sample at an industrial location in Delhi[1], high lead concentration of 3670 μg/gm was reported. The high prevalence of lead – almost five fold of the link highway – in the market place RDS could be attributed to additional sources of lead other than vehicular contribution.

The levels of Zn at NH-52 (1381 ± 29.3 μg/g) and link highway (994.1 ± 35.8 μg/g) were about 1000 fold higher compared to NH-37 (1.4 ± 0.35 μg/g). An unusually high concentration of Zn at NH-52 and link highway indicates additional sources of Zn besides vehicular contribution. At these two sampling locations motor vehicle and machinery repair work stations are present in close vicinity. The levels of Ni also showed intersite variations, though not as pronounced as in the case of Pb and Zn. An industrial site in Delhi[1] reported a high concentration (1000 μg/g) of Ni. However, our results are comparable with those of a rural traffic location (105 μg/g) and are much on the lower side than the industrial (365 μg/g) and heavy traffic (315 μg/g) location in the same study.

The region is fast moving towards economic development yet a systematic study of environmental status of the region is lacking. Human populations all through the stretch of NH-52, NH-37 and the link highway are at risk of pollution exposure contributed by vehicular traffic. Rich biodiversity adjoining these highways could also be exposed to metal pollution. As RDS is an indicator of the health of an environment, an extensive study on RDS in the region may be carried out to create a large database, which could be of use to understand the possible source of the pollutants and the extent of risk posed. Also, a study on chemical speciation of toxic metals would examine their bio-availability to cause toxic effects.

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Analysis of phytoplankton composition from southern Malabar Coast during the 2005 monsoon as a follow-up of September 2004 stench event

One of the main objectives of this study was to follow-up and deserve whether the holococcolithophore[1] that was predominant in all the samples from the southern Malabar coast during September–October 2004, was prevalent during the monsoon months of 2005. A brief background to this is as follows. During the third week of September 2004, particularly on 16 and 17, an unusual and strong stench was reported from the coast at Kollam and Vizhinjam, Kerala[2,3]. It was reported that the stench could be felt up to 5 km inland from the coast and over 200, mostly children below 15 years complained of nausea, chest pain and short periods of breathlessness[2]. Many were hospitalized, but were discharged within a couple of hours. A press report also stated that the stench was due to dead fish scattered on the beaches and in the water[3]. The report linked the fish death to oxygen depletion and choking of fish gills. Both were reported to be due to proliferation and eventual putrefaction of *Cochlodinium polykrikoides*[2]. Results reported here are from a follow-up study undertaken to decipher whether such organisms are common among the phytoplankton assemblages in the southern Malabar coastal waters. We also recorded their monthly compositional changes in particular, during nutrient enrichment as a consequence of upwelling. Sampling was carried out during the monsoon months of June–September 2005 along the same stretch that was sampled[1] during September–October 2004.

Near-shore water samples were collected once a month mostly during the last week during June–September 2005 from three locations, viz. off Kollam (Sankaccheri), Shankhamughom and off Vizhinjam (Figure 1). They were analysed for various chemical (dissolved oxygen, nitrate-N, nitrite-N, ammonia, phosphate-P and silicate-S) and biological (chlorophyll *a*, cell counts and identification of phytoplankton, total viable counts of bacteria) parameters following standard methods[4].

Monthly variations in different chemical and biological parameters are given in Figure 2. Dissolved oxygen varied from 2.41 to 4.93 ml/l (≡108 to 220 μM) and the location off Vizhinjam had the lowest concentration of oxygen. Nitrate was usually more than 5 μM, with little or insignificant contribution from nitrite (<0.8 μM). Concentration of ammonia was highest at Shankhamughom during July 2005. Silicates were usually more than 2 μM concentration at all the locations. Concentration of silicate was usually higher off Kollam, in particular during June and July, and off Vizhinjam in September. Chlorophyll *a* ranged between 2.27 and 7.74 μg/l. Incidentally, higher concentrations were seen mostly during July at all the locations. The total microphytoplankton cell counts ranged from 9 to 191 ($\times 10^3$)/l.

The predominant groups of phytoplankton contributing to more than 5% of the total at different sampling spots are listed in Table 1. For example, *Asterionella japonica* and *Thalassionema nitzschoides* were the most predominant in the samples collected during June off Kollam (open seaside). In general, August or September had higher number of phytoplankton species than the preceding months. Although over 78 species of phytoplankton were identified from the samples collected in this study, most of them were not abundant. This means that they contributed to less than 5% of total phytoplankton count. There were location-wise differences in the phytoplankton assemblages, and no single species was predominant in the whole sampling stretch.

The highest number of species was observed during August 2005 at Kollam 1 (open coast). Similarly, in another location nearby off Kollam 2 (protected site inside fishing harbour), only a few species predominated during June, whereas there were more number of species during August. Holococcolithophorids were not

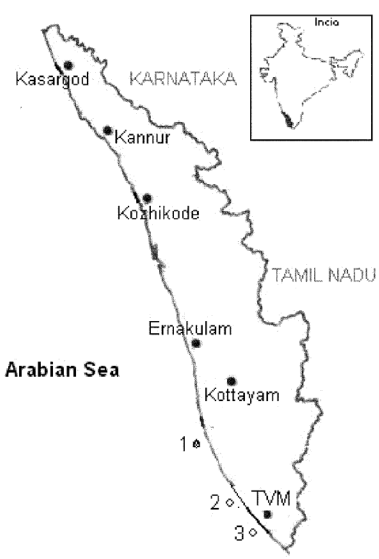

Figure 1. Sampling locations. Near-shore samples were collected off Kollam (1), Shankhamughom (2) and Vizhinjam (3) during June–September 2005. Two sites were sampled off Kollam, one in open coast and the other inside the fishing harbour.

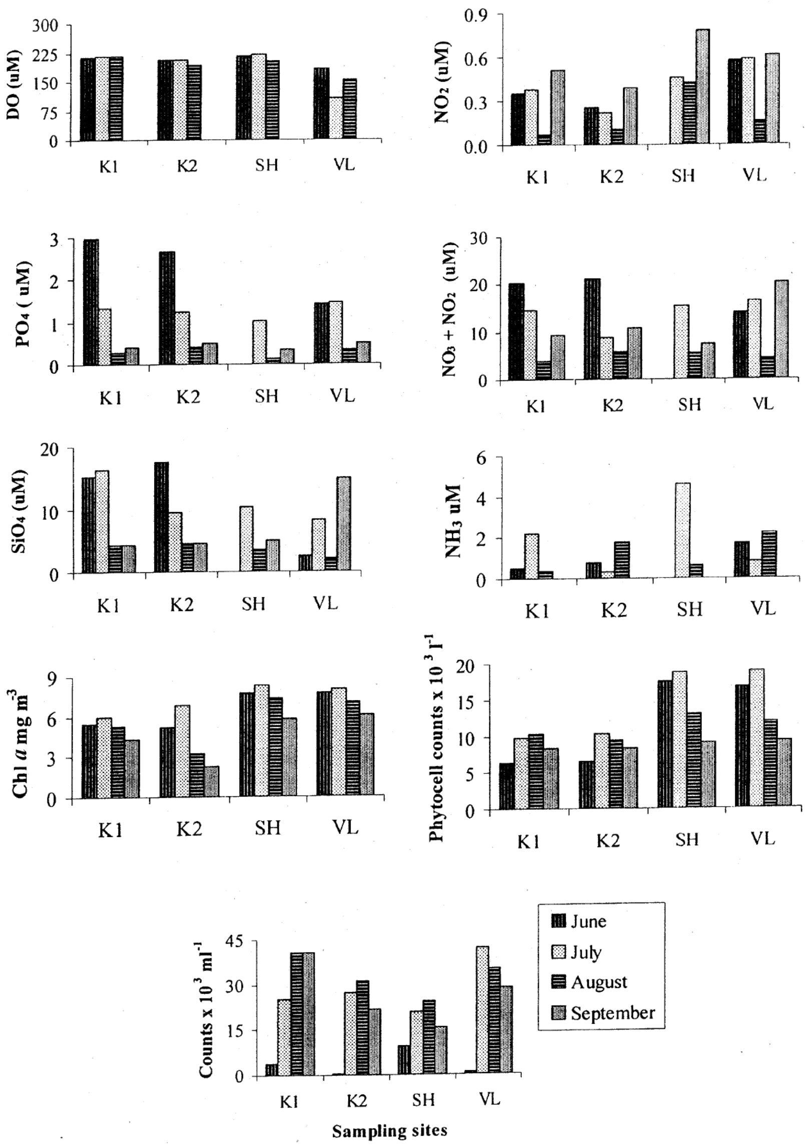

Figure 2. Variations in different chemical and biological parameters monitored along southern Malabar coast during June–September 2005. Sampling sites K1 and K2 are near Kollam (Sankacchheri), SH off Shankhamughom and VH, off Vizhinjam. See Figure 1 for site locations. Dissolved oxygen was fixed immediately after collection and measured in the laboratory within 48 h of fixing by following the Winkler procedure. Sub-samples for nutrients were transported on ice in an icebox to the NIO Regional Centre, Kochi. Later, they were deep-frozen, transported on ice to NIO and analysed in an auto-analyzer (SKALAR, The Netherlands) following standard procedures described in Grasshoff *et al.*[4]. All chemical analyses were completed within four days of collection. Chlorophyll *a* was measured fluorometrically (Turner Designs, USA) two 1L replicates from each location.

Table 1. Microphytoplankton species composition (% of total) in the near-shore samples collected from southern Malabar coast during the 2005 monsoon months#. Minor species contributing <5% of total are listed in the footnote

	Sampling months, 2005			
Phytoplankton species	June	July	August	September
Kollam (open coast)				
Asterionella japonica	40	–	–	–
Coscinodiscus radiatus	–	6.98	5.90	–
Guinardia striata	–	20.93	–	–
Leptocylindrus danicus	–	–	8.84	6.29
Melosira nummuloides	–	–	14.74	–
Navicula transitrans	–	–	9.30	–
Pseudonitzschia turgidula	–	–	–	8.81
Rhizosolenia curvata	–	–	–	5.03
Thalassionema nitzschoides	30	–	9.30	16.66
Coscinodiscus spp.	10	16.20	8.84	–
Fragillaria spp.	–	–	–	11.32
Licmophora spp.	–	–	–	5.03
Melosira spp.	–	9.30	–	–
Navicula spp.	–	–	8.84	6.29
Pleurosigma spp.	–	11.63	–	–
Pseudonitzschia spp.	–	5.90	–	–
Thalassiothrix spp.	–	–	14.74	–
Unidentified spp.	10	16.20	8.84	–
Kollam Fishing Harbour				
A. japonica	–	8.22	–	–
C. curvisetus	–	–	–	6.11
C. decipiens	–	–	–	6.87
C. didymus	33.33	–	–	–
Coscinodiscus gigas	10	–	–	–
L. danicus	–	–	5.71	–
M. nummuloides	–	–	25.71	–
P. turgidula	–	13.70	–	–
T. nitzschoides	–	–	11.43	8.40
Coscinodiscus spp.	26.67	6.85	–	–
Chaetoceros spp.	–	–	–	16.03
Navicula spp.	–	–	5.71	–
Pleurosigma spp.	–	–	5.71	–
Pseudonitzschia spp.	–	–	5.71	–
Thalassiosira spp.	–	–	5.71	–
Unidentified spp.	26.67	64.38	–	38.93
Off Shankhamughom				
A. japonica	–	–	–	5.42
C. curvisetus	5.04	–	56.51	–
C. decipiens	–	5.75	–	–
C. didymus	42.14	–	–	–
Eucampia zoodiacus	–	8.08	–	6.10
N. septentronalis	7.42	–	–	–
T. fauenfeldii	–	–	5.95	–
T. nitzschoides	28.19	21.84	26.02	49.15
Amphiprora spp.	–	5.75	–	–
Dactyliosolen spp.	–	8.74	–	–
Pleurosigma spp.	–	5.75	–	–
Skeletonema spp.	6.53	–	–	–
Off Vizhinjam				
A. japonica	–	–	–	7.39
C. curvisetus	39.02	–	10.01	7.39
C. decipiens	–	–	–	5.42
C. didymus	40.46	–	–	–
C. perforatus	–	5.34	–	–

(*Contd.*)

Table 1. (*Contd.*)

Phytoplankton species	Sampling months, 2005			
	June	July	August	September
E. zoodiacus	–	–	–	7.39
N. membranacea	–	–	–	5.91
Pleurosigma angulatum	–	–	6.31	–
T. nitzschoides	13.73	48.54	–	34.50
Coscinodiscus spp.	–	–	11.01	–
Chaetoceros spp.	–	–	–	9.86
Dactyliosolen spp.	–	8.74	–	–
Unidentified spp.	–	–	54.02	5.91

The following minor species of phytoplankton (dinoflagellates asterisked) contributing to less than 5% of the total counts observed at different sampling sites during June–September respectively, are listed here. Kollam (open coast): *C. perforatus* (0; 4.65; 0; 0), *C. gigas* (0; 0; 2.71; 0), *Navicula directa* (0; 0; 2.95; 2.52), *N. distans* (0; 0; 0; 1.26), *Pleurosigma elongatum* (0; 0; 0; 1.26), *Prorocentrum micans** (0; 0; 0; 1.26), *Rhizosolenia setigera* (0; 0; 2.95; 1.26), *T. frauenfeldii* (0; 0; 2.95; 0), *Detonula* spp. (0; 0; 0; 3.77), *Thalassiosira* spp. (0; 4.65; 2.95; 3.77) and *Synedra* spp. (0; 2.33; 0; 1.26). Off Kollam (fishing harbour): *Asterionella formosa* (0; 1.37; 0; 0), *Biddulphia sinensis* (3.33; 0; 0; 0), *Corethron criophilum* (0; 0; 0; 1.53), *C. perforatus* (0; 0; 2.86; 0), *C. gigas* (0; 0; 2.86; 0), *C. radiatus* (0; 0; 0; 0.76), *Melosira moniliformis* (0; 0; 0; 2.29), *N. membranacea* (0; 0; 0; 1.53), *Planktoniella sol* (0; 0; 0; 0.76), *P. elongatum* (0; 0; 0; 1.53), *P. macrum* (0; 1.37; 0; 3.05), *Rhizosolenia curvata* (0; 0; 0; 3.82), *Amphora* spp. (0; 1.37; 0; 0), *Oxytoxum* spp.* (0; 0; 0; 0.76), *Rhizosolenia* spp. (0; 1.37; 0; 0), *Thalassiothrix* spp. (0; 1.37; 2.86; 0) and *Synedra* spp. (0; 0; 0; 1.53). Off Shankhamughom: *Bacteriastrum delicatulum* (0; 3.45; 0; 0), *Biddulphia aurita* (0; 2.30; 0; 3.39), *B. sinensis* (2.08; 2.30; 0; 2.03), *Chaetoceros coarctatus* (0.30; 0; 0; 0), *C. costatus* (0; 0; 1.49; 0), *C. danicus* (0; 2.30; 0; 0), *Coscinodiscus granii* (2.08; 0; 0; 0), *C. perforatus* (0; 0; 0; 0.68), *C. gigas* (0; 4.60; 0.37; 0), *C. radiatus* (0; 0; 0.74; 1.02), *M. nummuloides* (0; 0; 0.74; 0), *Navicula directa* (0; 0; 0.74; 0.34), *N. distans* (0; 1.15; 0; 0), *N. membranecea* (0; 1.15; 0; 1.36), *N. transitrans* (0; 0; 0.37; 0), *Nitzschia delicatissima* (1.48; 0; 0.74; 0), *P. sol* (0.59; 0; 0; 2.37), *Protoperidinium oceanicum** (0; 0; 0; 1.02), *R. flaccida* (0.30; 0; 0; 0), *R. imbricata* (0; 1.15; 0; 3.39), *R. setigera* (0.30; 0; 0; 0), *R. striata* (0; 0; 0; 1.36), *Thalassiosira punctigera* (0; 0; 1.12; 1.69), *Amphora* spp. (0; 0; 0.74; 0.34), *Biddulphia* spp. (0; 0; 0.37; 0), *Coscinodiscus* spp. (0.59; 4.60; 0.74; 0.68), *Detonula* spp. (0; 0; 0; 0.34), *Eucampia* spp. (1.19; 0; 0; 0.68), *Gymnodinium* spp.* (0; 1.15; 0; 0), *Melosira* spp. (0; 4.60; 0; 4.07), *Navicula* spp. (0; 1.15; 0.37; 0), *Nitzschia* spp. (0; 0; 0; 0.34), *Rhizosolenia* spp. (0; 0; 0; 0.34) and *Thalassiosira* spp. (1.19; 0; 0; 1.69). Off Vizhinjam: *B. aurita* (0; 0.49; 0; 0), *B. sinensis* (0.72; 1.46; 0; 0.45), *C. danicus* (0; 0.49; 0; 0), *C. similis* (0; 1.94; 0; 1.97), *C. gigas* (0; 0.49; 0; 1.48), *C. radiatus* (0; 1.46; 1.01; 0), *C. subtilis* (0; 0; 4.04; 0), *Fragilaria cylindrus* (0; 0.97; 0; 0), *L. danicus* (0; 0; 0; 3.45), *M. nummuloides* (0; 0; 3.03; 0), *Navicula crabro* (0; 0; 0.96; 0), *N. directa* (0.14; 0; 2.02; 0), *N. delicatissima* (0.29; 0; 2.02; 0), *Pseudonitzschia turgidula* (0; 0; 0; 1.97), *R. imbricata* (0; 0; 0; 0.99), *R. styliformis* (0.14; 0; 0; 0), *T. punctigera* (0; 0; 1.01; 1.48), *Actinocyclus* spp. (0; 0; 1.94; 0), *Amphora* spp. (0; 2.91; 2.1; 0), *Biddulphia* spp. (0; 0.49; 0; 0), *Eucampia* spp. (0; 0; 0; 0.99), *Gymnodinium* spp.* (0; 0.97; 0; 0), *Melosira* spp. (0; 1.94; 0; 0), *Navicula* spp. (0; 0; 4.04; 0), *Nitzschia* spp. (0; 0; 0; 0.99), *Noctiluca* spp.* (0; 0.99; 0; 0), *Pleurosigma* spp. (0; 0.49; 0; 0), *Pseudonitzschia* spp. (2.17; 0; 0; 0), *Rhizosolenia* spp. (0; 0; 0; 0.49), *Triceratium* spp. (0; 1.94; 1.01; 0), *Thalassiothrix* spp. (0; 2.43; 0; 0) and *Thalassiosira* spp. (2.02; 1.94; 2.1; 0.49).

[#]Phytoplankton cell counts and composition, water samples from each depth were fixed in Lugol's iodine (1% w/v) and 3% formaldehyde and stored in dark until taken up for analyses. Samples were concentrated from 250 to 20 ml using settling and siphoning procedure. Enumeration and identification of microphytoplankton (>5 μm) up to the generic and, in many cases to species level, were carried out from two 1 ml replicates of such cell concentrates using Sedgwick Rafter plankton counting chamber under a microscope (Nikon E 400, Japan) at 200 and 400× magnifications. Generic and species identification was done following many keys[18–24]. Oil immersion objective at 100× on a Zeiss (Axioskop, 2plus, Germany) microscope was also made use of for confirming phytoplankton genera or species.

detected during most months, except for a rare encounter of a few cells (maximum of 35 cells/l) mostly off Kollam in July samples.

The highly diverse autotrophic marine phytoplankton comprising diatoms, dinoflagellates, coccolithophorids, cyanobacteria and many picoplanktonic forms at the base of the food chain are quite sensitive to changing environmental conditions. They integrate a range of hydro-meteorological conditions and may act as indicators of natural or anthropogenically induced environmental changes[5]. Investigations on phytoplankton community structure are thus important to allow us to observe their responses to environmental changes. As a consequence of seasonal variations[6], the Indian Ocean experiences four biologically distinct seasons: SW monsoon (SWM: June and August); NE monsoon (NEM: December–February); Winter intermonsoon (WIM: October and November) and Summer intermonsoon (SIM: March–May)[7]. Changes in meteorology and hydrography play an important role in determining the growth conditions of plankton[7]. Winds reverse in November to become northeasterly until May, leading to upwelling along the southwest coast of India[8–10]. Though data on daily tidal amplitude, wave and sea surface temperature could not be collected during this study, their general patterns during and following monsoon are adequately described, in particular for the upwelling periods[1,7].

Nutrient regimes from the southern Malabar coast are not described previously during monsoonal months. It can, however, be extrapolated that the nutrient distribution undergoes marked seasonal rhythm, induced by the local precipitation and land run-off[11]. However, changes in other environmental features such as temperature, salinity, dissolved oxygen, pH and alkalinity may be larger, vary daily and are different during the monsoon period when the freshening is intense and/or varying on an inter-annual scale.

Fertility of the sea is known to affect the composition of phytoplankton with diatoms dominating the nutrient-rich waters and dinoflagellates in nutrient-impoverished oceanic waters[12]. The dominance of diatoms was clearly evident in this study as well. Besides the various chemical and biological parameters were within the reported variations between the seasons[13]. Surface highs of chlorophyll *a* in the nearshore regions were common[14]. Surface discolouration by the blooming planktonic organisms is a phenomenon in the southern Malabar coast that needs validations through regular *in situ* measurements.

There are many reported fish kills and a few human fatalities due to toxic dinoflagellate blooms worldwide. A few species of dinoflagellates periodically form red tides and are implicated in fish kills[15] and paralytic shell-fish poisoning[16]. Among them, *Noctiluca miliaris* appears to be the most frequent[17]. Local press reported that the mass fish kills noticed on 17 September 2004 off Kollam, Shankhamughom and Vizhinjam near Thiruvananthapuram were due to blooms of *Cochlodinium* sp. and *Gonyaulax diegensis*[2,3].

Based on detailed analyses of numerous samples, the first case of stench and fish kills along the Kerala coast (most likely due to unusual blooms by a holococcolithophore[1]) was reported during September 2004. During that stench event, the diversity of phyotplankton was minimal. A total of 23 species of phytoplankton (including those contributing to less than 0.005% of total count) were observed from the entire sampling stretch. The holococcolithophorid accounted for over 95% of the total counts from almost all 30 samples. Probably the right conditions to any bloom forming flora were not prevalent during the whole of 2005, as no case of blooms was observed. When holococcolithophorids were almost nonexistent during all the four months in the entire sampling stretch during 2005, as many as 78 species of plankton were recorded. Apparently, this is significant information to suggest that inter-annual and seasonal differences are natural in phytoplankton assemblages.

A continuous monitoring programme for documenting phytoplankton assemblages along the coast at some pre-decided locations is called for. Many issues related to global change, climate considerations and coastal phytoplankton biodiversity changes/patterns can be understood when systematic data are accrued.

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