13. Kachroo, P., Sapru, B. L. and Dhar, U., *Flora of Ladakh: An Ecological and Taxonomic Appraisal*, Dehra Dun, 1977, p. 172.
14. Naithani, B. D., *Flora of Chamoli*, New Delhi, 1984, vols 1, 2, p. 796.
15. Aswal, B. S. and Mehrotra, B. N., *Flora of Lahul-Spiti* (*A Cold Desert in North West Himalaya*), BSMS Publications, Dehra Dun, 1994, p. 761.
16. Singh, S. K. and Rawat, G. S., *Flora of Great Himalayan National Park, Himachal Pradesh*, BSMS Publications, Dehra Dun, 1999, p. 304.
17. Gaur, R. D., *Flora of the District Garhwal North West Himalaya (with ethnobotanical notes*), Trans Himalayan Publications, Srinagar, Garhwal, 1999, p. 811.
18. Rawat, G. S., *Parks*, 1998, **8**, 27–36.
19. Rawat, G. S. and Adhikari, B. S., Report submitted to the ICIMOD, Nepal and Wildlife Institute of India, Dehra Dun, 2002, p. 32.
20. Sundriyal, R. C., *Environ. Ecol.*, 1989, **7**, 247–249.
21. Negi, G. C. S., Rikhari, H. C., Ram, J. and Singh, S. P., *J. Appl. Ecol.*, 1993, **30**, 383–394.
22. Rawat, G. S. and Uniyal, V. K., *Environ. Conserv.*, 1993, **20**, 164–167.
23. Sathyakumar, S., Ph D thesis, Saurashtra, University, Rajkot, 1994, p. 244.
24. Fox, J. L., Nurbu, C., Bhatt, S. and Chandola, A., *Mt. Res. Dev.*, 1994, **14**, 39–60.
25. Kala, C. P. and Rawat, G. S., *Trop. Ecol.*, 1999, **40**, 69–74.

ACKNOWLEDGEMENTS. We thank the Director, Wildlife Institute of India for facilities and encouragement. We also thank Dr J. L. Fox, Dr Y. V. Bhatnagar and two unknown referees for their valuable suggestions and comments.

Anjali Awasthi, Sanjay Kr. Uniyal, Gopal, S. Rawat and S. Sathyakumar are in the Wildlife Institute of India, P.O. Box #18, Chandrabani, Dehradun 248 001, India*
**For correspondence.*
e-mail: awasthy_9@yahoo.com

SCIENTIFIC CORRESPONDENCE

Emergence of a *Microcystis* bloom in an urban water body, Kandy lake, Sri Lanka

Restoration and management of eutrophic water bodies located in urban centres are priorities in the socio-economic agenda of local governments, urban councils, city missions, etc. A variety of bottom-up and top-down strategies have been tested (e.g. diversion of effluent outfalls, dredging, aeration, chemical treatment, bio-manipulation, watershed management, etc.) around the world, and there are success stories and failures[1,2]. Failures in restoration and sustainable management of eutrophic, urban water bodies, especially in developing countries are primarily linked with poor knowledge of hydraulic balance, limnological processes and dynamics of particular aquatic systems, and disturbances in the watershed or within the water body triggered by human activities. Trophic evolution and subsequent eutrophication is fundamentally a chronological phenomenon[3]. However, sudden outbreaks of algal blooms in eutrophic water may be linked with other unknown factors[4]. Silva and Schiemer[5] emphasize the human factor as the fourth dimension of reservoir limnology in the tropics. Hydraulic balance is rigorously manipulated in the tropics, resulting in sudden changes in limnological processes and dynamics[6]. Shallow man-made water bodies in monsoon Asia show a distinct annual trophic shift from mesotrophic to eutrophic, resulting from rainfall-bound filling and progressive water release to meet the demand in the command area[7].

A chronic cyanobacteria species, *Microcystis aeruginosa* which had some toxin-producing strains (L. P. Jayatissa, pers. commun.) emerged as a bloom and formed into a thick scum with the onset of the southwest monsoon in May 1999, in an aesthetic urban water body popularly known as the Kandy lake located in the tourist capital of Sri Lanka. The emergence of this bloom in the Kandy lake has become a major socio-political issue because of its very location, adjoining the world-famous Buddhist Temple, Dalada Maligawa where the sacred tooth relic of Lord Buddha is preserved. The unique characteristics of this water body and its watershed, and limnological structure and dynamics observed since 1997 to the dry season of 2002 are highlighted here to justify the most likely scenario for the sudden emergence of a *Microcystis* bloom. Some appropriate and important strategies that could be implemented for the restoration and management of eutrophic water bodies of this nature which are common in south and southeast monsoonal Asia, are also discussed.

The Kandy lake (7°18′N; 80°39′E) located at 510 m msl was constructed by the last King of the Sinhalese monarchy between 1810 and 1812 by forced labour, to enhance the panoramic beauty of the royal palace complex and the surrounding temples. It is 18 ha in area and 13 m in maximum depth and has a capacity of 0.348 MCM within a perimeter of 3.25 km. Kandy, the second largest city and also known as the hill capital of Sri Lanka, is presently renowned as one of the key heritage cities in the world because of its cultural legacy, archaeological importance and aesthetic value. Located adjoining the most esteemed religious centre, fishing and bathing are prohibited in the lake and the lake water is neither used for irrigation nor for other domestic purposes. Two small brooks feed the lake, and water spills over only during the rainy season (October–December). Evaporation losses are high during the dry months (February–March). Further, the lake which has two morphologically distinct basins (deep and shallow), has no prominent littoral zone and the entire perimeter is surrounded either by public roads or cement and concrete walls. Erosion and subsequent transport of sediment have resulted in substantial siltation of about 1.5 m sediment thickness in the central part of the deep basin. In addition, waste water drains into the lake via 28 inlets, including small-scale hotels, hospitals, schools and temples.

The lake has not been subjected to regular monitoring for its limnology or water quality since construction. Preliminary limnological studies carried out from January 1979 to December 1980 on some physico-chemical characteristics also described its meso and macro aquatic fauna[8]. Consequently, it has been reported that the Kandy lake has been enriched with P and N compounds[9] and polluted by some heavy metals[10]. It was further reported that the lake has been faecally contaminated to a greater extent[9] (Table 1). However, occurrence of an algal bloom or sudden mass mortality of fish within the water body had never been reported over a period of nearly two centuries. A detailed study was commenced in 1997, on temporal and spatial variations of physico-chemical limnology and phytoplankton diversity. In addition, primary productivity of phytoplankton, zooplankton diversity and fish species composition were examined intermittently.

The results showed that the lake was permanently stratified with a clinograde oxygen profile and there was a thick anoxic layer in the deeper basin beyond 6 m depth during calm days (Figure 1). Nitrogen was enriched mainly with ammonium-N and the lake water had a high turnover rate of dissolved phosphorus (Table 1). In addition, a slight physico-chemical gradient is established from inflow to outflow. The phytoplankton assemblage showed poor species diversity with two dominant species, a filamentous diatom, *Aulacoseira granulata* and green algae, *Pediastrum simplex*, with a moderately dominant cyanobacteria species, *Merismopedia punctata*. *A. granulata* and *P. simplex* showed rainfall-bound seasonal oscillation. The photosynthetic activity of the water body was confined to the uppermost layers with a prominent surface inhibition and subsurface maxima (Figure 1). Zooplankton was dominated by small-body-size rotifers with a few species of cyclopoid copepods and cladocerans. With respect to fish fauna, the Kandy lake is more or less a monoculture of cichlid fish, mainly *Oreochromis mossambicus* and *Oreochromis niloticus*.

Table 1 shows some limnological characteristics of the lake scattered over a period of twenty years before the emergence of *M. aeruginosa* bloom and collected on a regular basis from 1997 to 2002. Figure 1 *a* is a schematic diagram of the vertical profile of the deep basin which shows oxygen distribution, photosynthetic profile and Secchi disk visibility during high water level and proportionate sediment layer. Similar parameters are depicted in Figure 1 *b* under low water level. It is not possible to diagnose the trends in the enrichment process over the last two decades, since there are huge gaps of data on nutrients and trophic characteristics. Nevertheless, the Kandy lake was hypertrophic with a large pool of nutrients, but showed an ecological stability perhaps due to a balance in removal and loading of essential nutrients such as N, P and dissolved Si for the growth of phytoplankton. Apparently, several factors have caused the recent rapid enrichment of the lake. Increase in human population may make a direct or indirect contribution to the nutrient pool. In addition, the resident cormorant population (about 250) and roosting bats (about 2500) make direct contributions to the nutrient pool. Some of the tourist hotels discharge untreated sewage directly into the lake, though it is illegal. The peculiar feeding behaviour of cichlid fish may also mobilize sediment-bound phosphorus from the shallow area.

Water level of the lake was dropped by about 1m in March 1999 for the purpose of constructing a lower level sluice gate at the outflow. Towards the end of April 1999, *M. aeruginosa* appeared as a bloom at the shallow inflow area with the onset of the southwest monsoonal wind. The bloom concentrated in the shallow inflow area and the scum drifted to the small edges and bays. The intensity of the bloom was maximum during early July and chlorophyll-*a* concentrations increased up to 100 $\mu g\ l^{-1}$ in the shallow area. While removing the dead scum of the bloom manually, the water level increased gradually and reached its maximum towards August because of several scattered thunder showers. The bloom disappeared gradually, but *M. aeruginosa* has been retained since then in moderate densities. During the following inter-monsoonal rain (October–December), the two species of phytoplankton that showed a rhythmic oscillation (i.e.

Table 1. Limnological characteristics of Kandy lake scattered over a period of twenty years before the emergence of *Microcystis aeruginosa* bloom and collected on a regular basis from 1997 to 2002

Parameter	1979	1986	1991	1997	1998	1999	2000	2001	2002
Temperature (°C)	24.5			27.2	27.4	26.8	26.9	26.7	26.8
pH	7.14	8.3	8.12	8.01	8.04	8.21	8.02	8.12	8.14
EC (µS)	155	220	225	220	248	241	242	245	248
Turb. (NTU)		13	7.2	11	16	12	12.5	13.2	14.1
SD (cm)				109	105	95	110	95	105
Alk. (mg l^{-1})	1.8	99		112	118	120	118	112	129
NO_2-N (µg l^{-1})		19		30	42	20	16	20	14
NO_3-N (µg l^{-1})		7000	2860	1420	412	480	340	145	168
NH_4-N (µg l^{-1})		700		250	280	295	260	212	292
DP (µg l^{-1})	9			5	4	4	5	6	8
TP (µg l^{-1})		73	320	52	38	52	54	48	78
BOD_5 (mg l^{-1})			4.5	3.45	3.8	4.2	3.8	4.8	56
Chlorophyll-*a* (µg l^{-1})				24	28	54	26	28	32
T. coliform*		> 1000	> 1000	> 1000	> 1000	> 1000	> 1000	> 1000	> 1000
F. coliform*		830	770	810	700	790	800	600	> 400

*, Counts per 100 ml.

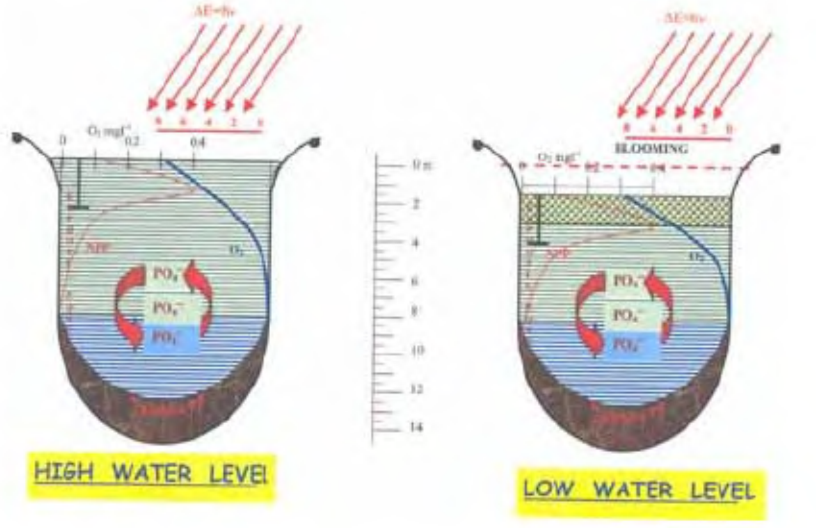

Figure 1. Schematic diagram of limnological processes taking place in Kandy lake during high and low water levels.

A. granulata and *P. simplex*) re-established themselves with several minor species such as non-nitrogen fixing cyanobacteria, *Merismopedia punctata*. Although *M. aeruginosa* appeared throughout the following years, it did not form a bloom as in the previous year.

The most likely limnological interpretation for the sudden emergence of *M. aeruginosa* is as follows. The lowering of the water level during the dry spell of 1999 may have resulted in greater access for *M. aeruginosa* to utilize phosphorous mobilized in the anoxic deeper layer, as shown in Figure 1. It is known that *Microcystis* shows good buoyancy; it comes to the surface and drifts along the wind direction. The schematic model shown in Figure 1 and the available limnological information clearly demonstrate that the biomass regulation or prevention of emergence of *Microcystis* biomass in Kandy lake is a combination of both top-down and bottom-up approaches[11]. Multiple techniques may also be relevant in the case of restoration, since the urban lakes are different from other man-made water bodies[1]. Nevertheless, sound knowledge of hydrology, limnological processes and dynamics of the water body and the human activities taking place in the watershed plays a key role in restoration and management.

1. Annadotter, H., Cronberg, G., Aagren, R., Lundstedt, B., Nilsson, P. and Ströbeck, S., *Hydrobiologia*, 1999, **395/396**, 77–85.
2. Lammens, E. H. R. R., *Hydrobiologia*, 1999, **395/396**, 191.
3. Pilaou, E. C., *Fresh Water*, The University of Chicago Press, 1998, p. 175.
4. Lewis, W. M., *Water Resour. Res.*, 1981, **17**, 169–181.
5. Silva, E. I. L. and Schiemer, F., *ACIAR Proc.*, 2001, **98**, 215.
6. Schiemer, F., Amarasinghe, U. S., Frouzova, J., Sricharoendham, B. and Silva, E. I. L., *ACIAR Proc.*, 2001, **98**, 111.
7. Talling, J .C. and Lemolle, J., *Ecological Dynamics of Tropical Inland Waters*, Cambridge University Press, Cambridge, 1998, p. 441.
8. De Silva, P. K. and De Silva, K. H. G. M., *Archaeol. Hydrobiol.*, 1984, **102**, 53.
9. Dissanayake, C. B., Semaratne, A., Weerasooriya, S. V. R. and De Silva, S. H. G., *Environ. Int.*, 1982, **17**, 343.
10. Dissanayake, C. B., Rohana Bandara, A. M. and Weerasooriya, S. V. R., *Environ. Geol. Water Sci.*, 1986, **10**, 81.
11. McQueen, D. J., Johannes, M. R. S., Post, J. R., Stewart, T. J. and Lean, D. R. S., *Ecol. Monogr.*, 1989, **59**, 289.

Received 5 January 2003; revised accepted 25 June 2003

E. I. L. SILVA

Institute of Fundamental Studies,
Hantana Road,
Kandy, Sri Lanka
e-mail: sil@ifs.ac.lk

Cadra cautella Walker (Lepidoptera: Crambidae: Phycitinae) – a pest on *Parkia timoriana* (DC.) Merr. in Manipur

Among the numerous less familiar food used by the local communities in northeast India is a tree legume, commonly known as tree beans (*Parkia timoriana*) or yongchak by the locals in Manipur. The tree bean, *P. timoriana* (DC.) Merr. syn. *P. roxburghii* G. Don belongs to the family Leguminosae and sub-family Mimosoideae[1]. It is one of the most common multipurpose trees in Manipur having high commercial value, and is commonly grown in the backyard of houses, *jhums* and forests throughout Northeast India[2]. It flowers during the months of September–October and the onset of fruiting starts from November onwards. The pod is available from November till April, and is consumed in all its developmental stages starting from the green, tender pods to the matured, black seeds, fresh or cleaned and sun-dried for future use during the off-season. The associating pungent smell in the seeds is due to the presence of thiazolidine-4-carboxylic acid (TCA, thioproline), a cyclic sulphur-containing amino acid[3]. Thioproline is known to be