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Observations on blue-green algal blooms in the open waters of Lake Victoria, Kenya

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Summary

Blue-green algae dominated the open waters of Lake Victoria during an algal bloom between February and August 1986. *Microcystis* sp. accounted for more than 90% of the bloom organisms with algal counts reaching a high density of 34,000 colonies per ml and chlorophyll *a* concentration at 77·6 $\mu g\, l^{-1}$. Secchi disc visibilities and the 1% light penetration were reduced to 0·2 m and 1 m, respectively. The release of nutrients from river inflows, from upwelling and from sediments into the euphotic zone, coupled with high temperatures, produced the observed blooms. The blooms subsequently declined as a result of physical flushing, temperature reduction associated with the rainy season and nutrient exhaustion.

Résumé

Les algues bleues et vertes ont prédominé dans les eaux libres du Lac Victoria durant une éclosion massive d'algues, de février à août 1986. *Microcystis* représentait plus de 90% des organismes éclos, avec des chiffres atteignant plus de 34,000 colonies par ml et une concentration en chlorophylle de 77·6 $\mu g\, l^{-1}$. La visibilité du disque de Secchi et la pénétration d'un pour cent de la lumière étaient réduits à 0·2 m et 1 m respectivement. L'apport de nutriments par les rivières, par les sources et par les sédiments vers la zone exposée à la lumière, combiné avec de hautes températures a causé le phénomène observé. Cette explosion diminua ensuite à cause de phénomènes physiques: une réduction de température associée à la saison des pluies et à l'épuisement des nutriments.

Introduction

Recent studies have examined the roles that horizontally distinct water masses, stratified water columns, warm weather, high incident-light levels and special nutrient sources such as upwelling and river run-off play in promoting blue-green algal blooms (Harrison, 1973; Shapiro, 1973; Reynolds & Walsby, 1975; Tyler & Seliger, 1981; Pearl & Ustach, 1982). Blooms can lead to the formation of surface scums, which are of environmental concern because of the rapid deterioration in water quality that often results from them. High epilimnetic rates of primary production associated with scums lead to nuisance conditions. These are characterized by hypolimnetic oxygen depletion, fish mortalities, and toxicity, foul odours and tastes in affected waters (Skulberg, Codd & Carmichael, 1984).

There has been little information on the algal blooms in Lake Victoria except the work carried out in shallow sheltered bays (Fish, 1957; Talling, 1957, 1966; Akiyama, Kajumulo & Olsen, 1977; Melack, 1979a). Only recently was the nature and potential significance of algal blooms reported (Ochumba, 1984) and an apparent relationship between the widespread occurrence of dead fishes and fish blooms recognized (Ochumba, 1985, 1987). Between February and August 1986, blue-green algal blooms were observed in the open waters of Lake Victoria, Kenya, and their abundance, diversity and photosynthesis investigated. Eight areas were studied; they were selected on the basis of reports of repeated heavy growths of algae. The sampling areas are numbered according to the sampling programme developed by the Lake Basin Development Authority, Kenya Marine and Fisheries Research Institute and Kenya National Academy of Sciences Scientists. The present communication is concerned with physico-chemical data associated with the bloom and discusses factors in bloom timing that can be used to identify bloom-sensitive waters. Such data may be incorporated in the design of water-quality management strategies for inland water users.

Materials and methods

Water temperature was measured with a Fluke 77 multimeter connected to a thermister (1985/86 data) and a Yellow Spring Instrument (YSI) model 51A (1984 data). Dissolved oxygen was determined with a pHOX polarographic electrode. Light penetration was estimated with a 0·2 m Secchi disc and Skye photometer SKP 200 fitted with a SKP 215 quantum sensor, PAR range 400–750 mm. Conductivity was measured with a Jenway PCMI meter corrected to 25°C. Turbidity was determined using a Hach Turbidimeter 16800.

Chemical determinations were made according to the methods of the American Public Health Association (1971) using a Pye Unicam SP 600 spectrophotometer. Water and phytoplankton samples were collected with a 3 m integrated Macvuti sampler (Litterick & Mavuti, 1985). Photosynthetic rates were measured as the difference in dissolved oxygen concentration between light and dark bottles determined by the azide modification of the Winkler method. Chlorophyll *a* concentration was measured according to the methods of Vollenweider (1974) and Melack (1979a). Phytoplankton samples were counted using an Olympus inverted microscope and Sedgewick rafter counting cell. Identification was based on Bachmann (1933) and Talling (1966).

Results

In February, May, July and August 1986, algal blooms were observed in the open waters of Lake Victoria between Stations 32, 34 and 103 (Fig. 1). The blooms formed thick scums at the surface and were concentrated in discrete patches 3–20 km long and 0·5–2·0 km wide. As the bloom died off the colour of the water changed from greenish yellow to reddish brown and then to the colour of murky tea. Temperature and oxygen profiles are presented in Fig. 2. The surface water temperature was between 24°C and 28°C while the bottom temperature was between 23·5°C and 25·8°C. The dissolved oxygen concentration varied from 13 mg l^{-1} at the surface to 3 mg l^{-1} near the bottom.

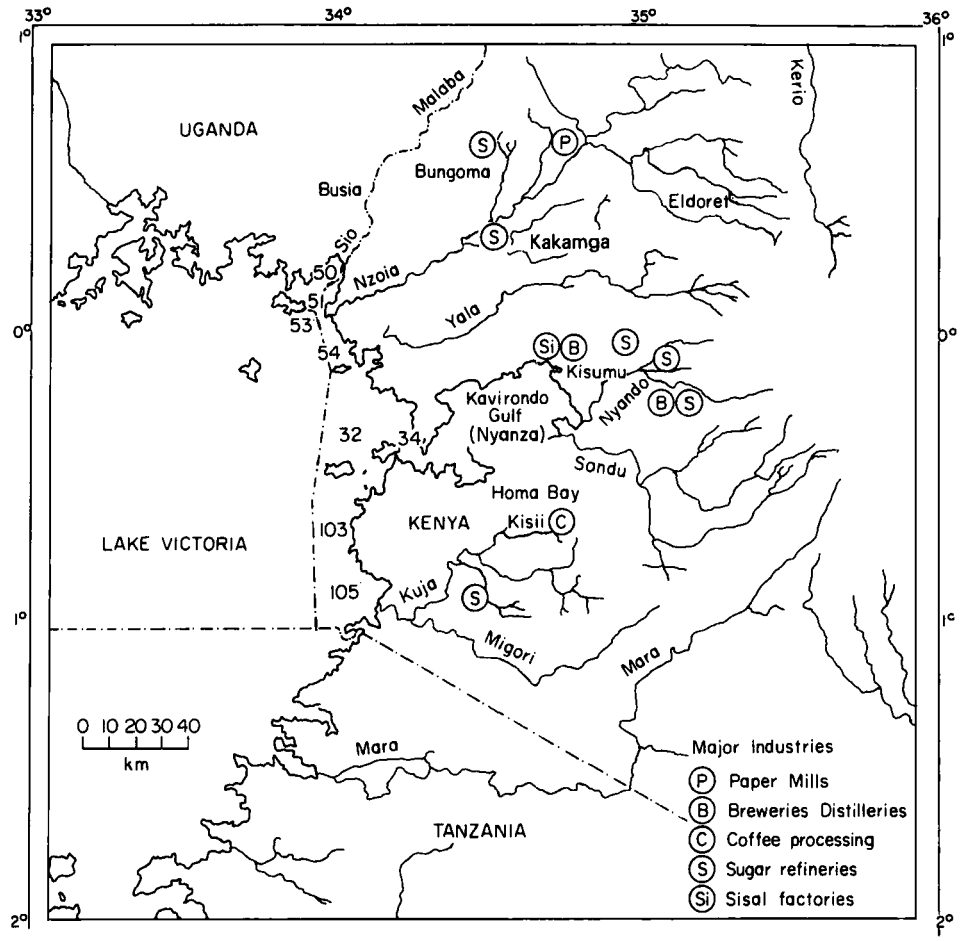

Fig. 1. The Kenyan portion of Lake Victoria showing drainage area sampling station and land sources of nutrients.

Conductivity, turbidity, alkalinity, pH and Secchi depth values are shown in Table 1. These are slightly higher than past studies (Talling & Talling, 1965; Visser, 1974). There was a decrease in conductivity, alkalinity, secchi depth and an increase in turbidity during the bloom period. High turbidity values were observed during the bloom period except at station 53 where river inflow could result in the high values. A decrease in alkalinity was observed in May off station 53 that could be attributed to river inflows. The mean pH values were from 7·5 to 9·4. The high pH value of 9·4 in February 1986 could have resulted from excessive algal growth. Secchi depth was lowest when algal blooms occurred and near river mouths. Figure 3 illustrates the light penetration. Maximum penetration of photosynthetically active radiation (PAR) was 1 m at station 34.

Orthophosphate (PO_4–P) and nitrate (NO_3–N) concentrations are shown in Fig. 4. The highest PO_4–P concentration (37 mg l^{-1}) was observed at station 32 in January 1985. The high PO_4–P concentration in August 1986 occurred during a period of weak thermal stratification. Possible mixing of the main lake and Nyanza

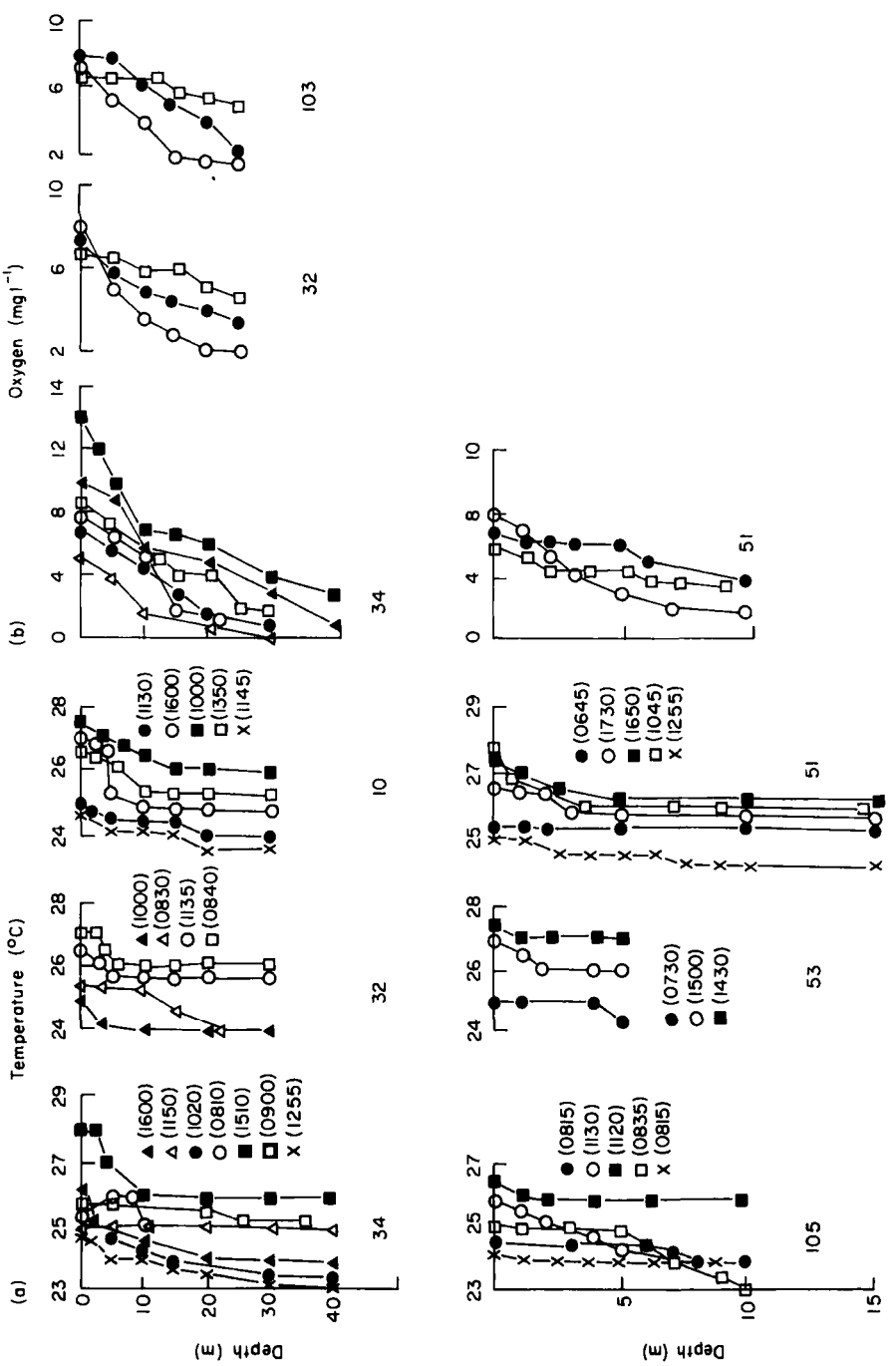

Fig. 2. Temperature (a) and oxygen (b) profiles from sampling stations in Lake Victoria during the study period. Dates of sampling ▲ Aug. 84, △ Oct. 84, ● Sept. 85, ○ Nov. 85, ■ Feb. 86, □ May 86 and × Aug. 86. The time of sampling in brackets.

Table 1. Variation in the mean conductivity, turbidity, alkalinity, pH and Secchi depth during the period of study NTU = nephelometric turbidity units

Station		34	32	103	105	53	51
Conductivity	Aug. 84	103·8	95·5	—	—	—	—
(uScm^{-1})	Sept. 85	117·2	99·8	99·1	—	99·3	98·4
	Nov. 85	103·3	102·0	100·2	—	123·0	104·6
	Feb. 86	95·0	88·1	87·0	—	91·0	85·6
	May 86	99·0	—	89·6	—	100·6	105·0
Turbidity	Sept. 85	3·6	2·6	1·5	8·8	10·4	14·7
(NTU)	Nov. 85	4·1	3·2	1·7	—	33·7	—
	Feb. 86	21·7	6·5	3·2	—	12·3	—
	May 86	4·1	—	2·5	9·7	4·7	19·0
Alkalinity	Sept. 85	52·0	4·5	4·6	4·3	4·5	—
mg($CaCO_3$)	Nov. 85	52·5	5·2	5·1	—	5·8	5·3
	Feb. 86	49·0	4·2	4·6	—	5·0	5·1
	May 86	47·1	—	4·9	6·0	3·7	6·3
pH	Sept. 85	8·14	8·85	8·15	8·15	8·8	—
	Nov. 85	7·96	8·82	7·94	—	7·75	7·6
	Feb. 86	7·51	7·76	7·86	—	9·40	7·65
	May 86	7·42	—	—	7·5	7·80	8·0
	Sept. 85	1·50	1·90	2·50	1·20	0·85	1·10
	Nov. 85	1·35	1·35	1·65	0·90	0·50	0·80
	Feb. 86	0·20	0·60	1·10	0·60	0·35	0·40
	May 86	1·40	—	1·70	—	0·50	0·80

Gulf waters off station 34 would have resulted in upwelling conditions and thereby increase the PO_4–P concentrations. The lowest PO_4–P concentrations (4 mg l^{-1}) were observed during the February bloom. Concentration off shallow stations increased slightly in response to river runoff. The highest NO_3–N concentration (513 mg l^{-1}) was at station 34 in August 1986. This value is higher than those of previous studies in Lake Victoria, e.g. 112 mg l^{-1} (Talling, 1966) and 122 mg l^{-1} (Akiyama *et al.*, 1977). There was a slight drop in NO_3–N concentration in May and then a slight increase in July and August. Nitrate nitrogen was high at the shallow river influenced stations.

Figure 5 shows the variation of chlorophyll *a* (range 8·0–77·6 μg l^{-1}). The observed values between February to August 1986 were higher than the maximum chlorophyll of 31·4 μg l^{-1} off Nyando River, a mean Nyanza (Kavirondo) Gulf value of 17·8 ± 2·8 μg l^{-1} (Winam Gulf Baseline Study Report, 1985) or values observed in shallow inshore areas of 20 μg l^{-1} by Talling (1966); 10 μg l^{-1} by Akiyama *et al.* (1977) for Mwanza Gulf and Homa Bay 17 μg l^{-1} (Melack, 1976). The dominant phytoplankton during the bloom were blue-green algae *Microcystis* sp., *Anabaena* sp., *Lyngbya circumcreta* and *Merismopedia* sp., as opposed to the diatom *Melosira* sp., *Nitzschia* sp., and *Synedra* sp. and the green algae *Oocystis* sp., and *Scenedesmus* sp. (Table 2). A large concentration of *Microcystis* sp. was observed in February 1986 at station 34 at an extremely high concentration

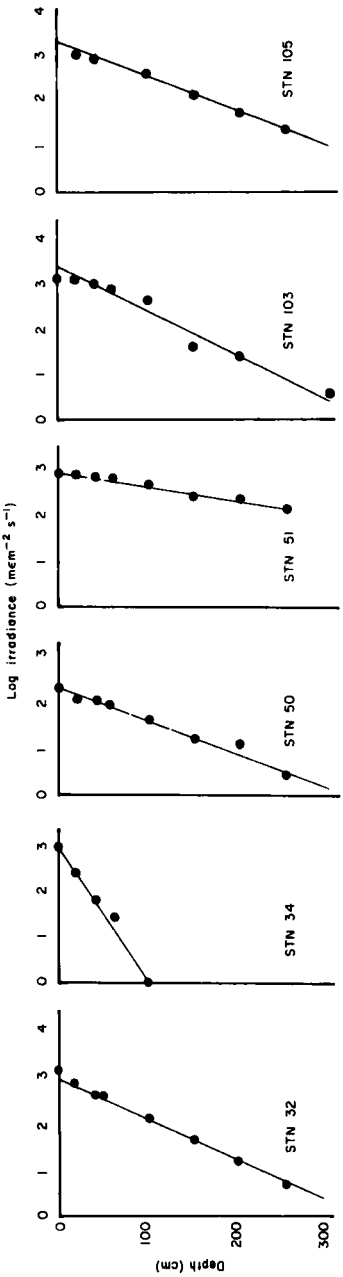

Fig. 3. Light attenuation at various sampling stations in February 1986.

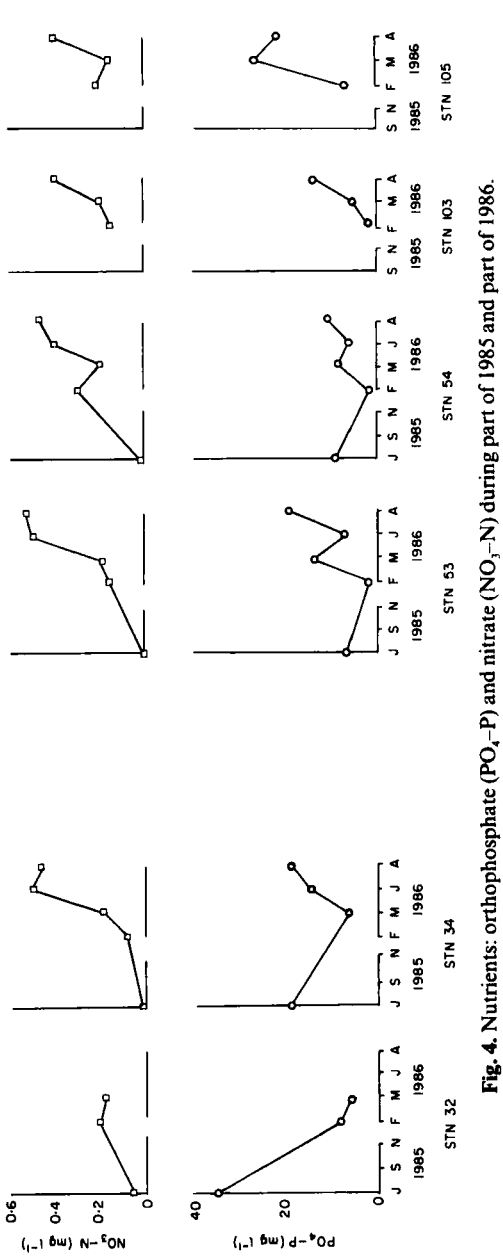

Fig. 4. Nutrients: orthophosphate (PO_4–P) and nitrate (NO_3–N) during part of 1985 and part of 1986.

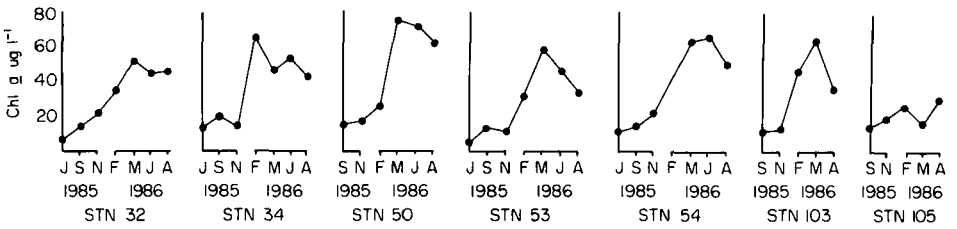

Fig. 5. Chlorophyll *a* at various stations during part of 1985 and 1986.

Table 2. Counts of algae other than *Microcystis* spp. per ml of late water for various stations and months. ce = cells; col = colonies; co = coils; fi = filament. Dashes show times when data were not collected

			Month				
	Algae species		Nov. 85	Feb. 86	May 86	July 86	Aug. 86
STN 32	Nitzschia	(ce)	400	100	540	8	8
	Synedra	(ce)	20	50	270	64	46
	Lyngbya	(co)	0	40	216	200	200
	Anabaena	(co)	0	2600	1440	—	6400
	Merismopaedia	(col)	0	230	780	0	0
STN 34	Nitzschia	(ce)	—	220	230	140	28
	Synedra	(ce)	—	48	0	54	14
	Lyngbya	(ce)	—	40	0	40	0
	Scenedesmus	(ce)	—	0	0	40	0
	Anabaena	(ce)	—	100	100	59	24
	Oocystis	(ce)	—	0	0	—	22
STN 53	Nitzschia	(ce)	400	400	—	—	10
	Synedra	(ce)	35	25	—	—	280
	Lyngbya	(ce)	100	0	—	—	0
	Melosira	(fi)	20	10	—	—	0
	Anabaena	(co)	400	0	—	—	0
STN 54	Nitzschia	(ce)	—	—	—	1200	0
	Synedra	(ce)	—	—	—	200	0
	Lyngbya	(ce)	—	—	—	200	340
	Anabaena	(ce)	—	—	—	0	55
	Anacystis	(col)	—	—	—	0	22
STN 104	Nitzschia	(ce)	—	220	—	—	—
	Synedra	(ce)	—	270	—	—	—
	Lyngbya	(ce)	—	320	—	—	—
	Anabaena	(ce)	—	1460	—	—	—
STN 105	Nitzschia	(ce)	—	100	—	—	—
	Synedra	(ce)	—	760	—	—	—
	Anabaena	(co)	—	540	—	—	—
	Melosira	(fi)	—	107	—	—	—

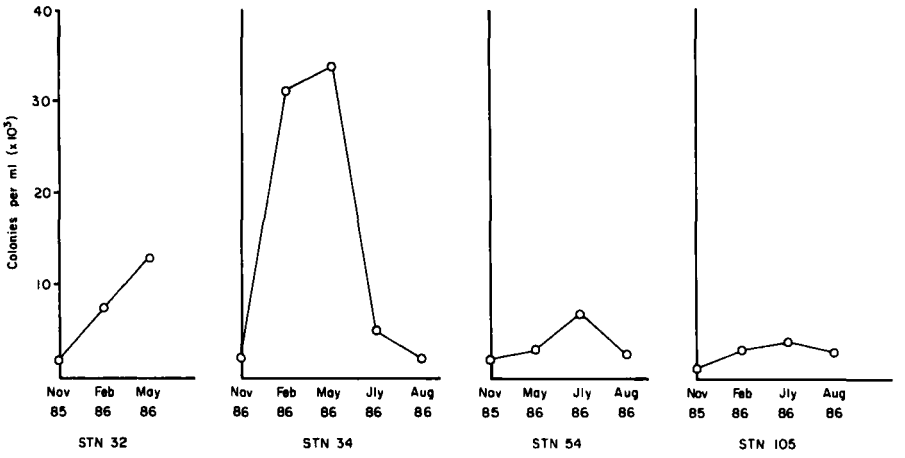

Fig. 6. Counts of *Microcystis* colonies per millitre of lake water at some stations during various months.

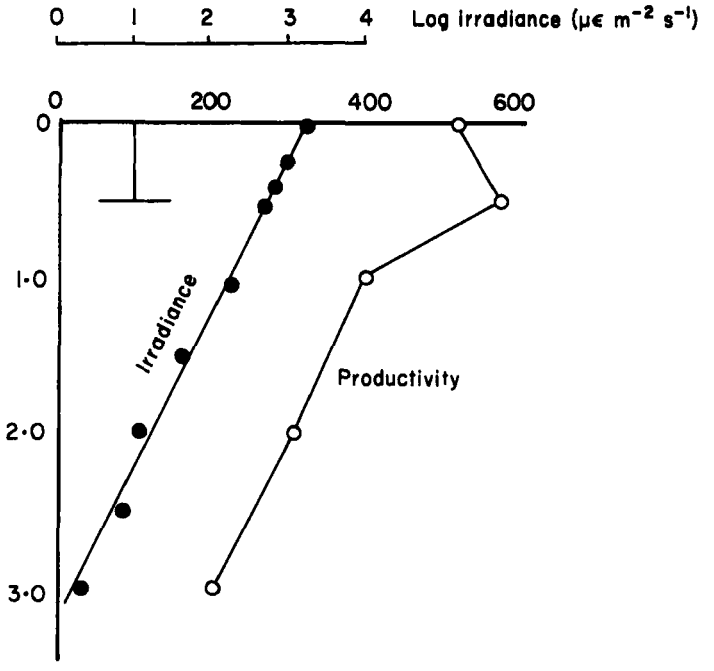

Fig. 7. Primary productivity at different depths and light attenuation at STN 53 at 1000–1200 h on 19 Feb. 1986. ⊥ represents the Secchi depth.

($3{\cdot}4 \times 10^5$ colonies ml^{-1}), Fig. 6. *Microcystis* accounted for between 50% and 99% of the total phytoplankton at all the sampled stations. Primary productivity estimates, light penetration and Secchi depth measurements at station 53 in February 1986 are shown in Fig. 7. The 1% light intensity level was at a depth of approximately 4 m. The primary productivity ranged from 200 to 580 mg O_2 m^{-3} h^{-1}.

Discussion

The predominance of blue-green algae in the phytoplankton of most tropical lakes is a complex function of many interacting factors (Rich, 1933; Melack, 1979b, 1981; Vareschi, 1982). Blooms of blue-green algae are often associated with high water temperatures (Hutchinson, 1967). The surface water temperature regime of the open waters of Lake Victoria between February and May 1986 (25·9–28°C) was probably near the optimum for growth. The shallow thermal stratification observed on 15 February 1986 off station 34 favoured the accumulation of blue-green algae at depths less than 3 m. Because blue-green algae can control vertical buoyancy (Reynolds, 1972), they can respond quickly to short-term increases in temperature. The *Microcystis* population crashed eventually as a result of a drop in temperature in July and August 1986 off station 34 owing to surface cooling (Talling, 1966) that accompanied the rainy season. Since the phytoplankton of other lakes in East Africa with similar temperature ranges are diatom dominated (Richardson, 1968; Kilham, 1971; Gasse, Talling & Kilham, 1983), the presence of blue-green algal blooms in Lake Victoria was not simply a function of temperature alone.

Most studies have linked bloom phenomena with localized nutrient enrichment (Moss, 1969; Harrison, 1973; Larsen *et al.*, 1973; Melack, Kilham & Fisher, 1982). Favourable physical conditions must act synergistically with localized nutrient enrichment for nuisance bloom formation (Fogg, 1969; Reynolds & Walsby, 1975). The physical mechanisms of nutrient enrichment by upwelling have been observed in Lake Victoria (Kitaka, 1972). Seasonal variation of nutrients are well defined (Talling, 1966; Akiyama *et al.*, 1977), but because of the release of nutrients from the sediments (Talling, 1966) and during the rains (Visser, 1974; Melack, 1979c) there is never a prolonged shortage. The capacity of sediments to release nutrients, particularly phosphorus, depends on whether the overlying waters become anoxic. Near anoxic conditions were observed in our study in November 1985. Fish (1957) and Talling (1966) observed the appearance of dissolved oxygen concentrations below 0·7 mg l^{-1} within 5 m of water column during windy periods in January, February and May. The release of nutrients and increased availability from river inflows and sediments into the euphotic zone, coupled with high temperatures, produced the observed blooms.

Our data on photosynthesis, chlorophyll *a* and nutrients off river mouths coincide with peak rainfall activity in May, July and August. Blooms declined as a result of unfavourable climatic events; temperature decline, physical flushing associated with the rainy seasons and wind mixing and nutrients exhaustion. The decreased Secchi depths and turbidity together with increased oxygen concentration at the surface and deficiency in the bottom layers and fish deaths (Ochumba, 1985, 1987), may indicate the severity of the blue-green algal blooms. The algal counts and chlorophyll *a* values agree with those reported for blooms in Lake McIlwaine, Zimbabwe (Marshall & Falconer, 1973); Lake George, Uganda (Burgis *et al.*, 1973); Hartbeespoort Dam (Scott *et al.*, 1977) and Rietvlei Dam, South Africa (Ashton, 1979); Lake Kinneret, Israel (Pollingher & Berman, 1982) and from culture experiments (Moss, 1969; Viner, 1973; Pearl, 1983). The maximum *Microcystis* sp. counts of 34,000 colonies ml^{-1} is higher than 100 colonies ml^{-1} recorded in January 1961 (Talling, 1966) and 300 colonies ml^{-1} in March 1974 (Akiyama *et al.*, 1977). The maximum *Anabaena* sp. of 1,000 colonies ml^{-1} in

January 1961 (Talling, 1966) and 5,600 colonies/ml in November 1973 (Akiyama *et al.*, 1971) are within the range of our observations. The two diatoms that occurred during the bloom, *Nitzschia* sp. and *Synedra* sp., have specialized forms which tend to reduce their sinking: *Synedra* sp. is a stellate form increasing surface area and therefore resistance and *Nitzschia* sp. was found enmeshed within the mucilage of floating *Microcystis* sp. colonies. The occurrence of *Melosira* sp. at stations 53 and 105 can be linked to the river inflows.

In other lakes, blooms are a much less stable and predictable feature (Wynne *et al.*, 1982) and can be maintained for a considerable period. Our study shows that it is possible to correlate algal blooms in Lake Victoria with the weather regime and the availability of a concentrated nutrient source. A shift to a near unialgal phytoplankton community of *Microcystis* sp. presents an intriguing problem for future investigations with implications for the management, conservation and exploitation of Lake Victoria's resources: the biomass of fish that may feed on *Microcystis* sp. (Moriarty *et al.*, 1973) is greatest around the shoreline of the lake and least in the open lake (Lowe-McConnell, 1975) but may have drastically declined due to predation by Nile perch (*Lates niloticus*) (Barel *et al.*, 1985; Ogari, 1984). The increased occurrence of blue-green algae, therefore, could possibly reflect the deterioration in water quality of Lake Victoria. Although lake deterioration and its causes have received attention and some rehabilitation approaches have been described (Ketelle & Uttomark, 1971; Boyter & Wanieslista, 1973; Dunst *et al.*, 1984; Torien, 1977), the continued urban and industrial development of Lake Victoria's catchment area may result in the escalation of the concomitant problems. Some signs of the worsening situations were observed and it is becoming increasingly apparent that sound and firm remedial action is necessary. From a management point-of-view, the ability both to control and to predict such blooms must include a diverse monitoring effort on the land use, nutrient run-off, agricultural practices, industrial, urban and rural development.

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