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Species diversity of pelagic algae in Lake Kivu (East Africa)

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Abstract – With regard to pelagic algae, Lake Kivu is the least known among the East-African Great Lakes. The data available on its phytoplanktic communities are limited, dispersed or outdated. This study presents floristic data obtained from the first long term monitoring survey ever made in Lake Kivu (over two and a half years). Samples were collected twice a month from the southern basin, and twice a year (once in each season) from the northern, eastern and western basins. In open lake habitats, the four basins presented similar species composition. The most common species were the pennate diatoms *Nitzschia bacata* Hust. and *Fragilaria danica* (Kütz.) Lange-Bert., and the cyanobacteria *Planktolyngbya limnetica* Lemm. and *Synechococcus* sp. The centric diatom *Urosolenia* sp. and the cyanobacterium *Microcystis* sp. were also very abundant, mostly near the surface under daily stratification conditions. Some typical low epilimnion/metalimnion species were *Cryptaulax* sp., *Cryptomonas* sp., *Rhodomonas* sp. and *Merismopedia trolleri* Bach. Vertical stratification appeared to be the most important factor of diversification. Limited changes were apparent in comparison with the situation described in 1937 after the first Belgian expeditions. No evidence of an effect of the planktivorous sardine *Limnothrissa miodon* Boulenger (introduced from Lake Tanganyika) on phytoplankton diversity is available.

Lake Kivu / algae / diversity / taxonomy / large tropical lake / East Africa

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Résumé – Diversité spécifique des algues pélagiques du Lac Kivu (Afrique de l'Est). Le lac Kivu est le moins connu des grands lacs d'Afrique de l'Est en ce qui concerne les algues de la zone pélagique. Les données existantes sur ses communautés phytoplanctoniques sont ponctuelles, dispersées ou anciennes. Ce travail présente les données floristiques du premier suivi sur un long terme (deux ans et demi) mené au lac Kivu. Les échantillons ont été prélevés toutes les deux semaines dans le bassin sud, et deux fois par an (une en saison sèche et une en saison des pluies) dans les bassins nord, est et ouest. En zone pélagique, les quatre bassins présentent la même composition spécifique. Les espèces les plus courantes sont des diatomées pennées *Nitzschia bacata* Hust. et *Fragilaria danica* (Kütz.) Lange-Bert., et des cyanobactéries *Planktolyngbya limnetica* Lemm. et *Synechococcus* sp.. La diatomée centrique *Urosolenia* sp. et la cyanobactérie *Microcystis* sp. sont également très abondantes, principalement au voisinage de la surface en période de stratification journalière. Quelques espèces typiques du métalimnion/bas epilimnion ont été mis en évidence, comme *Cryptaulax* sp., *Cryptomonas* sp., *Rhodomonas* sp. et *Merismopedia trolleri* Bach. Le spectre vertical s'est avéré un important facteur de diversification. De légères différences ont été observées par rapport à la situation décrite en 1937 suite aux premières expéditions belges. Les données existantes ne sont pas concluantes quant à un possible impact de l'introduction de la sardine planctonivore *Limnothrissa miodon* Boulenger (endémique du lac Tanganyika) sur la diversité du phytoplancton pélagique du lac Kivu.

Lac Kivu / algues / diversité / taxonomie / grand lac tropical / Afrique de l'Est

INTRODUCTION

Among the Great Lakes of the East African Rift Valley, Lake Kivu is peculiar, since it is geologically very young. In the Pleistocene period (20,000 years ago), during which volcanic eruptions gave rise to the formation of a new volcanic range, the waters of Lake Kivu, which previously flowed north towards Lake Albert, were blocked. After a considerable rise in water level, the water was reversed towards the south into Lake Tanganyika by the Ruizizi River. Lake Kivu (2°S and 29°E) is now a deep, meromictic, oligotrophic lake located at high altitude. It has a surface area of 2,370 km^2 and is 1,463 m above sea level; its coasts are shared by Rwanda and the Democratic Republic of Congo (Degens *et al.*, 1973). It ranks among the 14 largest lakes of the world in water volume (Herdendorf *in* Tilzer, 1990).

The average water depth in Lake Kivu is about 240 m and the pelagic area is most frequently no more than 50 m away from the shore. Mean annual rainfall precipitation is 1300 mm, but it is relatively higher along the western shore of the lake than the eastern shore. With a maximal depth of 490 m (in the northern basin), variation in water level is limited (less than 1 meter) between seasons and years (Spigel & Coulter, 1996).

Lake Kivu is permanently thermo- and halocline stratified, with the peculiarity of containing a considerable gas reserve in its deep waters (mostly CH_4 and CO_2). Another interesting feature of this lake is that temperature increases with depth, reaching 25.5°C at 450 m (Degens *et al.*, 1973). The oxygenated layer is confined to the first 25-70 meters, depending on the season: in the dry season (June to September) south-eastern winds induce a deeper mixing zone, whereas in the rest of the year (rainy season – October to May) physical conditions are more stable, and the "biozone" is generally limited to the first 25 meters.

Whereas information on fish ecology and biology (promoted by fisheries needs) is extensive, the overall ecology and biodiversity of Lake Kivu are poorly known. Data on phytoplankton and its primary production are scarce, as well as information on nutrient concentrations.

The first algal collections from Lake Kivu were made in 1928 by Helios Scaetta, an Italian agronomist working for the Belgian Ministry of Colonies. He collected algae, especially filamentous taxa, in a large area around the lake, including mountain ponds, thermal springs and other biota. Only a few collections were made from the lake proper. The diatoms included in these collections were studied by Zanon (1938). The most abundant diatoms observed in a sample of filamentous algae collected at the head of Idjwi Island belonged to the genera *Cymbella* and *Rhopalodia*. *Melosira granulata* (Ehrenb.) Ralfs was also frequent.

More important for the knowledge of the pelagic algae of Lake Kivu was the expedition of H. Damas in 1935-36 to the "Parc National Albert" (Damas, 1937). Damas collected more than 500 algal samples from Lake Edward, Lake Kivu (55 samples) and several other aquatic biota in the Albert National Park and surrounding areas. These samples were studied by several phycologists and the results were published in two issues of the publication of the Institute of National Parks of Belgian Congo devoted to the Mission H. Damas: fasc. 8 "Süsswasser-Diatomeen" by Hustedt (1949) for the diatoms, and fasc. 19 "Algues et Flagellates" (Frémy *et al.*, 1949) for several other groups of algae, namely Cyanobacteria (P. Frémy), Chrysophyta, Pyrrhophyta, Euglenophyta, Volvocales (A. Pascher), Heterokontae, Protococcales, Siphonocladales (W. Conrad). In the samples from Lake Kivu, 157 species and infraspecific taxa of diatoms were found (including benthic and epiphytic samples); 12 were described as new species. The most common diatoms in the pelagic northern and eastern basins were *Nitzschia confinis* Hust., *N. lancettula* O. Müller, *N. tropica* Hust., *N. gracilis* Hantzsch and *Synedra ulna* (Nitzsch) Ehrenb. Among the blue-green algae, *Microcystis flos-aquae* (Wittrock) Kirchner was the most frequent, together with other *Microcystis* species, such as *M. aeruginosa* (Kütz.) Kütz. and *M. ichthyoblabe* Kütz., and a few planktic *Lyngbya* (especially *L. circumcreta* West and *L. contorta* Lemm.). Among the other groups, *Botryococcus braunii* Kütz. and *Chlorella vulgaris* Beijerinck were rather abundant, together with several species of *Pediastrum* and *Scenedesmus*. Two new green algae were described from Lake Kivu: *Cosmarium kivuense* Conrad and *Scenedesmus cristatus* Conrad ex Duvigneaud. The data from Damas' expedition were used by Van Meel (1954) in his book on the phytoplankton of East African Great Lakes, but without any new addition to the knowledge of the algal flora of Lake Kivu.

In a diatom physiology study, Kilham & Kilham (1990) described a *Nitzschia-Stephanodiscus* dominance gradient from north to south in the sediments of the lake, following a Si:P gradient depletion. In a paleoclimatological study, Haberyan & Hecky (1987) reported several diatoms and scales of *Paraphysomonas vestita* Stokes (Chrysophyceae) in sediments cores. Drastic changes were recorded around 5,000 years ago in the fauna and flora of the lake, in particular the disappearance of *Stephanodiscus astraea* var. *minutula* (Kütz.) Grunow, and the replacement by several needle-like *Nitzschia*. The most likely cause of this shift may have been the hydrothermal input of CO_2 into the lake due to high volcanic activity in the region, which would have caused lake turnover and consequent disappearance of the plankton by excessive heat, anoxia, extremely low pH or toxic gases.

The most recent report concerning the pelagic flora is a comparative study of the composition and abundance of phytoplankton from several East

African Lakes (Hecky & Kling, 1987). An algal assemblage dominated by Cyanoprokaryota and Chlorophyta was reported for Lake Kivu, with higher biomass than in Lake Tanganyika. Hecky & Kling (1987) reported *Lyngbya circumcreta* West, *Cylindrospermopsis, Anabaenopsis* and *Rhaphidiopsis* as the dominant algae found in settled samples collected in March 1972. Among the green algae, *Cosmarium leave* Rab. was the most common species. In the northern basin, *Peridinium inconspicuum* Lemm., *Gymnodinium pulvisculus* Klebs and *Gymnodinium* sp. were considerably abundant, whereas diatoms (*Nitzschia* and *Synedra*) were abundant only in the isolated Sake Bay.

In this paper, we present an overview of the pelagic algal flora of Lake Kivu based on more than 200 samples, collected for over two and a half years from different sites, depths and seasons. This survey represents the first long-term monitoring investigation ever made in Lake Kivu; its temporal and spatial coverage is therefore much more extensive than for previous studies available for the lake. The information provided here focuses primarily on species diversity; this study is complemented by a detailed quantitative investigation on the temporal and spatial dynamics of the phytoplankton presented in Sarmento *et al.* (2006). The results presented here and in Sarmento *et al.* (2006) provide a basis of information that will be of critical importance for further research on phytoplankton diversity and ecology in this area.

MATERIALS AND METHODS

In the southern basin, samples were collected twice a month from February 2002 to September 2004. The northern, eastern and western basins were visited twice a year (once in each season), and sampling protocols and materials were the same as for the southern basin. The location of the sampling points was chosen according to Damas (1935-1936) that established four major basins in the open lake. Sampling took place at a point where the depth was close to the maximal depth of each basin (and sufficiently close to shore for logistic convenience). The positions and depths of the sampling sites were as follows: Southern basin – 02°33.94'S, 28°97.65'E, 120 m; Northern basin – 01°68.08'S, 29°15.69'E, 400 m; Eastern basin – 01°96.17'S, 29°12.26'E, 400 m; Western basin – 02°22.79'S, 28°97.35'E, 200 m (Fig. 1).

Nutrient analysis (using standard spectrophotometric techniques, [A.P.H.A., 1992], or Macherey-Nägel [Düren, Germany] analytical kits) were carried out during regular sampling at the southern basin and at all sites during the cruises. In the course of this study, dissolved phosphorus and nitrogen were under the detection limits in the epilimnion for most of the time (Tab. 1). Chlorophyll *a* (measured in a Waters HPLC system [Milford, USA] with a novaPak C18 column, as described in Sarmento *et al.*, 2006) in this layer was 2.2 mg m^{-3} (average 2002-2004, n = 400). Limnological profiles were carried out using a multiparameter sonde (Hydrolab DS4a, Loveland, USA). Average conductivity in epilimnion was 1200 µS cm^{-1} at 25°C and pH was relatively high (9.15). Close to the metalimnion, conductivity increased drastically and it doubled at 100 meters depth. Further data on the limnological features of Lake Kivu are available in Sarmento *et al.* (2006) and Isumbisho *et al.* (2006).

To collect qualitative samples, vertical plankton net (10 µm mesh size) hauls were carried out in the 0-60 meters layer. The samples were immediately

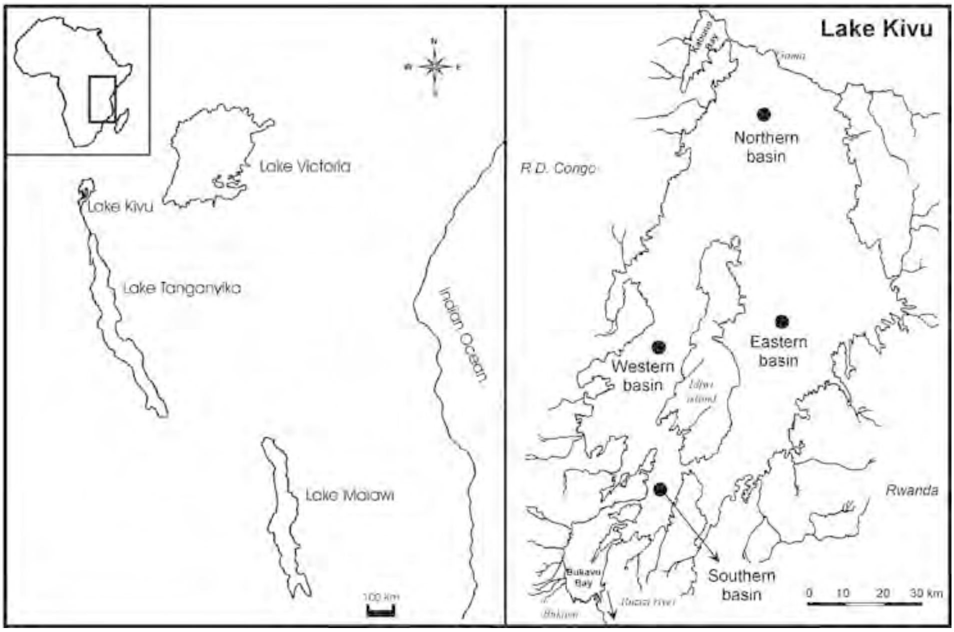


Fig. 1. Geographic situation of Lake Kivu. Black dots are the sampling sites (see text for GPS coordinates and depths).

Table 1. Major nutrients and chlorophyll a concentrations in Lake Kivu (average in epilimnion samples in the southern basin during the 2002-2004 period).

		Mean	*Min*	*Max*
P-PO_4	(mg.m^{-3})	**12.7**	< 2.5	55.5
N-NO_3	(mg.m^{-3})	**18.1**	< 10.0	64.9
N-NO_2	(mg.m^{-3})	**11.7**	< 10.0	62.1
N-NH_4	(mg.m^{-3})	**39.7**	< 10.0	223.4
Si	(mg.m^{-3})	**2795**	2105	3958
Alkalinity	(meq.l^{-1})	**15.8**	11.3	23.8
Chlorophyll *a*	(mg.m^{-3})	**2.2**	0.6	5.1

preserved with Lugol solution and glutaraldehyde at 1-2 % final concentration. To collect quantitative samples, a Van Dorn bottle was used at different depths (surface, 5, 10, 20, 30, 40, 50 and 60 metres). The samples were preserved immediately after collection with neutral formaldehyde (2-4% final concentration) and Lugol solution. Before observation, algal samples were concentrated by settling. For epifluorescence microscopy (EM) and scanning electronic microscopy (SEM), samples were fixed with glutaraldehyde at 1-2% final concentration. Although the quantitative data are presented and discussed in Sarmento *et al.* (2006), identifications were obtained from examination of both sets of samples.

The material was examined with several different methods: light microscopy (LM) with phase-contrast (Olympus BX-50 equipped with an Olympus Camedia digital camera), SEM (Philips XL-30) and EM (Zeiss Axioskop equipped with plan Neofluar objectives and an AxioCam digital camera). Digital images were treated in Corel Paint and Corel Draw software. For SEM investigation, samples were washed with distilled water, dehydrated by immersion in increasing ethanol concentrations, and dried at critical point with liquid CO_2, then coated with gold as described in Couté *et al.* (2004). Slides for EM observation were prepared by filtering 20 ml of sample on a 0,2 µm Millipore black filter, and placing it on a drop of low fluorescence immersion oil, over a glass-slide. A drop of oil was added and the filter was covered with a coverslip. The autofluorescence of the chlorophyll was clearly visible under blue light excitation (filter set 09, 450-490 nm) and red emission (> 590 nm). With green light excitation (filter set 15, 546 nm), phycoerythrin (Cyanophyceae and Cryptophyceae) produces golden/orange emission.

Identifications were based on Bourrelly (1976, 1978, 1980), Compère (1974-1977, 1986, 1989), Geitler (1930, 1932), Hindák (1980), Hustedt (1949), Iltis (1972), John *et al.* (2002), Komárek & Anagnostidis (1998), Komárek & Anagnostidis (2005), Komárek & Fott (1983), Krammer & Lange-Bertalot (1988, 1991a, 1991b), Rino (1979), Wehr & Sheath (2003), and some additional taxonomic works cited below in this paper.

The description of the morphology of each alga is followed by indications concerning its ecological status, *i.e.* quantity, occurrence in relation to season and location in the water column. The frequency of each taxon is defined as "very rare" if it was observed only once, "rare" if it was present in less than 10% of the samples, "very common" if it was present in at least 90% of the samples, and "common" in all the other cases. The season in which the alga was observed most often is reported. Finally, vertical distribution in the water column is specified as: surface – mostly in the 0-5 meter layer; epilimnion – vertical distribution homogeneous; metalimnion – usually present at deeper levels, near the thermocline.

RESULTS

In total, 42 taxa were recorded: 14 Cyanophyceae, 3 Cryptophyceae, 3 Dinophyceae, 7 Bacillariophyceae, 1 Chrysophyceae, 7 Chlorophyceae, 3 Trebouxiophyceae and 4 Charophyceae.

CYANOPROKARYOTA

CYANOPHYCEAE

Anabaena Bory de Saint-Vincent *ex* Bornet *et* Flahault

***Anabaena* sp.** **(Figs 14, 42)**

Solitary, free floating, straight trichomes, 5-7 µm wide. Cells barrel-shaped, wider than long, or as wide as long (up to 7 µm long), regularly constricted at cross-walls. End cells conically pointed and usually hyaline; cell content blue-green, pseudovacuolated. Heterocysts nearly spherical to slightly oval, 6-8 μm wide. Impossibility of akinete observation doesn't allow identification at species level. According to size and other morphological features, the material could be referred to *A. bergeii* f. *minor* Ostenf. Most probably noted for Lake Kivu as *Cylindrospermopsis* sp. by Hecky & Kling (1987: fig. 6b).

Occurrence: rare; rainy season; epilimnion.

Aphanocapsa Näg.

***Aphanocapsa* sp.** **(Figs 4, 39)**

Colonies microscopic, multicellular (up to 100 cells), irregular, gelatinous, with irregularly, loosely distributed cells. Mucilage colourless, fine and diffluent. Cells spherical, 0.9-1.2 μm in diameter, hemispherical after division, pale greyish blue-green, without aerotopes.

For the arrangement of the colonies in several small sub-colonies, this cyanobacterium is close to *A. nubilum* Komárek and Kling, reported for Lake Victoria (Komárek & Kling, 1991); but in the material from Lake Kivu cells are smaller and less densely arranged.

Occurrence: rare; all seasons; epilimnion.

Aphanocapsa holsatica (Lemm.) Cronb. *et* Kom. **(Fig. 8)**

Colonies spherical to irregular, with clearly visible mucilage, relatively densely aggregated cells, 1.5-(2) μm in diameter. Reported as cosmopolitan by Komárek & Anagnostidis (1998).

Occurrence: very rare.

Aphanothece Näg.

***Aphanothece* sp.** **(Figs 6, 36)**

Colonies microscopic, multicellular (up to 200 cells) mucilaginous, roughly spherical or irregular, with cells irregularly arranged in the colony. Colonial mucilage diffluent and colourless. Cells rod-like (sometimes ellipsoidal), 0.7-1.7 × 1.2-4.5 μm, straight or slightly curved, with rounded ends, pale greyish blue-green, without aerotopes.

Occurrence: rare; all seasons; epilimnion.

Chroococcus Näg.

***Chroococcus* sp.** **(Fig. 3)**

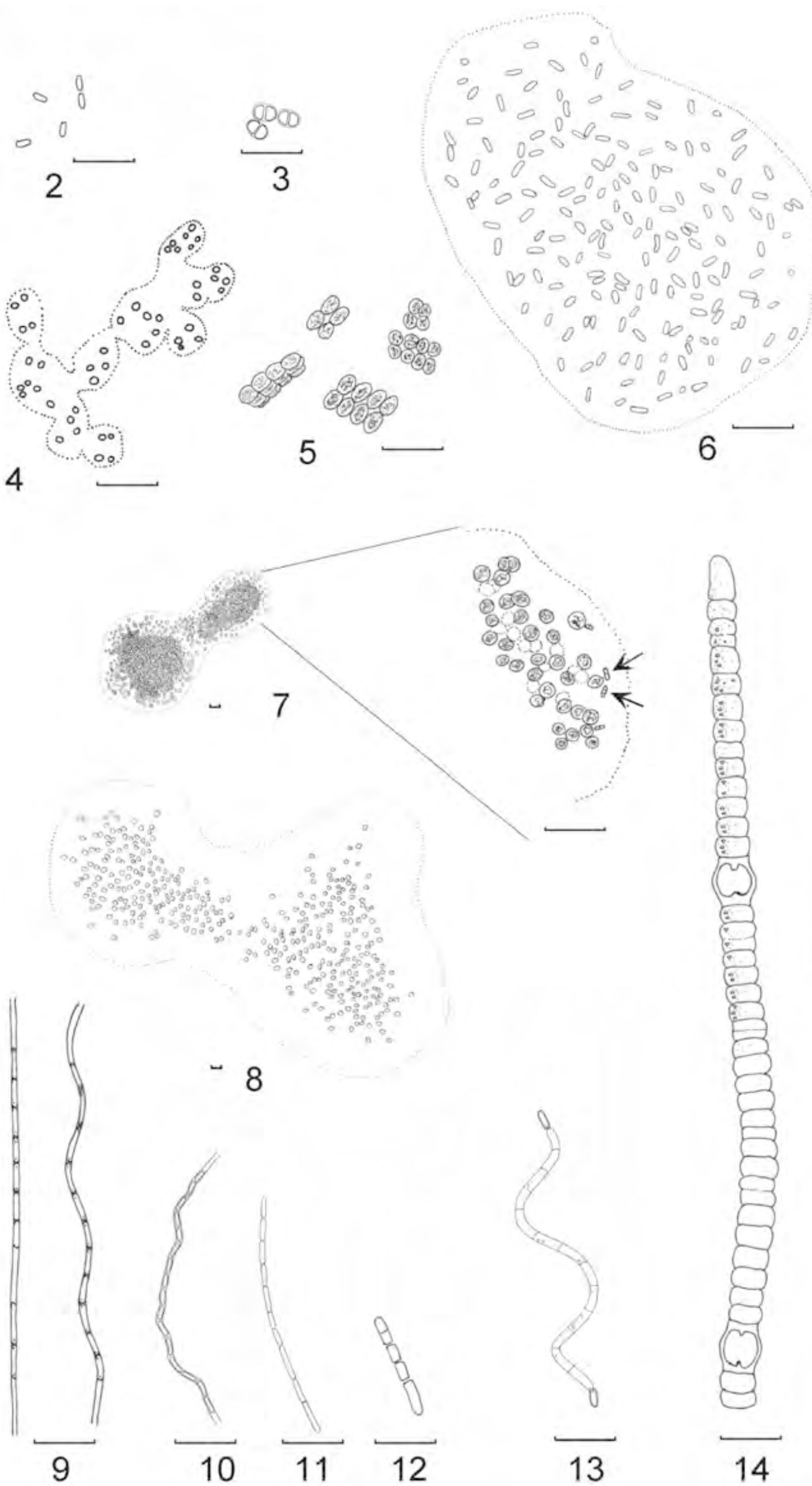
Colonies microscopic, 2-8-celled, with thin, colourless, homogeneous mucilage. Cells usually hemispherical, rarely spherical (young cells before division), 2-3 μm in diameter, with homogeneous pale blue-green content, without aerotopes.

The specimens collected are in agreement with *C. minimus* (Keissl.) Lemm., but according to Komárek & Anagnostidis (1998) records from tropical regions should be referred to other species.

Occurrence: rare; all seasons; epilimnion.

Cylindrospermopsis* cf. *curvispora Wat. **(Figs 13, 41, 59)**

Trichomes solitary, free floating, 30-120 μm long, spirally coiled, unconstricted or very slightly constricted at cross walls, not attenuated towards ends. Intercalary cells cylindrical, 2-3 μm wide, with a few occasional aerotopes.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Terminal heterocysts cylindrical, round, sometimes asymmetric, 8-10 × 3-4 μm, present in one or both ends. Although akinetes were not observed, all morphological features correspond well with *C. curvispora*. Most probably, different stages of the development of this alga were noted for Lake Kivu as *Cylindrospermopsis* sp. and *Raphidiopsis* sp. by Hecky & Kling (1987: fig. 3 and figs 4, 5 respectively).

Occurrence: common; all seasons; epilimnion.

Merismopedia trolleri Bach. **(Fig. 5)**

Colonies free floating, microscopic, flat, with 4 to 16 (rarely 64) cells situated in one plane, in rows perpendicular to each other. Mucilaginous envelopes of colonies colourless, homogeneous, fine. Cells slightly elongate, 2.5 × 3.3 μm, with pale blue-green content and 2 or 3 aerotopes per cell.

Komárek & Anagnostidis (1998) reported a very similar species, *Merismopedia marssonii* Lemm., for Lake Victoria with a remark that tropical records of *M. trolleri* probably represent other species. In the case of Lake Kivu, the shape and cell dimensions of the few specimens observed close to the metalimnion are morphologically closer to *M. trolleri*. The same authors didn't exclude the observation of this species in tropical regions, even though the need for reassessment was suggested.

Occurrence: rare; all seasons; metalimnion.

Microcystis Kütz. ex Lemm.

***Microcystis* sp.** **(Figs 7, 38)**

Colonies microscopic, more or less spherical or with irregular shape, neither clathrate nor lobate, with loosely to densely arranged cells. Fine hyaline, colourless, diffluent mucilage forming a narrow margin of the cells clusters. Cells spherical, with aerotopes, 3.5-4.8 μm in diameter. Komárek & Anagnostidis (1998) reported several species from this genus as hypothetically cosmopolitan.

The largest colonies found in our samples had only a few cells with a very thin mucilage, that disaggregated very easily (Fig. 42). Isolated *Microcystis* cells were the most common form encountered in our samples; this rendered the identification at species level impossible. However, the presence of short trichomes of *Pseudanabaena mucicola* (Naumann *et* Huber-Pestalozzi) Schwabe in the mucilage strongly suggests *Microcystis aeruginosa* (Kütz.) Kütz.

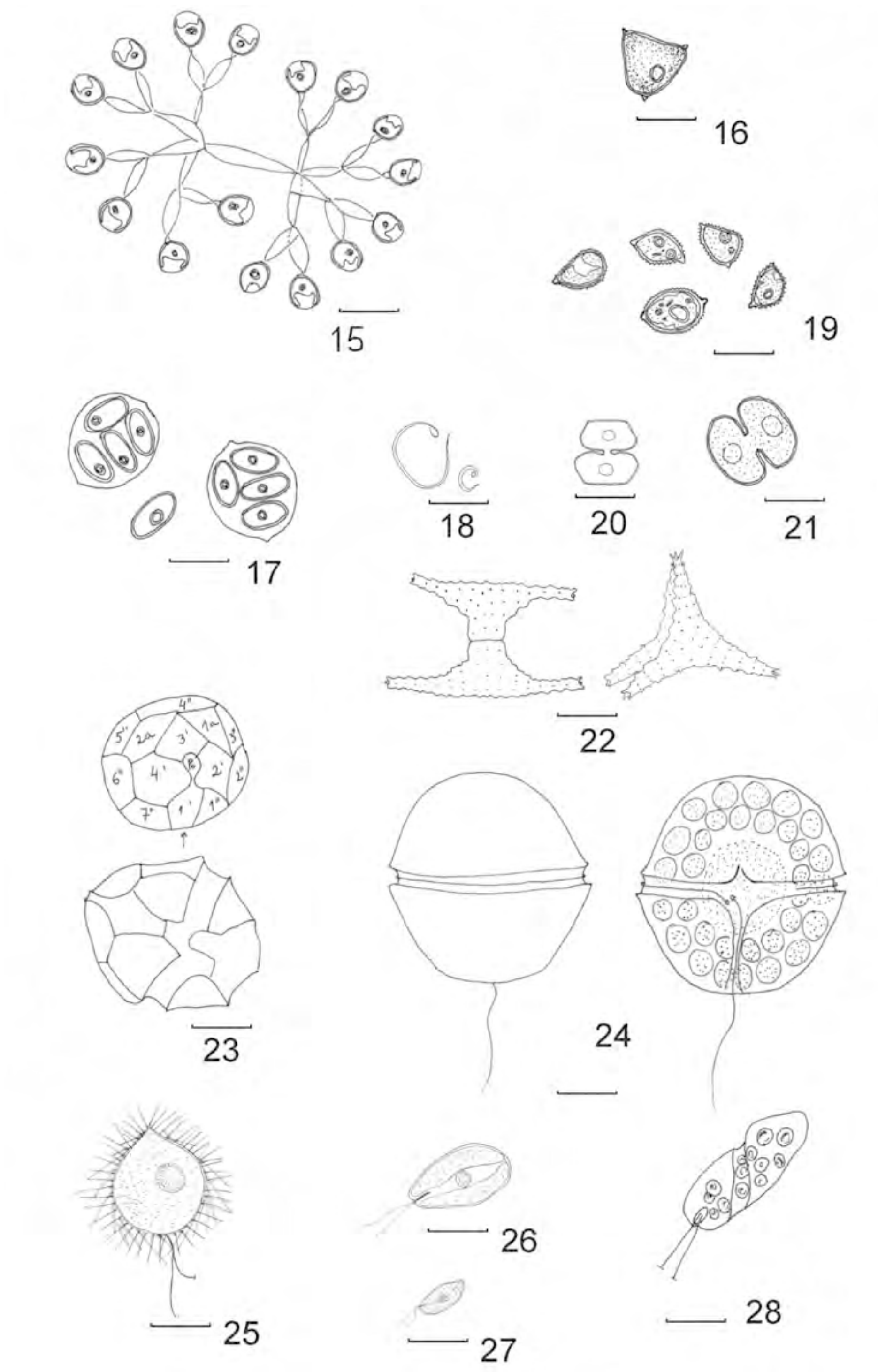
Occurrence: common; rainy season; surface.

Pannus microcystiformis Hind.

Colonies free floating, microscopic, flat, with numerous cells irregularly and densely arranged in one plane. Colonial mucilage fine, homogeneous, colourless, diffluent. Cells spherical, 2-3 μm in diameter, with pale blue-green content and several aerotopes.

◄———

Figs 2-14. **2.** *Synechococcus* sp. **3.** *Chroococcus* sp. **4.** *Aphanocapsa* sp. **5.** *Merismopedia trolleri* Bach. **6.** *Aphanothece* sp. **7.** *Microcystis* sp. (arrows indicate *Pseudanabaena mucicola* [Naumann *et* Huber-Pestalozzi] Schwabe). **8.** *Aphanocapsa holsatica* (Lemm.) Cronb. *et* Kom. **9.** *Planktolyngbya limnetica* Lemm. **10.** *Planktolyngbya undulata* Kom. *et* Kling **11.** *Pseudanabaena moniliformis* Kom. *et* Kling **12.** *Pseudanabaena mucicola* (Naumann *et* Huber-Pestalozzi) Schwabe. **13.** *Cylindrospermopsis* cf. *curvispora* Wat. **14.** *Anabaena* sp. (Scale: 10 μm).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Isolated cells are very similar to those of *Microcystis*. Moreover, these two taxa were often observed in the same samples.

Occurrence: rare; rainy season; surface.

Planktolyngbya limnetica (Lemm.) Komárková-Legnerová *et* Cronberg **(Figs 9, 37B, 43)**

Trichomes regularly or irregularly curved or straight, up to 600 μm long but usually shorter (100 μm), 0.7-1.3 μm wide, not attenuated at the ends. Sheaths very thin, firm, colourless, usually extending over the trichome at both ends. Trichomes cylindrical, composed of elongated cells, not constricted at the cross-walls. Cells cylindrical, 3.2-5.8 μm long, with pale homogenous, greyish blue-green content. Cross-walls conspicuous, with or without a single granule on both sides. False branching was rarely observed. Considered as a cosmopolitan taxon, very common in tropical regions (Komárek & Anagnostidis, 2005).

Occurrence: very common; all seasons; epilimnion.

Planktolyngbya undulata Komárek *et* Kling **(Fig. 10)**

Trichomes straight or irregularly to spirally coiled, up to 1.3 μm wide. Sheaths are thin, colourless, usually extending over the trichomes at both ends. Trichomes cylindrical, consisting of elongated cells arranged with a slightly zig-zag arrangement. Cells cylindrical, slightly tapered, with pale homogenous, greyish blue-green content, sometimes with small granules at one or both ends, 3.2-5.8 × 0.7-1.3 μm.

The only record found in the literature for this species is from Lake Victoria where it was originally described by Komárek & Kling (1991).

Occurrence: rare; all seasons; epilimnion.

Pseudanabaena moniliformis Komárek *et* Kling **(Figs 11, 40, 61)**

Trichomes solitary, free floating, straight or slightly irregularly waved, with up to 20 cells, 0.8-1.5 μm wide, with clear constrictions at the cross walls. Cells cylindrical, always longer than wide (2.6-5.3 μm long), with pale blue-green content and without aerotopes; few scattered granules occasionally observable.

This species was originally described from Lake Victoria by Komárek & Kling (1991).

Occurrence: common; all seasons; epilimnion.

Pseudanabaena mucicola (Naumann *et* Huber-Pestalozzi) Schwabe **(Figs 7, 12)**

Trichomes solitary, straight, free floating or inside *Microcystis* mucilage, not very long, 1.8-2.3 μm wide, composed of 1 to 6 cells, with constrictions at the distinct cross walls. In young trichomes, cross walls thin and unclear. Cells cylindrical, always longer than wide, with pale blue-green content and without aerotopes. This species is distributed worldwide (Komárek & Anagnostidis, 2005).

Occurrence: common; rainy season; surface.

Figs 15-28. **15.** *Dictyosphaerium pulchellum* Wood **16.** *Tetraedron regulare* Kütz. **17.** *Oocystis lacustris* Chod. **18.** *Monoraphidium contortum* (Thur.) Kom.-Legn. **19.** *Tetraedron* sp. **20.** *Cosmarium* cf. *regnellii* Wille **21.** *Cosmarium* cf. *laeve* Rabenh. **22.** *Staurastrum* sp. **23.** *Peridinium umbonatum* Stein (*P. inconspicuum* Lemm.) **24.** *Gymnodinium* sp. **25.** *Paraphysomonas vestita* Stokes **26.** *Cryptomonas* sp. **27.** *Rhodomonas* (?) sp. **28.** *Cryptaulax* sp. (Scale: 10 μm).

Synechococcus **Näg.**

***Synechococcus* sp.** **(Figs 2, 37A)**

Free-floating solitary cells (two-celled colonies occasionally observed, probably during division process), short, oval to rod-shaped, without mucilage, with homogeneous, pale blue-green content, 0.8-3.8 × 0.3-1.7 µm. Real abundance only revealed by epifluorescence microscopy or flow cytometry.

Occurrence: very common; all seasons; epilimnion.

CRYPTOPHYTA

CRYPTOPHYCEAE

Cryptomonas Ehrenb.

***Cryptomonas* sp.** **(Figs 26, 67)**

Cells ellipsoidal in dorsiventral view, not sigmoid, slightly flattened. Dimensions: 16 µm long, 7.5 µm large, 5 µm thick. The furrow extends for about one third of the cell length.

Occurrence: rare; all seasons; epilimnion.

Cryptaulax Skuja

***Cryptaulax* sp.** **(Fig. 28)**

Solitary, uncoloured, cylindrical-ellipsoidal cells, with conical antapex and a longitudinal helicoidal furrow. Numerous yellow-brownish vesicles observable; two unequal flagella protruding from a well distinct cytopharynx.

Occurrence: very rare.

Rhodomonas Karst.

cf. *Rhodomonas* sp. **(Fig. 27)**

Cells ellipsoidal, 2.5-4 × 5.5-8.5 µm, flattened at one end. Impossibility of observation on living material and SEM observation did not allow species-level identification.

Occurrence: common; all seasons; epilimnion.

DINOPHYTA

DINOPHYCEAE

Gymnodinium Lemm.

***Gymnodinium* sp.** **(Figs 24, 57)**

Cells free-swimming, broadly rounded, with equal epitheca and hypotheca, 32-38 µm in diameter; numerous rod-shaped, parietal yellow-green chloroplasts and central spherical nucleus. Cingulum median, sulcus narrow, running to antapex of hypocone, narrowing towards base. Probably corresponding to *Gymnodinium pulvisculus* (Ehrenb.) Stein. cited by Hecky & Kling (1987).

Occurrence: rare; all seasons; epilimnion.

Peridinium Ehrenb.

***Peridinium* sp.** **(Figs 56, 64, 65)**

Cells free-swimming, globular in ventral and dorsiventral views, 19-22 × 23-26 µm. Epitheca slightly longer than hypotheca. Wide and deep cingulum offset by one cingulum width. Sulcus slightly widening below the hypotheca, not reaching the cell antapex. Smooth thecal plates with many minute perforations arranged perpendicularly to the transapical axis.

Occurrence: common; all seasons; epilimnion.

Peridinium umbonatum Stein **(Figs 23, 55, 62, 63)**

Cells free-swimming, broadly ovoid in ventral view, slightly flattened dorsiventrally, 22-26 × 27-30 µm, with apical pore; epitheca longer than hypotheca. Plate formula: Po, x, 4', 2a, 7''. Wide and deep cingulum. Theca slightly ornamented with no particular arrangement.

Common in Lake Kivu, probably the same organism identified as *P. inconspicuum* Lemm. by Hecky & Kling (1987) since both names are considered as synonyms by Popovsky & Pfiester (1990).

Occurrence: common; all seasons; epilimnion.

OCHROPHYTA

BACILLARIOPHYCEAE

Cyclotella meneghiniana Kütz. **(Fig. 29)**

Cells cylindrical, wider than high, 12-16 µm in diameter. Valve surface slightly undulated, with 8-9 well marked striae in 10 µm, disposed in a radiant way, absent in the upper half of the cells.

Occurrence: very rare.

Fragilaria danica (Kütz.) Lange-Bert. **(Figs 35, 49)**
(Syn.: *Synedra ulna* var. *danica* (Kütz.))

Frustules are rectangular in girdle view, lanceolate and slightly capitate in valve view, with two labiate processes per valve, one near each end. Cells are 180-212 × 4.1-4.4 µm, with 12 uniseriate transapical striae in 10 µm, interrupted in the center in a longitudinal way (pseudoraphide), with no central area interruption.

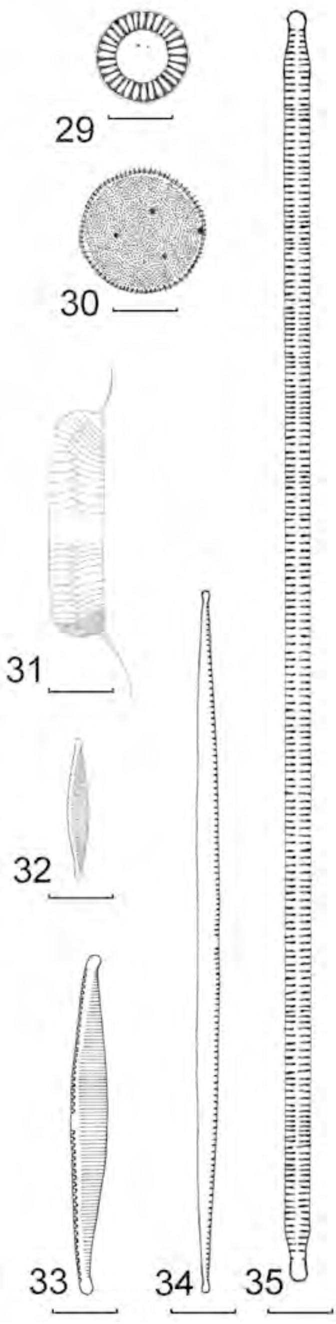
Reported in Lake Kivu by Hustedt (1949).

Occurrence: very common; all seasons; epilimnion.

Nitzschia bacata Hust. **(Figs 34, 72, 73)**

Solitary cells, long, straight and narrow, more or less capitate, 90-120 × 2-2.8 µm. Raphe system fibulate near the margin of the valve surface, in the opposite margins of the second valve of a frustule. The fibulae, equidistant, 12-14 in 10 µm, are slightly spaced at the centre. Striae not visible in LM (38-40 / 10 µm in SEM).

Some specimens in Lake Kivu have larger dimensions than the original material described by Hustedt (1937-1939) from Java. Hustedt (1949) himself had already pointed out this feature for the East-African region. Krammer & Lange-Bertalot (1988) included *N. bacata* in *N. paleacea* Grun., but size limits, number



of fibulae and number of striae seem to support the existence of a tropical species that differs from the cosmopolitan *N. paleacea*.

Hustedt (1949) described a new species, *N. spiculum*, close to *N. bacata* but more lanceolate, very abundant in Lake Edward but rather rare in Lake Kivu. In this study, SEM observations did not reveal differences in striation, even though in LM some frustules appear more lanceolate than others. It is possible that *N. spiculum* occurs now in smaller amounts in Lake Kivu, but no evidence supporting the differentiation of these two species was found in the course of this study.

Occurrence: very common; all seasons; epilimnion.

Nitzschia fonticola Grun. **(Figs 32, 69)**

Valves lanceolate 17-21 × 3.1-3.4 µm, with 9-16 equidistant fibulae in 10 µm and 30-32 striae in 10 µm (for the rare specimens observed in Lake Kivu). Reported in Lake Kivu by Hustedt (1949) and recently in Lake Tanganyika by several authors (Mpawenayo, 1985; Caljon, 1987; Cocquyt & Vyverman, 2005).

Occurrence: rare; all seasons; epilimnion.

Nitzschia tropica Hust. **(Fig. 33)**

Valves 48-57 × 3.8-4.5 µm, with 11-12 fibulae in 10 µm spaced at the center, and 27-30 striae in 10 µm. Reported in Lake Kivu by Hustedt (1949) and recently in Lake Tanganyika by Cocquyt & Vyverman (2005).

Occurrence: rare; all seasons; epilimnion.

Urosolenia Round *et* Crawford

***Urosolenia* sp.** **(Figs 31, 58, 70, 71)**

Long cylindrical cells, very lightly silicified, with section highly flattened, 40-150 × 6-15 µm, with robust spines at both ends, shorter than the rest of the cell. Girdle bands well visible, clearly imbricate. The calyptra presents 2-4 poroids on the process base.

Figs 29-35. **29.** *Cyclotella meneghiniana* Kütz. **30.** *Thalassiosira rudolfi* (Bach.) Hasle. **31.** *Urosolenia* sp. **32.** *Nitzschia fonticola* Grun. **33.** *Nitzschia tropica* Hust. **34.** *Nitzschia bacata* Hust. **35.** *Fragilaria danica* (Kütz.) Lange-Bert. (Scale: 10 µm).

Probably very abundant in epilimnion of Lake Kivu. These fragile organisms are easily destroyed with fixation and don't sediment as rapidly as others.

Probably the same species reported as *Urosolenia* sp. by Rott *et al.* (2006) in Lake Edward. It might be an undescribed East African species.

Occurrence: very common; all seasons; epilimnion.

Thalassiosira rudolfi (Bach.) Hasle **(Figs 30, 68)**
(Syn.: *Coscinodiscus rudolfi* Bach.)

Cells cylindrical, wider than high, 20-35 µm in diameter. Valve surface flat, with 20 areoles in 10 µm, roughly aligned in a radial way, with 6 marginal strutted processes in 10µm and 3 other strutted processes in the mid between the centre and the margin forming an equilateral triangle. Several records in East African lakes Cocquyt *et al.* (1993), but also in Lake Chad, in Congo and in Namibia under different names (with *Coscinodiscus rudolfi* as the most common synonym).

Occurrence: rare; all seasons; epilimnion.

CHRYSOPHYCEAE

Paraphysomonas vestita Stokes **(Figs 25, 60)**

Cells are solitary, free swimming, broadly round to droplet-shaped, 16-22 µm in diameter, with two unequal flagella, covered with numerous siliceous round-shaped scales.

Scales of this species were reported in sediment cores from Lake Kivu (Haberyan & Hecky, 1987).

Occurrence: rare; all seasons; epilimnion.

CHLOROPHYTA

CHLOROPHYCEAE

Coelastrum reticulatum (Dang.) Senn.

A single fragment of the coenobium of this alga was found in one sample, but the cells were empty. However, the typical cell connections and cell wall structure allowed identification at the species level. This species is widely reported in tropical waters (Komárek & Fott, 1983), particularly in the region of East Great Lakes and Tanganyika (Cocquyt *et al.*, 1993).

Occurrence: very rare.

Dictyosphaerium pulchellum Wood **(Figs 15, 44)**

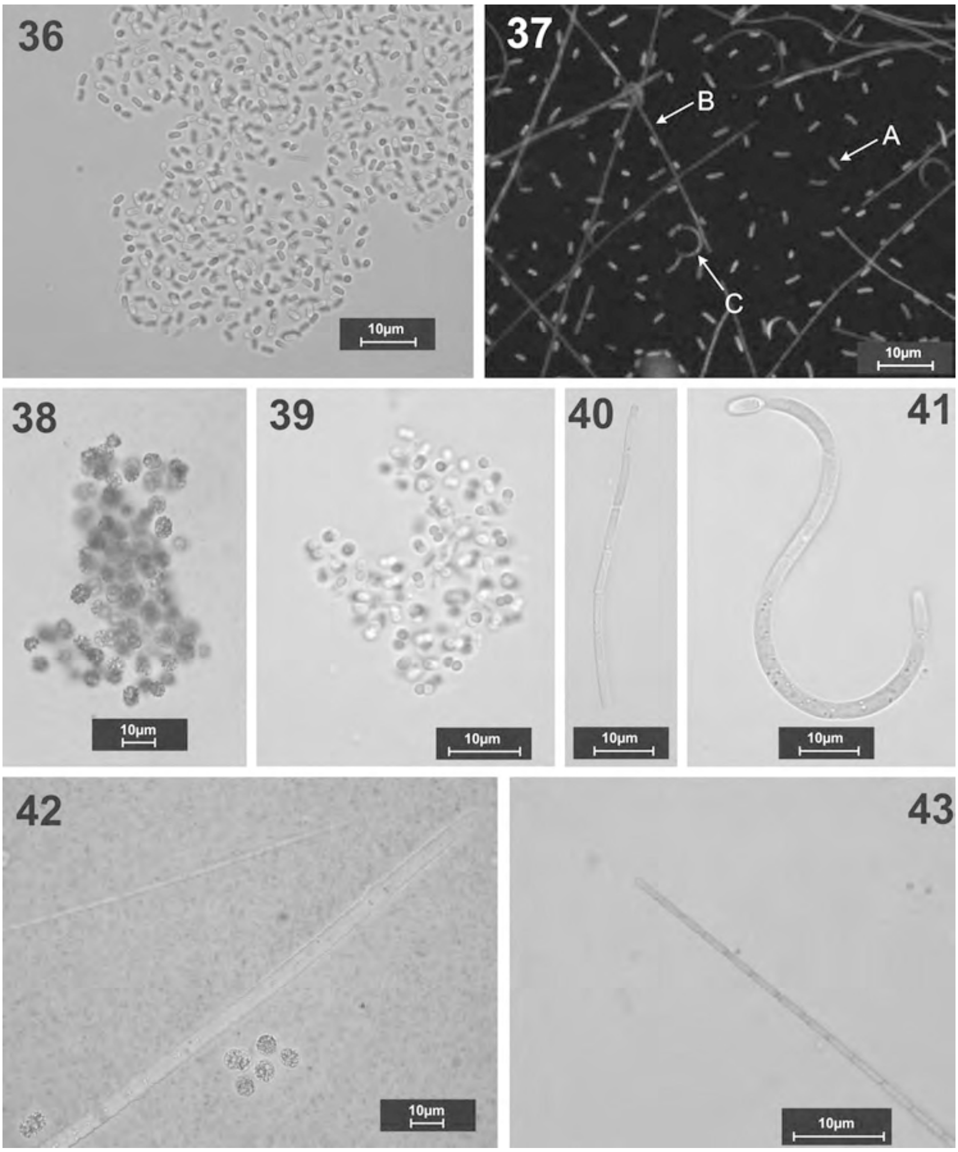
Colonies 4 to 32-celled, with colourless mucilage. Adult cells spherical, 4-7 µm in diameter, attached by tetrachotomously branched threads. Chloroplast basal, cup-shaped with one pyrenoid. Found in Lake Kivu by Hecky & Kling (1987).

Occurrence: rare; all seasons; epilimnion.

Dictyosphaerium tetrachotomum Printz

Colonies 16, 32 or 64-celled, with ovoid adult cells, 6-7 µm in diameter, attached by thick, mucilaginous, tetrachotomously branched threads, thicker and cross-like in the centre of the colonies. Chloroplast single, basal, cup-shaped, with one pyrenoid.

Occurrence: very rare.



Figs 36-43. **36.** *Aphanothece* sp. **37.** *A - Synechococcus* sp., *B - Planktolyngbya limnetica* Lemm., *C - Monoraphidium contortum* (Thur.) Kom.-Legn. (epifluorescence microscope) **38.** *Microcystis* sp. **39.** *Aphanocapsa* sp. **40.** *Pseudanabaena moniliformis* Kom. *et* Kling **41.** *Cylindrospermopsis* af. *curvispora* Wat. **42.** *Anabaena* sp. and *Microcystis* sp. (with Indian ink). **43.** *Planktolyngbya limnetica* Lemm.

Monoraphidium contortum (Thur.) Kom.-Legn. **(Figs 18, 37C)**

Cells free floating, solitary, fusiform, sigmoidally bent to helically twisted, narrowing to pointed apices. Dimensions: 0.6-1 × 6-21 µm. Cell content green, without visible pyrenoid. Presence of chlorophyll *a* proved by EM (Fig. 37C). Cosmopolitan taxon (Komárek & Fott, 1983).

Occurrence: very common; all seasons; epilimnion.

Sphaerocystis Chod.

cf. *Sphaerocystis* sp. **(Fig. 45)**

Coenobial alga, with autospore reproduction and thickened mother cell wall. Autospores 7-8 µm, round shaped, globular, with one chloroplast containing a single pyrenoid. Since only fragments of the coenobium were collected, no unambiguous identification at the species level was possible.

Occurrence: very rare.

Tetraedron Kütz.

Tetraedron regulare Kütz. **(Fig. 16)**

Cells 8-12 µm wide, tetrahedral, with sides straight to slightly convex, with thickened wall protuberance in each rounded corner. Cell wall scrobiculated. According to Komárek & Fott (1983), this species has been previously reported in other tropical regions.

Occurrence: rare; all seasons; epilimnion.

***Tetraedron* sp.** **(Figs 19, 47-50, 66)**

Solitary cells, free floating, ovoid, asymmetric to piriform when seen in side view and triangular (rarely quadrangular) in front view, (5)-7-12-(14) µm. Rough scrobiculated cell wall, sometimes with one or two thickened polar protuberances. Cells with a parietal, massive chloroplast, with a single pyrenoid and oil droplets. Reproduction by 4 (rarely 8) autospores embedded in the mother cell's wall and released after wall rupture. The features observed overlap partially with the descriptions of *Tetraedron regulare* Kuetz. [incl. var. *ornatum* Lemm.] and *T. minimum* var. *scrobiculatum* Lagerh. However, var. *minimum* and var. *scrobiculatum* differ only for the intensity of the surface warts network on the cell wall, which has the same ultrastructure in both varieties (Hegewald *et al.*, 1975; Kovačik & Kalina, 1975). Therefore var. *scrobiculatum* was not considered to be sufficiently supported (Kovačik, 1975; Hindák, 1980; Komárek & Fott, 1983).

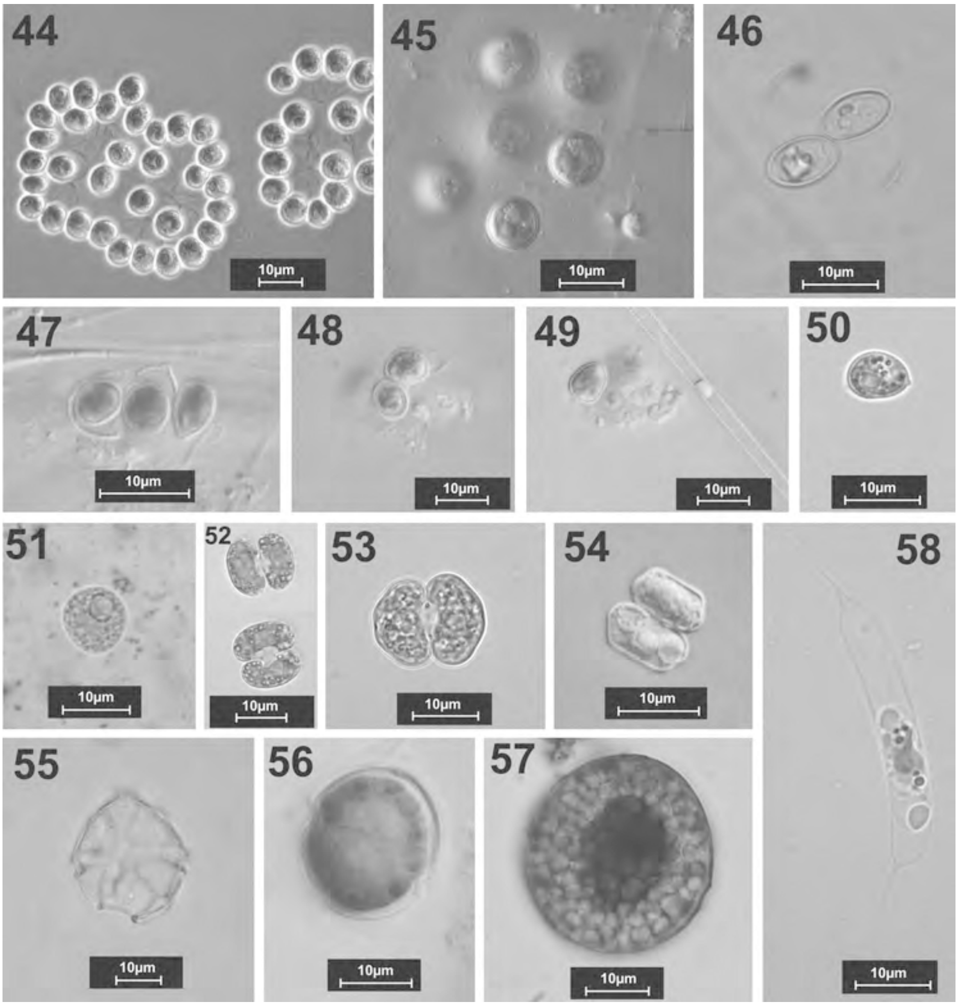
Common in Lake Kivu, probably the same organism identified as *Tetraedron minimum* var. *apiculato-scrobiculatum* with a question mark by Hecky & Kling (1987). However, the brownish short spines ('teeth') at the cell ends, which are typical for this variety, were not observed in the material studied.

Occurrence: very common; all seasons; epilimnion.

TREBOUXIOPHYCEAE

Oocystis lacustris Chod. **(Figs 17, 46)**

Coenobia of 2 or 4, occasionally solitary cells; with age, mother cell wall slightly or markedly expanding. Cells 3-9 × 6-15 µm, about twice as long as broad,



Figs 44-58. **44.** *Dictyosphaerium pulchellum* Wood (in phase contrast). **45.** *Sphaerocystis* (?) sp. **46.** *Oocystis lacustris* Chod. **47-50.** *Tetraedron* sp. [47. with Lugol, 49. with *Fragilaria danica* (Kütz.) Lange-Bert.] **51.** *Siderocelis irregularis* Hind. **52.** *Cosmarium* cf. *laeve* Rabenh. **53.** *Cosmarium* sp. **54.** *Cosmarium* cf. *regnellii* Wille **55.** *Peridinium umbonatum* Stein. **56.** *Peridinium* sp. **57.** *Gymnodinium* sp. (with gentian violet). **58.** *Urosolenia* sp.

narrow to broadly ellipsoidal; apices rounded to obtuse. Chloroplast single (number increasing up to 4 with age), trough-shaped, generally with a single pyrenoid. Previously reported for Lake Kivu by Hecky & Kling (1987).

Occurrence: rare; all seasons; epilimnion.

Oocystis* cf. *submarina Lagerh.

A single, four-celled colony was observed. Cells 3.8 × 7.7 µm, with parietal, trough-like chloroplast with one pyrenoid. Cell wall relatively thick.

Occurrence: very rare.

Siderocelis irregularis Hind. **(Fig. 51)**

Cells spherical, ellipsoidal or irregular, 6.4-8 μm in diameter, with granulations on the cell wall. One pyrenoid, with an obvious starch ring formed by 4 pieces. Some of the cells observed were free-floating and some were ingested by zooplankters.

Occurrence: very rare.

STREPTOPHYTA

CHAROPHYCEAE

Cosmarium* cf. *laeve Rabenh. **(Figs 21, 52)**

Cells 12-18 × 14-28 μm; sinus very deep, narrow, linear, open internally. Semicells semiellipsoidal; basal angles rounded; lower lateral margins parallel, then curving evenly to narrow; apex notched, truncate; wall regularly punctuate-scrobiculated. The apical depression usually observed in *C. laeve* was not a constant character in the few individuals observed; this did not allow a definitive identification. Reported among the most abundant algae of Lake Kivu by Hecky & Kling (1987).

Occurrence: rare; all seasons; epilimnion.

Cosmarium* cf. *regnellii Wille **(Figs 20, 54)**

Cells 10.2-12.8 μm wide, 12.8-18 μm long, with isthmus 2-2.6 μm wide. The sinus is linear. Semicells trapezoidal, with wide, flattened apex. Cell wall apparently smooth in LM. Most probably, noted for Lake Kivu as *Cosmarium* sp. by Hecky & Kling (1987: fig. 11).

Occurrence: rare; all seasons; epilimnion.

***Cosmarium* sp.** **(Fig. 53)**

Cells 11.5 μm wide, 12.8 μm long, with isthmus 3.8 μm wide and a linear, narrow sinus. Semicells elliptical, without undulations in outline, with a slight invagination on the apices. Cell wall apparently smooth in LM. The observation of a single specimen and lack of zygospores did not allow identification at the species level.

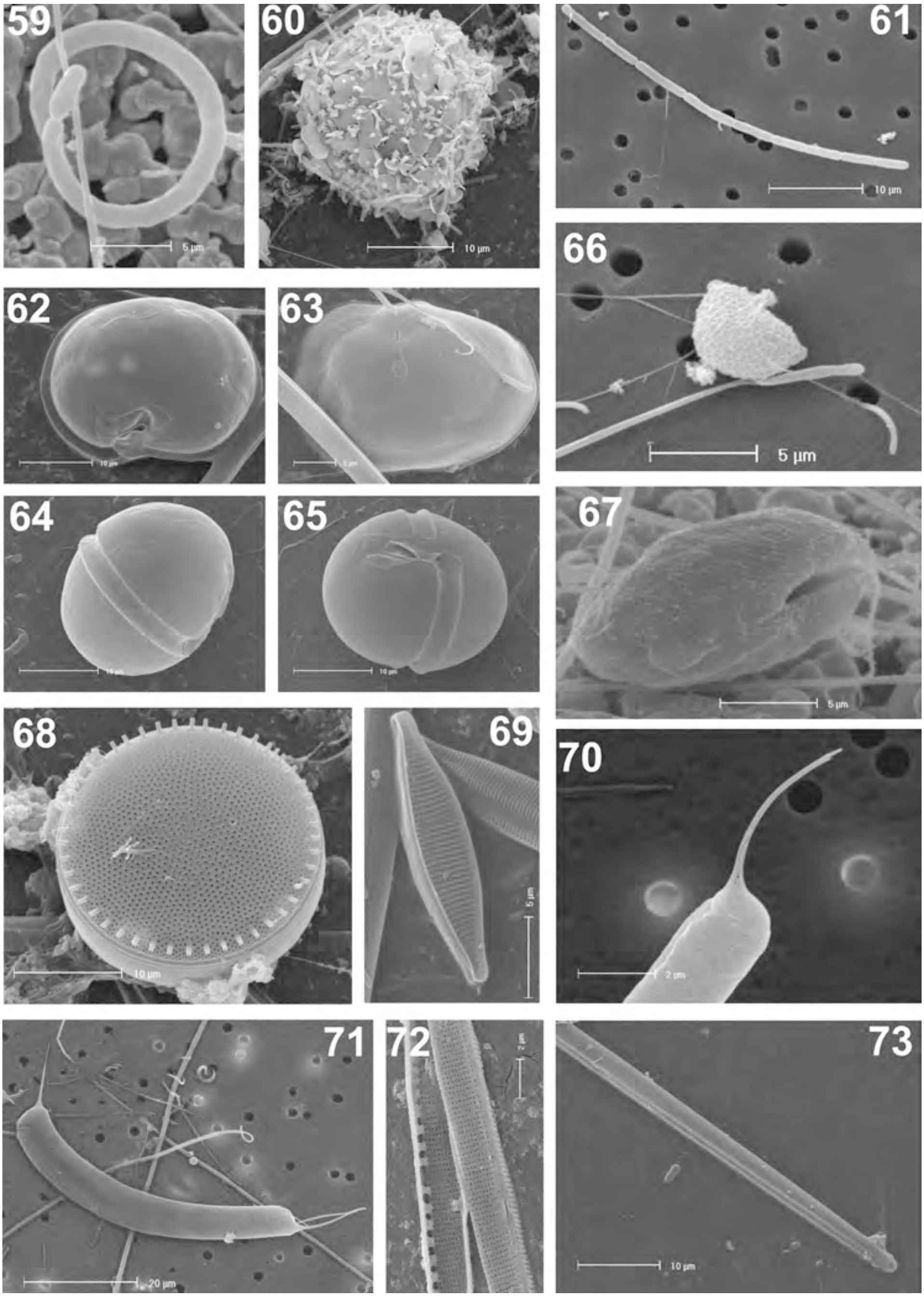
Occurrence: very rare.

Staurastrum Ralfs

***Staurastrum* sp.** **(Fig. 22)**

Cells deeply constricted, with an acute sinus widening outward. Semicells subcuneate, 9 × 10 μm, with almost flat apices and undulated cell walls, continuing in two or three processes with undulated walls, ending bifurcate. The processes run parallel to the isthmus axis and the distance between their ends is 37 μm. The material collected resembles some of the specimens of *Staurastrum nodulosum* Playfair found in Sri Lanka by Rott & Lenzenweger (1994), considered by these authors a tropical species.

Occurrence: Very rare.



Figs 59-73. **59.** *Cylindrospermopsis* cf. *curvispora* Wat. **60.** *Paraphysomonas vestita* Stokes **61.** *Pseudanabaena moniliformis* Kom. *et* Kling. **62-63.** *Peridinium umbonatum* Stein. **64-65.** *Peridinium* sp. **66.** *Tetraedron* sp. **67.** *Cryptomonas* sp. **68.** *Thalassiosira rudolfi* (Bach.) Hasle. **69.** *Nitzschia fonticola* Grun. **70-71.** *Urosolenia* sp. (70. detail of the calyptra with poroids on the process base). **72-73.** *Nitzschia bacata* Hust. (72. detail of fibulae median interruption).

DISCUSSION

This work provides an update of the algological records of Lake Kivu's pelagic system. The most common species encountered during observation of settled samples in conventional LM were pennate diatoms (*Nitzschia bacata* and *Fragilaria danica*) and Cyanophyceae (*Planktolyngbya limnetica*) (Tab. 2). However, EM revealed the real abundance of *Synechococcus* sp., which can reach several hundred thousand cells.L^{-1} in the water of the lake (Sarmento *et al.*, 2006).

Table 2. Summary of the taxa found in the pelagic waters of Lake Kivu, sorted by occurrence frequency.

Taxon	*Frequency*	*Seasonality*	*Vertical distribution*
Nitzschia bacata Hust.	very common	all seasons	epilimnion
Planktolyngbya limnetica (Lemm.) Komárková-Legnerová *et* Cronberg	very common	all seasons	epilimnion
Synechococcus sp.	very common	all seasons	epilimnion
Monoraphidium contortum (Thur.) Kom.-Legn.	very common	all seasons	epilimnion
Fragilaria danica (Kütz.) Lange-Bert.	very common	all seasons	epilimnion
Urosolenia sp.	very common	all seasons	surface
Cryptomonas sp.	very common	all seasons	epilimnion
Tetraedron sp.	very common	all seasons	epilimnion
Cylindrospermopsis cf. *curvispora* Wat.	common	all seasons	epilimnion
Microcystis sp.	common	rainy season	surface
Pseudanabaena moniliformis Kom. *et* Kling	common	all seasons	epilimnion
cf. *Rhodomonas* sp.	common	all seasons	epilimnion
Peridinium umbonatum Stein	common	all seasons	epilimnion
Peridinium sp.	common	all seasons	epilimnion
Anabaena sp.	rare	rainy season	epilimnion
Aphanocapsa sp.	rare	all seasons	epilimnion
Aphanothece sp.	rare	all seasons	epilimnion
Chroococcus sp.	rare	all seasons	epilimnion
Merismopedia trolleri Bach.	rare	all seasons	metalimnion
Pannus microcystiformis Hind.	rare	rainy season	surface
Planktolyngbya undulata Komárek *et* Kling	rare	all seasons	epilimnion
Pseudanabaena mucicola (Naumann & Huber-Pestalozzi) Schwabe	rare	rainy season	surface
Gymnodinium sp.	rare	all seasons	epilimnion
Nitzschia fonticola Grun.	rare	all seasons	epilimnion
Nitzschia tropica Hust.	rare	all seasons	epilimnion
Thalassiosira rudolfi (Bach.) Hasle	rare	all seasons	epilimnion
Paraphysomonas vestita Stokes	rare	all seasons	epilimnion
Dictyosphaerium pulchellum Wood	rare	all seasons	epilimnion
Tetraedron regulare Kütz.	rare	all seasons	epilimnion
Oocystis lacustris Chod.	rare	all seasons	epilimnion
Cosmarium cf. *laeve* Rabenh.	rare	all seasons	epilimnion
Cosmarium cf. *regnellii* Wille	rare	all seasons	epilimnion

Table 2. Summary of the taxa found in the pelagic waters of Lake Kivu, sorted by occurrence frequency. *(continued)*

Taxon	*Frequency*	*Seasonality*	*Vertical distribution*
Aphanocapsa holsatica (Lemm.) Cronb. *et* Kom.	very rare	–	–
Cryptaulax sp.	very rare	–	–
Cyclotella meneghiniana Kütz.	very rare	–	–
Coelastrum reticulatum (Dang.) Senn.	very rare	–	–
Dictyosphaerium tetrachotomum Printz	very rare	–	–
cf. *Sphaerocystis* sp.	very rare	–	–
Oocystis cf. *submarin*a Lagerh.	very rare	–	–
Siderocelis irregularis Hind.	very rare	–	–
Cosmarium sp.	very rare	–	–
Staurastrum sp.	very rare	–	–

The centric diatom *Urosolenia* sp. can also be very abundant, mostly near the surface under daily stratification conditions. Once again, formaldehyde-fixed and settled samples do not reveal the real abundance that these organisms can reach. Numerous, much bigger specimens were found in SEM from glutaraldehyde-fixed surface water.

Species composition did not appear to differ considerably between sampling sites. Vertical distribution seems to be the most important source of variation in Lake Kivu. Many species were uniformly distributed in the epilimnion, but there were several surface-specific taxa, such as *Urosolenia* sp. and *Microcystis* sp., lower epilimnion species (under 20 m), such as *Cryptomonas* and *Rhodomonas*, and strictly metalimnic taxa, such as *Merismopedia trolleri* and *Cryptaulax* sp. (Tab. 2). This vertical distribution pattern reflects contrasting environmental conditions along the water column, in particular light conditions, as euphotic layer is relatively shallow (~18 m) but also the increasing conductivity and nutrients (detailed vertical profiles in Sarmento *et al.*, 2006).

Algal composition did not seem to show a clear seasonal succession. Only their relative abundance seemed to vary in the open lake, where environmental conditions were relatively constant. During the dry season the proportion of diatoms appeared to be higher, whereas in the rest of the year (rainy season) dominance was shared between diatoms and cyanobacteria.

In general, tropical lakes are characterized by low phytoplankton diversity (Lewis, 1978, 1990). Compared with other East African Rift lakes, Lake Kivu has a particularly poor diversity. Hecky & Kling (1987) found 103 pelagic species in Lake Tanganyika, almost three times as many as in Lake Kivu; 78 taxa, nearly twice as many as in Lake Kivu, were found in Lake Malawi (Patterson & Kachinjika, 1995). As early as 1937, Damas wrote about the pelagic plankton of Lake Kivu: "*Ses eaux claires et transparentes sont un véritable désert*" ('its clear and transparent waters are a real desert'). Further studies, however, especially if based on molecular approaches, might bring to light higher diversity, namely among small cyanobacteria. Some of the species reported in this paper were observed in Lake Kivu for the first time (as it could be expected, given the limited and dispersed available data). On the other hand, some species cited in the previous literature were not observed in this study; this is the case of *Nitzschia lancettula*, *N. confinis*, *Cosmarium kivuense* Conrad and *Scenedesmus cristatus*

Conrad. For other organisms (taxa of *Planktolyngbya*, for example), the name has changed due to nomenclature updates.

The fact that Lake Kivu, as it is today, is relatively recent from a geological point of view, could be an explanation for its poverty in endemisms, demonstrated for example for fish populations (Snoeks *et al.*, 1997). Several pieces of evidence, particularly sediment cores analysis (Haberyan & Hecky, 1987), suggest that numerous "reset" phenomena in biotic communities took place during the geological history of the lake, due to high volcanic activity that is still going on today. However, a consideration of the living timescale and dispersal velocity of phytoplankton (Round, 1981) in relation to these geological events, suggests that the number of well-adapted species may rather be limited by constantly low nutrients and light conditions. Differently from the lakes Tanganyika and Malawi, in Lake Kivu the mixed layer is often greater than the euphotic layer; this represents a highly selective factor for a large number of phytoplanktic species. The low abundance and diversity of Chlorophyceae supports this hypothesis.

It is also reasonable to suppose that changes in phytoplankton composition may have occurred during the last 50 years as a result of environmental changes, in particular the introduction of the sardine *Limnothrissa miodon* (Boulenger) from Lake Tanganyika. Many studies have outlined the opportunistic feeding behaviour of this sardine and its wide-ranging omnivorous diet (Mandima, 1999, 2000; Isumbisho *et al.*, 2004). Its impact on zooplankton has been clearly demonstrated (Dumont, 1986; Isumbisho *et al.*, 2006); to provide evidence of a similar effect on phytoplankton is much more difficult, because sampling, fixation and observation methods are different among different studies, as well as the temporal and spatial coverage. It can be stated that, so far, no evidence of an effect of the introduction of the sardine on the phytoplanktic communities is available.

The results of the present investigation lead us to believe that extensive taxonomic studies, based on a combination of several different techniques, are very important to clarify past and future changes caused by human activities and climate change in the communities of Lake Kivu and other East African lakes.

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