PHYTOPLANKTON AND EUTROPHICATION OF FURNAS LAKE (S. MIGUEL ISLAND/AZORES)

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With 10 figures and 3 tables

ABSTRACT. Furnas lake is a shallow water body of volcanic origin situated in S. Miguel Island, Azores. Qualitative and quantitative study of phytoplankton communities was made from September 1988 to July 1989, in order to determine its trophic state. Cyanobacteria were the main organisms presented, specially in Summer and Autumn, and are responsible for the water quality degradation in Furnas lake. By the end of last century, the registered water quality of this lake was very good, as shown by BARROIS, who referred to the presence of *Dinobryon sertularia*, an indicator species of oligotrophic waters. Its disappearance will be connected with the increasing supply of nutrients (specially nitrogen and phosphorus compounds) in this century, that will be related to the cattle breeding development in S. Miguel island, which began in the early part of this century.

The utilization of permanent grazing ground zones for the bovine cattle in fields which belong to the drainage basin in Furnas lake, has contributed to an increasing eutrophication, as can be seen by high values of phytoplankton enumeration, biomass and chlorophyll *a* (annual averages of 7 991 500 cells.l^{-1}, 18.165 mg.l^{-1} and 37.47 µg.l^{-1}, respectively). The values of trophic state index also indicate eutrophic conditions. The cyanobacteria dominated most of the year and *Aphanizomenon flos-aquae* blooms occurred in July and November. This species, as well as others species of cyanobacteria, in special conditions, could produce toxic substances. These toxins, when present in great amounts, could provoke serious problems, not only to fish but also to other animals, including man if the water is used for human consumption.

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Bol. Mus. Mun. Funchal, Sup. no. 4: 637-649, 1995 ISSN 0870-3876

INTRODUCTION

S. Miguel island is situated in the eastern part of Azorean archipelago, in the Atlantic Ocean, between 37° 42' and 37° 55' latitude North and 25° 08' and 25° 52' longitude West, and its distance from the European continent is about 1 500 Km. It is the largest of the nine islands of Azores with a surface area of 779.05 Km^2 and a population of 131,908 inhabitants. The climate is oceanic with comparatively small variations in temperature.

The island is mountainous and may be divided into three zones, each possessing natural lakes: 1. The western zone, formed by Sete Cidades (Seven Cities) volcanic complex, whose highest peak is the Pico da Cruz (852 m above sea level). A number of lakes exist within this vast crater, the largest being Lagoa Azul (Blue Lake) and Lagoa Verde (Green Lake); 2. The central part of the island, a narrow strip having its greatest altitudes in the çgua de Pau range, whose highest peak is the Pico da Barrosa (949 m above sea level). Near this peak is the vast crater of Lagoa do Fogo (Fire Lake); 3. The eastern zone, the Achada das Furnas plateau, with altitudes between 400 and 500 m. The plateau ends at the edge of the Furnas crater, where Furnas Lake lies, 200 m above sea level.

Furnas lake (37° 46 N, 25° 19 W) is a small (about 2 Km^2) and shallow lake (12 m of maximum depth). The lake is surrounded by mountains whose peaks form a ring about 300 m high. On the North shore of the lake there are hot springs. Rosário and Salto da Inglesa are the main streams that feed Furnas lake and carry out nutrients and allochthonous matter of two important land pastures, Achada das Furnas and Castelo Branco.

By the end of last century, the water quality registered in Furnas lake was very good, as shown by BARROIS (1896), who referred to the presence of *Dinobryon sertularia*, an indicator species of oligotrophic waters (LEHMAN, 1976). Its disappearance will be connected to the increasing supply of nutrients (specially nitrogen and phosphorus compounds) in this century, that will be related to the cattle breeding development in S. Miguel island, which began in the early part of this century (MOREIRA, 1987). The utilization of permanent grazing ground zones for the bovine cattle in fields which belong to the drainage basin in Furnas lake, has contributed to decrease its depth and to increase the eutrophication process.

The qualitative and quantitative study of phytoplankton communities in Furnas lake of S. Miguel island was undertaken from September 1988 to July 1989, with the objective to study the structure of phytoplankton communities and to evaluate its trophic state.

MATERIAL AND METHODS

Sampling was undertaken from September, 1988 to July, 1989 in the center of the lake, which normally corresponded to maximum depth. Samples were collected on the surface, 2.5, 5 and 10 m. Phytoplankton enumeration and biovolume samples were undertaken every three months (November, January, May and July) and bimonthly for chlorophyll *a* (September, November, January, March, May and July). Samples for qualitative study of phytoplankton (identification) were taken with a plankton net of a mesh size of 10 µm, from bottom to surface. Chemical water and samples for quantitative study of phytoplankton (enumeration, biovolume and chlorophyll *a*) were taken with a Van Dorn bottle, except surface samples which were taken with a plastic bucket. Water transparency was measured with a Secchi disc. Temperature and dissolved oxygen were measured on shipboard immediately after samples were taken, with a portable Orion meter, model 290A. Phytoplankton samples were preserved with Lugol's solution (VOLLENWEIDER, 1974).

Phytoplankton was identified with a Leitz Wetzlar microscope and it was counted using a Sedgwick-Rafter chamber (A.P.H.A., 1985). Sample counts were made in duplicate and at least 100 individuals of every dominant species were enumerated (LUND *et al.*, 1958). Colonial species were considered as one unity in phytoplankton counting and the biovolume was calculated from the mean dimensions of the cell, assuming that its form corresponds roughly to simple geometrical solids (PAASCHE, 1960). The determination of the biomass expressed in fresh weight was based on the volume of each species (Table 1). The total volume of the phytoplankton cells was expressed in 109 µm3.l^{-1}, equal to mg.l^{-1} based on the assumption that the specific gravity of the phytoplankton is 1. Chlorophyll *a* was measured spectrophotometrically after phytoplankton extraction with 90% acetone and the results corrected for phaeophytin (LORENZEN, 1967). Total phosphorous was estimated using the vanadomolybdophosphoric acid colorimetric method. Trophic state index was used as an estimation of trophic level of the lake (CARLSON, 1977) and Shannon-Wiener information index to estimate phytoplankton diversity (HUTCHINSON, 1967).

RESULTS

Water temperature on the surface of Furnas lake ranged from 13.8 to 22.0 °C (Fig. 1). Thermal stratification was established in September and July, but the thermocline was not well developed, with a maximum temperature difference between surface and bottom of about 3 °C. The thermocline extended from about 5 m to near lake bottom. Dissolved oxygen frequently reached supersaturated concentrations in the water column (Fig. 2), except in those months when thermic stratification was observed and anoxic conditions prevailed at the bottom.

The transparency recorded ranged from 0.6 to 1.0 m (Fig. 3), reaching an annual average of 0.8 m, which indicates eutrophic conditions. Although the Furnas lake is shallow, the photic zone never reached the bottom, as a consequence of high phytoplankton biomass.

Phytoplankton species identified in Furnas lake included 26 species of algae, belonging to five divisions of algae, and 7 species of cyanobacteria (Table 1). Only a few of these phytoplankton species are important as biomass components.

Values registered for cell count (Table 2) and biomass expressed in fresh weight (Table 3) in Furnas lake were very high (annual averages of 7 991 500 cell.l^{-1} and 18.165 mg.l^{-1}, respectively), which is representative of an advanced trophic level. As a consequence of this luxurious development of phytoplankton, supersaturated concentrations of oxygen dissolved were observed in the upper layers. Phytoplankton counting recorded ranged from 6 208 000 cells.l^{-1} (July) to 9 340 500 cells.l^{-1} (May). Cyanobacteria were present throughout the year (Fig. 4), dominating in November and July. During the bloom of July they represented, as much as, 69.2% of the total cell count, while its annual average reached 44.6%. The normal bloom species was *Aphanizomenon flos-aquae* that increased in cell number in May, reaching its maximum in July (Fig. 5). The decline of this population occurs in January. Aphanizomenon flos-aquae is an indicator species of eutrophicated water bodies which has the possibility to form heterocysts when nitrogen concentration in the water is low (ROUND, 1973). So, it was possible that nitrogen fixation occurred in this species, as observed by HORNE and GOLDMAN (1972) in Clear lake, and had been responsible for the blooms occurring in Furnas lake.

Bacillariophyceae were the second major group in cell number and were found in large numbers throughout the year. They reached their maximum in November and January, when the dominant species were *Melosira ambigua* and *Synedra acus*. Diatoms minimum density was observed in July, probably as a consequence of low silica values registered (SANTOS *et al.*, 1991). Chlorophyceae were the third major group of phytoplankton cell number in Furnas lake, presenting an annual average of 23.7%. These algae were not abundant in November, January and July, but they registered its maximum development in May (42.6%), dominating *Staurodesmus* sp.. Species of dinophyceae, cryptophyceae and euglenophyceae never occurred in large quantities and were not significant in cell number.

Phytoplankton biomass recorded was lower in July (7.803 mg/l) and reached its maximum values in November and January (24.312 mg/l and 23.019 mg/l, respectively), when biomass was three times higher. The relative contribution of the major phytoplankton groups to the total biomass is shown in Fig. 6. While the cyanobacteria dominated in cell number, the diatoms predominated in biomass, except in July when dominants groups were chlorophyceae and cyanobacteria. *Melosira ambigua* dominates in biomass throughout the year, except in July when *Aphanizomenon flos-aquae* dominates (Fig. 7).

Bathymetric distribution of phytoplankton was closely related to the formation of the thermocline. In November, January and May, during homothermy, the phytoplankton was generally homogeneously distributed throughout the water column. Phytoplankton stratification occurred in July with thermal stratification of the lake. During stratification, the hipolimnion presented small amounts of dissolved oxygen and, consequently, phytoplankton density was very low.

Diversity index recorded (Fig. 8) was highest in May (2.72 bits.cell^{-1}) and lowest in July (2.72 bits.cell^{-1}), reaching an annual average value of 2.41 bits.cell^{-1}. Eveness followed the same trend, reaching an annual average value of 0.53. The lowest value for diversity index was due to a decrease in the evenness value determined by the high dominance of *Aphanizomenon flos-aquae*.

Seasonal variations of chlorophyll *a* (Fig. 9) follow the same trend of fresh weight biomass for the same months of sampling. The maximum amount of chlorophyll *a* was observed in November (64.59 $\mu g.l^{-1}$) and the minimum values in July (15.75 $\mu g.l^{-1}$), as observed for cell count and biomass.

In figure 10 the trophic state index for Furnas lake is shown, calculated by Secchi disk transparency chlorophyll *a* and total phosphorus. A seasonal variation can be seen with similar values by Secchi disc transparency and chlorophyll *a* and higher values for total phosphorus, specially in September, March and July.

CONCLUSIONS

Phytoplankton community of Furnas lake was dominated by cyanobacteria most of the year and blooms of *Aphanizomenon flos-aquae* occurred in November and July. This species may be related to the water quality degradation in Furnas lake, and contributes to increase its deterioration, because in special conditions, it can develop toxic substances (GORHAM and CARMICHAEL, 1980). The toxins produced by this species, as well as by others, when in great amounts, could provoke serious problems, not only to fish (CARMICHAEL *et al.*, 1975), but also to other animals (FULTON and PAERL, 1987), including man, if the water is used for human consumption (FALCONER *et al.*, 1983).

Cyanobacteria were associated with species commonly found in nutrient rich waters, as *Melosira ambigua* that dominates in November with *Aphanizomenom flos-aquae*.

High values of phytoplankton density, biomass and chlorophyll *a* indicated eutrophic conditions. This advanced eutrophic status is also confirmed by the values obtained for trophic state index, zooplankton community studies (RODRIGUES *et al.*, 1991) and physical and chemical analysis (SANTOS *et al.*, 1992).

ACKNOWLEDGMENTS

We thank Secretaria Regional de Habitação e Obras Públicas, do Governo Regional dos Açores and specially ENG. EDUARDO MOURA, the authorization to publish these results that were obtained in the "Eutrophication Control of S. Miguel Lakes Project". We also thank MR. JOSÉ GOUVEIA ANDRADE for the assistance in the fieldwork, as well as our colleagues that participated in this project.

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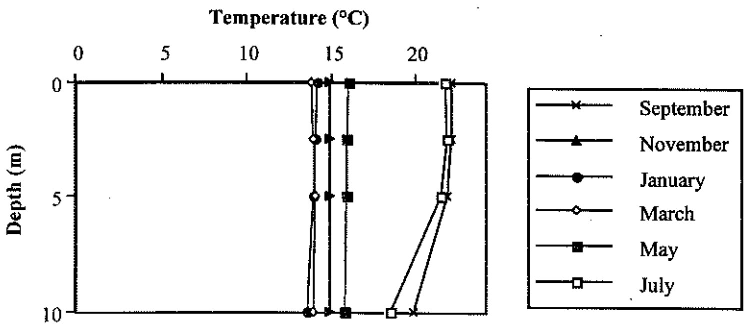

Figure 1 - Seasonal variation of temperature in Furnas lake.

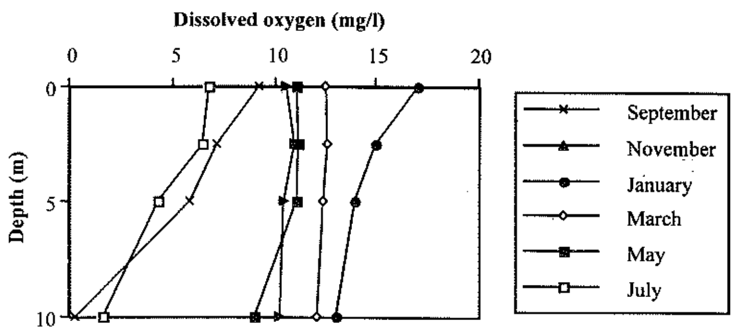

Figure 2 - Seasonal variation of dissolved oxygen in Furnas lake.

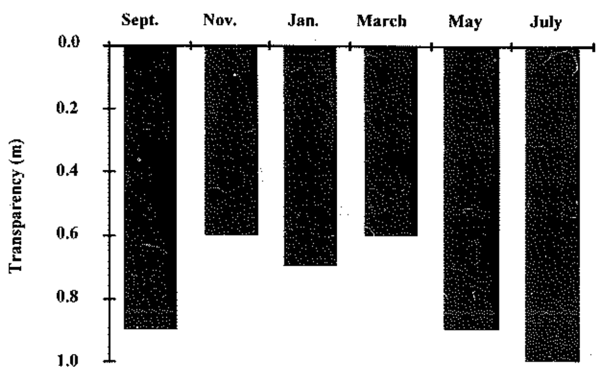

Figure 3 - Seasonal variation of transparency in Furnas lake.

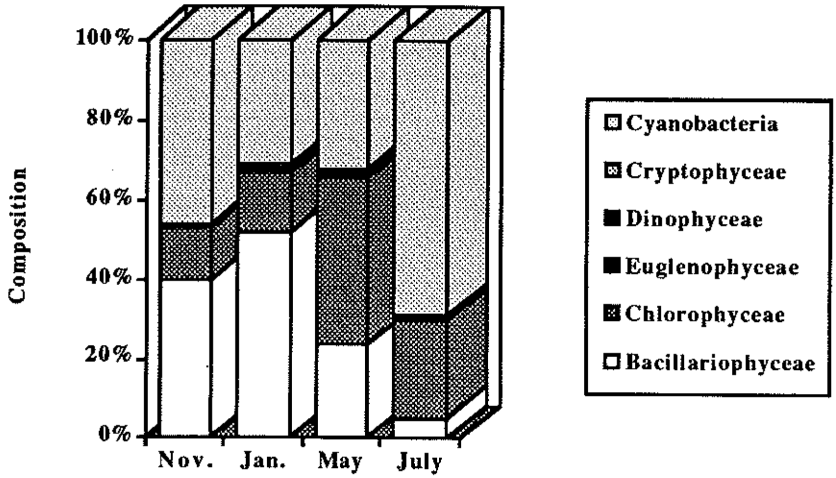

Figure 4 - Density (%) of the most important phytoplankton groups in Furnas lake.

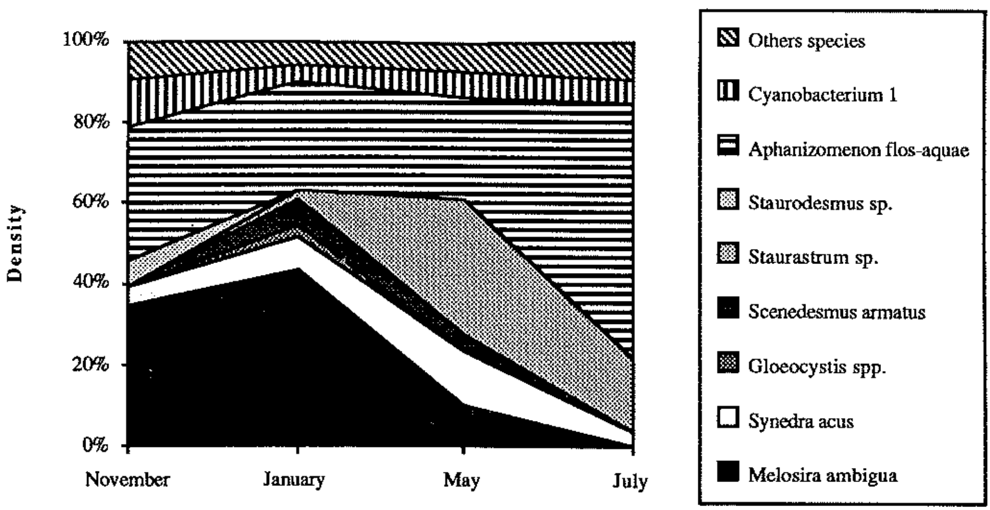

Figure 5 - Density (%) of the most important phytoplankton species registered in Furnas lake.

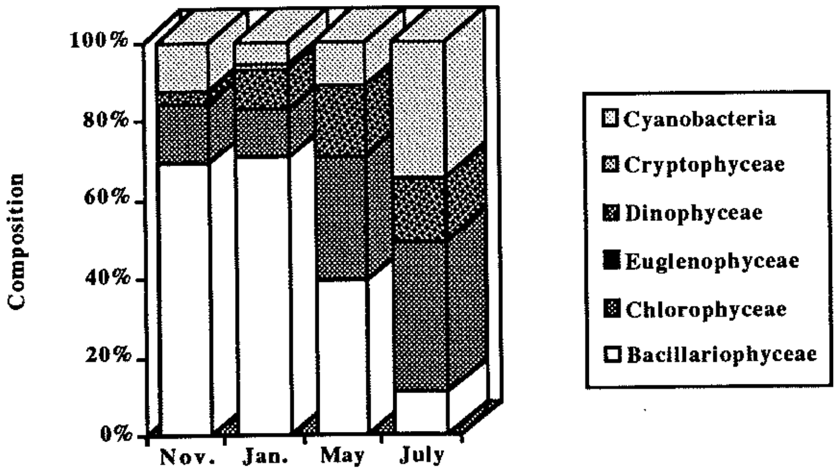

Figure 6 - Biomass (%) of the most important phytoplankton groups in Furnas lake.

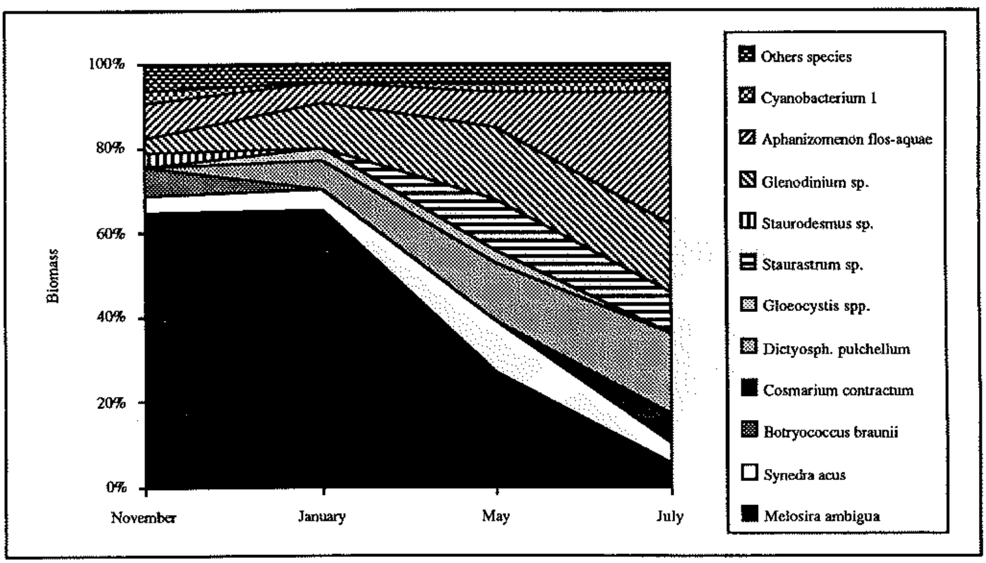

Figure 7 - Biomass (%) of the most important phytoplankton species registered in Furnas lake.

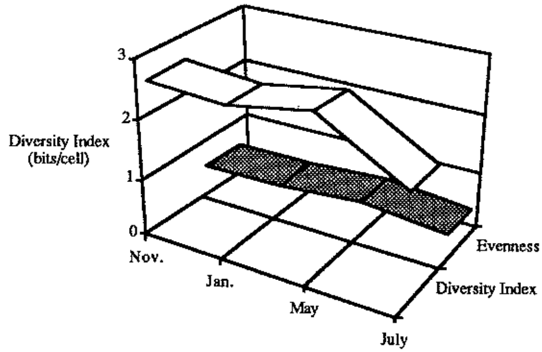

Figure 8 - Seasonal variation of diversity index and evenness registered in Furnas lake.

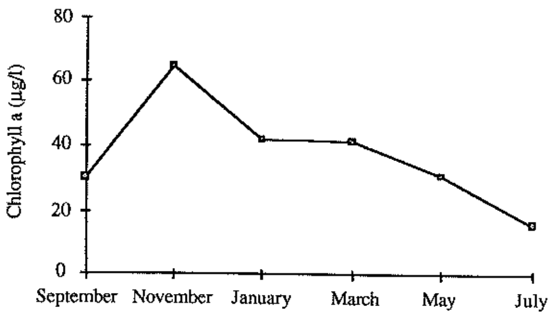

Figure 9 - Seasonal variation of chlorophyll *a* registered in Furnas lake.

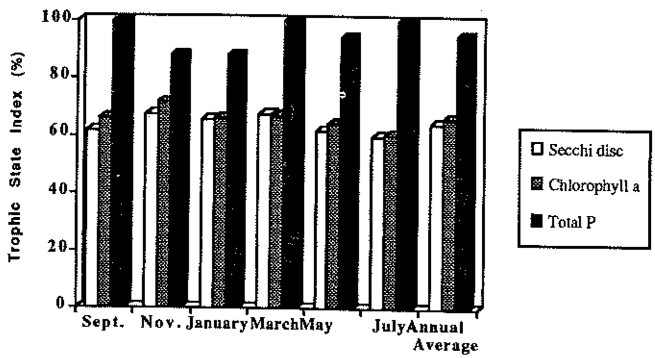

Figure 10 - Seasonal variation and annual average of trophic state index registered in Furnas lake.

TABLE 1 - Average biovolume of phytoplankton species in Furnas lake

TAXA	Average biovolume (µm3)	TAXA	Average biovolume (µm3)
CHLOROPHYCEA		BACILLARIOPHYCEAE	
Ankistrodesmus falcatus	370	*Melosira ambigua*	4900
Botryococcus braunii	21300	*Melosira granulata*	490
Cosmarium contractum	5300	*Navicula cryptocephala*	5100
Dictyosphaerium pulchellum	67500	*Navicula spp.*	2500
Gloeocystis spp.	3400	*Synedra acus*	1700
Golenkinia radiata	560		
Oocystis sp.	270	DINOPHYCEAE	
Pediastrum duplex	870	*Glenodinium sp.*	20600
Scenedesmus acuminatus (?)	320	*Peridinium inconspicuum*	5400
Scenedesmus armatus	280		
Scenedesmus dimorphus	600	CRYPTOPHYCEAE	
Scenedesmus quadricauda	680	Cryptophyceae not identif.	10600
Scenedesmus spp.	140		
Selenastrum westii	280	CYANOBACTERIA	
Staurastrum sp.	680	*Anabaena cylindrica*	2270
Staurodesmus sp.	1600	*Aphanizomenon flos-aquae*	620
Tetraedron minimum	320	*Aphanotece nidulans*	12300
		Merismopedia tenuissima	220
		Microcystis aeruginosa	2800
EUGLENOPHYCEAE		*Microcystis flos-aquae*	1700
Euglena spp.	1800	Cianobacterium 1	660

TABLE 2 - Phytoplankton density in Furnas lake (cells.l^{-1})

Month	Bacillari phyceae	Chlorop hyceae	Eugleno phyceae	Dinophy ceae	Crypto phycea	Cyanobac teria	Total
November	3760000	1210000	5000	42500		4310000	9327500
January	3710000	1030000		120000	15000	2215000	7090000
May	2207500	3975000		180000	5000	2973000	9340500
July	310333	1529333	5000	66667		4296667	6208000

TABLE 3 - Phytoplankton fresh weight biomass in Furnas lake (mg.l^{-1})

Month	Bacillari phyceae	Chloro phycea	Eugleno phyceae	Dino phyceae	Crypto phycea	Cyanobac teria	Total
November	16.792	3.747	0.009	0.838		2.926	24.312
January	16.189	2.871		2.396	0.159	1.405	23.019
May	6.905	5.488		3.176	0.053	1.904	17.526
July	0.822	2.993	0.009	1.272		2.707	7.803