

Seasonal changes in suspended particulate component in Bombay High oil field (Arabian Sea)

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Investigation on the influence of seasonal changes in physico-chemical factors on particulate matter in the "Bombay High" region from February'85 to January'86 suggests that dominance of physical factors in monsoon largely influence the production of phytoplankton biomass. Ratio of silicate and nitrate to phosphate was 16:16:1 for monsoon and postmonsoon periods. Annual values of particulate carbohydrates, particulate proteins and particulate lipids in surface waters ranged from 40 to 265 $\mu\text{g l}^{-1}$, 21 to 56 $\mu\text{g l}^{-1}$ and 14 to 51 $\mu\text{g l}^{-1}$ respectively. Significant correlation of particulate carbohydrate, particulate proteins and particulate lipids with chlorophyll *a* suggested that plankton biomass comprised a substantial percentage of these constituent fractions. Almost uniform ratios of particulate lipid to particulate organic carbon (PL/POC) during all the three seasons indicated incorporation of petroleum hydrocarbons in the suspended particles.

Study of particulate organic matter (POM) in the oceans has gained considerable impetus in the recent past owing to its importance in marine food web and significant role in biogeochemical cycles of elements. Bhosle *et al.*^{1,2} and Nandakumar *et al.*³ have shown considerable variation in particulate carbohydrate (PCHO) and particulate lipid (PL) in the surface and the deep waters of Arabian Sea and Bay of Bengal. While studying sedimentation rates Bhosle *et al.*⁴ demonstrated seasonality in the distribution of particulate material in the Arabian Sea. However, most of such results are based on observations undertaken during oceanographic cruises and pertain to a particular month in a year. In the present communication monthly variations of these parameters are presented for an annual cycle. Efforts are also made to determine the relation of the physico-chemical changes on the particulate organic constituents at a fixed station in Bombay High region of the Arabian Sea.

Materials and Methods

The study site ($19^{\circ}20'N$; $71^{\circ}20'E$) was located in an offshore oil field region "Bombay High" in the northern Arabian Sea (Fig. 1). The investigations were carried out from an oil processing platform from February 1985 to January 1986 at monthly intervals. The depth at this site is 80 m. Due to the

technical hitch on the oil processing platform data could not be obtained from May to July. Seawater samples were collected from five depths viz. surface, 10, 25, 50 m and near bottom (65 meters) using 5 liter Niskin samplers. Immediately after collection a known volume of water sample was

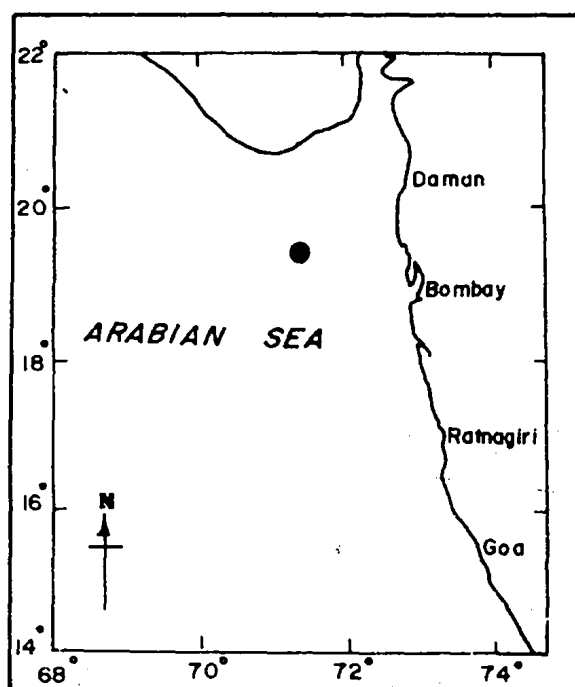


Fig. 1—Location of study area in the Arabian Sea

filtered through GF/C, 47 mm diameter filters, pre-weighed and pre-baked in a muffle furnace at 450°C for 3 hours. Suspended matter retained on the filters was rinsed with distilled water and was analyzed in duplicate for particulate organic carbon (POC), particulate carbohydrate (PCHO), particulate protein (PP), and particulate lipid (PL), fractions. Total suspended matter (TSM) expressed in terms of dry weight was determined by drying the filters in an oven at 50°C until no further wet weight loss occurred. POC and PL were analyzed following the method described by Parsons *et al.*⁵ PCHO was analyzed as suggested by Hitchcock⁶ using phenol-sulphuric acid method with glucose as standard, PP by the method described by Lowry *et al.*⁷ and as modified by Dortch *et al.*⁸ Chlorophyll *a* (chl-*a*) and physico-chemical parameters were analyzed by using standard procedures⁵. Total diatom counts were taken and analysed by the method discussed by Parsons *et al.*⁵ Zooplankton samples were collected using HT plankton net (0.25 m² mouth area, 100 µm mesh size) by a vertical haul (near-bottom to surface).

Secondary production was calculated based on the formula given by Cushing.⁹

Results

Data on hydrographical parameters are shown in Fig. 2. Annual sea surface temperature ranged from 24.8 to 29.2°C. Water column remained almost homogeneous from January to March due to strong vertical mixing. An upward tilt in low temperature isotherm was seen from 65 m depth in April to 25 m depth in November. The magnitude of the tilt increased continually up to November, then decreased gradually and vanished in January. Surface salinity was high from August to October and the lowest value of 34.3 ‰ was observed in February. Vertical distribution of salinity was homogeneous from January to July. In the beginning of monsoon, (June and July) density isolines showed a vertical trend while in the later period layers of high densities occupied the bottom waters. Dissolved oxygen in surface waters ranged from 4.45 to 6.7 ml l⁻¹.

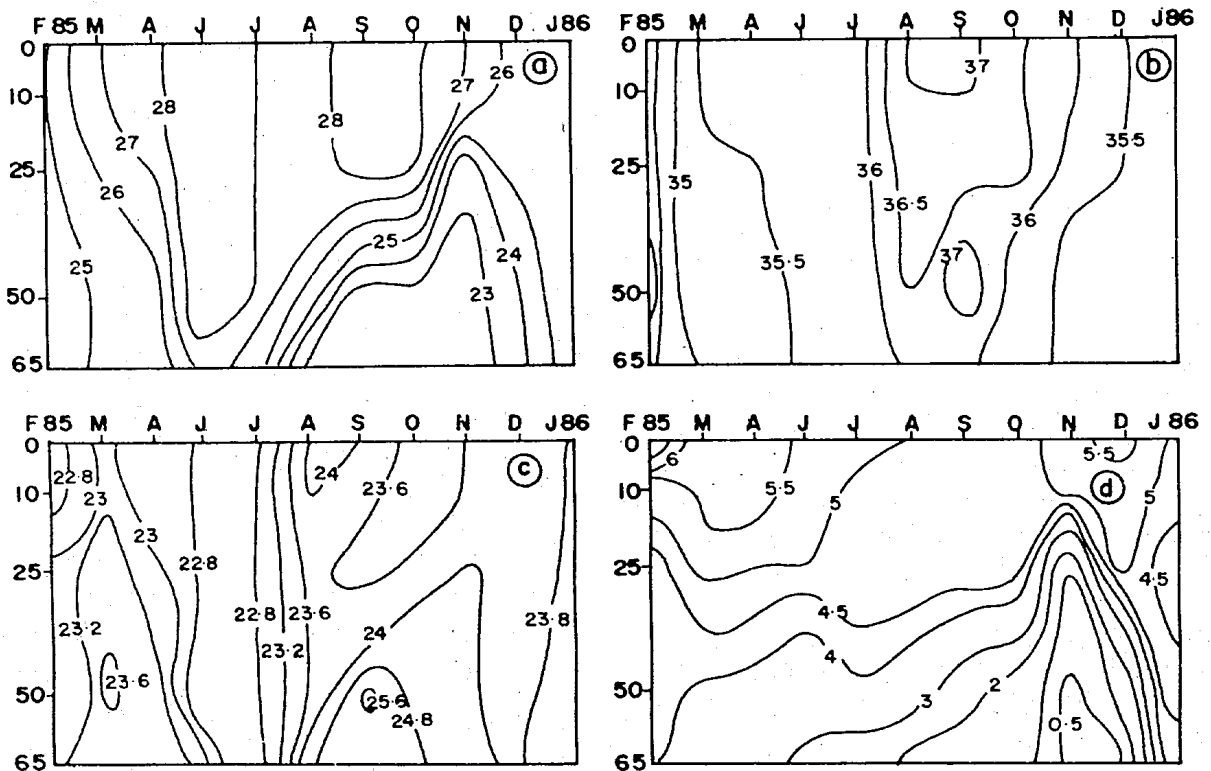


Fig. 2—Monthly variation in : a) temperature (°C), b) salinity (‰), c) sigma t (σ_t) and d) dissolved oxygen (ml l⁻¹) at different depths

Nutrients such as nitrate, phosphate and silicate (Fig. 3) in surface waters ranged from 0.06 to 1.4, 0.24 to 1.84 and 1.97 to 8.01 μm respectively. Vertical distribution indicated that nitrate and silicate remained high in bottom waters

Surface chlorophyll *a* (Fig. 4a) was low ranging from 0.05 to 0.50 $\mu\text{g l}^{-1}$. Vertical distribution of chl *a* showed peaks at different depths from February and December. Total suspended matter remained high in upper 10 m except for a high value of 11.9 mg l^{-1} in January at 65 m depth. Diatom concentration in surface waters ranged from 1 to 70×10^3 cells/l (Fig. 4d). Peak diatom concentration was observed in February, while during rest of the year the values were homogeneous.

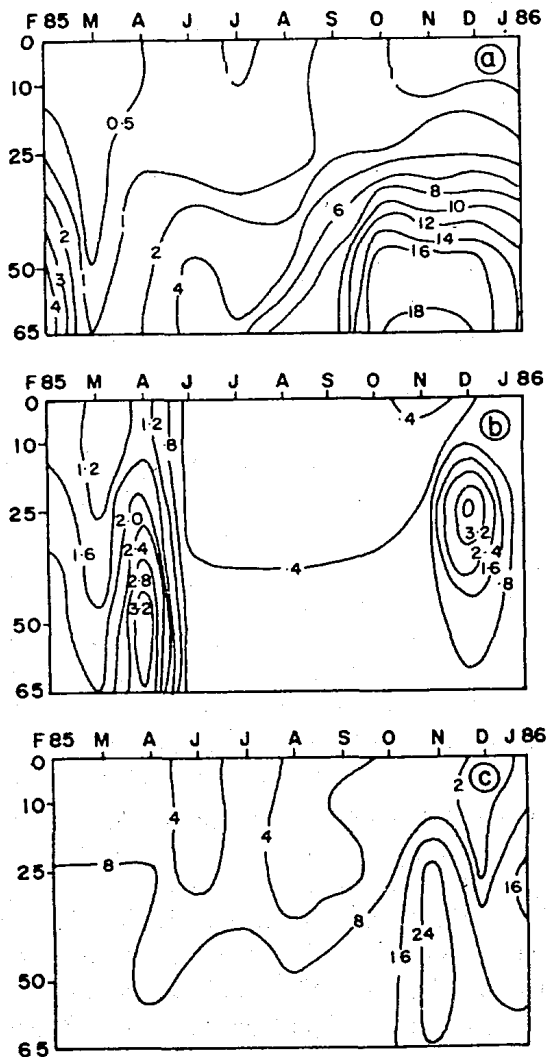


Fig. 3—Monthly changes in nutrients : (a) $\text{NO}_3\text{-N}$, (b) $\text{PO}_4\text{-P}$, (c) $\text{SiO}_3\text{-Si}$, (values are in μm)

Particulate carbohydrate (PCHO) in surface waters ranged from 39.6 to 265.3 $\mu\text{g l}^{-1}$ (Fig. 5a). Vertical distribution of PCHO values indicated low values in sub-surface waters as compared to the surface waters.

Particulate protein (PP) in surface waters attained a high in August with a maximum value of 56 $\mu\text{g l}^{-1}$ (Fig. 5b). Concentrations remained high from May to October and in March. Particulate lipid (PL) in surface waters ranged from 13.7 to 49.8 $\mu\text{g l}^{-1}$ (Fig. 5c) and the water column remained mostly homogenous. The ratios of POC with other biochemical constituents at different depths are shown in Fig. 6. In the surface waters the PCHO/POC ratio ranged from 0.06 to 0.63 while PP/POC and PL/POC ratios varied from 0.029 to 0.39 and 0.025 to 0.21 respectively.

Zooplankton biomass in the water column ranged from 0.17 to 0.65 ml m^{-3} . Zooplankton biomass (Table 1) was low during monsoon and premonsoon but reached a peak level from November to January. Copepods formed the major component of zooplankton community throughout the period of investigation with a peak population density of 1780 individuals m^{-3} in March (Table 1).

Discussion

Results indicated that the hydrographic features in the Arabian Sea are dominant during monsoon as reported in earlier studies¹⁰⁻¹². The energetic wind circulation during monsoon influences the sea surface temperature by spreading cooled upwelled water into the surface layers. While raise of isotherms and oxygen isolines close to surface in November suggest that the near surface circulation paths are restricted to shallow depth of 10 m, due to low winds during November to January.

The temperature distribution pattern was well reflected in the variation of nutrients, the isolines of nitrate and silicate showing increasing trend from November-January (Fig. 3a,b). Correlation of PO_4 with NO_3 and SiO_3 of the entire set of monthly values pooled together did not show any significance. But the seasonal split in values (Table 2) showed a significant correlation of PO_4 with NO_3 and SiO_3 . The ratios in premonsoon were much lower than the combined values for monsoon

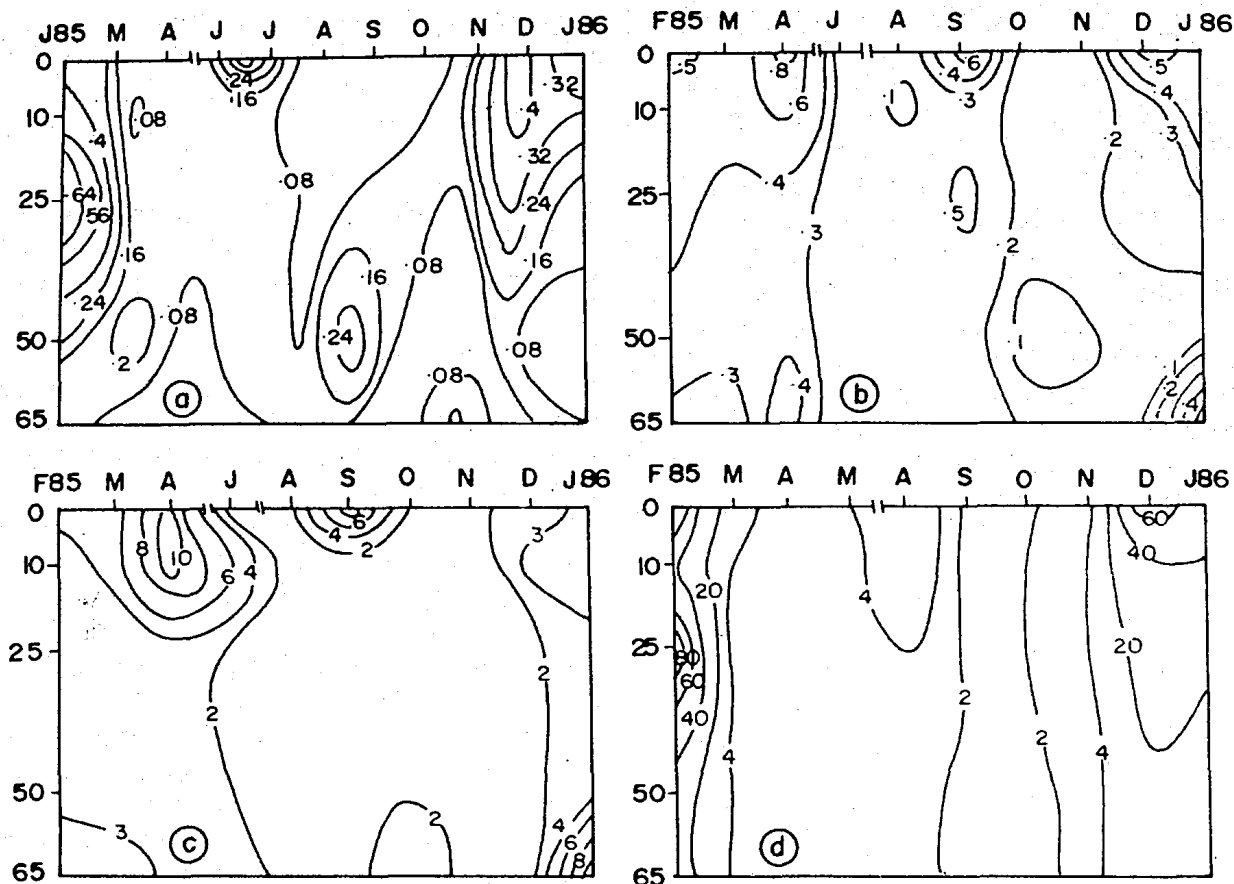


Fig. 4—Monthly changes in : (a) chlorophyll *a* ($\mu\text{g l}^{-1}$), (b) POC ($\mu\text{g l}^{-1}$), (c) TSM ($\mu\text{g g l}^{-1}$) and (d) diatom counts ($\text{no.} \times 10^3 \text{ cells l}^{-1}$)

and postmonsoon. The high ratios of 16 for NO_3 : PO_4 and 19.9 for SiO_3 : PO_4 were in agreement with values of Redfield *et al.*¹³

Variation in chlorophyll *a* was not consistent with nutrients except for high values in February and December (Figs. 3a, 4a). Annual chl-*a* concentrations plotted against each of the parameters such as POC, TSM, PCHO, PP and PL showed wide scatter. Data were therefore split on seasonal basis. The results showed valid correlation of chl-*a* with POC and PCHO in postmonsoon, PL during premonsoon and low correlation with PP in monsoon (Table 3). Significant correlation was seen between POC and PCHO during postmonsoon and POC and PL during monsoon.

Large fluctuation in chl-*a* and addition of organic wastes disposed from the oil platform, could mainly be responsible for the lack of good correlation of values between chl-*a* and other

biochemical constituents. Nevertheless significant correlation of chl-*a* with PCHO, PP and PL at selected seasons suggest that the plant biomass comprised a significant percentage of these biochemical components.

Mean values of ratio of the biochemical constituents with POC (Table 4) indicated that PCHO/POC ratio was low during pre-monsoon and increased to more than two-fold during the other two seasons. Similarly, the mean PP/POC ratio was low in premonsoon and high during monsoon and postmonsoon periods in surface waters, whereas, the mean seasonal ratio of PL/POC did not show any significant change. The results were compared by one way ANOVA test which showed significant seasonal difference in PCHO/POC and PP/POC ratio and insignificant seasonal difference in PL values.

Monthly mean ratios of PCHO, PP and PL with POC at different depths showed large fluctuation

in their values (Table 5). In the upper 100 m water column in the central Arabian Sea PCHO/POC was reported¹⁴ to range from 0.09 to 0.59 for March, 1986, and in the Bay of Bengal the values ranged from 0.05 to 0.49 in October-November, 1985. These values are in agreement with the present results. The higher PCHO/POC or PL/POC indicate the nutrient deficient conditions^{15,16}. The enrichment of nutrients is prominently shown by

the high ratios of $\Delta Si : \Delta N : \Delta P$ during monsoon and postmonsoon periods with consequent high ratios of both PCHO/POC and PP/POC (Table 4), whereas, they were low in the premonsoon.

Vertical profiles of chl-*a* and phytoplankton counts (Fig. 4a, d) suggest that high ratios of PCHO/POC and PP/POC in monsoon and postmonsoon were associated with increased

Table 1—Variation in different parameters of zooplankton

Month	Biomass (ml.m ⁻³)	Secondary production (mgC. m ⁻³ .d ⁻¹)	Major groups	No. m ⁻³
Feb.'85	0.46	27.2	Copepoda	1260
			Cladocera	86
			Appendicularia	80
March	0.36	21.7	Copepoda	1780
			Chaetognatha	47
April	0.23	14.8	Copepoda	720
			Appendicularia	35
May	0.24	116.7	Copepoda	564
			Appendicularia	41
June*				
July	0.23	155.0	Copepoda	892
			Chaetognatha	119
Aug.	0.30	18.5	Copepoda	1440
			Gastropod larvae	160
			Chaetognatha	75
			Appendicularia	74
Sept.	0.21	12.8	Copepoda	1200
			Appendicularia	170
			Chaetognatha	45
Oct.	0.17	10.1	Copepoda	520
			Chaetognatha	36
Nov.	0.58	31.8	Copepoda	520
			Polychaeta	240
			Appendicularia	57
			Chaetognatha	52
Dec.	0.65	37.5	Copepoda	1536
			Chaetognatha	87
			Ostracoda	40
Jan.'86	0.50	30.0	Copepoda	640
			Appendicularia	128
			Thaliaceae	60

* - Not Sampled

Table 2—Correlation coefficients with nutrients and assimilated ratios

Parameter	Premonsoon				Monsoon & postmonsoon			
	r	n	p<	ratio	r	n	p<	ratio
NO ₃ /PO ₄	0.941	13	0.001	0.650	0.489	38	0.01	16.01
SiO ₃ /PO ₄	0.416	15	0.100	1.280	0.399	38	0.02	19.90

Table 3—Correlation coefficients of different parameters

Parameter	Premonsoon			Monsoon			Postmonsoon		
	r	n	p<	r	n	p<	r	n	p<
Chl/PCHO	-0.134	15	ns	0.195	10	ns	0.779	17	0.01
Chl/PP	0.024	13	ns	0.521	10	0.10	0.187	19	ns
Chl/PL	0.744	15	0.001	0.121	10	ns	0.249	17	ns
Chl/POC	-0.028	15	ns	-0.212	15	ns	0.807	19	0.001
POC/PCHO	-0.359	15	ns	0.589	10	0.10	0.788	18	0.001
POC/PP	0.015	13	ns	-0.046	10	ns	0.310	19	ns
POC/PL	-0.223	15	ns	0.617	10	0.05	0.001	20	ns

r - regression coeff; n - number of values; p< - level of signif. ns - not signif.

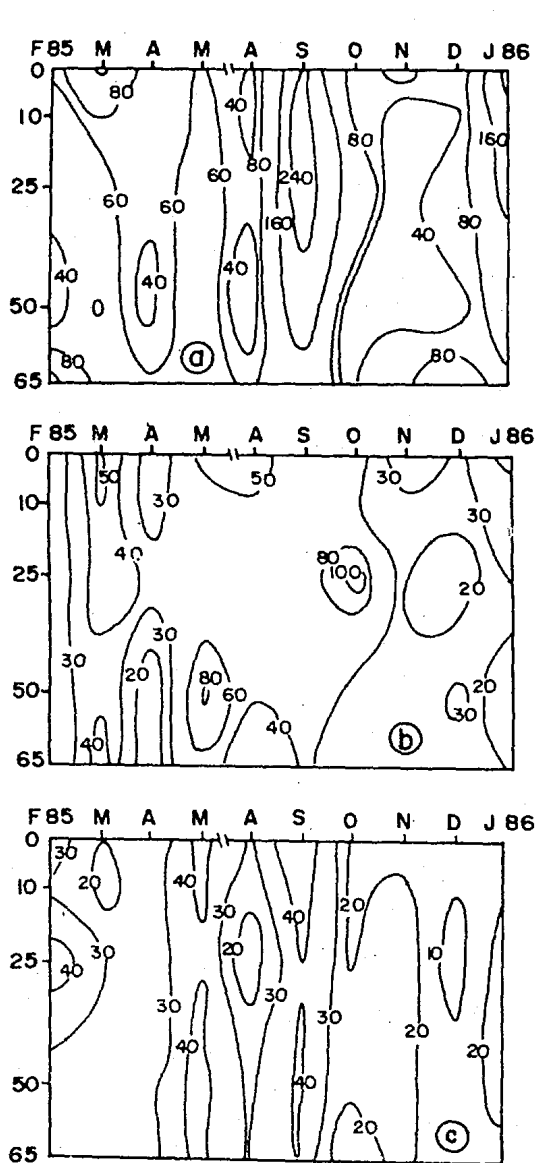


Fig. 5—Monthly changes in : (a) PCHO ($\mu\text{g l}^{-1}$), (b) PP ($\mu\text{g l}^{-1}$) and (c) PL ($\mu\text{g l}^{-1}$)

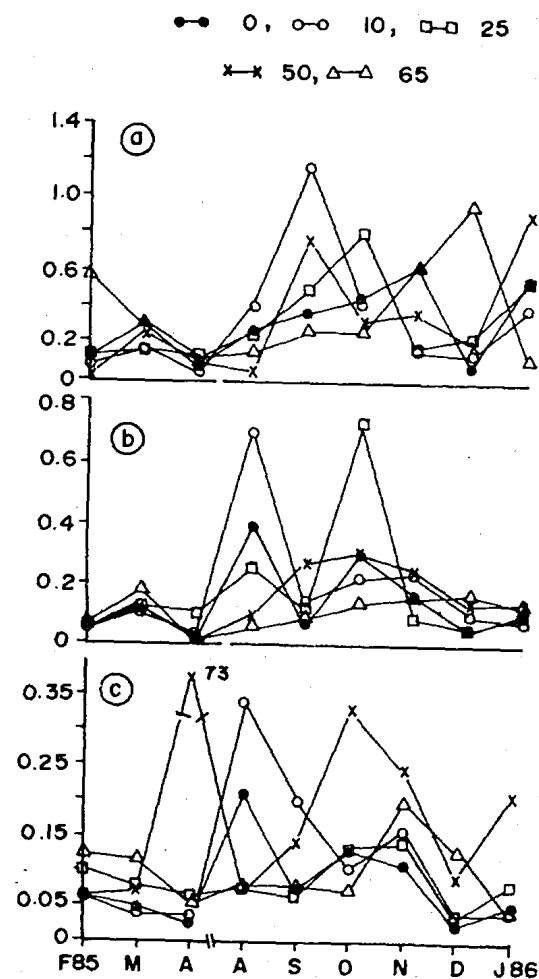


Fig. 6—Monthly changes in ratios of (a) PCHO/POC, (b) PP/POC and (c) PL/POC at different depths (0, 10, 25, 50 and 65 m)

phytoplankton biomass. Also the chl *a* in postmonsoon showed a high correlation to POC (Table 3) indicating significant contribution of living material to POC content. The higher ratios of

Table 4—Mean values of particulate biochemical fractions to POC for premonsoon (n-14), monsoon (n-10) and postmonsoon (n - 20) at all depths.

Parameter	Premonsoon (Mean±SD)	Monsoon (Mean±SD)	Postmonsoon (Mean±SD)	F value	P
PCHO/POC	0.17±0.14	0.42±0.32	0.43±0.26	5.173	0.0098
PP/POC	0.07±0.05	0.22±0.19	0.18±0.15	3.764	0.0314
PL/POC	0.07±0.03	0.07±0.03	0.12±0.08	0.092	0.9100*
TSM/POC	9.59±2.74	10.52±7.11	12.99±7.29	1.327	0.2750

Table 5—Annual mean ratios at different depths, n - 9.

Parameter	Surface (Mean±SD)	10 m (Mean±SD)	25 m (Mean±SD)	50 m (Mean±SD)	65 m (Mean±SD)
PCHO/POC	0.32±0.20	0.34±0.30	0.33±0.20	0.33±0.30	0.38±0.29
PP/POC	0.14±0.10	0.18±0.19	0.18±0.20	0.15±0.10	0.10±0.06
PL/POC	0.08±0.06	0.11±0.10	0.09±0.03	0.15±0.09	0.10±0.05
TSM/POC	10.99±3.13	12.22±7.37	7.54±2.66	13.79±9.96	11.59±5.80

PCHO and PP to POC in monsoon and postmonsoon reflect the increase in phytoplankton production.

The uniform values of PL/POC seem to prevail during all seasons and probably have some relation with the petroleum hydrocarbon fractions in the water column. Dissolved petroleum hydrocarbon values reported for Bombay High region¹⁷ in January, 1985 ranged from 6.2 to 30.8 $\mu\text{g l}^{-1}$ in surface waters with a decreasing trend with the depth. The petroleum hydrocarbons in the zooplankton samples near Bombay High have been reported to range from 10 to 35.6 $\mu\text{g gm}^{-1}$ (mean 23.3 $\mu\text{g gm}^{-1}$ by dry weight). These values were much lower than in some of the regions in the Arabian Sea especially the harbours where shipping and fishing activities were high.

The above observations suggest that the concentration of petroleum hydrocarbons in the water column or zooplankton may not directly effect the occurrence of lipid content in the particulate material. However, the zooplakton faecal pellets are responsible to carry sufficient amount of petroleum hydrocarbons in particulate form¹⁸⁻²⁰.

The results suggest that anthropogenic sources significantly affected the composition of particulate fractions. Uniform composition of PL during all seasons suggests prevalence of petroleum hydrocarbons in the particulate fractions, derived from oil drilling activities.

Homogeneous ratios of particulate fraction to POC in the vertical water column indicate that particulate matter is refractory and buoyant and remained in suspension continuously due to prominence of mixing process penetrating up to bottom layer.

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References

- 1 Bhosle N B, Dhople V M & Wagh A B, *Proc Indian Acad Sci*, 97 (1988) 35.
- 2 Bhosle N B, Nandakumar K & Venkat K, *Indian J Mar Sci*, 18 (1989) 71.
- 3 Nandakumar K, Bhosle N B & Wagh A B, *Indian J Mar Sci*, 16 (1987) 240.
- 4 Bhosle N B, Sawant S S, Prabha D S & Wagh A B, *Mar Ecol - Prog Ser*, 57 (1989) 225.
- 5 Parsons T R, Maita Y & Lalli C M, *A manual of chemical and biological methods* (Pergamon Press, New York) 1984.
- 6 Hitchcock G L, *Deep-Sea Res*, 24 (1977) 83.
- 7 Lowry O H, Rosenbrough N J, Farr A L & Randall R J, *J Biol Chem*, 193 (1951) 265.
- 8 Dortch Q, Clayton J R, Thoresen Jr S S & Ahmed S I, *Mar Biol*, 81 (1984) 237.
- 9 Cushing D, in *The biology of Indian Ocean : Ecological studies*, edited by B Zeitzschel, (Chapman & Hall, London) 1973, 455.

- 10 Shetye R S, *J Mar Res*, 44 (1986) 521.
- 11 Sarma Y B, Sarma M S S & Gangadhara Rao L V, *Oceanologica Acta*, 16 (1993) 45.
- 12 Shetye R S, Shenoi S S C, Anthony M K & Krishnakumar V, *Proc Indian Acad Sci*, 94 (1985) 129.
- 13 Redfield A C, Ketchum B H & Richards F A, in *The Sea : The influence of organisms on the composition of seawater*, edited by M N Hill (Interscience Publ., London) 1963, 26.
- 14 Nandakumar K, Bhosle N B & Wagh A B, *Indian J Mar Sci*, 17 (1988) 238.
- 15 Liebezeit G, *Polar Biol*, 2 (1984) 225.
- 16 Liebezeit G & Bolter M, *Mar Chem*, 35 (1991) 389.
- 17 Fondekar S P, *Studies on petroleum hydrocarbons in the marine environment around India*, Ph.D. thesis, University of Bombay, India, 1987
- 18 Conover R J, *J Fish Res Bd Can*, 28 (1971) 1327.
- 19 Parker C A, *AML Rep B*, (1970) 198.
- 20 Parker C A, in *Water Pollution by Oil : The effect of some chemical and biological factors on the degrading of crude oil at sea*, edited by P Hepple, (Institute of Petroleum, London) 1971, 237.