Sri Lanka J. Aquat. Sci. **10** (2005): 55-71

Limnology of Kandy Lake before the outbreak of a cyanobacteria bloom in May 1999. III. Phytoplankton composition and succession

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Abstract

Composition and succession of the phytoplankton community in Kandy lake were examined from September 1996 to August 1998, with a view to understand the community structure and its seasonal and spatial distribution patterns. Thirty-seven species of phytoplankton belonging to eight taxonomic groups were identified. The number of species per sampling occasion ranged from 15 to 25 with an average of 20. There were 15 Chlorophyceae species but only seven species were important in the community structure. *Pediastrum simplex* appeared as either dominant or sub-dominant species. Cyanophyceae, the second most important group was represented by nine species with moderate densities of *Micorcystis aeruginosa* and *Merismopedia punctata*. The diatom, *Aulacoseira granulata*, was also found as either a dominant or a sub-dominant species with three other diatom species of minor importance.

The occurrence of *A. granulata* and *P. simplex* showed a rhythmic oscillation under wet and dry weather conditions until the latter was curtailed by other species from April 1998 on wards. The phytoplankton density was low during the peak rainy season. Four functional species of phytoplankton were identified. These were a) large chain forming centric diatom, *A. granulata* dominating during the wet weather (K-strategist); b) a colony forming Chlorophyceae, i.e., *P. simplex* common during the dry weather (K-strategist); c) Colony forming Cyanobacteria namely scum forming *M. aeruginosa* (r-strategist); and d) *M. punctata*, a small colony forming non-heterocystous cyanobacteria, appearing in moderate numbers throughout the year (K-strategist).

Introduction

Phytoplankton is a key component in the pelagic zone reflecting the trophic status in both temperate and tropical standing waters. In the humid tropics, they play an additionally important role in the pelagic food web as a source of food for some fish (Hofer and Schiemer 1983; Payne 1986). It has been hypothesized that there is a progressive decline in phytoplankton diversity towards the tropical latitudes (Lewis 1996). Studies in floodplain lakes in Papua New Guinea have shown extremely high diversity of phytoplankton representing summer communities of temperate lakes with a large number of tropical taxa including pantropical and regional endemic elements (Vyvermann 1996). Phytoplankton communities in very large tropical water bodies are mainly dominated by non-motile species (Lewis 1978; Carney et al. 1987; Talling 1986). The role of seasonal hydrology on phytoplankton abundance was evident from Sri Lanka where plankton studies have a long history (Holsinger 1955b). Species succession have been reported during the early development of man-made lakes (van der Heide 1973; Biswas 1978; Matsumara-Tundisi et al. 1991; Branco and Senna 1996). Dissimilarities in species composition and diversity of phytoplankton in adjoining reservoirs have also been reported from Sri Lanka (Silva and Wijeyaratne 1999).

There is a high diversity of standing water bodies in the tropical latitudes. However, in the tropics, studies on distribution, composition and succession of phytoplankton in relation to environmental gradients are limited (Lewis 1978; Biswas 1978; Henry et al. 1984; Ramberg 1987; Mukankomeje et al. 1993; Branco and Senna 1994,1996). A few studies have addressed composition of phytoplankton communities and their temporal changes under eutrophic conditions (Thornton 1982; Sugunan 1980: Zafar 1986· Osborne 1991; Alvarez-Cobelas and Jacobsen 1992). In Sri Lanka, taxonomy of freshwater phytoplankton is well known (West and West 1902; Fritsch 1907; Lemmermann 1907; Crow 1923a, 1923b; Holsinger 1955a, 1955b; Foged 1976; Rott 1983; Rott and Lenzenwerger 1994). A few studies have been carried out to determine the succession of phytoplankton in lowland irrigation tanks (Rott et al. in press) and newly build highland reservoirs (De Silva 1993a, 1993b; Rott et al. in press). Phytoplankton in Kandy lake, an urban man-made aesthetic water body categorized as eutrophic (Silva 1996) were examined for two consecutive years in relation to some environmental factors in order to determine species composition and their seasonal and temporal distribution patterns.

Materials and Methods

Net samples were collected from four sites of the water body using 10 µm mesh plankton net and fixed in Lugol's solution for taxonomic examination. Simultaneously 100 ml of sub-surface water samples from four stations and from several depths of the deepest point were fixed in Lugol's solution for the enumeration of colony or filament units. In addition, water samples from respective sites and depths were processed in the field for laboratory analysis of the chlorophyll-a. In the laboratory, net samples fixed in Lugol's solution were examined under Olympus research microscope (Model BHS) for the identification of taxonomic groups using available keys (Abeywickrama 1979) and other publications (Rott 1983; Rott and Lenzenwerger 1994). Counting of phytoplankton was carried out under an inverted microscope (Olympus) using Sedgwick-rafter cells. Rainfall data of Kandy were obtained from the Department of Meteorology. Species composition and densities were analyzed for three weather conditions, i.e., rainy (October-January), moderately rainy (May-September) and dry (February-April) periods based on the annual rainfall pattern in order to determine seasonal patterns and succession.

Results

Thirty-nine species of phytoplankton belonging to eight taxonomic groups were identified during the study period. The number of species per sampling occasion ranged from 15 to 25 with an average of 20. Some of these common species are shown in Plate 1. The most abundant species in terms of total colonies or filaments per litre was denoted as the dominant species (d) and the next abundant species was ranked as the sub-dominant (s) species. When a species is common and found in more than 1% of the total density, it was considered as present in moderate numbers (p). Common species present in <1% of total density were considered as those present in small numbers (i). Phytoplankton found occasionally in small numbers, i.e., less than 0.1% of the total density were symbolized as rare (r) species and those found occasionally in very small numbers were considered as very rare species (v). Table 1 shows the occurrence of different species of phytoplankton at different densities during the three weather conditions. Figure 1 depicts the relative abundance of major taxa of phytoplankton in Kandy lake during the study period. A total of fifteen species of the family Chlorophyceae and nine species of the family Cyanophyceae were identified during the study period. In addition, there were four species of diatoms and three species of Euglenophyceae. Desmids (Family: Zygnemaphyceae) and Tribiophytes (Family. Xanthophyceae) were represented by two and one species respectively. The families Chrysophyceae and Dinophyceae were represented by only one species each.

Of the fifteen species of Chlorophyceae, *Pediastrum simplex* appeared as the dominant or sub-dominant species from the beginning of the study until March 1998 (Fig. 1). *Coelastrum reticulatum* appeared in moderate densities from September to November 1996 and then totally disappeared from the assemblage until May 1998 and became the dominant species in June 1996 and disappeared again. *Coelastrum indicum,* also appeared intermittently in small densities. More or less similar patterns were found for *Coenococcus* sp. and *Scenedesmus* sp. Rest of the Chlorophyceae species were rare in the phytoplankton assemblage during

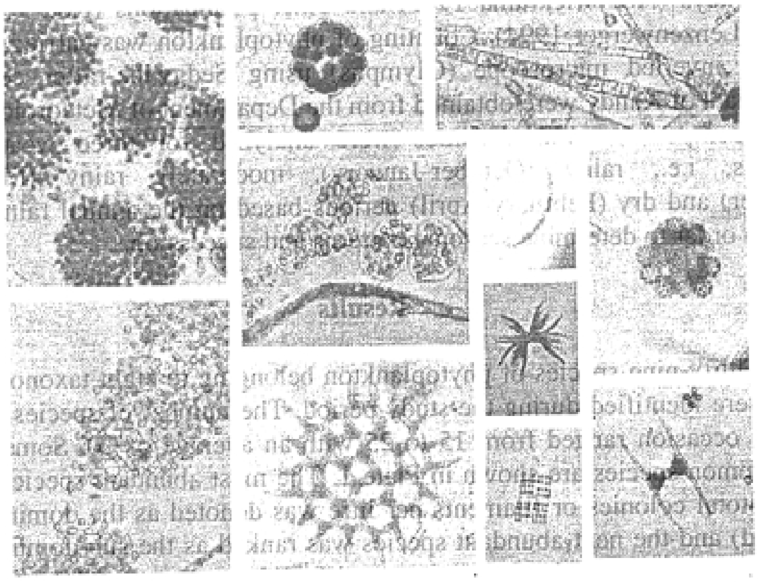

Plate 1. Common phytoplankton species found in the Kandy lake.

1. *Microcystis aeruginosa*
2. *Microcystis flos-aquae*
3. *Ceolastrum indicum*
4. *Aulacoseira granulata*
5. *Microcystis wesenbergi*
6. *Closterium* sp.
7. *Ankistrodesmus* sp.
8. *Coelastrum* sp.
9. *Pediastrum simplex*
10. *Merismopaedia punctata*
11. *Staurastrum* sp.

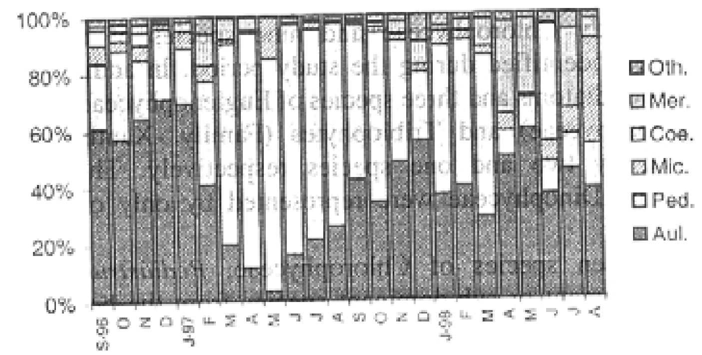

Figure 1. Relative abundance of major taxa in Kandy Lake under wet, dry and moderately rainy seasons during the study. Aul. : *Aulacpseria*; Ped. : *Pediastrum*; Mic. : *Microcystis*; Coe. : *Coelastrum*; Mer. : *Merismopedia*; Oth. : Others.

Table 1. The occurrence of phytoplankton in Kandy Lake during, the rainy, dry and moderately rainy seasons.

Taxa	rainy	dry	mod	rainy	dry	mod
Cyanophyceae						
01. *Aphanizomenon* sp[A]		I	V	p	p	I
02. *Aphanocapsa* sp[D]	i	I	I	i	i	I
03. *Chroococcus* sp[B]	i	I	I	i	i	I
04. *Coelosphaerium* sp[B]	i	P	S	p	p	S
05. *Merismopedia punctata*[A]	p	P	I	i	p	P
06. *Microcystis aeruginosa*[A]	i	I	I	i	i	I
07. *Microcystis flos aquae*[B]	i	I	I	i	i	I
08. *Microcystis incerta*[B]	i	I	I	i	i	I
09. *Microcystis wesenbergi*[B]	i	I	I	i	i	I
Dinophyceae						
01. *Peridinium* sp[D]	v		V	i		I
Diatomophyceae						
01. *Aulacoseira granulate*[A]	d	S	S	d	s	S
02. *Cyclotella* sp[B]	i	V	I	v	v	I
03. *Urosolenia* sp[B]	r	R	R	r	r	R
04. *Synedra acus*[B]	r	R	R	r	r	R
Chrysophyceae						
01. *Mallomonas* sp[D]	r		R	r	r	
Chlorophyceae	i	I	V	i	i	I
01. *Ankistrodesmus* sp[B]	i	I	I	i	i	I
02. *Botryococcus* sp[C]	r	R	R	r	r	R
03. *Chlamydomonas* sp[D]	i		I	i	i	I
04. *Coelastrum indicum*[B]	i	P	P	i	i	P
05. *Coelastrum reticulatum*[A]	i		I	i	i	I
06. *Coenococcus* sp[B]	i	I	I	i	i	I
07. *Kichneriella* sp[D]		R	R		r	
08. *Monoraphidium* sp[C]			R	r	i	I
09. *Oocystis* sp[D]	r		R		r	
10. *Pediastrum duplex*[D]			R			
11. *Pediastrum simplex*[A]	s	D	D	s	d	P
12. *Pediasturm tetras*[D]	r				r	
13. *Scenedesmus* sp[B]	r	R	R	i	i	I
14. *Tetraedron minimum*[D]		R		r	r	
15. *Volvocalese* sp[D]		R			r	
Zygnemaphyceae						
01. *Closterium* sp[B]	i	I	I	i	i	I
02. *Staurastrum* sp[B]	r	I	R	r	i	R

Table 1. Continued.

Xanthophyceae					
01. *Isthmochloron gracile*[D]		R		r	r
02. *Pseudostaurastrum* sp[D]			R		r
Eugenophyceae					
01. *Euglena* sp[D]			R	r	
02. *Phacus* sp[D]			R	r	
03. *Trachelomonas* sp[D]	r	R			r

A- abundant throughout; B- common throughout in low numbers; C- occasionally become common; D-rare in occurrence; d-dominant; s-sub dominant; p- Commonly occur in large numbers; i- Commonly occur in low numbers; v- Found occasionally in very small numbers; r- Found occasionally in small numbers

the study period. Of the Cyanophyceae, the genus *Microcystis* was represented by four species (Table 1). *M. aeruginosa* was found in moderate densities from the beginning of the study until April 1997 and became sub-dominant. In the subsequent months, its density reduced further and remained in moderate numbers and reappeared as the sub-dominant species in August 1998. *Merismopedia punctata* was also found as a common Cyanophyceae species in the phytoplankton assemblage with a more or less similar temporal abundance to that of *A. aeruginosa*. It became sub-dominant thrice towards the end of the study. The other three species of the genus *Microcystis* were common throughout the study. However, they were found in relatively small densities. The other species of Cyanophyceae were found in very small numbers and their occurrence was irregular.

Of the four diatom species found in the Kandy lake, the rod-shape centric diatom, *Aulacoseira granulata*, was dominant from September 1996 to February 1997 and reappeared as the dominant species in November and December 1997. *A. granulata* became dominant again from April to August 1998 except in June when it was suppressed by *C. reticulatum*. Of the other three species of diatoms, *Synedra* sp and *Urosolenia* sp. were found throughout the study period but in small numbers (Table 1). Three species of Euglenophyceae (i.e., *Euglena* sp., *Phacus* sp. and *Trachelomonas* sp.) and two species of Xanthophyceae (i.e., *Isthmochloron lobulatum* and *Pseudostraurastrum* sp) were rare. Two species of desmids (i.e, *Closterium* sp, and *Stauratsrum* sp) were common throughout the study period but occurred in relatively low densities. *Mallomonas* sp. and *Peridinium* sp. that belong to the families Crysophyceae and Dinophyceae respectively were also rare.

Figure 2 depicts the densities of phytoplankton and rainfall data for each month. Average rainfall during the rainy season was about 900 mm whereas it was less than 300 mm during the dry period. The rainfall during

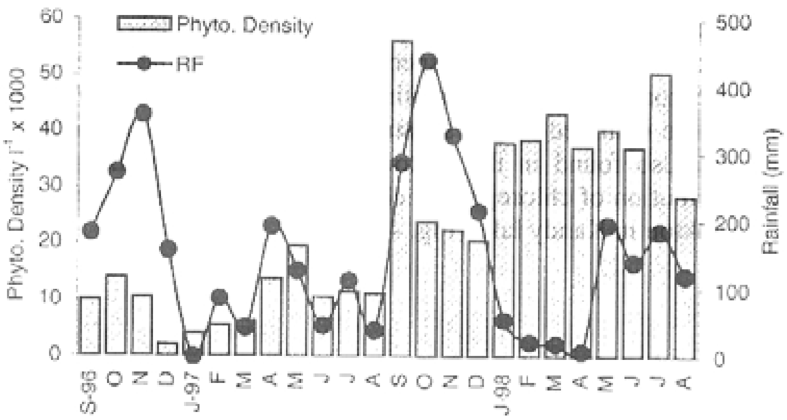

Figure 2. Monthly variations in density of phytoplankton in Kandy lake and total monthly rainfall.

moderately rainy season was between 300 mm and 900 mm. Phytoplankton densities showed a progressive increase over the time during the study period (Fig. 2). The total density was lowest in December 1996 (2,098 colony/filament units l^{-1}) and renamed at a level less than 7,000 colony/filament units l^{-1} until March 1997 (Fig. 2). Then the phytoplankton density increased gradually and reached the maximum density of 56,100 colony/filament units l^{-1} in September 1997. The density decreased in the following month by 50% with the increasing rainfall and it was 20,500 in December 1997.

Figure 3 illustrates the relative abundance of dominant phytoplankton taxa in Kandy lake under three different weather conditions. *A. granulata* was dominant from the beginning of the study until January 1997 under wet weather conditions and *P. simplex* appeared as the dominant species in February and remained so until October 1997 under dry and moderately rainy conditions. *A. granulata* reappeared as the dominant species from November to December 1998 during second rainy season. The relative abundance of *P. simplex* and *A. granulata* was more or less similar during the second dry period and *M. punctata* that was found in the water body in small numbers appeared in large numbers during this period (Fig. 3). Although the relative abundance of *A. granulata* was high (49%) from May to August, 1998 (second moderately rainy period), *P. simplex*, *M. punctata*, *C. reticulatum* and *M. aeruginosa* remained in more of less equal densities.

Vertical distribution pattern of major phytoplankton species and chlorophyll-a content at the deepest point of the Kandy lake are shown in Figure 4. Most of the *Microcystis* species were found in the upper layers in the euphotic zone during the sampling time whereas *P. simplex* and *A. granulata* were confined to the subsurface layers i.e., 3-4 m in depth. *P. simplex* was also found in the bottom layers throughout the study. The vertical distribution of chlorophyll-a clearly reflects the depth stratification of phytoplankton in Kandy lake (Fig. 4).

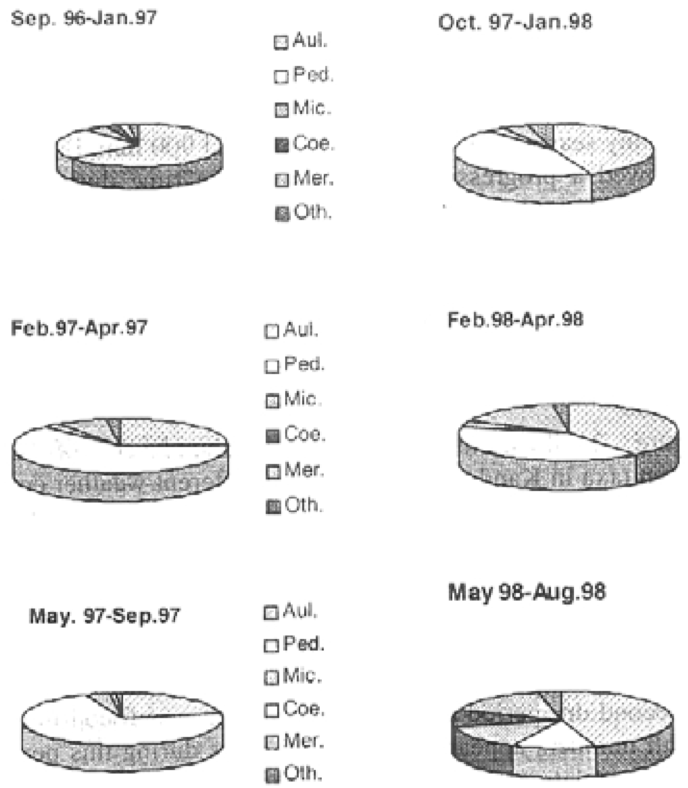

Figure 3. Relative abundance of dominant phytoplankton taxa in Kandy lake during three different weather conditions. Abbreviations are as mentioned in Figure 1.

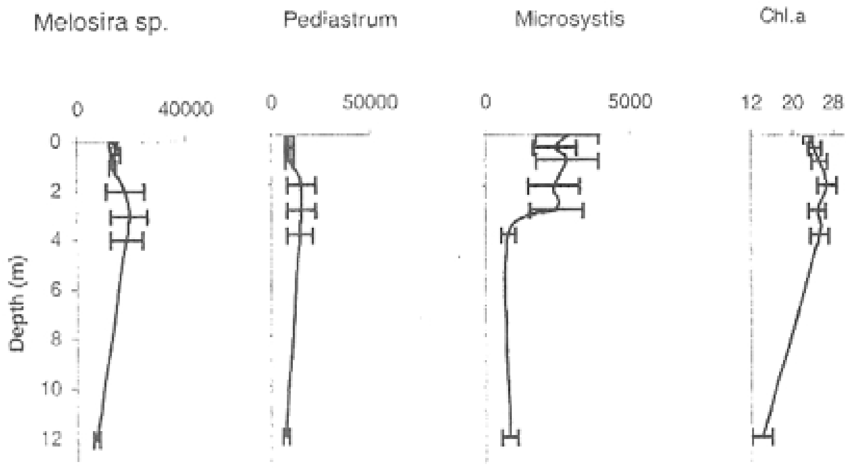

Figure 4. Vertical distribution of chlorophyll-a in the major taxa of phytoplankton at the deepest point of the Kandy Lake.

Discussion

Species composition of freshwater phytoplankton in Sri Lanka is fairly well known (Rott, 1983; Rott and Lenzenweger 1994). However, seasonal variation in species abundance, diversity, biomass or bio-volume, spatial distribution patterns and the factors governing spatial and temporal distribution patterns are poorly understood. The uniform distribution of phytoplankton taxa in Kandy Lake may be attributed to spatial homogeneity of this small water body. The temporal variation found in the density during the study period could be a result of high dilution effects and subsequent flushing occurring during the rainy season. Phytoplankton density in Kandy Lake was low during the rainy season compared to that of the dry period. Phytoplankton minimum and elevated turbidity are characteristic during the wet months in small ponds and reservoirs of the monsoon region (Sugunan 1980; Fatimah et al. 1984; Khondker and Parveen 1993). Kandy lake spills over only during heavy rainy season, usually with the onset of second inter-monsoonal rains (Nov-Dec). The accepted phenomenon is that temporal changes of phytoplankton densities in tropical standing water bodies are driven by seasonal rainfall and mixing (Prawse and Talling 1958; Talling 1986; Kilham et al. 1987). However, diel patterns in shallow water bodies and long-term stable types with sudden shifts are poorly understood.

Of the thirty nine species of phytoplankton belonging to eight families identified from Kandy lake, only six species of the family Chlorophyceae (i.e., *Ankistrodesmus* sp., *Botryococcus* sp., *Coelastrum indicum*, *Coelastrum reticulatum*, *Pediastrum simplex* and *Scenedesmus* sp.)

were mainly contributing for the community structure. The most dominant species, i.e., *P. simplex*, is a common species found in tropical eutrophic waters including Sri Lanka (Rott 1983; Rott & Lenzenweger 1994). This species was dominant during the dry and moderately rainy period. However, the rainfall dependant seasonal abundance was not discernible towards the end of the study. In 1998, the abundance of *P. simplex* was curbed from April to June by *M. punctata*, and in July and August by *C. reticulatum* and *M. aeruginosa* respectively.

Of the four diatom species, *Aulacoseira granulata*, which is a climax species in the humid tropics and widely distributed in Sri Lanka, was the dominant species throughout the study period. A new species of centric diatom, *Urosolenia denticulate*, which is considered as the freshwater counterpart of genus *Rhizosolenia*, was also found in Kandy lake as a rare species. This species has also been described from Victoria and Minneriya reservoirs in Sri Lanka (Rott and McGregor in press). Except *A. granualata*, the other diatom species, namely *Cyclotella* sp. and *Synedra* sp. found in the lake were either rare or of minor importance. Dissolved silica and its relationship to other reactive micronutrients may be a key factor regulating the growth of the centric diatom *A. granulata* (Adeniji 1977; Werner 1977; Lemoalle 1978; Paasche 1980). The concentration of dissolved silica during the rainy season and its relative proportion to total phosphorous or nitrogen may promote the growth of A. *granulata*. However, extremely low abundance of other species of diatoms compared to that of *A. granulata* can not be readily explained. The abundance of *A. granulata* and *P. simplex* showed a rhythmic oscillation under wet and dry weather conditions in Kandy lake until *P. simplex* was curtailed by other species from April 1998. The oscillation of these two species of phytoplankton in Kandy lake may be attributed to the rainfall pattern. A greater seasonal change of phytoplankton was seen in lake Naivasha, Kenya and was influenced by the re-suspension of sediment with nutrient exchange induced by the wind regime (Kalff and Watson 1986; Kalff and Brumelis 1993).

Two species of *Coelosphaerium, Merismopedia punctata* and *Microcystis aeruginosa* were the important species of Cyanophyceae in Kandy lake. *M. punctata* was the common Cyanophyceae species during the study period. However, it was found in relatively low numbers. *M. aeruginosa* was also recorded in small numbers with the other minor species. There were three clearly distinct cosmopolitan *Microcystis* species, i.e., *M. flos-aquae, M. incerta* and *M. wesenbergii*, in Kandy Lake in small numbers. Although several other species of the same genus such as *M. lamelliformis, M. comperei* and *M. smithi* are common in tropical freshwaters (Komarek et al. 2002), these were not reported from Kandy lake as from other water bodies of Sri Lanka (Rott and Lenzenweger 1994; Rott et al. in press). The progressive increase of *M. aeruginosa* in Kandy lake may be attributed to long term nutrient enrichment. Changes in density and species composition of phytoplankton also occur in tropical lakes and reservoirs with long-term nutrient enrichment (Henry et al. 1984; Ramberg 1987; Osborne 1991; Hecky 1993). Internal nutrient loading in shallow water bodies is higher than in deeper ones. Apparently, the accumulation of organic sediments resulting from rapid land use changes in the watershed during the latter part of the last century may have been high in the Kandy lake. Further, the climatic conditions with a pronounced dry and wet weather pattern may have direct effects upon the mixing of water and nutrient regeneration, which in turn affect physico-chemical environment and the phytoplankton community.

It has been clearly shown that the distribution of cyanobacteria varies from reservoir to reservoir irrespective of their geographical location and hydrological regime. A completely different spectrum of phytoplankton could be seen even in a reservoir cascade (Hart 1996). Attempts have also been made to correlate the occurrence of cyanobacteria to catchment characteristics and land use changes (Martin 1993). The growth of cyanobacteria was promoted in nitrogen limited aquatic environments when phosphorus is not limited. In Kandy lake, nitrogen limitation may not be the single factor that promote the growth of cyanobacteria. Colonization of non-heterocystous cynobacteria is an indication of N-saturation and low nitrogen to phosphorous ratio, which favours their dominance in the Phytoplankton community (Smith 1983). The relative abundance and the species composition of cyanobacteria may be determined by the dynamic changes of the relative proportions of nitrogen species.

Multivariate techniques have proved to be a viable tool to identify the most likely scenario for the abundance and distribution of phytoplankton in aquatic ecosystems in relation to ecological variables (Varis et al. 1989; van Tongeren et al. 1992; Alvarez-Cobelas et al. 1994; Romo and van Tongeren 1995). Nevertheless, neither environment characteristics nor community interactions correctly explain the abundance and distribution of phytoplankton species in eutrophic water bodies and the biology and ecology of phytoplankton assemblages in productive waters in the tropics still remain partly unknown. Several factors seem to influence the increased occurrence of cyanoprokaryotic micro-flora in Kandy lake. The abundance of *M. aeruginosa* was correlated positively to higher concentration of nitrogen compounds and total alkalinity which occurred during the dry period. During this period, eutrophic conditions could have been increased by the less dilution of nutrients and by the establishment of a marked temperature/density gradient.

Dinoflagellates and desmids were represented only by a few uncommon species. These were never plentiful in the lake. A Chrysophyceae species of the genus *Mallamonas* and a unicellular Xanthophyceae species (*Isthmochloron lobulatum*) had only a minor contribution to species richness. Two species of Euglenophyceae, i.e., *Euglena* sp. and *Phacus* sp. appeared in the Kandy lake during the dry months, sometimes in moderate numbers. Desmids were associated with low Ca^{2+} and a low N/P ratio (Reynolds 1984), while the abundance of cyanobacteria was correlated with the high concentrations of organic nitrogen. Water of the Kandy lake is rich in Ca^{2+} with extremely high inorganic nitrogen to total phosphorus ratio.

In Kandy lake, phytoplankton species composition showed sudden changes towards the end of the study period but their densities were low during the rainy season (high water levels) and high during dry season (low water level). Altogether four functional species of phytoplankton of both K- and r- strategists (Reynolds et al. 2002) were found in Kandy lake. These were as follows:

(A) Large chain forming centric diatom, namely A. *granulata*, dominating during the wet weather (K-strategist);

(B) A colony forming Chlorophyceae common in eutrophic waters, namely *P. simplex*, which is common during the dry weather (K-strategist);

(C) Colony forming Cyanobacteria namelyly scum forming *M. aeruginosa* (r-strategist); and .

(D) Small colony forming and non-heterocystous Cyanobacteria which does not aggregate into surface scum and appearing in moderate numbers throughout the year, *M. punctata* (K-strategist).

Vertical distribution pattern of phytoplankton is primarily linked with physiological adaptation for light, climate and buoyancy. Further studies on diurnal basis are necessary to determine the passive and active movements of phytoplankton.

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