.ongitudinal Phytoplanktonic Community Distribution in ı Tropical Reservoir (Americana, São Paulo, Brazil).

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RESUMO: Distribuição longitudinal da comunidade fitoplanctônica em uma represa tropical (Americana, Estado de São Paulo, Brasil). O trabalho apresenta o estudo da heterogeneidade espacial da comunidade fitoplanctônica resultante das diferentes condições ambientais encontradas no inverno de 1997 e no verão de 1998 na represa de Americana (São Paulo, Brasil). A represa está localizada em área de grande desenvolvimento econômico e industrial e seu principal tributário recebe, a montante, lançamentos de esgotos sanitários e industriais sem tratamento. Com o objetivo de identificar quais os principais fatores responsáveis pela distribuição longitudinal do fitoplâncton, as coletas foram feitas em 25 estações ao longo da represa. As diferenças mais significativas quanto a essa distribuição foram verificadas nas estações mais distantes da barragem, nas quais houve maior influência do Rio Atibaia, que contribuiu com grandes cargas de partículas em suspensão e nutrientes para o sistema. Nestas estações observou-se a dominância de Chlorophyceae, sendo *Monoraphidium griffithii* a espécie que mais contribuiu, em biovolume, para a biomassa nos dois períodos amostrados. Nas estações com características mais lênticas, próximas à barragem, houve dominância de Cyanophyceae, com maior contribuição de *Microcystis aeruginosa*, nos dois períodos amostrados. Os gradientes horizontais das variáveis ecológicas (material em suspensão, concentração de nitrogênio e fósforo) e de dominância das classes fitoplanctônicas encontradas evidenciaram o estágio final de sucessão que este ambiente apresenta.

Palavras-chave: Estrutura de comunidade fitoplanctônica, biovolume, represa hipereutrófica, distribuição horizontal.

ABSTRACT: Longitudinal phytoplanktonic community distribution in a tropical reservoir (Americana, São Paulo, Brazil). A study on the spatial heterogeneity of a phytoplanktonic community was carried out after an intensive sampling during two days (30 June 1997 and 22 January 1998) in Americana reservoir (São Paulo, Brazil). This reservoir is located in an area of extensive economic and industrial development and its main tributary receives untreated wastewater from both municipal and industrial sources. From the 25 sampling stations along the reservoir longitudinal axis, phytoplankton and water samples were collected in order to identify the phytoplanktonic horizontal distribution. The most significative differences in the spatial heterogeneity were found in the upstream stations near the reservoir headwater, where a high load of suspended particles and nutrients is introduced mainly by the Atibaia river. At these stations, Chlorophyceae dominance was detected in the two periods of the year and, in terms of biovolume, *Monoraphidium griffithii* was the most important for the phytoplankton biomass. In the lentic zone (near the dam), Cyanophyceae predominated and the greatest contribution to biomass was from *Microcystis aeruginosa*. The horizontal distribution of both abiotic variables and dominant phytoplanktonic classes showed the final stage of succession in this hypertrophic reservoir.

Key-words: Phytoplankton community structure, biovolume, hypertrophic reservoir, horizontal distribution.

Introduction

The different zones along a reservoir are due to physical, chemical, and biological characteristics peculiar to water from which longitudinal gradients can be identified (Thornton *et al.*, 1990).

Through the river, the upstream zone receives continuously a load of nutrients and particles from the drainage basin. Phytoplanktonic primary productivity is limited by light due to high concentrations of suspended matter. In the lentic zone, with increased water transparency and high light penetration, the production of autochthonous organic matter predominates (Kimmel *et al.*, 1990). According to Thornton *et al.* (1990), the advective supply of nutrients carried by the river is reduced since the intermediate zone of the reservoir and the phytoplanktonic production depends on in situ regeneration of nutrients. In eutrophic systems, the internal load of nutrients is highly significative for both, growth and spatial distribution of phytoplankton (Garcia-Gil & Figueiras, 1993).

The distribution of phytoplankton communities in reservoirs is limited not only by temporal but also by spatial scales, since longitudinal alterations of abiotic factors cause different effects on organisms.

Growth strategies of algae are determined by selected patterns of environmental conditions which vary with time. These strategies make it possible to explain and even to predict conditions which allow a specific group to predominate (Reynolds, 1988).

Seasonal changes and dam operation may produce marked effects, or "pulses", in reservoirs, such as input of suspended particles caused by increased rainfall. Other factors, such as increase of turbulence generated by wind and variations in theoretical water retention time during the year also contribute to the pulse effect in reservoirs (Calijuri, 1999).

There are several studies on temporal variations in reservoirs, but information on spatial heterogeneity have been limited to the vertical axis (Richerson *et al.*, 1978). According to Legendre & Demers (1984), in a phytoplanktonic community dynamics study, temporal and spatial (on both vertical and horizontal axes) scales must be considered simultaneously.

In the hypertrophic Americana reservoir, we studied the horizontal phytoplanktonic community distribution in order to show which abiotic factors determine community structure and, consequently, reservoir compartmentalization.

Material and Methods

Americana reservoir, formed by the damming of Atibaia river in 1949, is located in the State of São Paulo at 22° 44' S, 44° 19' W, at an altitude of 530 meters ASE (Fig. 1).

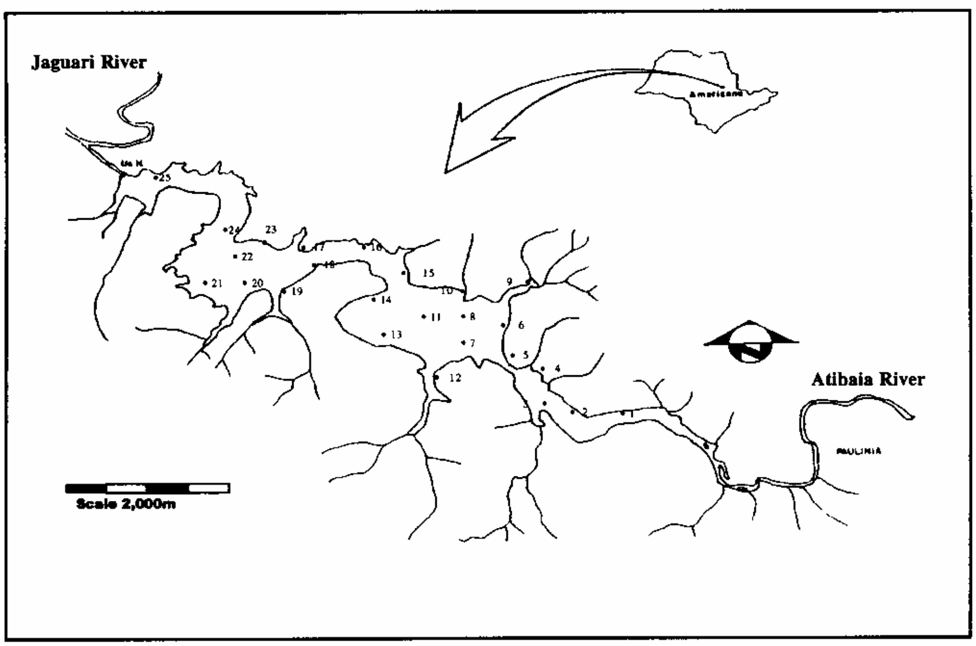


Figure 1: The sampling stations in Americana reservoir (São Paulo, Brazil).

According to the classification proposed by Straskraba (1999), it is a small reservoir (11.5 km²) with intermediate outflow, or class B (average annual theoretical water retention time of 57 days). For this study, water samples were taken from an integrated column from 25 stations along the longitudinal axis of Americana reservoir during two days (30/6/1997 and 22/1/1998).

Meteorological data at Americana reservoir (wind, air temperature, and pluviometric precipitation) and outflow data used to calculate theoretical water retention time during the collection periods, were made available by the CPFL (Companhia Paulista de Força e Luz). Water transparency was measured with a Secchi Disk.

In the laboratory, suspended matter was determined according to Teixeira *et al.* (1965). Ammonium (NH_4-N), total dissolved (TDP) and inorganic phosphate ($PO_4^{3-} - P$), nitrate (NO_3-N), nitrite (NO_2-N), and reactive silicate (SiO_2) were respectively determined by the methods of Koroleff (1976), Strickland & Parsons (1960), Mackereth *et al.* (1978), and Golterman *et al.* (1978). The trophic state index was calculated according to Kratzer & Brezonik (1981).

Organism identification was made through an inverted microscope (Zeiss), and counting by the Utermöhl (1958) method. The settling sample volume varied from 5 to 20 ml, depending on phytoplanktonic density. Sedimentation time was of at least three hours (Wetzel & Likens, 1991).

The individuals, cells, colonies, cenobios, and filaments, were enumerated in crossed transect and the fields were counted until a stabilization curve was reached. Relative abundance was estimated using the McCullough & Jackson (1985) procedure. The biovolume determination of predominant species in the sample was made using geometric equations (Wetzel & Likens, 1991). Compartmentalization of the system was determined by the similarity index between abiotic and biotic variables.

Results

Table I presents the mean air temperature (°C), total precipitation (mm), average outflow (m³/s), and theoretical water retention time (days) for Americana reservoir during the collection periods in the winter of 1997 and summer of 1998. Outflow, precipitation, and theoretical water retention time were practically the same when the two sampling periods were compared.

Table I: Meteorological dates, outflow and water retention time during the collection periods in Americana reservoir.

Seasons	Average Outflow (m³/s)	Total Precipitation (mm)	Average Air Temperature (°C)	Average Water Retention Time (days)
Dry Season	33	125	18	37
Rainy Season	37	121	26	33

Significant alterations in the euphotic zone and water transparency occurred in the two periods (Fig. 2 a and b). The largest values were found in the dry period. A longitudinal pattern of increasing Secchi Disk and of the euphotic zone towards the dam was observed in the two periods.

The longitudinal distribution of the suspended matter showed a decline towards the dam. The highest values were recorded in the stations near the main tributary inlet. A similar pattern for both fractions was detected (Fig. 3 a and b).

Table II shows, as expected, a decrease in dissolved and total phosphorus and nitrogen concentration from upstream zone to the dam, except for total dissolved phosphate in the rainy season.

Higher phytoplankton density values were found in the rainy period when compared to the dry period (Fig. 4). Cyanophyceae contributed most to community biomass density in both periods, but in the dry season Cryptophyceae and Chlorophyceae contribution was greater than in the rainy season, representing 40% of the total community (Fig. 5 a and b).

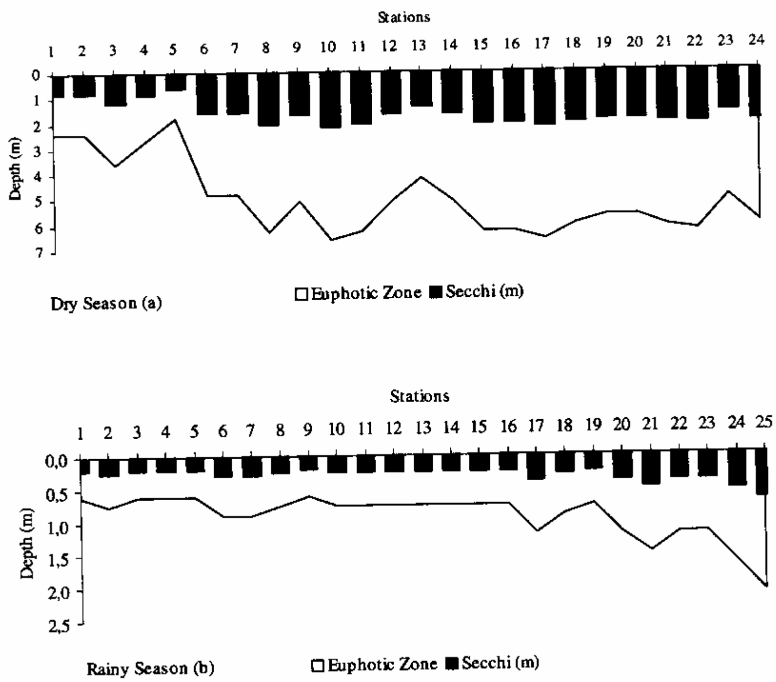


Figure 2: Longitudinal distribution of water transparency and zone euphotic depth in the dry (a) and rainy (b) seasons.

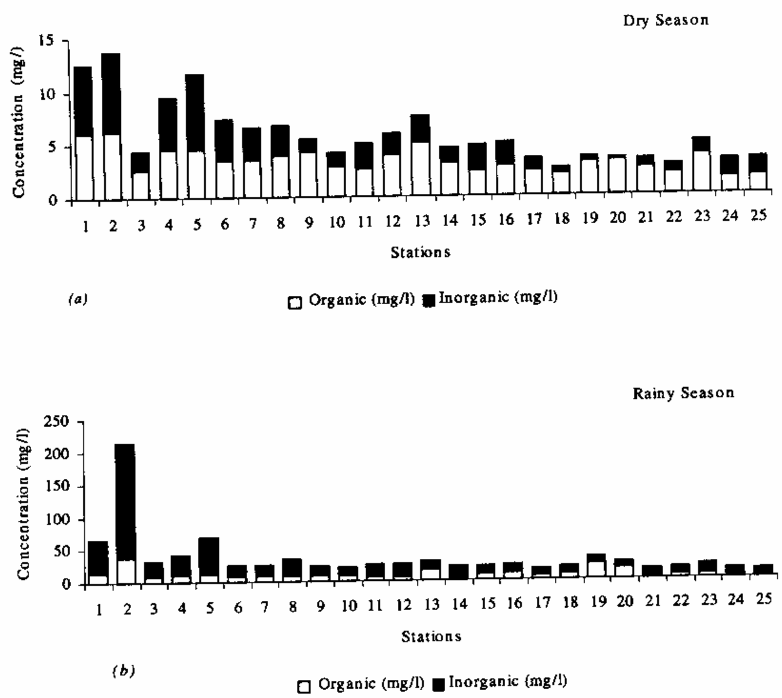
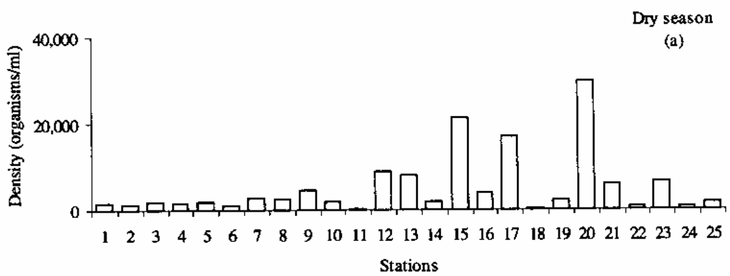


Figure 3: Longitudinal distribution of organic and inorganic suspended matter (mg/l) in the dry (a) and rainy (b) seasons.



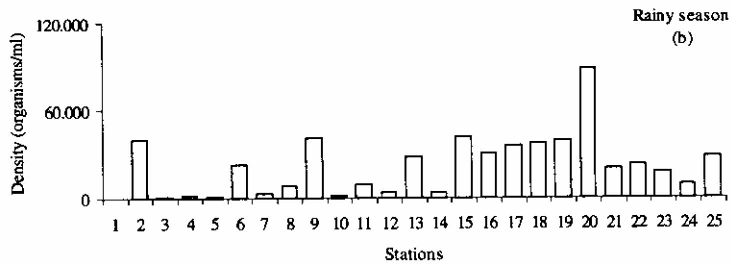
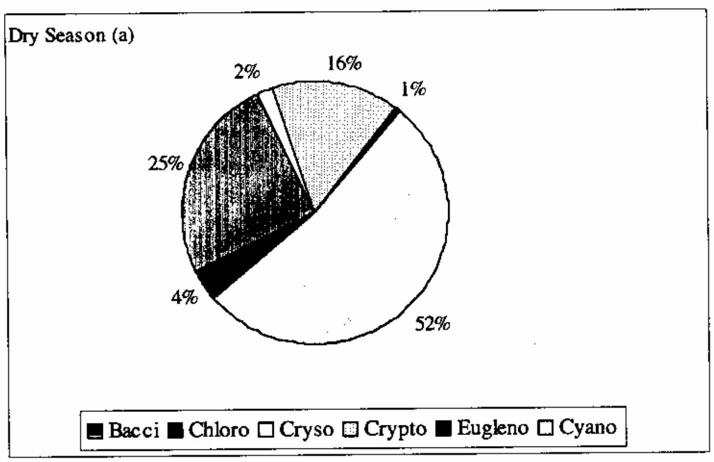


Figure 4: Longitudinal distribution of phytoplankton density (organism/ml) in the dry (a) and rainy (b) seasons.



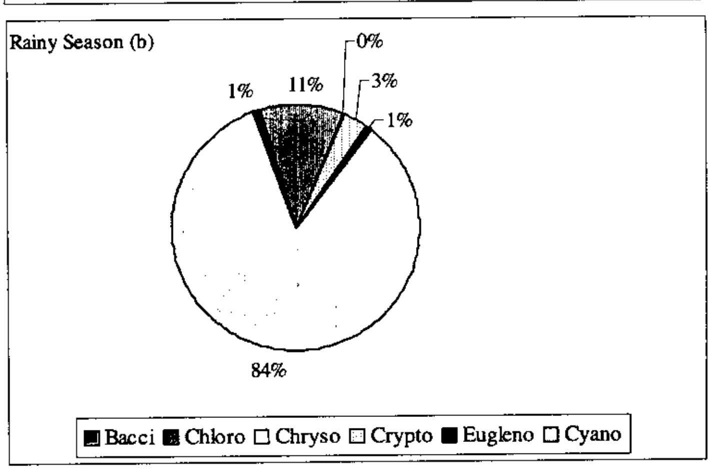


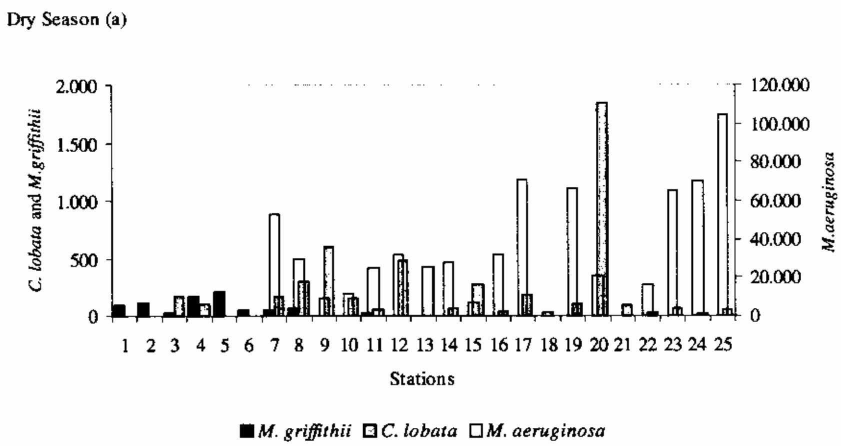
Figure 5: Phytoplankton classes contribution (%) in the dry (a) and rainy (b) seasons.

Table II: Longitudinal nutrient distribution (total and dissolved) between stations 2 and 25, during the collection periods in Americana reservoir.

Nutrient	Dry Season		Rainy Season	
	Station 2	Station 25	Station 2	Station 25
$NH_4 - N$ (µg/l)*	1,500	260	690	74
$NO_3 - N$ (µg/l)*	1,900	1,400	1,400	1,200
$NO_2 - N$ (µg/l)*	270	50	180	32
TDP (µg/l)*	150	25	72	77
$PO_4^{3-}-P$ (µg/l)*	90	6	41	30
S_iO_2 (mg/l)*	6	5	3	2

* Ammonium (NH_4-N); nitrate (NO_3-N); nitrite (NO_2-N); total dissolved phosphate (TDP); inorganic phosphate; $PO_4^{3-}-P$ and reactive silicate (SiO_2).

The phytoplanktonic biomass was represented by *Monoraphidium griffithii* (Chlorophyceae), *Cryptomonas lobata* (Cryptophyceae), and *Microcystis aeruginosa* (Cyanophyceae). The first two species presented higher density in the stations near the main tributary inlet: *Monoraphidium griffithii* predominated in the dry period and the *Cryptomonas lobata* contribution was limited to the rainy season in these stations. *Microcystis aeruginosa* dominated in the stations near the dam in the two periods (Fig. 6 a and b).



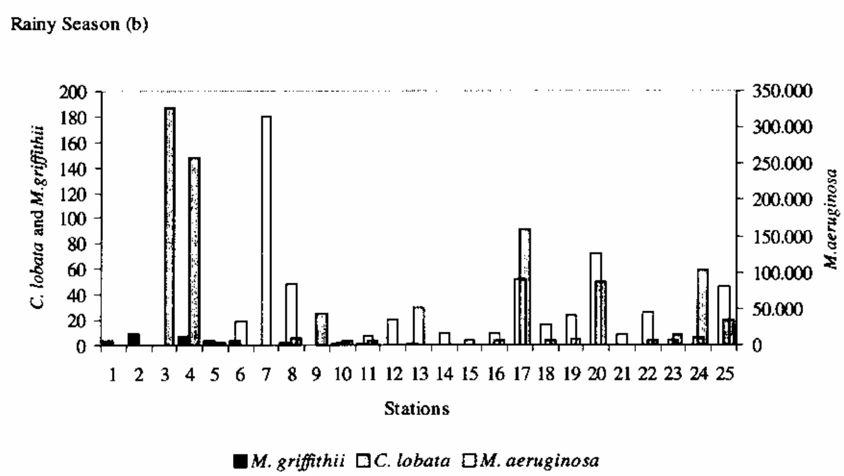


Figure 6: Longitudinal distribution of the dominant species biovolume (mm³/l) in the dry (a) and rainy (b) seasons.

Americana reservoir presented a hypertrophic state along the longitudinal axis during the rainy period (Fig. 7). A small decline in the trophic indexes towards the dam was observed in the dry season and, as expected, typically mesotrophic conditions were found at station 25.

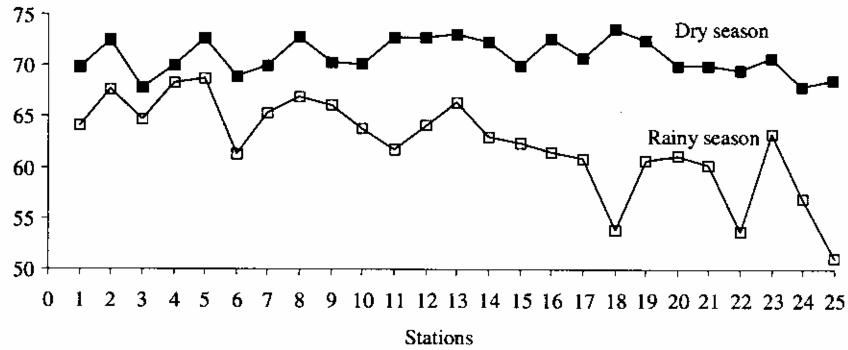


Figure 7: Longitudinal distribution of the state trophic indexes in the dry (a) and rainy (b) seasons.

Discussion

A reservoir dynamic is usually linked to dam operating mechanisms, such as alterations in outflow and spillage. Hence, these systems show relatively high physical instability and the behavior of each variable results from complex and independent processes depending on the dam operation (Ford, 1990). The hydrodynamic differences arising from locations, morphometry, and the main functions of a given system lead to horizontal and vertical gradients of particle and nutrient distribution which produce different ecological characteristics modifying the phytoplanktonic community structure.

The hypertrophic Americana reservoir showed Cyanophyceae biomass (mainly *Microcystis aeruginosa*) dominance in the two periods. The distribution of different strategist species is presented in Table III. This pattern was observed in the two periods and two compartments were identified: an area where C-strategist species (*Monoraphidium griffithii*) predominated, and another where S-strategist species (*Microcystis aeruginosa*) presented high densities. Furthermore, *Cryptomonas lobata* (R-strategist) predominated at some stations located near tributary mouths, such as station 3, 4, and 9.

When we compared the similarity index between the abiotic and biotic variables (Fig. 8), we observed two well-defined compartments: the stations 2, 3, 4, and 5 showed differences in the two sampling periods when compared with the other stations, which made up the second compartment. These compartments, considering phytoplankton composition, were also observed (Table III).

In Guarapiranga reservoir, Beyruth (2000) observed that Cyanophyceae growth occurs during warmer periods, when mixing of the water column is reduced, nutrient input occurs, and density increase is due not only to enrichment of nutrient from the watershed but also to in situ regeneration. In Americana reservoir, Cyanophyceae relative abundance was 98% of the phytoplanktonic community in the two periods and could be associated with the high temperatures in the rainy season and reduced mixing in the epilimnetic region. During the dry season, anoxia in hypolimnion is a condition that contributes to nutrient increase, mainly to phosphorus flux from sediment into the water column.

The phytoplankton distribution in Americana reservoir was associated with spatial variability of abiotic factors along the longitudinal axis. According to Thornton *et al.* (1990), upstream stations in reservoirs are characterized by greater turbulence, high amounts of suspended particles, and consequently decreased depth of the euphotic zone. In Americana reservoir, *Monoraphidium griffithii*, a C-strategist, dominated the stations. These organisms present high growth and respiration rates, and elevated nitrogen, phosphorus, and light intensity requirements. Moreover, being minute immobile cells (usually less than 50μm), these organisms are favored by shallow areas and reduced mixing (Calijuri, 1999).

Overall, composition changes were not observed in the phytoplanktonic community between samplings days. However, Cyanophyceae, the community representative, showed total density increase towards the dam during the study periods.

According to Paerl (1988), Cyanophyceae growth improves in stable systems since these organisms present physiological and morphological mechanisms for maintaining a vertical position. These include aerotropes, allowing flotation alterations, density reduction, and mucilage production to protect these organisms from high luminosity levels. Furthermore, the Cyanophyceae increase appears to be directly related to other variables like low N/P ratio, high water temperature, low light availability, and greater nutrient supply (Paerl, 1988; Reynolds, 1997).

In studies of temperate lakes with different trophic levels, Huszar & Caraco (1998) found a positive relationship between pH values and Cyanophyceae density. Of the six studied lakes, two were polymytic, shallow (from 4m – 8m depth), and highly eutrophic and mesotrophic. During the hottest season, the lakes presented similar biomass but larger than in the other four systems. In Americana reservoir, water temperature was very high in the rainy season, and a significant contribution of Cyanophyceae to total density was observed. The pH values were also higher, and a positive relationship with biomass was observed (Huszar & Caraco, 1998).

Cyanophyceae and Cryptophyceae can live in low light levels, characteristic of the rainy season, when higher levels of suspended matter cause significant reduction in light penetration. However, Cryptophyceae are less tolerant to pH increase and were replaced by Cyanophyceae, when stable conditions in the water column predominated (Klaveness, 1988; Reynolds, 1984). In Americana reservoir, Cryptophyceae dominance was greater in the dry season than in the rainy one when percentages of class contributions along all the stations sampled were compared.

Systems with low nitrogen and phosphorus concentrations are harmful to *Monoraphidium griffithii*, *Microcystis aeruginosa*, and *Cryptomonas lobata*, whereas shallow depths favor their development (Reynolds, 1997). This situation was observed in Americana reservoir, a shallow system with significant sediment and nutrient input and high turbidity in water. In the dry period, *M. griffithii* increased when suspended particles diminished. When there was an increase of suspended particles, the contribution, in the shallowest depth stations, of *M. griffithii* was smaller than that of *M. aeruginosa* and *C. lobata*. In the dry period, the input of suspended material was smaller, the euphotic zone increased, and larger biovolumes of *M. griffithii* at the stations near the main tributary inlet were detected.

Another factor affecting phytoplankton composition is the rotifer/crustacean ratio (Reynolds, 1997). When it was smaller than 4, the greater density of zooplanktonic crustaceans (cladocerans and copepods) leads to *Microcystis* density increases. However, when the ratio is high, *Cryptomonas* and *Monoraphidium* can grow significantly. According to a study on zooplanktonic distribution in Americana reservoir (Zanatta, 1999), the greatest rotifer density was found at the upper stations where *Cryptomonas* and *Monoraphidium* were dominant, and cladocerans and copepods increased in density towards the dam where *Microcystis* predominated.

Due to the association between the water body eutrophication and phytoplankton, much of the research has focused on identifying patterns in the structure of the community and its relationship to the trophic state. Most of the research (Seip & Reynolds, 1995; Watson *et al.*, 1997; Dasi *et al.*, 1998; Reynolds, 1998; Trifona, 1998) has showed a relationship between physical and chemical variables, and phytoplankton distribution and abundance. According to Reynolds (1998), the trophic gradient is not attributable to a single factor, but is rather a result of a set of environmental conditions, since different nutrient and particle loads affect both the availability and intensity of other factors, e.g., light and carbon dioxide.

In two systems with different trophic state, Negro *et al.* (2000) found that, although Cyanophyceae were dominant, each species makes a different contribution. In the more eutrophic lakes, nitrate storage during the summer favored the development of *Anabaena* sp. The emergence of heterocited Cyanophyceae in the other poorer systems was attributed to increased phosphorus concentration.

Table III: Distribution of different strategist species in Americana reservoir, in the dry and rainy seasons. (C: *M. griffithii*; R: *C. lobata*; S: *M. aeruginosa*).

Stations	Dry season	Rainy season
1	C	C
2	C	C
3	R	R
4	R	R
5	C	C
6	C	S
7	S	S
8	S	S
9	S	R
10	S	S
11	S	S
12	S	S
13	R	S
14	S	S
15	S	S
16	S	S
17	S	S
18	S	S
19	S	S
20	S	S
21	S	S
22	S	S
23	S	S
24	S	S
25	S	S

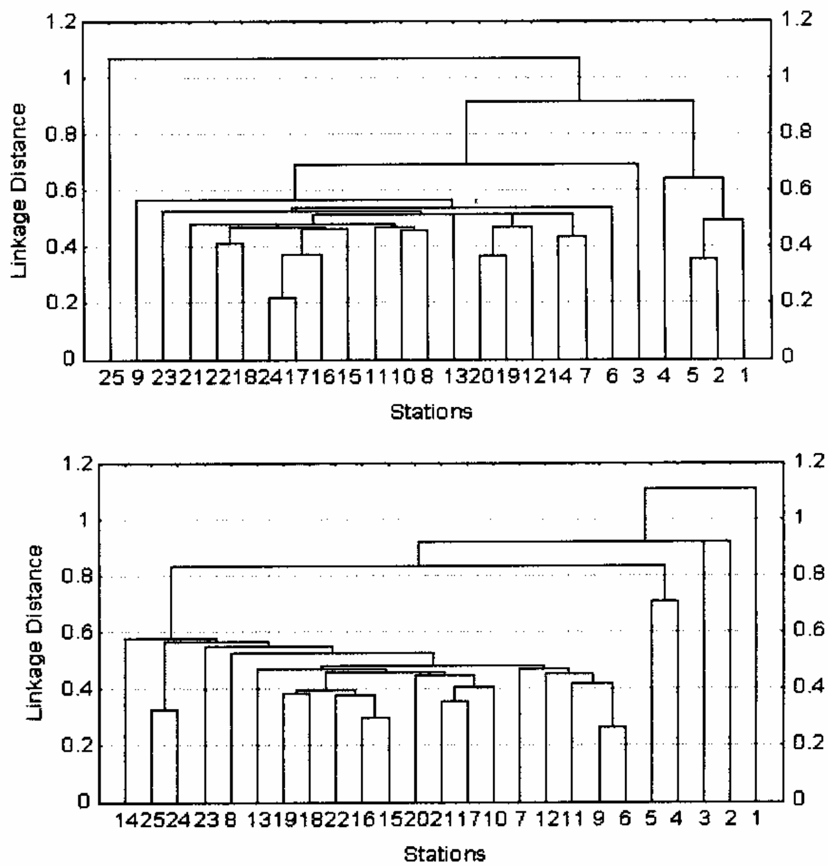


Figure 8: Similarity index between biotic and abiotic variables in the dry (a) and rainy (b) seasons. (Single linkage and Euclidean distances).

Due to the limited number of studies on horizontal distribution of phytoplanktonic communities, this work represents a useful contribution because it shows that a highly impacted system, such as Americana reservoir can be divided, according to the phytoplanktonic community structure, into two compartments: the lotic region, where *M. griffithii* (C-strategist) predominates, and the lentic region, dominated by *M. aeruginosa* (S-strategist).

In the two periods, the dominant class was found to be Cyanophyceae, with *M. aeruginosa* making a large contribution to the biomass. This finding can be considered a characteristic of the final stage of succession presented by Americana reservoir (São Paulo, Brazil).

Acknowledgements

To FAPESP, for a scholarship grant (Process 97/14071-2) and Process 95/09584-5.

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Recebido em: 19 / 12 / 2000
Aprovado em: 04 / 03 / 2002