Natural eutrophication and fish kill in a shallow freshwater lake

V. P. Venugopalan, K. Nandakumar, R. Rajamohan, R. Sekar* and K. V. K. Nair†

Marine Biology Programme, Water and Steam Chemistry Laboratory, BARC Facilities, Kalpakkam 603 102, India
*CAS in Botany, University of Madras, Chennai 600 025, India

We record our observations on natural eutrophication and associated fish kill in a natural lake, caused entirely by roosting aquatic birds. Phosphate import via bird droppings led to monospecific blooming of the green alga *Chlorella* sp. in the lake void of any human interference, paving the way for bottom hypoxia and large-scale fish kill.

EUTROPHICATION, a process by which rivers, lakes and coastal seas become increasingly rich in nutrients and plant biomass, is a direct consequence of increased urbanization and changes in land use pattern[1,2]. Several lakes, rivers, estuaries, enclosed bays and seas are known to be undergoing this kind of nutrient enrichment with deleterious consequences[3,4]. The source of nutrients can often be traced to anthropogenic emissions such as agricultural run-off, phosphate-rich detergents, washings from intensive farming units, etc.[5]. The eutrophication that ensues from such causes is referred to as cultural eutrophication. Natural eutrophication, on the other hand, is a slow process from human point of view, taking place over periods of thousands of years[6]. We had an opportunity to observe such a phenomenon in a natural lake. In May 1995, large-scale fish mortality (ca 900 kg) was observed in the Kokilimedu lake and found that most of the dead fish were grass carp (*Ctenopharyngodon* sp.), introduced into the lake about 15 years back. The incident of such a large-scale fish kill in an isolated lake, totally prohibited from human activities, was at first baffling. A preliminary survey showed that the lake was eutrophic. Surface-dissolved oxygen levels were low (about 1.5 mg/l) and temperature was high (about 35°C). Based on such observations it was hypothesized that the fish kill had occurred due to bottom hypoxia which drove fishes to the surface water where the prevailing high summer temperatures killed them. Subsequently, a detailed study was undertaken to estimate the nutrient levels and phytoplankton standing crop in the lake. Factors leading to nutrient enrichment in the lake were ascertained.

The Kokilimedu lake is a shallow perennial freshwater lake, located about 1.5 km from the seacoast at Kalpakkam (60 km south of Chennai), on the east coast of India. It has a spread of 0.6 km^2, with a maximum depth of 2.8 m ($z = 1.3 \pm 0.3$ m). Being located within a protected area, the lake has not been subjected to any human or industrial activity (including fishing) for the past 15 years. There is no human settlement within about 10 km radius of the lake. The lake is fed entirely by rainfall during the two monsoons and has no tributaries leading to it.

Samples of water in duplicate and sediment (cores) were collected from ten stations spanning three transects in the lake in June 1996. Surface water samples were collected in a clean bucket and the subsurface samples using a Nansen water sampler fitted with reversible thermometer. The transparency of the water column was measured using a secchi disc. All water parameters were analysed based on standard methods[7]. Phytoplankton enumeration was done using a haemocytometer. Bird droppings were scraped from tree leaves and analysed for total nitrogen (by CHN analyser) and soluble reactive fractions of ammonia, nitrite, nitrate and *o*-phosphate by dissolving a known amount of the sample in a known volume of distilled water[7].

Sediment cores (18–20 cm long) were taken manually with 2.5 cm dia PVC tubes. The sediment was extruded by gently pushing it out from one end and cutting it into 1 cm sections. Vertical profile of organic carbon and sulphur in the lake sediment was estimated using a Perkin Elmer PE 2400 CHNS Analyser. Analytical precision, in terms of coefficient of variation for 6 replicates, was 1.8% at a carbon level of 1% (by weight).

The water had an average chloride content of 620 and 665 mg l^{-1} and a conductivity of 3040 and 3040 µS cm^{-1} at surface and 1 m depth, respectively (Table 1). Temperature and dissolved oxygen measurements showed that the lake was stratified with respect to temperature and dissolved oxygen, with a surface temperature of 31.8°C and a subsurface (1 m depth) temperature of 29.9°C. Secchi disc transparency was <0.5 m. Among the nutrients, phosphate levels were surprisingly high: 63 µg–P l^{-1} at the surface and 65 µg–P l^{-1} at 1 m depth (Table 2). The respective levels of nitrate were 5.2 and 9.1 µg–N l^{-1}. Chlorophyll *a* values were also uniformly high with a mean of 46 µg l^{-1}. Microscopic examination of the water samples showed that *Chlorella* sp. was the major (97.6%) microalga, along with a few diatoms (1.5%) and

Table 1. Distribution of chloride, conductivity, temperature, dissolved oxygen, and chlorophyll *a* values (mean ± SD) in the Kokilimedu lake during the study

Variables	Surface	1 m depth
Chloride (mg l^{-1})	620 ± 67	664 ± 12
Conductivity (µs cm^{-1})	3040 ± 50	3040 ± 40
Temperature (°C)	31.8 ± 0.7	29.9 ± 0.4
Dissolved oxygen (mg l^{-1})	5.0 ± 1.1	3.6 ± 0.4
Chlorophyll *a* (µg l^{-1})	45.2 ± 13.6	9.4 ± 12.5

†For correspondence.

Table 2. A comparison of nutrient contents (mean ± SD) in the Kokilimedu lake and the reservoir

	Koklimedu lake		
Nutrients	Surface	1 m Depth	Reservoir
Nitrite (μg N l^{-1})	2.7 ± 1.7	2.8 ± 0.6	5.5 ± 1.1
Nitrate (μg N l^{-1})	5.2 ± 3.3	9.1 ± 9.7	167.5 ± 52.3
Phosphate (μg P l^{-1})	62.8 ± 6.5	60.3 ± 16.9	13.6 ± 7.8
Silicate (μg Si l^{-1})	896 ± 328	1035 ± 582	2675 ± 1662

Table 3. Phytoplankton compositon in Kokilimedu lake during the study

Group	Species	% Composition
Green algae	*Chorella* sp.	97.6
	Kircheriella obesa	0.3
	Ankistrodesmus sp.	0.2
	Tetradesmus sp.	0.2
	Scenedesmus sp.	0.2
Diatoms	*Nitzschia* sp	0.9
	Navicula sp.	0.2
	Achnanthes sp.	0.1
	Cymbella sp.	0.2
	Amphora sp.	0.1

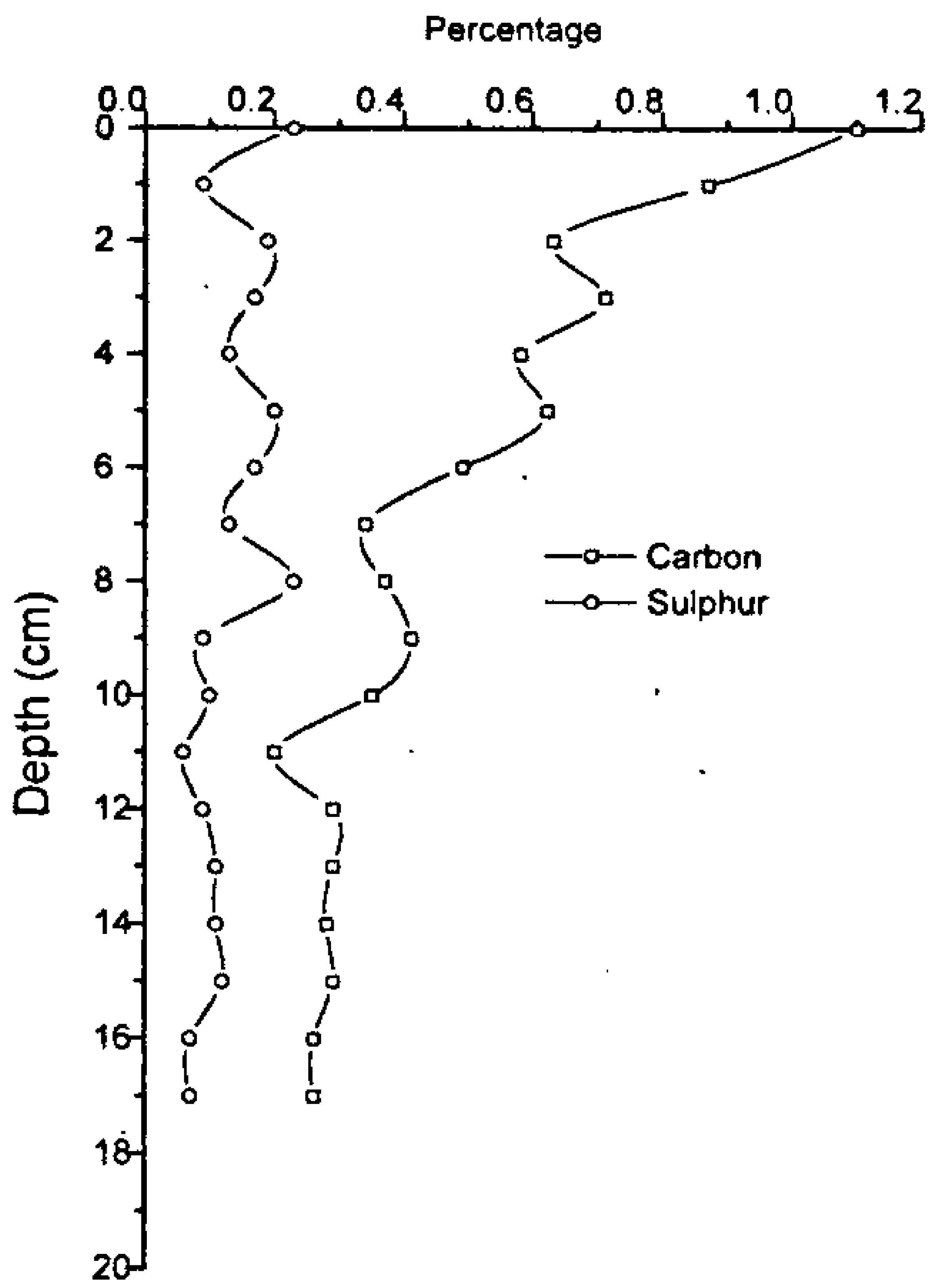

Figure 1. Vertical profile (typical) of organic carbon and sulphur in the lake sediment. Data given are for Sta #2.

other green algae (0.9%) (Table 3). The sediment samples were all sandy in composition. Typical profile of organic carbon and sulphur contents is shown in Figure 1.

According to the generally accepted eutrophication guidelines[8] (total $P > 20\ \mu g\ l^{-1}$, chlorophyll $a > 10\ \mu g.l^{-1}$, Secchi disc transparency < 2 m), the Kokilimedu lake can be reckoned to be eutrophic. The N:P (nitrate to *o*-phosphate) ratios are far lower than the Redfield ratio and indicate an import of phosphate into the lake. Since anthropogenic routes of nutrient supply into the Kokilimedu lake are discounted, the only possible source is by natural enrichment. It is observed that many overhanging tree (e.g. *Ficus* sp. and *Casuarina equisetifolia*) branches are colonized by a large population of aquatic birds, especially little cormorants *Phalacrocorax niger*. Cormorants are gregarious birds and build nests on trees. They fly long distances in search of food and return to their nest after feeding[9]. They are well-known guano producers, who withhold excreta for nest building[10]. Bird guano is rich in nitrogen (11–16%) and phosphate (8–12%)[11]. The nutrient analyses showed that the droppings were indeed rich in nutrients (total N 13.8%, NH_3 19.3 μg N g^{-1}, NO_2 3.7 μg N g^{-1}, NO_3 3.7 μg N g^{-1}, PO_4 3.0 mg P g^{-1}). The birds routinely feed in the nearby Sadras and Edaiyur backwaters (ca 10 and 3 km away, respectively) and return to their nests by the banks of the Kokilimedu lake. This leads to a net import of nitrogen and phosphorus into the lake, causing a phytoplankton bloom.

We compared the nutrient levels in the Kokilimedu lake with those in a nearby freshwater reservoir situated about 5 km away, within the same complex. This artificial reservoir (spread 0.17 km^2, hold-up 28400 m^3 receiving water from a sub-soil river bed of the river Palar) is used for reactor cooling. A comparison of data (Table 2) shows that the Kokilimedu lake has significantly high levels of *o*-phosphate. Earlier, Ryther and Dunstan[12] have shown that phosphate is an index of organic pollution, resulting from duck farms in the Moriches Bay, Long Island.

Organic carbon and sulphur in sediment cores have been used by earlier workers to reconstruct eutrophication history[13,14]. Our observations indicate a gradual increase in the sediment organic carbon in recent sediments (Figure 1). Sediment sulphur levels of > 1% indicate anaerobic sedimentary conditions[14]. In the present study, the sediment sulphur levels do not point to such conditions. However, eutrophic conditions can result in decline of species diversity of the phytoplankton and increase in single species dominance, as overall population and biomass increase[8]. This is evident from the monospecific explosion of *Chlorella* in the lake. The lake water phytoplankton gave a low value of Shannon's species diversity index (0.15) and high value of species dominance index (0.95). The selection of a green alga like *Chlorella* sp. in the lake is probably due to its inherent low nitrogen to phosphorus ratio which matches well with the low N:P ratio of the lake water. In Moriches Bay, receiving effluents from duck farms, Ryther and Dunstan[12] have reported that the phytoplankton consisted of an almost pure culture of the green algae *Nannochloris atomus* and *Stichococcus* sp. and suggested that low C:N ratio of the Chlorophyceae was partly responsible for their predominance. It is interesting to note that such natural eutrophication and associated bottom hypoxia, combined with surface warming and thermal stratification, could lead to fish kills in a water body which is entirely free from human intervention. Earlier, Leah *et al.*[15] have reported a case of phosphate enrichment in a brackish water environment (Hickling Broad), caused mainly by excretion of migratory gulls. To our knowledge, this is the first report of a case of eutrophication and associated fish kill in a lake caused solely by natural processes mediated by birds.

1. Golterman, H. L. and N. T. de Oude, in *The Handbook of Environmental Chemistry, Part A. Water Pollution* (ed. Hutzinger O.), Springer-Verlag, Berlin, 1995, pp. 79–124.
2. Rosenberg, R., *Mar. Pollut. Bull.*, 1985, **16**, 227–232.
3. Hasler, A. D., *Ecology*, 1947, **28**, 383–391.
4. Vollenweider, R. A., *Water Qual. Bull.*, 1981, **6**, 59–61.
5. Harrison, R. M., *Pollution: Causes, Effects and Control*, Royal Society of Chemistry, Cambridge, 1992, p. 393.
6. Turk, A., Turk, J., Witter, J. T. and Witter, R., in *Environmental Science*, W. B. Saunders Co., Philadelphia, 1974, p. 563.
7. Parsons, T. R., Yoshiaki, M. and Lalli, C. M., *A Manual of Chemical and Biological Methods for Seawater Analysis*, Pergamon Press, Oxford, 1984, p. 173.
8. Mason, M. F., in *Pollution: Causes, Effects and Control* (ed. Harrison, R. M.), Royal Society of Chemistry, Cambridge, 1992, pp. 99–125.
9. Dharmakumarasami, R. S. and Lavkumar, K. S., in *Sixty Indian Birds*, Publication Division, Ministry of Information and Broadcasting, Govt. of India, New Delhi. 1972, pp. 56–58.
10. Baretta-Bekker, R. G., Duursma, E. K. and Kuipers, B. R., in *Encyclopaedia of Marine Sciences*, Springer-Verlag, Berlin, 1992, p. 311.
11. Anonymous, in *The New Encyclopaedia Britannica. vol. 5. Micropaedia*, 15th edn., Encyclopaedia Britannica Inc., Chicago, 1994, p. 982.
12. Ryther, J. H. and Dunstan, W. M., *Science*, 1971, **171**, 1008–1013.
13. Turner, R. E. and Rabalais, N. N., *Nature*, 1994, **368**, 619–621.
14. Cooper, S. R. and Brush, G. S., *Science*, 1994, **214**, 992–996.
15. Leah, R.T., Moss, B., Forrest, D. E., *Int. Rev. Hydrobiol.*, 1978, **63**, 291.

ACKNOWLEDGEMENTS. We thank Shri. L. V. Krishnan, Director and B. Saha, S. R. and H. P. G., IGCAR for extending facilities during the cruise.

Received 6 December 1997; revised accepted 4 March 1998.