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Occurrence of *Noctiluca scintillans* bloom off Mangalore in the Arabian Sea

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ABSTRACT

A bloom of the dinoflagellate *Noctiluca scintillans* (Macartney) with a cell density of 10.5 lakh cells l^{-1} was observed along the Mangalore coast on 12th May 2011. The high wind velocity during the period caused further movement and dispersion of the bloom and its presence was observed 250 km away from Mangalore at Karwar by 2nd June 2011. A comparison of the nutrients in the water samples from January to May 2011 with the corresponding period during the previous year showed that the levels of silicate (26.86 µg-at l^{-1}), nitrate (59.47µg-at l^{-1}) and total suspended solids (61mg l^{-1}) were highest during March 2011 in the bloom area. It was observed that the average wind velocity during January to May was 4.4 km h^{-1} (2010) and 8.6 km h^{-1} (2011) respectively. During the first week of June, a total rainfall of 206 mm was recorded. This brought down the salinity in the river as well as coastal water and the bloom completely disappeared. Significant correlation was observed between rainfall and silicate in 2010 ($p<0.01$) and 2011 ($p<.005$), as well as with phosphate in 2010 and in 2011 ($p<0.025$), indicating that rivers Gurupur and Nethravathi bring nutrient rich water towards the coast. The phytoplankton bloom in the Arabian Sea is strongly influenced by the seasonal wind shifts (monsoon) that dominate the area. Significant negative correlation ($p<.01$) was observed with nitrate and maximum wind velocity during the bloom.

Keywords: Algal bloom, Arabian Sea, *Noctiluca scintillans,* Nutrients, Rainfall

Introduction

Incidence of *Noctiluca scintillans* bloom off Mangalore in Arabian Sea and in Indian waters has been reported by earlier researchers (Prasad, 1953; Subrahmanyan, 1953; Prasad and Jayaraman, 1954; Katti *et al.,* 1988; Shetty *et al.,*1988; Sargunam *et al.,* 1989; Eashwar *et al.,* 2001; Nayar *et al.,* 2001, Mohanty *et al.,* 2007, Gomes *et al*., 2008, Gopakumar *et al.,* 2009). The seasonality of the phytoplankton blooms in the Arabian Sea is well researched (Banse, 1987, Alvarinho and Hiroshi 2004) but the inter-annual variations is less understood (Prasanna Kumar *et al.,* 2010). The coupling between the air-sea, sea surface temperature and rainfall is yet to be understood (Alvarinho and Hiroshi, 2004) over the Indian subcontinent. A bloom of the dinoflagellate *N. scintillans* (Macartney) was observed along the Mangalore coast on 12th May 2011. It extended from Mangalore bar mouth area to Sasihithlu spanning a distance of about 15 km and to about 2 km towards west rendering the sea surface a greenish tinge. *N. scintillans* bloom has been observed in the months from November to February off Mangalore by earlier researchers (Bhimachar and George, 1950; Nayar *et al.,* 2001). The south-west coast of India is known for intense upwelling during the south-west monsoon period which occurs due to a variety of physical processes introduced by semiannual reversal of monsoon winds (Banse, 1987). This brings nutrient rich subsurface water to the surface, which is conducive for high productivity at the primary level. This study relates to the nutrient and hydrographic status during the bloom period and a comparison with that of the previous year.

Materials and methods

Surface water (S) samples during the bloom were collected onboard fishing vessel from the surrounding waters off Mangalore. The latitude and longitude of the sampling stations (Table 1) were marked using a portable Global Positioning System (Garmin GPS map 76,USA). The sampling stations (Fig. 1) in the bloom area were stations : St 1, 2 and 3. To know the extent of bloom and river discharge effect during rainfall, off shore surface and bottom (B) water at 10 m depth (St 4), 15 m depth (St 5) and Gurupur River (St 8) samples were taken to compare with the previous year. In addition, during the bloom period water sample was collected from St 7, which is 15 km away from St 2. During the subsequent days, as the south-west monsoon advanced, the bloom had spread into the estuarine areas by current, and its presence was observed in St 6 and St 9 both 15 km and 230 km respectively from St 2.

The water samples were collected and analysed following standard procedures (APHA, 1995). The pH and salinity were analysed using WTW Germany- series Multi 720 water analyser. The dissolved oxygen (DO) was measured by Winkler's titration method using a digital burette and nutrients as per Parsons *et al*. (1984). The total suspended solids (TSS) were determined using a millipore filtration unit by estimating the residue retained on pre-weighed glass fiber filter after drying. The different species of phytoplankton in the <100 µm size fraction were counted on a

Table l. GPS locations of the study area

Station number	Place	Latitude and longitude
St 1	Tannirbhavi	12º 54' 0.36" N; 74º 48' 51.12" E
St 2	Panambur	12º 55' 59.03" N; 74º 47' 45.51" E
St 3	Chithrapur	12º 57' 32.76" N; 74º 47' 59.46" E
St 4	10 m depth	12º 54'13.06" N; 74º 47' 22.54" E
St 5	15 m depth	12º 54'13" N; 74º 47' 11.14" E
St 6	Mulky	13° 5'20.21"N; 74°46'45.89"E
St 7	Someshwar	12º 47'21.92" N; 74º 51' 3.96" E
St 8	Gurupur River- Kulur	12º 55'31.14" N; 74º 49' 38.16" E
St 9	Karwar	14º 48'24.5" N; 74º 6' 42.16" E

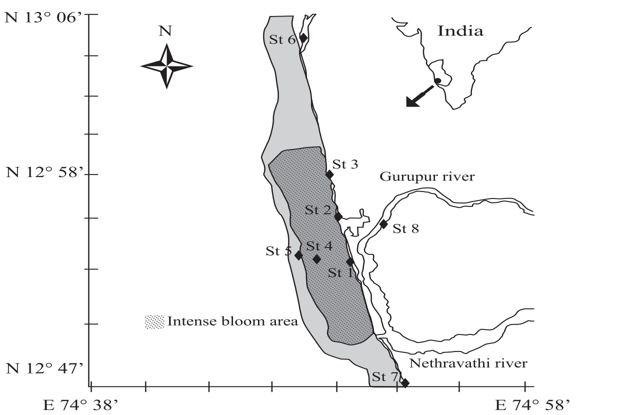

Fig.1. Map showing location of the study site

Sedgwick-Rafter counting chamber under an Olympus binocular microscope and the density (cells l^{-1}) was calculated. The taxonomic identification was carried out following Hasle and Syversten (1997) for diatoms and Steidinger and Tangen (1997) for dinoflagellates. Chlorophyll *a* was extracted by adding 90% v/v acetone as per standard procedure. The meteorological data during the period was obtained from the India Meteorological Department. Pearson correlation (2-tailed) during the bloom period and correlation (1-tailed) for St 4 (10 m depth), St 5 (15 m depth) and St 3 (intense area of bloom) was carried out using SPSS software to find the correlation between the hydrological parameters.

Results and discussion

The coastal waters had a deep green colour during the bloom period. Microscopic examination revealed the presence of *N. scintillans*. The organism is bioluminescent, inflated and sub-spherical. The size ranged from 400 to 1200 µ. Though the species is colourless, the presence of photosynthetic green endosymbionts *Protoeuglena noctiluca* Subrahmanyan turned the water green. During the intense period of the bloom on 12th May 2011, the concentration of *N. scintillans* was around 10.5 lakh cells l^{-1} at St 3. Further offshore at St 4 the density was 68,400 cells l^{-1} and at St 5 it was 800 cells l^{-1}. A decrease in density of bloom beyond 10 m depth was observed. The other phytoplankton cells observed during the period were *Coscinodiscus centralis, Pleurosigma directum, Rhizosolenia cylindrus, Planktoniella sol*, *Cyclotella* sp., *Gymnodinium* sp., *Ceratium furca*, *Chaetoceros* sp. and *Biddulphia* sp. Major zooplankton groups were tintinnids, copepods, chaetognaths, decapod larvae, lucifer, amphipods, gastropods, foraminifera and polychaete larvae. In the zooplankton sample, copepods were found to be dominant at all stations with a maximum 1×10^{5} nos. l^{-1} observed on 12th May 2011 at St 3, followed by decapod larvae (1600 nos. l^{-1}) . Dominance of copepod during *N. scintillans* bloom was reported by Eashwar *et al.* (2001) in Port Blair Bay. By 27th May 2011, the density of *N. scintillans* at St 3 had reduced to 1.13 lakh cells l^{-1}. The variation in cell density in the intense area of the bloom is shown in Fig. 2. At St 6 (estuarine area) the cell density was 50 cells l^{-1} on 27th May 2011. On 2nd June 2011, at St 9 *N. scintillans* cell count was 71,000 cells l^{-1}. Table 2 gives the correlation of the hydrological parameters with the cell density during the bloom period. Significant correlation was not observed with cell density. Significant correlation between the hydrological parameters was observed in the years 2010 and 2011 for the stations St 4, St 5 and St 3 (Table 3).

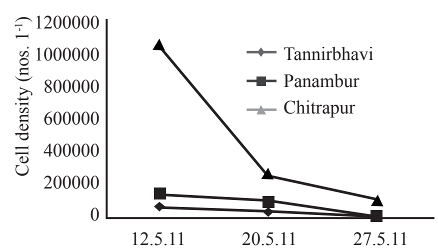

Fig. 2. Cell density of *N. scinitillans* during bloom period in nearshore coastal stations

Table 2. Pearson Correlation (2 tailed) during bloom period

Parameter	Pearson correlation
SST and pH	-0.568*
pH and salinity	0.633*
pH and DO	-0.787**
DO and average wind velocity	0.604*
Nitrate and average wind velocity	-0.618*
Nitrate and maximum wind velocity	-0.694**
Nitrite and sea level pressure (hpa)	-0.878**
Silicate and chlorophyll a	0.578*

**Significant at 0.05 level; ***Significant at 0.01 level (N=15)*

The sea surface temperature (SST) and dissolved oxygen (DO) variations during the years 2010 and 2011 are given in Fig. 3 and 4 respectively. In 2010, at St 3 the maximum SST of 32.5 °C was observed in May, while in 2011 a maximum of 31 °C was observed in April. During the bloom in May-June 2011 the SST in the coast at various stations ranged between 28.2 °C-33 °C (Table 4). For St 4 and 5 (B) DO varied between 3.12 - 4.27 ml l^{-1} in 2010 and 1.94-4.63 ml l^{-1} in 2011 respectively. The least DO and temperature was observed in bottom water from St 4 and 5 in May 2011. The average wind velocity (Fig. 5) was higher during 2011 and also the corresponding sea level pressure during bloom period. This would have caused higher tidal incursion into the river, mixing the nutrient rich nearshore and

Table 3. Correlation (1-tailed) at St 4 (10 m depth), St 5 (15 m depth) and St 3 (bloom area)

Station/Parameters	2010	p value	2011	p value
St 4				
SST and salinity	0.99	p<0.005	0.54	n.s
BWT and salinity	0.91	p<0.01	0.12	n.s
Chlorophyll a and phosphate (S)	0.66	n.s	0.05	n.s
Chlorophyll a and phosphate (B)	0.88	p<0.025	-0.40	n.s
St 5				
SST and salinity	0.97	p<0.005	0.54	n.s
BWT and salinity	0.95	p<0.01	0.08	n.s
Chlorophyll a and phosphate (S)	0.97	p<0.005	-0.28	n.s
Chlorophyll a and phosphate (B)	0.44	n.s	-0.31	n.s
St 3				
SST and salinity	0.94	p<0.0005	0.59	p<0.05
pH and wind velocity	-0.30	n.s	-0.83	p<0.0005
Rainfall and salinity	0.85	p<0.005	0.99	p<0.01
Rainfall and TSS	0.55	p<0.05	0.58	p<0.05
Rainfall and DO	-0.89	p<0.0005	-0.89	p<0.0005
Rainfall and phosphate	0.68	p<0.025	0.60	p<0.025
Rainfall and silicate	0.73	p<0.01	0.79	p<0.005
Rainfall and chlorophyll *a*	-0.41	n.s	0.77	p<0.005
Rainfall and chlorophyll *b*	-0.21	n.s	0.60	p<0.025
Rainfall and chlorophyll *c*	-0.44	n.s	0.63	p<0.05

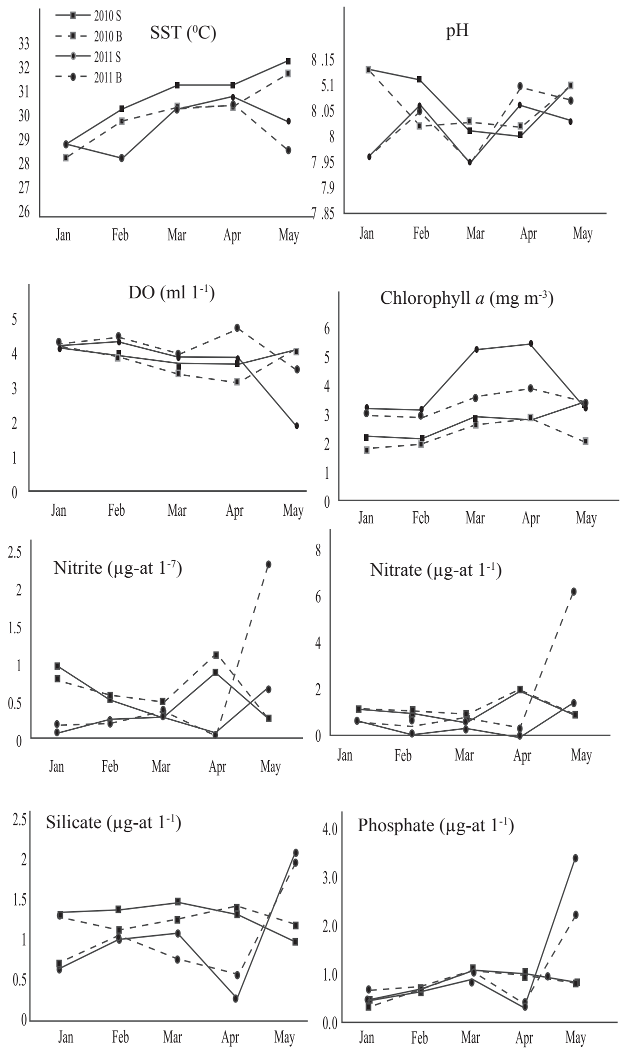

Fig. 3. Monthly variation in hydrological parameters (2010 and 2011) at St 4 (S) and (B)

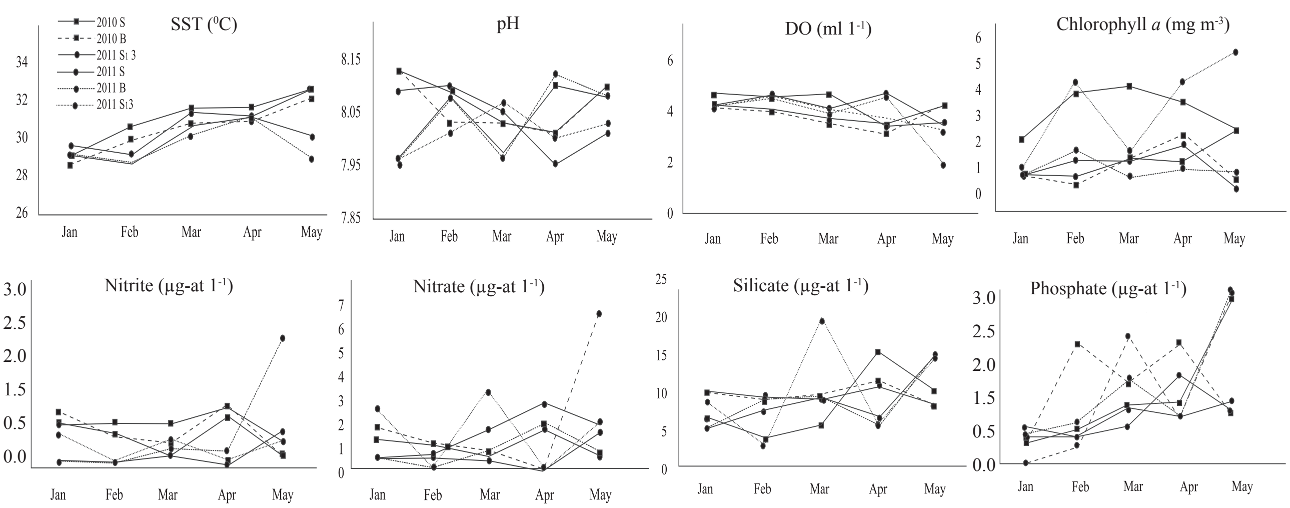

Fig. 4. Monthly variation in hydrological parameters (2010 and 2011) at St 5 (S) and (B) and St 3 (bloom area)

Table 4. Physicochemical parameters observed during and after the bloom period off Mangalore and coastal waters

Date	Station	SST (°C)	pH	Salinity (ppt)	D.O. (ml l^{-1})	Phosphate (µg-at l^{-1})	Nitrate (µg-at l^{-1})	Nitrite (µg-at l^{-1})	Silicate (µg-at l^{-1})	Chlorophyll a (mg m^{-3})
12.5.11	St 4 (S)	30	8.07	35.8	3.59	3.44	1.39	0.66	16.18	3.393
12.5.11	St 4 (B)	28.8	8.03	35.8	1.94	2.25	6.29	2.29	15.23	3.135
12.5.11	St 5 (S)	30	8.08	35.9	3.43	1	1.55	0.66	14.52	1.363
12.5.11	St 5 (B)	28.8	8.08	35.9	1.94	2.76	6.63	2.42	14.4	2.262
12.5.11	S t1	30	8.06	35.7	3.4	2.07	4.74	1.08	13.47	6.27
12.5.11	St 2	28.2	8.06	35.8	3.16	1.58	3.08	0.95	14.66	10.918
12.5.11	St 3	28.2	8.03	35.6	3.29	2.67	1.95	0.49	14.83	9.138
12.5.11	St 6	32	7.8	35	5.1	1.61	1.45	0.65	5.46	6.87
20.5.11	St 1	28.6	7.99	35.6	4.46	2.16	0.2756	0.471	13.53	8.13
20.5.11	St 2	28.7	7.95	35.6	4.5	2.27	0.31	0.45	19.5	7.51
20.5.11	St 3	29	7.9	35.6	3.89	2.59	0.3756	0.531	18.89	6.53
23.5.11	St 1	30	7.99	35.8	4.72	2.305	0.5088	0.92	13.87	8.12
23.5.11	St 2	33	8	35.6	3.67	1.985	0.4452	1.033	13.387	6.47
25.5.11	St 2	31.2	7.87	35.6	4.72	2.773	1.802	5.143	19.96	14.74
25.5.11	St 7	30	8	35.6	4.68	1.36	2.5228	5.615	15.63	6.264
27.5.11	St 1	30	7.96	35.9	3.56	1.217	4.85	1.74	20.92	5.803
27.5.11	St 2	30	7.96	35.9	2.98	0.855	6.131	1.997	20.33	12.096
27.5.11	St 3	30.5	7.99	35.9	3.96	2.26	0.795	0.488	26.86	56.19
27.5.11	St 6	33	7.73	35.6	5.175	1.682	0.276	0.365	23.881	11.817
13.6.11	St 1	29	8	31.8	4.2	1.59	4.64	1.53	19.46	6.177
13.6.11	St 2	29	8.03	30.7	4.19	1.32	3.58	0.72	20.35	6.209
13.6.11	St 3	28.6	7.83	32.7	4.36	3.94	17.52	1.49	32.46	9.37
12.7.11	St1	26.7	7.82	32.3	4.39	1.59	8.27	3.84	28.02	4.872
12.7.11	St 2	26.6	7.78	33.8	4.32	3.76	11.42	5.2	27.77	6.154
12.7.11	St 3	26.9	7.78	33.5	4.5	1.72	8.79	4.51	24.77	6.612

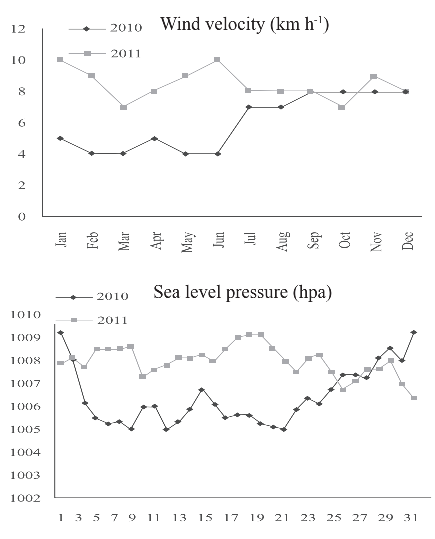

Fig. 5. Wind velocity during 2010 and 2011 and sea level pressure variation during May 2010 and 2011.

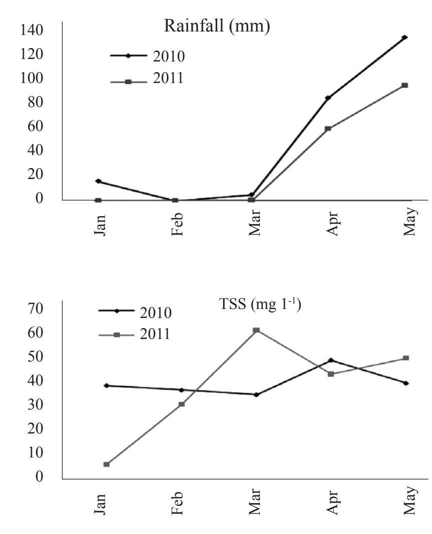

Fig. 6. Variation in rainfall and total suspended solids (TSS) at St 3

nearshore and estuarine water. Luis and Kawamura (2002) observed that an equator driven coastal jet advects cold water southward, where the irregular topography of the west coast of India enhances wind mixing, and a sharp gradient at the shelf (~500 m) modulates upwelling strength through cross-isobath flow from subsurface. Hence, prior to the bloom, the coastal upwelling phenomenon would have commenced. Gopakumar *et al.* (2009) observed that a favorable wind direction towards nutrient rich shores as a trigger for blooms. The pH ranged between 7.95 - 8.1 (2010) and 7.96 - 8.07 (2011) at St 3 (Fig. 4). The lower pH in Jan 2011 could be due to mixing of coastal surface water with bottom water due to higher wind velocity. The pH was significantly negatively ($p<0.005$) correlated with wind velocity at St 3 (Table 3) in 2011. pH was also significantly negatively correlated with DO during the bloom period. Nayar *et al.* (2001) observed lower pH during the bloom of *N. scintillans* in November 1988 off Mangalore. In summer, the phytoplankton bloom in Arabian Sea is influenced by the monsoon winds, the strong south westerly winds which blow from the ocean towards land mixing the water (Gomes *et al*., 2008).

Rainfall was significantly negatively ($p<0.005$) correlated with DO in 2010 and 2011 respectively (Table 3). The total rainfall observed during the period from January to May was 231.2 mm (2010) and 149.5 (2011) respectively. More than the fluctuations in total amount, it is the temporal variations in the rainfall that affects the water availability of a region (Walsh and Lawyer, 1981). Rainfall and total suspended solids (TSS) showed significant ($p<0.05$) correlation for 2010 and 2011 respectively at St 3. The rivers Gurpur and Nethravathi bring large quantities of silt rich in organic matter during monsoon. The tidal incursion effect was reflected in the increasing salinity trend observed from January to May at St 8 in Gurupur River for both the years. The TSS values (Fig. 6) were higher in March 2011 in St 3 and so also the nutrients. Salinity and rainfall showed significant correlation during 2010 ($p<0.005$) and 2011($p<0.01$). The SST and salinity showed significant ($p<0.05$) correlation at St 4 and St 5 in the year 2010. Bottom water temperature (BWT) and salinity was significantly correlated ($p<0.05$) at St 4 and St 5 in 2010. But in 2011, the correlation was not significant for bottom water. This could be due to bottom upwelling water as the nutrients were higher in the bottom water in May 2011. Sea surface temperature and salinity showed significant correlation ($p<0.05$) at St 3 in 2010 and 2011. The salinity and temperature changes in coastal surface waters could also be attributed to the tidal incursion into the rivers Gurupur and Nethravathi. As reported by Shetye *et al*. (1991) that if the wind component along the shore during the period is directed towards the equator, the tidal incursion into the rivers results in mixing of water. Shankar and Shetye (1999) noted that lower (higher) salinity along the coast leads to higher (lower) coastal sea level. This is because during south-west monsoon, the discharge from these rivers will be more and hence the tidal incursion effect into the river will be less which is reflected in the lower salinity during the period in the river.

Silicate in surface water at St 4 and St 5 (S) ranged between 7.53-11.46 µg at l^{-1} (2010) and 2.2-16.18 µg at l^{-1} (2011), and that in bottom water varied between 7.74-11.53 µg at l^{-1} (2010) and 4.24-15.23 µg at l^{-1} (2011) respectively. The nutrients, nitrite and nitrate were higher in the bottom water in May 2011 (Fig. 3 and 4). For a phytoplankton bloom to occur in summer an optimum N:P ratio of 16:1 to 20:1 (Redfield, 1958) is required. At St 3 during March 2011, an N:P ratio of 16.5:1 was observed. This could have triggered a diatom bloom preceding the *N. scintillans* bloom. This may be the reason for reduced silicate in April 2011 at St 3 as well as St 4 (S) and consequent decrease in nitrite and nitrate in April 2011. During May 2011, low dissolved oxygen and high nutrients were observed at St 4 and St 5 (B) indicating upwelling. This when combined with the high nutrient coastal waters could have triggered the bloom near shore, as is evidenced by the highest chlorophyll *a* content at St 3 in May 2011 (Fig. 4). Earlier researchers too found that *N. scintillans* blooms occurred after diatom blooms (Tiselius and Kiorboe, 1998, Zakaria and Ibrahim, 2007). Rainfall correlated with chlorophyll *a, b* and *c* at St 3 in 2011, but not in 2010. This indicates that the variability of rainfall can affect the coastal productivity. At St 3, the bloom had completely disappeared after the rainfall of south-west monsoon commenced on 1st June 2011. By the end of the first week of June, a total rainfall of 206 mm was recorded, which reduced the salinity in the river as well as in the near shore waters. There was more silicate in the coastal waters (Table 4) and dominance of diatom *Biddulphia* sp. (11200 cells l^{-1}) which could utilise the silicate brought by the rivers. Rainfall was observed to bring down the *N. scintillans* bloom in Gulf of Mannar (Gopakumar *et al*., 2009).

During the intense period of the bloom, no fishing boats (both mechanised and motorised) were seen along this stretch as the fishes appeared to move far, due to the bloom. Enquiry with local fishermen revealed that fishing boats were operating beyond 20 m depth. The bloom continued for the next couple of days showing a decreasing trend, but had spread further northwards to Karwar and into the river mouths up to 5-10 km in Kulur and Mulky due to tidal influence. Lierheimer and Banse (2002) examined seasonal and interannual variability of phytoplankton pigment, between 5 and 16° N, and pointed out that phytoplankton blooms promoted by upwelling during summer monsoon are restricted to the shelf and, on a few occassions, the phytoplankton blooms did occur in Lakshadweep Sea and to the south of India. In the present study also the bloom was restricted nearshore. The higher wind velocity during the period caused further movement and dispersion of the bloom and its presence was observed in Karwar by 2nd June 2011. Mangalore port adjacent to St 3 is one of the iron ore ports. Here, periodic dredging is carried out up to a depth of 15 m and dredged material is dumped beyond 20 m depth. This could also lead to suspension of sediments and nutrient variations. The contribution by west flowing rivers to the Arabian Sea is 364.7 billion cubic meters (Smakhtin and Anputhas, 2006). These rivers traverse through steeper slopes and are of lesser length compared to the east flowing rivers in India. Hence with increasing urbanisation and the variability of rainfall in the Western Ghats, more nutrient rich water may flow to the sea. The sudden shifts in wind velocity, temporal variations in the rainfall combined with increased coastal nutrient input due to anthropogenic activities could trigger changes in coastal productivity and subsequent blooms.

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