Distribution of Nutrients in the Bay of Bengal

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Abstract

The spatial distribution of nutrients (nitrite + nitrate, silicate and phosphate) was determined during the joint research survey on the Ecosystem-Based Fishery Management in the Bay of Bengal by M.V. SEAFDEC between 25 October to 21 December 2007. Water samples from twenty-eight stations were analyzed onboard by the Integral Futura Continuous Flow Automated Analysis. The detectable ranges of nitrite + nitrate, silicate and phosphate in the northern Bay of Bengal were 0.07-37.87, 0.01-48.56 and 0.10-3.13 µM; in the western Bay of Bengal 2.06-35.23, 2.89-46.03 and 0.15-3.16 µM; and in the eastern Bay of Bengal 0.35-36.63, 0.05-46.63 and 0.36-2.76 µM, respectively. The vertical section profiles indicated that the concentrations of nutrients in the mixed layer depth were very low and undetectable in several sampling stations. In the thermocline layer, a strong nutricline concentration was noticed to be rapidly increasing with depth but below 200-250 m, it tended to be constant. Furthermore, several near shore stations were observed to have higher concentrations of nutrients than the stations in the open sea.

Key words: nutrient, nitrite + nitrate, silicate, phosphate, Bay of Bengal

Introduction

Nutrient is functionally involved in the process of living organisms. Traditionally, in chemical oceanography the term has been applied almost exclusively to silicate, phosphate and inorganic nitrogen. The role of nutrients in the ocean is to support the ocean food chains. Phytoplanktons are primary food producers in the sea and through photosynthesis, they produce food for zooplanktons which are then consumed by organisms higher up in the food chain (Spencer, 1975).

Generally, nutrient is also present in sea water in very small amounts, but only minute quantities of these are required by living organisms. Nutrient is essential for phytoplankton growth as it is taken up by phytoplankton cells and built in as atoms in amino acids, proteins, nucleic acids, fats, etc. Among the nutrient elements, silicate is essential for diatoms to build up their skeletons which consist of biogenic silicate (Baretta-Bekker *et al.*, 1998).

When phytoplankton, zooplankton or higher organisms are dead, these are decomposed by marine bacteria. This in turn takes a particle form of nutrient and in a dissolved form so that phytoplankton can use it more easily. Distribution of nutrients is useful for predicting the phytoplankton abundance and assemblages. Moreover, it could also be used as indicator of the status of nutrient loading or to predict productivity (De-Pauw and Naessens, 1991).

With the importance of nutrients as mentioned above, this study aimed to measure the nutrient level (nitrite + nitrate, silicate and phosphate) and to illustrate the nutrients distribution in the Bay of Bengal.

Materials and Methods

Site Location

From the 42 oceanographic observation stations, station 25-28, 32-33, 35-45 were cancelled because of the influence of Northeast Monsoon and rough sea conditions. Water samples were collected using the M.V. SEAFDEC from 28 stations in the Bay of Bengal covering three areas, namely: the northern Bay of Bengal (area A: latitude $16°$N-$19°$N, longitude $88°$E-$91°$E); the western Bay of Bengal (area B: latitude $09°$N-$14°$N, longitude $82°$E-$85°$E); and the eastern Bay of Bengal (area C: latitude $10°$N-$12°$N, longitude $95°$E-$97°$E) from 25 October to 21 December 2007. Fig. 1 illustrates the map of the sampling locations.

Water Collection

At each station, the top 400 m of the water column was divided into 12 levels of standard depths (0, 10, 30, 50, 75, 100, 125, 150, 200, 250, 300, and 400 m). Water samples from each depth were collected with 2.5 l Go-Flo Niskin bottle on a 12 bottle rosette. Replicate nutrient samples were sub-sampled from the Niskin bottles then filtered through Whatman GF/C filter papers and were collected into 60 ml polypropylene bottles which were then rinsed three times with the sample before storing at $-20°$C until analysis.

Analysis of Water Samples

Nitrite + nitrate (NO_2+NO_3-N), silicate (SiO_4-Si) and phosphate (PO_4-P) were analyzed in 3 replicates using standard colorimetric methods as adapted for auto-analyzers according to Gordon *et al*. (1995). The Integral Futura Continuous Flow Automated Analysis was used to analyze the samples onboard. Nutrient concentrations were determined from the mean peak heights and calculated using linear regression achieved from a seven point standard curve prepared in low nutrient seawater matrix. The vertical profile of nutrients and environmental data were prepared using Ocean Data View (ODV) software (Schlitzer, 2006).
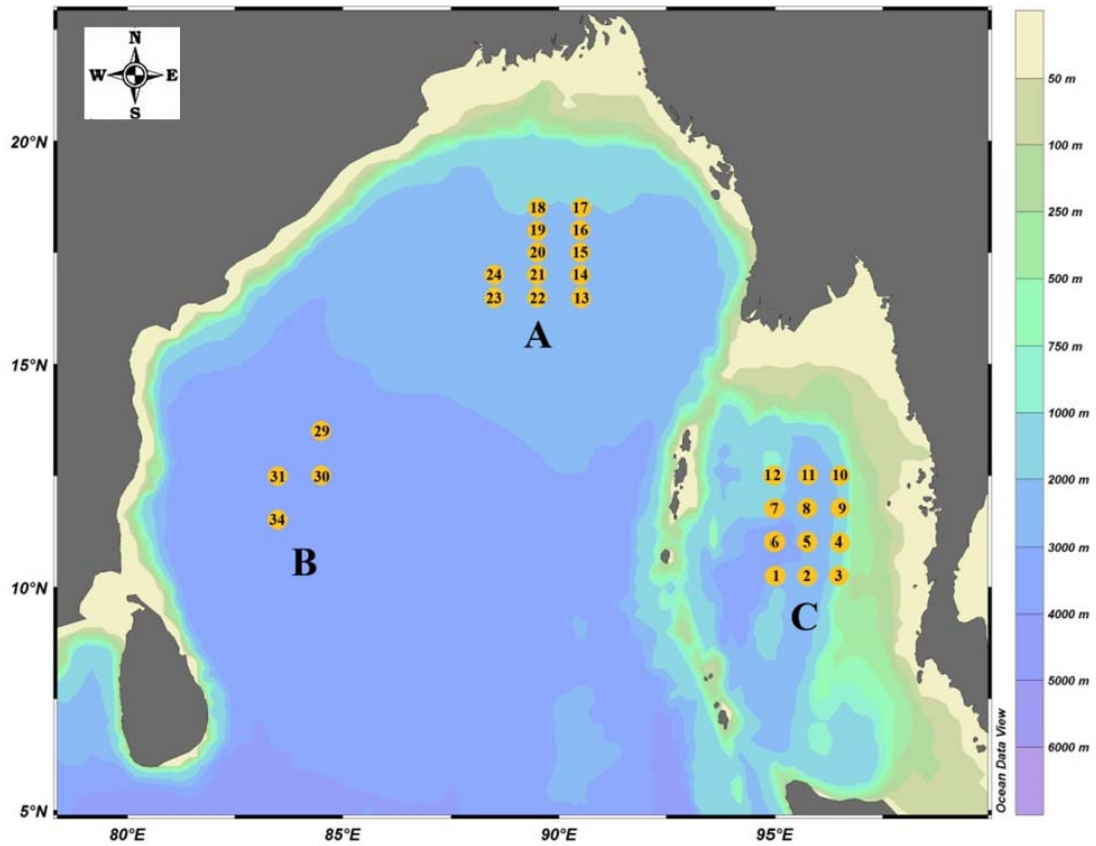
Figure 1 Map of survey area showing the water sampling stations.

Results and Discussions

Water samples from the three areas that included 28 sampling stations were analyzed. The results of sample analysis are shown in tables 1, 2 and 3.

Nutrients in Area A: the Northern Bay of Bengal

Fig. 2a shows the vertical profiles of nutrients and environmental data in the northern Bay of Bengal. The mixed layer depth (MLD) and thermocline layer determined by temperature profile are identified with depths 0-50 m and 51-250 m, respectively. The vertical sections profile of the nutrient in this area was divided into two sections: section A1 (Fig. 3a) includes station 18-22 and section A2 (Fig. 3b) includes station 13-17. In this area A, the nitrite + nitrate concentration (Table 1, Figs. 3a and 3b) in the MLD layer ranged between undetectable (N.D.) to 21.31 µM. Although the concentration was extremely low and could be detectable only in few stations, the observation was consistent with many similar studies conducted in the Bay of Bengal (Kumar *et al.*, 2002; Madhupratap *et al.*, 2003), Except for the high concentration in station 18 and 23 which nearly located the cold-core eddy area (Kumar *et al.*, 2004). Thereby it was possible that the influence of cold-core eddy bring nutrients into this area between our study period. In the thermocline layer, the nitrite + nitrate concentration ranged between 9.82 and 35.70 µM. Fig. 2a shows a strong nitricline level which was noticed to increase rapidly with depth, however until below 250 m, it tended to be constant. At the sub-thermocline layer, the values ranged from 32.55 to 37.87 µM with maximum value of 37.87 µM observed in station 16 at 400 m depth.

**Table 1** Concentration of nitrite + nitrate at standard depths.

| Area	Station	Concentration (µM)											
		Depth (m)											
		0	10	30	50	75	100	125	150	200	250	300	400
A	13	-	N.D.	N.D.	N.D.	13.78	23.30	30.34	-	34.20	35.20	36.10	37.21
	14	-	N.D.	N.D.	N.D.	11.04	27.55	25.30	-	34.24	35.01	36.20	37.24
	15	-	N.D.	N.D.	N.D.	24.35	30.39	31.91	-	34.08	34.94	36.54	33.62
	16	-	N.D.	N.D.	0.07	28.02	29.92	31.31	-	33.71	35.50	35.37	37.87
	17	-	N.D.	N.D.	0.27	16.58	23.26	27.10	-	34.51	32.20	33.53	36.49
	18	-	N.D.	2.30	21.31	-	30.14	27.93	32.18	34.62	35.52	35.94	37.29
	19	-	N.D.	N.D.	1.87	21.83	25.02	24.60	-	31.46	34.91	33.95	33.97
	20	-	N.D.	N.D.	3.64	14.56	26.17	30.84	-	32.73	34.02	33.80	35.57
	21	-	N.D.	N.D.	N.D.	22.81	25.63	27.70	-	30.46	34.03	32.55	35.10
	22	-	N.D.	1.47	4.53	9.82	28.03	25.20	-	31.81	31.00	35.77	37.10
	23	N.D.	5.58	8.66	7.60	10.57	29.91	26.97	-	34.85	35.70	33.48	34.41
	24	N.D.	N.D.	N.D.	4.56	23.70	28.21	29.73	-	32.76	34.10	34.42	35.84
B	29	N.D.	N.D.	N.D.	12.76	23.96	27.52	29.30	-	31.06	33.70	34.33	35.23
	30	N.D.	N.D.	N.D.	12.38	21.89	25.85	27.02	-	31.99	32.32	31.36	33.62
	31	N.D.	N.D.	N.D.	21.25	23.29	23.62	27.30	-	30.31	32.11	33.47	34.28
	34	N.D.	N.D.	N.D.	2.06	20.72	25.96	16.11	-	29.37	26.51	33.22	31.87
C	1	-	-	-	-	8.28	20.30	-	32.32	34.42	-	35.32	35.43
	2	N.D.	-	N.D.	N.D.	6.43	20.72	-	30	30.55	35.30	32.65	32.98
	3	N.D.	N.D.	N.D.	N.D.	14.83	22.42	-	30.06	33.91	32.14	33.21	35.71
	4	-	N.D.	N.D.	23.32	17.00	23.90	25.04	-	34.17	34.20	31.28	31.56
	5	-	N.D.	-	N.D.	1.29	16.98	30.10	29.61	34.49	35.60	35.89	36.29
	6	-	N.D.	N.D.	N.D.	10.45	22.74	30.70	-	34.97	34.41	35.98	36.49
	7	N.D.	N.D.	N.D.	N.D.	10.19	28.87	30.63	-	34.95	35.85	35.49	-
	8	N.D.	N.D.	8.28	23.52	29.35	33.15	35.00	-	36.09	35.70	36.59	36.32
	9	N.D.	N.D.	N.D.	0.35	9.83	20.23	24.45	-	30.14	29.53	30.35	32.68
	10	N.D.	N.D.	N.D.	N.D.	10.57	20.26	27.40	-	33.12	35.30	35.74	36.07
	11	N.D.	N.D.	N.D.	N.D.	3.14	20.34	-	30.61	33.58	35.60	36.33	36.63
	12	N.D.	N.D.	N.D.	3.48	17.33	16.38	23.20	-	34.33	35.80	36.40	36.54

"-"= samples not collected, "N.D." = not detected
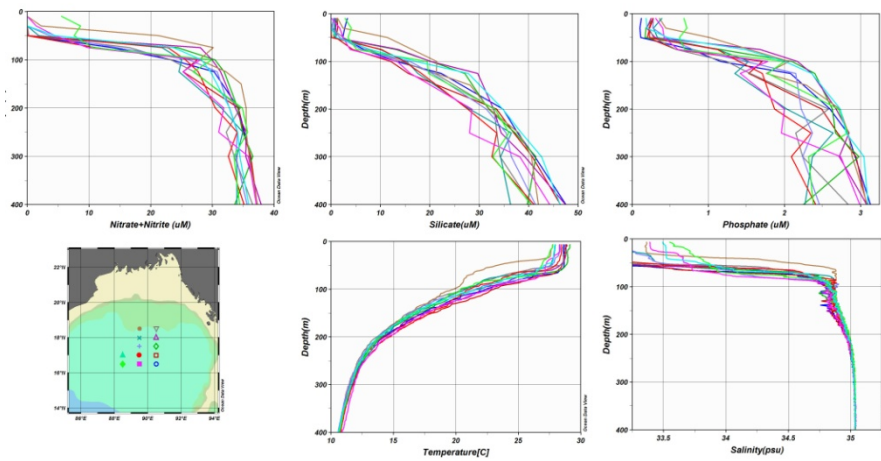
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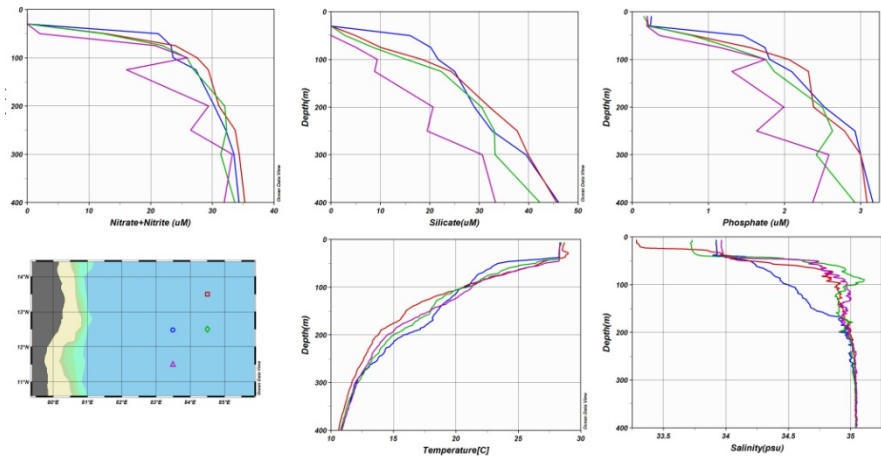
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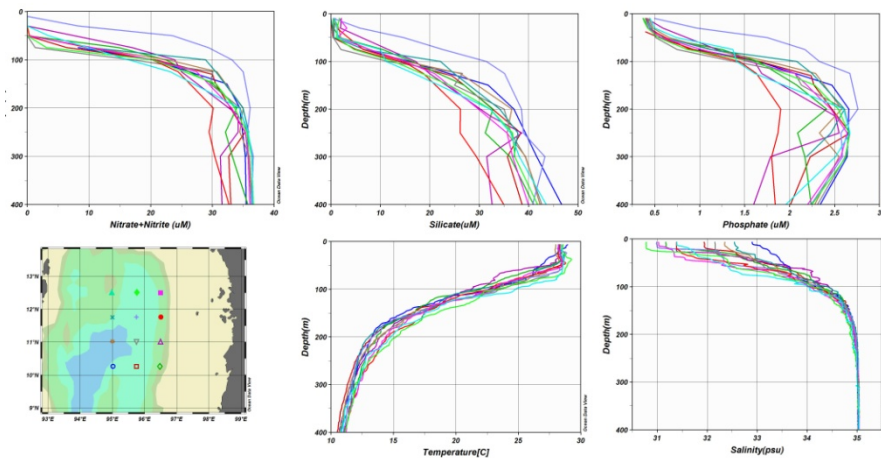
(c)

Figure 2 Vertical profile of nutrients (nitrate + nitrite, silicate and phosphate) (µM),
temperature (°C) and salinity (psu) in upper 400 m, 25 Oct.-21 Dec. 2007.
(a) area A: station 13-24
(b) area B: station 29-31 and 34
(c) area C: station   1-12

(a)

(b)
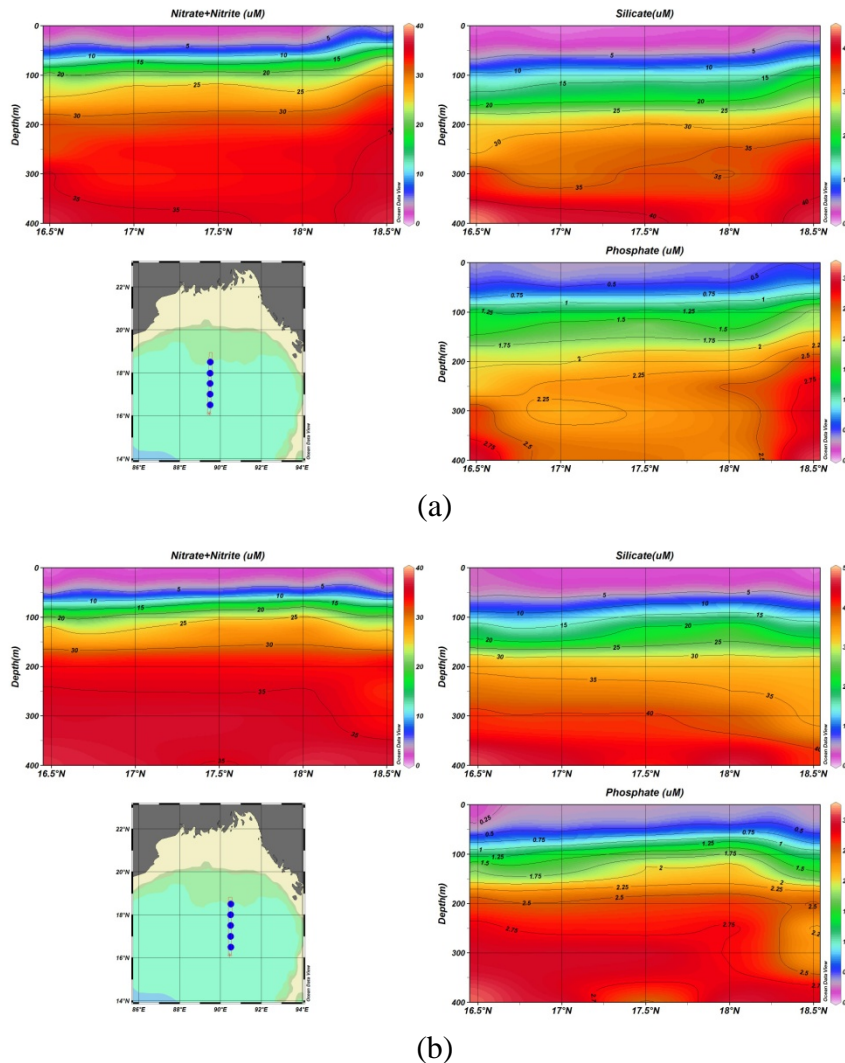
Figure 3 The vertical section profiles of nitrite + nitrate, silicate and phosphate in area A.
      (a)   section A1: station 18, 19, 20, 21 and 22
      (b)   section A2: station 13, 14, 15, 16 and 17

The silicate distribution (Table 2, Figs. 3a and 3b) was also similar to that of the nitrite + nitrate. The concentration of silicate at the MLD ranged between undetectable (N.D.) to 10.87 µM. Thus, the area was generally devoid of silicate except for a noticeable high concentration in station 13, 18 and 23, which indicated that the nutrient must have originated from the river discharge around the area (Subramanian, 1993; Kumar, *et al.*, 2002 and Madhupratap *et al.,* 2003). In the thermocline layer, a strong nutricline was also noticed to have silicate concentration rapidly increasing with depth, ranging from 2.98 to 38.70 µM. Silicate concentration at the sub-thermocline layer ranged between 39.78 and 48.56 µM, The highest silicate concentration of 48.56 µM was found in station 13 at 400 m depth.

Phosphate values (Table 3) in the MLD were also low and gradually increasing with depth. The values were between 0.10-1.02 µM and the distinctly value also found in station 18 and 23. In the thermocline layer, a strong nutricline was also noticed to have phosphate concentration rapidly increasing with depth, ranging from 0.58 to 2.85 µM. At the sub-thermocline layer, phosphate values ranged between 2.09 to 3.13 µM, with the highest concentration of 3.13 µM at 400 m depth in station 13.

Table 2 Concentration of silicate at standard depths.

Area	station	Concentration (µM)											
		Depth (m)											
		0	10	30	50	75	100	125	150	200	250	300	400
A	13	-	2.24	1.64	1.32	5.82	12.65	-	22.2	35.06	38.70	42.22	48.56
	14	-	0.14	0.26	N.D.	3.46	12.92	14.91	-	33.81	37.63	41.55	47.42
	15	-	0.38	N.D.	N.D.	13.17	22.03	26.80	-	33.91	37.43	41.86	40.02
	16	-	N.D.	N.D.	N.D.	14.51	20.15	29.20	-	33.52	36.70	38.53	48.44
	17	-	N.D.	N.D.	1.45	7.40	14.23	20.80	-	34.88	33.42	35.79	44.62
	18	-	0.43	1.44	10.87	-	20.78	21.54	27.8	33.72	38.33	41.01	47.03
	19	-	N.D.	N.D.	0.01	9.17	14.94	16.92	-	28.19	37.00	35.34	39.78
	20	-	N.D.	N.D.	1.1	5.21	15.52	21.90	-	31.78	35.44	37.24	42.80
	21	-	N.D.	N.D.	N.D.	9.07	14.32	17.23	-	27.81	33.71	33.64	40.60
	22	-	N.D.	0.86	1.44	2.98	12.45	15.42	-	28.87	28.30	38.55	44.69
	23	-	1.94	3.24	2.6	4.32	19.29	19.72	-	32.97	35.71	34.43	41.28
	24	N.D.	N.D.	N.D.	1.17	7.94	17.21	27.80	-	34.73	38.50	42.57	46.34
B	29	N.D.	N.D.	N.D.	4.98	10.07	18.43	24.30	-	32.03	37.71	39.86	45.67
	30	N.D.	N.D.	N.D.	2.89	8.58	15.23	22.34	-	30.43	33.11	33.17	42.23
	31	N.D.	N.D.	N.D.	16.00	20.21	21.66	25.00	-	28.99	32.61	39.39	46.03
	34	N.D.	N.D.	N.D.	N.D.	5.12	9.35	8.81	-	20.65	19.44	30.59	33.28
C	1	-	-	-	-	6.63	15.86	-	-	31.81	37.04	41.59	46.63
	2	-	-	0.32	0.39	5.11	13.71	24.40	26.92	-	38.44	35.69	38.66
	3	5.18	0.52	0.56	1.71	10.49	16.41	-	26.93	32.77	31.22	36.19	40.98
	4	-	2.11	1.92	18.40	11.57	17.10	19.93	-	32.27	38.61	31.49	32.59
	5	-	0.9	-	0.49	2.00	11.48	26.62	24.97	34.99	36.42	39.26	42.60
	6	-	0.66	1.59	1.96	7.85	15.19	26.12	-	36.57	35.62	39.35	42.29
	7	0.05	N.D.	0.42	0.63	6.77	22.14	24.91	-	34.11	37.81	37.01	-
	8	0.43	0.49	5.86	14.64	22.6	31.42	35.13	-	38.52	38.94	43.26	40.81
	9	0.61	0.67	1.22	3.47	6.54	14.65	18.74	-	26.15	26.10	29.43	34.93
	10	-	1.69	3.19	1.32	7.79	14.93	-	20.93	29.82	35.60	36.72	39.92
	11	2.03	1.73	1.29	1.10	4.67	12.69	-	23.95	32.2	36.72	37.15	41.78
	12	1.15	0.69	1.24	1.38	9.97	11.15	16.80	-	32.18	36.30	38.08	43.51

"-"= not collected sample, "N.D." = not detected

Nutrients in Area B: the Western Bay of Bengal

Fig. 2b shows the vertical profiles of nutrients and environmental data in the western Bay of Bengal. The mixed layer depth (MLD) and thermocline layer are similar to that described for area A, i.e. 0-50 m and 51-250 m, respectively. The vertical sections of the nutrients are illustrated in fig. 4. The nitrite + nitrate concentration (Table 1, Fig. 4) at MLD layer was between undetectable (N.D.) to 21.25 µM. In the upper 30 m layer, it was undetectable in all stations and gradually increasing with depth. The thermocline layer showed a strong nitricline and was noticed to show concentration that is rapidly increasing with depth, ranging from 16.11 to 33.70 µM, and at the sub-thermocline layer between 31.36 and 35.23 µM. Maximum value of 35.23 µM was found at 400 m in station 29.
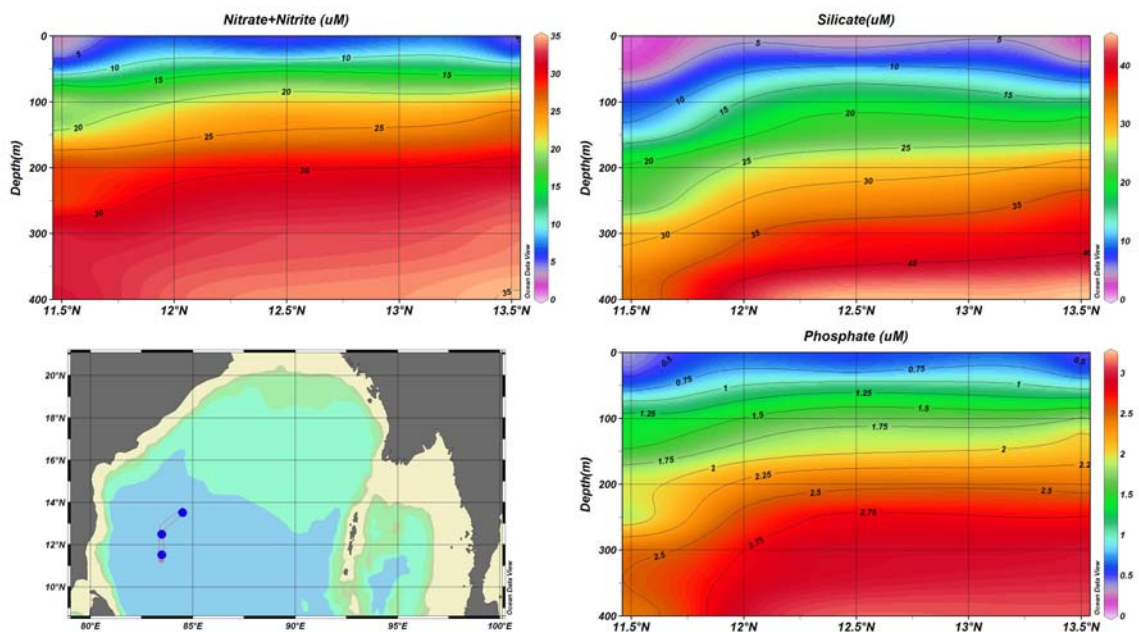
The silicate concentration in the MLD and thermocline layer (Table 2, Fig. 4) was similar to that of the nitrite + nitrate concentration. In the MLD layer, the range was between undetectable (N.D.) to 16.00 µM. The high concentration was also found at station 31. In the thermocline layer, the value was between 5.12 and 37.71 µM, while at the sub-thermocline layer it was between 30.59 and 46.03 µM. A maximum value of 46.03 µM was found at 400 m in station 31.

Table 3 Concentration of phosphate at standard depths.

Area	Station	Concentration (μM)											
		Depth (m)											
		0	10	30	50	75	100	125	150	200	250	300	400
A	13	-	0.12	0.10	0.11	0.78	1.16	2.08	-	2.60	2.83	2.93	3.13
	14	-	0.28	0.23	0.2	0.58	1.71	1.53	-	2.49	2.70	2.94	3.08
	15	-	0.28	0.18	0.17	1.16	2.10	2.40	-	2.63	2.67	2.98	2.25
	16	-	0.25	0.19	0.30	1.68	2.17	2.36	-	2.68	2.85	2.72	3.08
	17	-	0.27	0.22	0.28	0.58	1.24	1.55	-	2.58	2.15	2.24	2.84
	18	-	0.36	0.44	1.02	-	2.06	1.76	2.29	2.73	2.84	2.89	3.09
	19	-	0.39	0.28	0.33	1.13	1.53	1.35	-	2.03	2.64	2.37	2.27
	20	-	0.28	0.27	0.45	0.80	1.49	2.15	-	2.22	2.37	2.24	2.46
	21	-	0.27	0.22	0.23	1.12	1.40	1.71	-	1.87	2.35	2.09	2.41
	22	-	0.31	0.40	0.42	0.60	1.78	1.42	-	2.00	1.96	2.74	2.99
	23	-	0.68	0.72	0.62	0.69	2.00	1.78	-	2.71	2.83	2.32	2.38
	24	0.21	0.18	0.19	0.47	1.48	2.00	2.36	-	2.74	2.81	3.04	3.10
B	29	0.24	0.19	0.21	0.81	1.55	2.06	2.32	-	2.38	2.79	3.00	3.09
	30	0.18	0.15	0.23	0.79	1.30	1.75	1.87	-	2.50	2.63	2.41	2.93
	31	0.34	0.25	0.24	1.45	1.74	1.81	2.09	-	2.53	2.93	3.00	3.16
	34	0.26	0.20	0.19	0.36	1.15	1.75	1.31	-	1.99	1.63	2.59	2.37
C	1	-	-	-	-	0.99	1.65	-	2.47	2.66	-	2.64	2.34
	2	0.37	-	0.40	0.55	0.93	1.66	2.24	2.27	-	2.67	2.23	2.01
	3	0.36	0.37	0.42	0.57	1.25	1.65	-	2.08	2.41	2.09	2.17	2.24
	4	-	0.41	0.59	1.38	1.19	1.61	1.69	-	2.51	2.55	1.79	1.60
	5	-	0.42	-	0.51	0.75	1.38	2.06	2.13	2.61	2.67	2.62	2.31
	6	-	0.44	0.48	0.66	1.13	1.76	2.29	-	2.58	2.33	2.55	2.28
	7	0.40	0.41	0.45	0.60	1.12	2.08	2.25	-	2.61	2.46	2.19	-
	8	0.42	0.5	0.97	1.75	2.17	2.33	2.67	-	2.76	2.57	2.59	2.24
	9	0.41	0.42	0.62	0.89	1.44	1.63	1.90	-	1.87	1.80	1.84	-
	10	-	0.40	0.43	0.57	1.02	1.54	2.06		2.46	2.64	2.57	2.20
	11	0.39	0.39	0.42	0.54	0.86	1.60	-	2.28	2.54	2.66	2.63	2.25
	12	0.42	0.45	0.50	0.74	1.37	1.41	1.61	-	2.60	2.67	2.51	1.96

"-"= not collected sample, "N.D." = not detected

Figure 4 The vertical section profiles of nitrite + nitrate, silicate and phosphate in area B, station 29, 31 and 34.

For the phosphate concentration (Table 3, Fig. 4) in the MLD layer, the range was between 0.15 and 1.45 µM, the highest concentration was in station 31 at 50 m depth. In the thermocline layer, the value was between 1.15 and 2.93 µM, and 2.37-3.16 µM at the sub-thermocline layer. The highest concentration of 3.16 µM was also found at 400 m in station 31.

**Nutrients in Area C: the Eastern Bay of Bengal**

Fig. 2c shows the vertical profiles of nutrients and environmental data in the eastern Bay of Bengal. The MLD and thermocline layer are also described at depths 0-50 m and 51-200 m, respectively. The vertical sections of the nutrients in this area were divided into three sections: section C1 (Fig. 5a) included station 1, 6, 7, 12; section C2 (Fig. 5b) consist of station 2, 5, 8, 11 and section C3 (Fig. 5c) with station 3, 4, 9, 10.

The nitrite + nitrate concentration (Table 1) ranged between undetectable (N.D.) to 3.52 µM in the MLD. Most of them were undectable. The low salinity in the surface waters in the North of this area and near shore section (Fig. 5c) suggests that there was influence of river inputs from the land to the open ocean. However, there was no significant input of nitrite + nitrate in the water mass. It is possible that the nitrate transported by the river runoffs is biologically consumed within the estuarine and coastal regions (Kumar *et al.,* 2002). However, in station 8 of section C2 (Fig. 5b) located at the center of area C, a remarkable high value of nitrite + nitrate. In the thermocline layer the concentration of nitrite + nitrate ranged between 1.29 and 36.09 µM. A strong nitricline concentration was noticed to be rapidly increasing with depth until below 200 m when it tended to be constant (Fig. 5 a-5 c). While in the sub-thermocline layer, the range was 29.53-36.63 µM with the maximum value of 36.63 µM found at 400 m in station 11. The concentration of nitrite + nitrate in this area was also similar to other studies in the Bay of Bengal (Obromwan, 2006 and Kumar *et al*., 2007).

In all stations in area C, the concentration of silicate also increased with depth. The silicate value (Table 2) was also low at the MLD layer, between 0.05-18.40 µM except in station 8 which had high value similar to that of the nitrite + nitrate value (Fig. 5b). In the thermocline layer, a strong nutricline was also noticed to have silicate concentration rapidly increasing with depth similar to that in areas A and B, ranging from 2.00 to 38.52 µM. At the sub-thermocline layer, the range was between 26.10 and 46.63 µM and the highest value (46.63 µM) was found at depth 400 m of station 1. Comparing the silicate concentration in section C3 located near shore with that in section C1 and C2 which are in the open sea, the concentration at surface layer (section C3) was slightly higher than in C1 and C2 (Fig. 5a-5c). This suggests that there was influence of river runoff of silicate from the rivers such as the Irrawady river, etc. (Subramanian, 1993).

As for the phosphate concentration, at MLD layer the range was between 0.36 and 1.75 µM. In thermocline layer, it was between 0.75 and 2.76 µM. A strong nutricline showed a trend of phosphate concentration increasing with depth until approximately 200 m. Station 8 at MLD and thermocline layer had high value similar to nitrite + nitrate and silicate. At the sub-thermocline layer, the range was between 1.60 and 2.67 µM. The concentration of phosphate in this study was also in the same range as that observed by Obromwan (2006).
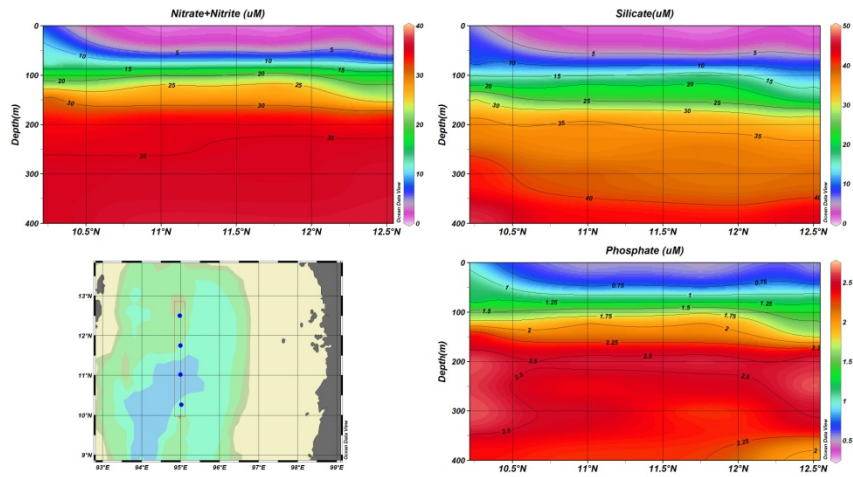
(a)
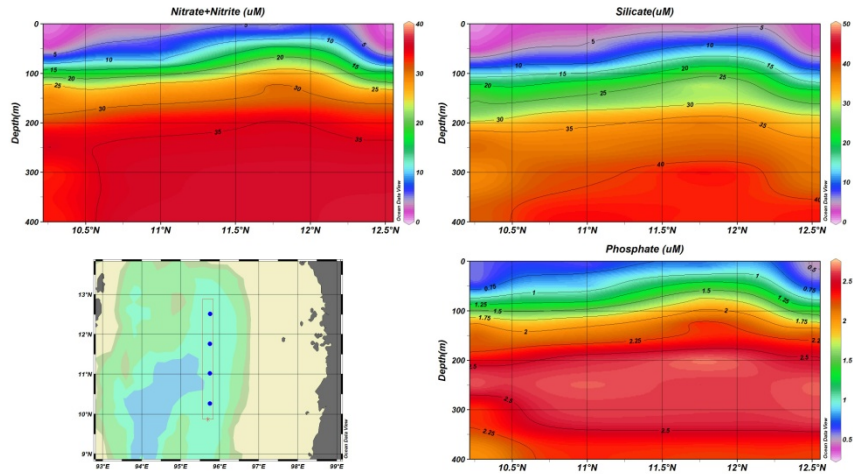
(b)
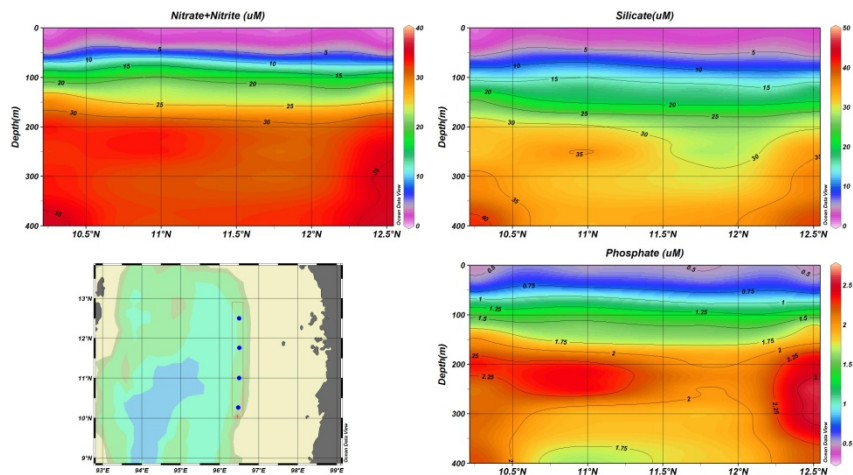
(c)

Figure 5 The vertical section profiles of nitrite + nitrate, silicate and phosphate in area C.

    (a)   section C1: station 1, 6, 7 and 12

    (b)   section C2: station 2, 5, 8 and 11

    (c)   section C3: station 3, 4, 9 and 10

Conclusions

The result of this study showed that the distribution of the nutrients: nitrite + nitrate, silicate and phosphate uniformly increased with depth at all sampling stations. Generally, the MLD layer in the Bay of Bengal had very low nutrient concentrations or sometimes even undetectable. In addition, there were several near shore stations that had nutrient concentration higher than those in stations in the open sea. Nutricline concentration was noticed to be rapidly increasing with depth beyond 50 m. Until about 200-250 m, the nutrient values were nearly constant or slightly changed. Finally, spatial distribution of nutrient studies will certainly provide better scientific basis to understand the ecosystem of the Bay of Bengal.

Acknowledgement

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