Periphytic community of reservoirs cascade in the Paranapanema river, Brazil

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ABSTRACT. Along its course, the Paranapanema River presents some hydroelectric dams. During the year 2001, seven of these (Chavantes, Salto Grande, Canoas II and I, Capivara, Taquaraçu and Rosana) had their periphytic community studied. Samples of periphyton in natural substratum of the epiphyton type were collected from the river banks during the dry and the rainy seasons. Overall, the periphytic biomass in reservoirs of the Paranapanema River was characterized according to the rain regime of the area with higher and irregular values in the rainy period. The periphytic community demonstrated higher values of biomass, composition and abundance in the reservoirs located in middle Paranapanema, especially in Salto Grande and Canoas I. The Rosana and the Capivara Reservoirs presented higher values of algal density, chlorophyll *a* and species richness. The structure of the phycoperiphytic community was controlled by several factors, especially oscillation in precipitation, secchi depth, depth, retention time, temperature and water nutrients.

Key words: epiphytic algae, river banks, reservoir, cascade of reservoirs.

RESUMO. Comunidade perifítica nos reservatórios em cascata do rio Paranapanema, Brasil. O rio Paranapanema, um dos principais tributários do alto rio Paraná, apresenta, ao longo de seu percurso, vários reservatórios. Em 2001, sete desses foram estudados quanto à comunidade perifítica: Chavantes, Salto Grande, Canoas II e I, Capivara, Taquaraçu e Rosana. As coletas do perifíton (epifíton) foram realizadas em dois períodos e sempre na região litorânea. A biomassa perifítica nos reservatórios do rio Paranapanema foi caracterizada pelo regime pluviométrico da região, sendo os valores mais elevados e irregulares no período chuvoso. Foi observada maior semelhança entre a biomassa, a composição e a abundância nos reservatórios situados no médio Paranapanema, especialmente em Salto Grande e Canoas I. Os reservatórios de Rosana e de Capivara apresentaram uma maior riqueza de táxons, densidade algal e maiores valores de clorofila *a*. Sugere-se que a estrutura da comunidade ficoperifítica foi controlada por vários fatores, como precipitação, transparência, profundidade, tempo de retenção, temperatura e nutrientes da água.

Palavras-chave: algas epifíticas, região litorânea, reservatório, cascata de reservatórios.

Introduction

Reservoirs are artificial systems of water storage for multiple uses. Depending on the location of a watershed, the size of the drainage area, the basin geomorphology, and the size and climatic factors associated with anthropogenic activity, the water quality can be affected, with probable effect on its biological diversity and on the pattern of functioning of the reservoir as a whole (Tundisi, 1999; Tundisi *et al.*, 1999).

In reservoirs, the structure of communities is influenced by some events that occur upstream and downstream, such as the regime of flow, the degree of fluctuation in water level, the retention time, the water chemical composition (Tundisi *et al.*, 1993), and also by the different uses of the draining basin (Barbosa *et al.*, 1999).

Periphytic algae constitute the basis of many food webs and thus they can profoundly influence other aquatic communities (Lowe and Pan, 1996). Moreover, they present high species richness and high densities in a few square centimeters of substratum (Wetzel, 1983). They are also adherent and, thus, easy to collect and to store (Lowe and Pan, 1996). Therefore, comparative periphyton community studies in reservoirs with a range of distinct characteristics may provide important information about their structure and biodiversity, especially if the reservoirs are in cascade.

The present study represents an initial contribution regarding periphytic algae of reservoirs in cascade in the Paranapanema River. The main objectives are: a) to determine periphyton biomass, species richness and algae abundance; b) to verify the epiphytic community seasonal and spatial patterns in the reservoirs. This research work adds to the knowledge of periphytic community structure, since studies on the subject are still very incipient in Brazil.

Material and methods

Study area

The Paranapanema River is 929 km long and there are eight large hydroelectric dams along its course built in the last three decades. So they are: the UHE Armando Avelanal Laydner (Jurumirim), UHE Chavantes, UHE Lucas Nogueira Garcez (Salto Grande), UHE Escola de Engenharia Mackenzie (Capivara), UHE Escola Politécnica (Taquaraçu), UHE Rosana, UHE Canoas I and UHE Canoas II. The Paranapanema River can be divided into three parts: a) the upper Paranapanema, which includes Jurumirim and Chavantes; b) the middle Paranapanema, where Salto Grande, Canoas II, Canoas I and Capivara are located; and c) the low Paranapanema, which includes Taquaruçu and Rosana.

Seven of these reservoirs are shown in Figure 1. Their morphometry are heterogeneous, but two of them store a large volume of water (Chavantes and Capivara) and five present low water retention time (Salto Grande, Canoas II, Canoas I, Taquaruçu and Rosana) (Table 1). Some of these reservoirs are very dendritic (Chavantes and Capivara), while others present a "fluvial shape" (Salto Grande, Canoas II, Canoas I, Taquaruçu and Rosana). In this cascade of reservoirs, there is a predominance of oligo-mesotrophic conditions, tending to mesotrophy (Nogueira *et al.*, 2002). The Capivara Reservoir presents the greatest volume; Chavantes is the deepest (registered near the dam), and the mean depth in the lentic zones of the other reservoirs exceptionally exceeds 25 m. Canoas II, Canoas I and Salto Grande occupy smaller areas, while Chavantes, Capivara, Taquaruçu and Rosana are larger reservoirs (Table 1).

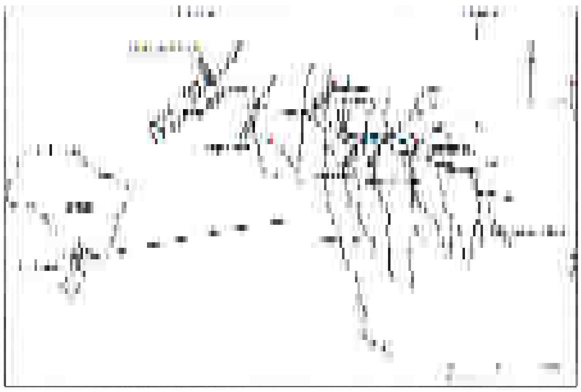

Figure 1. Location of the reservoirs in the Paranapanema River basin (Southeast Brazil).

The main agriculture activities in the upper Paranapanema are coffee, sugar cane, banana and pasture; in the middle Paranapanema, there is also pasture practice and cultivation of sugar cane, soy bean and corn in great amounts; in the low Paranapanema, there is a predominance of pasture. Regarding the vegetation, there are isolated small forests, except for the State Park of Morro do Diabo, near the Rosana Dam (Nogueira *et al.*, 2001).

Methods

Samples of periphyton were taken from the river banks near the dam, during 2001 – from July to August (dry periods) and in December (rainy period). Samples were taken from the natural substratum of the epiphyton type (petioles) – *Eichhornia azurea* Kunth from the reservoirs of Salto Grande, Canoas I and II, Taquaruçu and Rosana; *Polygonum* sp. from the Chavantes Reservoir, and fanerogamic vegetation from the Capivara Reservoir.

All substrata collected were stored in wet and cold chambers. Removal of the periphytic community from substrata (two petioles of different plants) was made in the field, using a shaving blade and gush of distilled water. After the periphyton was removed from the substratum, it was filtered through GF/C glass filters for determination of the chlorophyll *a* concentration through spectrophotometric method of Golterman *et al.* (1978). Dry mass was estimated according to Schwarzbold (1990). For quantitative and qualitative analysis of epiphytic community, the periphyton removed was stored in flasks (of known volume and area), fixed and preserved in 0.5% acetic lugol. Organisms were quantified using inverted microscope at 400X, according to Utermöhl (1958), and through random camp, according to Bicudo (1990). Values of chlorophyll *a*, ash dry mass (ADM), ash-free dry mass (AFDM), algae composition and density were converted into values per unit area of substratum.

Table 1. Morphometric features of the studied reservoirs.

Reservoirs	Chavantes	Salto Grande	Canoas II	Canoas I	Capivara	Taquaruçu	Rosana
Dam closure	1971	1960	1999	1999	1978	1989	1987
Surface area (km^2)	400	12	22.5	30.85	576	80.1	220
Volume (10^6 m^3)	8.795	44.5	207	207	10.540	672.5	1.920
Mean depth (m)	22	4	9	7	18	8	9
Maximum depth	80	14	18.5	27	59	55	34
Retention time (days)	352.7	1.4	4.4	6	126.8	7.9	19.7
Total length (km)	50	30	33	33	120	80	116
Secchi depth (m)	5.2	1.5	1.2	2.0	2.2	1.6	2.2
Water temperature	21.9	21.8	23.4	23.9	23.7	23.5	24.2

Biotic (periphyton) and Abiotic variables (wind, water temperature, dissolved oxygen, pH, conductivity, alkalinity and transparency) were collected simultaneously and they were supplied by the Laboratory of Basic Limnology, at the Research Nucleus in Limnology, Ichthyology and Aquiculture of the State University of Maringá – Nupelia/UEM. Reservoir features (Table 1) and precipitation data (Figure 2) were supplied by Power Companies.

Principal Components Analysis (PCA) and Detrended Correspondence Analysis (DCA) were used to reduce the dimensionality of abiotic (14 variables) and biotic (149 species) data. For abiotic and biotic variables' transformation [log10 (x + 1)], the software PC-ORD, version 4.0 for Windows, was used. The principal components axes interpreted were those presenting eigenvalues higher than the eigenvalues produced by the Broken-Stick model (McCune and Mefford, 1999).

Results

In tropical aquatic ecosystems, seasonal dynamics are more characterized with precipitation. Specifically, in the region of the Paranapanema River, there are two climatic periods well marked by the rain regime: the rainy period (Summer) and the dry period (Winter). The total mean annual rainfall was 1245.9 mm, but scarse rains occurred in April, July and August, 2001. High precipitation was recorded mainly in January, February and December, 2001. The highest values of precipitation occurred in the rainy period (Summer), mainly in the region of the Chavantes and the Rosana Reservoirs (287.3 and 226.2 mm, respectively, in December) (Figure 2).

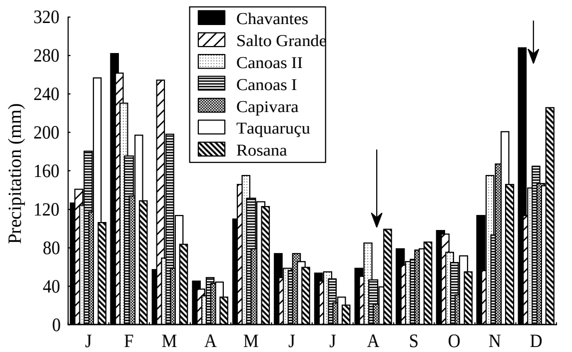

Figure 2. Monthly total precipitation during the year 2001 from January to December. (Arrows indicate sampling months).

Limnological characterization

Results of the Principal Components Analysis applied on the abiotic variables are shown in Table 2 and in Figure 3. Two axes were interpreted and together they explained 55.6% of the total variability (30.9% and 24.7%, respectively). It is possible to identify a group of sampling sites, mostly concentrated on the right side of axis 1, which positively correlated with the high values of turbidity and electrical conductivity, corresponding to the reservoirs of Salto Grande, Canoas II and I, Rosana and Taquaruçu. The other reservoirs were positioned on the left side of axis 1, basically due to the influence of retention time, wind and depth. This sampling was characterized by high values of these variables in the Chavantes and the Capivara Reservoirs (Table 2; Figure 3).

The second PCA axis differed among the reservoirs mainly with respect to periods (temporal scale). The variables that positively correlated were water temperature and pH, corresponding to the rainy period. Water temperature in the dry period ranged from 18.1 to 20.6°C, while in the rainy period the range was from 25.1 to 28.3°C. Total phosphorus and dissolved oxygen negatively correlated with high values in the dry period (Table 2; Figure 3).

Table 2. Results of the Principal Component Analysis applied on abiotic variables.

	Axes	
Results	1	2
Eigenvalues	4.325	3.459
Percentage of variance	30.895	24.709
Broken-stick	3.252	2.252
Variables	**Eigenvectors**	
Turbidity	0.4246	-0.0387
Electrical conductivity	0.3273	0.0229
Water temperature	0.2845	0.3978
Periphyton phosphorus	0.2538	-0.2721
pH	0.1637	0.3667
Total nitrogen	0.1052	-0.1213
Total phosphorus	0.0630	-0.4542
NH_4	0.0434	0.2324
Retention time	-0.3812	0.2586
Wind	-0.3786	-0.148
Depth	-0.3255	0.3441
Dissolved oxygen	-0.2554	-0.2647
Alkalinity	-0.2315	-0.1896
Ortho-phosphorus	-0.1005	0.2075

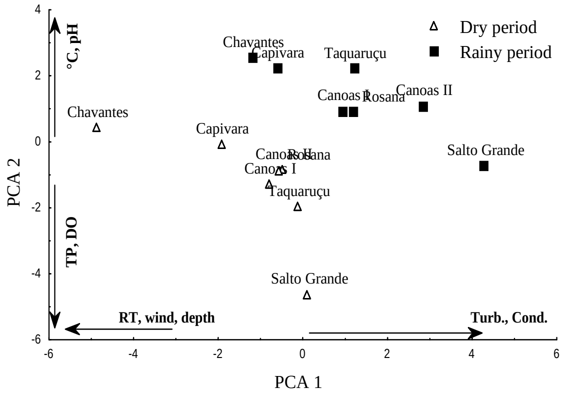

Figure 3. Ordination of the reservoirs zones (axes 1 and 2 of the Principal Component Analysis) according to the abiotic variables. (Abbreviations: °C= Water temperature; TP= total phosphorus; DO= dissolved oxygen; RT= Retention time; TURB= Turbidity; COND= Electrical conductivity).

Periphytic Biomass

In general, the reservoirs presented more homogeneous values of periphytic biomass in the dry period, when compared to the rainy period.

Higher photosynthetic biomass was registered in Canoas I, Capivara (middle Paranapanema) and Taquaruçu (low Paranapanema). In Capivara, the mean chlorophyll *a* concentration was 5.06 mg.cm^{-2} in the rainy period, and in the Taquaruçu Reservoir, it was 1.39 mg.cm^{-2} in dry period. Salto Grande presented the lowest chlorophyll *a* concentration, independent of the sampling period (mean of 0.19 mg.cm^{-2} and 0.14 mg.cm^2, in the dry and in the rainy periods, respectively) (Figure 4).

The values of organic (AFDM) and inorganic material (ADM) followed the same tendency discussed for chlorophyll *a*. Therefore, higher homogeneity occurred in the dry period when compared to the rainy period (Figure 5). The sample reservoirs from the dry period presented organic fraction (AFDM) as the main contributor to the values of total dry mass. In the rainy period, the inorganic fraction (ADM) was the greatest contributor to the values of total dry mass. A slight increase in the dry mass occurred in the reservoirs of the middle Paranapanema, especially Canoas I, Canoas II and Capivara. In Canoas I, ADM represented 89.5% of the total dry mass of periphytic community.

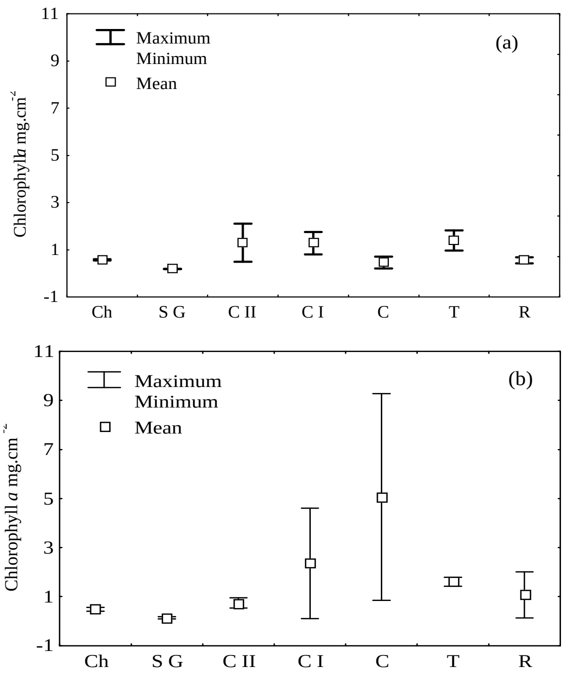

Figure 4. Mean chlorophyll *a* (n = 2, mean, maximum, minimum) in the dry (a) and in the rainy (b) periods. (Ch = Chavantes; SG = Salto Grande; CII = Canoas II; CI = Canoas I; C = Capivara; T = Taquaruçu; R = Rosana).

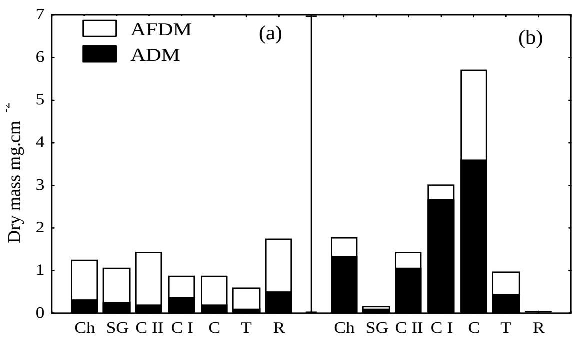

Figure 5. Mean dry mass (n = 2, ADM = ash dry mass, AFDM = ash-free dry mass) in the dry (a) and in the rainy (b) periods. (Ch = Chavantes; SG = Salto Grande; CII = Canoas II; CI = Canoas I; C = Capivara; T = Taquaruçu; R = Rosana).

Community structure of periphytic algae

The community of periphytic algae presented 91 taxa in the dry period and 119 taxa in the rainy period. The algae classes registered in the periphyton were Bacillariophyceae, Chlorophyceae, Chrysophyceae, Cyanophyceae, Dinophyceae, Euglenophyceae, Oedogoniophyceae, Rhodophyceae, Ulotrichophyceae, Xanthophyceae and Zygnemaphyceae. These classes occurred in both periods and in distinct reservoirs. Nevertheless, in the Rosana Reservoir, the Dinophyceae class was registered in the rainy period only, whereas Rhodophyceae occurred only in the dry period.

There was a predominance of Bacillariophyceae (diatoms) in the dry period in almost all reservoirs. However, in the rainy period, richness of taxa was greater than in the dry period in some reservoirs, and diatoms predominated mainly in Salto Grande and Canoas I (middle Paranapanema) (Figures 6a, b).

Chavantes (upper Paranapanema), Capivara (middle Paranapanema), Taquaruçu and Rosana (low Paranapanema) presented a high number of taxa and other algae classes, with a great increase of Zygnemaphyceae (Figure 6b) in the rainy period.

Among the reservoirs, Rosana presented higher richness of taxa per class, independent of the period (Figure 6). In Canoas II, the lowest number of taxa was observed in the dry period (Figure 6a), and in Salto Grande, this fact occurred in the rainy period (Figure 6b).

Higher algae density values were observed in the dry period than in the rainy period. Only Chavantes and Canoas I presented reverse values, i.e. higher density in the rainy period than in the dry period (Figure 7).

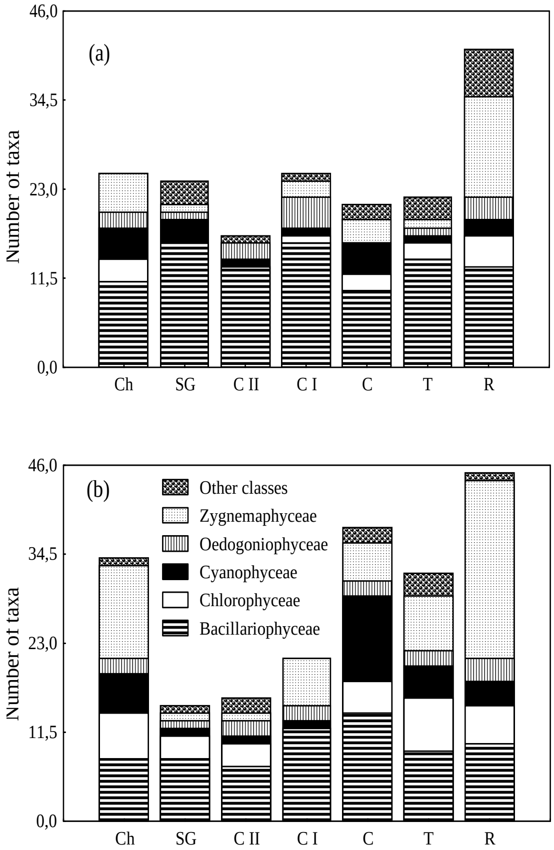

Figure 6. Number of species (total richness) per algae classes in the reservoirs in the dry (a) and in the rainy (b) periods, in 2001. (Ch = Chavantes; SG = Salto Grande; CII = Canoas II; CI = Canoas I; C = Capivara; T = Taquaruçu; R = Rosana).

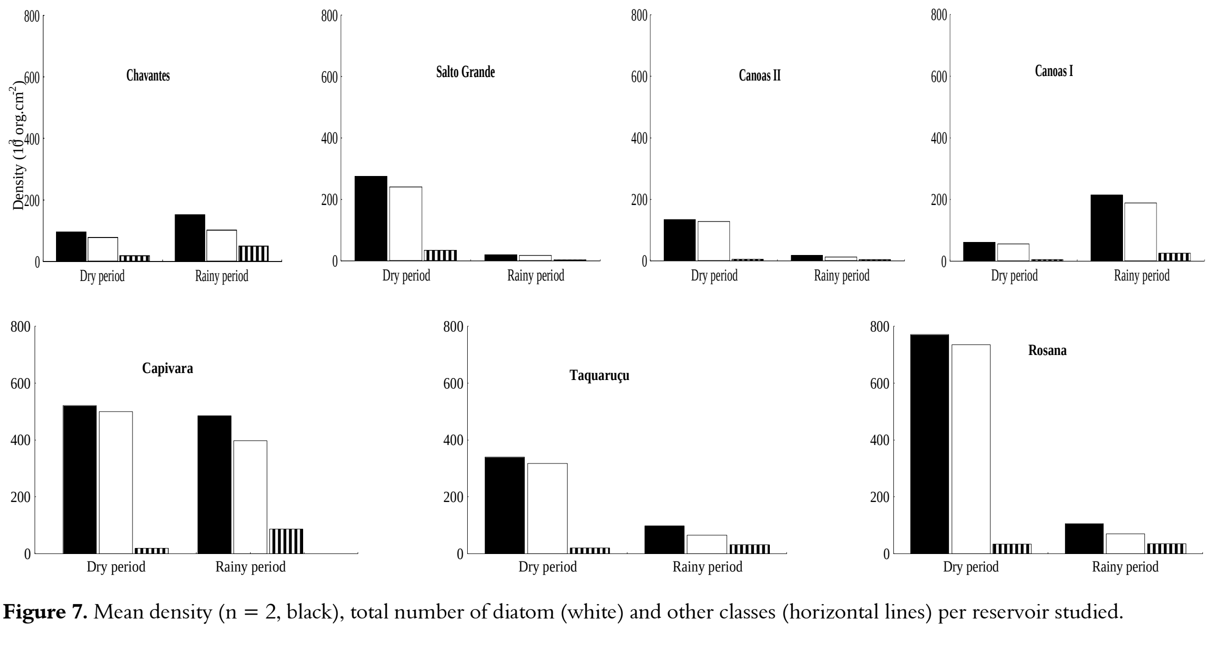

Figure 7. Mean density (n = 2, black), total number of diatom (white) and other classes (horizontal lines) per reservoir studied.

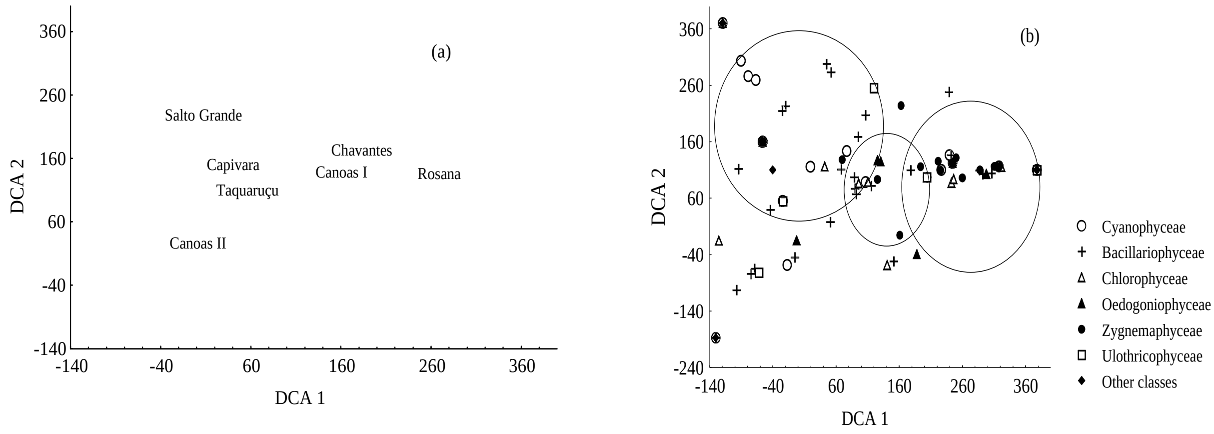

Figure 8. First two axes of the Detrended Correspondence Analysis ordination diagram. (a) ordination of the environment/zones scores and (b) ordination of the desmids species.

Independent of the reservoir or the seasonal period, the Bacillariophyceae was predominant, representing about 85% to 98% of the total number of individuals (Figure 7). Therefore, diatoms determined a seasonal community pattern among the reservoirs.

Cyanophyceae and Zygnemaphyceae were registered in both periods and in all the reservoirs during 2001, but with low densities. In the dry period, a higher abundance of Cyanophyceae (59 ind.cm^{-2}) occurred, whereas in the rainy period, a higher abundance of Zygnemaphyceae (89 ind.cm^{-2}) occurred, mainly desmids.

The axes of the Detrended Correspondence Analysis, applied to the density of algae species, presented eigenvalues of 0.50 and 0.27 for the first and the second, respectively. Distribution of the reservoirs/species scores of the first axes differed Rosana, Chavantes and Canoas I from Salto Grande, Canoas II, Taquaruçu and Capivara. Consequently, two main groups were formed. It was possible to identify a group of sampling sites, mostly concentrated on the right side of axis 1, formed especially by desmids, which correspond to Rosana and Chavantes. In addition to desmids, the Canoas I Reservoir also presented higher densities of filamentous green algae (Oedogoniophyceae) and diatoms. The other reservoirs were positioned on the left side of axis 1 basically due to their higher densities of diatoms and Cyanophyceae, especially in Salto Grande, Capivara and Taquaruçu. Canoas II presented a lower density when compared to the other reservoirs, which was basically due to diatoms (Figure 8a, b).

Discussion

In general, the periphytic biomass of reservoirs of the Paranapanema River was characterized by the rain regime of the region. Chlorophyll *a*, ADM and AFDM concentrations were higher and varied more in the rainy period. In the dry period, variation in the periphytic biomass, although in different degrees, was less conspicuous among the reservoirs. This suggests that fluctuations of periphytic biomass in the rainy period, regarding chlorophyll *a* concentration and ash-free dry mass, can be due to the elevated amount of sediment transported to the reservoirs cascade, either by means of diffusion drainage, caused by higher precipitation (Figure 2), or by means of tributaries flow. According to Tundisi *et al.* (1993) the rainfall introduces a pulse effect into the river-reservoir system, which results in a strong pulse interfering with the development of organisms. There may also be interference in biogeochemical cycles due to the introduction of particles onto which phosphate is adsorbed. Thus, inputs to suspend solids gather nutritive substances, which favor the periphytic algae growth (Moschini-Carlos *et al.*, 2001).

These characteristics are more pronounced, mainly in Canoas I and Capivara (middle Paranapanema) and Taquaruçu or Rosana (low Paranapanema), which are situated in regions of intensive agriculture and with large quantities of tributaries, such as the Tibagi River. This river probably contributed to increase the photosynthetic biomass in the Capivara Reservoir, increasing the number of species in the periphyton. Another important factor that increases the metabolic activity of periphytic community and, therefore, raises its biomass is high temperature (Denicola, 1996;

Rodrigues, 1998). This fact was observed in the rainy period, which presented water temperature higher than in the dry period, approximately 5 to 8° C (Thomaz *et al.*, 2003).

Low periphytic biomass, registered in the Salto Grande Reservoir, mainly in the rainy period, was probably related to the low water retention time, as Nogueira *et al.* (2002) also observed, and to phytoplanktonic biomass.

In the dry period, the great portion of periphytic dry mass was characterized as organic (AFDM). This might be related to the autotrophic portion of the periphytic community, coinciding with the expressive chlorophyll *a* values, which for instance, may be related to the specific composition, physiological state and size of the periphytic algae. According to Fernandes and Esteves (2003), temporal variation in ash and chlorophyll *a* contents indicates a change from the predominantly autotrophic organisms to heterotrophic ones, or in the presence of organic or inorganic material deposited on the substrates.

Analyzing the epiphytic algae composition and richness in both sampling periods, we observed the predominance of diatoms, mainly in the dry period. Diatoms are fast and efficient colonizers, and present many periphytic representatives, which have special structures to adhere to the substratum. These structures are short or long mucilaginous stalk in genus such as *Gomphonema* Ehrenberg, the producer of mucilaginous matrices, such as *Cymbella* C. A. Agardh, *Frustulia* Rabenhorst and *Navicula* Bory, and also a star or branch-shaped colonies adhered to the base, as in *Eunotia* Ehrenberg and *Fragilaria* Lyngbye (Stevenson, 1996).

Regarding the taxa richness periphytic algae, it was higher in Chavantes, Capivara and Rosana than in the other reservoirs. Salto Grande, Canoas II and Canoas I presented very analogous species composition. This fact may be attributed to the high or low water retention time. In the first three reservoirs, water retention time is higher than in the others, which can propitiate the establishment of a high number of algae in the periphyton, including metaphytic species.

Entrance of water from the Tibagi River in the Capivara Reservoir plays an important role in the system, contributing to great species diversity. Bittencourt-Oliveira (2002) registered elevated planktonic algae diversity in this river. It is believed that a great input of propagules in the water column can derive from this tributary, which uses the substrata for refuge and reproduction, contributing to an increase of species and individual organisms in the periphytic community. This fact, associated with the input of allochthonous material, an increase of dissolved nutrients (Thomaz *et al.*, 2003) and with elevated temperature in the rainy period, stimulates the growth of species of other algae groups.

Richness of desmids may also be related to the type of substratum. The great quantity of aquatic macrophytes, mainly in the Rosana Reservoir, represents an important habitat for desmids. Thomaz *et al.* (2003) states that the reduced depth, the high secchi depth, the low declivity and the large development of the banks in this reservoir contribute to the richness and the establishment of the aquatic plants. Therefore, the macrophyte constitutes an excellent host for the epiphytic algae, especially for those metaphytic species, such as some desmids.

The pattern of total density of the periphytic algae during the sampling periods was determined by the density of Bacillariophyceae. The Capivara Reservoir presented similar densities in both periods. However, in the rainy period, a great number of individuals of other classes, mostly Zygnemaphyceae (desmids) and Chlorophyceae, occurred. The same was observed for the Rosana and the Taquaruçu Reservoirs. This suggests that entrance and development of propagules from tributary rivers influenced the increase of phycoperiphytic organisms.

Moschini-Carlos (1996), when studying the periphytic community of natural substratum in the Jurumirim Reservoir, observed a peak in primary productivity and biomass in the rainy period, also related with a change in abundance of algae groups. There was a decrease in the relative abundance of diatoms and an increase in the abundance of green filamentous algae. Diatoms usually present no significant biomass regarding chlorophyll *a* concentration when compared to green algae. Then, it is understandable that, in the dry period, the photosynthetic biomass in the reservoirs had been more homogeneous.

According to Straškraba *et al.* (1993), the degree of influence of a reservoir located upstream upon another located downstream depends on the river order, the trophic state and the distance between the reservoirs. The results of the analysis of spatial autocorrelation conducted by Bini (1995) indicated that reservoirs apart up to 100 km were highly interdependent, demonstrating that the observed limnological characteristics of a given reservoir is dependent on the processes that occur in the reservoirs located before it. Our results also suggest dependence or independence between the systems and, therefore, reservoirs apart over 100 km are more independent.

The data obtained on the periphytic community were more similar as for biomass, species composition and abundance in the reservoirs located in the middle Paranapanema, especially in Salto Grande and Canoas I. Rosana and Capivara, about 110 km long, presented high chlorophyll *a*, species richness and algae density. This may be related to depth, nutrients, and retention time, which consequently can be related to size and location of a reservoir in the Paranapanema River cascade.

Apparently, the periphytic community suffers great influence from the river banks and the entrance of tributaries. In addition, in a cascade system such as the Paranapanema River, the shorter the distance among the reservoirs makes them more interdependent, i.e. small and close reservoirs form interdependent systems (for example, Salto Grande, Canoas II and Canoas I), whereas larger ones are far apart and, thus, more independent from one another (larger reservoirs are Capivara, Taquaruçu and Rosana). This fact indicates a differentiated tendency for the establishment and development of periphyton.

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