

CHAPTER 5

# *Results*

## Chapter 5

### RESULTS

#### 5.1 Distributional patterns of the fluxes of total particulate, total coccolithophore and various taxa in the Northern Bay of Bengal

*(Although, it is being widely referred to both the shallow and deep traps in the following results and discussions chapters, owing to the non availability of full set of 13 deep trap samples, clear picture on temporal distribution could not be obtained. However, some trends and useful information could be derived for those intervals wherever samples were available).*

##### 5.1.1 Total particulate flux

Total particulate fluxes in the northern Bay of Bengal traps varied between 37.08 - 147.66 mg m<sup>-2</sup>d<sup>-1</sup> for the shallow trap and 47.39 and 134.98 mg m<sup>-2</sup>d<sup>-1</sup> for the deep trap with average values of 83.84 mg m<sup>-2</sup>d<sup>-1</sup> and 89.90 mg m<sup>-2</sup>d<sup>-1</sup> respectively (Tables 5.1 and 5.2). The shallow trap showed a seasonality characterized by a distinct bi-modal distributional pattern. The highest fluxes with a major peak were associated with the SW monsoon during August/September followed by a minor peak occurring during NE-SW intermonsoon (April-May) and lowest fluxes during NE monsoon (Fig. 5.1a). The deep trap also reflected somewhat similar distributional pattern corresponding with the shallow trap with a distinct major peak associated with the late SW monsoon (September) and a secondary peak during NE-SW intermonsoon period (May) (Fig. 5.1a).

##### 5.1.2 Total coccolithophore flux

The total coccolithophore fluxes from the shallow trap varied between 12.89 and 85.35 x 10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup> with an average value of 41.55 x 10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup> (Table 5.3). But, based on only five samples collected during January-May it was observed that these fluxes in the deep trap varied significantly showing values between 13.38 and 42.22 x 10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup> with an average flux value of 31.41 x 10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup> (Table 5.4). Due to the malfunctioning of trap, samples for the remaining period of the year could not be collected. The total coccolithophore fluxes in the shallow trap were moderately distributed with relatively minor and major peaks noticed during early and late SW monsoons

**Table 5.1.** Temporal variation of total particulate flux and the major components (calcium carbonate, lithogenic, biogenic opal and organic carbon fluxes) in the Northern Bay of Bengal (NBBT) for the period 29 January-16 December 1992 in the shallow trap.

Northern Bay of Bengal Trap (NBBT 06) (Shallow Trap)						
Stn. No.	Sampling period	Calcium carbonate	Litho- genic	Biogenic opal	Organic carbon	Total particulate
		Flux ( $\text{mg m}^{-2}\text{d}^{-1}$ )				
1	29 January - 8 February 1992	18.58	6.86	6.48	2.86	37.08
2	8 February - 5 March 1992	33.26	7.84	8.18	2.64	54.04
3	5 March - 31 March 1992	30.69	16.05	16.49	5.29	72.75
4	31 March - 26 April 1992	47.05	15.64	15.14	5.29	87.36
5	26 April - 22 May 1992	37.64	25.01	14.51	6.15	88.23
6	22 May - 17 June 1992	32.99	18.39	14.36	5.78	76.15
7	17 June - 13 July 1992	32.91	28.18	13.83	6.67	86.93
8	13 July - 8 Aug 1992	48.08	21.14	10.32	3.99	86.72
9	8 August - 3 September 1992	46.56	56.15	29.93	8.35	147.66
10	3 September - 29 September 1992	33.59	42.45	27.26	6.52	115.02
11	29 September - 25 October 1992	26.46	24.47	19.86	5.34	80.39
12	25 October - 20 November 1992	22.21	32.59	22.87	6.27	88.94
13	20 November - 16 December 1992	22.73	19.04	17.21	5.37	68.66
<b>Average</b>		<b>32.28</b>	<b>24.14</b>	<b>16.65</b>	<b>5.42</b>	<b>83.84</b>

**Table 5.2.** Seasonal variation of total particulate flux and the major components (calcium carbonate, lithogenic, biogenic opal and organic carbon fluxes) in the Northern Bay of Bengal (NBBT) for the period 29 January-16 December 1992 in the deep trap.

Northern Bay of Bengal Trap (NBBT 06) (Deep Trap)						
Stn. No.	Sampling period	Calcium carbonate	Litho- genic	Biogenic opal	Organic carbon	Total particulate
		Flux ( $\text{mg m}^{-2}\text{d}^{-1}$ )				
1	29 January - 8 February 1992	16.55	13.50	11.82	3.07	47.39
2	8 February - 5 March 1992	23.66	14.63	13.74	3.45	58.24
3	5 March - 31 March 1992	22.37	17.73	16.62	4.64	65.06
4	31 March - 26 April 1992	31.37	21.30	19.11	5.42	81.55
5	26 April - 22 May 1992	33.80	43.07	20.73	11.42	118.15
6	22 May - 17 June 1992	24.83	24.05	18.51	5.81	77.85
7	17 June - 13 July 1992	30.21	28.08	18.51	6.35	88.23
8	13 July - 8 August 1992	40.92	29.32	18.36	5.29	98.13
9	8 August - 3 September 1992	36.07	41.22	21.61	5.87	109.46
10	3 September - 29 September 1992	54.38	43.13	26.84	5.90	134.98
11	29 September - 25 October 1992	27.06	37.54	25.51	5.68	100.35
12	25 October - 20 November 1992	28.72	34.89	24.87	5.38	98.15
13	20 November - 16 December 1992	36.54	26.94	19.49	4.54	91.15
<b>Average</b>		<b>31.27</b>	<b>28.88</b>	<b>19.67</b>	<b>5.60</b>	<b>89.90</b>

**Table 5.3.** Seasonal variation of fluxes of various coccolithophore taxa in the Northern Bay of Bengal (NBBT) for the period 29 January-16 December 1992 in the shallow trap.

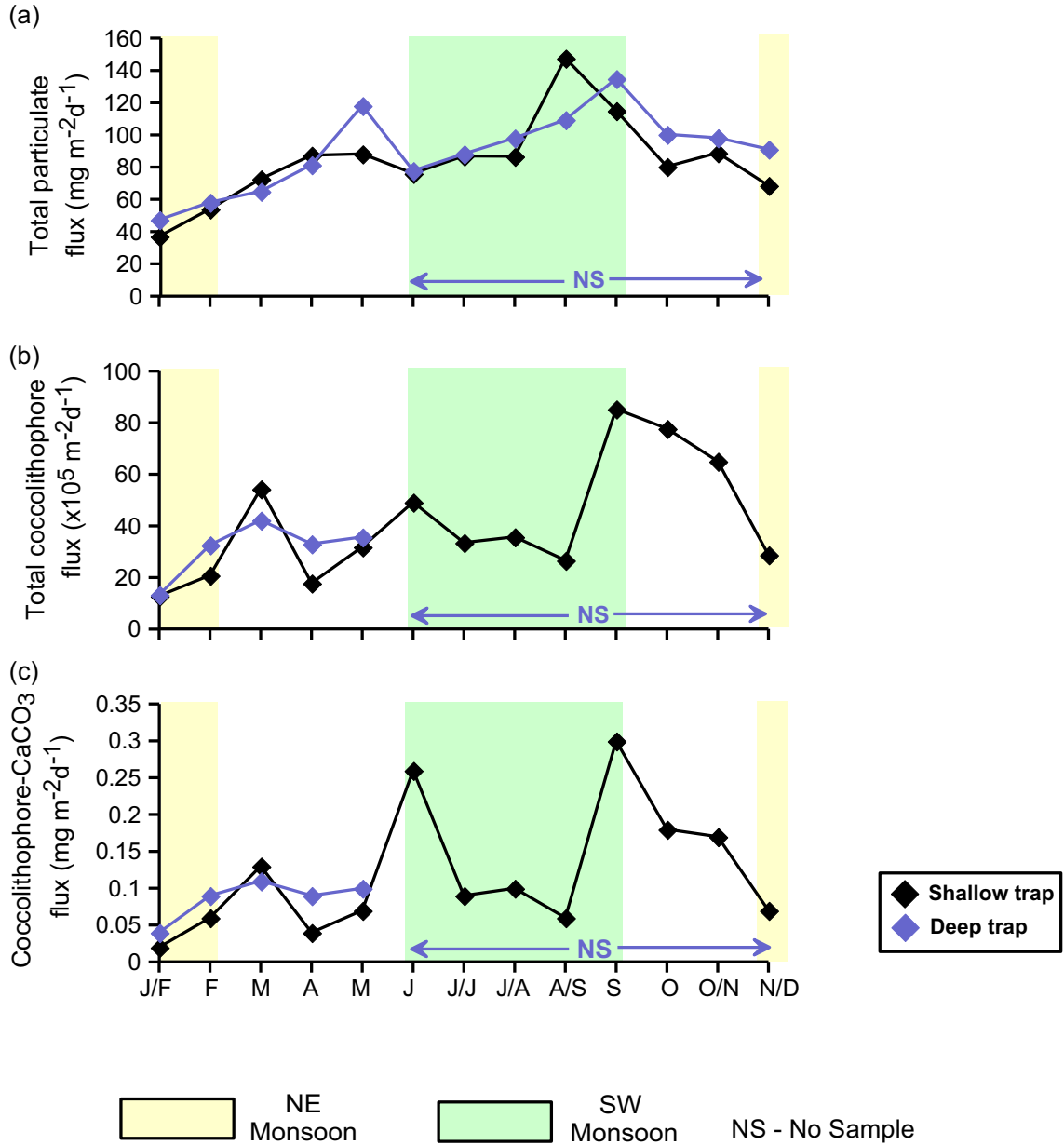
Northern Bay of Bengal Trap (NBBT 06) (Shallow Trap)															
Flux ( $\times 10^5 \text{ m}^{-2} \text{ d}^{-1}$ )												Average			
Interval	29/1/92- 8/2/92	8/2/92- 5/3/92	5/3/92- 31/3/92	31/3/92- 26/4/92	26/4/92- 22/5/92	22/5/92- 17/6/92	17/6/92- 13/7/92	13/7/92- 8/8/92	8/8/92- 3/9/92	3/9/92- 29/9/92	29/9/92- 25/10/92	25/10/92- 20/11/92	25/10/92- 20/11/92	13	Average
Station No.	1	2	3	4	5	6	7	8	9	10	11	12	13		
<b>Species</b>															
<i>G. oceanica</i>	6.84	10.87	28.76	7.75	15.32	28.29	14.16	20.92	14.46	44.35	35.71	27.38	13.52		20.64
<i>E. huxleyi</i>	0.47	1.30	2.29	1.38	1.30	1.74	0.47	1.13	0.77	2.62	0.39	0.83	0.36		1.16
<i>C. mediterranea</i>			1.38	0.91	1.30	1.74	0.47	0.39		0.44	1.60	0.83			1.01
<i>S. pulchra</i>					0.44		0.47	0.39		0.88	0.39				0.51
<i>U. sibogae</i>	1.82	3.04	9.13	2.73	2.62	6.95	7.31	2.65	6.46	19.12	13.49	7.89	4.39		6.74
<i>U. irregularis</i>	0.47	1.74	3.64	1.38	4.77	3.04	4.55	3.04	1.52	3.04	2.79	0.83	1.46		2.48
<i>U. tenuis</i>												0.41			0.41
<i>H. carteri</i>			1.82			0.88	0.47	0.77	0.77	2.18	1.99	2.48			1.42
<i>C. leptopora</i>		0.44		0.47	0.88	1.32	2.35	0.77		0.88	0.80	1.24			1.02
<i>F. profunda</i>	1.41	1.30	2.73	1.82	0.88	1.74	1.41	1.52	1.90	4.77	14.68	20.34	6.21		4.67
<i>Calciosolenids</i> sp.			0.47			0.88		0.39		0.88	0.80		0.72		0.69
<i>D. tubifera</i>	0.94		0.47		0.88			0.39			0.39	0.41			0.58
<i>R. clavigera</i>				0.47	0.44								0.36		0.42
<i>O. antillarum</i>					0.44	0.44			0.39	1.32	0.80	0.83	0.36		0.65
<i>S. pulchra</i>			0.47												0.47
<i>S. pirus</i>							0.47	0.77							0.62
<i>S. lamina</i>	0.94	1.74	1.82			0.44			0.39	0.88	1.99	0.41	0.72		1.04
<i>Syracosphaera</i> sp.			0.47		0.88		0.47	0.39		0.88					0.62
<i>N. coccolithomorpha</i>			0.94	0.47	1.30	0.44	0.47	1.52		0.88	0.80				0.85
<i>A. oryza</i>				0.47		0.88									0.68
<i>C. cristatus</i>					0.44		0.47			0.44	0.39				0.43
Total coccolith flux	12.89	20.42	54.39	17.86	31.90	48.79	33.53	35.02	26.66	83.59	77.00	63.88	28.09		41.08
Total coccosphere flux		0.44			0.44	0.44		0.77		1.76	0.78	1.24	0.72		0.47
<b>Total coccolithophore flux</b>	<b>12.89</b>	<b>20.86</b>	<b>54.39</b>	<b>17.86</b>	<b>31.90</b>	<b>49.23</b>	<b>33.53</b>	<b>35.79</b>	<b>26.66</b>	<b>85.35</b>	<b>77.78</b>	<b>65.12</b>	<b>28.81</b>		<b>41.55</b>

**Table 5.4.** Seasonal variation of fluxes of various coccolithophore taxa in the Northern Bay of Bengal (NBBT) for the period 29 January-16 December 1992 in the deep trap.

Northern Bay of Bengal Trap (NBBT 06) (Deep Trap)														
Flux ( $\times 10^5 \text{ m}^{-2} \text{ d}^{-1}$ )												Average		
Interval	29/1/92- 8/2/92	8/2/92- 5/3/92	5/3/92- 31/3/92	31/3/92- 26/4/92	26/4/92- 22/5/92	22/5/92- 17/6/92	17/6/92- 13/7/92	13/7/92- 8/8/92	8/8/92- 3/9/92	3/9/92- 29/9/92	29/9/92- 25/10/92	25/10/92- 20/11/92	20/11/92- 16/12/92	13
Station No.	1	2	3	4	5	6	7	8	9	10	11	12	13	
<i>G. oceanica</i>	8.33	22.60	23.49	17.83	19.57									18.36
<i>E. huxleyi</i>		0.88	1.74	0.88										1.17
<i>C. mediterranea</i>			0.44	1.74	0.88									1.02
<i>S. pulchra</i>			0.44	0.44	0.44									0.44
<i>U. sibogae</i>	2.73	5.22	8.69	8.69	5.66									6.20
<i>U. irregularis</i>	0.91	0.44	1.30	0.88	2.62									1.23
<i>U. tenuis</i>			0.44											0.44
<i>H. carteri</i>	0.47	1.74	1.74	1.30	1.30									1.31
<i>C. leptopora</i>	0.47	0.88	0.88	0.88	1.30									0.88
<i>F. profunda</i>			0.88	0.44	0.44									0.59
<i>O. antillarum</i>	0.47				0.44									0.46
<i>S. lamina</i>		0.44	1.30		0.44									0.73
<i>N. coccolithomorpha</i>		0.44	0.88		1.74									1.02
<i>C. cristatus</i>					0.88									0.88
<b>Total coccolithophore flux</b>	<b>13.38</b>	<b>32.65</b>	<b>42.22</b>	<b>33.09</b>	<b>35.71</b>									<b>31.41</b>

No Sample

**Fig. 5.1.** Seasonal variation of (a) total particulate (b) total coccolithophore and (c) coccolithophore-CaCO<sub>3</sub> fluxes in the shallow and deep traps from the northern Bay of Bengal (NBBT). The shaded bands represent the periods of different monsoon seasons.



(June and September) (Fig. 5.1b). Whereas, the fluxes were relatively low during NE monsoon which marginally increased during NE-SW intermonsoon (March) (Fig. 5.1b). Deep trap also followed more or less the same trend as that of the shallow trap with marginally increased fluxes occurring during NE-SW intermonsoon (Fig. 5.1b).

### 5.1.3 Flux patterns of various taxa

In the northern Bay of Bengal (NBBT), twenty one species of coccolithophores were encountered in the shallow trap deployed at a depth of 1156 m, among which dominant species were *G. oceanica* ( $20.64 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ), *U. sibogae* ( $6.74 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ), *F. profunda* ( $4.67 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ), and *U. irregularis* ( $2.48 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ) (Table 5.3). Whereas, *E. huxleyi*, *H. carteri*, *C. leptopora*, *C. mediterranea*, *D. tubifera*, *S. lamina*, *N. coccolithomorpha* and *A. oryza* were the common species (Table 5.3 and Plates (1 - 6)). The remaining species such as *S. pulchra*, *U. tenuis*, *Calciosolenids* sp., *R. clavigera*, *O. antillarum*, *S. pulchra*, *S. pirus*, *C. cristatus* and *syracosphaera* sp. were sparsely distributed (Table 5.3).

On the other hand, the diversity in the deep trap (2146 m) was low with fourteen species. The dominant species among them were *G. oceanica* ( $18.36 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ), *U. sibogae* ( $6.20 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ), *U. irregularis* ( $1.23 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ) and *H. carteri* ( $1.31 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ) (Table 5.4). Whereas, *E. huxleyi*, *C. leptopora*, *C. mediterranea*, *O. antillarum*, *N. coccolithomorpha* and *C. cristatus* were common among the coccolithophore assemblage (Table 5.4). Besides, the remaining minor species such as *S. pulchra*, *U. tenuis*, *F. profunda* and *S. lamina* distributed sporadically.

***G. oceanica*:** This species dominated the coccolithophore assemblage throughout the sampling period both in the shallow and deep traps. The fluxes in the shallow trap ranged from 6.84 to  $44.35 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average flux value of  $20.64 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  (Table 5.3). Whereas, in the deep trap the fluxes varied from 8.33 to  $23.49 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $18.36 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  (Table 5.4). The fluxes of *G. oceanica* also displayed a similar seasonal trend as that of total coccolithophore fluxes with major and minor peaks

coinciding with the early and late SW monsoons (June and September) (Fig. 5.2a). Besides it also showed a secondary minor peak during NE-SW intermonsoon (March) (Fig. 5.2a). Relatively higher fluxes were observed in the deep trap during NE and NE-SW intermonsoons with a peak associated with NE-SW intermonsoon (March) (Fig. 5.2a).

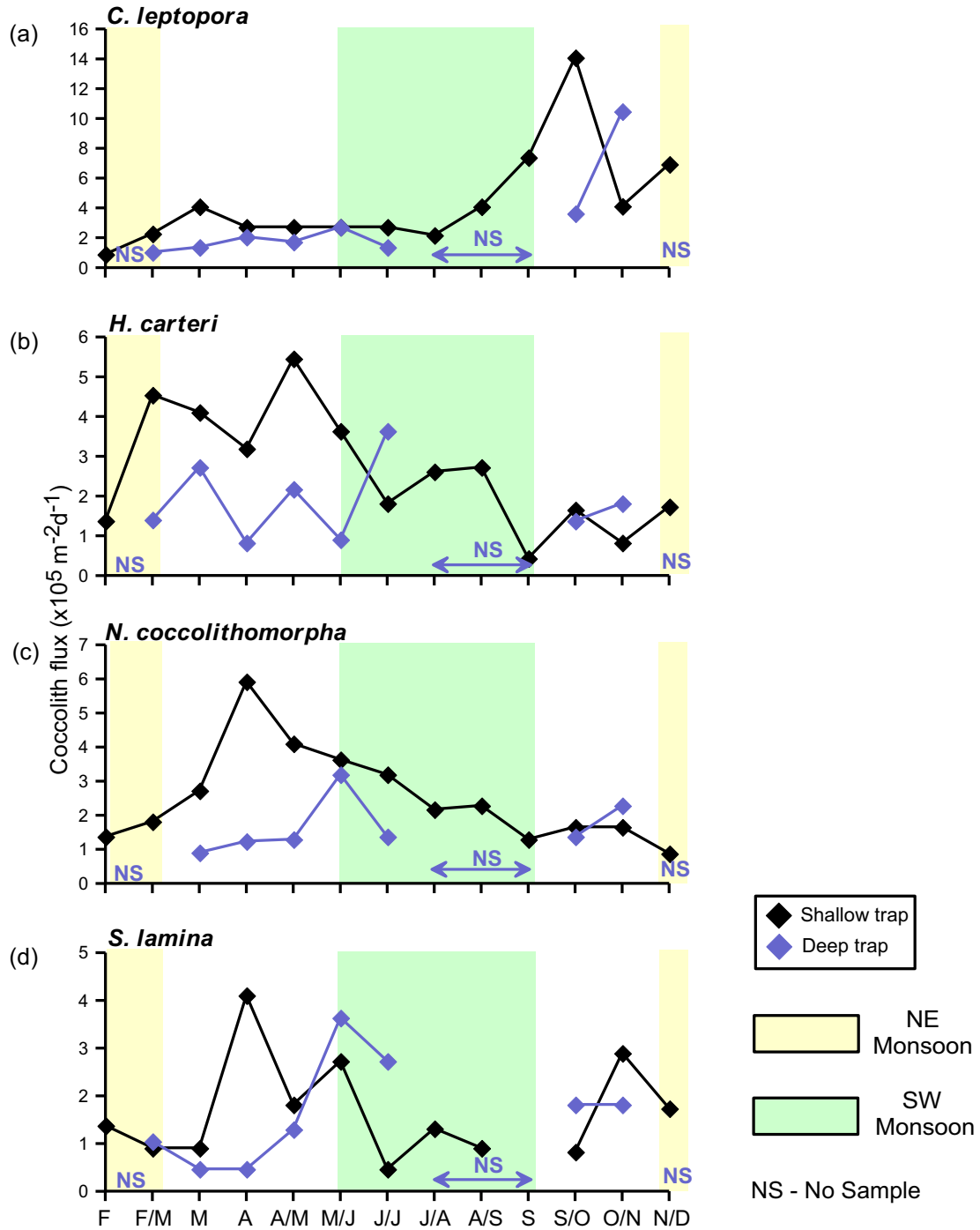
***U. sibogae***: It was the second dominant species among the coccolithophore assemblage in both the shallow and deep traps. The fluxes in the shallow trap ranged between  $1.82$  and  $19.12 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $6.74 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  (Table 5.3), while it varied between  $2.73$  and  $8.69 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $6.20 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  in the deep trap (Table 5.4). The distributional trend of fluxes of this species in the shallow trap corresponds with the total coccolithophore fluxes displaying a prominent peak associated with late SW monsoon (September) and a minor peak during NE-SW intermonsoon (March) (Fig. 5.2b). Besides, a second minor peak was also displayed during SW monsoon (June/July) (Fig. 5.2b). The deep trap showed relatively increased fluxes of *U. sibogae* during NE-SW intermonsoon (March-May) as observed in the shallow trap (Fig. 5.2b).

***E. huxleyi***: Its fluxes varied from  $0.36$  to  $2.62 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $1.16 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  in the shallow trap (Table 5.3). It also followed more or less a similar distributional pattern displayed by total coccolithophore fluxes with a prominent peak associated with late SW monsoon (September) and two minor peaks during early NE-SW intermonsoon (March) and early SW monsoon (June) (Fig. 5.2c). While the fluxes in the deep trap ranged from  $0.88$  to  $1.74 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $1.17 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  (Table 5.4). *E. huxleyi* fluxes recorded in the deep trap were comparatively lower during NE-SW intermonsoon compared to shallow trap. But, it did show a peak during NE-SW intermonsoon (March) (Fig. 5.2c).

***U. irregularis***: The flux values varied from  $0.47$  to  $4.77 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average flux value of  $2.48 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  for the shallow trap with two peaks associated with NE-SW intermonsoon and early SW monsoon (May and June/July) respectively (Table 5.3). Besides, a minor peak was also observed during NE-SW intermonsoon (March) (Fig. 5.2d). Whereas, in the deep trap,



**Fig. 5.8.** Seasonal variation of coccolith fluxes of (a) *C. leptopora* (b) *H. carteri* (c) *N. coccolithomorpha* and (d) *S. lamina* in the shallow and deep traps from the central Bay of Bengal (CBBT). The shaded bands represent the periods of different monsoon seasons.



fluxes ranged from 0.44 to  $2.62 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average flux value of  $1.23 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  and it recorded comparatively lower fluxes than shallow trap. A marginally increased flux was observed during NE-SW intermonsoon similar to that of shallow trap (Table 5.4 and Fig. 5.2d).

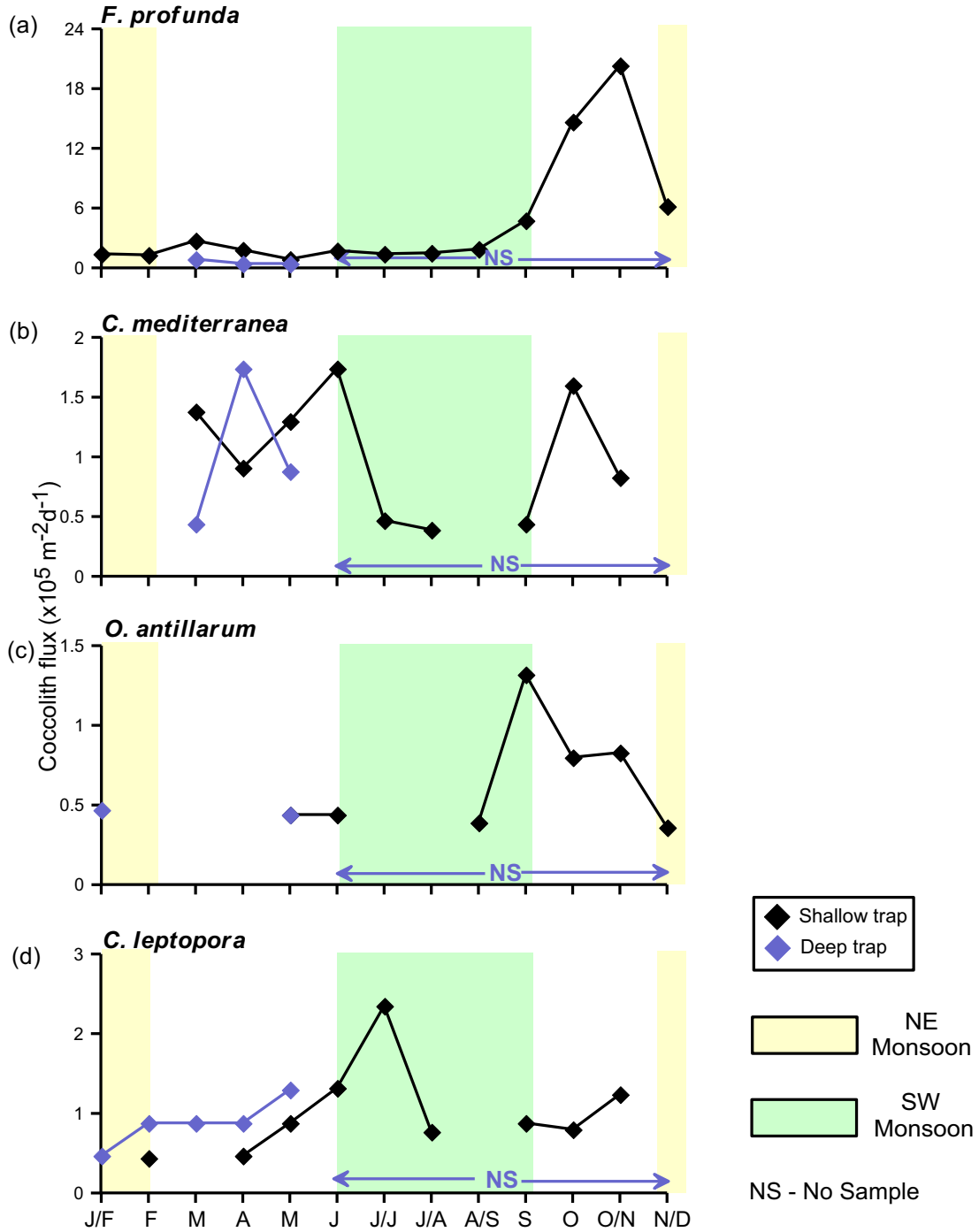
***F. profunda***: The flux value for this species varied between 0.88 and  $20.34 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $4.67 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  in the shallow trap and remained very low throughout the sampling period except for a prominent peak value of  $20.34 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  during SW-NE intermonsoon (October/November) (Table 5.3 and Fig. 5.3a). The deep trap recorded very low fluxes, which ranged from 0.44 -  $0.88 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average flux value of  $0.59 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  (Table 5.4 and Fig. 5.3a).

***C. mediterranea***: This species showed a patchy distribution which varied between 0.39 and  $1.74 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $1.01 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  in the shallow trap (Table 5.3). The fluxes showed peak abundance during early SW monsoon (June) and SW-NE intermonsoon (October) (Fig. 5.3b). While the fluxes in deep trap ranged between 0.44 and  $1.74 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $1.02 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  (Table 5.4).

***O. antillarum***: This was also a very sparsely distributed species which ranged from 0.36 to  $1.32 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $0.65 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  in the shallow trap (Table 5.3). Fluxes were slightly increased during late SW monsoon (September) (Fig. 5.3c). While in the deep trap the fluxes varied between 0.44 and  $0.47 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average of  $0.46 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  (Table 5.4).

***C. leptopora***: It exhibited a patchy distribution in the shallow trap with a varied flux values between 0.44 to  $2.35 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $1.02 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  (Table 5.3). Increased fluxes were observed during SW monsoon (June/July) (Fig. 5.3d). The fluxes in the deep trap varied from 0.47 to  $1.30 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average of  $0.88 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  (Table 5.4). It recorded moderate fluxes which increased marginally during late NE and NE-SW intermonsoon (February-March) (Fig. 5.3d).

**Fig. 5.3.** Seasonal variation of coccolith fluxes of (a) *F. profunda* (b) *C. mediterranea* (c) *O. antillarum* and (d) *C. leptopora* in the shallow and deep traps from the northern Bay of Bengal (NBBT). The shaded bands represent the periods of different monsoon seasons.



**H. carteri:** This is also one of the species which exhibited a patchy distribution with flux ranging from 0.47 to  $2.48 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  and an average value of  $1.42 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  in the shallow trap (Table 5.3). The highest flux value of  $2.48 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  was recorded during SW-NE intermonsoon (October/November) (Fig. 5.4a). While in the deep trap the flux ranged from 0.47 to  $1.74 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $1.31 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with increased fluxes occurring during NE and NE-SW monsoons (February-March) (Table 5.4 and Fig. 5.4a).

**N. coccolithomorpha:** It's flux values varied between 0.44 to  $1.52 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $0.85 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  in the shallow trap displaying increased fluxes during NE-SW intermonsoon (May) followed by a maximum value of  $1.52 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  during SW monsoon (July/August) (Table 5.3 and Fig. 5.4b). While in the deep trap, the fluxes varied from 0.44 to  $1.74 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $1.02 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ , with a maximum fluxes ( $1.74 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ) associated with NE-SW intermonsoon (May) (Table 5.4 and Fig. 5.4b).

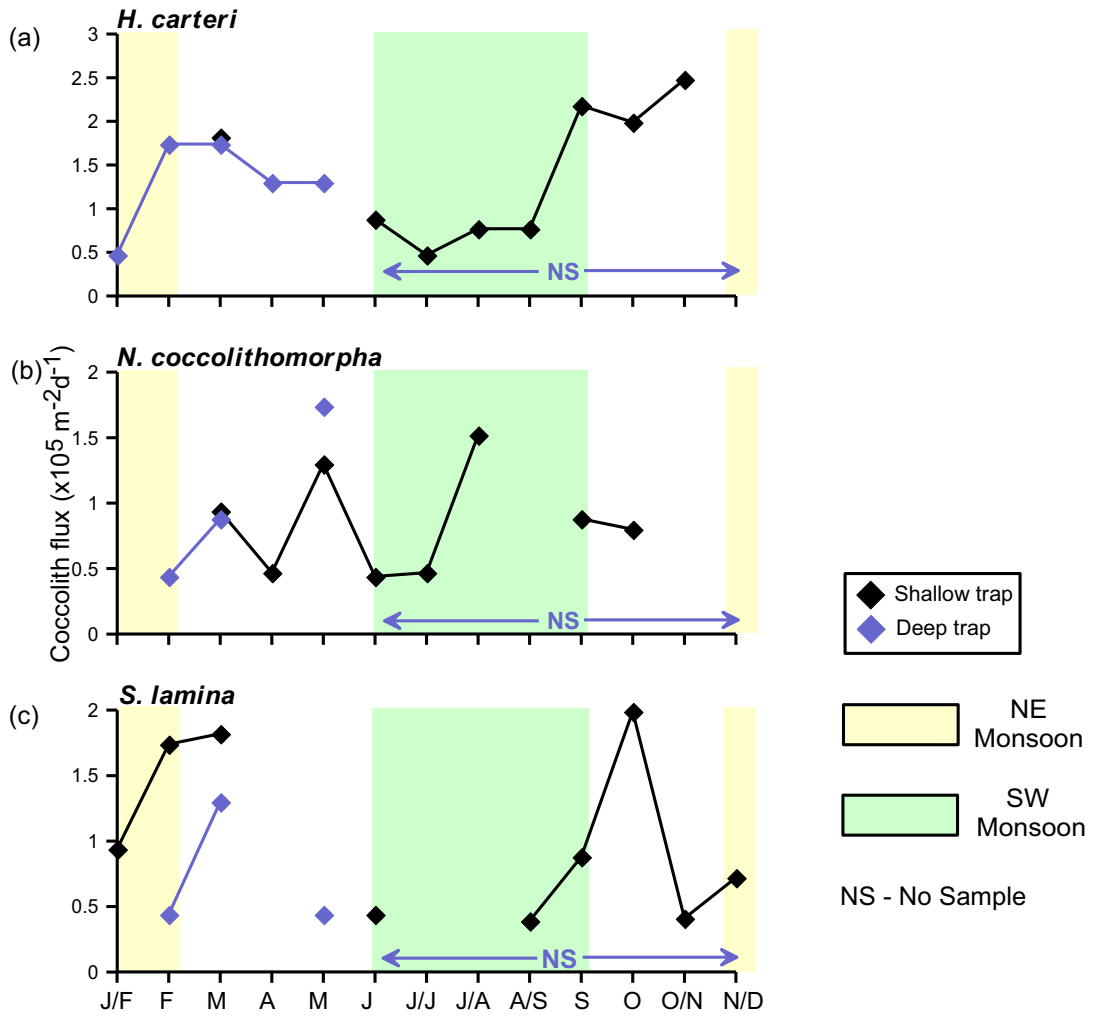
**S. lamina:** It exhibited a patchy distribution in the shallow trap and ranged from 0.39 to  $1.99 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $1.04 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  (Table 5.3). It showed increased fluxes during SW-NE intermonsoon (October) followed by a peak during late NE and NE-SW monsoons (February-March) (Fig. 5.4c). While in the deep trap, it varied from 0.44 to  $1.30 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $0.73 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  (Table 5.4). The deep trap recorded slightly increased fluxes of  $1.30 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  during NE-SW intermonsoon (March) (Fig. 5.4c).

## **5.2 Distributional patterns of the fluxes of total particulate, total coccolithophore and various taxa in the Central Bay of Bengal**

### **5.2.1 Total particulate flux**

Total particulate fluxes from the central Bay of Bengal (CBBT) varied between 49.50 and 150.50  $\text{mg m}^{-2}\text{d}^{-1}$  for the shallow trap and 63.26 to 135.37  $\text{mg m}^{-2}\text{d}^{-1}$  for the deep trap with average fluxes of 95.09  $\text{mg m}^{-2}\text{d}^{-1}$  and 98.91  $\text{mg m}^{-2}\text{d}^{-1}$

**Fig. 5.4.** Seasonal variation of coccolith fluxes of (a) *H. carteri* (b) *N. coccolithomorpha* and (c) *S. lamina* in the shallow and deep traps from the northern Bay of Bengal (NBBT). The shaded bands represent the periods of different monsoon seasons.



mg m<sup>-2</sup>d<sup>-1</sup> respectively (Tables 5.5 and 5.6). The fluxes in the shallow trap showed a distinct seasonality with relatively high fluxes occurring during SW monsoon with peak abundances observed during (September) and (July/August) (Fig. 5.5a). Whereas during NE monsoon higher fluxes (85.10 mg m<sup>-2</sup>d<sup>-1</sup>) was recorded during (February) and a very low flux value of 49.50 mg m<sup>-2</sup>d<sup>-1</sup> was recorded during NE-SW intermonsoon (April). While, the deep trap recorded lower fluxes compared to that of the shallow trap during NE-SW intermonsoon through SW monsoon (April – September) (Fig 5.5a). And showed a seasonal trend with higher fluxes during SW-NE intermonsoon till NE monsoon (October - March) (Fig. 5.5a).

### 5.2.2 Total coccolithophore flux

The total coccolithophore fluxes in the shallow trap at CBBT varied between 62.20 and 164.34 x 10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup> with an average value of 114.68 x 10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup> (Table 5.7). But, due to the malfunctioning of trap, samples for the periods (February, July –September and November/December) were not available for the deep trap and the available eight samples showed an average value of 114.14 x 10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup>, which varied between 81.05 and 172.62 x 10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup> (Table 5.8). The total coccolithophore fluxes in the shallow trap displayed seasonality with major and three minor peaks wherein, higher fluxes were represented by a major peak associated with NE-SW intermonsoon (March/April) and minor peaks with SW monsoon (July/August) and late NE monsoon (February/March) and with a distinct low value (62.20 x 10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup>) during late SW monsoon (September) (Fig. 5.5b). The deep trap displayed more or less similar trend as that of the shallow trap with comparatively lower fluxes, but with peak occurring during NE-SW intermonsoon (April) wherein observed fluxes were higher than shallow trap (Fig. 5.5b).

### 5.2.3 Flux patterns of various taxa

The shallow trap at a water depth of 1588 m at CBBT encountered a total of twenty one species of coccolithophores among which dominant species were *G. oceanica* (43.00 x 10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup>), *U. sibogae* (18.83 x 10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup>), *F. profunda* (13.70 x 10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup>), *U. irregularis* (13.08 x 10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup>), *E. huxleyi*

**Table 5.5.** Seasonal variation of total particulate flux and the major components (calcium carbonate, lithogenic, biogenic opal and organic carbon fluxes) in the Central Bay of Bengal (CBBT) for the period 3 February-16 December in the shallow trap.

Central Bay of Bengal Trap (CBBT 06) (Shallow Trap)						
Stn. No.	Sampling period	Calcium carbonate	Litho- genic	Biogenic opal	Organic carbon	Total particulate
		Flux ( $\text{mg m}^{-2}\text{d}^{-1}$ )				
1	3 February – 8 February 1992	30.90	24.60	20.30	5.20	85.10
2	8 February – 5 March 1992	20.90	31.00	19.00	6.50	82.50
3	5 March – 31 March 1992	25.90	12.40	12.60	4.70	59.50
4	31 March – 26 April 1992	16.80	11.80	12.20	4.80	49.50
5	26 April – 22 May 1992	31.30	29.90	20.80	9.90	99.70
6	22 May – 17 June 1992	42.90	19.80	16.70	6.70	91.50
7	17 June – 13 July 1992	33.90	26.00	22.00	7.40	95.10
8	13 July – 8 Aug 1992	65.60	28.20	25.20	7.60	132.60
9	8 August - 3 September 1992	41.40	24.10	31.70	6.70	109.30
10	3 September – 29 September 1992	54.40	27.90	52.00	9.00	150.50
11	29 September – 25 October 1992	29.40	22.10	43.60	6.60	107.00
12	25 October – 20 November 1992	35.30	22.30	37.70	9.30	112.00
13	20 November – 16 December 1992	29.10	9.00	17.40	3.60	61.90
<b>Average</b>		<b>35.22</b>	<b>22.24</b>	<b>25.48</b>	<b>6.77</b>	<b>95.09</b>

**Table 5.6.** Seasonal variation of total particulate flux and the major components (calcium carbonate, lithogenic, biogenic opal and organic carbon fluxes) in the Central Bay of Bengal (CBBT) for the period 3 February-16 December in the deep trap.

Central Bay of Bengal Trap (CBBT 06) (Deep Trap)						
Stn. No.	Sampling period	Calcium carbonate	Litho- genic	Biogenic opal	Organic carbon	Total particulate
		Flux ( $\text{mg m}^{-2}\text{d}^{-1}$ )				
1	3 February – 8 February 1992	44.70	38.70	28.70	7.20	125.19
2	8 February – 5 March 1992	41.20	35.60	30.30	5.70	117.41
3	5 March – 31 March 1992	23.30	32.60	23.80	5.00	88.73
4	31 March – 26 April 1992	21.60	20.40	15.80	4.20	65.39
5	26 April – 22 May 1992	20.90	18.70	15.70	4.50	63.26
6	22 May – 17 June 1992	26.30	28.80	19.50	6.60	86.43
7	17 June – 13 July 1992	41.90	19.20	13.70	4.00	82.04
8	13 July – 8 August 1992	27.50	23.20	19.40	5.40	79.80
9	8 August - 3 September 1992	45.60	24.40	21.10	6.30	102.53
10	3 September – 29 September 1992	59.20	16.80	17.10	3.70	99.71
11	29 September – 25 October 1992	44.40	21.90	30.00	5.70	106.44
12	25 October – 20 November 1992	46.00	25.90	50.40	7.30	135.37
13	20 November – 16 December 1992	44.60	25.40	49.00	8.10	133.48
<b>Average</b>		<b>37.48</b>	<b>25.51</b>	<b>25.73</b>	<b>5.67</b>	<b>98.91</b>

**Table 5.7.** Seasonal variation of fluxes of various coccolithophore taxa in the Central Bay of Bengal (CBBT) for the period 3 February-16 December 1992 in the shallow trap.

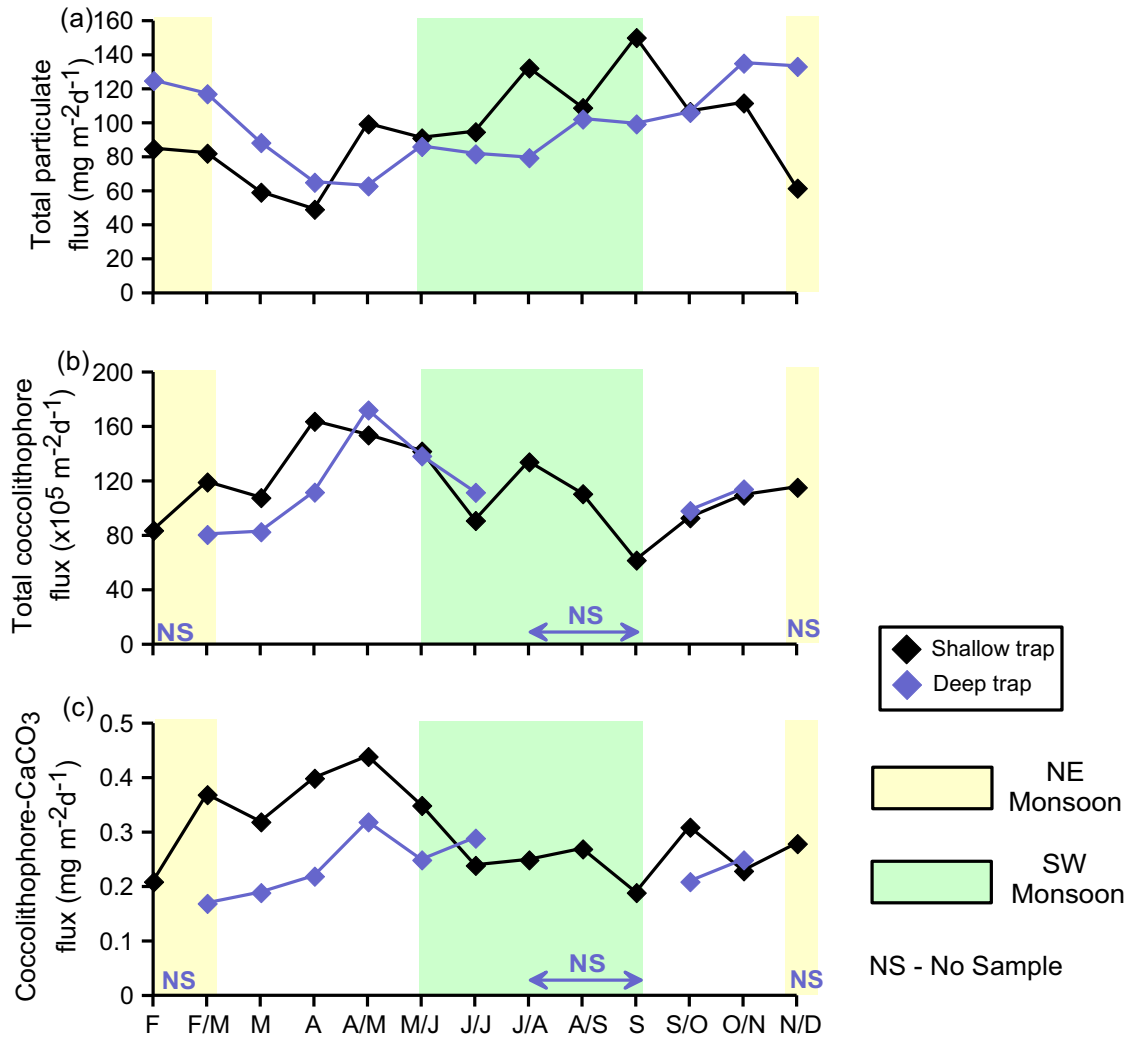
Central Bay of Bengal Trap (CBBT 06) (Shallow Trap)														
Interval	Flux ( $\times 10^5 \text{ m}^{-2} \text{ d}^{-1}$ )													
Station No.	1	2	3	4	5	6	7	8	9	10	11	12	13	Average
<i>G. oceanica</i>	43.35	41.06	42.00	59.80	37.42	46.09	32.87	61.73	46.09	24.78	37.75	46.89	39.13	43.00
<i>E. huxleyi</i>	4.11	7.75	1.82	7.75	6.84	3.64	5.93	13.05	8.22	2.18	0.83	2.48	3.04	5.21
<i>C. mediterranea</i>	0.91	1.82	0.91	0.91	1.38	3.64	1.38	0.44	0.91	0.88	0.83	2.07	1.30	1.34
<i>S. pulchra</i>	0.47	0.91	1.82		1.38	1.38		0.44	0.47	0.44	1.24	0.41	0.44	0.86
<i>U. sibogae</i>	19.18	31.05	15.98	25.55	19.18	22.82	14.16	13.47	15.51	15.21	18.68	17.41	16.53	18.83
<i>U. irregularis</i>	1.82	8.67	18.74	23.26	41.06	21.44	13.25	5.22	7.75	1.30	6.24	8.72	12.61	13.08
<i>U. tenuis</i>		2.29	0.91	0.47	0.91				0.91				0.44	0.99
<i>H. carteri</i>	1.38	4.55	4.11	3.20	5.46	3.64	1.82	2.62	2.73	0.44	1.66	0.83	1.74	2.63
<i>C. leptopora</i>	0.91	2.29	4.11	2.73	2.73	2.73	2.73	2.18	4.11	7.40	14.10	4.14	6.95	4.39
<i>F. profunda</i>	0.91	6.84	4.55	16.89	25.11	19.18	10.05	28.70	15.51	6.95	4.97	13.69	24.78	13.70
<i>Calcosoleniodsp.</i>	0.47	2.29	1.82	2.73	0.91	2.29			1.38		0.83	1.24	0.88	1.48
<i>D. tubifera</i>	0.47	0.91	1.38	1.38		1.38								1.10
<i>A. onza</i>		0.91		0.91										0.91
<i>R. clavigera</i>	0.47		1.82	2.73	1.82	1.38			1.88					1.68
<i>O. antillarum</i>	0.47	1.38	2.73	2.29	0.91	3.64	1.82	2.18	1.38	0.88	2.48	5.80	2.62	2.20
<i>S. pirus</i>	5.52	0.91	0.47	0.47		2.29					0.41	1.24	1.74	1.63
<i>S. lamina</i>	1.38	0.91	0.91	4.11	1.82	2.73	0.47	1.32	0.91		0.83	2.90	1.74	1.67
<i>Syracosphaera sp.</i>		0.91		0.91		1.82	1.82							1.21
<i>N. coccolithomorpha</i>	1.38	1.82	2.73	5.93	4.11	3.64	3.20	2.18	2.29	1.30	1.66	1.66	0.88	2.52
<i>C. cristatus</i>		0.47	0.91		0.47		0.47	0.44	0.47		0.41	0.41	0.44	0.50
<i>G. flabellatus</i>				1.82	1.82		0.47							1.37
Total Coccolith flux	83.21	117.76	107.74	163.87	153.36	141.93	90.44	133.98	110.53	61.76	92.92	109.89	115.27	114.05
Total Cocosphere flux	0.94	1.85	0.47	0.47	0.91	0.47	0.91	0.44	0.47	0.44	0.41		0.44	0.63
Total Coccolithophore Flux	84.15	119.61	108.21	164.34	154.27	142.40	91.35	134.42	111.00	62.20	93.33	109.89	115.71	114.68



**Table 5.8.** Seasonal variation of fluxes of various coccolithophore taxa in the Central Bay of Bengal (CBBT) for the period 3 February-16 December 1992 in the deep trap.

Central Bay of Bengal Trap (CBBT 06)														
(Deep Trap)														
Flux ( $\times 10^5 \text{ m}^{-2} \text{ d}^{-1}$ )														
Interval	3/2/92-8/2/92	8/2/92-5/3/92	5/3/92-31/3/92	31/3/92-26/4/92	26/4/92-22/5/92	22/5/92-17/6/92	17/6/92-13/7/92	13/7/92-8/8/92	8/8/92-3/9/92	3/9/92-29/9/92	29/9/92-25/10/92	25/10/92-20/11/92	20/11/92-16/12/92	Average
Station No.	1	2	3	4	5	6	7	8	9	10	11	12	13	
<i>G. oceanica</i>		31.96	34.69	38.99	42.17	41.06	34.69				31.49	42.00		37.13
<i>E. huxleyi</i>		3.50	1.38	4.55	7.84	2.73	3.20				3.20	7.31		4.22
<i>C. mediterranea</i>				0.47	0.88	0.91	1.82				2.29	0.47		1.14
<i>S. pulchra</i>		1.41	0.91	0.83	1.30	1.38	0.47				1.38	0.91		1.07
<i>U. sibogae</i>		19.29	15.51	18.27	26.08	15.07	21.00				15.51	8.22		17.37
<i>U. irregularis</i>		1.41	1.82	10.38	18.27	16.89	25.55				10.96	8.67		11.74
<i>U. tenuis</i>					1.30	0.47						0.47		0.75
<i>H. carteri</i>		1.41	2.73	0.83	2.18	0.91	3.64				1.38	1.82		1.86
<i>C. leptopora</i>		1.05	1.38	2.07	1.74	2.73	1.38				3.64	10.49		3.06
<i>F. profunda</i>		15.10	20.09	27.79	55.19	39.24	52.46				16.42	22.35		25.18
<i>Calcosolenid</i> spp.		0.69	0.91	1.24	1.74	3.20	2.73				1.82	1.38		1.71
<i>D. tubifera</i>		0.69		1.24	0.88	0.47					0.47	1.38		0.86
<i>A. oryza</i>		0.69												0.69
<i>R. clavigera</i>	No Sample	1.05	0.91	0.83	2.18	1.38	1.82				0.47		No Sample	1.23
<i>O. antillarum</i>		1.05		2.07	5.66	5.02	4.11				5.02	2.73		3.67
<i>S. pirus</i>		0.36	1.38	0.47	1.74		0.91				1.38	1.38		1.09
<i>S. lamina</i>		1.05	0.47	0.47	1.30	3.64	2.73				1.82	1.82		1.66
<i>N. coccolithomorpha</i>			0.91	1.24	1.30	3.20	1.38				1.38	2.29		1.67
<i>C. cristatus</i>		0.36				1.38						0.91		0.88
Total Coccolith flux		81.05	83.09	111.74	171.74	138.32	112.07				98.63	114.61		113.91
Total Coccosphere flux				0.47	0.88	0.47								0.23
<b>Total Coccolithophore Flux</b>		<b>81.05</b>	<b>83.09</b>	<b>112.21</b>	<b>172.62</b>	<b>138.79</b>	<b>112.07</b>				<b>98.63</b>	<b>114.61</b>		<b>114.14</b>

**Fig. 5.5.** Seasonal variation of (a) total particulate (b) total coccolithophore and (c) coccolithophore-CaCO<sub>3</sub> fluxes in the shallow and deep traps from the central Bay of Bengal (CBBT). The shaded bands represent the periods of different monsoon seasons.



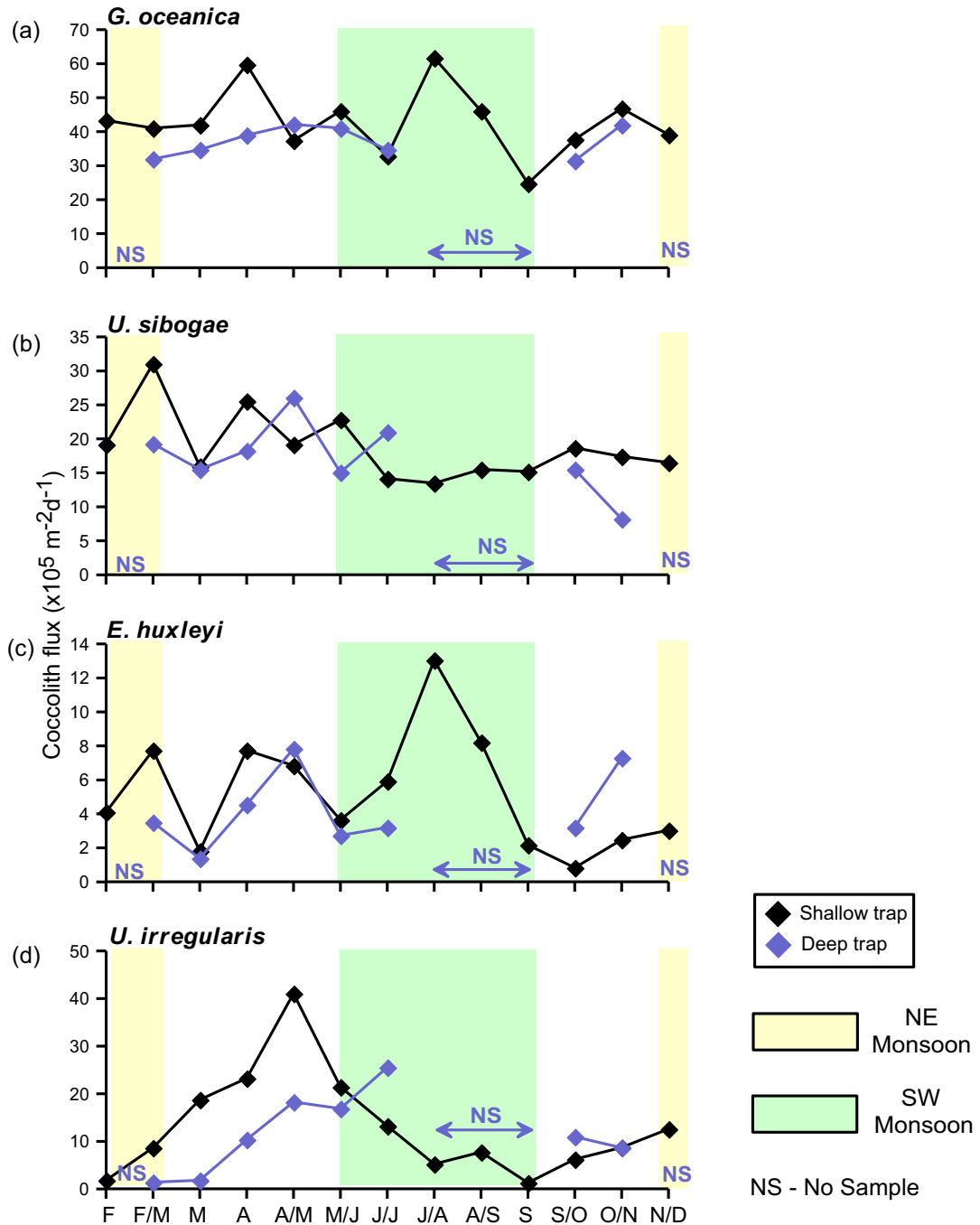
( $5.21 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ) and *C. leptopora* ( $4.39 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ) (Table 5.7). Whereas, *H. carteri*, *N. coccolithomorpha* and *O. antillarum* were the common species, and the remaining species such as *C. mediterranea*, *S. pulchra*, *U. tenuis*, *Calciosolenids* sp., *D. tubifera*, *A. oryza*, *R. clavigera*, *S. pirus*, *S. lamina*, *C. cristatus*, *G. flabellatus* and *Syracosphaera* sp. were rarely distributed (Table 5.7).

While the deep trap at a depth of 2527 m recorded only nineteen species among which the dominant species were *G. oceanica* ( $37.13 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ), *F. profunda* ( $25.18 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ), *U. sibogae* ( $17.37 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ) and *U. irregularis* ( $11.74 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ) (Table 5.8). Whereas *E. huxleyi*, *C. leptopora* and *O. antillarum* were the common species and the remaining species, *C. mediterranea*, *S. pulchra*, *U. tenuis*, *H. carteri*, *Calciosolenids* sp., *D. tubifera*, *A. oryza*, *R. clavigera*, *S. pirus*, *S. lamina*, *N. coccolithomorpha* and *C. cristatus* were rarely distributed.

**G. oceanica:** This species dominated the coccolithophore assemblage throughout the sampling period both in the shallow and deep traps. The fluxes in the shallow trap ranged between  $24.78$  and  $61.73 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $43.00 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  (Table 5.7). While, in the deep trap the fluxes varied from  $31.49$  to  $42.17 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $37.13 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  (Table 5.8). The fluxes of *G. oceanica* in the shallow trap displayed with three peaks, of which a major peak was associated with the SW monsoon (July/August) followed by two minor peaks during NE-SW intermonsoon (April) and during SW-NE intermonsoon (October/November) (Fig. 5.6a). It also showed a distinct low value ( $24.78 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ) during late SW monsoon (September). The deep trap displayed a similar trend as in total coccolithophore fluxes with a marginally increased fluxes during NE-SW intermonsoon (April/May) (Fig. 5.6a).

**U. sibogae:** It was the second dominant species both in the shallow and deep traps. The fluxes in the shallow trap ranged between  $13.47$  and  $31.05 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average flux of  $18.83 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ , while in the deep trap it varied from  $8.22$  to  $26.08 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $17.37 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  (Tables 5.7 and 5.8). These fluxes in the shallow trap displayed a major peak

**Fig. 5.6.** Seasonal variation of coccolith fluxes of (a) *G. oceanica* (b) *U. sibogae* (c) *E. huxleyi* and (d) *U. irregularis* in the shallow and deep traps from the central Bay of Bengal (CBBT). The shaded bands represent the periods of different monsoon seasons.



associated with NE monsoon (February/March) followed by two minor peaks during NE-SW intermonsoon and early SW monsoon (April and May/June) (Fig. 5.6b). However it did not show any significant variation during SW monsoon. The deep trap recorded relatively lower fluxes compared to the shallow trap except during NE-SW intermonsoon (April/May) which showed marginally increased fluxes (Fig. 5.6b).

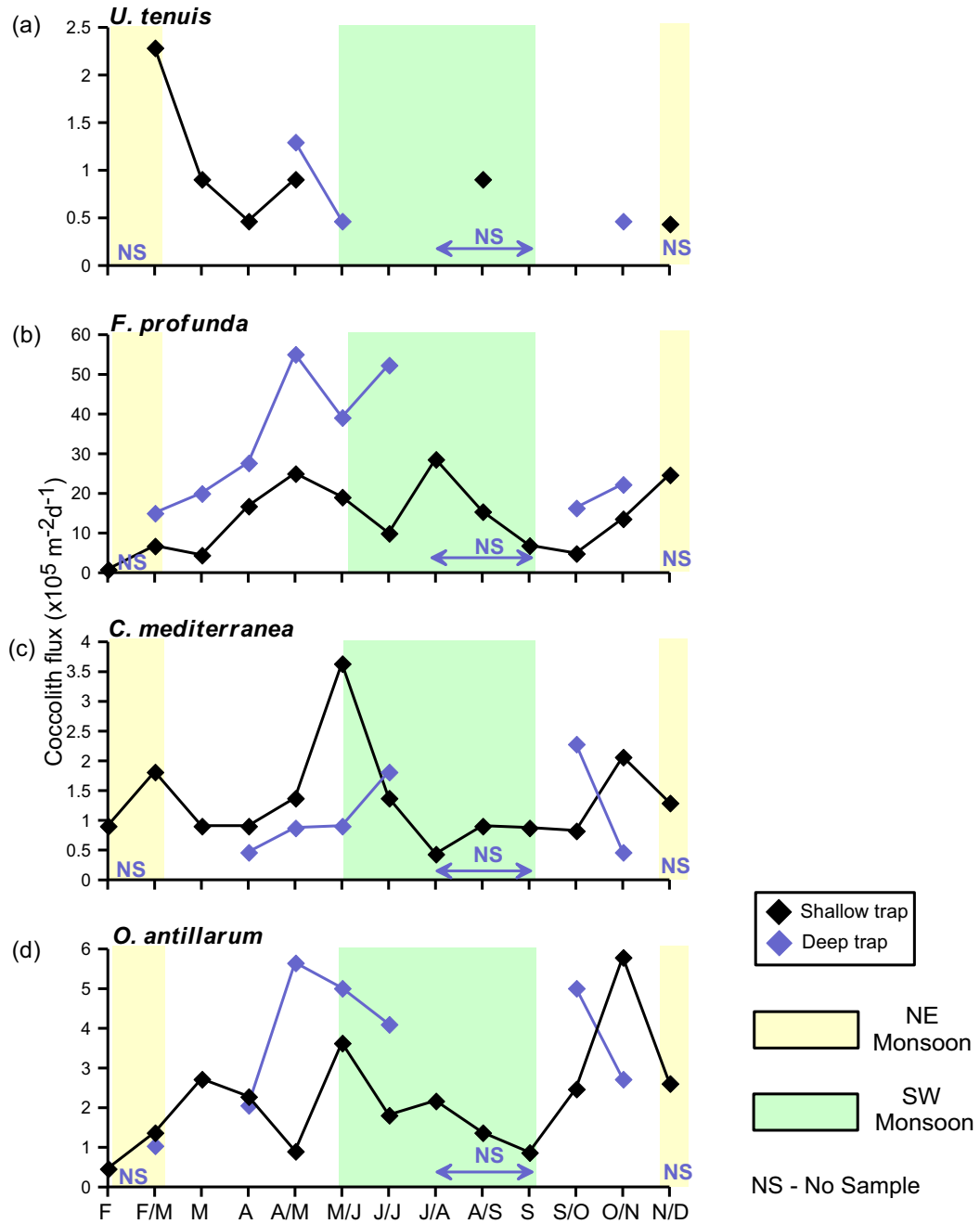
***E. huxleyi***: The flux value in the shallow trap varied between 0.83 and 13.05  $\times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of 5.21  $\times 10^5 \text{ m}^{-2}\text{d}^{-1}$  (Table 5.7). These fluxes reflected the distributional pattern of total coccolithophore fluxes with a major peak occurring during SW monsoon (July/August) along with two minor peaks during NE and NE-SW monsoons (February/March and April) (Fig. 5.6c). Lowest flux values (1.82  $\times 10^5 \text{ m}^{-2}\text{d}^{-1}$  and 0.83  $\times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ) were recorded during NE-SW and SW-NE intermonsoons (March and September/October). The fluxes in the deep trap ranged from 1.38 and 7.84  $\times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of 4.22  $\times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with a peak occurrence associated with NE-SW intermonsoon (April/May) (Table 5.8 and Fig. 5.6c).

***U. irregularis***: The flux value varied from 1.30 to 41.06  $\times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of 13.08  $\times 10^5 \text{ m}^{-2}\text{d}^{-1}$  for the shallow trap (Table 5.7). The highest peak abundance was associated with NE-SW intermonsoon (April/May) (Fig. 5.6d). While deep trap recorded lower fluxes compared to that of the shallow following same trend and varied from 1.41 to 25.55  $\times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of 11.74  $\times 10^5 \text{ m}^{-2}\text{d}^{-1}$  (Table 5.8). Highest fluxes were recorded during early SW monsoon (June/July) (Fig. 5.6d).

***U. tenuis***: This species was very sparsely distributed which ranged from 0.47 to 2.29  $\times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average of 0.99  $\times 10^5 \text{ m}^{-2}\text{d}^{-1}$  in the shallow trap and showed increased flux value of 2.29  $\times 10^5 \text{ m}^{-2}\text{d}^{-1}$  during late NE monsoon (February/March) (Table 5.7 and Fig. 5.7a). They were present only at three sampling periods for the deep trap, hence no distributional trend could be seen (Table 5.8).

***F. profunda***: The flux values in the shallow trap varied from 0.91 to 28.70  $\times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average flux value of 13.70  $\times 10^5 \text{ m}^{-2}\text{d}^{-1}$  (Table 5.7). The

**Fig. 5.7.** Seasonal variation of coccolith fluxes of (a) *U. tenuis* (b) *F. profunda* (c) *C. mediterranea* and (d) *O. antillarum* in the shallow and deep traps from the central Bay of Bengal (CBBT). The shaded bands represent the periods of different monsoon seasons.



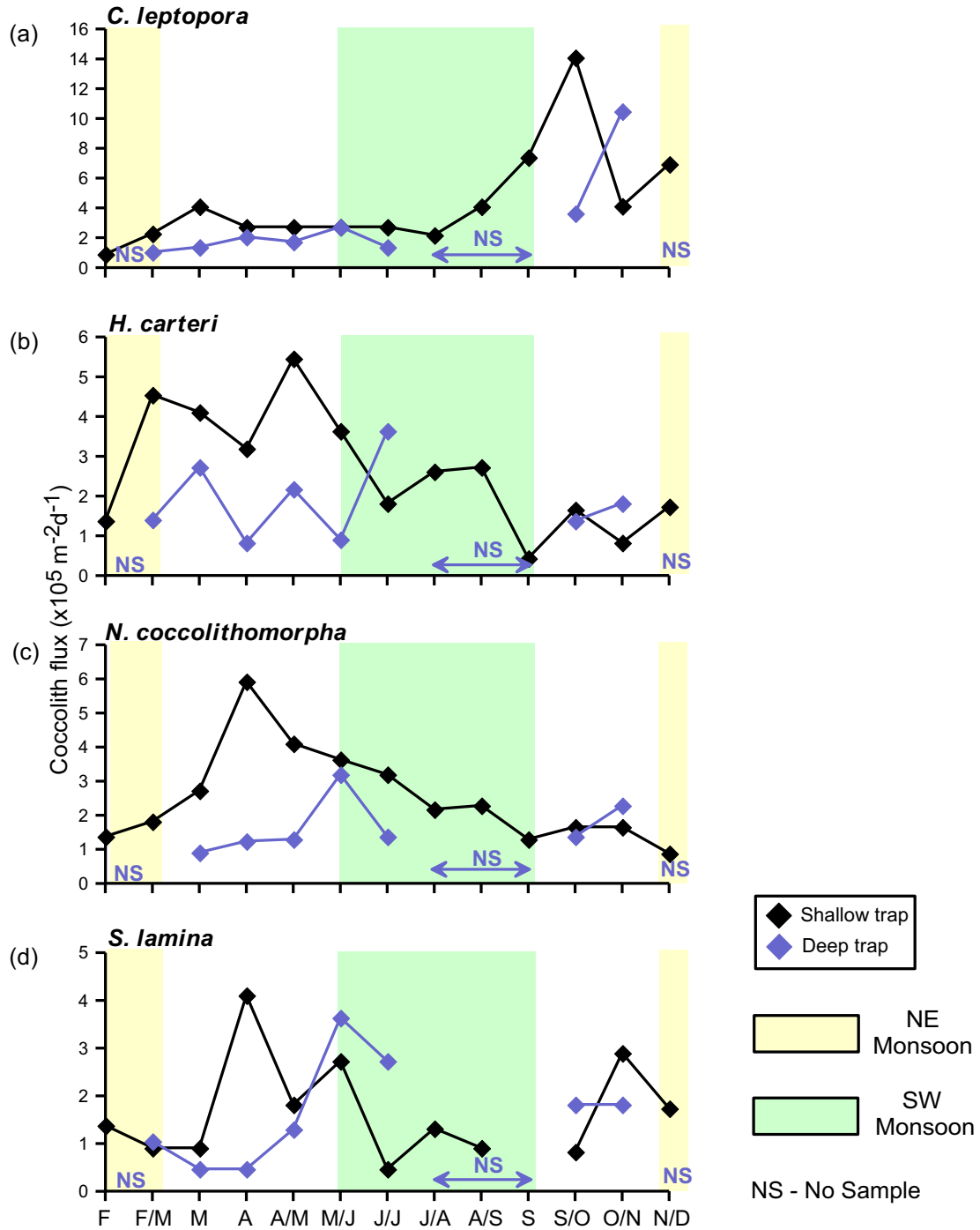
fluxes showed a bi-modal distributional pattern with major peaks occurring during NE-SW intermonsoon (April) and SW monsoon (July/August) (Fig. 5.7b). It also showed an increased fluxes ( $13.70 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ) during NE monsoon (November/December). Interestingly, the deep trap recorded relatively higher fluxes compared to the shallow trap which ranged from  $15.10$  to  $55.19 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $25.18 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  (Table 5.8.) The fluxes showed a major peak associated with NE-SW intermonsoon (April/May) with a high flux value of  $52.46 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  observed during SW monsoon (June/July) (Fig. 5.7b).

**C. mediterranea:** The flux values in the shallow trap varied from  $0.44$  to  $3.64 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average flux value of  $1.34 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  (Table 5.7). The fluxes of this species showed some increase during early SW monsoon (May/June) with marginal increases during NE monsoon and SW-NE intermonsoon (February/March and October/November) (Fig. 5.7c). Fluxes in the deep trap varied from  $0.47$  to  $2.29 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with increased fluxes found during early SW monsoon and SW-NE intermonsoon (Table 5.8 and Fig. 5.7c).

**O. antillarum:** The flux values varied from  $0.47$  to  $5.80 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $2.20 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  in the shallow trap (Table 5.7). The fluxes recorded a major peak during SW-NE intermonsoon (October/November) and also minor peaks during early SW monsoon (May/June) and NE-SW intermonsoon (March) (Fig. 5.7d). The deep trap the fluxes varied from  $1.05$  to  $5.66 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $3.67 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  (Table 5.8). The fluxes were higher compared to the shallow trap with a major peak occurring during NE-SW intermonsoon (April/May) (Fig. 5.7d).

**C. leptopora:** The flux values for this species varied from  $0.91$  to  $14.10 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $4.39 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  in the shallow trap (Table 5.7). The fluxes of this species in the shallow trap showed a prominent peak associated with SW-NE intermonsoon (September/October) and a minor peak during late NE-SW intermonsoon (March) (Fig. 5.8a). While the fluxes in the deep trap ranged from  $1.05$  to  $10.49 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of

**Fig. 5.8.** Seasonal variation of coccolith fluxes of (a) *C. leptopora* (b) *H. carteri* (c) *N. coccolithomorpha* and (d) *S. lamina* in the shallow and deep traps from the central Bay of Bengal (CBBT). The shaded bands represent the periods of different monsoon seasons.





$3.06 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  and recorded relatively low fluxes except for an increase during SW-NE intermonsoon (October/November) (Table 5.8 and Fig. 5.8a).

***H. carteri***: The flux values of this species varied from 0.44 to  $5.46 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $2.63 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  in the shallow trap (Table 5.7). *H. carteri* showed increased fluxes during NE-SW intermonsoon (April/May) in the shallow trap along with minor peaks occurring during NE monsoon (February/March) and SW monsoon (August/September) (Fig. 5.8b). The fluxes in the deep trap varied from 0.83 to  $3.64 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $1.86 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  and recorded lower fluxes compared to the shallow trap with peaks during SW monsoon (June/July) and NE-SW intermonsoon (March and April/May) (Table 5.8 and Fig. 5.8b).

***N. coccolithomorpha***: The flux values of this species varied between 0.88 and  $5.93 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $2.52 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  in the shallow trap (Table 5.7) and showed a distinct peak abundance associated with NE-SW intermonsoon (April) which eventually decreased gradually until the NE monsoon (Fig. 5.8c). Whereas, fluxes in the deep trap ranged from 0.91 to  $3.20 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $1.67 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  and recorded a peak during the early SW monsoon (May/June) (Table 5.8 and Fig. 5.8c).

***S. lamina***: The fluxes of *S. lamina* varied from 0.47 and  $4.11 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $1.67 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  in the shallow trap with a major peak occurring during NE-SW intermonsoon (April) and minor peaks during early SW monsoon (May/June) and SW-NE intermonsoon (October/November) (Table 5.7 and Fig. 5.8d). Whereas, in the deep trap the fluxes ranged from 0.47 to  $3.64 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $1.66 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  and recorded very low fluxes during NE-SW intermonsoon which then increased gradually reaching a peak during early SW monsoon (May/June) (Table 5.8 and Fig. 5.8d).

***S. pulchra***: It exhibited patchy distributional trend in the shallow trap where fluxes ranged from 0.41 to  $1.82 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $0.86 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  (Table 5.7). The shallow trap recorded a maximum value ( $4.11 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ) during late NE monsoon (March) and also a peak during SW-NE

intermonsoon (September/October) (Fig. 5.9a). While in the deep trap the fluxes ranged from 0.47 to  $1.41 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $1.07 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  and a major peak during early SW monsoon (May/June) (Table 5.8 and Fig. 5.9a).

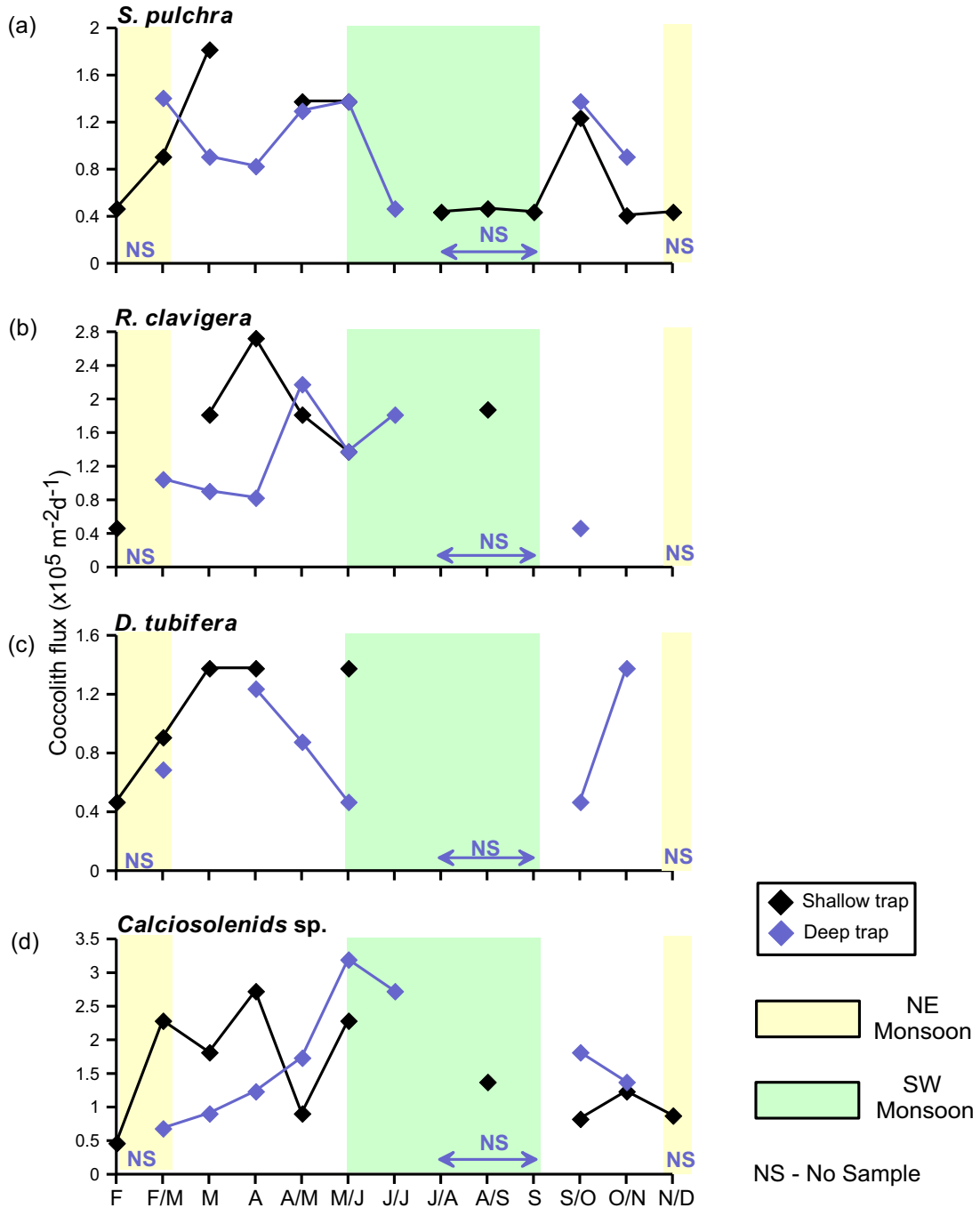
**R. clavigera:** It showed a patchy distribution in the shallow trap and maximum fluxes were observed during April (Table 5.7 and Fig. 5.9b). Similarly in the deep trap the fluxes varied from 0.47 to  $2.18 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $1.23 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  and recorded lower fluxes compared to the shallow trap with a major peak during NE-SW intermonsoon (April/May) (Table 5.8 and Fig. 5.9b).

**D. tubifera:** It also showed a patchy distribution in the shallow trap and displayed maximum fluxes associated with NE-SW intermonsoon and also during early SW monsoon (March-April and May/June) respectively (Table 5.7 and Fig. 5.9c). Similarly, patchy distribution continues in deep trap also with increased fluxes associated with NE-SW and SW-NE intermonsoons (April and October/November) (Table 5.8 and Fig. 5.9c).

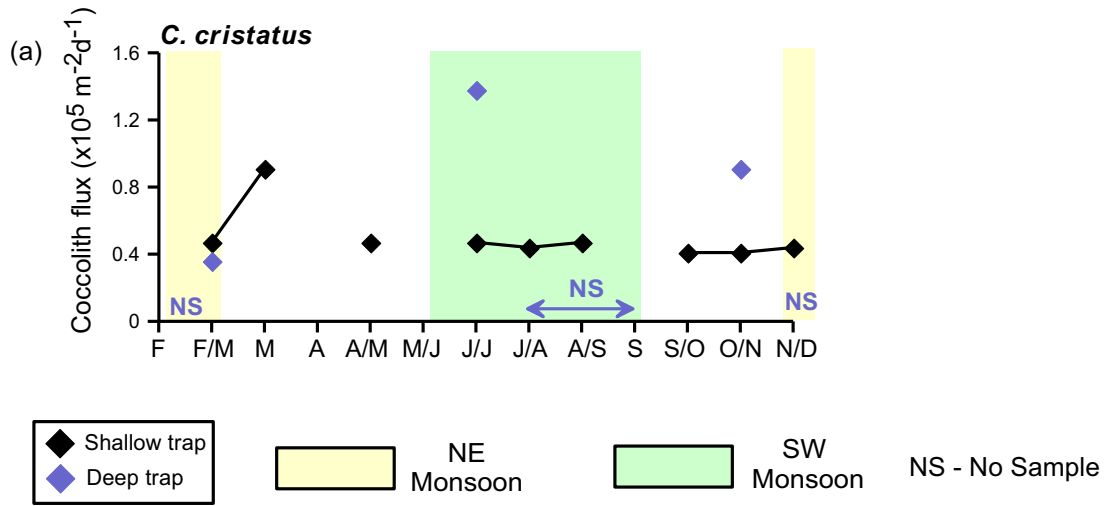
**Calciosolenids sp.:** Fluxes in the shallow trap ranged from 0.47 to  $2.73 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $1.48 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  (Table 5.7). It also showed high fluxes during NE-SW intermonsoon (April) in the shallow trap (Fig. 5.9d). Fluxes in the deep trap ranged from 0.69 to  $3.20 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $1.71 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  and recorded lowest fluxes during the beginning of NE-SW intermonsoon to highest fluxes during the early SW monsoon (May/June) (Table 5.8 and Fig. 5.9d).

**C. cristatus:** This species was very sparsely distributed which ranged from 0.41 to  $0.91 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $0.50 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  and showed a maximum value ( $0.91 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ) during NE-SW intermonsoon (March) (Table 5.7 and Fig. 5.10a). However the fluxes in deep trap were observed only in three samples with maximum fluxes occurring during SW monsoon (June/July) (Table 5.8 and Fig. 5.10a).

**Fig. 5.9.** Seasonal variation of coccolith fluxes of (a) *S. pulchra* (b) *R. clavigera* (c) *D. tubifera* and (d) *Calciosolenids* sp. in the shallow and deep traps from the central Bay of Bengal (CBBT). The shaded bands represent the periods of different monsoon seasons.



**Fig. 5.10.** Seasonal variation of coccolith fluxes of (a) *C. cristatus* in the shallow and deep traps from the central Bay of Bengal (CBBT). The shaded bands represent the periods of different monsoon seasons.



### **5.3 Distributional patterns of the fluxes of total particulate, total coccolithophore and various taxa in the Southern Bay of Bengal**

#### **5.3.1 Total particulate flux**

Total particulate flux at SBBT varied from 46.01 to 327.41 mg m<sup>-2</sup>d<sup>-1</sup> with an average value of 132.80 mg m<sup>-2</sup>d<sup>-1</sup> in the shallow trap (Table 5.9). But, only samples between February and July interval were available for the deep trap, while the remaining samples could not be collected due to malfunctioning of the trap. The fluxes varied significantly from 44.84 to 147.06 mg m<sup>-2</sup>d<sup>-1</sup> with an average value of 69.08 mg m<sup>-2</sup>d<sup>-1</sup> (Table 5.10). The fluxes in shallow trap showed a seasonality characterized by a bi-modal distribution with very highest fluxes occurring during end of SW monsoon (September) and its associated minor peak during mid SW monsoon (July/August). During the remaining period fluxes were significantly decreased (Fig. 5.11a). While the fluxes in the deep trap followed the same trend as that of shallow trap with a maximum flux observed during SW monsoon (Fig. 5.11a)

#### **5.3.2 Total coccolithophore flux**

The total coccolithophore fluxes from the shallow trap varied between 14.16 and 165.78 x 10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup> with an average flux value of 109.35 x 10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup> (Table 5.11). The samples were not available for the period between April and (July and December) due to malfunctioning of the deep trap. However, the fluxes from five available samples were estimated which varied from 55.58 to 187.36 x 10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup> with an average value of 127.00 x 10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup> (Table 5.12). The fluxes in the shallow trap recorded three major peaks during NE-SW intermonsoon (April), SW monsoon (August/September) and SW-NE intermonsoon (October/November) (Fig. 5.11b). It has also showed low fluxes during NE monsoon with a lowest value observed during late SW monsoon (September) (Fig. 5.11b). While the deep trap shows more or less similar trend as that of shallow trap and recorded comparatively higher fluxes during NE-SW intermonsoon and early SW monsoon (March and April-June) (Fig. 5.11b).

**Table 5.9.** Seasonal variation of total particulate flux and the major components (calcium carbonate, lithogenic, biogenic opal and organic carbon fluxes) in the Southern Bay of Bengal (SBBT) for the period 5 February-16 December in the shallow trap.

Southern Bay of Bengal Trap (SBBT 06) (Shallow Trap)						
Stn. No.	Sampling period	Calcium carbonate	Litho- genic	Biogenic opal	Organic carbon	Total particulate
		Flux (mg m <sup>-2</sup> d <sup>-1</sup> )				
1	5 February – 8 February 1992	55.95	5.91	23.93	7.23	98.80
2	8 February – 5 March 1992	25.02	4.20	17.00	5.59	56.29
3	5 March – 31 March 1992	26.36	3.55	13.57	3.15	49.15
4	31 March – 26 April 1992	30.23	4.93	22.14	4.32	65.09
5	26 April – 22 May 1992	26.62	4.92	17.89	3.44	55.63
6	22 May – 17 June 1992	24.47	3.70	12.81	2.79	46.01
7	17 June – 13 July 1992	101.25	15.53	88.38	13.95	230.28
8	13 July – 8 Aug 1992	89.08	15.56	74.78	18.67	213.02
9	8 August– 3 September 1992	117.49	6.36	133.73	19.23	292.19
10	3 September – 29 September 1992	150.48	33.31	124.56	10.59	327.41
11	29 September – 25 October 1992	63.67	9.80	38.44	9.29	128.62
12	25 October – 20 November 1992	58.15	4.62	12.21	3.36	81.02
13	20 November – 16 December 1992	50.59	3.07	9.34	11.08	82.94
<b>Average</b>		<b>63.03</b>	<b>8.88</b>	<b>45.29</b>	<b>8.67</b>	<b>132.80</b>

**Table 5.10.** Seasonal variation of total particulate flux and the major components in the (calcium carbonate, lithogenic, biogenic opal and organic carbon fluxes) in the Southern Bay of Bengal (SBBT) for the period 5 February-16 December in the deep trap.

Southern Bay of Bengal Trap (SBBT 06) (Deep Trap)						
Stn. No.	Sampling period	Calcium carbonate	Litho- genic	Biogenic opal	Organic carbon	Total particulate
		Flux (mg m <sup>-2</sup> d <sup>-1</sup> )				
1	5 February – 8 February 1992	37.33	2.69	9.75	3.41	55.91
2	8 February – 5 March 1992	37.61	10.40	22.85	4.23	78.47
3	5 March – 31 March 1992	27.62	3.45	16.52	2.93	52.87
4	31 March – 26 April 1992	29.58	2.84	18.47	3.17	56.59
5	26 April – 22 May 1992	23.17	3.86	15.65	2.85	47.82
6	22 May – 17 June 1992	21.68	4.32	14.32	2.51	44.84
7	17 June – 13 July 1992	58.62	17.15	53.82	9.71	147.06
8	* 13 July – 8 Aug 1992					
9	* 8 August – 3 September 1992					
10	* 3 Sept ember – 29 September 1992					
11	* 29 September – 25 October 1992					
12	* 25 October – 20 November 1992					
13	* 20 November – 16 December 1992					
<b>Average</b>		<b>33.66</b>	<b>6.39</b>	<b>21.63</b>	<b>4.12</b>	<b>69.08</b>

\* No Sample

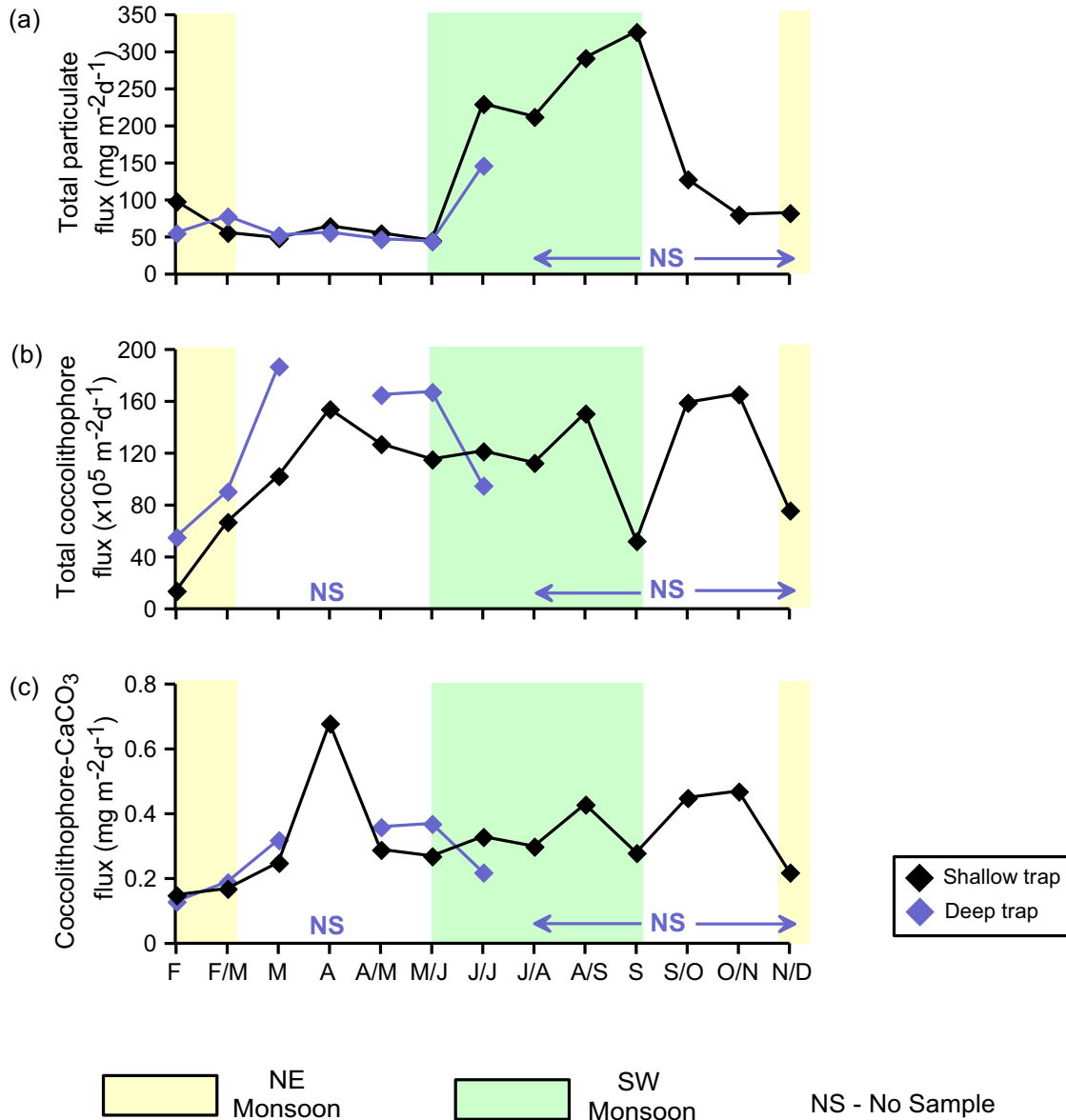
**Table 5.11.** Seasonal variation of fluxes of various coccolithophore taxa in the Southern Bay of Bengal (SBBT) for the period 5 February-16 December 1992 in the shallow trap.

Southern Bay of Bengal Trap (SBBT 06) (Shallow Trap)														
Interval		$(\times 10^5 \text{ m}^2 \text{ d}^{-1})$												
Station No.	1	2	3	4	5	6	7	8	9	10	11	12	13	Average
<i>G. oceanica</i>	5.71	26.02	37.42	31.05	37.42	26.02	63.45	45.65	73.02	18.68	33.78	46.56	16.42	35.48
<i>E. huxleyi</i>	0.77	5.93	3.20	5.46	3.20	12.34	8.67	6.84	11.40	1.66	16.42	20.09	0.91	7.45
<i>C. mediterranea</i>	0.39	2.29	2.29	1.38	0.91		0.91	1.82	0.47		0.91	0.91	2.29	1.32
<i>S. pulchra</i>					0.91	0.91	1.38	1.38	0.91	0.41	0.91	0.91	1.82	1.06
<i>U. sibogae</i>	3.04	1.52	13.25	14.60	15.07	10.96	11.40	10.05	27.85	5.80	14.60	7.75	10.49	11.26
<i>U. irregularis</i>	0.77	7.31	7.75	21.44	18.71	21.44	3.20	7.31	5.93	3.31	6.84	7.75	2.29	8.78
<i>U. tenuis</i>				2.29	4.58	1.38	0.47	0.47	0.91			0.91	0.91	1.49
<i>H. carteri</i>	0.77	1.38	3.20	18.27	2.76	3.64	4.11	1.82	1.38	0.83	1.38	0.91	1.82	3.25
<i>C. leptopora</i>		2.76	5.46	18.27	2.76	3.64	11.40	1.38	20.53	4.97	7.31	5.93	2.29	7.23
<i>F. profunda</i>	0.39	2.76	6.40	13.25	12.78	8.67	2.29	6.84	2.73	6.24	19.18	25.55	15.51	9.43
<i>Calcosolenids</i> sp.	0.77	1.82	1.82	0.91	1.38	1.38	0.91	1.38	0.91	0.83	0.47	0.47	0.91	1.07
<i>D. tubifera</i>		1.38	2.29	0.91	3.20	0.47	0.47	1.82	0.47	0.41	0.91	0.47		1.16
<i>R. clavigera</i>		1.38	1.82	1.38			0.91	1.38	1.82	0.83	1.38	1.82		1.41
<i>O. antillarum</i>	0.39	8.67	10.05	11.40	15.51	14.16	6.84	12.34	1.82	2.48	30.58	33.78	8.67	12.05
<i>S. pirus</i>	0.39					0.91	0.91	1.38				0.91		0.90
<i>S. lamina</i>	0.77	1.38	3.20	3.64	2.29	2.35	1.82	1.82	0.91	0.41	3.20	1.82		1.97
<i>Syracosphaera</i> sp.								3.64						3.64
<i>N. coccolithomorpha</i>		0.47	1.38	2.76	1.82	3.20	0.91	1.38		1.24	0.91	0.91	1.82	1.53
<i>C. cristatus</i>		0.47	0.47		1.38	0.47	0.47			0.83	0.47			0.65
<i>G. flabellatus</i>				1.38		0.91						1.38	2.29	1.49
<i>S. rotula</i>				0.47				0.47					0.47	0.47
<i>A. onyza</i>		0.91	2.76	2.29	1.82	1.82	1.38	1.38		1.24	8.67	2.29	0.91	2.32
<i>S. anthos</i>													4.55	4.55
<i>C. multipora</i>											0.47			0.47
Total Coccolith flux	14.16	66.45	102.77	151.15	126.50	114.67	121.90	110.55	151.07	50.17	148.39	161.14	74.37	107.18
Total Coccosphere flux		0.91		3.23	0.94	0.94		2.32		2.46	10.95	4.64	1.88	2.17
Total Coccolithophore Flux	14.16	67.36	102.77	154.38	127.44	115.61	121.90	112.87	151.07	52.63	159.34	165.78	76.25	109.35





**Fig. 5.11.** Seasonal variation of (a) total particulate (b) total coccolithophore and (c) coccolithophore-CaCO<sub>3</sub> fluxes in the shallow and deep traps from the southern Bay of Bengal (SBBT). The shaded bands represent the periods of different monsoon seasons.



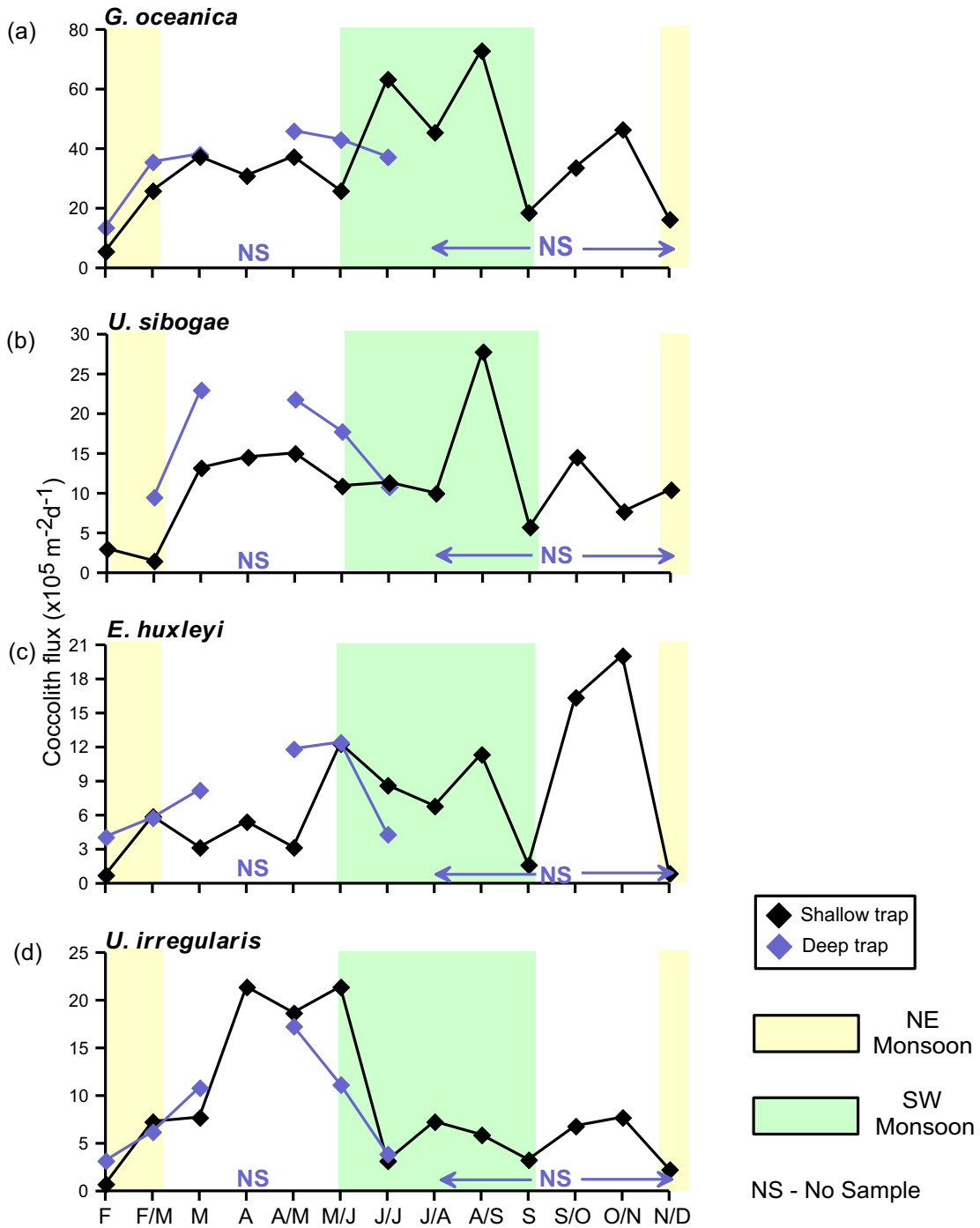
### 5.3.3 Flux patterns of various taxa

The shallow trap at a depth of 1518 m at SBBT yielded a total of twenty four species of coccolithophores highest diversity among the three trap locations. Among them, *G. oceanica* ( $35.48 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ) most dominant followed by *U. sibogae* ( $11.26 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ), *O. antillarum* ( $12.05 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ), *F. profunda* ( $9.43 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ), *U. irregularis* ( $8.78 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ), *E. huxleyi* ( $7.45 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ) and *C. leptopora* ( $7.23 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ) which were commonly distributed (Table 5.11). Whereas *S. anthos*, *H. carteri*, *S. lamina*, *Syracosphaera* sp., *A. oryza*, *C. mediterranea*, *S. pulchra*, *U. tenuis*, *Calciosolenids* sp., *D. tubifera*, *R. clavigera*, *S. pirus*, *N. coccolithomorpha*, *C. cristatus*, *G. flabellatus*, *S. rotula* and *C. multipora* were rarely distributed.

The deep trap at a depth of (3011 m) recorded only twenty two species among which the dominant species were, *G. oceanica* ( $35.71 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ), *U. sibogae* ( $15.11 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ), *F. profunda* ( $19.90 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ), whereas *O. antillarum*, *E. huxleyi*, *U. irregularis*, *A. oryza*, *S. pulchra*, *C. mediterranea*, *H. carteri*, *C. leptopora*, *Calciosolenids* sp., *D. tubifera*, *R. clavigera*, *S. pirus*, *S. lamina*, *N. coccolithomorpha* and *C. cristatus* were commonly distributed. The remaining species *G. flabellatus*, *U. tenuis*, *M. adriaticus* and *C. multipora* were sparsely distributed (Table 5.12).

***G. oceanica*:** This species dominated the coccolithophore assemblage throughout the sampling period both in shallow and deep taps. The flux values ranged from 5.71 to  $73.02 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $35.48 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  (Table 5.11). While in the deep trap the fluxes varied from 13.69 to  $46.09 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $35.71 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  (Table 5.12). The fluxes showed a distinct seasonality with major peaks associated with the SW monsoons during June/July and August/September (Fig. 5.12a). A minor peak was also observed during SW-NE intermonsoon (October/November) lowest fluxes recorded during NE monsoon. The deep trap also reflected a similar trend as that of total coccolithophore flux and recorded relatively higher fluxes at some intervals than that of shallow trap (Fig. 5.12a).

**Fig. 5.12.** Seasonal variation of coccolith fluxes of (a) *G. oceanica* (b) *U. sibogae* (c) *E. huxleyi* and (d) *U. irregularis* in the shallow and deep traps from the southern Bay of Bengal (SBBT). The shaded bands represent the periods of different monsoon seasons.



***U. sibogae***: It was a second dominant species in both the traps. The fluxes in the shallow trap ranged from 1.52 to 27.85 x 10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup> with an average value of 11.26 x 10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup> (Table 5.11). Fluxes in the shallow trap displayed seasonality with a prominent peak occurring during SW monsoon (August/September). It has also displayed minor peaks associated with SW-NE and NE-SW intermonsoons (September/October and April-May) (Fig. 5.12b). While in the deep trap, the fluxes varied from 7.51 to 23.04 x10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup> with an average value of 15.11 x 10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup> (Table 5.12b). The distributional trend was similar to that of total coccolithophore flux with relatively higher fluxes compared to that of the shallow trap (Table 5.12 and Fig. 5.12b).

***E. huxleyi***: The flux values ranged from 0.77 to 20.09 x 10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup> with an average value of 7.45 x 10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup> (Table 5.11). The fluxes in the shallow trap showed a seasonal trend with a major peak observed during SW-NE intermonsoon (October/November) followed by a relatively higher fluxes during SW monsoon with its associated minor peaks occurring during May/June and August/September (Fig. 5.12c). Whereas the fluxes in deep trap ranged from 4.11 to 12.45 x 10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup> with an average of 7.81 x10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup> with a major peak associated with the early SW monsoon (May/June) (Table 5.12 and Fig. 5.12c).

***U. irregularis***: The fluxes of this species ranged from 0.77 to 21.44x10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup> with an average value of 8.78 x 10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup> in the shallow trap with increased fluxes recorded during NE-SW intermonsoon through early SW monsoon (April-June) (Table 5.11 and Fig. 5.12d). Whereas, *U. irregularis* fluxes decreased significantly from June/July to February/March intervals. Fluxes in the deep trap varied from 3.20 to 17.33 x 10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup> with an average value of 8.79 x 10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup> and followed the same trend as seen in the shallow trap with relatively lower fluxes (Table 5.12 and Fig. 5.12d).

***U. tenuis***: *U. tenuis* showed a patchy distribution in the shallow trap and its fluxes varied between 0.47 and 4.58 x 10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup> with an average value of 1.49 x 10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup> (Table 5.11). Which recorded a relatively higher fluxes during NE-SW intermonsoon (April/May) and lower fluxes during rest of the period

(Fig. 5.13a). While in the deep trap lowest fluxes were recorded during April – June) (Table 5.12 and Fig. 5.13a).

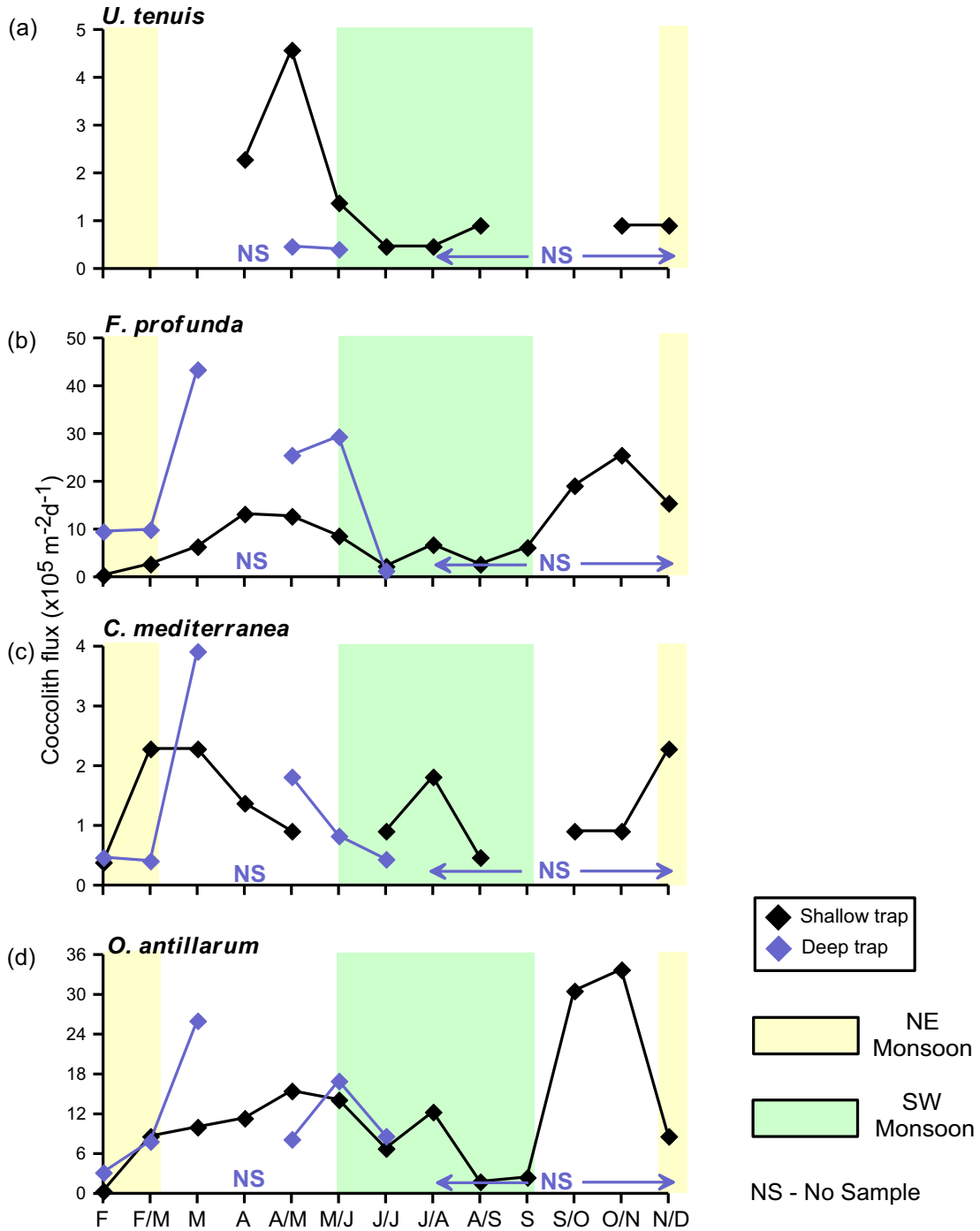
***F. profunda***: The flux values varied between 0.39 and  $25.55 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $9.43 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ , and characterized by a bi-modal distribution pattern with a major peak associated with SW-NE intermonsoon (October/November) followed by a minor peak during NE-SW intermonsoon (April) (Table 5.11 and Fig. 5.13b). Besides, fluxes during SW monsoon (July/August) showed a marginal increase. The deep trap recorded relatively higher fluxes compared to the shallow, which varied from 1.38 to  $43.47 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $19.90 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  (Table 5.12). Higher fluxes were recorded during NE-SW intermonsoon and early SW monsoon (March and April-June) (Fig. 5.13b).

***C. mediterranea***: This species exhibited a patchy distribution in the shallow trap with a varied flux values between 0.39 and  $2.29 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  and an average value of  $1.32 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  (Table 5.11). Increased fluxes were recorded during NE monsoons (November/December and February/March), NE-SW intermonsoon (March) and SW monsoon (July/August) (Fig. 5.13c). In the deep trap, the fluxes varied from 0.41 to  $3.92 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with a maximum value of  $3.92 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  during NE-SW intermonsoon (March) (Table 5.12 and Fig. 5.13c).

***O. antillarum***: The fluxes ranged between 0.39 to  $33.78 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $12.05 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  (Table 5.11). It showed a prominent peak during SW-NE intermonsoon (October/November) in the shallow trap. Besides, it also displayed minor peaks during NE-SW intermonsoon (April/May) and during SW monsoon (July/August) (Fig. 5.13d). The fluxes in the deep trap ranged from 3.20 to  $26.08 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $11.85 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  and recorded a maximum value of  $26.08 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  during NE-SW intermonsoon (March) (Table 5.12 and Fig. 5.13d).

***C. leptopora***: The flux values varied between 1.38 to  $20.53 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $7.23 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  in the shallow trap (Table 5.11). It is characterized by poly modal distribution with a major peak occurring during

**Fig. 5.13.** Seasonal variation of coccolith fluxes of (a) *U. tenuis* (b) *F. profunda* (c) *C. mediterranea* and (d) *O. antillarum* in the shallow and deep traps from the southern Bay of Bengal (SBBT). The shaded bands represent the periods of different monsoon seasons.



SW monsoon (August/September) followed by minor peak abundances recorded during NE-SW intermonsoon, SW monsoon and SW-NE intermonsoon (April, June/July and September/October) (Fig. 5.14a). The fluxes in deep trap showed patchy distribution (Table 5.12 and Fig. 5.14a).

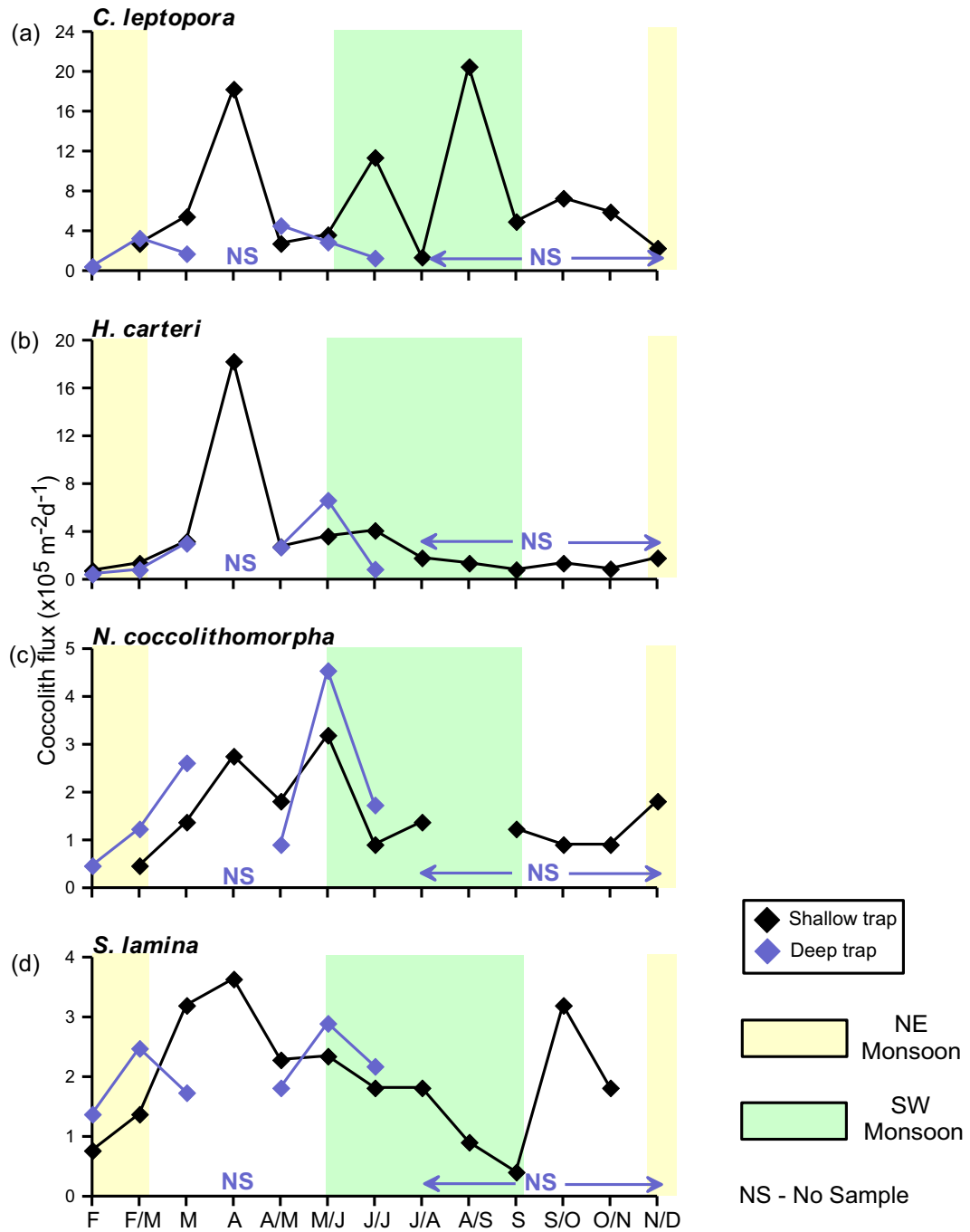
***H. carteri***: The flux values varied between 0.77 and  $18.27 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average flux of  $3.25 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  in the shallow trap (Table 5.11). It showed uni-modal distribution pattern with a peak occurring during NE-SW intermonsoon (April) which significantly decreased during rest of the sampling period (Fig. 5.14b). In the deep trap fluxes varied from 0.47 to  $6.55 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  from the available samples between February and June/July intervals (Table 5.12).

***N. coccolithomorpha***: This species was sparsely distributed and the flux values ranged between 0.47 to  $3.20 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average flux of  $1.53 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  in the shallow trap (Table 5.11). It showed relatively increased fluxes during NE-SW intermonsoon (April) and the beginning of SW monsoon (May/June) (Fig. 5.14c). Similarly in the deep trap the fluxes ranged from 0.47 to  $4.55 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  and recorded increased fluxes during early SW monsoon (May/June) followed by a minor peak during NE-SW intermonsoon (March) (Table 5.12 and Fig. 5.14c). In general, deep trap showed higher fluxes than that of shallow trap.

***S. lamina***: The flux values varied between 0.41 to  $3.64 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $1.97 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  in the shallow trap (Table 5.11). The fluxes showed a bi-modal distributional pattern, the abundance peaks were associated with NE-SW and SW-NE intermonsoons (April and September/October) (Fig. 5.14d). In the deep trap the fluxes varied from 1.38 to  $2.90 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  and showed two peaks during NE monsoon (February/March) and early SW monsoon (May/June) (Table 5.12 and Fig. 5.14d).

***S. pulchra***: The flux values varied between 0.41 and  $1.82 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $1.06 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  (Table 5.11). Fluxes recorded were significantly low without showing much variation from SW monsoon to SW-NE

**Fig. 5.14.** Seasonal variation of coccolith fluxes of (a) *C. leptopora* (b) *H. carteri* (c) *N. coccolithomorpha* and (d) *S. lamina* in the shallow and deep traps from the southern Bay of Bengal (SBBT). The shaded bands represent the periods of different monsoon seasons.





intermonsoon (Fig. 5.15a). While in the deep trap, fluxes increased marginally showing values of  $3.92 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  during SW monsoon (June/July) (Table 5.12 and Fig. 5.15a).

**R. clavigera:** This species showed a patchy distributional pattern in the shallow trap (Table 5.11 and Fig. 5.15b). Not much variation could be observed. However, fluxes were marginally recorded in the deep trap (Table 5.12 and Fig. 5.15b).

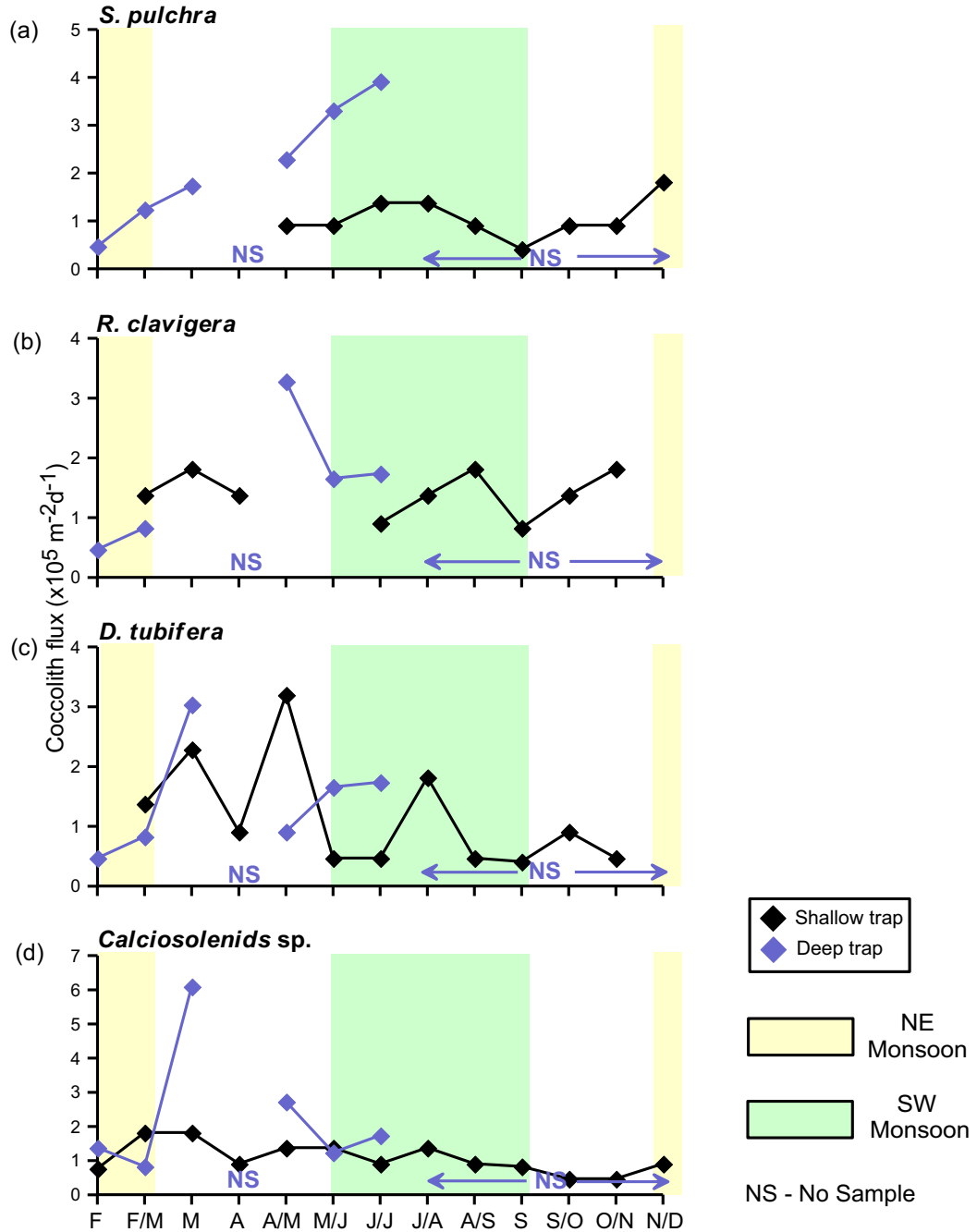
**D. tubifera:** Fluxes recorded were very low both in shallow and deep traps (Tables 5.11 and 5.12). A maximum flux of  $3.2 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  was observed in the shallow trap during NE-SW intermonsoon (April/May) (Fig. 5.15c). While the fluxes in the deep trap showed patchy distribution, with a maximum flux of  $3.04 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  during NE-SW intermonsoon (March) (Table 5.12 and Fig. 5.15c).

**Calciosolenids sp.:** Lowest fluxes were observed in the shallow trap and it did not display any seasonality (Table 5.11 and Fig. 5.15d). However, fluxes in the deep trap increased, with a maximum flux of  $6.10 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  during NE-SW intermonsoon (Table 5.12 and Fig. 5.15d)

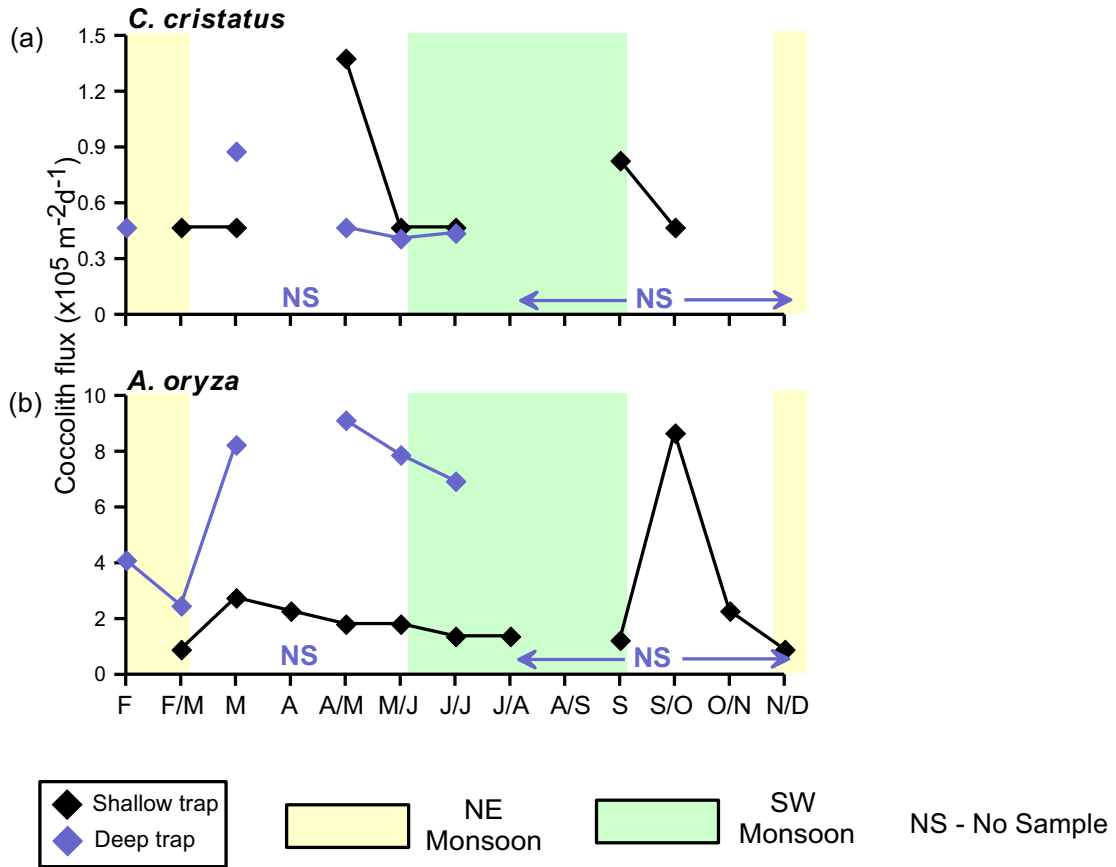
**C. cristatus:** Patchy distribution was observed in both the traps with a maximum flux of  $1.38 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  occurring during NE-SW intermonsoon in the shallow trap (Table 5.11 and Fig. 5.16a). While, the fluxes in the deep trap were sparsely distributed (Table 5.12 and Fig. 5.16a).

**A. oryza:** The fluxes of *A. oryza* in the shallow trap varied between 0.91 and  $8.67 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average flux value of  $2.32 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  and remained very low throughout the sampling period except for a pronounced peak during SW-NE intermonsoon (September/October) (Table 5.11 and Fig. 5.16b). While in the deep trap the fluxes varied from 2.48 to  $9.13 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  with an average value of  $6.47 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  and recorded higher fluxes compared to that of the shallow trap with peaks of  $8.25 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  and  $9.13 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  observed during NE-SW intermonsoons (March and April/May) (Table 5.12 and Fig. 5.16b).

**Fig. 5.15.** Seasonal variation of coccolith fluxes of (a) *S. pulchra* (b) *R. clavigera* (c) *D. tubifera* and (d) *Calciosolenids* sp. in the shallow and deep traps from the southern Bay of Bengal (SBBT). The shaded bands represent the periods of different monsoon seasons.



**Fig. 5.16.** Seasonal variation of coccolith fluxes of (a) *C. cristatus* in the shallow and deep traps from the southern Bay of Bengal (SBBT). The shaded bands represent the periods of different monsoon seasons.



#### 5.4 Coccolithophore-CaCO<sub>3</sub> fluxes in the Bay of Bengal

**Northern Bay of Bengal:** Coccolithophore-CaCO<sub>3</sub> flux at NBBT varied between 0.02 and 0.30 mg m<sup>-2</sup>d<sup>-1</sup> in the shallow trap and 0.04 and 0.11 mg m<sup>-2</sup>d<sup>-1</sup> in the deep trap with an average values of 0.12 mg m<sup>-2</sup>d<sup>-1</sup> and 0.09 mg m<sup>-2</sup>d<sup>-1</sup> respectively (Table 5.13). The total coccolithophore and coccolithophore-CaCO<sub>3</sub> fluxes displayed similar distribution pattern in both the shallow and deep traps (Fig. 5.1c). The fluxes in the shallow trap showed major peaks during the early and late SW monsoons (June and September) and minor peak during NE-SW intermonsoon (March). While the deep trap showed a major peak during NE-SW intermonsoon (March) (Fig. 5.1c).

**Central Bay of Bengal:** The coccolithophore-CaCO<sub>3</sub> flux in the shallow trap varied between 0.19 and 0.44 mg m<sup>-2</sup>d<sup>-1</sup>, while in the deep trap it was between 0.17 and 0.32 mg m<sup>-2</sup>d<sup>-1</sup> with an average values of 0.30 and 0.24 mg m<sup>-2</sup>d<sup>-1</sup> respectively (Table 5.13). Its fluxes in the shallow trap recorded higher fluxes during NE-SW and SW-NE intermonsoons (April/May and September/October) (Fig. 5.5c). While, the deep trap showed lower fluxes compared to the shallow trap with a peak abundance during NE-SW intermonsoon (April– May) (Fig. 5.5c).

**Southern Bay of Bengal:** Coccolithophore-CaCO<sub>3</sub> flux values varied from 0.15 to 0.68 mg m<sup>-2</sup>d<sup>-1</sup> with average values of 0.33 mg m<sup>-2</sup>d<sup>-1</sup> in the shallow trap and 0.13 to 0.37 mg m<sup>-2</sup>d<sup>-1</sup> with average value of 0.27 mg m<sup>-2</sup>d<sup>-1</sup> in the deep trap (Table 5.13). These fluxes in the shallow trap showed a major peak associated with NE-SW intermonsoon (April) with also minor peaks occurring during SW and SW-NE monsoons (August/September and October/November) (Fig. 5.11c). Similarly the deep trap also reflected the same trend as that of total coccolithophore fluxes (Fig. 5.11c).

**Table 5.13.** Seasonal variation of average coccolithophore-calcium carbonate fluxes (calculated) in  $\text{mg m}^{-2}\text{d}^{-1}$  in the Bay of Bengal.

Northern Bay of Bengal Trap (NBBT 06)														
(Shallow Trap)														
Interval	29/1/92- 8/2/92	8/2/92- 5/3/92	5/3/92- 31/3/92	31/3/92- 26/4/92	26/4/92- 22/5/92	22/5/92- 17/6/92	17/6/92- 13/7/92	13/7/92- 8/8/92	8/8/92- 3/9/92	3/9/92- 29/9/92	29/9/92- 25/10/92	25/10/92- 20/11/92	Average	
Station No.	1	2	3	4	5	6	7	8	9	10	11	12	13	
Average Coccolithophore - $\text{CaCO}_3$ ( $\text{mg m}^{-2}\text{d}^{-1}$ )	0.02	0.06	0.13	0.04	0.07	0.26	0.09	0.10	0.06	0.30	0.18	0.17	0.12	
<b>(Deep Trap)</b>														
Average Coccolithophore - $\text{CaCO}_3$ ( $\text{mg m}^{-2}\text{d}^{-1}$ )	0.04	0.09	0.11	0.09	0.10	No Sample						0.09		
Central Bay of Bengal Trap (CBBT 06)														
(Shallow Trap)														
Interval	3/2/92- 8/2/92	8/2/92- 5/3/92	5/3/92- 31/3/92	31/3/92- 26/4/92	26/4/92- 22/5/92	22/5/92- 17/6/92	17/6/92- 13/7/92	13/7/92- 8/8/92	8/8/92- 3/9/92	3/9/92- 29/9/92	29/9/92- 25/10/92	25/10/92- 20/11/92	Average	
Station No.	1	2	3	4	5	6	7	8	9	10	11	12	13	
Average Coccolithophore - $\text{CaCO}_3$ ( $\text{mg m}^{-2}\text{d}^{-1}$ )	0.21	0.37	0.32	0.40	0.44	0.35	0.24	0.25	0.27	0.19	0.31	0.23	0.30	
<b>(Deep Trap)</b>														
Average Coccolithophore - $\text{CaCO}_3$ ( $\text{mg m}^{-2}\text{d}^{-1}$ )	No Sample	0.17	0.19	0.22	0.32	0.25	0.29	No Sample				0.21	No Sample	0.24
Southern Bay of Bengal Trap (SBBT 06)														
(Shallow Trap)														
Interval	3/2/92- 8/2/92	8/2/92- 5/3/92	5/3/92- 31/3/92	31/3/92- 26/4/92	26/4/92- 22/5/92	22/5/92- 17/6/92	17/6/92- 13/7/92	13/7/92- 8/8/92	8/8/92- 3/9/92	3/9/92- 29/9/92	29/9/92- 25/10/92	25/10/92- 20/11/92	Average	
Station No.	1	2	3	4	5	6	7	8	9	10	11	12	13	
Average Coccolithophore - $\text{CaCO}_3$ ( $\text{mg m}^{-2}\text{d}^{-1}$ )	0.15	0.17	0.25	0.68	0.29	0.27	0.33	0.30	0.43	0.28	0.45	0.47	0.33	
<b>(Deep Trap)</b>														
Average Coccolithophore - $\text{CaCO}_3$ ( $\text{mg m}^{-2}\text{d}^{-1}$ )	0.13	0.19	0.32	No Sample	0.36	0.37	0.22	No Sample				0.27	0.27	

## 5.5 Seasonal variation of lithogenic and biogeochemical fluxes (calcium carbonate, biogenic opal and organic carbon) from the shallow and deep traps of the Bay of Bengal

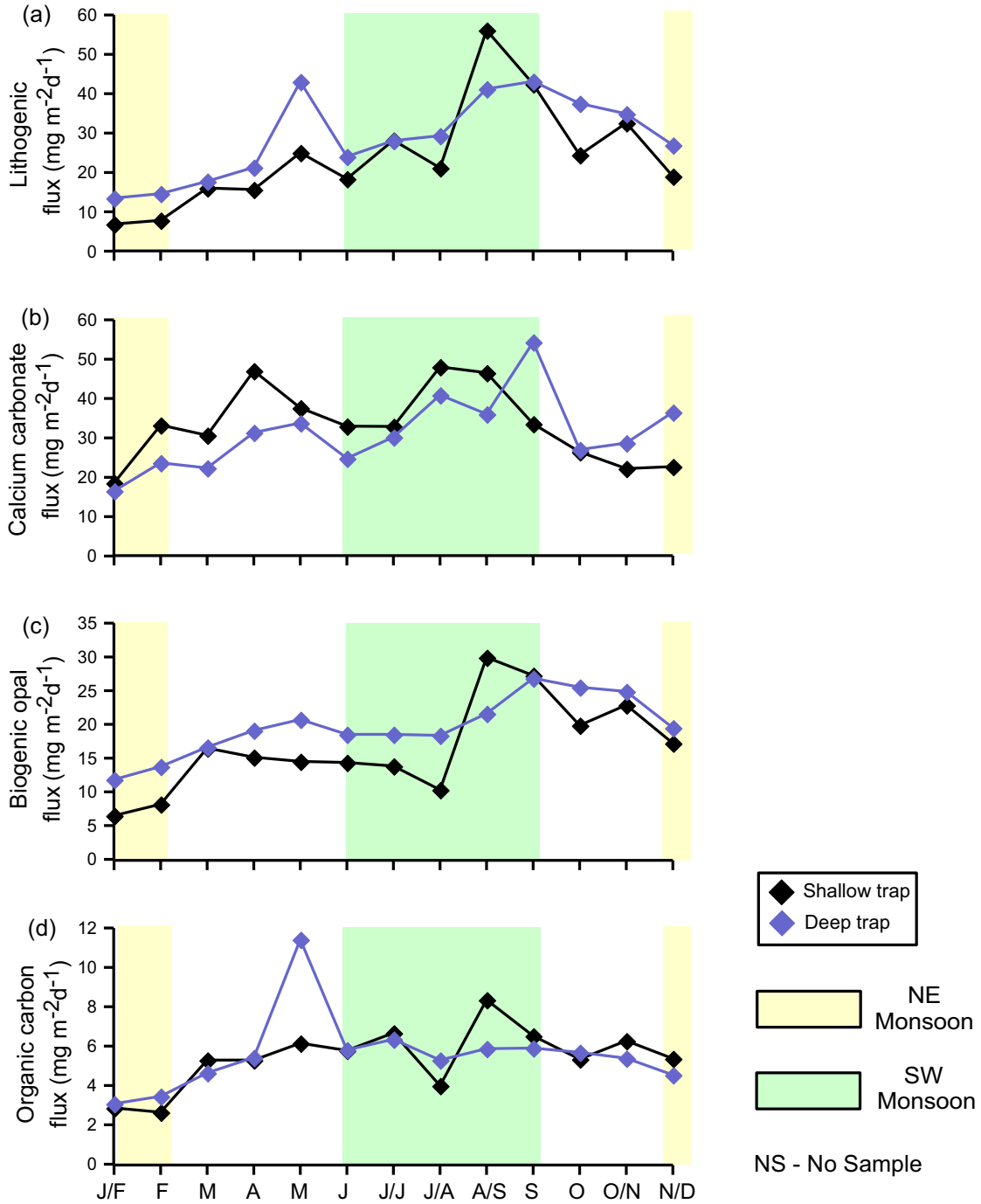
In addition to the total particulate fluxes, total coccolithophore fluxes, fluxes of individual taxa and coccolithophore-CaCO<sub>3</sub> fluxes, we touch upon briefly on the fluxes of lithogenic, calcium carbonate, biogenic opal and organic carbon. The data of which was supplied by Dr. Daniela Unger.

### 5.5.1 Northern Bay of Bengal

**Lithogenic flux:** The fluxes in the shallow trap varied from 6.86 to 56.15 mg m<sup>-2</sup>d<sup>-1</sup> with an average value of 24.14 mg m<sup>-2</sup>d<sup>-1</sup> (Table 5.1). While in the deep trap it varied from 13.50 to 43.13 mg m<sup>-2</sup>d<sup>-1</sup> with an average value of 28.88 mg m<sup>-2</sup>d<sup>-1</sup> (Table 5.2). The fluxes in the shallow trap showed a seasonality with a major peak observed during SW monsoon (August/September) followed by minor peak during (June/July) (Fig. 5.17a). The fluxes in the deep trap were relatively low during NE monsoon which progressively increased through SW monsoon with a major peak associated with SW monsoon (Fig. 5.17a). While the fluxes in the deep trap showed a bi-modal distribution pattern with its peaks associated with NE-SW and late SW monsoons (May and September) (Fig. 5.17a).

**Calcium carbonate flux:** Calcium carbonate was also one of the dominant biogenic components in both the shallow and deep traps with fluxes ranging from 18.58 to 48.08 mg m<sup>-2</sup>d<sup>-1</sup> in the shallow trap and from 16.55 to 54.38 mg m<sup>-2</sup>d<sup>-1</sup> in the deep trap with average fluxes of 33.29 mg m<sup>-2</sup>d<sup>-1</sup> and 31.27 mg m<sup>-2</sup>d<sup>-1</sup> respectively (Tables 5.1 and 5.2). The shallow trap showed seasonality characterized by a distinct bi-modal distribution pattern with its peaks associated with SW (July/August) and NE-SW (April) monsoons (Fig. 5.17b). While the deep trap showed relatively lower fluxes with a major peak observed during late SW monsoon (September) and a minor peak during NE-SW intermonsoon (May) (Fig. 5.17b).

**Fig. 5.17.** Seasonal variation of (a) lithogenic (b)calcium carbonate (c) biogenic opal and (d) organic carbon fluxes in the shallow and deep traps from the northern Bay of Bengal (NBBT). The shaded bands represent the periods of different monsoon seasons.



**Biogenic opal flux:** The fluxes of opal varied from 6.48 to 29.93 mg m<sup>-2</sup>d<sup>-1</sup> with an average value of 16.65 mg m<sup>-2</sup>d<sup>-1</sup> for the shallow trap and fluxes in deep trap varied from 11.82 to 26.84 mg m<sup>-2</sup>d<sup>-1</sup> with an average value of 19.67 (Tables 5.1 and 5.2). It also displayed a seasonality with major and minor peaks associated with SW (August/September) and NE-SW (March) monsoons (Fig. 5.17c). The deep trap recorded comparatively higher fluxes with peak abundance observed during late SW monsoon (September) followed by a minor peak during NE-SW intermonsoon (May) (Fig. 5.17c).

**Organic carbon:** The fluxes of organic carbon varied from 2.64 to 8.35 mg m<sup>-2</sup>d<sup>-1</sup> with an average value of 5.42 mg m<sup>-2</sup>d<sup>-1</sup> in the shallow trap while in the deep trap the fluxes varied from 3.07 to 11.42 mg m<sup>-2</sup>d<sup>-1</sup> with an average value of 5.60 mg m<sup>-2</sup>d<sup>-1</sup> (Tables 5.1 and 5.2). In the shallow trap it recorded increased flux with a major peak associated with SW monsoon (August/September) (Fig. 5.17d). On the other hand, the deep trap showed a uni-modal distribution with a prominent peak occurring during NE-SW intermonsoon (May) (Fig. 5.17d).

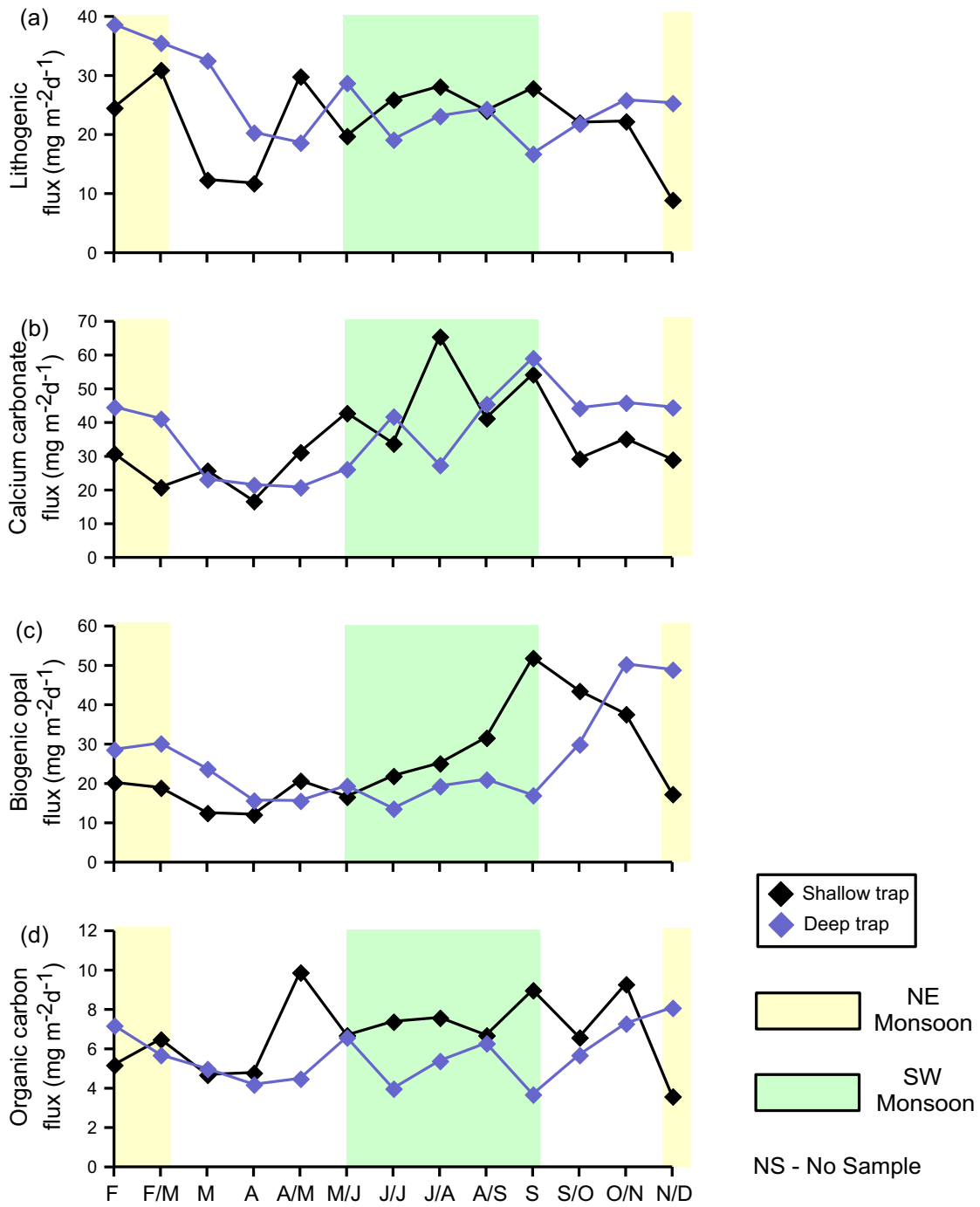
### 5.5.2 Central Bay of Bengal

**Lithogenic flux:** Lithogenic fluxes varied from 9.00 to 31.00 mg m<sup>-2</sup>d<sup>-1</sup> with an average value of 22.24 mg m<sup>-2</sup>d<sup>-1</sup> in the shallow trap similarly, it varied from 16.80 to 38.70 mg m<sup>-2</sup>d<sup>-1</sup> with an average value of 25.51 mg m<sup>-2</sup>d<sup>-1</sup> in the deep trap (Tables 5.5 and 5.6). The fluxes in the shallow trap showed seasonality and recorded major peaks during NE monsoon (February/March) and NE-SW intermonsoon (April/May) in the shallow trap, followed by increased fluxes during SW monsoon (Fig. 5.18a). Whereas the fluxes in the deep trap remained high with a peak abundance during NE monsoon followed by minor peak during early SW and SW-NE monsoons (May/June and October/November) (Fig. 5.18a).

**Calcium carbonate flux:** Calcium carbonate was the dominant biogenic component both in the shallow and deep traps. Its fluxes in the shallow trap varied from 16.80 to 65.60 mg m<sup>-2</sup>d<sup>-1</sup> with an average of 35.22 mg m<sup>-2</sup>d<sup>-1</sup>, whereas in the deep trap, fluxes varied from 20.90 to 59.20 mg m<sup>-2</sup>d<sup>-1</sup> with an



**Fig. 5.18.** Seasonal variation of (a) lithogenic (b) calcium carbonate (c) biogenic opal and (d) organic carbon fluxes in the shallow and deep traps from the central Bay of Bengal (CBBT). The shaded bands represent the period of different monsoon seasons.



average value of  $37.48 \text{ mg m}^{-2}\text{d}^{-1}$  (Tables 5.5 and 5.6). The fluxes in the shallow trap showed seasonality with relatively higher fluxes occurring during SW monsoon with a major peak during (July/August) followed by minor peak during (September) (Fig. 5.18b). Similarly the deep trap also showed a seasonality with major peak associated with SW monsoon (September) and a minor peak during June/July (Fig. 5.18b). Besides it also recorded increased fluxes during NE monsoons and were also comparatively higher than shallow trap (Fig. 5.18b).

**Biogenic opal:** Biogenic opal was also one of the dominant components contributing to the biogenic material with fluxes ranging from 12.20 to 52.00  $\text{mg m}^{-2}\text{d}^{-1}$  with an average value of  $25.48 \text{ mg m}^{-2}\text{d}^{-1}$  in the shallow trap (Table 5.5). The fluxes in the deep trap ranged from 13.70 to 50.40  $\text{mg m}^{-2}\text{d}^{-1}$  with an average value of  $25.73 \text{ mg m}^{-2}\text{d}^{-1}$  (Table 5.6). The fluxes in the shallow trap showed a prominent abundance peak during late SW monsoon (September) (Fig. 5.18c). The fluxes in the deep trap also followed the same trend with maximum fluxes occurring during SW-NE intermonsoon (October/November) (Fig. 5.18c).

**Organic carbon flux:** It was a minor component of the biogenic material where the fluxes varied from 3.60 to 9.90  $\text{mg m}^{-2}\text{d}^{-1}$  with an average value of  $6.77 \text{ mg m}^{-2}\text{d}^{-1}$  in the shallow trap (Table 5.5). In the deep trap fluxes varied from 3.70 to 8.10  $\text{mg m}^{-2}\text{d}^{-1}$  with an average value of  $5.67 \text{ mg m}^{-2}\text{d}^{-1}$  (Table 5.6). The fluxes in the shallow trap showed a major peak during NE-SW intermonsoon (April/May) with a minor peaks associated with SW monsoon (September) and SW-NE intermonsoon (October/November) (Fig. 5.18d). While the deep trap recorded relatively lower fluxes compared to the shallow trap with increased fluxes occurring during NE monsoons (November/December and February) and SW monsoons (May/June and August/September) (Fig. 5.18d).

### 5.5.3 Southern Bay of Bengal

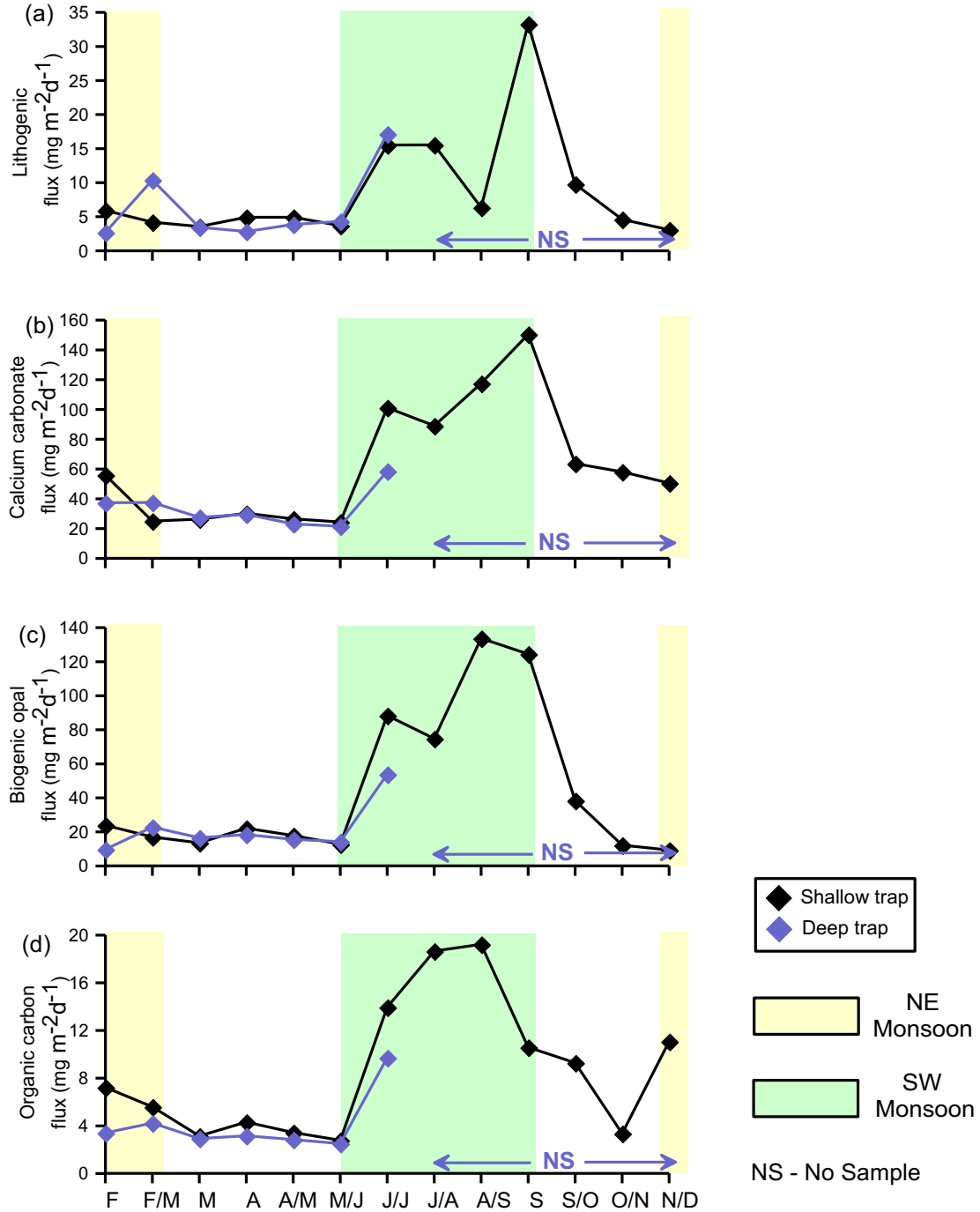
**Lithogenic matter:** Lithogenic matter was the minor component found at the SBBT traps. In the shallow trap it varied from 3.70 to 33.31  $\text{mg m}^{-2}\text{d}^{-1}$  with an average value of 8.88  $\text{mg m}^{-2}\text{d}^{-1}$  (Table 5.9). While in the deep trap the fluxes were significantly low and varied from 2.69 to 17.15  $\text{mg m}^{-2}\text{d}^{-1}$  with an average value of 6.39  $\text{mg m}^{-2}\text{d}^{-1}$  (Table 5.10). The shallow trap displayed a distinct seasonality with higher fluxes largely associated with SW monsoon with minor and major peaks during (June – August and September) (Fig. 5.19a). The deep trap also followed the same trend as that of shallow trap with a major peak observed during SW monsoon (June/July) (Fig. 5.19a).

**Calcium carbonate:** Calcium carbonate was the most dominant biogenic component in both the traps. The fluxes in the shallow trap varied from 24.47 to 150.48  $\text{mg m}^{-2}\text{d}^{-1}$  with an average value of 63.03  $\text{mg m}^{-2}\text{d}^{-1}$ , whereas it varied from 21.68 to 58.62  $\text{mg m}^{-2}\text{d}^{-1}$  with an average value of 33.66  $\text{mg m}^{-2}\text{d}^{-1}$  in the deep trap (Tables 5.9 and 5.10). The fluxes displayed seasonality with a major peak observed during late SW monsoon (September) (Fig. 19b). The deep trap followed the same trend as seen in shallow trap (Fig. 5.19b).

**Biogenic opal flux:** Biogenic opal was the second dominant component of the biogenic material. The fluxes in the shallow trap varied from 9.34 to 133.73  $\text{mg m}^{-2}\text{d}^{-1}$  with an average value of 45.29  $\text{mg m}^{-2}\text{d}^{-1}$  (Table 5.9). Whereas the fluxes in the deep trap varied from 9.75 to 53.82  $\text{mg m}^{-2}\text{d}^{-1}$  with an average value of 21.63  $\text{mg m}^{-2}\text{d}^{-1}$  (Table 5.10). The fluxes in the shallow trap displayed distinct seasonality with higher fluxes associated with SW monsoon (August/September), followed by same trend in the deep trap (Fig. 5.19c).

**Organic carbon flux:** Organic carbon fluxes in the shallow trap varied from 2.79 to 19.23  $\text{mg m}^{-2}\text{d}^{-1}$  with an average value of 8.67  $\text{mg m}^{-2}\text{d}^{-1}$  (Table 5.9). And in the deep trap the fluxes varied from 2.51 to 9.71 with an average value of 4.12  $\text{mg m}^{-2}\text{d}^{-1}$  (Table 5.10). Fluxes in the shallow trap displayed a distinct seasonality with highest fluxes observed during SW monsoon (Fig. 5.19d).

**Fig. 5.19.** Seasonal variation of (a) lithogenic (b) calcium carbonate (c) biogenic opal and (d) organic carbon fluxes in the shallow and deep traps from the southern Bay of Bengal (SBBT). The shaded bands represent the periods of different monsoon seasons.



The deep trap also followed the same trend as shown by shallow trap (Fig. 5.19d).

CHAPTER 6

*Discussion*

## Chapter 6

### DISCUSSION

#### 6.1 Seasonal variation of total particulate and coccolithophore fluxes in the Bay of Bengal (NBBT, CBBT and SBBT)

The Bay of Bengal which comes under the influence of semi-annual seasonality of the Asian monsoon system experiences enormous fluvial input through the world's major rivers such as the Ganges, the Brahmaputra etc. draining through the Himalayas (Milliman and Meade, 1983). Furthermore, the oceanic circulation is also affected by seasonally changing wind field (Wyrcki, 1973). Thus, this region with its specific characteristics represents a unique environmental setting ideal to examine the effects of seasonally changing oceanographic processes on marine biogeochemical processes. In this regard, the study of total particulate fluxes and particularly the coccolithophore fluxes from the sediment traps in the diverse oceanographic settings of the Bay of Bengal would facilitate in understanding of the biogeochemical variability and the factors responsible thereof.

**Total particulate flux:** The oceanographic and biological processes are strongly influenced by the monsoons (SW monsoon and NE monsoon). The main factors controlling particle fluxes in the Bay of Bengal are upwelling, mixed layer deepening due to wind stress and influence of fresh water influx by river discharge.

The total particulate fluxes progressively increased from the northern to southern Bay of Bengal. At NBBT, the total particulate fluxes displayed a distinct seasonality in shallow trap which ranged from 37.08 to 147.66 mg m<sup>-2</sup>d<sup>-1</sup>. Increased fluxes observed in both traps during SW monsoon was due to the influx of fresh water which bring along nutrients facilitating biological productivity. Whereas, decreased fluxes recorded at the fag end of NE-SW intermonsoon was mainly attributed to low input from the rivers (Fig. 5.1a). Higher fluxes encountered during NE-SW and SW-NE

intermonsoons was due to the Bay of Bengal Western Boundary Current (BBWBC) and prevalent anticyclone gyre which advected nutrients from the upwelling region along the eastern Bay (March/May and October/November) (Legeckis, 1987; Potemra et al., 1991; Shetye et al., 1993; Sanilkumar et al., 1997; Babu et al., 2004). Similarly, Unger et al. (2003) also reported highest fluxes in 1989, 1994 and 1996 during the pre-SW monsoon when low wind velocities and decreased river runoff prevalent and attributed to the advection of nutrients from the upwelling region along the western margin of the basin.

At CBBT the total particulate fluxes in the shallow trap showed a distinct seasonality where fluxes ranged from 49.5 to 150.5 mg m<sup>-2</sup>d<sup>-1</sup> associated with the late SW monsoon (August/September) (Fig. 5.5a). This was accomplished by the prevalent cyclonic flow of a strong eastward current at 13°N which passes through CBBT location facilitating advection of nutrient rich upwelled water from the east coast of India (Shetye et al., 1991). Besides, the strong wind-curl stress during this season also caused a SW-NE oriented band of divergence in the central Bay of Bengal (Murty et al., 1992). During SW-NE intermonsoon a cyclonic circulation evident from altimeter data prevailed off the east coast of India (V.S.N. Murty, pers. comm.) with the upwelling from October till December was responsible for the flux maxima. Lowest fluxes recorded during NE-SW intermonsoon (April/May) in both the traps was resulted by low wind speeds and stratification caused by elevated SST (Unger et al., 2003). The deep trap showed high fluxes during SW-NE intermonsoon and early NE monsoon (October-December) was due to upwelling. Although nutrient injection into the euphotic zone takes place by convective mixing or forcing as proposed for the northern Arabian Sea during the NE monsoon (Madhupratap et al., 1996), it was less effective in the Bay of Bengal due to strong stratification of the upper water column.

The total particulate fluxes at SBBT ranged from 46.01 to 327.41 mg m<sup>-2</sup>d<sup>-1</sup> displaying seasonality with a sharp peak fluxes associated with SW monsoon (September) and low fluxes during NE monsoon (Fig. 5.11c). The deep trap also showed maximum values during SW monsoon (June/July). The increasing winds from May onwards cause a deepening of the mixed



layer resulting in decrease of SST's by ca. 2°C facilitating productivity (Unger et al., 2003). As reported by Schäfer et al., (1996) the stronger wind speeds in the southern Bay of Bengal caused a decrease in SST's of about 3°C during the SW monsoon. In addition to wind-induced mixing, advection of cold upwelled water from the southwest coast of India (Sharma, 1978; Murty et al., 1992) contributed to the low SST's by triggering primary productivity. Lower fluxes were recorded during NE-SW intermonsoon and early SW monsoon (May/June) in both the traps due to low wind speeds and elevated SST's of ~30°C leading to oligotrophic conditions (Unger et al., 2003).

The deep traps at NBBT and CBBT sites recorded anomalously higher total particulate fluxes attributable to the lateral input from the steep shelf region along the east coast of India (Schäfer et al., 1996). While lower total particulate flux observed at SBBT must have resulted due to dissolution (Table 5.10).

**Total coccolithophores fluxes:** The present study on coccolithophores revealed a strong seasonal variation from the northern to southern Bay of Bengal. The temporal distribution patterns distinctly reflected the variability of hydrographic conditions in the overlying water masses at all the trap locations. In general, the biogenic flux was one of the major components largely comprised of coccolithophores contributed to the total particulate flux at both the shallow and deep trap.

Overall fluxes of coccolithophores observed in the Bay of Bengal were comparatively lower than those reported in the northeastern Arabian Sea off Pakistan (Andruleit et al., 2000), upwelling region off Somalia (Broerse et al., 2000a) and central Arabian Sea (Mergulhao et al., 2006) in the northern Indian Ocean. Besides, the fluxes increased in the deep traps at certain intervals from all the three traps.

Coccolithophore fluxes among the three locations in the Bay of Bengal showed highest fluxes occurred at CBBT with an average flux of  $114.68 \times 10^5 \text{ m}^{-2} \text{ d}^{-1}$  followed by SBBT and NBBT with the average values of  $109.35 \times 10^5$

$\text{m}^{-2} \text{d}^{-1}$  and  $41.55 \times 10^5 \text{m}^{-2} \text{d}^{-1}$  respectively in the shallow traps (Tables 5.3, 5.7 & 5.11).

The shallow trap at NBBT deployed at a depth of 1156 m was situated in the vicinity of the region influenced by fresh water discharge from the Ganges, the Brahmaputra rivers (Fig. 4.2). The temporal distribution of total coccolithophore fluxes at NBBT traps displayed a strong seasonality both during SW and NE monsoons (Fig. 5.1b). Comparatively lower coccolithophore fluxes and diversity observed at NBBT was attributed to the strong stratification (up to 100-150 m depth) resulted by the spread of a low salinity water caused by freshwater influx (Murty et al., 1992) during SW monsoon. Furthermore, it prevented the vertical mixing and injection of nutrients into the upper layers due to stratification. Based on foraminiferal studies, salinity gradient was reflected by the dominance of *Neogloboquadrina dutertrei* in the low salinity waters at NBBT (Guptha et al., 1997). Shenoi et al. (2002) also reported that the strong stratification did inhibit the vertical mixing in the surface layers at NBBT. Murty et al. (1996) reported that the wind induced divergence caused by positive wind stress curl over the northern Bay and the associated subsurface upwelling processes were limited to the base of the barrier layer (~30 m depth) resulting in lower fluxes during SW monsoon. Based on their studies in the Bay of Bengal, Prasannakumar et al. (2002), inferred that in general, the Bay of Bengal was less productive during SW monsoon compared to the Arabian Sea and attributed to the fact that the heavy rainfall and the influx of river water freshened the upper layers of the Bay by 3 - 7 psu (practical salinity unit) during summer and SST was warmer by 1.5° to 2°C. This led to a strong stratification as the prevalent winds were unable to erode the stratification thereby inhibiting injection of nutrients into the upper layers. Nevertheless, the peak occurrence of fluxes was observed during late SW monsoon (September), resulted by the nutrient input largely brought by the river plumes (Ittekkot et al., 1991). Antoine et al. (1996) also reported nutrient supply associated with the river discharge facilitating high average rates of primary productivity up to  $2 \text{g Cm}^{-2}\text{d}^{-1}$  in the coastal area and in the northern part of the Bay. Later the fluxes showed a decreasing trend through SW-NE intermonsoon (October – November) and NE monsoon

(December-February) as the supply of nutrients was minimal due to low riverine input (Fig. 5.1b). Decreased SST's observed during NE monsoon in the northern Bay was related to the reduced insolation rather than upwelling (Unger et al., 2003).

However, secondary peaks were recorded in both the traps at NBBT during late NE monsoon (March) (Fig. 5.1b) due to anticyclonic gyre at 16°N, 86°E supplying nutrient rich upwelled waters into the interior Bay (Babu et al., 2004). La Violette (1967) reported upwelling along the east coast of India and Burma during winter which must have advected nutrient rich waters facilitating productivity. The lower fluxes seen during NE–SW intermonsoon (March/April) attributed to low riverine input, low nutrient supply and relatively high temperatures. Highest fluxes observed during pre-SW monsoon when wind speed and river run-off decreased was attributed to the supply of nutrients from upwelling region triggered by elevated winds and strong BBWBC developed during March-April (Legeckis, 1987; Potemra et al., 1991; Shetye et al., 1993; Sanilkumar et al., 1997; Babu et al., 2004).

Although the riverine flux may bring in nutrients, it was thought to be lost to the deep sea because of the narrow shelf (Qasim, 1977; Sen Gupta et al., 1977; Radhakrishna et al., 1978). Besides, comparatively heavier cloud cover during SW monsoon might be another reason for relatively low productivity at NBBT.

The sediment trap mooring deployed at CBBT which lies close to the steep eastern continental margin of India was largely influenced by both the coastal and oceanic upwelling processes (Fig. 4.2). The seasonal variation of total coccolithophore fluxes displayed a distinct seasonality (Fig. 5.5b). Interestingly, the peak abundance flux of  $164.34 \times 10^5 \text{ m}^{-2} \text{ d}^{-1}$  was observed during NE-SW intermonsoon (March/April) in the shallow trap and increased in the deep trap with highest fluxes ( $172.62 \times 10^5 \text{ m}^{-2} \text{ d}^{-1}$ ) during April/May (Fig.5.5b). These intermonsoon peaks must have resulted due to the upwelling driven by BBWBC which developed and extended all along the east coast of India during February-May (Legeckis, 1987; Potemra et al., 1991;

Shetye et al., 1993; Sanilkumar et al., 1997; Babu et al., 2004). It was further supported by the earlier work of La Fond (1954) who reported upwelling along the east coast of India during February-April. Later, Balaramamurty (1958) reported a strong upwelling caused by advection of nutrients off the coast of Visakhapatnam which extended until May. Furthermore, based on thermal structure along the east coast of India they inferred that the upwelling off Visakhapatnam was more intense than off Madras. Rao et al. (1986) observed upwelling of cold water close to the surface from February-May off Visakhapatnam. Mojumder (1967) reported the seasonal fluctuations of the SST, salinity, dissolved O<sub>2</sub> and other nutrient salts during 1964-66 and suggested the occurrence of upwelling (April-June) and sinking (September-October) off Visakhapatnam during certain months of the year.

Relatively moderate fluxes ( $134.42 \times 10^5 \text{ m}^{-2} \text{ d}^{-1}$ ) were also recorded during SW monsoon (July/August) (Fig. 5.5b) resulted by the upwelling along the east coast of India (Shetye et al., 1991) and also the strong wind curl stress which caused the divergence in the central Bay substantiated by prevalent low temperatures (Murty et al., 1992). Anand et al. (1968) found that upwelling occurred off Madras and further north off Visakhapatnam during the summer monsoon. Gopalakrishna et al. (1996), Vijaykumaran et al. (1996) and Gopalakrishna and Sastry (1985) indicated the occurrence of coastal upwelling off Tamil Nadu during SW monsoon. Similarly, De Souza et al. (1981) reported two regions of upwelling near Madras and Visakhapatnam during August-September. Despite the occurrence of upwelling in the central Bay of Bengal the observed relatively moderate fluxes during SW monsoon were attributed to dissolution.

Coccolithophore fluxes at SBBT at a shallow trap depth of 1518 m displayed seasonality with a major peak ( $164.34 \times 10^5 \text{ m}^{-2} \text{ d}^{-1}$ ) coincided with NE-SW intermonsoon (March/April) due to the advection of high chlorophyll 'a' waters through the WMC from the Car-Nicobar islands (V.S.N. Murty, pers. comm.). Relatively increased fluxes ( $151.07 \times 10^5 \text{ m}^{-2} \text{ d}^{-1}$ ) were also observed during SW monsoon (August/September) and attributed to the supply of nutrients from subsurface layers by wind induced upwelling processes

(Ittekkot et al., 1991; Schäfer et al., 1996). Wind induced entrainment of nutrients supplied both nitrate and silica and the wind mixing facilitated primarily carbonate production as observed in 1988 by Unger et al. (2003). However, wind speed was not only the factor regulating the supply of nutrients, but the alternate factor was the advection of nutrient-rich upwelled waters through SMC from the upwelling region along the southwest coast of India (Sharma, 1978; Shetye et al., 1990; Rahul Mohan, 1997). The peak fluxes ( $159.34 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$ ) were also observed during SW-NE intermonsoon (October/November). Decreased fluxes recorded during late SW monsoon (September) was due to dissolution resulted by the biologically mediated processes (Fig. 5.5b). Besides, mechanical breakdown of coccoliths was also observed due to grazing. The deep trap at SBBT depicted similar trend as that of the shallow trap with relatively higher fluxes. And recorded maximum value during late NE monsoon (March) and during NE-SW intermonsoon (April-June) due to the advection of high chlorophyll 'a' waters through the WMC from the Car-Nicobar islands (V.S.N. Murty, pers. comm.).

This study inferred that the coccolithophores displayed seasonality largely related to productivity. Earlier it was believed that the coccolithophores were regarded as a phytoplankton group adapted to stable and oligotrophic conditions which tend to dominate in the waters of less productivity (Winter, 1985; Mitchell-Innes and Winter, 1987; Kleijne, 1993; Winter et al., 1994). Recently, Schiebel et al. (2004) also stated that the coccolithophore cell density does not follow nutrient concentration. But, on the contrary, based on the extensive studies carried out during the last few years by utilizing satellite imageries in oceanographic research, it was inferred that the coccolithophores were seasonally dominating in a high productivity region (Broerse, 2000).

The contribution of intact coccospheres to the total coccolith flux was relatively small in comparison to the settling coccoliths. The coccosphere and coccoliths are generally too small to sink on their own through the water column (Honjo, 1976, 1980), their incorporation into settling aggregates (scavenging) or fecal pellets is required for gaining a reasonable sinking velocity (Honjo, 1982; Pilskaln and Honjo, 1987). Therefore, absolute

coccolithophore fluxes did not seem to represent truly the real production as they were dependent on the availability of transportation vehicles, which are linked to production and/or to re-suspension, lateral advection, dissolution and grazing processes. Consequently, due to the uncertainty concerning the actual coccolithophore fluxes more emphasis was given to floral assemblages, which are assumed to be not, or only slightly overprinted by the input of lithogenic material and also by lateral advection. Besides, these assemblages helped in delineating various biogeographic and hydrographic settings.

The coccospheres were distributed sporadically in all the three trap locations. The northern traps (NBBT) recorded maximum flux of  $1.76 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  during late SW monsoon (September) corresponding to the total coccolithophore fluxes (Table 5.3). The central traps (CBBT) also recorded a maximum coccospheres flux of  $1.85 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  during late NE monsoon February/March (Table 5.7). Whereas, the southern traps (SBBT) recorded the highest coccosphere flux of  $10.95 \times 10^5 \text{ m}^{-2}\text{d}^{-1}$  during SW-NE intermonsoon (September/October). The occurrence of these coccospheres implied the new production. The coccosphere of *G. oceanica* and *E. huxleyi* were dominant at all the three traps, followed by a sparsely distributed species like *U. sibogae*, *O. antillarum*, *A. oryza*, *U. irregularis*, *C. leptopora*, *F. profunda*, *N. coccolithomorpha* and *G. flabellatus*.

## **6.2 Seasonal variation of various coccolithophore taxa in the Bay of Bengal (NBBT, CBBT and SBBT)**

Despite the fact that this study has yielded 25 species of coccolithophores, only a few species such as *G. oceanica*, *U. sibogae*, *U. irregularis*, *U. tenuis*, *F. profunda*, *C. leptopora*, *E. huxleyi*, *H. carteri* and *O. antillarum* which are ecologically important represented significantly. Hence seasonal variation of these species were discussed in relation to various physical processes. Whereas, the remaining ecologically lesser important species viz: *C. mediterranea*, *N. coccolithomorpha*, *S. lamina*, *S. pulchra*, *R.*

*clavigera*, *D. tubifera*, *Calciosolenids* sp., *C. cristatus* and *A. oryza* showed a patchy distribution, hence their seasonal variation was not discussed.

***Gephyrocapsa oceanica* (Plate – 1 (1)):** It is predominantly a low – latitude species very commonly observed in tropical – subtropical waters with a temperature range of 12° to 30°C (McIntyre et al., 1970) and widely reported along ocean margins (Okada and Honjo, 1973). It was also known to preferentially thrive in high-nutrient environments, such as upwelling areas or continental shelves (Mithchell-Innes and Winter, 1987; Houghton and Guptha, 1991; Kleijne, 1993; Broerse et al., 2000a; Andruleit et al., 2000; Andruleit and Rogalla, 2002; Guptha et al., 2005; Mergulhao et al., 2006).

*G. oceanica* was the most important and dominant species throughout the investigating period at all the three trap sites of NBBT, CBBT and SBBT in both the shallow and deep traps. The temporal distribution of *G. oceanica* and the total coccolithophore fluxes displayed similar distributional trend at NBBT. It recorded highest fluxes during late SW monsoon (September), which must have resulted by nutrient input particularly brought by the river plumes during the SW monsoon (Ittekkot et al., 1991). Similarly, Broerse et al. (2000a) reported high relative and absolute abundances during the height of the SW monsoon (upwelling period) in a region off Somalia. Ziveri et al. (1995a) showed that the production of this species in San Pedro Basin was controlled by temperature and nutrient concentrations and also flourished when nutrients supply was high during the upwelling period. Similarly, Schiebel et al. (2004) and Mergulhao et al. (2006) also reported *G. oceanica* to be positively related to upwelling conditions during the periods of upwelling in the Arabian Sea. Guptha (1985, 1986), Houghton and Guptha (1991), Andruleit et al. (2000) and Andruleit et al. (2003) also reported abundance of *G. oceanica* reflecting the prevalent upwelling conditions in the Arabian Sea.

Whereas, the peak abundance recorded during late NE monsoon (March) in both the shallow and the deep traps was due to anticyclonic gyre centered at 16°N, 86°E during this period. The nutrient-rich coastal waters might have been advected into the interior through the clockwise circulation of

the waters (Babu et al., 2004) (Fig. 5.2a). Similarly, Andrulleit et al. (2000) reported higher fluxes during the onset of NE monsoon in the eastern Arabian Sea when the nutrient levels were increased. Lower fluxes were observed during NE–SW intermonsoon when the strong stratification developed in the photic zone due to elevated SST's and also low wind speeds (Fig. 5.2a). Thus, this species clearly indicated its preference for high nutrients during SW monsoon.

*G. oceanica* fluxes at CBBT were characterized by seasonality displayed by a peak abundance of fluxes in the shallow trap during SW monsoon (July/August) which must have resulted by the upwelling as reported by Shetye et al. (1991) and also by the reported divergence in the interior Bay (Murty et al., 1992). Whereas, the secondary peaks associated with NE-SW intermonsoon (March/April) in the shallow trap and later (April/May) in the deep trap must have resulted by the supply of nutrients by the strong BBWBC, which developed during March/April (Legeckis, 1987; Potemra et al., 1991; Shetye et al., 1993; Sanilkumar et al., 1997; Babu et al., 2004). Interestingly, *G. oceanica* fluxes displayed decreasing trend at the end of SW monsoon (September) apparently attributed to intense dissolution resulted by biologically mediated processes (Fig. 5.6a).

*G. oceanica* at SBBT displayed a distinct seasonality with higher fluxes recorded during SW monsoon (June/July and August/September) and relatively lower fluxes during NE monsoon (Fig. 5.12a). Despite the fact that the southern Bay of Bengal waters were less productive or oligotrophic, it registered a very significant productivity. Increased fluxes in both the traps during SW monsoon indicated the tremendous influence of surface layer processes such as advection of nutrient-rich and elevated chlorophyll 'a' waters through SMC from the upwelling regions of southwest coast of India leading to high productivity (Sharma, 1978; Rahul Mohan, 1997; Shetye et al., 1990; Murty et al., 1992) and the origin of the cold water band in the southern Bay was believed to have originated from the southwest coast and the southern tip of India (Hastenrath and Lamb 1979; Rao et al., 2006).



The decreased fluxes recorded during late SW monsoon (September) must have resulted mainly due to dissolution caused by the biological mediated processes.

***Umbilicosphaera sibogae* (Plate – 5 (2)):** *U. sibogae* was the second dominant species in the present study with an average flux of 6.74, 18.83 and  $11.26 \times 10^5 \text{ m}^{-2} \text{ d}^{-1}$  in shallow traps at NBBT, CBBT and SBBT locations respectively (Tables 5.3, 5.7 and 5.11). *U. sibogae* is considered to be a temperate to subtropical species in the water temperatures between 21° and 28°C (McIntyre and Bé, 1967) (Plate 5(2)). The coccolith fluxes at NBBT trap followed the same trend as that of total coccolithophore fluxes and recorded a maximum peak during late SW monsoon (September), resulted mainly due to nutrient influx by the rivers (Ittekkot et al. 1991) (Fig. 5.2b). The maximum fluxes during late NE monsoon (March) in both the shallow and deep traps were mainly due to the BBWBC and anticyclonic gyre developed at 16°N, 86°E (Babu et al. 2004).

At CBBT, *U. sibogae* fluxes in the shallow trap were characterized by a polymodal distribution pattern with a maximum peak associated with the fag end of NE monsoon (February-March) followed by a minor peak during NE-SW intermonsoon (February/March and March/April) (Fig. 5.6b), attributed to the BBWBC and the anticyclonic gyre during March/April (Legeckis, 1987; Potemra et al., 1991; Shetye et al., 1993; Sanilkumar et al., 1997; Babu et al., 2004). While lower fluxes recorded during SW monsoon was attributed to dissolution. However, this species may not represent a realistic picture of seasonal changes in the production due to the fact that the coccospheres of *U. sibogae* get easily disaggregated and may not survive the passage through a zooplankton gut except as individual coccoliths (Steinmetz, 1991).

*U. sibogae* fluxes at SBBT showed a distinct seasonal trend (Fig. 5.12b), with a peak abundance occurred during SW monsoon (August/September) which must have also resulted by the advection of nutrient-rich waters from the upwelling region along the southwest coast of India (Sharma, 1978; Shetye et al., 1990). Increased fluxes were observed during late NE monsoon and NE-SW intermonsoon (April/May) due to the

advection of nutrient rich waters from Car-Nicobar islands which must have triggered the productivity (V.S.N. Murty, pers. comm). A distinct minimum value was recorded during late SW monsoon (September), which much have resulted mainly due to the dissolution from the biological mediated process.

The increase of *U. sibogae* var. *foliosa* observed during late SW monsoon at NBBT and SBBT trap locations indicated their preference for high nutrients. Roth and Coulbourn (1982) reported that *U. sibogae* to prefer moderately nutrient-rich waters in the Pacific tropical waters between 10°S and 20°N. Andrulleit et al. (2000) reported its response to the onset of NE monsoon in the eastern Arabian Sea when higher nutrients were available. Broerse et al. (2000a) also reported its response to upwelling areas off Somalia. Recently, Mergulhao et al. (2006) reported higher fluxes form the central Arabian Sea during NE monsoon due to advection of nutrient rich waters from the Pakistan shelf.

***Emiliania huxleyi* (Plate – 1 (2)):** *E. huxleyi* is the most ubiquitous coccolithophore species in the world oceans (McIntyre and Bé 1967; Winter and Siesser 1994) (Plate 1(2)). It is also a cosmopolitan species of tropical and subtropical waters (2-30°C) occurring over a wide range of salinities (16-45 psu) (Okada and McIntyre, 1977). The distribution of this species in the surface waters is largely independent of water temperature and thermocline depth (Samtleben et al., 1995a, b). *E. huxleyi* is reported in abundance in a nutrient-rich environments such as along the edges of the subtropical central gyres, in upwelling area, and along the outer continental shelves (Brand, 1994).

The higher fluxes occurred during early and late SW monsoon (May/June and September at NBBT (Fig. 5.2c), were largely due to the availability of high nutrients at the surface brought by the rivers during this period (Ittekkot et al. 1991). The maximum fluxes were also recorded during late NE monsoon (March) in both shallow and deep traps was mainly due to the presence of BBWBC and anticyclonic gyre at 16°N, 86°E which supplies nutrient rich waters (Babu et al. 2004).

At CBBT *E. huxleyi* fluxes displayed a seasonality with a sharply increased fluxes associated with SW monsoon (July/August) resulted by upwelling of nutrients in to the photic zone (Fig. 5.6c) (Shetye et al., 1990). And relatively high fluxes observed during NE monsoon and NE-SW intermonsoon (February/March and March/April) in the shallow trap and during NE-SW intermonsoon (April/May) in the deep trap could be due to the development of BBWBC and the anticyclonic gyre (Shetye et al., 1993; Sanilkumar et al., 1997; Babu et al., 2004).

*E. huxleyi* fluxes at SBBT also displayed a seasonality with a peak occurrences during SW-NE intermonsoon (October/November) followed by a secondary peak during SW monsoon (May/June and August/September) (Fig.11c) which have resulted by the advection of nutrient rich upwelled water from the southeastern Arabian Sea. The deep trap also showed a maximum peak during early SW monsoon (May/June). The decreased fluxes observed during late SW monsoon (September) must have resulted due to carbonate dissolution caused by biologically mediated process.

*G. oceanica* and *E. huxleyi* were the dominant species reported from the northern Indian Ocean by Guptha (1985), Guptha (1986), Houghton and Guptha (1991) and Kleijne et al. (1989) are known to respond to nutrient enrichment by increasing their population size both in the ocean as well as in culture. Zeltner (1998) reported maximum coccolithophore fluxes during upwelling relaxation with *G. oceanica* and *E. huxleyi* as dominant species in the Central Arabian Sea. Broerse et al. (2000a) explained the dominance of *G. oceanica* over *E. huxleyi* to its preference for elevated nutrient levels, which can be used as a proxy of intense upwelling in the Arabian Sea. However, Andruleit et al. (2000) reported higher concentration during early SW monsoon, which decreased in relative abundances during the onset of NE monsoon, thus this species did not indicate any upwelling, but showed its preference for stable regimes with relatively high nutrient availability rather than upwelling in the northeastern Arabian Sea. Andruleit and Rogalla (2002) suggested that this species may not be regarded as an indicator of upwelling

processes, but may be more typical of stable regimes with relatively high nutrient availability. However, Mergulhao et al. (2006) reported *G. oceanica* in the moderately nutrient rich waters from the Arabian Sea.

***Umbellosphaera* sp. (*Umbellosphaera irregularis* and *Umbellosphaera tenuis*) (Plates – 1 (4) and 5(7)):** *U. irregularis* is the most abundant in tropical waters with a temperature range of 25° to 30°C (McIntyre et al., 1970; Winter et al., 1994) (Plates 1(4) and 5(7)). These Umbelliform coccoliths have been found to dominate in subtropical gyres (Okada and Honjo, 1973; Okada and McIntyre, 1979; Kleijne et al., 1989) where they are thought to be adapted to oligotrophic conditions (Young, 1994).

*U. irregularis* was one of the important species indicative of oligotrophic conditions showed its average fluxes of 2.48, 13.08 and 8.78  $\times 10^5$   $\text{m}^{-2} \text{d}^{-1}$  at NBBT, CBBT and SBBT respectively (Tables 5.3, 5.7 and 5.11). The fluxes recorded at NBBT was the lowest among the three trap sites, whereas the highest fluxes were observed at CBBT followed by SBBT. *U. irregularis* did display seasonality in the shallow trap at NBBT with a relatively increased fluxes during NE-SW intermonsoon (May) and SW monsoon (June/July) (Fig. 5.2d). The decreased fluxes were attributed to the productivity related to the variable supply of nutrients during monsoons and intermonsoons, thus, inferring its preference for oligotrophic conditions but not for eutrophic condition.

The fluxes at CBBT were characterized by a unimodal distributional pattern with a sharp peak associated with NE-SW intermonsoon (April/May) followed by a lowest fluxes observed during SW and NE monsoons (Fig. 5.6d). The decreased fluxes observed during SW and NE monsoons was attributed to the prevalent eutrophic conditions resulted by upwelling and also by advection of nutrients leading to productivity. Whereas, highest fluxes recorded during NE-SW intermonsoon (April/May) was attributed to the oligotrophic conditions caused by stratification of surface waters by elevated SST's. Varkey et al. (1996) reported high temperatures (30.5°C) in the central Bay during pre-summer monsoon season. Similarly climatological data

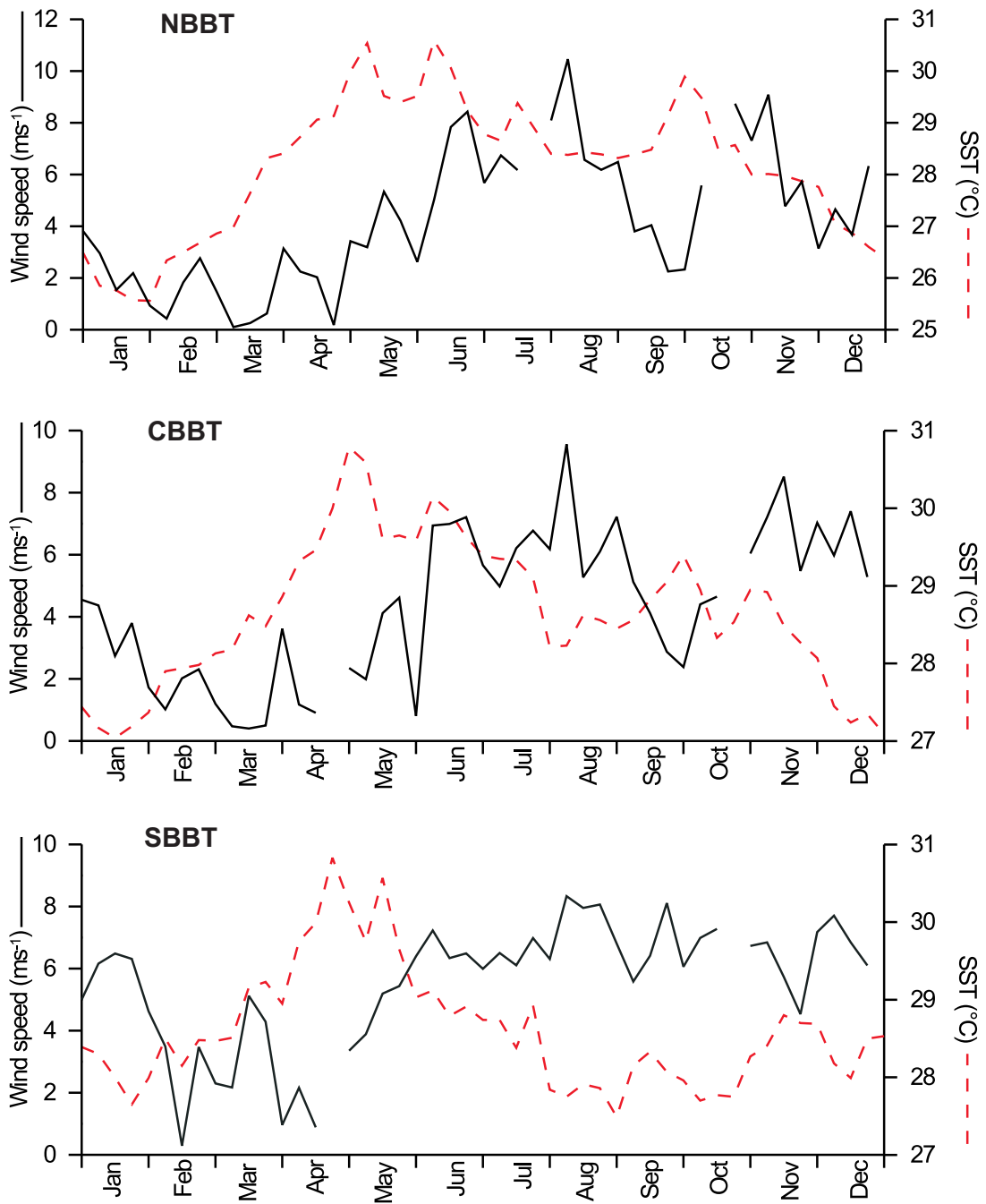
(Verploegh, 1960; Colborn, 1975; Hastenrath and Lamb, 1979) and data from various cruises (Somayajulu et al., 1987) during the pre-summer monsoon months showed higher SST's exceeding 30°C up to 30.5°C in the central Bay. The AVHRR SST maps of the Bay also showed SSTs exceeding 30°C up to 31°C in the central Bay for April-May (Viswambharan and Mathew 1992; Murty et al., 1994). Thus, this species confirms the assumption that it prefers oligotrophic conditions at CBBT. The lowest fluxes during SW were due to dissolution.

At SBBT, it displayed seasonality in both the traps with peak fluxes associated with NE-SW intermonsoon (April-May) (Fig. 5.12d) due to elevated SST's of ~31°C leading to oligotrophic conditions (Fig. 6.1) (Unger et al., 2003). Thus, it was inferred that low abundances of *U. irregularis* during SW monsoon and its increase during NE-SW intermonsoon supports its preference for high temperatures (25-30°C) and oligotrophic waters in the Bay of Bengal.

*U. tenuis* at CBBT occurred sporadically and recorded increase during NE monsoon (February/March) (Table 5.3) and NE-SW intermonsoon (April/March). Because, like *U. irregularis*, this species also prefers oligotrophic waters due to elevated SST's of 30.5°C (Varkey et al., 1996). While it remained absent during SW monsoon for most of the sampling period and was totally absent at NBBT due to eutrophic conditions.

At SBBT, fluxes were recorded sporadically with a marginally increased fluxes during NE-SW intermonsoon (April/May) (Fig. 5.13a) and proving the assumption that they thrive in the oligotrophic conditions developed by elevated temperatures.

Therefore, the maximum fluxes of Umbellosphaera species (*U. tenuis* and *U. irregularis*) were recorded in the oligotrophic waters during NE-SW intermonsoon and lower fluxes during the SW and NE monsoon which is in close agreement with the results of Kleijne et al. (1989). Furthermore, Kleijne (1991) also revealed the dominance of *U. irregularis* in warm oligotrophic



**Fig. 6.1.** Monthly variation of wind speed and SST during the period January - February 1992 at the three mooring sites NBBT, CBBT and SBBT in the Bay of Bengal.

conditions in Gulf of Aden and Red Sea during summer (June and July). Nishida (1979) also revealed the general dominance of these species in oligotrophic regions of the Pacific. Andruleit et al. (2000) reported higher relative abundances of *Umbellosphaera* sp. in the intermonsoon and decreased with the onset of NE monsoon in the northeastern Arabian Sea, which also agrees with our findings in the Bay of Bengal. Broerse et al. (2000a) reported maximum fluxes during late upwelling relaxation, but with highest relative abundances occurred during the non-upwelling period in the upwelling area off Somalia. Recently, Guptha et al. (2005) reported its preference for oligotrophic conditions in the equatorial Indian Ocean. Mergulhao et al. (2006) reported a peak occurrence of *U. irregularis* during NE-SW intermonsoon due to the prevalence of oligotrophic conditions in the central Arabian Sea.

***Florisphaera profunda* (Plate – 3 (7)):** *F. profunda* is generally found abundantly in low latitude regions within the lower photic zone (100-150 m) (Okada and Honjo, 1973; Okada and McIntyre, 1977) (Plate 3(7)). The variation in the abundance of *F. profunda* through time has been used as a proxy for past changes in the position of nutricline (Molfinio and McIntyre, 1990a, b; McIntyre et al., 1992). However, its distribution is not only related to water depth but also to various oceanographic conditions such as nutrient-content, water-transparency and/or-turbidity.

The average fluxes at three trap locations were 4.67, 13.70 and 9.43 x 10<sup>5</sup> m<sup>-2</sup>d<sup>-1</sup> (Tables 5.3, 5.7 and 5.11). The fluxes showed unimodal trend at NBBT with a prominent peak occurred during SW-NE intermonsoon (October/November) (Fig. 5.3a), attributed to minimum river discharge which otherwise would have hampered its production by turbidity. Besides, it could be due to the fact that the nutrients were still present in the deep layers. The decreased fluxes observed at NBBT was attributed to the turbid conditions leading to poor transparency caused by the influx of lithogenic material brought by the rivers during SW monsoon. Ahagon et al. (1993) also showed a close relationship between the relative abundance of *F. profunda* and

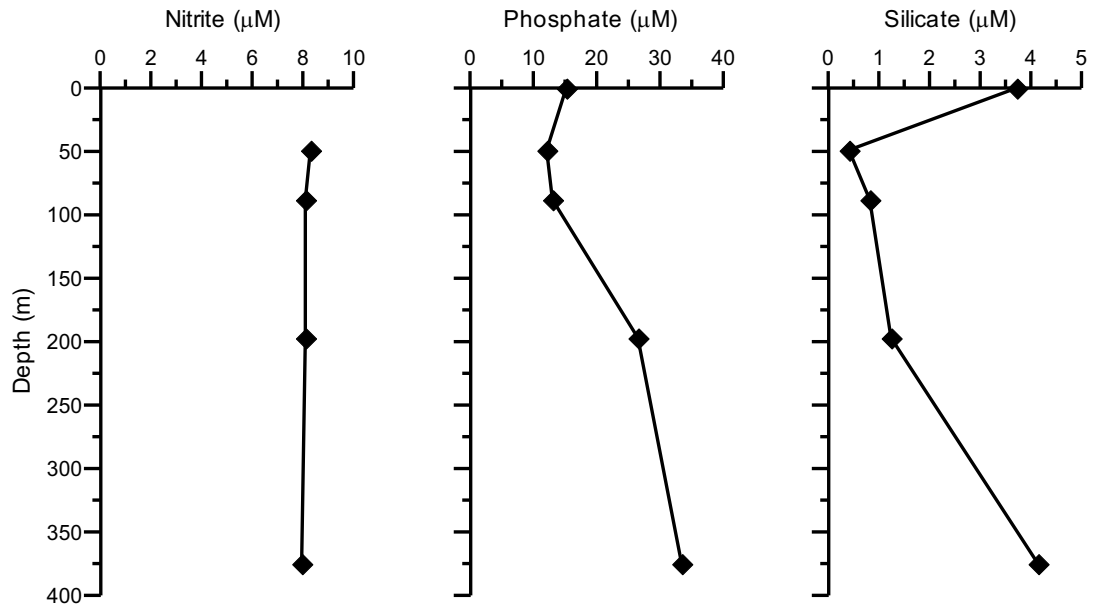
seawater transparency, where it was not only affected by biological productivity, but also by terrestrial particle supply.

Similarly, it also showed seasonality at CBBT with a maximum peak observed during SW monsoon (July/August) resulted by the strong wind-curl stress during this season causing a SW-NE oriented band of divergence in the central Bay of Bengal (Murty et al., 1992), which brings nutrient-rich water to the subsurface (50 m). The fluxes also showed a sharp peak in both shallow and deep traps during NE-SW intermonsoon (April/May) during which oligotrophic waters were prevalent at the surface of the central Bay (Fig. 5.7b) (Unger et al., 2003). Nevertheless, the deep nutricline developed by increased nutrients in the subsurface layers facilitated increased fluxes (Fig. 6.2), whereas, Increased fluxes seen in the deep traps must have resulted by lateral advection caused by the prevalent circulation pattern.

*F. profunda* fluxes at SBBT displayed seasonality recorded by lower fluxes during SW monsoon due to shallow thermocline with a prominent peak associated with SW-NE intermonsoon (October/November) (Fig. 5.13b) corresponding to that of total coccolithophore flux was due to cyclonic circulation evident from altimeter data prevailed off the east coast of India (V.S.N. Murty, pers. comm.) and also EICC which advected nutrients.

Tanaka and Kawahata (2001) reported high concentration of *F. profunda* and *G. flabellatus*, which are related to high temperatures in the upper euphotic zone and also the high light intensity. According to the model of Molfino and McIntyre (1990a), high relative abundance of *F. profunda* is associated with a deep nutricline and deep thermocline, whereas low relative abundances are characteristic of a shallow a nutricline and thermocline. Kawahata et al. (1998) reported increase of *F. profunda* in nutrient rich surface waters. Molfino and McIntyre (1990b) reported inverse relationship to both productivity and upwelling for *F. profunda* abundance. Ziveri and Thunell (2000) reported an inverse relationship between *F. profunda* flux and diatom export production, thus suggesting its inverse relationship to upwelling in the Guaymas Basin. Similarly Ziveri et al. (1995a) reported lowest abundance for





Latitude: 12°  
Longitude: 84°  
April 1987

**Fig. 6.2.** Profiles of (a) nitrate ( $\mu M$ ), (b) phosphate ( $\mu M$ ) (c) silicate ( $\mu M$ ) up to 350 m depth at (12°N: 84°E) during April 1987. (Source, Indian National Oceanographic Center, NIO, Goa)

*F. profunda* in San Pedro Basin during the upwelling period when the nutricline was shallow and also the seasonal flux pattern suggesting that *F. profunda* did not prefer shallow thermocline and high light levels. It also recorded a relatively increased flux during NE-SW intermonsoon (March/April) when the waters were oligotrophic resulted by the deep nutricline. Similarly, Broerse et al. (2000a) reported that the deep photic zone species *F. profunda* and *G. flabellatus* were dominant in the early SW monsoon in the upwelling region off Somalia. Andruleit et al. (2000) in their study of coccolithophore fluxes in the northeastern Arabian Sea reported that *F. profunda* was negatively correlated to *G. oceanica* with the deepening of mixed layer depth with a decreased fluxes. Andruleit and Rogalla (2002) reported positive correlation of *F. profunda* to the mean annual mixed layer depth in the surface sediments from southeast Arabian Sea, which resulted due to deep thermocline. However, Mergulhao et al. (2006) reported increased fluxes during January, April and June when nutrient concentrations were high in the central Arabian Sea. Schiebel et al. (2004) reported *F. profunda* at a shallow depth of 20-60 m during May/June with an assumption that *F. profunda* shows its affinity for enhanced nutrients rather than for a specific water depth. The present study also inferred that the *F. profunda* was also a temperature dependent rather than only to the specific depth (eg. deep photic depth).

***Oolithotus antillarum* (Plate – 3 (5)):** *O. antillarum* is commonly found to thrive in middle photic depths in the tropics (Okada and McIntyre, 1977; Winter et al., 1994) and also reported in the lower photic zone (Takahashi and Okada, 2000) (Plate 3(5)). This species was distributed sporadically at NBBT with a marginal increase during late SW monsoon (September), due to the availability of nutrients at the surface. (Fig. 5.3c). While at CBBT, it displayed increased fluxes associated with SW-NE intermonsoon (October/November) due to nutricline conditions (Fig. 5.7d). At SBBT this species registered the highest abundance among the three trap locations with a prominent peak during SW-NE intermonsoon (October/November) was due to cyclonic circulation evident from altimeter data prevailed off the east coast of India (V.S.N. Murty, pers. comm.) and also EICC which advected nutrients (Figs.

3.6.c and d), followed by lowest fluxes during SW monsoon (August/September) (Fig. 5.13d). In the deep trap the maximum value was recorded during late NE monsoon (March) (Fig. 5.13d). kleijne (1993), concluded that *O. antillarum* is indicative of upwelling condition in the winter Arabian Sea, based on increased concentrations in surface waters towards the upwelling areas. Zeltner (2000) also found a positive reaction of *O. antillarum* to nutrient enrichment in the northern Indian Ocean. Similarly, a positive correspondence of coccolith concentrations in surface sediments with the PO<sub>4</sub> concentration in surface waters was interpreted as an affinity of this species to high nutrient concentrations (Andruleit and Rogalla, 2002).

***Calcidiscus leptopora* (Plate – 1 (3)):** *C. leptopora* is one of the most common species found in waters ranging from equatorial to polar in a wide ranging temperature (5-30°C) (McIntyre and Bé 1967; Okada and McIntyre 1979) (Plate - 1 (3)).

*C. leptopora* recorded relatively higher fluxes during early stages of SW monsoon (June/July) (Fig. 5.3d) at NBBT when there was high nutrient input brought by river plumes during SW monsoon (Ittekkot et al. 1991). Whereas at CBBT it recorded increased fluxes during SW-NE intermonsoon (September/October) in the shallow (Fig. 5.8a). At SBBT, increased fluxes were recorded during NE-SW intermonsoon (March/April) and SW monsoon (June/July and August/September) in the shallow trap when the nutrient rich waters advected from the southwest coast of India.

Thus, this is in agreement with the previous studies by Broerse et al. (2000a) who revealed that the moderate increase during local spring periods. Andruleit et al. (2000) reported that *C. leptopora* positively responds to high nutrient rich waters. The co-occurrence of *C. leptopora* and *H. carteri* in upwelling area was also reported in the San Pedro Basin (Ziveri et al., 1995a) and in the Gulf of California (Ziveri and Thunell, 2000) in association with intermediate to low nutrient concentration. Schiebel et al. (2004) reported its preference for higher temperature in the Arabian Sea.

***Helicosphaera carteri* (Plate 1(5)):** Like, *C. leptopora* this species was also sparsely distributed. *H. carteri* is considered to be thermophilic (McIntyre, 1967; Roth and Berger, 1975; Okada and McIntyre, 1979; Winter et al., 1979) (Plate 1(5)) and most abundant in tropical – subtropical areas (20°S – 30°N) but also present at high latitudes (50°N – 40°S) (Roth and Berger, 1975). Based on water column and surface sediment data *H. carteri* is believed to thrive in waters of moderately high fertility (Roth and Berger, 1975).

This species increased from NBBT to SBBT and showed higher fluxes during NE-SW intermonsoon, where the waters were rich in nutrient, but it showed lower fluxes during SW monsoon due to dissolution.

### **6.3 Coccolithophore-CaCO<sub>3</sub> fluxes and dissolution of coccolithophores in the Bay of Bengal (NBBT, CBBT and SBBT traps)**

Coccoliths are considered to be major contributors to the biogenic carbonate flux, which are generally preserved at shallow depths (Murray and Renard, 1891; Svedrup et al., 1942) and also play a prominent role in the global carbon cycle. Coccolithophores constitute a dominant component of biogenic carbonate (Neuer et al., 1997; Honjo, 1986; Broerse et al., 2000b; Steinmetz, 1991; Čepek and Wefer, 2000). However, the estimation of Coccolithophore-CaCO<sub>3</sub> and its export to the deep sea has been a problematic until Honjo (1976) used for the first time the averaged masses of coccoliths for computation which was followed by Samtleben and Bickert (1990) and Steinmetz (1991) in their studies. Later workers, Knappertsbusch and Brummer (1995) and Young and Ziveri (2000) enabled to refine and evolve a more accurate estimation of the volume and mass of individual coccoliths. Recently, Ramaswamy and Gaye (2006) have also reported the estimated Coccolithophore-CaCO<sub>3</sub> fluxes from the northern Indian Ocean.

The coccolithophore-CaCO<sub>3</sub> fluxes in the Bay of Bengal showed highest occurrence at SBBT with an average flux of 0.33 mg m<sup>-2</sup>d<sup>-1</sup> followed by CBBT and NBBT trap with the average values of 0.30 mg m<sup>-2</sup>d<sup>-1</sup> and 0.12 mg m<sup>-2</sup>d<sup>-1</sup> respectively (Table 5.13). Similarly, annual fluxes also followed the same

trend with values showing  $13.6 \text{ g m}^{-2} \text{ yr}^{-1}$ ,  $12.5 \text{ g m}^{-2} \text{ yr}^{-1}$  and  $5.0 \text{ g m}^{-2} \text{ yr}^{-1}$  for SBBT, CBBT and NBBT respectively. But, when compared to the reported values for same locations of different periods by Ramaswamy and Gaye (2006), only NBBT flux values were comparable with the present results. Whereas, these values for CBBT and SBBT were not matching due to the presence of coccospheres in great number which when computed, number of isolated coccoliths increased thereby showing enhanced fluxes (Table. 6.1).

Higher coccolithophore- $\text{CaCO}_3$  flux was invariably observed during NE-SW intermonsoon periods resulted by productivity caused by BBWBC and anticyclonic gyre, whereas, the decreased fluxes during SW monsoon was attributed to dissolution. Lower average values of  $0.09 \text{ mg m}^{-2} \text{ d}^{-1}$ ,  $0.24 \text{ mg m}^{-2} \text{ d}^{-1}$  and  $0.27 \text{ mg m}^{-2} \text{ d}^{-1}$  were recorded at NBBT, CBBT and SBBT respectively (Table 5.13). While settling coccoliths are subjected to advection, dissolution, grazing etc. The coccolithophore- $\text{CaCO}_3$  fluxes followed the same trend as that of total fluxes at all the locations (Figs. 5.1c, 5.5c and 5.11c). The species affected by dissolution were, *G. oceanica*, *U. sibogae*, *C. leptopora*, *N. coccolithomorpha*, *E. huxleyi* and *H. carteri* (Plate 4 (1-8)).

### 6.3.1 Preservation of coccolithophores

Calcareous organisms secrete  $\text{CaCO}_3$  (both calcite and aragonite) to build their hard skeletal parts, which have a tendency to dissolve in deep water layers (Millero, 1996; Broecker and Peng, 1982). These  $\text{CaCO}_3$  polymorphs are sparingly soluble in sea water with aragonite being more soluble than calcite. Organisms with calcareous skeletons are largely restricted to the tropics due to the fact that the solubility of  $\text{CaCO}_3$  decreases with increase in temperature resulting in supersaturation. Whereas, the solubility of carbonates increases with increasing pressure/depth.

It has been well established that the marine calcium carbonates are largely contributed by coccoliths, which are generally preserved at shallow oceanic depths (Murray and Renard, 1891; Svedrup et al., 1942). Many researchers believed that the calcium carbonate displays a very significant

**Table 6.1.** Annual fluxes of coccolithophore-calcium carbonate ( $\text{g m}^{-2} \text{yr}^{-1}$ ) at NBBT, CBBT and SBBT.

Sediment Trap	Annual coccolithophore-calcium carbonate flux ( $\text{g m}^{-2} \text{yr}^{-1}$ )	
	Present study	Ramaswamy and Haake (2006)
NBBT (Shallow)	5.0	5.7
NBBT (Deep)	-	4.8
CBBT (Shallow)	12.5	6.5
CBBT (Deep)	-	7.6
SBBT (Shallow)	13.6	-
SBBT (Deep)	-	5.9

dissolution effects at deeper depths (Peterson, 1966; Berger, 1967; Milliman, 1977 and Troy et al., 1997). Furthermore, it has been observed that the dissolution of carbonates in the oceanic environment is a post-depositional process. Milliman (1993) opined that more than half of the global production of pelagic carbonates occur in water depths shallower than the lysocline, i.e. shallower than 3500 m depth in the Indian Ocean. Broecker (1974) reported that about four-fifths of all the carbonate fixed by organisms in surface water is dissolved.

It has been demonstrated that the dissolution largely occurs beneath the lysocline as indicated by *in situ* measurement that the interstitial dissolution removes only about 20-40% of the carbonate in supralysocline sediment (Emerson and Archer, 1990; Jahnke et al., 1994). Milliman et al. (1999) documented added evidence to suggest considerable dissolution of calcium carbonate well above the chemical lysocline and concluded that the biological processes or biologically mediated processes were responsible for dissolution. The effect of dissolution on coccolith assemblage was first recognized by McIntyre and McIntyre (1971) who concluded that *E. huxleyi*, *G. oceanica*, *U. sibogae* and *C. leptopora* are the most resistant. Roth and Berger (1975) reported that the dissolution of nanoplankton is more pronounced as depth increases. Till recently, it was believed that the shallow water dissolution of carbonates as an unusual phenomenon. But, Andrulleit et al. (2000) reported new evidences suggesting coccolith dissolution taking place in the near surface waters of the East Greenland Current. Recently, Guptha et al. (2005) reported dissolution of coccoliths in the shallow depths of photic zone from the equatorial Indian Ocean. Broerse et al. (2000c) showed that the preservation of coccoliths strongly depends on rapid transport for protection from corrosive water masses. And when the sedimentation rate is high they can escape dissolution by getting incorporated into the fecal pellets and other oceanic macroaggregates that are responsible for the rapid vertical transport to the sea floor. Samtleben and Bickert (1990) reported similar findings in the sediment trap samples from the Subarctic Atlantic Lofoten Basin. Andrulleit (2000) also reported dissolution of *C. pelagicus*, while other species in the same assemblage did not show any signs of dissolution

inferring that the dissolution did not take place during or after entrapment of the coccoliths assemblages, but originated from different sources or experienced different settling conditions. Recently, Mergulhao et al. (2006) also encountered dissolution of coccoliths during NE monsoon (December-March) in the shallow trap from the central Arabian Sea, showing intense dissolution during NE monsoon (January/February) period, when the total coccolithophore fluxes were high.

In the present study, the dissolution of coccolithophores (*G.oceanica*, *U. sibogae*, *C. leptopora*, *E. huxleyi*, *H. carteri*, *N. coccolithopmorpha* etc, (Plates 4 and 5) was recorded suggesting that the carbonate dissolution was already taking place in the Bay of Bengal. The northern trap (NBBT) at a water depth of 1156 m showed dissolution during SW-NE intermonsoon (October – November) following high productivity and degradation of the resultant organic matter. It was also believed that pH of the waters decrease with the increased productivity eventually leading to dissolution. Whereas at CBBT, coccolithophore fluxes water depth of 1588 m showed dissolution throughout the sampling period due to high productivity resulted by upwelling, except during NE-SW intermonsoon (April – June) when the productivity was relatively low. Whereas at SBBT, shallow trap at a water depth of 1518 m recorded dissolution throughout the sampling period except during early NE monsoon (February - March), which was attributed to high productivity or bottom water circulation.

While, the more intense dissolution was observed in the deep traps compared to that of shallow traps at all the three trap locations suggesting a strong corrosive environment. Therefore, it was inferred that the dissolution was related to primary production in the shallow traps. However, the intense dissolution observed in the deep traps could be mainly due to disintegration of fecal pellets and marine snow aggregates resulting in the re-suspension of coccoliths and their long exposure to the corrosive environment during sinking and also due to the bottom water circulation. Consequently, coccoliths with relatively longer residence time were more susceptible for dissolution.



There are several evidences for dissolution as reported by many researchers in the Bay of Bengal. Sen Gupta et al. (1978) reported increased Ca/Cl ratio in the deeper layers (below 1000 m) in the Bay of Bengal, Gulf of Mannar and Arabian Sea, which they attributed to the dissolution of CaCO<sub>3</sub> resulted by the degradation of organic matter which subsequently released calcium leading to increase of Ca/Cl ratio. Also, Broecker et al. (1980) reported respiration and hard part dissolution occurring on the floor of the Bengal Fan mainly from ventilation of the benthic mixed layer, which produces the excess nutrient concentrations and O<sub>2</sub> deficiency within this layer. Sen Gupta et al. (1977) reported a distinct O<sub>2</sub> minimum layer, lying between 100 and 1000 m, with O<sub>2</sub> concentration lower than 1 ml litre<sup>-1</sup> in the Bay of Bengal. Considering the fact that the deep waters of the Arabian Sea and Bay of Bengal were fed by different western-boundary currents flowing through different terrains (Warren, 1981), differential CaCO<sub>3</sub> dissolution does occur in these waters may be plausible.

It was also believed that pH of the waters decrease with the increased productivity eventually leading to dissolution. Rahul Mohan and Guptha (2006) reported the occurrence of corroded specimens of *Globorotalia menardii* in the deep trap (3011 m) at SBBT during February-March 1992 in association with the less resistant species of foraminifera and explained that these corroded specimens of *Gr. menardii* tests must have resulted by lateral advection and mixed up with the settling particles at SBBT, thus suggesting of two different sources during this particular period. Similarly, von der Borch et al. (1974) reported strongly corroded keels of *Globorotalia* on the seafloor below lysocline from the DSDP Leg 22, Site 218 in the vicinity of SBBT mooring location.

The hydrographic setting in oceans which regulates the distribution of calcite in deep-sea sediments are the levels at which the water passes from super – to undersaturations where the rate of dissolution increases abruptly is called lysocline. The Calcium carbonate compensation depth (CCD), the depth below which a total dissolution of carbonates takes place resulting from roughly linear increase in the rate of solution of calcite with depth below the

lysocline. The CCD lies at about 4500-4700 m depth in the low latitudes of the Indian Ocean (Belyaeva, 1963). The depth of CCD is not constant in the oceans and is related to surface productivity. Increased productivity tends to raise the lysocline by supplying more oxidizable organic matter and depress the compensation depth by supplying more calcareous tests (Berger, 1970). Naqvi and Naik (1983) examined the factors controlling dissolution of calcite in deep-sea basins of northwestern Indian Ocean and reported that the dominant factor controlling deep-sea carbonate dissolution is the degree of saturation.

Coccolithophores showed mechanical break down throughout the sampling periods and at all the trap locations (Plate 5 (3 & 5)). The species, which exhibited mechanical break down, were *G. oceanica*, *U. sibogae*, *H. carteri*, *C. leptopora*, *N. coccolithomorpha* and *E. huxleyi*. The severe fragmentation or mechanical break down of both coccolith and coccosphere was mainly caused by grazing. Similarly, Broerse et al. (2000b) reported fragmentations of coccolith and coccosphere and defined fragmentation, as mechanical breakage where a part from distal and /or proximal shields is missed. And also reported that the fragmentation encountered in both well-preserved and etched coccoliths, hence the disintegration cannot be related to dissolution. Etching starts normally in the central area of a coccolith, which is most susceptible for dissolution, while fragmentation is largely encountered at the outer parts of a coccolith (Plate 5(5)). Samtleben and Bickert (1990) also reported that zooplankton activity affecting the coccolith fluxes, where more fragile holococcoliths were broken up by zooplankton grazing and digestion, and the fragments formed the unidentifiable fine fractions in the fecal pellets. Thus, both the dissolution and mechanical breakdown of coccolith was attributed to a biologically mediated processes.

#### **6.4 Biogeochemical fluxes from the sediment taps in the Bay of Bengal (NBBT, CBBT and SBBT)**

The data on biogeochemical parameters supplied by Dr. Daniela Unger was utilized and discussed briefly in relation to various physical processes. The principal components of biogeochemical fluxes in the Bay of Bengal were

carbonates, biogenic silica (opal), lithogenic matter and organic carbon. These biogeochemical fluxes were dominated by carbonates followed by lithogenic matter, biogenic opal and organic carbon.

**Lithogenic flux:** The lithogenic fluxes at NBBT showed a seasonal trend with higher fluxes occurring during SW monsoon (August/September) (Fig. 5.17a), mainly from the huge quantities of run off from the Ganges and the Brahmaputra rivers which empty into the Bay (La Violette, 1967; Wyrski, 1973; Ittekkot et al., 1985; Murty et al., 1990; Varkey et al., 1996; Milliman and Meade, 1983). These two-rivers have their combined peak discharge of approximately  $70 \times 10^3 \text{ ms}^{-1}$  in August (Emery and Aubrey, 1989). Distribution of lithogenic fluxes displayed a decreasing trend from northern Bay to southern Bay (Tables 5.1, 5.2, 5.5, 5.6, 5.9 and 5.10), with increased fluxes observed in the deep traps at NBBT and CBBT attributed to the enormous terrigenous influx brought by the major Indian rivers during SW monsoon and also by lateral advection of lithogenic material from the steep shelf region along the east coast of India (Schäfer et al., 1996). Additionally, the storm-induced remobilization of shelf sediments might have contributed to the high lithogenic fluxes, especially to the deep CBBT trap (Unger et al., 2003). The increased fluxes during May to October was accomplished by the large cyclonic circulation with inflow from the western Bay coastal region (V.S.N. Murty, pers. comm).

However, the increase in the lithogenic flux during SW monsoon (September) at SBBT trap location was due to the continuation of the southwestward flow from the northern Bay towards SBBT and also from the eastward flow (encompassing the CBBT) towards the SBBT (Fig. 5.19a) (V.S.N. Murty, pers. Comm.).

**Calcium carbonate Flux:** Calcium carbonate was one of the major components observed at all the trap locations, which is largely composed by foraminifera, calcareous nanoplankton, pteropods and gastropods. The average fluxes showed an increasing trend from north to south and in general, the flux decreased with increased depth except at CBBT trap where there was

a slight increase in the average fluxes in the deep trap (Tables 5.1, 5.2, 5.5, 5.6, 5.9 and 5.10).

The Calcium carbonate fluxes at NBBT shallow trap showed a distinct seasonality with a relatively higher flux observed during SW monsoon (July/August), whereas, the deep trap recorded the maximum peak during late SW monsoon (September) (Fig. 5.17b). The maxima in both the traps must have resulted by productivity caused by the large influx of nutrients brought by the Ganges and the Brahmaputra. The shallow trap also showed a sharp peak during NE-SW intermonsoon period (March/April) mainly from the prevalent anticyclonic gyre at 16°N, 86°E (Babu et al., 2004). And also from the upwelling along the coasts of India and Burma during winter, which advected nutrient rich waters facilitating productivity (La Violette, 1967). The fluxes at CBBT showed a peak abundance during SW monsoon (July/August) and (September) (Fig. 5.18b), which could be attributed to upwelling along the east coast of India (Shetye et al., 1991) and also to the divergence reported in the central Bay substantiated by low temperatures (Murty et al., 1992). Similarly, calcium carbonate fluxes at SBBT shallow trap showed a distinct seasonality with a maximum fluxes associated with late SW monsoon (September) (Fig. 5.19b) mainly due to the advection of nutrient-rich waters from the upwelling region along southwest coast of Indian (Sharma, 1978; Shetye et al., 1990).

In general, relatively lower carbonate fluxes observed at NBBT and CBBT during SW monsoon was due to the sharp decrease in salinity values resulting in drastic reduction in planktic foraminifera which otherwise would have contributed significantly to the biogenic carbonates (Ramaswamy and Gaye, 2006).

**Biogenic Opal flux:** Opal fluxes were mainly contributed by diatoms, silicoflagellates and radiolarians which increased from northern to southern Bay of Bengal (NBBT to SBBT trap locations) (Tables 5.1, 5.2, 5.5, 5.6, 5.9 and 5.10). Higher biogenic opal fluxes were recorded during SW monsoon (August/September) in the shallow trap at NBBT (Fig. 5.17c) mainly due to

riverine input from the Ganges and the Brahmaputra which supplied nutrients including large quantities of dissolved silicate to the surface layers stimulating biological productivity.

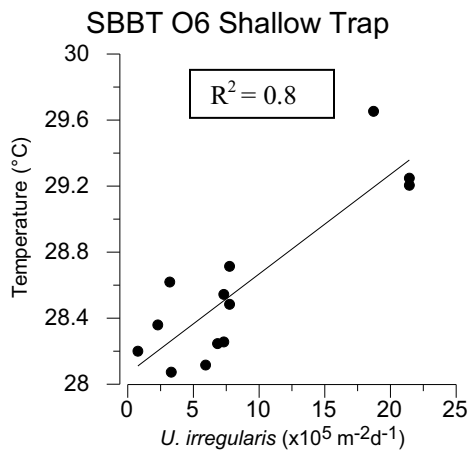
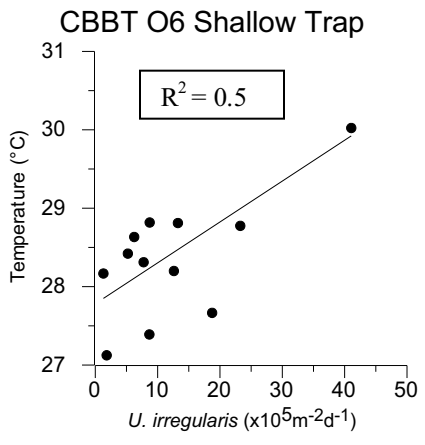
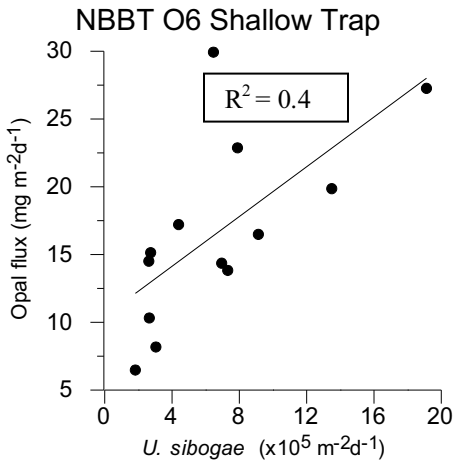
Opal fluxes in the shallow trap at CBBT showed a uni-modal distributional pattern with a maximum peak associated with the SW monsoon (September) (Fig. 5.18c). Similarly, in the shallow trap at SBBT also showed a peak flux during late SW monsoon (August/September) (Fig. 5.19c) resulted by the same processes that governed calcium carbonate flux.

**Organic carbon:** The high organic carbon flux in the Bay of Bengal was not related to any plankton bloom, but to the nature of particles present in the water column. Ramaswamy and Parthiban (1992) reported that the organic matter flux in the Bay of Bengal traps was among the highest reported for the open ocean contrary to the Arabian Sea traps. The average fluxes for organic carbon in the present study increased from northern to southern traps (Tables 5.1, 5.2, 5.5, 5.6, 5.9 and 5.10).

Organic carbon fluxes at NBBT trap showed seasonality with a maximum peak occurring during SW monsoon (August/September) which was resulted by high productivity triggered by the nutrient supply by the river plumes (Fig. 5.17d). Whereas, it recorded higher fluxes at CBBT during NE-SW intermonsoon (April/May) resulted by the supply of nutrients leading to productivity by the strong BBWBC (Legeckis, 1987; Potemra et al., 1991; Shetye et al., 1993; Sanilkumar et al., 1997; Babu et al., 2004), anticyclonic gyre and by upwelling during SW monsoon (September) (Fig. 5.18d). Similarly, shallow trap at SBBT also showed distinct seasonality with a sharp peak occurring during late SW monsoon (August/September) (Fig. 5.19d) which was resulted by high productivity caused by the advection of nutrients from the southwest coast of India (Sharma, 1978; Shetye et al., 1990).

An attempt has been made to ascertain if any direct relationship exists between coccolithophores and various biogeochemical parameters. This revealed that *U. sibogae* showed a fairly good correlation with opal ( $R^2 = 0.4$ )

as it shows affinity for nutrient rich waters leading to productivity. Whereas, *U. irregularis* displayed its positive correlation with temperature at SBBT ( $R^2 = 0.8$ ) and CBBT ( $R^2 = 0.5$ ) as it prefers oligotrophic conditions (Fig. 6.3).



**Fig. 6.3.** Correlation graphs of fluxes of *U. sibogae* with biogenic opal and *U. irregularis* with temperature from the three mooring sites NBBT, CBBT and SBBT in the Bay of Bengal.