatively low for the SWM (8.2 ± 2.4), and FIM (5.7 ± 2.2) (figure 4d). Marine bacteria and microalgae have a ratio of $< 4-6$ (Elser *et al* 2000). In contrast, the C/N ratio of the terrestrial organic matter varied from 20 to 200 (Hedges *et al* 1986). The low C/N values (< 10) indicate the presence of relatively fresh organic matter derived from bacteria and microalgae during the SWM and FIM periods. In contrast, high (12.4 ± 4.2) C/N ratio in SPIM indicates the presence of degraded organic matter and/or the influence of terrestrial organic matter in the study area.

3.3 TPCHO

TPCHO showed some spatial and seasonal variation, and ranged between 0.85 and $4.24 \mu\text{M C}$ (average = $1.53 \pm 0.65 \mu\text{M C}$) (table 2). Except for high concentration at station 1, TPCHO showed

small changes at the stations sampled along the Chennai–Andaman transect (table 2). As compared to the Chennai–Andaman transect, TPCHO concentrations were relatively higher at stations sampled along the Andaman–Kolkata transect. However, spatial variations in the distribution of TPCHO were small at the stations sampled along this transect. During the WM and FIM, station 1 located in the southern Bay showed relatively higher concentration of TPCHO. In contrast, during SWM higher concentration of TPCHO was recorded at station 10 in the northern Bay. In general, these TPCHO trends are in line with those recorded for the distribution of POC, TPN and Chl *a*. TPCHO values observed during the present study are in the range of values earlier reported for the Bay of Bengal (Khodse *et al* 2007 and the references therein). These values also compare well with those reported from the Red Sea ($2.12-3.14 \mu\text{M C}$), northern and central Indian Ocean ($0.73-1.5 \mu\text{M C}$), and western and southern Australian areas of Indian Ocean ($0.4-1.31 \mu\text{M C}$) (Mistic *et al* 2006).

Contribution of carbohydrate-carbon to bulk organic carbon is defined as the yield. Carbohydrate yield is high for the freshly derived organic matter, and relatively low for the degraded organic matter. Because of this, carbohydrate yield is a useful tool to assess the freshness or the degradation state of organic matter (Skoog and Benner 1997; Khodse *et al* 2007). In the present study, TPCHO-C accounted for 6.6% to 32.5% of POC (figure 3a, b). For the stations sampled along the

Chennai–Andaman transect, the average TPCHO yield was high ($20.3 \pm 7.0\%$) in SPIM, low in WM ($10 \pm 2.9\%$), and intermediate during SWM ($15.4 \pm 5.0\%$) and FIM ($15.0 \pm 3.6\%$), suggesting the presence of fresh organic matter during these seasons (figure 4a). However, in SPIM, high TPCHO yield ($20.3 \pm 7.0\%$) was associated with high C/N ratio (12.4 ± 4.1) indicating that the organic matter was influenced by the presence of terrestrial organic matter. Interestingly, along the Chennai–Andaman transect, although the TPCHO yields were similar during SWM and FIM, the average C/N ratio was low (8.2) for the former and high (12.0) for the latter (figure 4d). This difference in the C/N ratio strongly indicates the presence of relatively more fresh organic matter in the SWM as compared to the FIM at the stations sampled along the Chennai–Andaman transect. For the stations sampled along the Andaman–Kolkata transect TPCHO yields, with exception of a few values, showed small spatial variations. The average yields were similar for the WM (14.2 ± 1.2) and SWM (14.3 ± 2.3), and higher (19.7 ± 3.4) for the FIM (figure 4a). Moreover, the C/N ratio of the organic matter was high (10.7 ± 6.6) for SWM and low (5.7 ± 2.2) for the FIM (figure 4d). From these data it is evident that during FIM, relatively fresh organic matter was present at these stations along the Andaman–Kolkata transect. This conclusion was also supported by the fairly good inverse correlation ($r = -0.552$, $p < 0.01$) relation between the TPCHO yields and the C/N ratios.

Carbohydrate production by micro-organisms is influenced by phase of growth, nutrient status, phytoplankton species composition and/or bacterial activity (Morris 1981; D'Souza and Bhosle 2001). Phytoplankton composition varied spatially and seasonally, but generally, diatoms were most abundant in the Bay of Bengal (Paul *et al* 2007). Diatoms are known to produce higher amounts of carbohydrates during the stationary phase of growth and under nutrient deficient conditions (D'Souza and Bhosle 2001). In surface waters nutrients were rarely present (Sardessai *et al* 2007). Therefore, variations in some of these factors may have been involved in controlling the abundance of carbohydrates in the Bay.

3.4 TPURA

Acidic carbohydrates such as uronic acids are produced by many marine organisms including bacteria, fungi, phytoplankton, microalgae, plants and animals. Some commercially important plant structural polysaccharides, such as pectin and alginic acid are almost entirely composed of glycosidically bound uronic acids. In aquatic environments, uronic acids are produced by algae

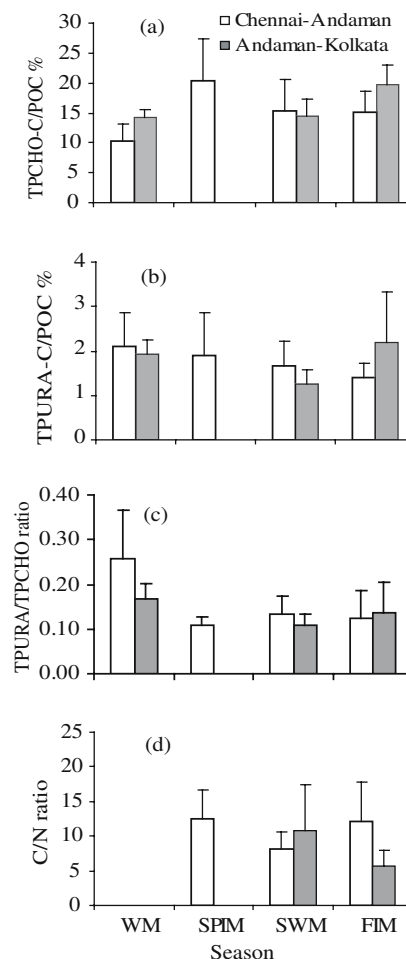


Figure 4. Seasonal variation of the average %TPCHO-C/POC (a), %TPURA-C/POC (b), average TPURA/TPCHO ratio (c) and average (weight/weight) C/N ratio (d) for the stations sampled along the Chennai–Andaman and Andaman–Kolkata transect in the Bay of Bengal.

and bacteria during low nutrient condition and higher metal stress (Decho 1990). They are surface-active compounds, and are known to perform many important functions in marine environments (Decho 1990). For example, they are involved in the removal of toxic metal ions, detoxification of toxic chemicals, adsorption of dissolved organic matter and microbial adhesion and biofilm development, etc. (Decho 1990). Although numerous functions have been described to uronic acids, we know little about their distribution, dynamics and sources in marine environments. TPURA concentrations in the Bay of Bengal showed large variations, and ranged from 0.09 to $0.91 \mu\text{M C}$ (average = $0.20 \pm 0.14 \mu\text{M C}$) during the period of study (table 2). For both transects, concentrations of TPURA were higher during the WM due to biological production as seen from high Chl *a* distribution (figure 2). Along the Chennai–Andaman transect, TPURA concentration was

highest at station 1, and the concentrations generally decreased from station 1 to station 5 along this transect during all seasons. While along the Andaman–Kolkata transect, the TPURA concentration showed a small increase from station 6 to station 10 during the WM while small differences were observed during other periods of sampling (table 2). TPURA concentration was greater at station 1 in the southern Bay, and was lower at station 10 in the northern Bay during WM and the SWM periods. While no particular trend was evident during the FIM. Generally, the trends observed for the distribution of TPURA were similar to those recorded for the POC and TPCHO.

The contribution of TPURA-C to POC is defined as yield. The yields varied from 0.87 to 3.5% along the Chennai–Andaman transect (figure 3c, d). Along this transect, the yields decreased from station 1 to station 5 with some exceptions (figure 3c). The average TPURA yield was highest (2.1%) during WM and decreased in SPIM (1.9%), SWM (1.7%), and FIM (1.4%) (figure 4b). On the other hand, for the Andaman–Kolkata transect, the average yield was higher (1.9%) during WM that decreased (1.3%) during the SWM, and increased (2.2%) again in FIM (figure 4b). TPURA/TPCHO ratio provides useful information on the relative distribution of these compounds. The ratio generally was high at station 1, and decreased up to station 5 along the Chennai–Andaman transect during SPIM, SWM, and FIM (table 2). The average TPURA/TPCHO ratio was higher (0.26 ± 0.11) during the WM and decreased during the SPIM (0.11 ± 0.02), SWM (0.13 ± 0.04) and FIM (0.12 ± 0.06) (figure 4c). Similarly, along the Andaman–Kolkata transect, the ratio showed small increase (0.12 to 0.20) from station 6 to station 10, whereas no consistent trend was recorded during SWM and FIM periods (table 2). The average TPURA/TPCHO ratio was high (0.17 ± 0.03) during the WM and relatively low in SWM (0.11 ± 0.02) and FIM (0.14 ± 0.07) (figure 4c). High TPURA/TPCHO indicates that the organic matter was relatively degraded. This is also supported by low TPCHO yield during WM. The decrease TPURA/TPCHO ratio indicates higher production of carbohydrates relative to TPURA by phytoplankton. Both the concentrations and the yields are in the range of values reported earlier from different environments (Bergamaschi *et al* 1999; Hung *et al* 2001, 2003; Khodse *et al* 2007). The production of TPURA by micro-organisms is influenced by many factors, especially nutrients and the composition of micro-organisms (Decho 1990; Hung *et al* 2003). Both these factors showed spatial and seasonal variation and thus may have influenced the abundance of

TPURA in the Bay (Paul *et al* 2007; Sardesai *et al* 2007; Fernandes *et al* 2008).

4. Conclusions

Seasonal and spatial variations in the distribution of POC, TPN, TPCHO, and TPURA were monitored in the surface waters of the Bay of Bengal. These constituents of the organic matter varied seasonally and spatially during the period of observation. Concentrations of POC, TPN, TPCHO and TPURA were relatively higher during the WM period. This distribution compares well with the distribution of Chl *a*. However, the low TPCHO yield, high TPURA yield and high TPURA/TPCHO ratio suggest the presence of poor quality organic matter during WM. Whereas in SPIM, the organic matter was characterized with high TPCHO yield and high C/N ratio (> 10) indicating that it was degraded and/or influenced by the presence of terrestrial organic matter. On the other hand, high TPCHO yields and low C/N ratio during the FIM and SWM, implies that the organic matter was freshly produced during these periods. Our data showed strong seasonal variation in the quality of organic matter in Bay.

Acknowledgements

The authors are grateful to Dr Satish Shetye, the Director NIO, for encouragement and facilities. The first author (VK) is grateful to the INCOIS for financial support. We also thank Mr Ravidas Naik, Mr Gourish, Mr Suprit Kumar and Ms Nisha Kurian for their help in the collection of samples. We are grateful to the captains and crew of the ships of the Shipping Corporation of India (SCI) for their help in sampling. This is NIO contribution no. 4498.

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MS received 2 June 2008; revised 22 December 2008; accepted 6 January 2009