

A first report on a bloom of the marine prymnesiophycean, *Phaeocystis globosa* from the Arabian Sea

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Received 20 July 1998; revised 30 June 1999; accepted 20 August 1999

Abstract – A thick bloom of the marine prymnesiophycean, *Phaeocystis globosa* was observed in the central Arabian Sea during the summer monsoon period (July–August, 1996). The cells were mostly in colonial form, embedded in gelatinous matrices. The cell diameter was approximately 7 μm and showed a distinct double feature form. The intensity of the bloom was as high as 3750×10^6 cells m^{-2} and the carbon content ranged between 33 and 550 $\mu\text{g L}^{-1}$. Almost 90 % of the phytoplankton population was composed of *P. globosa* in the bloom area. Other common forms were chain-forming diatoms like *Rhizosolenia* spp., *Nitzschia* spp. and *Chaetoceros* spp. The photosynthetic pigment chlorophyll *a*, however did not show any concomitant rise with the bloom intensity probably because the bloom was sampled during a senescent phase. The carbon chlorophyll ratio varied between 112 and 810. This is the first report on the occurrence of *Phaeocystis* from the Arabian Sea. It seems pertinent to ask whether this is a result of the genus being introduced and adapted to new environments due to human influence and whether it will influence food chains in the future. © 2000 Ifremer/CNRS/IRD/Éditions scientifiques et médicales Elsevier SAS

Prymnesiophyceae / *Phaeocystis* / bloom / Arabian Sea

Résumé – Premières observations de la prymnésiofycée marine *Phaeocystis globosa* en mer d'Arabie. Une floraison importante de la prymnésiofycée marine *Phaeocystis globosa* est observée au centre de la mer d'Arabie pendant la mousson d'été, en juillet–août 1996. Les cellules forment en général une colonie incluse dans une gangue gélatineuse. D'un diamètre d'environ 7 μm , les cellules ont une forme caractéristique double. L'intensité de la floraison est de $3\,750 \times 10^6$ cellules par m^2 , avec une teneur en carbone comprise entre 33 et 550 $\mu\text{g L}^{-1}$. La population phytoplanctonique est composée, pour près de 90 % de *P. globosa*; les autres formes communes sont des chaînes de diatomées telles que *Rhizosolenia* spp., *Nitzschia* spp. et *Chaetoceros* spp. La teneur en chlorophylle *a* ne présente cependant pas d'augmentation concomitante à la poussée de la floraison, probablement parce que celle-ci a été échantillonnée dans une phase de sénescence. Le rapport chlorophylle/carbone varie entre 112 et 810. Cette première observation de *Phaeocystis* en mer d'Arabie pose des questions: provient-elle d'un genre introduit par l'homme et qui se serait adapté à de nouveaux environnements? Quel sera son effet éventuel sur les chaînes alimentaires? © 2000 Ifremer/CNRS/IRD/Éditions scientifiques et médicales Elsevier SAS

prymnesiophycée / *Phaeocystis* / floraison / mer d'Arabie

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1. INTRODUCTION

The colony forming prymnesiophyte, *Phaeocystis*, is an important component of phytoplankton community in marine ecosystems. It occurs worldwide, both in temperate [10] and cold polar waters [12, 22, 40] with occasional references to warmer seas [1]. *Phaeocystis* is one of the few marine phytoplankton species often found in gelatinous colonial aggregation of non-motile cells, containing hundreds to thousands of cells in colonies, which may exceed 10 mm in diameter [13, 18]. Large blooms of colonial *Phaeocystis* have been documented for over 100 years [14] from the marine environment.

While some controversy exists on the taxonomical identity of various *Phaeocystis* species [25, 37], the most important are *P. pouchetii*, dominant in the northern boreal and polar waters, *P. antarctica*, found in the Southern Ocean and *P. globosa*, a warm water counterpart, found in temperate and at times in tropical waters. The blooming of this prymnesiophyte is found to be associated with the nutrient enrichment often as a result of anthropogenic inputs into the water column [38] and therefore, their occurrence is most common in coastal waters. However, it rarely blooms in the open ocean as well [31].

The Arabian Sea is part of the Indian Ocean and is a warm tropical basin. It is land-locked on three sides, bordered by the African continent to the west, the Indian subcontinent to the east and Asia to the north. To the west, the Red Sea and Arabian Gulf open into it. The main characteristics of the area are general high salinity (ca. 36) and seasonal reversals in circulation generated by the monsoons. During southwest (summer: June to October) monsoon, circulation is clockwise and it reverses during northeast monsoon (winter: November to May). These seasonal changes profoundly influence the physics, chemistry and biology of the area [20, 41].

Phytoplankton in the Arabian Sea is generally dominated by diatoms [30] and their blooms are a common feature [27]. These reports are mainly on diatoms like *Fragilaria oceanica*, *Coscinodiscus* spp., *Chaetoceros* spp., *Leptocylindrus* spp., *Navicula* spp., *Nitzschia* spp., *Pleurosigma* spp., *Rhizosolenia* spp., and *Skeletonema* spp. Blooms of the dinoflagellate *Noctiluca* and the blue green alga *Trichodesmium erythraeum* are also regular [6]. However, interestingly, there is no record so far on the presence/domi-

nance of *Phaeocystis* in the Arabian Sea. The only record of this genus from this region is from the coastal waters of the Arabian Gulf [1].

Our observations on *Phaeocystis globosa*, apart from being the first report from the Arabian Sea, is all the more interesting since the bloom occurred in the open ocean waters.

2. MATERIAL AND METHODS

The *Phaeocystis* bloom was observed during the 115th cruise of O.R.V. *Sagar Kanya*, during the summer monsoon period (July–August, 1996). The stations were located at 2° intervals along the 64° E between 13–19° N in the open waters. At each station, water samples were collected from eight depths (0, 10, 20, 40, 60, 80, 100 and 120 m) using GO-Flo samplers fitted on a CTD rosette, attached to a plastic-coated winch wire. 250 mL of the water samples were immediately fixed in 1 % Lugol's Iodine and preserved by adding a few drops of buffered formaldehyde solution. The preserved samples were stored at a low temperature until enumeration, i.e. within a period of one month.

Identification of *Phaeocystis* to species level as *P. globosa* was independently confirmed from samples sent to the Alfred–Wegener Institute, Germany. The algal cells were concentrated following settling and siphoning procedure (through 20 µm mesh) to obtain a 20 mL concentrate. 1 mL of this concentrate was then mounted on a Sedgewick-Rafter counting chamber for qualitative and quantitative analysis of phytoplankton. The analysis was done in triplicates under a Leica Inverted microscope (100 × and 400 × magnifications). Size analysis of cells and colonies was done using an ocular-micrometer. *Phaeocystis* cell carbon was a value of estimated from cell numbers using 8.6 pg cell⁻¹ [11]. Chlorophyll *a* was determined by filtering one litre of water sample through GF/F Whatman filter. The pigments were extracted using 10 mL of 90 % acetone. The fluorescence was then measured in a Turner Design Fluorometer before and after acidification with two drops of 1.2N HCl to the pigment extracts [35].

Particulate organic carbon (POC) was measured by filtering one litre of water sample onto a precom-

busted 25 mm GF/F filter (nominal pore size 0.7 μm). These filters were wrapped in precombusted aluminium foil and stored frozen ($-20\text{ }^{\circ}\text{C}$) before analysis [35]. Later, these filters were dried overnight at $60\text{ }^{\circ}\text{C}$. The dried filters were exposed to fuming HCl to remove inorganic carbonate. The filters dried again at $60\text{ }^{\circ}\text{C}$ were analysed for POC on a Perkin Elmer 2400 CHN analyser. Standards and blanks were run before analysis of the samples. The POC carbon was used in estimating C:Chl *a* ratios.

3. RESULTS AND DISCUSSION

The thick bloom of *Phaeocystis globosa* was observed continuously from 14° – 18° N (ca. 240 nautical miles)

and was analysed at 15° and 17° N. The water was green in colour due to the bloom. The cells were mostly in the form of colonies and were embedded in a gelatinous matrix, secreted by the cells themselves. Although larger colonies lost their shape due to preservation, the smaller colonies showed distinct spherical shape and some of them were found attached to the larger colony matrix (*figure 1*). The cells were generally round and had typical double feature form with a size of approximately $7\text{ }\mu\text{m}$ in diameter. The number of cells forming colonies had a very wide range. The minimum number of cells per colony was 9 whereas the largest colony had as many as 2700 cells per colony in the matrix. However, this is much less than the number of cells (10000 cells per colony) previously reported from the coastal waters of the North Sea [28].

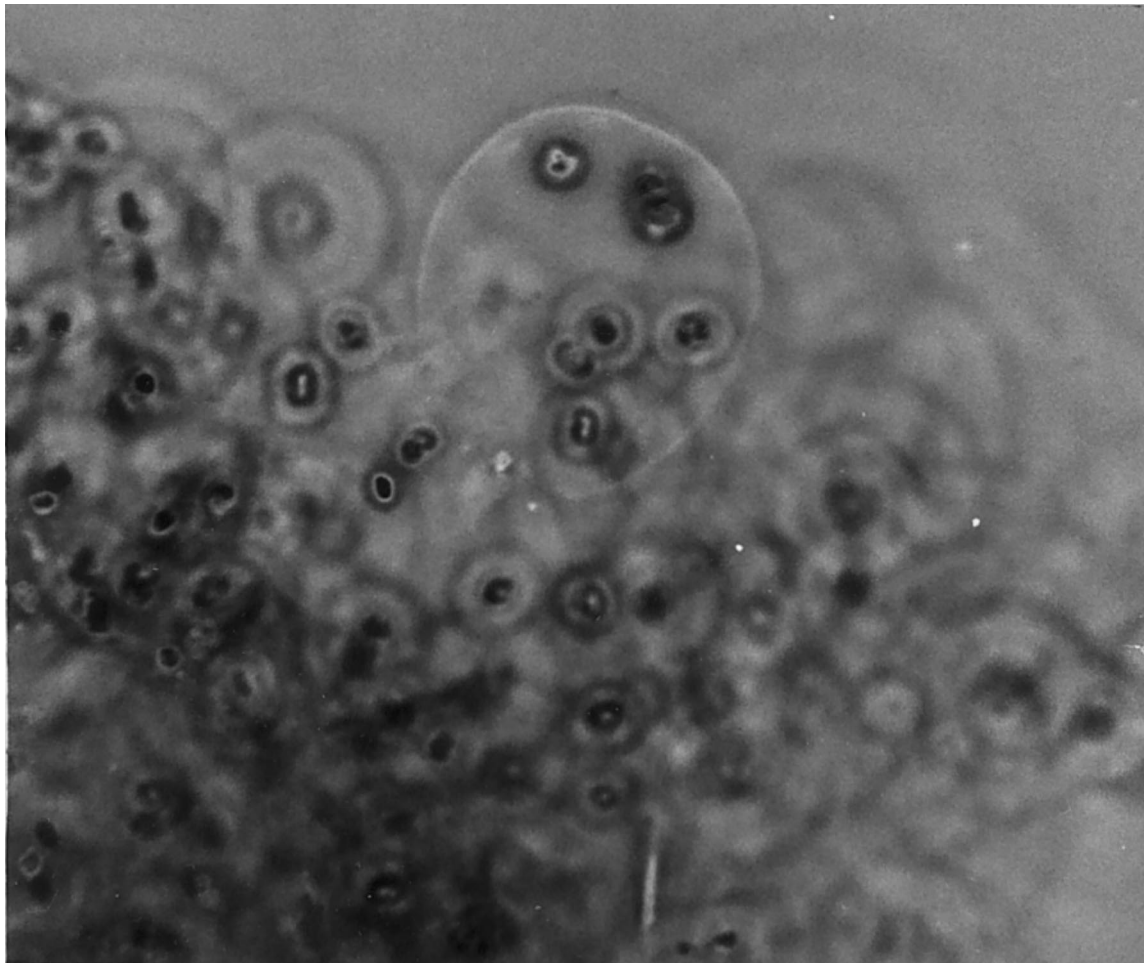


Figure 1. Photograph showing spherical *Phaeocystis globosa* colonies attached to larger colony.

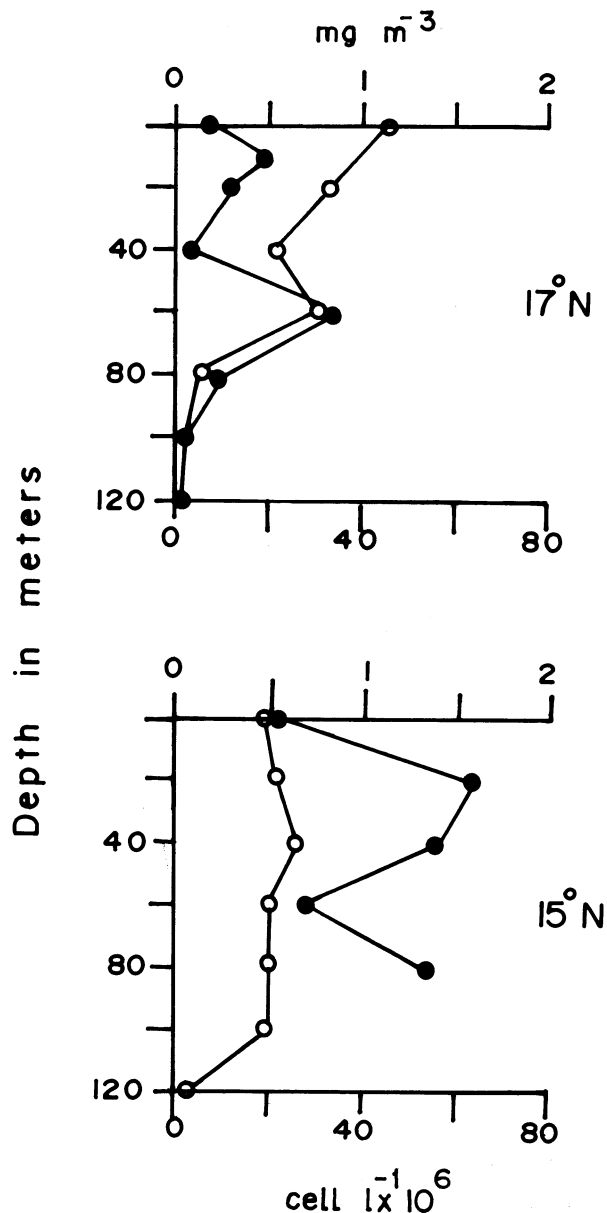


Figure 2. Vertical profiles of chlorophyll *a* distribution (mg m^{-3} , open circles) and *Phaeocystis* counts ($\text{cells L}^{-1} \times 10^6$, closed circles) at 17°N and 15°N stations in the upper 120 m.

At 15°N *Phaeocystis* cell counts ranged from $23 \times 10^6 \text{ L}^{-1}$ in the upper 80 m and this was between $2.2 \times 10^6 \text{ L}^{-1}$ and $35 \times 10^6 \text{ L}^{-1}$ at 17°N (figure 2). This is comparable to the cell numbers ($22 \times 10^6 \text{ cells L}^{-1}$) observed along the Dutch coast of the North Sea [38]. The integrated cell counts were 3750×10^6 and $1410 \times 10^6 \text{ cells m}^{-2}$ respectively. Thus, the

bloom density was higher at 15°N (almost three-fold) as compared to 17°N . The colonies were randomly distributed in the water column with maximum densities occurring between 20–80 m depth. The population of *P. globosa* below 80 m depth was almost negligible. Around 99 and 86 % of the total phytoplankton biomass was *Phaeocystis* at 15°N and 17°N respectively. In terms of carbon this was $32\text{--}297$ and $198\text{--}550 \mu\text{g L}^{-1}$ at 15°N and 17°N . Abundances of other phytoplankton however showed a reverse trend within these latitudes, cell counts were $0.7 \times 10^6 \text{ cells m}^{-2}$ at 17°N and down to $0.5 \times 10^6 \text{ cells m}^{-2}$ at 15°N (table I). However, these were higher compared to a station sampled in the south implicating availability of higher nutrients supply at northern locations.

Other phytoplankton mainly consisted of species like *Nitzschia longissima*, *N. bilobata*, *N. directa*, *Rhizosolenia hebetata*, *R. stolterfothii*, *R. styliformis*, *R. cylindrus*, *R. alata*, *R. imbricata*, *R. fragillima*, *Chaetoceros didymus*, *C. peruvianus*, *C. borealis*, *C. indicus*, *Coscinodiscus* sp., *Navicula* sp., *Melosira sulcata*, *Cyclotella* sp., *Thalassiothrix frauenfeldii*, *Thalassiosira* sp., *Ditylum* sp., *Pleurosigma* sp., *Guinardia* sp., *Synechra robusta*, *Pyxidicula minuta*, *Bacteriastrum hyalinum*, *Actinopterychus* sp., *Climacodium frauenfeldianum*, *Climacosphenia elongata*, *Planktoniella sol*, *Ceratium furca*, *C. gibberum* and *Gymnodium lunula*. The most abundant forms among these were chain forming diatoms *Rhizosolenia stolterfothii*, *R. styliformis*, *Nitzschia* spp. and *Chaetoceros* spp.

Table I. Counts of phytoplankton (cells L^{-1}) other than that of *Phaeocystis* at stations along 64°E longitude

Depth (m)	13°N	15°N	17°N	19°N
0	600	3 300	12 200	3 900
10	1 400	— ^a	10 700	3 000
20	1 600	5 100	11 800	2 600
40	1 100	6 600	10 100	5 400
60	1 100	3 500	12 600	1 700
80	400	4 900	2 000	100
100	300	1 900	100	—
120	500	100	100	—
Integr. Counts	104 000	474 000	717 000	231 500

^a —, no data.

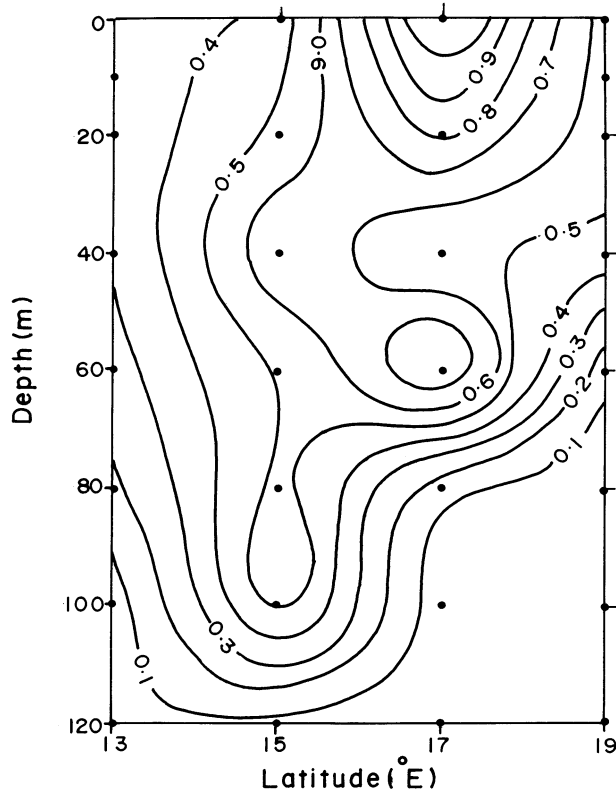


Figure 3. Latitudinal Chlorophyll *a* profile along 64° E.

In the course of this study chlorophyll *a* was generally moderate at all stations (figure 3) although this pigment was expected to show a concomitant increase with the bloom. The chlorophyll *a* values in the upper 120 m of the water column ranged from 0.07 to 0.65 mg m^{-3} at 15° N and from 0.02 to 1.10 mg m^{-3} at 17° N. The column values at the respective stations were 59.4 and 57.6 mg m^{-2} . Chlorophyll *a* values as high as 50 mg m^{-3} associated with *Phaeocystis* blooms has been reported [23]. Nitrate was at undetectable levels in the upper water column (figure 4), whereas phosphate was at moderate levels (0.02 to 0.57 $\mu\text{M L}^{-1}$)

P. globosa cells forms colonies embedded in a mucus matrix made up of polysaccharides. This mucus envelope, besides from mediating the exchange between the external medium and the colonial cells, also forms an energy substrate which could be used for pursuing growth in the absence of light [21]. Prymnesiophyte blooms are often known to co-occur with the chain forming diatoms [7], as we observed. The presence of a few dinoflagellate *Noctiluca* sp. indicated that the

bloom was in a senescent phase (Christian Hamm, pers. comm.).

One interesting feature was the low chlorophyll *a* and high biomass condition during the bloom which ranged from 112 to 810. This is typical of late bloom conditions when nitrogen becomes limiting, as in our study. In a nitrogen-limited medium, it has been shown that the C:Chl *a* ratio can become quite high (up to 620 [39]) so that the absolute biomass can still be high while chlorophyll *a* concentration is low. Growth of *Phaeocystis* is limited either by nitrogen [21] or phosphate [4, 17, 36, 38].

During the summer monsoon extensive upwelling brings up nutrients along the Somalia and Arabian coast through Ekman pumping [33]. In the open ocean, upwelling in northern Arabian Sea occurs north of the Findlater Jet which approximately passes along 15° N at 64° E [24]. This happens as a result of positive wind stress curl north of the jet. The mixed layer depth shoaled from 100 m at 13° N to 45 m at the bloom area (S.P. Kumar, pers. comm.). This open ocean upwelling pumps up nutrients to the upper layers as a result of Ekman suction and has been already demonstrated ([3], see also figure 4). As mentioned earlier, we probably sampled the bloom at a late phase. Thus, the bloom occurred as a result of increase in nutrients, but not because of eutrophication or anthropogenic inputs as commonly observed in European waters [cf. 5, 38].

Studies have shown that *Phaeocystis* is ingested by some zooplankton species [8] but grazing is not very important in controlling the abundances [15]. Usually the isolated cells and the small colonies are used as food by grazers. Lack of efficient grazing on large *Phaeocystis* colonies leads to production of thick foam apart from export to the deep. The aggregates rapidly sink out of the euphotic zone [40] thus contributing to the carbon cycle and particle flux. Transparent Exopolymer Particle concentrations were as high as 102 mg equivalents of alginic acid per litre at 600 m depth in the bloom area [19]. Up to two metres' thickness of slimy foam, resembling egg whites, with a strong smell has been seen deposited on the beaches of Netherlands and Germany [23] causing a hindrance to the recreational activities. We do not yet know if such scenarios are a possibility on the beaches around the Arabian Sea in the future. A more worrying question is whether this newcomer

will affect the food chains. Ephemeral and innocuous as it may seem, *Phaeocystis* bloom is known to increase in density over the years [5] and if it spreads to the coastal eutrophicated waters of India, it may affect the fisheries badly.

Phaeocystis sp. often forms massive blooms in temperate and polar regions and is an important contributor both to global primary productivity and flux of the volatile sulfur compounds from the ocean to the atmosphere. *Phaeocystis* blooms are also thought to have an impact on global climatic changes as it is one of the few phytoplankton genus known to produce dimethyl sulfide, DMS [2, 22]. Although this sulfur compound counteracts the greenhouse effects it may locally contribute to acid rain as the oxidised prod-

ucts of DMS are a major source of marine aerosol particles to the atmosphere [2, 16, 34].

4. CONCLUSIONS

Several questions should be considered. Documentation of phytoplankton species occurring in the Arabian Sea goes back to the 1930s (e.g. [26, 32]). *Phaeocystis* appears to be a new introduction to the Arabian Sea, as has been the case for some zooplankton species elsewhere, through ballast tanks (cf. [9]). We can expect blooms in coastal waters to lead to the formation of foams on the beaches or affect food chains and fisheries in the future. The Arabian Sea is

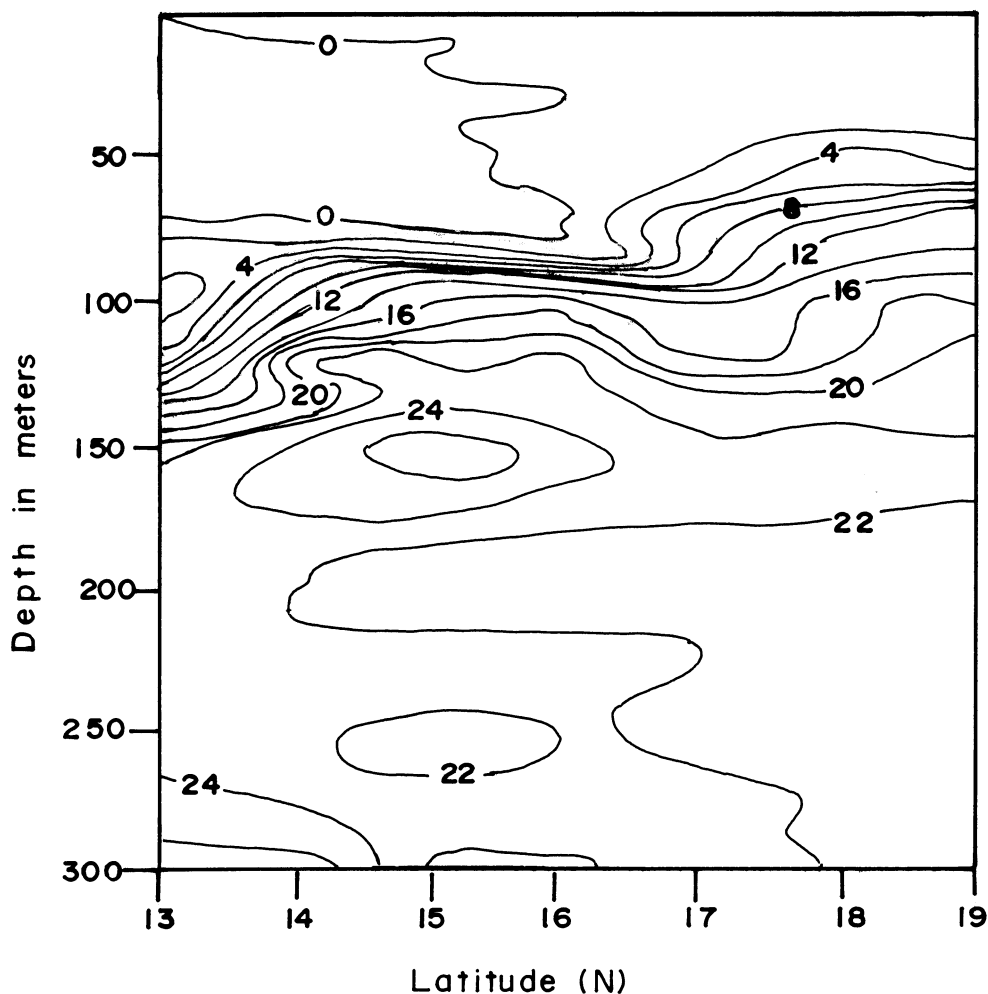


Figure 4. Latitudinal nitrate profile along 64° E.

apparently a source of greenhouse gases [29]; can such blooms change it to a sink through carbon fixation and rapid export of particles?

Acknowledgements

Our sincere thanks are due to Dr Christian Hamm and Prof. Victor Smetacek, Alfred-Wegener Institute, Germany, for identifying the species of *Phaeocystis* and information on *P. globosa*. Authors also thank Dr Lata Raghukumar of NIO, Goa for her help in this research. This study was conducted as part of the JGOFS (India) programme under a grant from the Department of Ocean Development, New Delhi. NIO contribution no: 2659.

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