

## Red tide of *Noctiluca scintillans* and its impact on the coastal water quality of the near-shore waters, off the Rushikulya River, Bay of Bengal

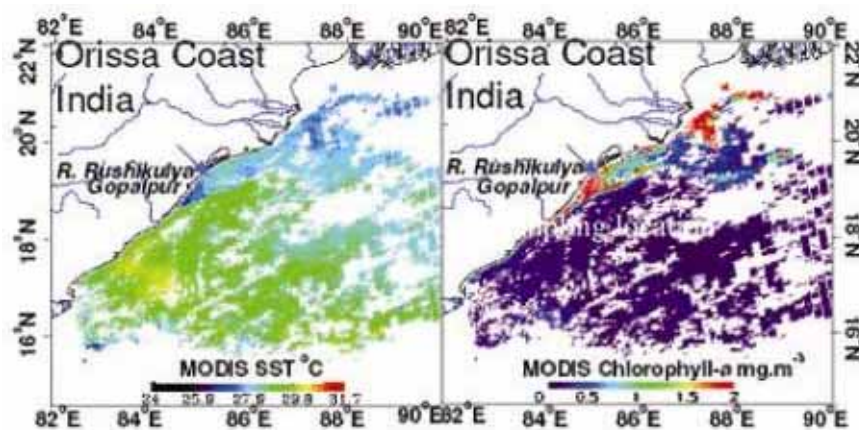
*Noctiluca* is a substantial bloom-forming marine dinoflagellate in the world ocean. Reports in the literature point out that the occurrence of *Noctiluca* bloom in coastal waters of the Indian subcontinent is not uncommon<sup>1–5</sup>, but the causes of its occurrence are not well understood. Although several instances of phytoplankton blooms in the coastal waters of the southern Orissa coast have been reported<sup>6–8</sup>, there has been no report of 'red tide' formation by *Noctiluca scintillans*. During a regular study, a prominent discolouration of the surface water was noticed in coastal waters off the Rushikulya River mouth at lat. 19°22'N and long. 85°02'E (Figure 1) on 5 April 2005. The bloom was dense and created red-coloured patches near the sea surface (Figure 2 a), covering a wide area of approximately 16 sq. km. The phytoplankton responsible for discolouration was identified as *N. scintillans* (Figure 2 b). In addition to the data collected on physico-chemical characteristics, Moderate Resolution Imaging Spectrometer (MODIS)-derived chlorophyll *a* and sea surface temperature (SST) datasets corresponding to this bloom were obtained from the database of the Distributed Active Archive Center (DAAC), Goddard Space Flight Center, Washington DC, USA in order to locate the spatial distribution of this bloom in the north-western Bay of Bengal.

Water samples were collected (between 10 and 11 a.m.) from the surface, mid-depth and bottom (6–7 m) using clean polythene bottles at fortnightly intervals and analysed for various physico-chemical parameters such as temperature, dissolved oxygen (DO), salinity, nitrite, nitrate, silicate and phosphate using standard methods<sup>9</sup>. Temperature was measured using a mercury thermometer having a resolution of 0.1°C. Phytoplankton density was measured using Utermohl's sedimentation technique<sup>10</sup> and counted using Sedgwick–Rafter counting chamber, with the aid of an inverted microscope. Phytoplankton was identified by following standard taxonomic monographs for diatoms<sup>11</sup>, dinoflagellates<sup>12,13</sup> and green and blue-green algae (cyanobacteria)<sup>14</sup>.

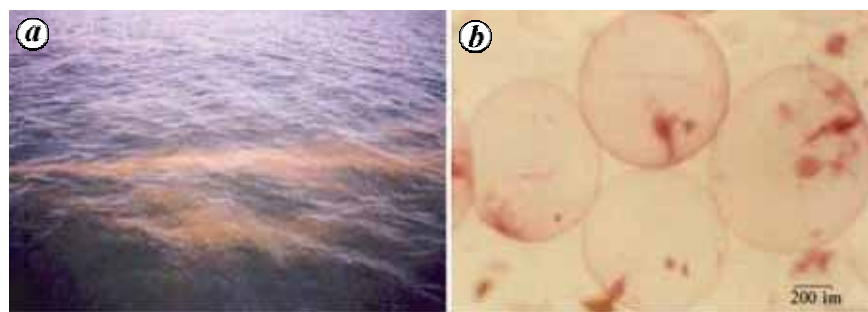
Stable temperature and muggy weather without rain are considered to be favourable for *Noctiluca* bloom<sup>15</sup>. The surface sea-water temperature during this period ranged from 26.7°C to 30.6°C (Table 1). It has been reported that a relatively low temperature is favourable for triggering the appearance of the bloom<sup>3,6–8</sup>. In the present case, a relatively low sea-water temperature of 28.5°C was observed during the bloom period (April) compared to that in March and May. In this context, it is worthwhile to mention that the studies by Rajesh *et al.*<sup>15</sup> and Dharani *et al.*<sup>16</sup> revealed a marginal decrease in sea-water temperature during the *Noctiluca* bloom period. The salinity values ranged from 27.75 ppt in January to 33.87 ppt in May. As expected, a gradual increase in salinity was observed from January to May

and no clear trend in salinity values in relation to bloom could be found. DO gradually increased from January to March and decreased during the bloom period, i.e. in April and again increased during the post-bloom period. Decrease in DO during the bloom period may be due to rapid consumption of oxygen by *Noctiluca*, which is a heterotroph. It can be also attributed to the increased oxygen demand of rapidly reproducing asexual spores, nonmotile spores and homogenes of the algae and bacteria that thrive in the putrefying algal bloom<sup>17</sup>. Similar reduction of DO content during *Noctiluca* bloom has been reported<sup>3,16</sup>.

In spite of the frequent occurrence of dinoflagellate blooms, detailed investigations into the nature of the chemical changes associated with such phenomena



**Figure 1.** Study area (arrow points to the sampling location) showing MODIS-derived sea-surface temperature and chlorophyll *a* map on 5 April 2005.



**Figure 2.** a, Phytoplankton bloom on 5 April 2005 dominated by *Noctiluca scintillans* off the Rushikulya River mouth along south Orissa Coast, India. b, Magnified view of the bloom-forming phytoplankton, *N. scintillans*.

**Table 1.** Physico-chemical properties of the near-shore waters off the Rushikulya River mouth, northwestern Bay of Bengal during January to May 2005

Parameter	Mean (min.–max.)				
	January	February	March	April	May
Sea-water temperature (°C)	26.7 (26.4–27.2)	26.8 (26.5–27.2)	30.1 (28.5–31.8)	28.5 (27.8–29.1)	30.6 (29.7–31.2)
Salinity (‰)	27.75 (27.22–28.41)	29.50 (28.21–30.93)	32.28 (28.23–34.86)	32.65 (30.21–34.33)	33.87 (32.74–35.28)
pH	8.01 (7.6–8.5)	7.94 (7.1–8.4)	8.25 (7.6–8.6)	8.28 (7.3–8.7)	8.50 (8.3–8.6)
DO (mg l <sup>-1</sup> )	4.2 (3.8–5.0)	4.4 (4.0–4.9)	5.3 (3.0–6.5)	4.6 (3.3–5.3)	5.0 (4.5–5.2)
Phosphate (μM l <sup>-1</sup> )	0.65 (0.28–1.06)	1.55 (0.43–3.03)	1.41 (0.68–2.81)	2.10 (1.41–2.88)	0.57 (0.50–0.62)
Nitrite (μM l <sup>-1</sup> )	0.75 (0.49–1.04)	0.75 (0.41–0.93)	0.58 (0.17–0.97)	0.59 (0.42–0.76)	4.63 (3.86–5.25)
Nitrate (μM l <sup>-1</sup> )	1.80 (0.69–4.06)	3.55 (1.47–5.87)	2.82 (0.56–6.24)	4.29 (1.97–6.21)	2.57 (2.11–3.42)
Silicate (μM l <sup>-1</sup> )	33.01 (21.2–47.9)	32.67 (25.96–41.38)	27.08 (13.36–46.89)	32.61 (19.19–44.61)	27.93 (24.98–31.2)

are meagre. In the present study, an increase in phosphate content was encountered during the bloom period compared to the pre- and post-bloom periods. Phosphate values ranged from 0.28 to 3.03 μmol l<sup>-1</sup> during the study period, having monthly average value of 0.65 μmol l<sup>-1</sup> in January to 2.10 μmol l<sup>-1</sup> in April 2005 (Table 1). This increase in phosphate level during the bloom period may be due to the decomposition of plankton, resulting in oxygen consumption and liberation of phosphate. Similar reports on increase in phosphate content during the occurrence of phytoplankton blooms in coastal waters are available<sup>3,5,16,18</sup>. Silicate, utilized for the formation of siliceous frustules of diatoms, constitutes one of the most important nutrients regulating the phytoplankton growth and proliferation, and ultimately to its blooming. Its values ranged from 13.36 to 47.9 μmol l<sup>-1</sup>, with monthly average values ranging from 27.08 μmol l<sup>-1</sup> in March to 32.67 μmol l<sup>-1</sup> in February. The marginal increase in silicate concentration during the bloom period, compared to pre- and post-bloom periods, could be due to its non-utilization by the dinoflagellate bloom from the nutrient-rich upwelled water. Observations, similar to ours have also been reported<sup>4,16</sup>. Nitrate, considered to be the most stable nitrogenous nutrient responsible for the metabolism and growth of phytoplankters, is readily assimilated by the phytoplankters in aquatic medium leading to its

large-scale variations<sup>19,20</sup>. The monthly average nitrate concentrations varied between 1.80 and 4.29 μmol l<sup>-1</sup>, the highest value being observed during the bloom period. The monthly average values of nitrite ranged from 0.58 to 4.63 μmol l<sup>-1</sup>. The concentration of nitrite decreased marginally during the bloom period; the highest value was obtained during the post-bloom period. Raghuprasad<sup>5</sup> has also observed similar increase in nitrate content during the *Noctiluca* bloom in Palk Bay and the Gulf of Mannar.

Analysis of qualitative and quantitative aspects of phytoplankton revealed that the *N. scintillans* density was  $2.38 \times 10^5$  cell l<sup>-1</sup> against the total cell count of  $3.01 \times 10^5$  cell l<sup>-1</sup>, sharing almost 80% of the total phytoplankton standing crop. This bloom was associated with 29 other species of phytoplankton, which included nine species of dinoflagellates, 19 species of diatoms and one species of cyanobacteria (*Trichodesmium erythraeum*). *Ceratium furca*, *C. tripos*, *Dinophysis caudata* and *Prorocentrum micans* among dinoflagellates, and *Chaetoceros affinis*, *Coscinodiscus radiatus*, *C. asteromphalus*, *Nitzschia longissima*, *N. sigma*, *Asterionella glacialis*, *Thalassiothrix longissima* and *Rhizosolenia alata* among diatoms were relatively abundant compared to other species.

The MODIS sensor of SST (Figure 1) was found to be in the region of 27°C or less and restricted to the near-shore water. This temperature is about 2°C less than

the usual March value, indicating intensification of upwelling and thus supporting phytoplankton blooming. Blooming was also reflected in the MODIS sensor of chlorophyll *a* value, which was found to be high during this period and again restricted to the near-shore region. Both these features clearly complemented the upwelling phenomenon in this region during the period, as reported by others<sup>21,22</sup>.

Although planktonic blooms have been observed on this coast during several occasions, the present one was unique in many ways: (i) appearance of *N. scintillans* bloom and its photographic record has not been reported so far; (ii) among the reported cell densities on *N. scintillans* bloom, the present one was relatively high and (iii) bloom appearance exhibited visible changes in physico-chemical properties of coastal water.

1. Naqvi, S. W. A. *et al.*, *Curr. Sci.*, 1998, **75**, 543–544.
2. Sreekumaran Nair, S. R., Devassy, V. and Madhupratap, M., In *Science of the Total Environment*, Elsevier, Amsterdam, 1992, pp. 819–828.
3. Sahayak, S. *et al.*, *Curr. Sci.*, 2005, **89**, 1472–1473.
4. Sargunam, C. A., Rao, V. N. R. and Nair, K. V. K., *Indian J. Mar. Sci.*, 1989, **18**, 289–290.
5. Raghuprasad, R., *Proc. Indian Acad. Sci.*, 1958, **36**, 331–337.
6. Misra, S. and Panigrahy, R. C., *Indian J. Mar. Sci.*, 1995, **24**, 99–101.

7. Sasamal, S. K., Panigrahy, R. C. and Misra, S., *Int. J. Remote Sensing*, 2005, **26**, 3853–3858.
8. Mishra, S. *et al.*, *Asian J. Water, Environ. Pollut.*, 2006, **3**, 71–77.
9. Parsons, T. R., Maita, Y. and Lalli, C. M., *A Manual of Chemical and Biological Methods for Seawater Analysis*, Pergamon Press, New York, 1984, p. 173.
10. Vollenweider, R. A., *A Manual on Methods for Measuring Primary Production in Aquatic Environments*, IBP Handbook No. 12, Blackwell, London, 1974, p. 225.
11. Desikachary, T. V., *Atlas of Diatoms, III & IV*, Madras Science Foundation, Madras, 1987, p. 239.
12. Subramanian, R., *The Dinophyceae of Indian Seas Part – I. Genus Ceratium*, Marine Biological Association of India, 1968, vol. 129.
13. Subramanian, R., *The Dinophyceae of Indian Seas Part – II. Peridiniaceae*, Marine Biological Association of India, 1971, vol. 134.
14. Frisch, F. E., *The Structure and Reproduction of Algae, Vol. II*, Cambridge University Press, London, 1935.
15. Rajesh, K. M., Mridula, Mendon, R., Gupta, T. R. C., Arun Padiyar and Chandramohan, K., *INFOFISH Int.*, 2002, **1**, 60–64.
16. Dharani, G. *et al.*, *Curr. Sci.*, 2004, **87**, 990–994.
17. Daniel, A., Nagabhusanam, A. K. and Krishnamurthy, P., *J. Bombay Nat. Hist. Soc.*, 1978, **75**, 88.
18. Satpathy, K. K. and Nair, K. V. K., *Indian J. Mar. Sci.*, 1996, **25**, 145–147.
19. De Souza, S. N., *Estuarine Coastal Shelf Sci.*, 1983, **16**, 299–308.
20. Zepp, R. G., In *Marine Chemistry* (eds Gianguzza, A., Pelizzetti, E. and Sammarkano, S.), Kluwer, London, 1997, pp. 329–352.
21. Potemra, J. T., Luther, M. E. and O'Brien, J. J., *J. Geophys. Res.*, 1991, **96**, 12667–12683.
22. McCreary, J. P., Kundu, P. K. and Molinari, R. L., *Prog. Oceanogr.*, 1993, **31**, 81–244.

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## Effect of water stress on seedling growth of four tropical dry deciduous tree species under an elevated CO<sub>2</sub> regime

Due to fossil-fuel burning and deforestation, the concentration of atmospheric CO<sub>2</sub> may exceed 700 ppm by the end of the present century<sup>1</sup>. The elevated CO<sub>2</sub> affects plants either by increasing carbon fixation due to repression of photorespiration and increased substrate supply, or by decreased water loss due to partial closure of the stomata or by CO<sub>2</sub>-driven changes in ecosystem nutrient dynamics and changed soil structure<sup>2</sup>. Dry tropical forests often experience frequent droughts during which an increased soil-water deficit develops<sup>3</sup> and seedlings experience desiccation<sup>4</sup>. The present study investigates the interactive impact of water stress and elevated CO<sub>2</sub> on seedlings of four native tree species, *Acacia catechu* Willd., *Bauhinia variegata* L., *Dalbergia latifolia* Roxb. and *Tectona grandis* L.f. We address two broad questions: (a) Do elevated CO<sub>2</sub> and water stress affect seedling growth differentially in different species? (b) Does the elevated CO<sub>2</sub> interact with water stress in affecting the growth performance of seedlings?

The interactive impact of two levels of CO<sub>2</sub> concentration and four water levels was assessed in a pot culture experiment conducted at the Botanical Garden, De-

partment of Botany, Banaras Hindu University, Varanasi, India (25°18'N, 83°03'E, 129 m asl). One-week-old seedlings of each species were transplanted into earthen pots (1710 cubic cm), one seedling per pot. The soil in the pots was inceptisol (33% sand, 16% clay and 33% water holding capacity (WHC)). Organic C, total N and total P were 2.4, 0.18 and 0.03% respectively. The transplanted seedlings were equally well-watered during the first three weeks. Seedlings were subsequently subjected to four soil moisture levels: 1, ½, ¼ and ¼ WHC following Khurana and Singh<sup>5,6</sup>.

For exposing seedlings to a relatively elevated CO<sub>2</sub> level, the method described by Khurana and Singh<sup>7</sup> and Devakumar *et al.*<sup>8</sup> was followed, in which higher concentration of CO<sub>2</sub> (700–750 ppm) was obtained from decomposition of organic matter. A set of 24 (4 water levels × 3 replicates × 2 sampling dates = 24) pots was used for each species in ambient and elevated CO<sub>2</sub>.

Before exposure of these seedlings to elevated CO<sub>2</sub>, a set of three seedlings was harvested to record the initial growth parameters (0-day harvest). After 30 days

of exposure, three seedlings of each species from each treatment were harvested. Height and leaf area were recorded. Leaf area per plant was obtained as the product of number and area of leaves. Leaf area for each plant species was calculated from regression equations relating leaf area to leaf biomass, developed from destructive harvests of leaves from a separate set of seedlings. Plants were then separated into stem, leaves and roots. All plant parts were oven-dried at 80°C to constant weight. Similarly, after 60 days of exposure, the remaining plants were harvested and final growth data were recorded.

The impact of species, water level, CO<sub>2</sub> concentration and days of exposure was analysed through multivariate ANOVA.

Results of the present study show that growth performance of seedlings significantly differed across species, water stress and CO<sub>2</sub> level. Interactions species × water level, species × CO<sub>2</sub> level and water level × CO<sub>2</sub> level were significant. Water stress had a profound adverse effect on the growth performance of seedlings of all the four tree species. Seedlings of *A. catechu* did not survive at ¼ WHC beyond 30 days and those of *B. variegata* did not