Abundance of periphytic desmids in two Brazilian reservoirs with distinct environmental conditions.

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ABSTRACT: Abundance of periphytic desmids in two Brazilian reservoirs with distinct environmental conditions. In order to evaluate and relate the abundance of periphytic desmids with abiotic and biotic factors of UHE Rosana and UHE Salto do Vau reservoirs, periphyton samples were carried out during 2002. Periphytic material was collected during two occasions, summer and winter, in the riverine, transition and lacustrine zones. Samples for determination of density were removed from substrata, stored in flasks, fixed and preserved with Transeau solution. Periphytic desmids community presented larger density during summer in both reservoirs. In the transition zone of Rosana Reservoir, it was registered greater densities values; while in Salto do Vau it occurred in the lacustrine zone. In riverine zone of both reservoirs, the abundance differed significantly from the other zones. A Principal Components Analysis using 15 environmental variables explained 76.7 % of the total variability of the data. A Detrended Correspondence Analysis applied on the density of desmids species identified a group of sampling sites, formed by some genera, especially Closterium, from the Salto do Vau Reservoir, whereas in the Rosana Reservoir, the other group was formed basically due to the higher density of Cosmarium. Pearson correlations suggest that nutrients, conductivity, water temperature, wind and aquatic macrophytes were the environmental variables that most explained the relation of sampling sites and desmids species.

Key-words: epiphytic desmids, littoral region, periphyton, reservoir.

RESUMO: Abundância de desmídias perifíticas em dois reservatórios brasileiros situados em diferentes condições ambientais. Com o objetivo de analisar a abundância de desmídias no perifíton e relacioná-la com os fatores abióticos e bióticos dos reservatórios UHE Rosana e UHE Salto do Vau, coletas do perifíton foram realizadas durante o ano de 2002. O material perifítico foi coletado em dois períodos (verão e inverno) nas regiões fluvial, transição e lacustre. Para determinar a densidade, o material removido do substrato foi acondicionado em frascos, fixado e preservado com solução de Transeau. Os resultados sobre a densidade das desmídias na comunidade perifítica demonstraram uma maior abundância no verão em ambos reservatórios, sendo que na região de transição do reservatório situado no rio Paranapanema registraram-se maiores valores, enquanto em Salto do Vau este fato ocorreu na região lacustre. Em ambos os reservatórios a região fluvial diferenciou significativamente das demais regiões. A Análise de Componentes Principais explicou 76,7 % da variabilidade total dos dados (15 variáveis ambientais). A Análise de Correspondência Destendenciada aplicada com espécies de desmídias identificou dois grupos: um formado principalmente pelo gênero Closterium, no Reservatório de Salto do Vau, enquanto no Reservatório de Rosana o grupo foi formado por Cosmarium. Análises de Correlações de Pearson sugerem que os nutrientes, a condutividade, a temperatura de água, o vento e as macrófitas aquáticas foram as variáveis ambientais que mais explicaram a relação dos locais amostrados com as espécies de desmídias.

Palavras-chave: Desmídias perifíticas, reservatório, macrófitas aquáticas.

Introduction

Littoral zone of reservoirs is affected by water level changes that result in sedimentation and resuspension events. Thus, organisms may spend part of their life cycle in the plankton, periphyton or benthos, and therefore these environmental processes in a water body determine the occurrence and composition of algal flora at each site.

Periphytic algae are of interest because these organisms play an important role as primary producers in both lotic and lentic water bodies (Lam & Lei, 1999). They are also an important food source and shelter for many invertebrates and fishes (Cattaneo & Kalf, 1978).

In spite of the relationship among periphyton/macrophytes to be little understood, the macrophytes play a relevant part as available substratum for periphyton colonization. Periphytic algae present high species richness and densities in a few squared centimeters of substratum (Wetzel 1983). The participation of the periphytic community together with aquatic macrophytes is important in the regulation of biogeochemical cycles and energy flows of aquatic systems due to their high productivity (Wetzel, 1990). Thus, changes in water quality and disappearance of macrophytes can directly affect the abundance and composition of desmids (Brook, 1981; Coesel, 1982), since a great quantity of aquatic macrophytes represents important habitat for desmids.

These algae may be used as a tool for management and conservation of aquatic ecosystem, because they are highly sensitive to environmental changes (Coesel, 2001). The plasticity of desmid cells allows that many of its representatives obtain fast adaptation to inhabit diverse habitats, such as acid waters, from 4.0 to 7.0 pH and alkaline waters (Brook, 1981). Usually this group of periphytic algae occurs in oligotrophic to eutrophic environments (Coesel, 1982; 1996). Therefore, studies contrasting periphytic desmids from reservoirs with quite distinct characteristics may reveal important information about their structure and ecology.

Therefore, this paper about the ecology of periphytic desmids, aimed i) to verify desmids spatial variation along the longitudinal axis of the reservoirs, and ii) to verify the influence of some abiotic variables on desmids abundance in two reservoirs.

Material and methods

Study area

Rosana Reservoir is located in the Paranapanema River watershed, in the lower Paranapanema River (Fig. 1) and is located separating the Paraná from São Paulo States. Salto do Vau Reservoir, is part of the Iguaçu River watershed (Fig. 1), near by the border between the states of Paraná and Santa Catarina.

Rosana Reservoir presents a mean width of 500 m, a 30 m depth, near the dam. The reservoir filling occurred in 1964, and it has length of 116 km, surface area of 220 km^2 and volume of 1,920 10^6 m^3. Adjacent area is dominated by extensive ranching, but some isolated small forest are found near the Rosana Dam (the State Park of Morro do Diabo) (Nogueira et al., 2001). Salto do Vau Reservoir presents a width between 10 and 15 m and depth of 4 m near the dam. This reservoir (8.2 km length; 0.5 km^2 surface area and 0.3 10^6 m^3 volume) was formed in a valley region, with intense native forest. The reservoir filling occurred in 1959.

Sampling methods

Periphyton samples were taken from the littoral region, in the riverine, transition and lacustrine zones (sensu Thornton, 1990). Samples were taken from natural

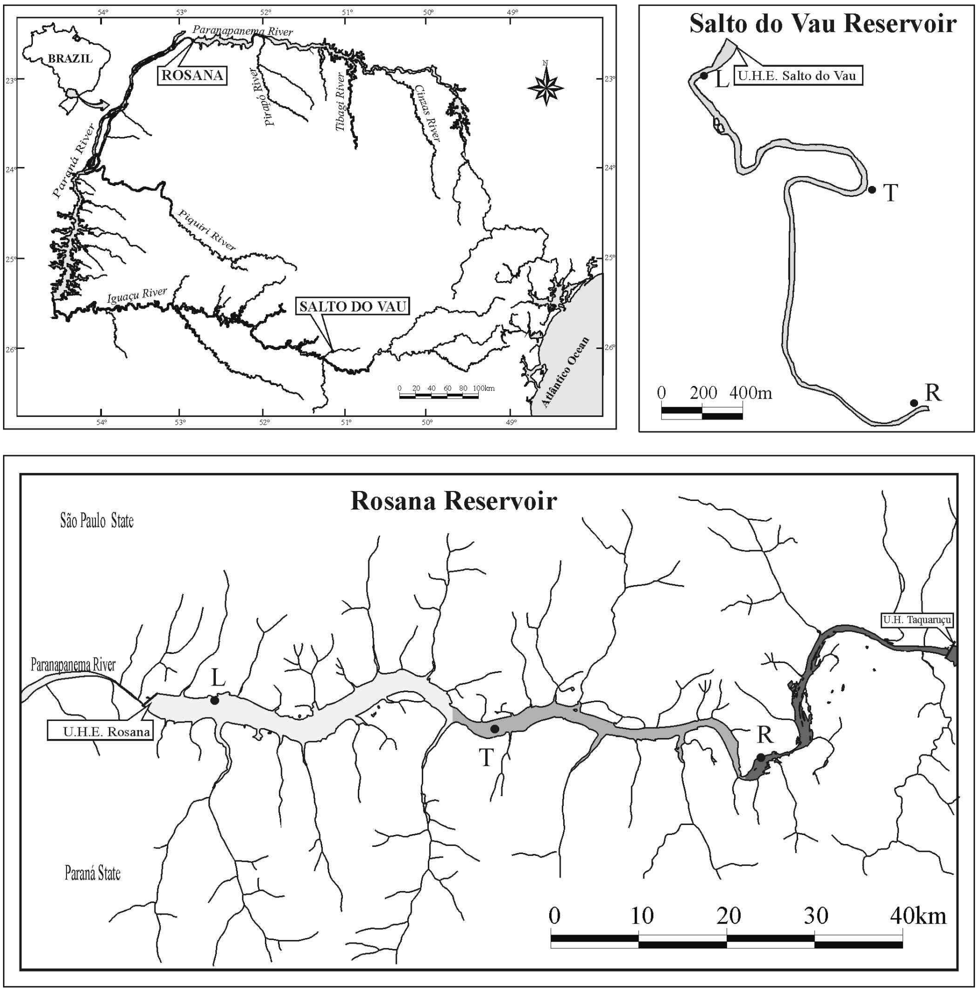

Figure 1: Location and morphometry of the sampled reservoirs: Rosana (Paranapanema River Basin) and Salto do Vau (Iguaçu River Basin). Riverine - R; Transition - T and Lacustrine zones - L.

substratum of the epiphyton type. Eichhornia azurea Kunth, a rooted macrophyte with several stands in arms of the Rosana Reservoir was abundant and was collected in all zones of this reservoir. In Salto do Vau Reservoir, phanerogamic vegetation was the substratum collected.

For each reservoir, 6 samples in duplicates were collected in late summer and winter 2002 at each zone (riverine, transition and lacustrine zones). Removal of periphytic community from substrata was made in field, using a spell and distilled water. The periphyton removed from substratum was stored in flasks, fixed and preserved with Transeau solution. Each petiole was measured using a caliper, converted in cm², to obtain the area of the cylinder.

Abiotic variables (pH, conductivity, turbidity, dissolved oxygen, water temperature, total nitrogen (TN), nitrate (NO_3^-), ammonia (NH_4^+), total phosphorus (TP), total dissolved phosphorus (TDP), orthophosphate (PO_4^{3-}), total particulated phosphorus (TPP), depth and wind) were measured simultaneously to the biotic (periphyton and aquatic macrophytes richness). Precipitation data was supplied by the Power Companies.

Data analyses

Organisms were quantified using inverted microscope at 400X, according to Utermöhl (1958). Only live algae were counted for the densities calculation expressed in ind.cm^{-2}. Filaments desmids were counted as filament numbers. Identification of species was made according to Förster (1982). The density was calculated according to Ros (1979).

Dominant species were considered the species with densities greater than 50 % of the total density of sample and abundant with densities greater than the mean densities of each sample (Lobo & Leighton, 1986).

Statistical analyses

In order to compare the mean values of desmid abundance (log10 (x + 1) transformed) between the periods and among reservoir zones, we applied an analysis of variance (two-way ANOVA) with significance level (p) = 0.05, using the package StatSoft 5.5.

Principal Components Analysis (PCA) and Detrended Correspondence Analysis (DCA) were used to reduce dimensionality of data, using the package PC-ORD version 4.0 for Windows. For PCA, the 15 abiotic variables were transformed (log10 (x + 1)) and the principal components axes retained for interpretation were those that presented eigenvalues higher than the eigenvalues produced by the Broken-Stick model (Jackson, 1993). In the construction of the biological matrix (DCA), all desmids taxa (densities for each one of 167 species) registered in the two periods and both reservoirs were used without of data transformation. For to make interpreting the ordination easier the species of Actinotaenium, Cosmocladium, Cylindrocystis, Desmidium, Euastrum, Hyalotheca, Micrasterias, Netrium, Penium, Onychonema, Pleurotaerium, Staurodesmus and Sphaerozosma were included as 'others taxa'.

Results

Limnological characterization

In the region of the Paranapanema River, the climate is well marked by the pluviometric regime (a rainy season during summer and a dry season during winter). In the region of the Iguaçu River, the temperature presents more conspicuous variations (Fig. 2).

Among physical and chemical water parameters, temperature and electrical conductivity presented greater variation between the reservoirs and the two periods (Felisberto & Rodrigues, 2005). In Salto do Vau Reservoir, temperatures were lower, ranging from 13.4 to 23.7 °C, than in Rosana Reservoir (range: 21.7 - 27.7 °C). Electrical conductivity was lower in two periods at Salto do Vau Reservoir (mean = 23 mS cm^{-1}) than in Rosana (mean = 60 mS cm^{-1}). Turbidity and dissolved oxygen were higher in Salto do Vau, mainly in the winter (Felisberto & Rodrigues, 2005). In Rosana Reservoir, 24 taxa of aquatic macrophytes were identified whereas in Salto do Vau Reservoir, only seven were found (Thomaz et al., 2005).

Results of the Principal Components Analysis applied on the abiotic variables are shown in Tab. I and Fig. 3. Two axes were retained for interpretation and together they explained 76.7 % of the total variability (56.4 % and 20.3 %, respectively). Variables that most contributed to the formation of the first PCA axis were related mainly with respect to the river basins and morphometry. Rosana has a mean depth of 9 m, a longer retention time (18 days) and complex reservoir morphometry (more dendritic), while Salto do Vau has a mean depth of 1.6 m, a short retention time (one day), simple morphometry (little dendritic). It is possible to identify a group of sampling sites, mostly concentrated on the right side of axis 1, and positively correlated with high values of total phosphorus and ammonia, corresponding to the

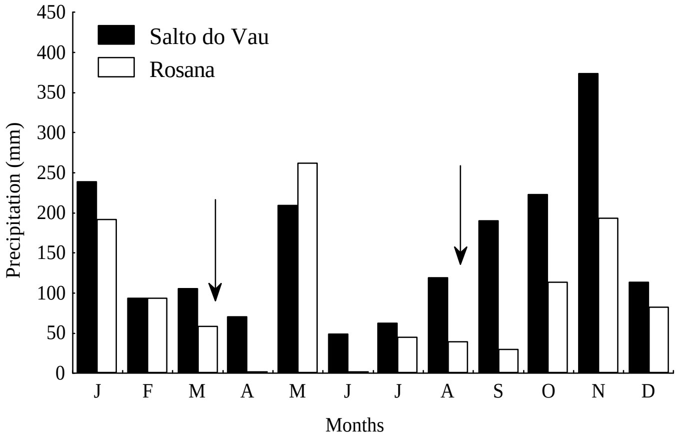

Figure 2: Monthly total precipitation from January to December, 2002. (Arrows indicate sampling months).

Table I: Results of the principal component analysis applied on abiotic variables.

	Eigenvectors	
Variables	**1**	**2**
Total P	**0.2784**	-0.0823
NH_4	**0.2555**	-0.1389
Turbidity	0.2518	**-0.3609**
Ortho-P	0.2453	0.2105
Dissolved oxygen	0.2066	**0.4200**
Total dissolved P	0.1948	**-0.3507**
Total particulated P	0.1631	0.0157
Electrical conductivity	**-0.3282**	0.0973
Depth	**-0.3213**	0.1456
Nitrate	**-0.3153**	0.0988
Aquatic macrophytes	**-0.3029**	-0.0502
Water temperature	-0.2730	**-0.3251**
pH	-0.2726	-0.2609
Total nitrogen	-0.2042	**0.3240**
Wind	-0.1838	**-0.4219**
Eigenvalues	8.454	3.046
Percentage of explained variance	56.359	20.310
Broken-stick eigenvalues	3.318	2.318

reservoir of Salto do Vau (Fig. 3). The other reservoir was positioned on the left side of axis 1, basically due to the influence of high values electrical conductivity, depth, nitrate, and aquatic macrophytes in Rosana Reservoir (Tab. I, Fig. 3).

The second PCA axis showed a separation of the reservoirs with respect to the temporal scale. Positively correlated variables were dissolved oxygen and total nitrogen in winter. In general, dissolved oxygen range was higher than nitrate, when comparing reservoirs. In summer dissolved oxygen varied from 6.6 to 7.5 mg/L in Rosana Reservoir, while the range was 6.9 to 8.0 mg/L in Salto do Vau. In winter, dissolved oxygen the variation was small in both reservoirs (from 8.2 to 9.6 mg/L). Wind, turbidity, total dissolved phosphorus and water temperature were higher in summer (Tab. I, Fig. 3).

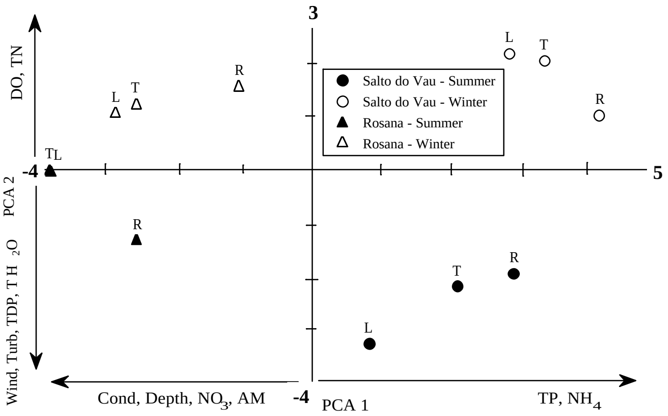

Figure 3: Ordination of reservoirs zones (axes 1 and 2 of the Principal Component Analysis) concerning the abiotic variables (total phosphorus - TP; ammonia - NH$_4$; turbidity - Turb; conductivity - Cond; nitrate - NO$_3$, Aquatic macrophytes - AM; total dissolved phosphorus - TDP; water temperature - T H$_2$O; dissolved oxygen - DO and total nitrogen - TN). Riverine - R; Transition - T and Lacustrine zones - L.

Desmid densities

A total of 15,644 individuals were counted in 24 samples and 167 desmids taxa were identified. Concerning Rosana Reservoir, 14,461 individuals and 145 species were found. In Salto do Vau Reservoir, 1,183 individuals and 69 species were found. Higher desmid densities were observed in Rosana Reservoir in both seasons. In Rosana Reservoir, the genera Cosmarium Corda and Staurastrum Meyen presented greater densities while in Salto do Vau Reservoir, most abundant genera were Cosmarium and Closterium Nitzsch ex Ralfs.

Among species recorded in Rosana Reservoir, 35 were abundant in summer and 19 species were abundant in winter. Only Cosmarium abbreviatum Raciborski var. minus (West & West) Krieger & Gerloff was common to both zones and periods (Tab. II). In Salto do Vau Reservoir, eight species were abundant in summer whereas 13 were abundant in winter. In this reservoir, Euastrum denticulatum (Kirchner) Gay was common to all zones and periods. Hyalotheca dissiliens (Smith) Brébisson ex Ralfs was abundant in summer in all three zones of this reservoir, while Staurastrum cf. dilatatum (Ehrenberg) Ralfs was abundant in all zones in winter (Tab. II).

Comparing periods and zones in Rosana, densities were greater in summer, but not statistically differents ($F = 0.033$, $p = 0.86$). In this reservoir, 5.6 x 10^3 ind.cm^{-2} of desmids were found in summer, in the transition zone, while in winter it occurred 2.5 x 10^3 ind.cm^{-2} in the lacustrine zone (Fig. 4). Desmid densities were significantly different ($F = 7.57$, $p = 0.02$) in zones and periods in Rosana Reservoir. The abundance in the riverine zone differed from the transition zone in summer and lacustrine in both periods (Tukey test, $p = 0.02$, 0.01 and 0.02, respectively).

In Salto do Vau Reservoir, desmid densities were lower in winter, however the differences in densities were not statistically significant ($F = 1.83$, $p = 0.22$). In this reservoir, the lacustrine zone presented 1.2 x 10^3 ind.cm^{-2} in summer and 0.19 x 10^3 ind.cm^{-2} in winter (Fig. 4). Desmid densities were significantly different ($F = 10.48$, $p = 0.01$) in zones and periods in this reservoir. The abundance in the riverine zone differed from the transition zone in summer and lacustrine in both periods (Tukey test, $p = 0.01$, 0.03 and 0.04, respectively). The desmids densities found in lacustrine and transition zones did not present significant differences between themselves.

Table II: Species of desmid densities (individuals cm^{-2}, n = 2) in the Riverine (R), Transition (T) and Lacustrine (L) zones of two reservoirs (Blank cells not detected).

	Rosana Reservoir						**Salto do Vau Reservoir**					
	Summer			**Winter**			**Summer**			**Winter**		
Taxa	**R**	**T**	**L**	**R**	**T**	**L**	**R**	**T**	**L**	**R**	**T**	**L**
Closterium cynthia de Not.								68				
C. ehrenbergii Menegh. ex Ralfs											19	
C. incurvum Bréb.											10	10
C. cf. intermedium Ralfs											16	
C. moniliferum (Bory) Ehrenb. ex Ralfs	2			19				26			13	
C. navicula (Bréb.) Lütkem.								20				
Cosmarium abbreviatum Racib. var. minus (West & G.S. West) W. Krieg. & Gerl.		3168	487	22	168	523				20		
C. cf. anisochondrun Nordst.			171			54						
C. blyttii Wille			116									
C. exiguum Arch.			49		29							
C. granatum Bréb. ex Ralfs	8		61	268	16							
C. impressulum Elfv.					23	29				6		
C. laeve Rabenh.	4			62	14							
C. margaritatum (Lund.) Roy & Biss. var. margaritatum f. minor (Boldt) West			66									
C. portianum Arch.			89			53						
C. pseudoconnatum Nordst.	2											
C. pseudoexiguum Racib.			45									
C. cf. punctulatum Bréb.	3		67			51						
C. quadrum Lund. var. minus Nordst.		1602	539		14	48						
C. regnellii Wille										6		
C. regnesi Reinsch						30						
C. reniforme (Ralfs) Arch.			52			60						
C. reniforme (Ralfs) Arch. *						44						
C. subspeciosum Nordst.								39				
C. trilobulatum Reinsch	1		198		15	34				16		
C. vexatum West				76								
Cosmarium sp.			187									
Cosmarium sp.1			150									
Cosmocladium sp.						684						
Cylindrocystis brebissonii (Menegh. ex Ralfs) de Bary									151			
Euastrum denticulatum (Kirchn.) Gay							2	73	153	19	16	16
Gonatozygon aculeatum Hast.			49									
G. brebissonii de Bary			48									
G. monotaenium de Bary	3					64		33	99			
Hyalotheca dissiliens (Smith) Bréb. ex Ralfs						47	8	116	552			47
Onychonema laeve Nordst.			170									
Onychonema laeve Nordst. var. rectangulare Grönbl.			67									
Pleurotaenium ehrenbergii (Bréb.) de Bary											6	

Table II: Cont.

Sphaerozosma aubertianum West			80			
Spondylosium moniliforme Lund.	2	438				
S. planum (Wolle) West & G.S. West		61				
Staurastrum ambiguum Turner		45				
S. anatinum Cooke & Wills		53				
S. cf. dilatatum (Ehrenb.) Ralfs		149		24	28	21
S. leptacanthum Nordst. var. borgei Först.		56				
S. quadrangulare Brébisson ex Ralfs		54				
S. sebaldi Reinsch var. ornatum Nordst.		114				
S. tetracerum (Kütz.) Ralfs		64				
Staurastrum sp.		86				
Staurodesmus corniculatus (Lund.) Teil. var. spinigerum W. West		106				
S. cuspidatus (Bréb. ex Ralfs) Teil.		48				
S. dickiei (Ralfs) S. Lill.		58				21

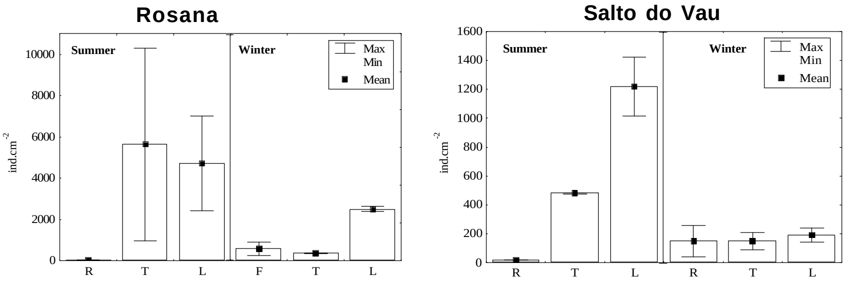

Figure 4: Desmid densities (ind.cm^{-2}) for each reservoir in 2002. (Riverine - R; Transition - T and Lacustrine zones - L).

Detrended Correspondence Analysis showed that the axes (eigenvalues 0.82 and 0.57, respectively) separated desmids of Rosana Reservoir from Salto do Vau Reservoir. Consequently, two main groups were identified one group of sampling sites, mostly concentrated on the right side of axis 1, formed by some species, specially Closterium genera, of Salto do Vau Reservoir and the other on the left side of axis 1, corresponding to their higher distribution and composition of species Cosmarium genera in Rosana Reservoir (Figs. 5a, b).

Pearson correlation between the scores of axis 1 of the DCA and axis 1 of the PCA was significant (r = 0.97; p = 0.05), indicating that abiotic variables (nutrients, conductivity, water temperature, wind, depth and aquatic macrophytes) influenced composition and density of periphytic desmid.

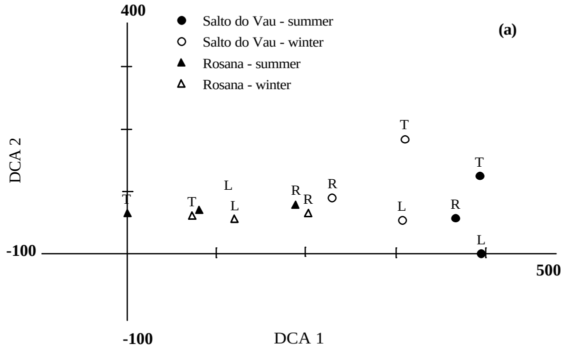

Figure 5(a): Detrended Correspondence Analysis ordination diagram ordination of the environment/zones scores (Riverine - R; Transition - T and Lacustrine zones - L)

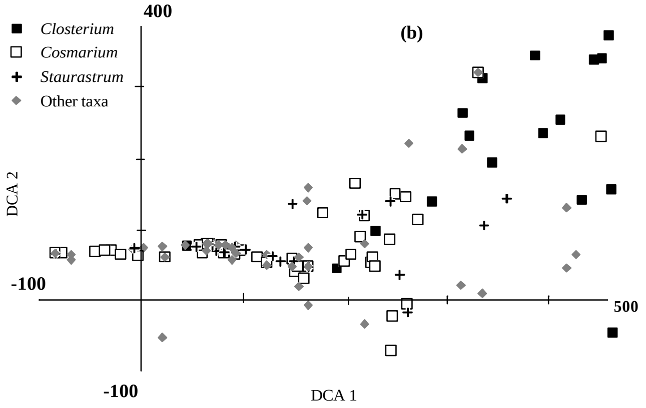

Figure 5(b): Detrended Correspondence Analysis ordination diagram: ordination of the desmids species. (Other taxa; see material and methods).

Discussion

Both reservoirs showed a gradient on periphytic desmids along the river-dam axis-differences among zones. As observed by Felisberto & Rodrigues (2005) for desmids taxonomic similarity between both reservoirs, high periphytic desmid densities in Rosana Reservoir were probably related with environmental conditions of each reservoir, mainly temperature and presence of aquatic macrophytes. In reservoirs, structure of communities is influenced by some phenomena that occur in the littoral, where spatial heterogeneity and diversity of aquatic vegetation are ideal conditions (inorganic and organic matter), resulting in an increase in surface area, important to the colonization of periphytic algae (Wetzel, 1981).

Higher desmid densities were registered in summer in Rosana Reservoir, related to higher differences in electric conductivity, nitrate, water temperature and presence of aquatic macrophytes. In Salto do Vau Reservoir, low densities may be due to the low water temperature (average of 19.6 °C) since that Coesel & Wardenaar (1990) stated that optimal growth temperature for desmids species corresponds to a range 25-30°C.

Higher densities of desmids in the transition in summer and in the lacustrine zone of Rosana Reservoir in winter are related to the higher richness of macrophytes, that include extensive stands of aquatic plants, as Eichhornia azurea (rooted in sediment), E. crassipes (floating), Egeria densa and E. najas (submerged). Periphytic and metaphytic habitats supplied by aquatic macrophytes in littoral regions of Paraná floodplain are very important for the establishment and development of desmids (Rodrigues & Bicudo, 2001). In the riverine zone of both reservoirs, the fluvial characteristics, difficult the establishment and permanence of aquatic plants and consequently little habitats of desmid species can be found.

The aquatic plant roots stabilize the sediment and abundant dissected leaves of submersed macrophytes reduction of water flow reduce turbidity in systems (Dieter, 1990), provide environmental conditions and habitats for a profuse development of periphytic algae, specially for those metaphytic species, as some desmids. According to Coesel (1982), in environments with abundant aquatic vegetation, with finely divided leaves or floating leaves, Cosmarium, Staurastrum and Closterium appear to be the dominant genera. This pattern between aquatic vegetation and desmid densities was also observed in the present study.

Detrended Correspondence Analysis showed that in Rosana Reservoir, the structure of periphytic desmids was slightly similar between periods than among the zones along the river-dam axis. On the other hand, higher similarity among zones than between periods was recorded in Salto do Vau Reservoir. Pearson correlation between the first axis of the PCA and the first axis of the DCA suggest that some abiotic variables (principally nutrients, conductivity, water temperature, wind, depth) and aquatic macrophytes were the most important in explaining the relation of sampling sites and desmids species.

Thus we can conclude that periphytic desmids are distributed along the longitudinal axis of the reservoirs, showed a spatial variation, with most species occurred at the distant sites riverine zones. Therefore, great spatial heterogeneity, aquatic vegetation diversity and higher temperature of the Paranapanema river basins than Iguaçu river basins provide habitats for a development of desmids, with a clear separation of groups of the each reservoir.

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