Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 3, Issue, 9, pp.005-013, August, 2011

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

ISSN: 0975-833X

RESEARCH ARTICLE

NUTRIENT FLUXES AND ADAPTATION TO ENVIRONMENTAL DYNAMICS BY PHYTOPLANKTON IN THE GULF OF KHAMBHAT

***Jiyalal Ram M. Jaiswar, Arvind V. Mandalia, Saily M. Narvekar, Siddhesh H. Karangutkar**

National Institute of Oceanography, Regional Centre, Lokhandwala Road, Mumbai

ARTICLE INFO

Article History:
Received 13th May, 2011
Received in revised form
5th June, 2011
Accepted 28th July, 2011
Published online 25th August, 2011

Key words:
Phytoplankton,
Nutrients,
SS,
Bhavnagar,
Gulf of Khambhat.

ABSTRACT

Environmental dynamics with a view of understanding the nutrient fluxes and the factors regulating phytoplankton production, in waters off Bhavnagar, Gulf of Khambhat, were investigated during 1996-2007. The coastal waters of Bhavnagar revealed normal pH (7.97±0.12) and enhanced DO (4.81±1.47 ml/l) level. The fluctuation of salinity (29.7 ± 4.21 ppt) was due to freshwater influx through several rivers. The coastal water of Bhavnagar was characterized with poor concentration of chlorophyll *a* (0.76±0.34 mg/m^3), high phaeophytin (1.24±0.68 mg/m^3), poor species diversity of phytoplankton (0.693-1.495, av. 0.749), high SS concentration (1502.58±1038.62 mg/l) and poor irradiance (secchi depth, mean 0.11 cm), with high concentration of NO_3^--N (32.52 ± 12.37 µmol/l), NO_2^--N (2.38 ± 4.12 µmol/l), NH_4^+-N (2.33 ± 4.43 µmol/l) and PO_4^{3-}-P (9.04 ± 10.37 µmol/l). The positive significant correlation between SS and NO_3^--N (r=0.443, p=0.000), NO_2^--N (r=0.302, p=0.010) and NH_4^+-N (r=0.229, p=0.055) indicated that the strong currents churning out the bed sediments and eroding the shoreline and inputs through several rivers draining into the Gulf, were sources of nutrient fluxes and an enhanced concentration in the region. The presence of *Thalassiosira gravida* and *Navicula distans* continuously and *Cylindrotheca closterium* sometime as the major species in the coastal waters of Bhavnagar over the period of 11 years suggested their adaptation to the environmental condition of the region. Thus, the high concentration of suspended solids was the regulating factor for phytoplankton production.

INTRODUCTION

Phytoplankton dynamics are mainly influenced by a wide range of environmental conditions in the sea such as different gradients in light, temperature, turbidity of water, salinity, nutrient concentration and grazing pressure by other trophic level organisms. (Flemming *et al.,* 2000; Bange *et al.,* 2005; Seintzinger *et al.,* 2005; Wiggery *et al.,* 2006; Verlencar *et al.,* 2006; Alory *et al.,* 2007; Levy *et al.,* 2007 and Zarauz *et al.,* 2008). The sea of Gulf of Khambat is a dynamically complex and highly variable system with circulation features and biogeochemical properties that are unusual in many respects. Primary productivity, phytoplankton abundance, and species diversity are influenced by number of common environmental factors (Mazda *et al.,*1990 and Ridd *et al.,*1990). Factors that control phytoplankton composition and abundance and its fate in the Indian ocean are not well understood (Geeta and Kondalarao, 2004; Nair *et al.,* 2005 and Naqvi *et al.,* 2006). Phytoplankton composition and abundance and its limiting factors in the coastal water of Bhavnagar, Gulf of Khambhat, are not known. The highly muddy coast with strong currents of this Gulf and lacking information makes it essential to understand the nutrient fluxes, phytoplankton dynamics and regulatory factors for phytoplankton production and abundance. The comparative analysis and quantitative estimates of long-term changes in phytoplankton and physicochemical properties off Bhavnagar, Gulf of Khambhat was thought to contribute to the evaluation of functional response of this coastal ecosystem to anthropogenic stress. With this view, the present investigation on physicochemical parameters and phytoplankton, being the first record, in Bhavnagar Creek, Sonrai Creek, Malcolm Channel and off Bhavnagar, Gulf of Khambat, was carried out, during premonsoon and postmonsoon between 1996-2007. Thus this integrated coastal area of Bhavnagar was examined for nutrient fluxes. The study was also aimed to understand the temporal and spatial variability of phytoplankton production, abundance and it's limiting factor in dynamically complex system of the Gulf.

Corresponding author: jiyalal@nio.org

MATERIALS AND METHODS

Water samples from surface were collected with the help of a clean plastic bucket and bottom sampling was carried out using a Niskin sampler. Sampling was conducted at 9 stations i.e. 2 stations in Bhavnagar Creek, 2 stations in Sonrai Creek, 3 stations in Malcolm Channel and 2 stations towards offshore at the depth varying from 0.5-19 m (Figure 1). Diurnal variation studies were also conducted at stations 3 and 5. Water temperature, pH, Suspended Solids (SS), Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), salinity, nutrients viz. nitrates (NO_3^--N), nitrites (NO_2^--N), ammonia (NH_4^+-N), phosphates (PO_4^{3-}-P) were studied to know the dynamics of physicochemical characteristics. Secchi disc reading was recorded only during 2006. Chlorophyll *a,* phaeophytin, phytoplankton cell counts and total species were studied at same locations. Since the study area was under high pressure of erosion causing remarkably high load of SS and received anthropogenic pollutants, the studies were carried out 5 times over a period of 11 years in both, premonsoon and postmonsoon seasons during 1996-2007.

pH was measured on pH scan 2 (Eutech Cybernetics) meter by using the standard buffers and suspended solids were determined by filtering known quantity of sample through pre-weighed 0.45 µm Millipore membrane filter paper (Grasshoff *et al.,* 2002). Salinity was analysed by titrating 5 ml sample against silver nitrate using potassium chromate as an indicator. DO was determined by Winkler method and BOD was determined by using unseeded method after incubating BOD bottles for 3 days (Grasshoff *et al.,* 2002). Absorbance for nitrite was measured at 543 nm. Nitrate was determined as nitrite and was measured at 630 nm as per the methods of Grasshoff *et al.,* (2002). Phosphate was allowed to react with ammonium molybdate and the absorbance was measured at 882 nm following the method of Grasshoff *et al.,* (2002). For estimation of chlorophyll *a* and phaeophytin the samples were filtered through millipore filter paper (47 mm dia and 0.45 µm pore size) and absorbance was measured using Shimadzu 1201 spectrophotometer (APHA, 1985) till 2003. Further analyses of pigments, for the year 2006 and 2007, were done using Fluorometer (Turner designs). Phytoplankton cell counts, and species identification were carried out with the help of books (Lebour, 1977 and Tomas, 2002) using a compound microscope (APHA, 2005).

a. Study site

Southern strip of Saurashtra coast displays variegated geomorphic features with numerous cliffs rising up to 25m, islets and extensive tidal flats, deposits of littoral concrete in rocky and sandy beaches, bars and dunes. The coastline at study area has vertical eroded banks and the intertidal area consists of soft alluvial deposits of coarse and fine sand mixed with silt and clay. The nearshore area of Bhavnagar sustains a vast intertidal region. The entire coast in general and the shore from Bhavnagar Creek to Sonrai Creek in particular are highly eroded because of having loose soil and getting affected by strong currents, tidal movements and monsoonal waves. The several major rivers such as Sabarmati, Mahi Sagar, Dhadar, Narmada and Tapi and many minor rivers like Utavali Nadi, Malesari Nadi, Shetrunji River, Mindola River and Dhantavadi River are the perennial which drain into the Gulf of Khambhat. Bhavnagar Creek receives some domestic wastewater from the city and effluents from small-scale industries situated in the city in addition to the effluents from soda ash plant discharged in Malcolm Channel after 2000. The study site was located in Bhavnagar Creek, Sonrai Creek, Malcolm Channel and off Bhavnagar between Lat 21°42'N-22°01'N and Long 72°10'E-72°28'E (Figure 1).

RESULTS

a. Physicochemical characteristics

The physicochemical characteristics of Bhavnagar Creek, Sonrai Creek, Malcolm Channel and off Bhavnagar were found similar. Water temperature in the coastal water of Bhavnagar showed seasonal variability with the values as low as 21.0 ± 0.00 °C during January 1996 at Sonrai Creek and as high as 29.9 ± 0.92 °C during November 2001 at Malcolm Channel as evident in Table 1. The pH showed a narrow range of variation (7.97±0.12) in this coast as expected for the buffered system of the seawater. The results analysed for standard deviation showed marked fluctuation in physico-chemical properties with significantly high concentration of SS (653.67±312.96 - 5186 ±949.4 mg/l) (Table 1). The highest concentration of SS was observed at bottom water. Spatial variation in SS was also discernible by recording highest value in Bhavnagar Creek in the comparison of other locations. .

A marked fluctuation in salinity with mean between 22.4 ± 0.71 – 36.9 ± 0.70 ppt (Table 1) was due to fresh water influx through several rivers. Highest salinity was recorded at upstream location of Bhavnagar Creek during May 2003 whereas lowest was determined during November 2006 off Bhavnagar (Table 1). The influence of fresh water due to heavy monsoon during September 2006 on salinity was discernible by recording decreased concentration of salinity at all locations and even to a distance of 6 km towards offshore from the mouth region of Bhavnagar Creek during November 2006 as depicted in Figure 2. An enhanced concentration of DO (6.9 ± 0.21 -7.6 ± 0.64 mg/l), was observed during January 1996 whereas occasional depletion with mean variation of 3.3 ± 0.07 - 4.5 ± 0.7 was seen in the region. The depletion of DO could be clearly seen in Bhavnagar Creek only after 2000 when the industrial effluent release took place. Average DO saturation for surface and bottom was 80% which reduced to <65% at the upper segment of the creeks (station 1 and 2) as illustrated in Figure 3. A wide fluctuation and significant enhancement in the concentration of nutrients in terms of NO_3^--N (18.3 ± 4.31 – 60.4 ± 5.02 µmol/l), NO_2^--N (0.2* – 8.6 ± 10.75 µmol/l), NH_4^+-N (0.15 ± 0.07 – 20.4 ± 8.13 µmol/l) and PO_4^{3-}-P (2.3 ± 0.00 - 34.8 ± 8.24 µmol/l) was evident from the results (Table 1). The temporal study suggested the higher concentrations of NO_3^--N during ebb than that of flood. The values of PO_4^{3-}-P were also generally higher during ebb periods than that of flood (Figure 4 and 5). Regression analysis showed significant negative correlation of DO with PO_4^{3-}-P (r= -0.321, p=0.006) and also negative correlation with NO_3^--N and NO_2^--N but not significant. The positive significant correlation of SS at marked level of significance with NO_3^--N (r=0.443, p=0.0001), NO_2^--N (r=0.302, p=0.010) and NH_4^+-N (r=0.229, p=0.05) was recorded (Figure 6).

Table 1: Physico-Chemical Parameters (mean ± SD) at different locations in the coastal waters off Bhavnagar during 1996-2007

Para-meters	Bhavnagar Creek					Sonrai Creek				
	January 1996	November 2001	May 2003	November 2006	March 2007	January 1996	November 2001	May 2003	November 2006	March 2007
Temp (^{0}C)	22.3 ± 1.84	28.0 ± 0.64	27.8 ± 1.00	25.7 ± 0.85	27.8 ± 0.35	21.0 ± 0.00	28.2± 1.11	28.6*	26.1 ± 0.36	26.9 ± 0.23
pH	8.1 ± 0.07	7.9 ± 0.21	7.9 ± 0.21	7.8 ± 0.28	7.9 ± 0.14	8.1 ± 0.00	8.0 ± 0.00	8.0*	8.0 ± 0.06	8.0 ± 0.00
SS (mg/l)	5186 ± 949.4	398.5 ± 304.76	1989 ± 2063	2150 ±2614.89	1406 ± 55.90	709 ± 684.5	653.67 ±312.96	2003*	2393 ± 881.8	2632 ± 1098.86
Salinity (ppt)	30.1 ± 0.00	31.5 ± 0.50	36.9 ± 0.70	22.8 ± 0.14	31.1 ± 0.78	29.9 ± 0.3	30.5 ± 0.5	34.9*	22.5 ± 0.26	30.1 ± 0.20
DO (ml/l)	6.9 ±. 0.21	3.3 ± 0.07	4.4 ± 0.27	3.8 ± 1.27	4.0 ± 0.64	7.5 ± 0.3	3.9 ± 0.44	4.7*	4.3 ± 0.35	4.0 ± 0.32
BOD (mg/l)	2.7 ± 0.14	1.4 ± 0.42	3.5 ± 1.29	1.5 ± 0.78	2.9 ± 1.41	1.2 ± 0.6	3.7 ± .87	1.7*	1.3 ± 0.89	2.5 ± 0.95
PO_4^{3-}P (µmol/l)	5.2 ± 1.84	5.0 ± 1.34	2.9 ± 0.45	3.4 ± 0.35	18.0 ± 0.71	4.0 ± 0.8	34.8± 8.24	2.7*	2.8 ± 0.06	11.8 ± 3.86
NO_3^-N (µmol/l)	60.4 ± 5.02	18.6 ± 1.56	44.7 ± 13.91	31.0 ± 6.51	41.9 ± 5.45	19.6 ± 2.6	20.9 ± 1.3	32.9*	47.2 ± 3.12	42.0 ± 2.8
NO_2^-N (µmol/l)	5.8 ± 4.88	5.6 ± 0.42	2.2 ± 3.18	8.6 ± 10.75	1.0 ± 0.21	0.3 ± 0.1	1.3 ± 0.78	0.5*	0.7 ± 0.15	0.8 ± 0.1
NH_4^+-N (µmol/l)	20.4 ± 8.13	0.2 ± 0.07	2.5 ± 1.80	1.1 ± 0.07	2.1 ± 0.35	1.3 ± 0.1	0.2 ± 0.1	0.6*	2.0 ± 0.15	1.9 ± 0.68

Para-meters	Malcolm Channel					Offshore				
	January 1996	November 2001	May 2003	November 2006	March 2007	January 1996	November 2001	May 2003	November 2006	March 2007
Temp (^{0}C)	22.1 ± 1.56	29.9 ± 0.92	28.5*	26.3 ± 0.85	27.9 ± 0.92	23.3 ± 0.52	28.8 ± 0.35	28.4*	27.3 ± 0.58	27.0 ± 1.6
pH	8.2 ± 0.07	8.0 ± 0.07	7.9*	8.0 ± 0.00	8.0 ± 0.07	8.1 ± 0.06	8.0 ± 0.14	7.8*	7.9 ± 0.10	8.0 ± 0.00
SS (mg/l)	3186 ± 1976.36	711 ± 2.83	1138*	2368 ± 258.09	1123 ± 1296.83	1054.67 ± 267.73	1351 ± 248.90	900*	1970 ± 804.36	2878 ± 295.79
Salinity (ppt)	31.85 ± 0.07	30.1 ± 0.42	34.4*	23.1 ± 0.21	30.2 ± 0.64	31.8 ± 0.29	30.9 ± 0.63	34.2*	22.4 ± 0.71	30.1 ± 0.48
DO (ml/l)	7.6 ± 0.64	3.9 ± 0.50	4.6*	5.0 ± 0.35	4.4 ± 0.07	7.5 ± 0.25	4.2 ± 0.14	4.6*	4.5 ± 0.7	3.9 ± 0.91
BOD (mg/l)	1.6 ± 0.64	3.7 ± 1.27	1.0*	1.4 ± 0.07	1.8 ± 0.85	1.1 ± 0.26	4.6 ± 0.63	2.8*	1.3 ± 0.67	3.4 ± 1.36
PO_4^{3-}P µmol/l)	2.8 ± 0.28	29.7 ± 37.48	2.5*	4.3 ± 2.12	12.8 ± 1.63	3.8 ± 1.06	8.4 ± 8.63	2.3*	2.9 ± 0.62	8.7 ± 2.29
NO_3^-N µmol/l)	18.3 ± 4.31	22.55 ± 6.29	29.2*	39.65 ± 6.44	33.5 ± 4.88	24.5 ± 7.69	19.4 ± 0.64	26.1*	39.8 ± 8.30	33.5 ± 3.36
NO_2^-N µmol/l)	0.7 ± 0.07	0.6 ± 0.07	0.3*	1.1 ± 0.78	0.7 ± 0.14	0.8 ± 0.1	0.7 ± 0.21	0.2*	0.5 ± 0.10	0.9 ± 0.22
NH_4^+-N µmol/l)	1.3 ± 0.70	0.15 ± 0.07	1.7*	1.7 ± 1.06	1.4 ± 0.57	1.5 ± 0.32	0.7 ± 0.78	1.5*	1.1 ± 0.31	1.0 ± 0.45

* : single value

Table 2: Phytoplankton and pigments (mean ± SD) at different locations in the coastal waters off Bhavnagar during 1996-2007

Area	Period	Chlorophyll *a* (mg/m^3)	Phaeophytin (mg/m^3)	Cell count (no.x10^3/l)	*Total genera*
Bhavnagar Creek	January 1996	0.5 ± 0.00	0.35 ± 0.07	1350 ± 636.4	2 ± 0.71
	November 2001	0.7 ± 0.21	1.1 ± 0.35	13600 ± 5656.8	5 ± 2.83
	May 2003	0.3 ± 0.12	0.8 ± 0.23		
	November 2006	0.4 ± 0.07	0.4 ± 0.14	3775 ± 2085.9	3 ± 2.83
	March 2007	0.4 ± 0.28	1.1 ± 0.35	8800 ± 1131.37	2 ± 2.12
Sonrai Creek	January 1996	4.6 ± 4.9	2.0 ± 1.7	172900 ± 238577.8	6 ± 3.54
	November 2001	0.6 ± 0.23	0.7 ± 0.31	3750 ± 2486.46	5 ± 3.54
	May 2003	0.2*	0.8*		
	November 2006	0.3 ± 0.06	1.57 ± 0.76	19400 ± 16822.60	6 ± 5.66
	March 2007	1.0 ± 0.38	2.0 ± 0.75	52467 ± 58523.27	6 ± 6.36
Malcolm Channel	January 1996	0.5 ± 0.00	0.65 ± 0.07	1650 ± 1060.67	2 ± 0.00
	November 2001	0.8 ± 0.35	0.45 ± 0.35	4700 ± 707.11	4 ± 0.71
	May 2003	0.3*	0.8*		
	November 2006	0.5 ± 0.07	2.5 ± 0.85	6401 ± 1129.96	2 ± 1.41
	March 2007	0.6 ± 0.00	1.3 ± 0.71	11900 ± 2404.16	6 ± 5.66
Offshore	January 1996	0.6 ± 0.12	0.5 ± 0.1	1100 ± 526.78	3 ± 2.12
	November 2001	1.1 ± 0.42	1.0 ± 0.21	12800 ± 7418.90	5 ± 0.71
	May 2003	0.2*	0.3*		
	November 2006	0.6 ± 0.15	2.0 ± 0.72	7600 ± 2653.3	3 ± 2.12
	March 2007	0.4 ± 0.10	1.1 ± 0.36	1600 ± 282.84	4 ± 3.54

b. Phytoplankton

Phytoplankton pigments

A wide variation in the concentration of chlorophyll *a* was seen in Sonrai Creek (0.2 ± 0.00 – 4.6 ± 4.9 mg/m^3), Bhavnagar Creek (0.3 ± 0.12 – 0.7 ± 0.21 mg/m^3), Malcolm Channel (0.3 – 0.75 ± 0.35 mg/m^3) and offshore (0.2– 1.1 ± 0.42 mg/m^3) water (Table 2). The overall mean of standing crop was higher at surface (50.9 mg/m^3) than that of bottom water (36.9 mg/m^3). The ratios of chlorophyll *a* / phaeophytin were often <1 at all the locations. The correlation between phaeophytin and SS was significant (r=0.251, p=0.035)

Table 3: Overall average distribution of phytoplankton species in the coastal waters off Bhavnagar during 1996-2007

Sr no.	Species	January 1996	November 2001	November 2006	March 2007
1	*Amphora spectabilis*	-	-	1.2	-
2	*Amphiprora alata*	0.4	-	-	-
3	*Bacteriastrum hyalinum*	1.5	-	-	1.2
4	*Biddulphia sinensis*	-	-	0.3	2.2
5	*Ceratium lineatum*	-	0.3	-	-
6	*Chaetoceros sp.*	-	-	0.5	-
7	*Climacospeania sp.*	-	0.2	-	-
8	*Corethron criophilum*	-	0.4	-	-
9	*Coscinodiscus marginatus*	19	8	-	-
10	*Cyclotella striata*	-	-	14	7
11	*Fragilariopsis oceanica*	-	0.1	-	2.1
12	*Grammatophora marina*	-	0.5	-	-
13	*Guinardia flaccida*	-	-	-	0.8
14	*Gyrosigma wansbeckii*	0.2	-	1.5	1.8
15	*Hemiaulus hauckii*	-	-	-	1.9
16	*Leptocylindrus danicus*	-	0.3	-	-
17	*Melosira borreri*	-	-	-	2.3
18	*Navicula distans*	18	23	24	17
19	*Navicula delicatula*	-	-	0.7	-
20	*Cylindrotheca closterium*	42	39	4.1	4
21	*Nitzschia seriata*	-	-	1.3	-
22	*Phormidium sp.*	-	0.3	1.6	-
23	*Peridinium sp.*	-	-	-	2.7
24	*Planktoniella blanda*	-	-	-	1.5
25	*Pleurosigma normanii*	2.3	1.2	2	-
26	*Rhizosolenia stolterforthii*	1.6	0.3	-	-
27	*Skeletonema costatum*	-	5	5	-
28	*Surirella ovalis.*	-	0.2	1.3	2.5
29	*Synedra sp.*	-	0.2	-	-
30	*Thalassionema fraunfeldii*	-	-	1.5	4
31	*Thalassiosira gravida*	15	21	31	47
32	*Thalassiothrix longissima*	-	-	10	2

Figure 1: Sampling locations in coastal water of Bhavnagar

Fig. 1: Sampling locations in coastal water of Bhavnagar

whereas the overall value of chlorophyll *a* showed negative significant correlation (r= -0.250, p=0.035) with NO_3^--N. The tidal impact was discernible on chlorophyll *a* showing higher values during flood than that of ebb periods (Figures 7 and 8).

Phytoplankton population

Phytoplankton population also showed a markedly wide variation in cell counts at Sonrai Creek, (3750 ± 2486.46 – 172900 ± 238577.8 cells/l), Bhavnagar Creek (1350 ± 636.4 – 13600 ± 5656.8 cells/l), Malcolm Channel (1650 ± 1060.67 – 11900 ± 2404 .16cells/l) and offshore (1100 ± 526.78 – 12800 ± 7418.9 cells/l) as evident in Table 2. The vertical variation in phytoplankton population was prominent by recording higher values at surface (19040 ± 52692 cells/l) than that of bottom (7223 ± 5743 cells/l). The markedly low cell counts

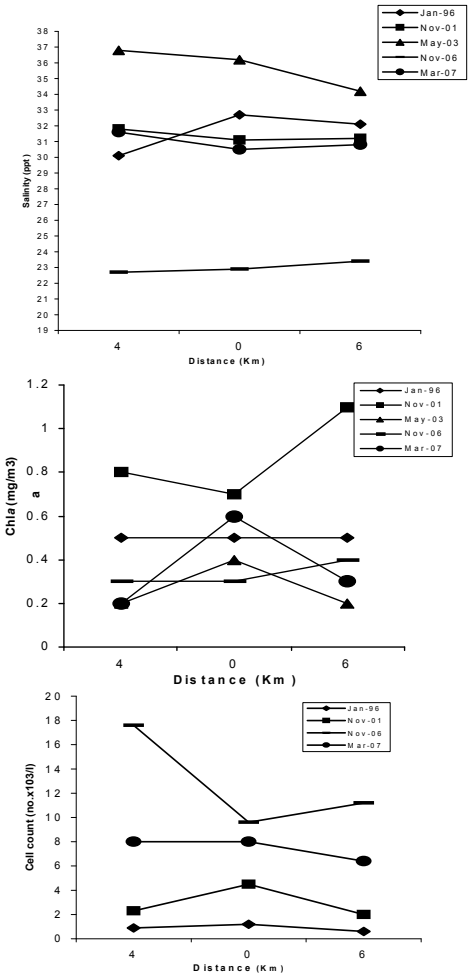

Figure 2: Distance wise variation of salinity, chlorophyll *a* and cell count in coastal water of Bhavnagar during 1996-2007

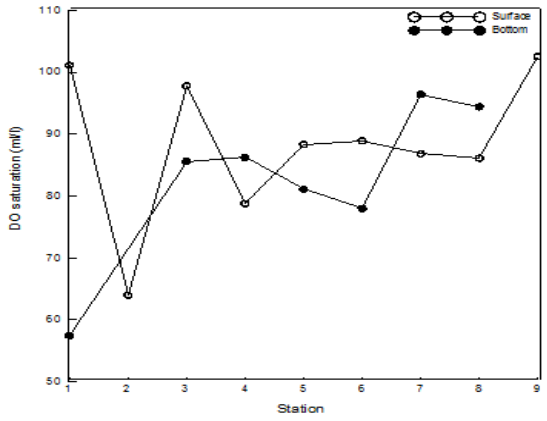

Figure 3: DO saturation (%) in coastal water of Bhavnagar during March 2007

(mean 1350 ± 636.4 /l) was associated with highest SS (5186 ± 949.4 mg/l) at Bhavnagar Creek during 1996. Correlation between phytoplankton cell count and nutrients was not significant in the present study (Figure 9). The species diversity indices of phytoplankton computed only for two years indicated markedly poor values (0.693-1.495, mean 0.749) during November 2006 and (0.199-2.085, mean 0.828) during March 2007. A single species recorded often, could not be computed for species diversity indices. A total of 32 species were recorded during 1996-2007 (Table 3). The predominance of *Cylindrotheca closterium* during 1996 (42%) and during 2001 (39%) over phytoplankton community was superseded by *Thalassiosira gravida* during 2006 (31%) and 2007 (47%) which indicated a succession of species (Figure 10). *Cylindrotheca closterium* was also present contributing only 4.1% and 4.0% during 2006 and 2007 respectively.

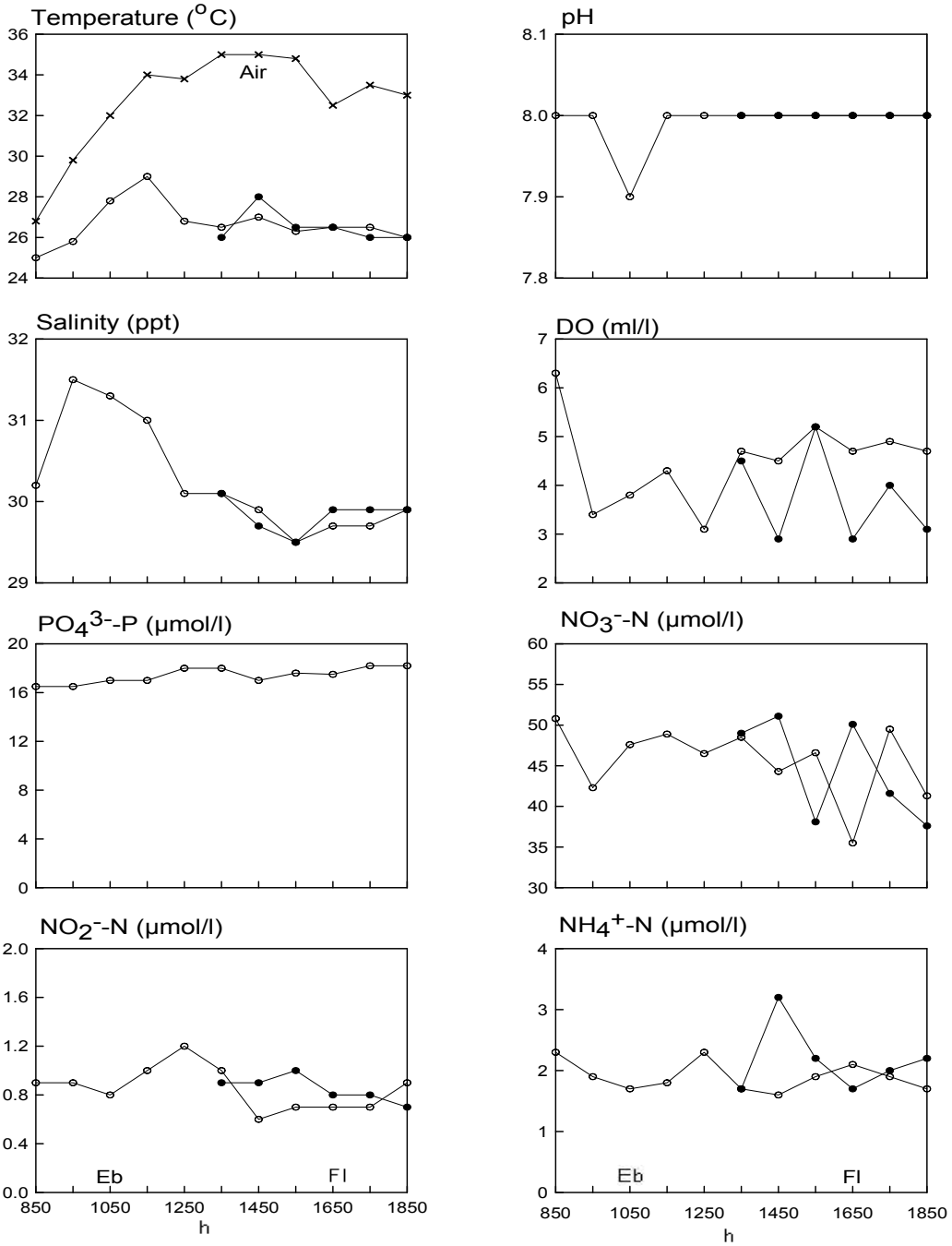

Fig.4: Temporal variation (S—○— B —●—) in water quality at station 3 on March 18, 2007

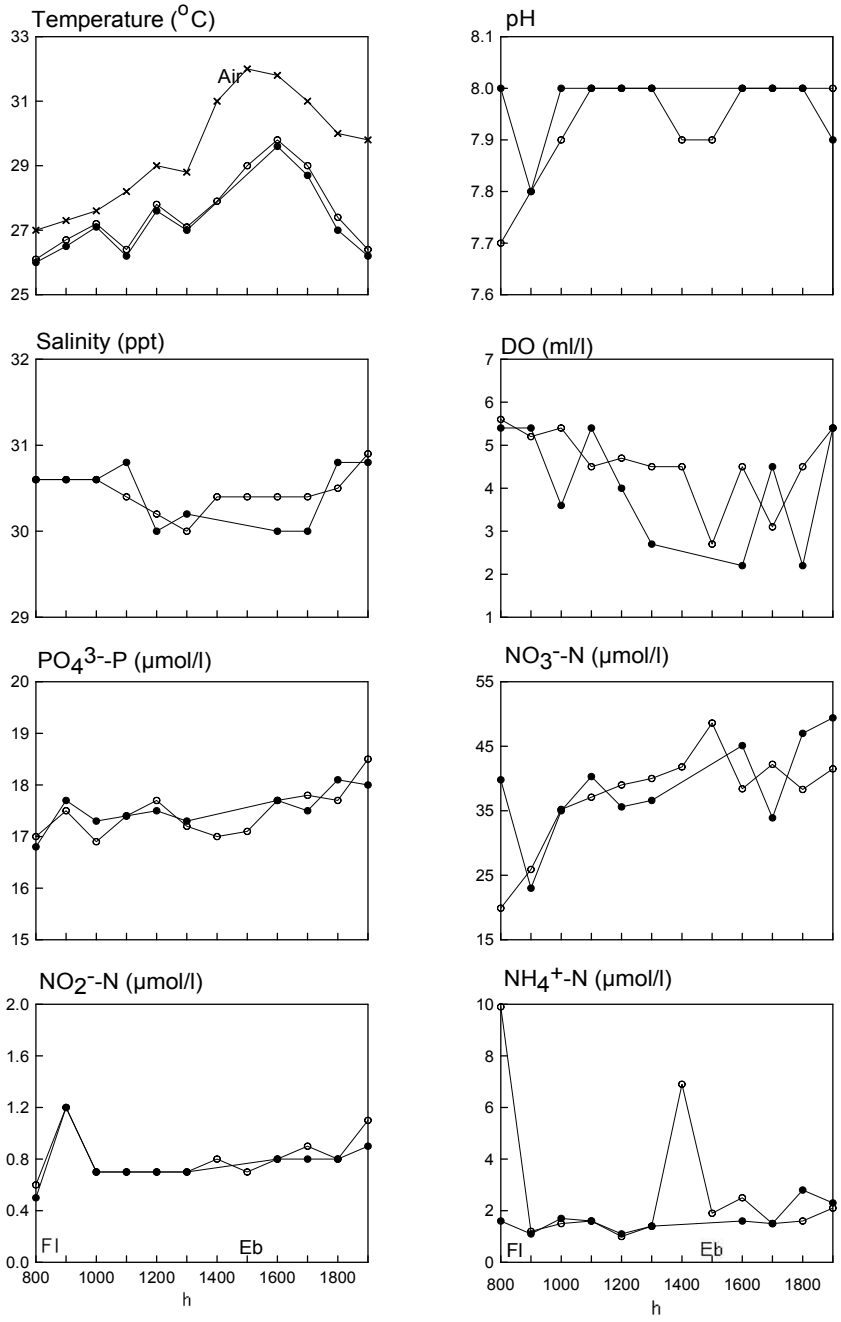

Fig.5: Temporal variation (S—○— B —◆—) in water quality at station 5 on March 24, 2007

Thus the regular presence of *Thalassiosira gravida* and *Navicula distans* and sometime *Cylindrotheca closterium* as the major species over the period of 11 years was observed (Table 3 and Figure 10).

DISCUSSIONS

The coastal water of Bhavnagar was similar to the other parts of the Gulf of Khambhat with the characteristic of seasonal variability in water temperature and pH, as expected for the buffered system of seawater (NIO, 2002; Jiyalal *et al.,* 1990 and Neelam *et al.,* 1998). The enhanced concentration of DO throughout the study period associated with markedly high SS suggested that SS did not play any major role on DO saturation as it was more than 80% in the offshore water and Malcolm Channel. Significantly high concentration of SS in the Gulf of Khambhat could be due to dispersion of fine-grained sediment in the water column by strong tidal currents sweeping the bed (NIO, 2002), extensive shore erosion along the coast (Plate 1) and inputs of high SS load through several rivers draining into the Gulf. Thus the combined effect of all the processes could be the reason for nutrient fluxes resulting in high concentration in the Gulf. The erosion or modification of shoreline was often associated with changes in the sediment load of water column similar to the result of present study, which could be redistributed from one place to another as

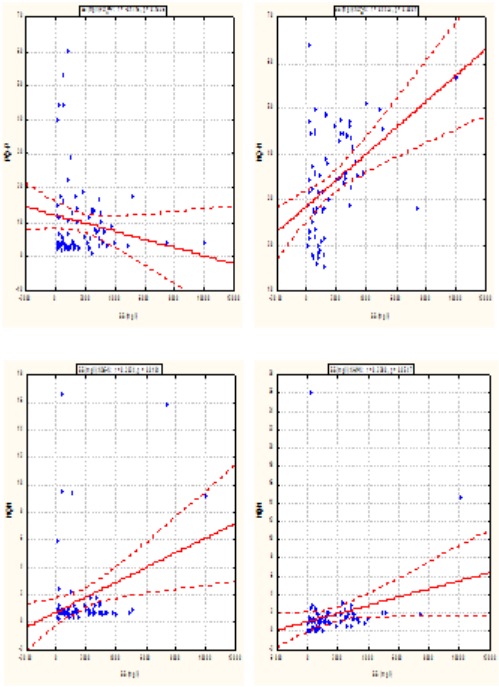

Fig. 6: Overall interrelationship of nutrients with SS in the nearshore coastal waters off Bhavnagar during 1996-2007

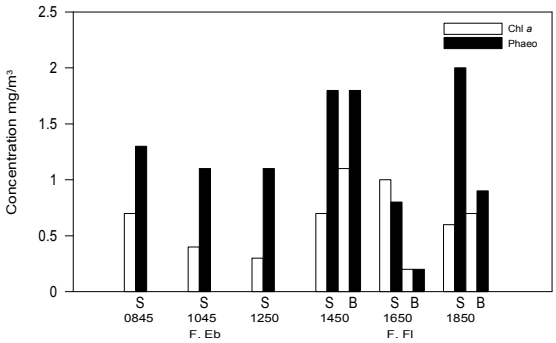

Fig. 7: Temporal variation in phytopigments at station 3 on March 18, 2007

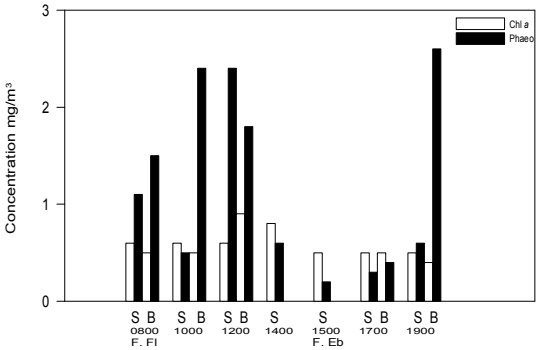

Fig. 8: Temporal variation in phytopigments at station 5 on March 24, 2007

Malcolm Channel might be formed (Figure 1). Ke and Collins (2000); Flemming *et al.* (2000) and Dunn *et al.* (2007) have also reported similar sediment dispersal pattern. The comparatively high values of salinity at the station close to the shore in the comparison of offshore stations particularly during ebb periods and also during summer season suggested

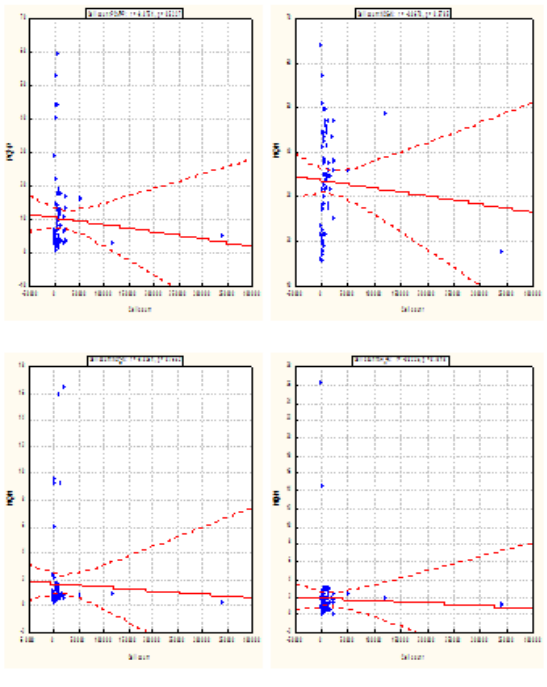

Fig. 9: Overall interrelationship of nutrients with cell counts in the nearshore coastal waters off Bhavnagar during 1996-2007

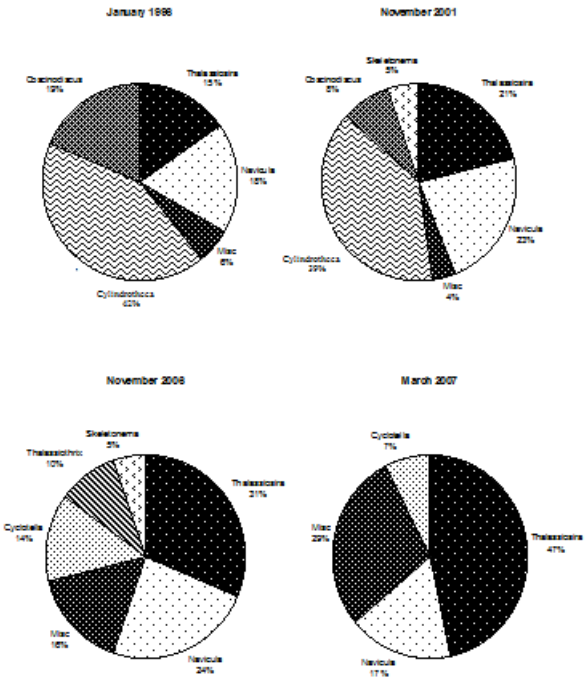

Fig. 10: Composition of phytoplankton in coastal water of Bhavnagar during 1996-2007

the combined effect of seepage from the saltpans surrounding the study location and the higher rate of evaporation at the shallow creek region. A marked reduction in salinity during November 2006 could be due to fresh water influx by heavy monsoon during September 2006 since several rivers were draining into the Gulf. This resulted an intrusion of fresh water towards offshore even to the distance of 6 km from the shore. The DO level often recorded higher (4.5-8.0 mg/l) suggested that the consumption of DO for oxidizing the dissolved and

particulate organic matter, was lower than replenishment except at few occasions. The slight increase in BOD only after 2001 indicated an anthropogenic contamination but not significant. Though the N:P ratio in clear water was reported to be nearly 15 (NIO, 2002), the present study showed the ratio, depleted to less than 7, describing a high concentration of phosphate in the region that might be due to high concentration of SS and anthropogenic release in the region.

The negative significant correlation between DO and PO_4^{3-}-P, and also between DO and NO_3^--N and NO_2^--N suggested that the nutrient fluxes through the sediments led an enrichment in the nutrient levels and DO was utilized for oxidizing the organic particulate matter. Since the individual nutrients revealed significant positive correlation with SS, the possibility of nutrients fluxes was through SS which was inputs of 6 major and 5 minor rivers draining into the Gulf and shore erosion due to high waves and strong currents. The dynamics of phytoplankton with the association of such a high concentration of nutrients and DO in the coastal water of Bhavnagar was typical. The concentrations of chlorophyll *a* were markedly poor as compared to the results of Dehadrai *et al.* (1972); Jiyalal *et al.* (1990); Bhattathiri *et al.* (1996); Sawant *et al.* (1996); Jiyalal *et al.* (1998); Nair *et al.* (2005) and Shenoy *et al.* (2006) and suggested poor phytoplankton production, which could be due to noticeably high SS prevailing in the area. High chlorophyll occurrence elsewhere in the Gulf of Khambat due to cyclonic – anticyclonic eddies in the northern Arabian Sea was reported (NERCI, 2005-06) which needed the checking of values. The spatial variations, similar to the present study, are reported by Bhattathiri *et al.,* (1996), Nair *et al.* (2005), Henriquez *et al.* (2007) and Zarauz *et al.* (2008). Significantly poor ratios of chlorophyll *a* / phaeophytin often recorded <1 could be due to exorbitant concentration of SS and suggested an unhealthy condition of phytoplankton cells (Jiyalal *et al.* 1990 and 1998). The positive significant correlation between phaeophytin and SS suggested a high rate of degradation of chl *a* due to high concentration of SS in the region. Phytoplankton cell counts and total genera also indicated significantly poor phytoplankton production and abundance in this coast as compared to the results reported by Dehadrai *et al.* (1972); Sawant *et al.*(1996); Geeta and Kondalarao, (2004); Verlencar *et al.* (2006) and Shenoy *et al.* (2006) in the west coast of India. The results of phytoplankton population (av. 22.8 x 10^3 cells/l) with significantly high SS in Gulf of Khambat recorded during present study were compared to the values reported for Gulf of Kachchh (av. 152.9 x 10^3 cells/l) sustaining comparatively very low SS (av. 38 mg/l) (Jiyalal *et al.,* 1990 and NIO, 1997) which imply the major role of SS in regulating phytoplankton production and abundance though the nutrients were essential to be a limiting factor (Wu *et al.,* 2003 and Gle *et al.,* 2007). In spite of very high nutrients and DO availability over the period of 11 years in the coastal waters off Bhavnagar, the phytoplankton production was markedly poor, which suggested the vulnerability of phytoplankton to SS due to hindrance in photosynthesis and poor irradiance in the region and indicated the SS playing a major role as a limiting factor. The impact of SS on phytoplankton species diversity indices (Shannon and Wiener, 1963) was also evident by recording markedly poor values. However, the presence of *Thalassiosira gravida* and *Navicula distans* continuously and *Cylindrotheca closterium* sometimes as a major species, over the period of 11 years imply their hardy nature and adaptation to such environmental conditions of high level of suspended solids of the Gulf of Khambhat.

CONCLUSION

The DO was in enhanced concentration in the coastal water of Bhavnagar. Significantly decrease in salinity during November 2006 was because of heavy monsoon in the surrounding area of the Gulf, which resulted an intrusion of freshwater towards offshore to the distance of 6 km from shore. The fluxes of nutrients in the coastal waters of Bhavnagar, Gulf of Khambhat were due to markedly high SS load, resulted by inputs through several rivers draining into the Gulf area and strong currents churning out the bed sediments, causing shore erosion. Poor irradiance in the region due to high SS load hampered photosynthetic activities and restricted phytoplankton production and consequently resulted in a marked reduction in the pigments and species diversity of phytoplankton. Thus SS was a limiting factor for phytoplankton production in the region. Predominance of *Thalassiosira gravida, Navicula distans* continuously and *Cylindrotheca closterium* sometimes over the period of 11 years confirmed their hardy nature and adaptation to the environmental condition of the Gulf of Khambhat.

ACKNOWLEDGEMENTS

Authors wish to thank Dr. B. N. Desai and Dr. M D. Zingde for their support and facilities provided to undertake this study. Our sincere thanks are also due to Dr. S. A. H. Abidi, for his encouragement and suggestions in the manuscript. Authors are also thankful to Ms. Sharayu Phadke, Mr. Nitin Walmiki and Kirti Konkar for their help rendered in preparation of the manuscript. This is NIO Contribution No. 5034.

REFERENCES

Alory, G., Wijffels, S. and Mayers, G. 2007. Observed Temperature Trends in the Indian Ocean over 1960-1999 and associated mechanisms, Geophys. Res. Lett.: 34.

APHA. 1985. Standard Methods for water examination, American Public Health Association, 16:1085.

APHA. 2005. Standard Methods for water examination, American Public Health Association, 21:1207.

Bange, H.W., Naqvi, S.W.A. and Codispoti, L.A. 2005. The nitrogen cycle in the Arabian sea, Prog. Oceanogr., 65:145-158.

Bhattathiri, P.M.A., Pant, A., Sawant, S., Gauns, M., Matondkar, S.G.P. and Mohanraju, R. 1996. Phytoplankton production and chlorophyll distribution in the eastern and central Arabian Sea in 1994-1995, *Current Science,* 71:857-862.

Dehadrai, P.V. and Bhargava, R.M.S. 1972. Distribution of Chlorophyll, Carotenoids and Phytoplankton in relation to certain Environmental Factors along the Central West Coast of India, *Marine Biology*, 17:30-37.

Dunn, R.J.K., Ali, A., Lemckert, C.J., Teasdale, P.R. and Welsh, D.T. 2007. Short-term variability of physico-chemical parameters and the estimated transport of filterable nutrients and chlorophyll-*a* in the urbanized

Coombabah lake and Coombabah Creek system, Southern Moreton Bay, *Australia, Journal of Coastal Research*, 50:1062-1068.

Flemming, B.W., Delafontaine, M.T. and Liebzeit, G. 2000. Muddy coast dynamics and resource management, Elsevier Science, Germany.

Geeta, V. M. and Kondalarao, B. 2004. Distribution of phytoplankton in the coastal waters of India, *Indian Journal of Marine Sciences,* 33:262-268.

Gle, C., Amo, Y.D., Sautour, B., Laborde, P. and Chardy, P. 2007. Variability of nutrients and phytoplankton primary production in a shallow macrotidal coastal ecosystem (Arcachon Bay, France), Estuarine, *Coastal and Shelf Science,* 76:642-656.

Grasshoff, K., Ehrhardt, M., Kremling, K. 2002. Methods of seawater analysis, Verlag Chemie, Gmbh, 419.

Henriquez, L.A., Daneri, G., Munoz, C.A., Montero, P., Veas, R. and Palma A.T. 2007. Primary production and phytoplanktonic biomass in shallow marine environments of Central Chile: Effect of coastal geomorphology, Estuarine, *Coastal and Shelf Science,* 73, 137-147.

Jiyalal M.J., Nair, V.R., and Desai, B.N. 1990. Distribution of phytoplankton off Mithapur (Gujarat), *Journal of the Indian Fisheries Association*, 19:49-57.

Jiyalal, M.J., Mehta P. and Govindan K. 1998. Phytoplankton pigments and macrobenthos in nearshore waters off an oil terminal at Uran (Maharashtra), west coast of India, *Indian Journal of Marine Sciences,* 27:317-322.

Ke, X. and Collins, M. 2000. Tidal characteristics of an accretional tidal flat (The Wash, U.K.) Muddy Coast Dynamics and Resource Management, Elsevier Science, 13-38.

Lebour, M.V. 1977, Planktonic diatoms of Northern Seas, Adlard and Son Limited, London and Dorking, 244.

Levy, M., Shankar, D. J., Andre, M., Shenoi, S.S.C., Durand, F. and De Boyer, C. M. 2007. Basin-wide seasonal evolution of the Indian ocean's phytoplankton blooms, *Geophys. Res.,* 112.

Mazda, Y., Sato, Y., Swamoto, S., Yakochi, H. & Wolanski, E. 1990. Links between physical, chemical and biological processes in Bashita-Minato, a mangrove swamp in Japan. Estuarine, *Coastal and Shelf Science,* 31:817-833.

Nair, V.R., Gajbhiye, S.N. and Jaiswar, J.M. 2005. Biogeography of plankton of Gulf of Kachchh, Northwest Coast of India, Dynamic Planets, Cairns Australia.

Naqvi, S.W.A., Narvekar, P.V. and Desa, E. 2006. Coastal biogeochemical processes in the North Indian Ocean, The Sea, Vol. 14, edited by A. Robinson and K. Brink, Harvard Univ. Press, Cambridge, Mass, 723-780.

Neelam R., Ramaiah, N. and Nair, V.R. 1998. Phytoplankton characteristics in a polluted Bombay harbour – Thane creek – Bassein creek estuarine complex, *Indian Journal of Marine Sciences,* 27:281-285.

NERCI Annual Report 2005-06. Persistent occurrence of high chlorophyll in the Gulf of Khambat due to cyclonic – anticyclonic eddies in the northern Arabian sea.

NIO Report 1997. Monitoring of Coastal waters off Bhavanagar.

NIO Report 2002. Monitoring of Coastal waters off Bhavanagar.

Ridd, P.V., Wolanski, E. & Mazda, Y. 1990. Longitudinal diffusion in mangrove- fringed tidal creeks. *Estuarine, Coastal and Shelf Science*, 31:541-544.

Sawant, S. and Madhupratap, M. 1996. Seasonality and composition of phytoplankton in the Arabian Sea, *Current Science,* 71:869-873.

Seintzinger, S.P., Harrison, J.A., Dumont, E., Veusen, A.H.W. and Bouwman A.F. 2005. Sources and delivery of carbon, nitrogen and phosphorus to the coastal zone: and overview of Global Nutrient Export from Watersheets (NEWS) models and their applications, *Global Biogeochem. Cycles,* 19.

Shannon, C.E. and Weiner, W. 1963. The Mathematical Theory of Communication, University of Illinois Press, Urbana.

Shenoy, D.M., Paul J.T., Gauns, M., Ramaiah, N. and Kumar, M.D. 2006. Spatial variations of DMS, DMSP and phytoplankton in the Bay of Bengal during the summer monsoon 2001, Marine Environmental Research, 62:83-97.

Tomas, C.R., 2002, Identifying Marine Phytoplankton, Academic Press, California, 858.

Verlencar, X.N., Desai, S.R., Sarkar, A. and Dalai, S.G. 2006. Biological indicator in relation to coastal pollution along Karnataka coast, India, *Water Research*, 40:3304-3312.

Wiggery, J.D., Multitude, R.G. and Christian, J.R. 2006. Annual ecosystem variability in the tropical Indian Ocean: Results of a couple biophysical ocean general circulation model, Deep Sea Research - Part II, 53:644-676.

Wu, J.T. and Chou, T.L. 2003. Silicate as the limiting nutrient for phytoplankton in a subtropical eutrophic estuary of Taiwan, *Estuarine, Coastal and Shelf Science*, 58:155 - 162.

Zarauz, L., Irigoien, X. and Fernandes, J.A. 2008. Modelling the influence of abiotic and biotic factors on plankton distribution in the Bay of Biscay, during three consecutive years (2004-06), *Journal of Plankton Research*, 30:857-572.

****