The September 2004 stench off the southern Malabar coast – A consequence of holococcolithophore bloom

During the third week of September 2004, particularly on 16th and 17th, an unusual and strong stench was reported from the coast at Kollam and Vizhinjam in Kerala[1,2] (Figure 1). Local dailies reported that over 200 children, mostly below 15 years, complained of nausea, chest pain and short periods of breathlessness because of the stench. Many were hospitalized, but were discharged within a couple of hours. A press report stated that the stench was due to dead fish scattered on the beaches and in the water. The report linked the fish death to oxygen depletion and choking of fish gills. Both were reported to be possibly due to proliferation and eventual putrefaction of a fish-toxic alga *Cochlodinium polykreikoides*[2]. Information was put up on the web that the bloom was caused by *Karenia brevis*[3], a toxic dinoflagellate. It was reported that the stench could be felt up to 5 km inland from the coast.

On 20 September 2004, the Government of Kerala requested the National Institute of Oceanography (NIO), Goa to determine the cause of the phenomenon. In response, a team from NIO collected near-shore samples of water on 23 and 26 September off Vizhinjam, Shanghumugham and Kollam (Figure 1). During 3–7 October 2004, *RV Sagar Sukti*, a coastal research vessel of NIO, was used to collect samples in the waters offshore of Vizhinjam, Veli, Kollam in the depth zones of 20–50 m (numbered locations in Figure 1). The water samples collected on 23 and 26 September from the near-shore spots were analysed for various chemical (dissolved oxygen, hydrogen sulphide, nutrients, and salinity) and biological (microbiological, phytoplankton counting and identification) variables. Data from sea-level records at Cochin Port were also examined to learn about the possible evolution of physical conditions before and after the episode described above. In this preliminary report we present our inferences based on analysis of the data.

The most striking finding from the samples collected during 23–26 September 2004, is the high abundance of a holococcolithophorid in the near-shore waters. The observed abundance was in excess of 1,800,000 cells per litre. This number is two to three orders of magnitude larger than the number of cells normally found in these waters. All these cells autofluoresced under epifluorescence (UV) microscope. Under a light microscope, we were able to observe mostly bare (without coccoliths), aflagellar cells of 3–8 μm diameter (Figure 2). Scanning electron microscopy (Figure 3) of the sample showed that the holococcolithophore resembled the genus *Helladosphaera*[4].

Our main inference is that the stench was a consequence of a bloom (i.e. a rapid increase in number) of the holococcolithophore. Such blooms, often referred to as Harmful Algal Blooms (HAB), have been reported elsewhere in coastal waters. There is a general opinion among oceanographers that HABs have become more frequent in recent times. Anomalous blooms of coccolithophorids with maximal cell density in the range of 2.8 to 4.5×10^6 cells ml^{-1}, accounting for greater than 99% of the phytoplankton density and biomass in the Bering Sea, have been reported[5]. Exclusively marine, coccolithophores (Prymnesiophyta) are calcifying autotrophs. The question of potential toxicity of these organisms has rarely been addressed[6]. Reifel *et al.*[7] showed that bloom samples dominated by the coccolithophore, *Pleurochrysis pseudoroscoffensis* Gayral *et* Fresnel, were moderately toxic to experimental animals, implying the presence of toxin in this group of organisms. They further argued that there was a need to elucidate the nature and mode of action of the potential toxic substance(s).

HABs, including those caused by coccolithophorids, arise when environmental conditions are 'right' (such as appropriate levels of nutrient, light, suitable temperature) for a particular alga. Following the bloom, the right conditions disappear (often because the nutrients are assimilated into their cell masses), and the cells begin to decay. Many autotrophs, in particular most HAB-forming phytoplankton, form cysts that fall to the bottom and lie in dormancy until the right conditions arise again. It appears that the HAB off the southern coast of Kerala this year peaked about the time the stench set in. The coccolithophorid HAB appears to have clogged the fish gills, leading to mass mortality as also the stench. After the HAB peaked, the conditions turned unfavourable, and apparently there was a reduction in its abundance. Thus, within a week from when the stench was reported, individual cells (Figures 2 and 3) varying in size from 2 to 8 μm were still the most abundant in comparison to other identifiable phytoplankton (Table 1).

We suggest that following growth of this coccolithophore far above the normal conditions (under normal conditions concentration of most phytoplankton cells is generally in the range of 10^3–10^4 cells l^{-1}), its death and decay must have consumed oxygen in the water column leading to hypoxic conditions. Apparently, cell numbers during the peak bloom periods must have been much higher. Although newspaper reports[2,3] suggest identified organisms both toxic to fish, we infer that the predominant coccolithophorid cells in all water samples on 23 and 26 September might have been connected with the events ten days earlier. The very low to hypoxic level of dissolved oxygen concentrations as a consequence of excessive organic loading due to crash of the bloom and the high cell densities of this and/or other autotrophs together must have caused an add-on burden on the marine fauna in the region, causing mobile forms to migrate

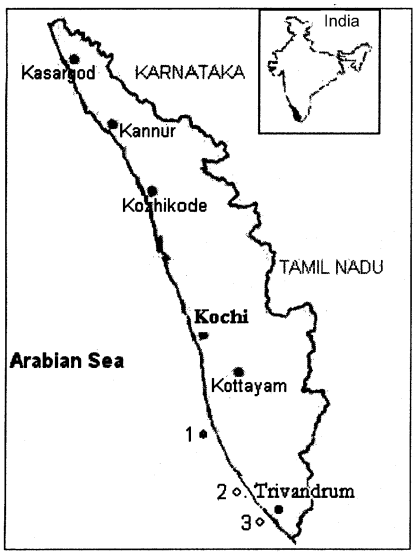

Figure 1. Sampling locations. Both near-shore and offshore samples were collected off Kollam (1), Shanghumugham/Veli (2), and Vizhinjam (3) during September–October, 2004. Offshore samples were collected at locations where depth was 20, 30 and 50 m respectively.

Table 1. Phytoplankton cell counts and identification carried out following Tomas[14] in various near shore and offshore surface samples collected from southern Malabar coast

Sampling spot	Counts of coccolithophore species $\times 10^6$ l^{-1}	Other identifiable phytoplankton cells l^{-1}	Total phytoplankton cells ($\times 10^6$ l^{-1})	*Order of abundance of identifiable species
Cell counts as of 26 September 2004				
Kollam 1	10.11	Nil	10.11	
Kollam 2	57.69	15850	57.70	9, 7
Kollam 3	15.15	1600	15.15	2
Shanghumugham	1.86	500	1.86	10, 3, 4, 1, 8, 11
Vizhinjam 1	3.50	1020	3.50	10, 4, 5
Vizhinjam 2	17.46	1188	17.46	10, 9, 6
Vizhinjam 3	11.42	Nil	11.42	
Vizhinjam 4	11.84	172	11.84	10
Cell counts in surface-water samples at 20 m depth–contour collected on 4 October				
Kollam	0.19	5952	0.20	N, Q, K, O, M, H, B, P, J, A, I, F, D, E, C, L, G,
Veli	0.08	240	0.08	K, R
Vizhinjam	0.17	64	0.17	B

*Identifiable phytoplankton species were: 1, *Chaetoceros coarctus*; 2, *C. curvisetus*; 3, *Coscinodiscus radiatus*; 4, *Coscinodiscus* sp.; 5, *Ditylum brightwelli*; 6, *Keratella* sp.; 7, *Navicula distans*; 8, *Planktoniella sol*; 9, *Thallasionema nitzschiodes*; 10, *Thallasiosira* sp. and 11, *Triceratium weissei*. In October samples: A, *Biddulphia* sp.; B, *Chaetoceros* sp.; C, *C. radiatus*; D, *N. distans*; E, *Nitzschia* sp.; F, *Pseudonitzschia* sp.; G, *Rhizosolenia setigera*; H, *R. styliformis*; I, *T. nitzschiodes*; J, *Thallasiosira* sp.; K, *Ceratium furca*; L, *Gonyualax scrippsae*; M, *Oxytosum* sp.; N, *Prorocentrum arcuatum*; O, *Prorocentrum micans*; P, *Protoperidinium oceanicum*; Q, Unidentified (other than bloom species); R, *Coscinodiscus* sp.

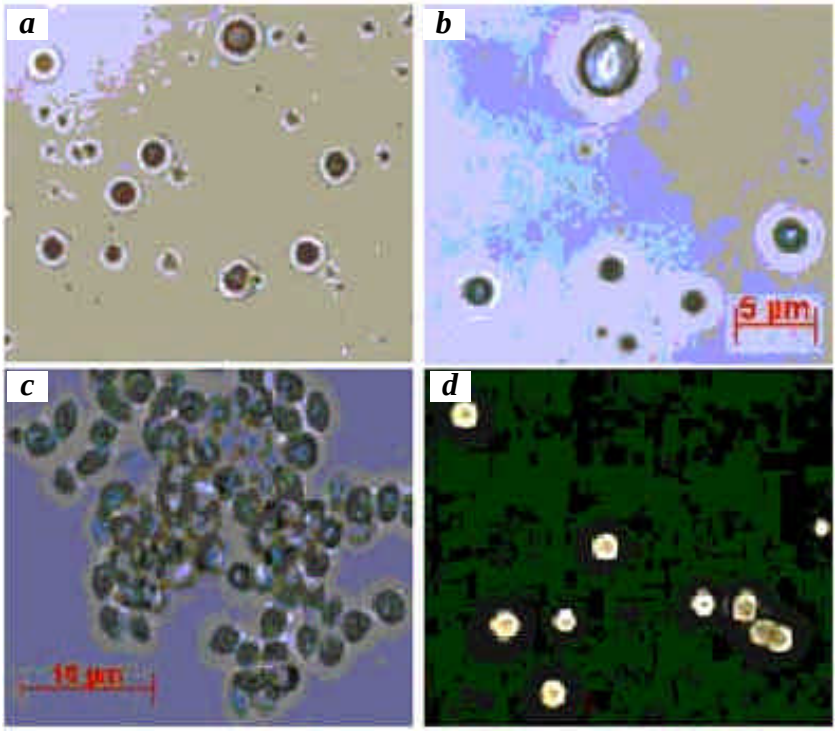

Figure 2. Photomicrographs of unidentified holococcolithophore. ***a***, ***b***, Light microscope pictures. ***c***, Phase contrast, and ***d***, Dark field (all at 100 × magnification).

away from their normal living zones. Bacterial decomposition would continue even in the absence or under very low oxygen concentrations. Presence of substantially high number of anaerobic sulphate-reducing bacteria in the near-shore water samples taken on 26 September supports this possibility (Table 2). In addition, the marked under-saturation of surface water as well as the high nitrate values indicate oxygen-poor (peculiarly without elevated BOD), nutrient-rich water still close to the surface.

The HAB caused by this coccolithophore off the coast of Kerala and the asso-

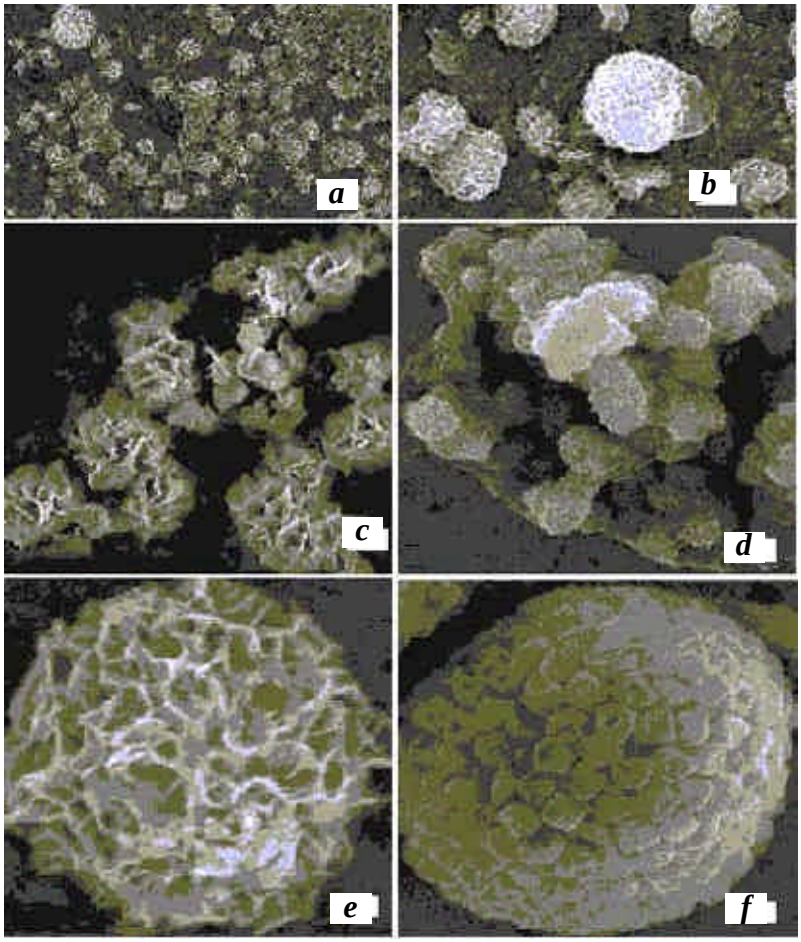

Figure 3 ***a–f.*** Scanning electron photomicrographs of bloom samples depicting anomalous abundance (***a***, Magnification: 1000 ×; photo width, ca 60 µm; ***b***, 3300 ×; 20 µm; ***c***, 1300 ×; 50 µm; ***d***, 2500 ×; 52.8 µm) of probably a species of *Helladosphaera*, a holococcolithophore (***e***, 12000 ×; ca 8 µm). The other co-occurring coccolithophore belonging to *Algirosphaera* (***f***, 9000 ×; 9 µm) was quite rare.

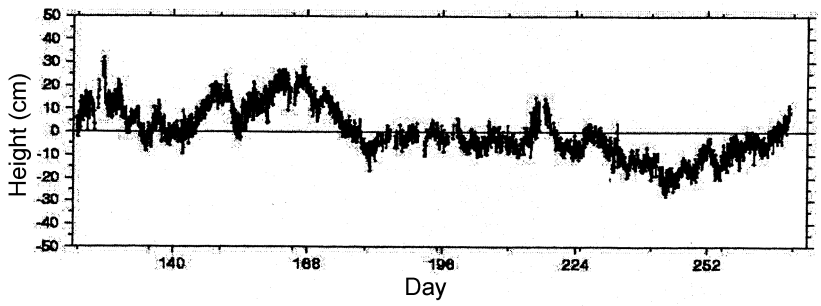

Figure 4. De-tided sea level at Cochin Harbour from 1 May 2004 (Day of Year 121) to 27 September 2004 (Day of Year 270). The minimal level was reached on Day of Year 247 (6 September 2004).

ciated oxygen depletion disappeared by the first week of October. There was no anoxic/hypoxic condition either in the nearshore samples nor in the 20–50 m depth zone in any of the 48 water samples analysed on-board *RV Sagar Sukti* between 3 and 7 October 2004. Although ammonia levels were slightly elevated in the near-shore samples collected on 23 September, hydrogen sulphide was totally untraceable in any of the near-shore or offshore samples. Increase in ammonia and hydrogen sulphide often occurs in hypoxic/anoxic conditions due to bacterial intervention.

There are many reported fish-kills and a few human fatalities in particular, due to toxic-blooms worldwide[8,9], including those caused by coccolithophores[7]. Although this is first case of stench, fish-kills along the Kerala coast due to dinoflagellate blooms have been reported previously[10]. This is probably the first time that coccolithophore are observed in such high numbers in the coastal waters of India. We believe that, it was responsible for the stench event. It is pertinent to mention here that following an anomalous bloom in the Bering Sea during 1997, Sukhanova *et al.*[5] have consistently observed higher densities of coccoliths in the following years. Determining what the 'right' conditions are for this coccolithophore to

Table 2. Concentration/abundance of various chemical and biological parameters in the near-shore surface samples collected at different locations along southern Malabar coast on 23 and 26 September 2004. Standard chemical[15] and microbiological[16] methods were followed for analysis

Parameter	Sampling spot		
	Kollam	Shanghumugham	Vizhinjam
Chemical			
NO_3 (μmol l^{-1})	9.88	7.43	3.20
NO_2 (μmol l^{-1})	0.50	1.30	1.10
PO_4 (μmol l^{-1})	1.15	1.05	1.45
SiO_4 (μmol l^{-1})	8.40	7.60	8.80
NH_4 (μmol l^{-1})	7.30	8.85	11.15
Dissolved oxygen (ml l^{-1})			
Near-shore	4.40	6.02	4.26
Offshore (20 m contour)	2.90–3.40	2.80–3.60	2.40–3.80
Pecentage saturation*	64–75	62–80	51–84
Salinity		36.54	36.41
	36.12		
pH	7.60	7.90	7.66
BOD (ml l^{-1})	1.91	2.61	0.93
Microbiological			
Total bacterial [AODC] count (no. × 10^{10} l^{-1})	3.50 ± 0.21	4.53 ± 0.46	4.99 ± 0.71
Plate count (no. × 10^3 l^{-1})	3300	4800	3500
Sulphate-reducing bacteria (no. × 10^3 l^{-1})	77.20	–	219.00

*Oxygen saturation calculated only for offshore samples (20 m contour sampled in October) as both salinity and temperature data were available.

become so proliferative, is of immense research interest. In addition, this group is known to shed its coccoliths during intense bloom phase[11].

Occurrence of this phenomenon in September does suggest that physical processes might have helped this autotroph to bloom. De-tided sea level (i.e. sea level from which tidal variation has been removed) along the coast of Kerala reaches its minimal value around September[12,13]. This implies that the thermocline is shallow. Thus, the region becomes vulnerable to events (such as mixing by bursts of wind) that can bring high quantities of nutrients to the surface. Indeed, the minimum de-tided sea level was recorded by the tide-gauge in the Cochin port area on 6 September (Day of Year 247, Figure 4), that is roughly ten days before the stench was reported. The autotroph may have found the right conditions with respect to nutrients at this time and bloomed, thus triggering events that led to the stench. Further research is needed to check the validity of this argument. However, it does open the possibility that regular monitoring of the physical, chemical and biological environment along the Indian coast can help develop forecasting or warning systems on HABs and consequent fish mortality (and related stench) along the coast. In addition, such systems will also enable understanding of the global changes and regime shifts taking place in the seas around us. A national collaborative programme ought to be in place involving leading institutions carrying out fisheries-related research to investigate plankton biodiversity, bio-organic chemistry, physical oceanography, remote sensing and biogeochemistry related to HABs.

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N. RAMAIAH[1,*]
JANE T. PAUL[1]
VERONICA FERNANDES[1]
T. RAVEENDRAN[2]
O. RAVEENDRAN[2]
D. SUNDAR[1]
C. REVICHANDRAN[2]
D. M. SHENOY[1]
G. MANGESH[1]
SIBY KURIAN[1]
V. J. GERSON[2]
D. T. SHOJI[2]
N. V. MADHU[2]
S. SREE KUMAR[1]
P. A. LOKABHARATHI[1]
S. R. SHETYE[1]

[1]*National Institute of Oceanography, Dona Paula, Goa 403 004, India*
[2]*National Institute of Oceanography, Regional Centre, Dr Salim Ali Road, P. B. 1616, Kochi 682 014, India*
**For correspondence.*
e-mail: ramaiah@darya.nio.org