Phytoplankton assemblages and limnological characteristics in lotic systems of the Paranapanema Basin (Southeast Brazil).

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ABSTRACT: Phytoplankton assemblages and limnological characteristics in lotic systems of the Paranapanema Basin (Southeast Brazil). The main aim of this study was to analyze, comparatively, distinct stretches of the Paranapanema River and its tributaries based on the structure of the phytoplankton assemblages (composition, richness, diversity and abundance) and biomass (chlorophyll a). Such as the other large rivers of the Southeast Brazil, the Paranapanema has a series of reservoirs (eleven) constructed for electrical generation purpose. The reservoirs were not directly sampled in this study, although their influence in the results was evident. The sampling points were located in fluvial stretches of the basin – before the first reservoir, in the downstream zones of 9 reservoirs and in the inferior stretch of 10 tributaries. The data were obtained during the winter (August/2002) and summer (January/2003), corresponding to the dry and rainy periods, respectively. The total number of taxa identified was of 205. The richness and diversity, for both periods, were higher in the stretchs located downstream the dams when compared to the tributaries. The phytoplankton abundance was higher in the downstream zones of the reservoirs during the winter and in the tributaries during the summer. In the winter there was the predominance of the classes Bacillariophyceae, Chlorophyceae and Cryptophyceae. In the summer predominated Cyanophyceae and Cryptophyceae. Mean values for chlorophyll concentration were higher during winter. In general, considering the abundance of phytoplankton per classe, there was better similarity among the sampling points during the summer. This fact indicates the effect of homogenization due to the strong rains, typical of this period. The data of the limnological characteristics showed that the tributary rivers have more deteriorated conditions when compared to the main river of the basin, especially seen during the rainy season. During this period there was a remarkable increase in the concentration of suspended solids and nutrients (watershed runoff). The variables that better indicated the differences in the water quality were conductivity, dissolved oxygen and transparency. The study showed that phytoplankton assemblages respond quickly to the environmental changes in the basin, spatial and temporally. The data also demonstrated the importance of considering the lateral dimension, in addition to the longitudinal one, in the limnological studies carried out in large hydrographic basins.

Key-words: Paranapanema River, tributaries, reservoirs, phytoplankton, physical and chemical variables

RESUMO: Assembléias fitoplanctônicas e características limnológicas em sistemas lóticos da bacia do Paranapanema (SE-Brasil). O principal objetivo deste trabalho foi fazer uma análise comparativa dos diferentes trechos do rio Paranapanema e seus tributários em base a estrutura das biocenoses fitoplanctônicas (composição, riqueza, diversidade e abundância) e sua biomassa (clorofila a). Como os demais grandes rios do sudeste brasileiro, o rio Paranapanema possui uma série de reservatórios (onze) construídos para a geração de energia elétrica. Estes reservatórios não foram diretamente amostrados nesse estudo, embora a influência dos mesmos sobre os resultados tenha sido evidente. Os pontos de coleta estiveram sempre localizados em trechos fluviais da bacia – antes do primeiro represamento, a jusante de 9 reservatórios e nos trechos inferiores de 10 tributários. Os dados foram obtidos durante o período de inverno (agosto/2002) e de verão (janeiro/2003). O número total de táxons fitoplanctônicos identificados foi de 205. A riqueza e a diversidade, em ambos os períodos, foram maiores a jusante dos reservatórios quando comparado aos tributários. A abundância de organismos foi maior a jusante dos reservatórios durante o inverno e nos tributários durante o período de verão. No inverno houve predominância das classes Bacillariophyceae, Chlorophyceae e Cryptophyceae. No verão predominaram as Cyanophyceae e Cryptophyceae. A clorofila a apresentou uma maior concentração média durante o período de inverno. Em geral, considerando-se a abundância de organismo por classe, houve uma maior similaridade entre os pontos de coleta durante o verão. Isso indica os efeitos da homogeneização devido às fortes chuvas, típicas deste período. Os dados das variáveis limológicas mostraram que os tributários estavam em condições mais deterioradas quando comparados ao rio principal da bacia, especialmente durante o período chuvoso. Durante este período houve um notável incremento na concentração de sólidos suspensos e de nutrientes (escoamento superficial). As variáveis que melhor indicaram as diferenças na qualidade da água foram a transparência, a condutividade e o oxigênio dissolvido. O estudo mostra que a comunidade do fitoplâncton responde rapidamente as variações ambientais na bacia, espacial e temporalmente. Os dados também demonstram a importância de se considerar a dimensão lateral, além da longitudinal, no estudo limnológico de bacias hidrográficas de grande porte.

Palavras chaves: rio Paranapanema, tributários, reservatórios, fitoplâncton, variáveis físico-químicas

Introduction

The studies of the structure and functioning of large hydrographic basins, including the role of the constructed reservoirs and its tributaries, are of great importance due to their ecological, economic and social relevance.

During the last years intensive efforts have been undertaken for the studies of reservoirs in our country, generating significant advances in the limnological knowledge of this kind of ecosystem (Tundisi, 1988; Henry, 1999; Tundisi & Straškraba, 1999; Nogueira et al., 2005). However, an integrated approach of the interactions between these environments and their watersheds are still scarce (Pinto-Coelho et al., 2005). These interactions occur mainly through the inputs of the tributary rivers. In terms of volume the contribution of small and medium-size tributaries is generally of minor importance. Nevertheless, the influence in the water quality conditions can be relevant, as they come from different regional areas with particular urban and agricultural characteristics. One of the main compartments of Barra Bonita Reservoir (Tietê River, SP) has its limnological characteristics highly influenced by the entrance of two tributaries with very different trophic states (Moretto & Nogueira, 2003).

Studies carried out in the Jurumirim Reservoir (SP) also verified that the second main tributary (Taquari River) contributed with significant values for the loads entrance into the reservoir (Henry et al., 1999). More recently, the influence of the lateral contributions (tributary rivers) for 9 large reservoirs of the Paranapanema River was estimated, showing that the loads of nutrients and sediments introduced by these rivers are very high, especially in summer (rainy season), and cannot be neglected in the mass balance studies (Ferrareze et al., 2005).

Additionally, the entrance of tributaries in lakes and reservoirs generally creates periodic or permanent wetland areas, which can play an important role in the dynamics and diversity of the entire lentic system or in large compartments of it (Tundisi, 1988; Matsumura-Tundisi et al., 1990; Henry et al. 2005; Kudo et al., 2005). Such areas are very important for the nutrient cycles, maintenance of reproductive habitats and trophic resources for many aquatic and terrestrial species of the fauna and flora.

It is well know that the phytoplankton plays an important role in the primary productivity of rivers and reservoirs and certain assemblages of these organisms are also considered as good indicators of different environment conditions (e.g. hydrodynamics and trophic state) (Rosén, 1981; Vincent & Dryden, 1989, Sommer, 1984; Reynolds, 1992; 1999; Padisak et al., 1999). The structure of algae communities, determined by indicators such as specific composition, cellular density, species richness and uniformity, can be used to evaluate the aquatic system quality, and the specific diversity measurements could constitute an appropriate index to compare environment conditions (Rosa et al., 1988). An example of an attempt to relate pollution conditions and algae structure (diatom assemblages) in Brazilian lotic ecosystems is the study of Lobo et al. (2002) for the Guaíba basin in the Rio Grande do Sul State.

In this study the phytoplankton from lotic stretches (non reservoir) of the

Paranapanema River (SP/PR) and also from its main tributaries were analyzed in two periods of the year (winter and summer). The main aim was to characterize the different environmental conditions in the basin using these organisms as indicator.

The factors that influence the structure and dynamics of the populations and are also very useful to evaluate the ecosystems integrity, such as transparency, temperature, pH and concentrations of dissolved oxygen, suspended material and nutrients were also analyzed and considered for comparative purposes: stretches of the main river, tributaries and dry/rainy periods.

Materials and methods

The hydrographic basin of the Paranapanema River is located between the coordinates 22° - 26° S and 47° - 54° W. The drainage area is of 100.800 km^2 (47% in the southwest of São Paulo State and 53% in the north Paraná State) and the river main course, from east to west, has an extension of 929 km. The region is characterized by the transition of low latitudes mesothermic and mean latitudes temperate climates (Nimer, 1979). A conspicuous seasonal change is verified mainly by the alternation in the precipitation regime: concentration of rains during late spring and summer and dry weather in autumn and winter. A general description of the watershed characteristics and the main characteristics of its reservoirs can be found in Nogueira et al. (2005).

The data for this work were collected at twenty sampling stations (Tab. I) distributed along the Paranapanema basin. It was included ten main tributaries and ten fluvial stretches on the Paranapanema River - one before the first reservoir and nine in the downstream zones of each reservoir (Fig. 1). The fieldwork was carried out during two expeditions: in August/2002 (dry-winter) and January/2003 (wet-summer).

Unfiltered samples were collected in the middle of the channel of each sampling station at the subsurface (c.a. 1 m) (Van Dorn bottle), fixed and preserved in acetic lugol, which is the solution special used for quantitative analysis of the phytoplankton (Bicudo & Menezes, 2005).

Table I: Location of sampling stations.

Points	Sampling Stations	Geographic Coordinates
01	Upstream of Jurumirim	23° 28’ 55.2” S / 48° 37’ 12.8” W
02	Taquari River	23° 29’ 46.3” S / 49° 10’ 06.4” W
03	Downstream of Jurumirim	22° 12’ 31.7” S / 45° 14’ 32.8” W
04	Downstream of Piraju	23° 08’ 26.9” S / 49° 26’ 21.8” W
05	Itararé River	23° 35’ 59.7” S / 49° 37’ 09.6” W
06	Downstream of Chavantes	23° 06’ 39.3” S / 49° 43’ 33.3” W
07	Pardo River	22° 54’ 29.2” S / 49° 57’ 27.9” W
08	Downstream of Salto Grande	22° 55’ 17.9” S / 49° 59’ 30.9” W
09	Downstream of Canoas II	22° 56’ 13.5” S / 50° 15’ 33.0” W
10	Pari Veado River	22° 54’ 15.2” S / 50° 20’ 30.1”W
11	Downstream of Canoas I	22° 56’ 16.2” S / 50° 31’ 35.2”W
12	Cinzas River	22° 56’ 22.7” S / 50° 31’ 42.7”W
13	Tibagi River	23° 08’ 51.6” S / 50° 59’ 18.1” W
14	Downstream of Capivara	22° 39’ 54.1” S / 51° 24’ 17.5” W
15	Anhumas River	22° 38’ 39.0” S / 51° 26’ 48.6” W
16	Downstream of Taquaruçu	22° 32’ 15.6” S / 52° 01’ 29.5” W
17	Pirapó River	22° 32’ 42.8” S / 52° 01’ 38.3” W
18	Pirapozinho River	22° 31’ 48.1” S / 52° 01’ 35.8” W
19	Inhancá River	22° 29’ 55.8” S / 52° 03’ 28.5” W
20	Downstream of Rosana	22° 36’ 03.9” S / 53° 00’ 49.7” W

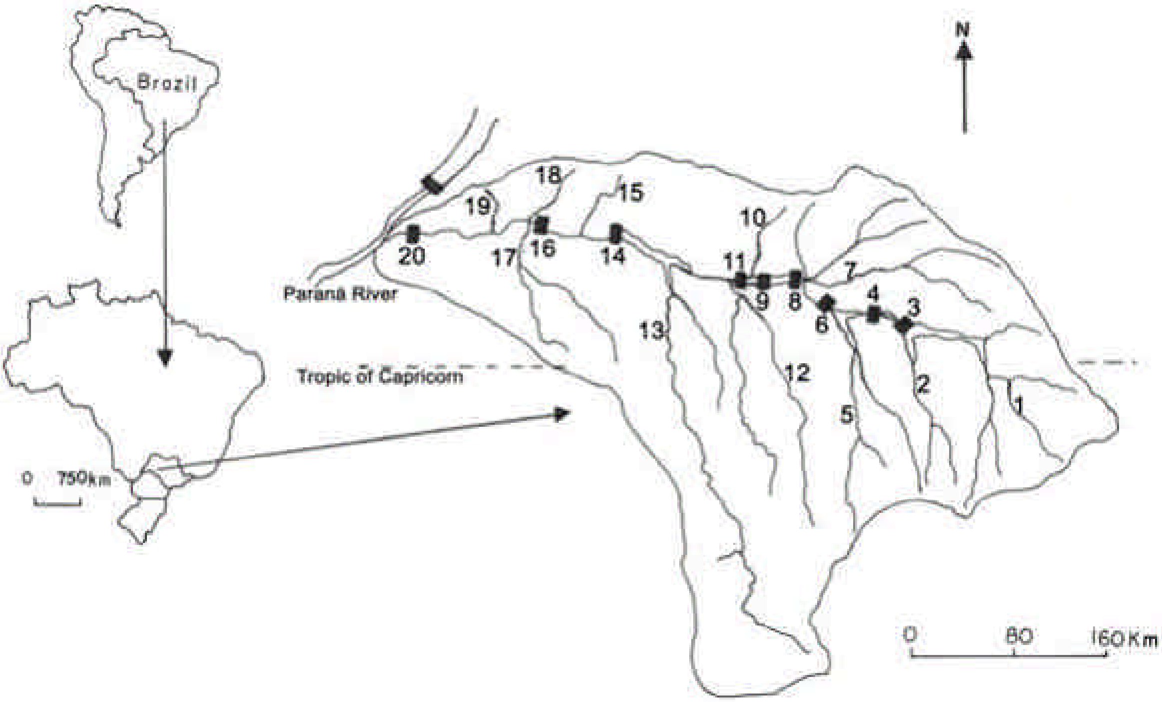


Figure 1: Location of Paranapanema Basin and the indication (numbers) of sampling points.

In each sampling point it was also colleted a filtered sample, through vertical and horizontal net hauls (20 mm of mesh size) and preserved in 4% formalin. These samples were analyzed in optical microscope (maximum magnification of 1000x) for the identification of the phytoplankton organisms, in order get familiar with the material before counting. New taxa that appeared during the quantitative analyzes were also considered for qualitative purpose (list of taxa).

For the phytoplankton identification it was used as basic reference, for genera level, the key of Bicudo & Menezes (2005), which is the most recent publication for Brazil. For the species level it was used the specialized literature and eventual consults to taxonomists, assuring that most of the species, specially the dominant ones, were properly identified.

The organisms were counted using an inverted microscope (Leica) following the Uthermöhl (1958) method. One hundred of optical fields (magnification of 400x), randomly distributed, were counted per sample. The counting unit was the individual (unicellular or colonies). The settling sample volume varied from 5 to 23 mL, depending on the phytoplankton density and detritus concentration. Sedimentation time was of at least three hours per centimeter of chamber (Margalef, 1983).

Phytoplankton diversity was estimated using the Shannon-Weaver Index (log$_2$). In order to compare the sampling points on the basis of the phytoplankton assemblages structure it was performed a cluster analysis (r-Pearson similarity) (Pcordwin). For this analyzes it was used the abundance per class that, despite the high taxonomical level, in general constitute well defined ecological groups indicating distinct environmental conditions.

The abiotic variables and chlorophyll a were measured in 3 points of the transversal sections (left edge, middle and right edge). In the results it is presented the average values among these three points. The chlorophyll a concentration was determined filtering a sample volume of 500 mL. The extraction was made by hand maceration of the filters (Millipore AP40) in cold acetone 90% (Talling & Driver, 1963). Data on this variable can be used as an indicative of the phytoplankton biomass and also have been recently considered for water quality classification (CONAMA, 2005).

The temperature, dissolved oxygen, conductivity and pH were measured in situ using the water analyzer Horiba (mod. U-22). The suspended matter was determined by gravimetry (Cole, 1979) and total nitrogen and total phosphorus were determined by the methods of Mackereth et al. (1978) and Strickland & Parsons (1960), respectively. The correlation between abiotic and biotic variables was determined by the canonic correspondence analyses, CCA (Pcordwin). All data were previously standardized (log x+1), except the pH.

Results

A relatively high number of phytoplankton taxa, 205, was identified considering all the samples for both study periods (Tab. II). Considering individual sampling sites the number of taxa varied from 44 to 100 in the winter and from 41 to 105 in the summer (Fig. 2). For genera the numbers varied between 32 and 63 during the winter and between 40 and 69 during the summer. The richness was slightly higher in the summer, but the pattern of changes along the basin was similar for both periods of the year. After an increasing tendency in the middle stretch of the basin, there was a diminution of the richness into the mouth direction. In the station located right after the Canoas I dam it was found the highest number of taxa in winter and summer. Other stations with relatively high richness were the downstream stretches of Piraju, Chavantes, Canoas II, Taquaruçu and Rosana reservoirs, in summer, and Piraju, Chavantes, Salto Grande, Canoas II reservoirs, in winter. In general a higher richness was verified in the Paranapanema River, rather than in its tributaries.

Table II : Taxonomic list of the phytoplankton of the Paranapanema Basin and occurrence in the sampling periods.

Bacillariophyceae	**Aug/ 02**	**Jan/ 03**	**Bacillariophyceae**	**Aug/ 02**	**Jan/ 03**	**Bacillariophyceae**	**Aug/ 02**	**Jan/ 03**
Achnanthidium exiguum	X	X	Eunotia flexuosa	X	X	Nitzchia palea	X	X
Achnanthes inflata var. inflata	-	X	Eunotia monodon	X	-	Nitzchia paleaeformis	X	X
Achnanthidium minutissimum	X	X	Eunotia praerupta var.bidens	X	X	Pinnularia gibba	X	-
Amphipleura lindheimerii	X	X	Eunotia valida	X	X	Pinnularia platycephala	X	X
Amphora delphinea var. minor	-	X	Fragilaria capucina	X	X	Planothidium lanceolatum	X	-
Amphora ovalis var. libyca	X	X	Frustulia krammeri	X	X	Planothidium lanceolatum var. dubia	X	-
Asterionella formosa	X	X	Gomphonema augur	X	-	Planothidium lanceolatum var. lanceolata	X	X
Asterionella sp	X	-	Gomphonema gracile	X	X	Stauroneis phoenicentron	X	X
Aulacoseira alpigena	X	X	Gomphonema parvulum	X	X	Stephanodiscus hantzschii	X	X
Aulacoseira ambígua var. ambigua f. ambígua	X	X	Gomphonema truncatum	X	-	Surirella biseriata	X	X
Aulacoseira ambígua var. ambigua f. spiralis	X	X	Gyrosigma spencerii	X	X	Surirella capronii	X	-
Aulacoseira granulata var. ambigua f. spiralis	X	X	Hydrosera whampoensis	X	X	Surirella linearis var. constrita	X	X
A. granulata var. angustissima f. angustissima	X	X	Luticola mutica	X	X	Surirella robusta	X	X
Aulacoseira granulata var. granulata f. granulata	X	X	Melosira lineata	X	X	Surirella sp1	X	X
Capartogramma crucicola	X	-	Melosira nummuloides	X	-	Surirella sp2	X	-
Cocconeis placentula var. lineata	-	X	Melosira varians	X	X	Synedra capitata	X	X
Cyclostella stelligera	X	X	Navicula anglica	X	X	Synedra delicatissima	X	X
Cyclotella meneghiniana	-	X	Navicula cuspidata	-	X	Synedra delicatissima var. delicatissima	X	X
Cymbella tumida	-	X	Navicula sp1	X	-	Synedra goulardii	X	X
Cymbella tumida var. tumida	-	X	Navicula sp2	X	X	Synedra ulna	X	X
Cymbopleura naviculiformis	X	-	Navicula sp3	-	X	Terpsinoe musica	X	-
Encyonema perpusillum	X	X	Neidium affini	X	-			
Encyonema silesiacum	X	X	Neidium sp	X	-			
Epithemia sp	-	X	Nitzchia levidensis	X	X			
Eunotia bilunaris	X	-	Nitzchia levidensis var. victoriae	X	-			

X indicates presence; - indicates absence

Table II : Cont.

Chlorophyceae	**Aug/ 02**	**Jan/ 03**	**Chlorophyceae**	**Aug/ 02**	**Jan/ 03**	**Chlorophyceae**	**Aug/ 02**	**Jan/ 03**
Actinastrum hantzchii var. fluviatile	X	X	Kirchneriella obesa var. obesa	X	-	Tetraspora lacustris	X	X
Actinastrum sp	-	X	Micractinium bornheimiensis	-	X	Treubaria setigera	X	X
Ankistrodesmus cf. falcatus	X	X	Micractinium pusillum	X	X	Volvox aureus	-	X
Ankistrodesmus convolutes var. minutus	X	X	Monoraphidium cf. contortum	X	X			
Botryococcus braunii	X	X	Monoraphidium sp	X	-	Dinophyceae		
Chlorella vulgaris var. vulgaris	X	X	Nephrocytium agardianum	X	-			
Chlorella zofingiensis	X	X	Nephrocytium sp	X	-	Ceratium hirundinella	-	X
Coelastrum cambricum	X	X	Oocystis spp	X	X	Peridinium cinctum	X	X
Coelastrum indicum	X	X	Pandorina morum	X	X	Peridinium gatunense	X	X
Coelastrum microporum	X	X	Pediastrum biradiatum	X	-	Peridinium tabulatum	X	X
Coelastrum reticulatum	X	-	Pediastrum duplex	X	X			
Crucigenia tetrapedia	X	X	Pediastrum obtusum	X	X	Chrysophyceae		
Desmodesmus bicaudatus	X	X	Pediastrum simplex	X	X			
Desmodesmus denticulatus	X	X	Pediastrum tetras	X	X	Dinobryon bavaricum	X	X
Desmodesmus opoliensis	X	X	Planktosphaeria gelatinosa	X	X	Dinobryon cylindricum	X	X
Desmodesmus quadricauda	X	X	Pleudorina californica	X	X	Dinobryon divergens	-	X
Dictyosphaerium pulchellum	X	X	Scenedesmus acuminatus	X	X	Mallomonas spp	X	X
Dimorphococcus lunatus	X	-	Scenedesmus acutus f. alternans	X	-	Synura sp	X	X
Dimorphococcus sp	X	X	Scenedesmus arcuatus	-	X			
Elakatothrix gelatinosa	X	X	Scenedesmus bernardii	X	X			
Eudorina elegans	X	X	Schroederia judayi	X	X			
Gloeocystis ampla	X	X	Schroederia setigera	X	X			
Gloeocystis gigas	X	X	Selenastrum gracile	X	X			
Kirchneriella lunaris	X	X	Sorastrum spinulosum	X	X			
Kirchneriella lunaris var. irregularis	X	-	Sphaerocystis spp	X	X			
Kirchneriella obesa var. major	X	X	Tetraedron caudatum	X	X			
Actinastrum hantzchii var. fluviatile	X	X	Tetraedron minimum	X	-			

Zygnemaphyceae	**Aug/ 02**	**Jan/ 03**	**Zygnemaphyceae**	**Aug/ 02**	**Jan/ 03**	**Euglenophyceae**	**Aug/ 02**	**Jan/ 03**
Closterium cynthia	X	-	Spirogyra sp	X	X	Euglena oxyuris	X	X
Closterium rostratum	X	X	Staurastrum alternans	X	X	Lepocinclis acus	X	X
Closterium setaceum	X	X	Staurastrum gracile var. cyathiforme	X	X	Lepocinclis spirogyroides	X	X
Cosmarium binum	-	X	Staurastrum invocator	X	X	Phacus acuminatus	X	-
Cosmarium bioculatum	X	X	Staurastrum leptocladum var. cornutum	X	X	Phacus longicauda	X	X
Cosmarium ornatum	X	X	Staurastrum rotula	X	X	Phacus sp1	-	X
Cosmarium pachydermum	X	-	Staurastrum sebaldi	X	X	Phacus sp2	-	X
Cosmarium pseudobromei	X	X	Staurastrum sebaldi var. ornatum f. elongata	X	-	Phacus sp3	-	X
Desmidium baileyi	X	-	Staurodesmus clepsydra var. obtusus	X	-	Phacus tortus	X	-
Euastrum denticulatum	X	X	Staurodesmus croasdaleae	-	X	Trachelomonas armata	X	X
Gonatozygon pilosum	X	X	Staurodesmus glaber	X	X	Trachelomonas armata var. longispina	-	X
Micrasterias radians	-	X	Staurodesmus psilosporus var. retusus	-	X	Trachelomonas bernadinensis	X	-
Micrasterias truncate	-	X	Xanthidium cristatum	-	X	Trachelomonas cf. allia	-	X
Onychonema leave	X	X	Xanthidium forcipatum	X	X	Trachelomonas cf. volvocina	X	X
Sphaerozosma aubertianum	X	X						

X indicates presence; - indicates absence

Table II : Cont.

Cyanophyceae	**Aug/ 02**	**Jan/ 03**	**Cyanophyceae**	**Aug/ 02**	**Jan/ 03**	**Cryptophyceae**	**Aug/ 02**	**Jan/ 03**
Anabaena circinalis	X	X	Lyngbya sp1	X	X	Cryptomonas sp1	X	X
Anabaena reta	X	X	Merismopedia punctata	X	X	Cryptomonas sp2	-	X
Anabaena spiroides	X	X	Merismopedia sp	X	X			
Aphanocapsa delicatissima	X	X	Microcystis aeruginosa f. aeruginosa	X	X			
Aphanotece sp	X	X	Microcystis spp	X	X			
Chroococcus limneticus	X	X	Nostoc muscorum	-	X			
Chroococcus minutus	X	X	Ocillatoria princes	X	X			
Coelosphaerium sp	X	X	Phormidium autumnale	X	X			
Cyanophyceae (não identificada)	-	X	Phormidium mucicola	X	X			
Cylindropermopsis raciborsky	X	X	Pseudanabaena sp	X	X			
Lyngbya putealis	X	X	Raphidiopsis sp	X	X			
			Synechoccocus sp	X	X			

X indicates presence; - indicates absence

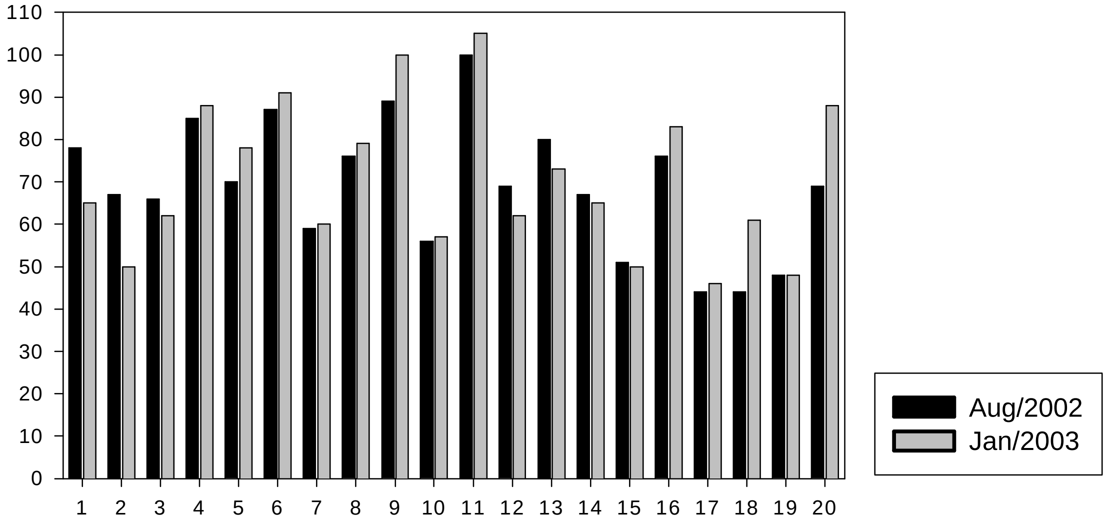


Figure 2: Total number of phytoplankton taxa in the Paranapanema Basin during two sampling periods.

Nevertheless the Rivers Itararé (in summer) and Tibagi (in winter) also had a relatively high number of taxa.

The differences among the sampling points in terms of total organisms abundance (Fig. 3) were higher during the winter, ranging from 48,557 (Pardo River) to 589,179 (Tibagi River) individuals L^{-1}. In summer the abundance of phytoplankton varied between 136,212 (Inhancá River) to 453,278 individuals L^{-1} (Cinzas River). Higher densities of phytoplankton were found in the main tributaries of the middle and low stretches of the Paranapanema Basin (Cinzas, Tibagi and Pirapó).

In terms of relative abundance (Fig. 4), the Bacillariophyceae ranged from 7.9 to 61.2% of the total phytoplankton in the winter and from 9.7 to 31.1% in the summer; the Chlorophyceae from 9.5 to 63.9% in the winter and from 7.5 to 26.6% in the summer; Cyanophyceae from 4.4 to 24.4% in the winter, and from 10.4 to 45.3% in the summer and Cryptophyceae from 8.5 to 37.6% in the winter to 21.9 to 48.7% in the summer. The Dinophyceae, Chrysophyceae, Zygnemaphyceae and Euglenophyceae were also found in the quantitative samples, but generally in a low density of organisms.

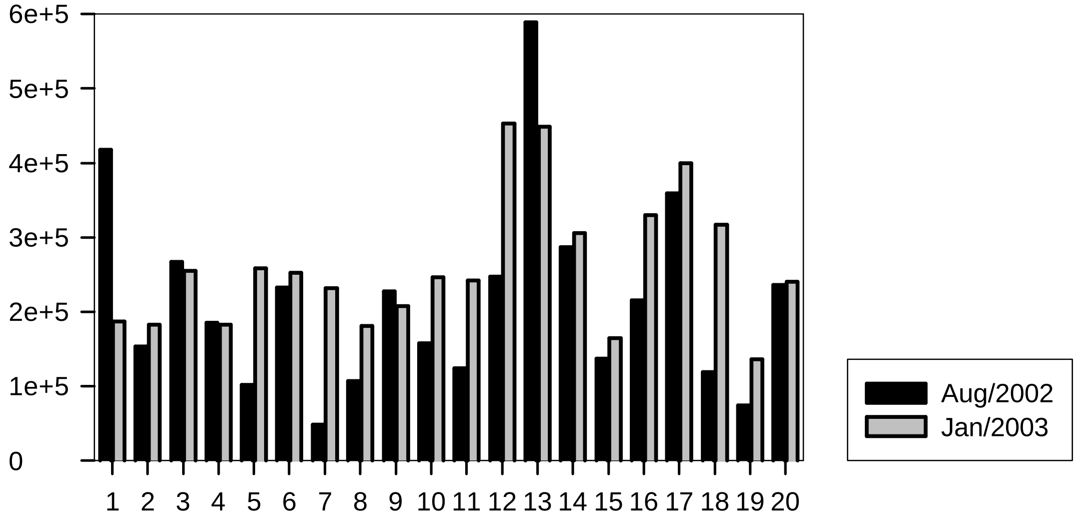


Figure 3: Abundance (ind. L^{1}) of phytoplankton in the Paranapanema Basin during two sampling periods.

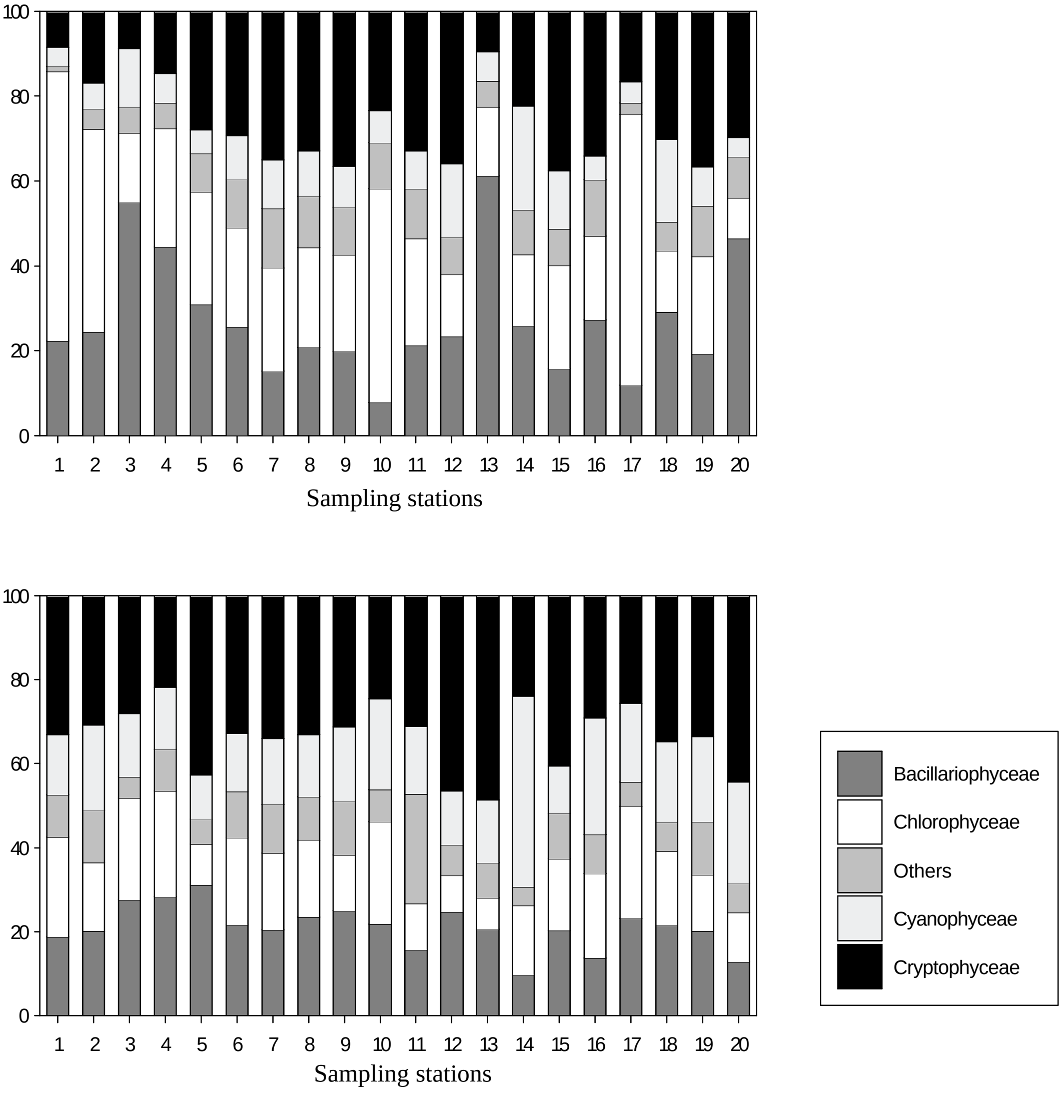


Figure 4: Relative frequency (%) of the phytoplankton groups in the Paranapanema Basin during the winter (a.) and summer (b.).

These classes were grouped in the analysis as others. Among these classes the highest relative abundance was obtained for the Euglenophyceae, in the downstream of Canoas I, with 22.5% of the total phytoplankton in summer.

The main taxa, in terms of abundance and distribution were Discostella stelligera and Asterionella formosa, among the Bacillariophyceae; Monoraphidium cf. contortum, Schroederia setigera and Chlorella spp. among the Chlorophyceae; Lepocinclis acus and Phacus longicauda, among the Euglenophyceae; Synechoccocus sp and Synechocystis sp among the Cyanophyceae; and Cryptomonas spp. among the Cryptophyceae.

It can be pointed out a remarkable individual contribution, in relation to the total phytoplankton, of D. stelligera in the Pirapozinho River (12.7% in the winter) and A. formosa in the Tibagi River (43.8% in the winter), among the diatoms. In relation to the green algae it can be mentioned M. cf. contortum in the Pirapó River (57.7% in winter); S. setigera in the fluvial (upstream) stretch of Jurumirim (25.5% in winter) and Chlorella spp. in the Pari Veado River (14.6% in winter); L. acus in the Cinzas River (5.7% in the winter) and P. longicauda in the downstream stretch of Canoas II (4.2% in winter) were the main Euglenales; among the cianobacteria it was found Anabaena spiroides (23% in summer) in the downstream stretch of Capivara and Synechocystis sp in the Cinzas River (9.6% in winter) and the Cryptophyceae Cryptomonas spp in the Cinzas River (46.5% in summer).

For the Bacillariophyceae it was also calculated the proportion between the orders Pennales and Centrales (Tab. III).

Table III: Relative abundance (%) of the Bacillariophyceae orders (Pennales and Centrales) in the Paranapanema Basin during two sampling periods.

Sampling stations	**August/2002**		**January/2003**	
	Pennales	**Centrales**	**Pennales**	**Centrales**
Upstream of Jurumirim	30.4	69.6	20.6	79.4
Taquari River	80.8	19.2	50.0	50.0
Downstream of Jurumirim	4.8	95.2	7.6	92.4
Downstream of Piraju	18.2	81.8	34.6	65.4
Itararé River	55.6	44.4	72.5	27.5
Downstream of Chavantes	24.7	75.3	22.6	77.4
Pardo River	76.9	23.1	40.0	60.0
Downstream of Salto Grande	45.2	54.8	48.1	51.9
Downstream of Canoas II	28.8	71.2	42.6	57.4
Pari Veado River	63.6	36.4	30.0	70.0
Downstream of Canoas I	31.6	68.4	35.7	64.3
Cinzas River	53.8	46.2	62.0	38.0
Tibagi River	84.4	15.6	78.7	21.3
Downstream of Capivara	11.0	89.0	19.2	80.8
Anhumas River	45.9	54.1	52.0	48.0
Downstream of Taquaruçu	7.4	92.6	39.5	60.5
Pirapó River	54.2	45.8	46.8	53.2
Pirapozinho River	43.8	56.3	42.1	57.9
Inhancá River	76.2	23.8	41.7	58.3
Downstream of Rosana	12.8	87.2	50.0	50.0

In the winter the maximum dominance of Pennales occurred in the Tibagi River (84%) (especially A. formosa) and the maximum for Centrales in the downstream stretch of Jurumirim (95%) (especially Aulacoseira granulata). During the summer the percentage of Pennales was higher in Tibagi (79%) (mainly Amphora ovalis and Encyonema silesiacum) and for Centrales the maximum was in the downstream stretch of Jurumirim (92 %) (especially D. stelligera). In general it was observed a higher contribution of Centrales for both sampling periods.

Diversity values ranged from 2.43 to 4.16 in the winter and from 3.55 to 4.47 in summer (Fig. 5). The highest phytoplankton diversity, for both periods, was verified in the downstream stretch of Piraju Reservoir. As observed for richness a lower diversity was also observed into the lower stretches of the basin.

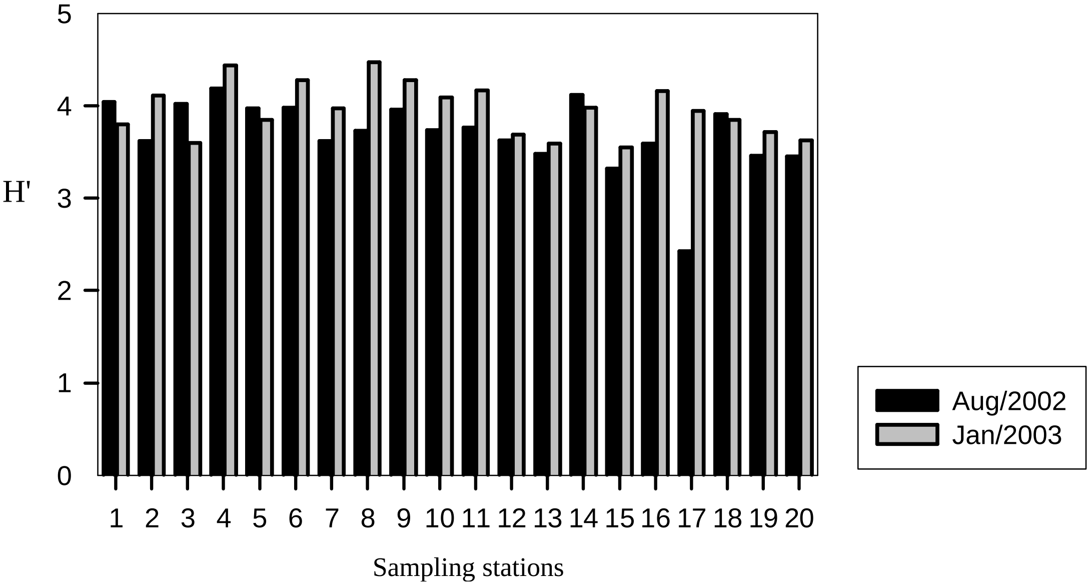


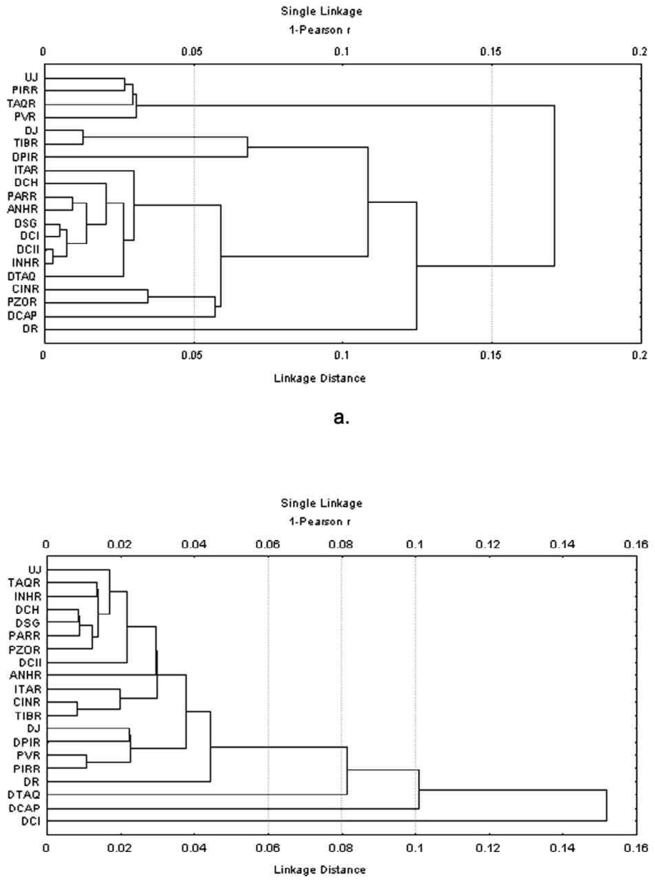
Figure 5: Diversity of phytoplankton community in the Paranapanema Basin during two sampling periods.

For the winter, the cluster analysis (Fig. 6) showed that better correlated groups included stations located in the middle Paranapanema River (downstream stretches of Canoas I, Canoas II and Salto Grande Reservoirs and also the Pardo River). In this period the group including the stations upstream of Jurumirim and the Rivers Pirapó, Taquari and Pari Veado, remained more isolated, probably due to the higher contribution of the Chlorophyceae. The similarity among the sampling points was higher in the summer period. The best groups were the following ones: the downstream stretches of S. Grande and Chavantes and Pardo River, with a relatively homogeneous contribution of Cryptophyceae, Bacillariophyceae, Cyanophyceae and Chlorophyceae; Cinzas and Tibagi Rivers with the highest dominance of Cryptophyceae, and Pirapó and Pari Veado Rivers with the lowest proportion of Cryptophyceae. In this last period, the downstream of Canoas I was discriminated in the analysis, due to the fact that in this point it was found a high abundance of Euglenophyceae.

In general, the fact that better statistical correlations have been observed during the summer (January 2003) indicates the homogenization effect due to the strong rains.

Chlorophyll a concentrations (Tab. V) were lower in the winter sampling, varying between 0.6 (downstream of S. Grande and Anhumas River) and 8.2 mg L^{-1} (upstream of Jurumirim). In this period a relatively high value was also found in the Tibagi River (7.6 mg L^{-1}). During the summer the values ranged from of 1.1 (downstream of Chavantes) to 21.4 mg L^{-1} (Cinzas River). In this period the chlorophyll was also high in the Rivers Itararé (9.6 mg L^{-1}), Pardo (11.1 mg L^{-1}) and Tibagi (12.1 mg L^{-1}).

The limnological variables (Tab. IV) that better indicated the differences in the water quality were conductivity, dissolved oxygen and transparency. The maximum electric conductivity was measured in the Cinzas River (133.7 mS cm^{-1}) during the winter. The



a.

b.

Figure 6: Similarity analysis of the sampling points in the Paranapanema Basin during the winter (a) and summer (b), considering the abundance of the phytoplankton classes.

Table IV: Physical and chemical characteristics in the Paranapanema Basin during two sampling periods.

Sampling stations	**Z (m)**		**pH**		**K (mS cm^{-1})**		**D.O. (mg L^{-1})**		**T (°C)**	
	Aug/ 02	**Jan/ 03**	**Aug/ 02**	**Jan/ 03**	**Aug/ 02**	**Jan/ 03**	**Aug/ 02**	**Jan/ 03**	**Aug/ 02**	**Jan/ 03**
Upstream of Jurumirim	1.0	0.2	6.2	6.2	74.3	55.7	10.0	10.0	20.2	22.6
Taquari River	0.9	0.4	6.6	6.1	103.3	57.3	10.3	7.8	19.4	22.5
Downstream of Jurumirim	4.5*	0.6	6.7	6.2	66.3	59.3	10.6	9.4	20.2	25.4
Downstream of Piraju	2.7	1.5	6.9	6.7	66.7	59.0	11.7	9.4	20.9	25.6
Itararé River	1.0	0.1	6.8	6.4	85.0	65.0	10.9	10.5	20.4	22.4
Downstream of Chavantes	4.5*	1.0	7.0	6.8	69.3	59.0	12.4	11.4	20.7	25.5
Pardo River	1.1	0.3	6.7	6.7	87.0	93.0	11.8	11.1	20.9	23.8
Downstream of Salto Grande	2.1	0.5	6.1	6.4	73.0	70.0	8.0	10.7	21.0	25.0
Downstream of Canoas II	2.0*	0.6	6.8	6.1	79.0	67.3	10.4	9.5	21.7	25.5
Pari Veado River	2.0*	0.4	6.4	6.6	77.7	61.3	6.8	10.1	20.9	25.3
Downstream of Canoas I	1.5*	1.8	6.9	6.5	73.7	70.0	10.4	10.1	21.8	27.5
Cinzas River	1.1	0.1	7.3	6.5	133.7	58.3	10.7	9.6	23.5	23.8
Tibagi River	0.7	0.2	6.6	6.4	73.0	39.0	10.4	10.2	22.1	22.5
Downstream of Capivara	2.7	1.2	6.3	6.7	72.0	66.7	9.1	9.7	21.0	27.4
Anhumas River	1.2	0.2	6.6	6.5	64.7	55.0	10.0	10.2	21.2	25.7
Downstream of Taquaruçu	5.5	0.9	6.8	6.7	81.0	60.3	10.1	8.4	21.6	27.1
Pirapó River	1.0	0.3	6.6	6.9	107.3	106.3	9.8	8.2	22.1	25.8
Pirapozinho River	0.9	0.2	6.5	6.8	58.0	52.0	9.5	7.9	21.6	26.2
Inhancá River	0.5*	0.3	6.8	6.4	27.7	29.3	10.6	8.2	21.8	25.7
Downstream of Rosana	3.5	0.7	6.2	6.2	72.3	66.7	11.2	9.6	22.7	27.9

*= bottom

minimum oxygen concentration was found in the Pari Veado River (6.8 mg L^{-1}) during the winter. The minimum transparency was observed in the Cinzas River (0.05 m), during the summer. There was also a noticeable increase in the concentration of nitrogen, phosphorus and suspended solids (Tab. V) in the water during the summer, due to direct effects of the rains. In case of suspended solids the concentration in January was about 40 times higher than in August. The maximum nitrogen and phosphorus was observed in the Cinzas River, during summer, with 1,703 mg L^{-1} and 432 mg L^{-1}, respectively.

Table V: Chlorophyll a, total nutrients and suspended matter concentrations in the Paranapanema Basin during two sampling periods.

Sampling stations	**Chorophyll a****		**Total Phosphorus****		**Total Nitrogen****		**Suspended Matter***	
	Aug/ 02	**Jan/ 03**	**Aug/ 02**	**Jan/ 03**	**Aug/ 02**	**Jan/ 03**	**Aug/ 02**	**Jan/ 03**
Upstream of Jurumirim	8.2	5.4	44.8	115.5	359	744	5.5	51.8
Taquari River	1.3	5.7	44.9	104.1	480	574	5.2	27.0
Downstream of Jurumirim	1.5	1.2	15.9	17.0	392	364	3.1	1.1
Downstream of Piraju	2.0	1.8	27.1	35.6	378	359	2.2	3.5
Itararé River	3.5	9.6	48.2	165.4	518	840	7.4	81.0
Downstream of Chavantes	1.3	1.1	10.3	49.2	359	378	0.1	6.0
Pardo River	1.5	11.1	57.0	127.6	345	611	5.4	28.4
Downstream of Salto Grande	0.6	3.7	27.1	62.1	396	490	1.0	5.9
Downstream of Canoas II	2.1	3.7	16.2	52.2	429	350	1.2	4.2
Pari Veado River	3.4	3.8	43.6	69.7	345	541	1.3	7.4
Downstream of Canoas I	2.1	2.1	26.1	21.7	378	359	4.3	1.7
Cinzas River	1.1	21.4	54.0	432.0	466	1703	4.2	352.4
Tibagi River	7.6	12.1	66.5	215.1	382	812	8.1	201.7
Downstream of Capivara	1.4	3.4	15.0	40.9	354	415	0.9	3.6
Anhumas River	0.6	2.1	35.7	125.9	345	639	3.6	21.1
Downstream of Taquaruçu	2.0	3.7	16.7	55.2	378	382	0.6	4.0
Pirapó River	4.4	5.6	49.8	156.4	410	417	6.1	84.6
Pirapozinho River	1.9	4.5	53.4	142.2	471	709	7.8	18.9
Inhancá River	1.4	1.7	37.7	68.5	406	401	4.9	12.4
Downstream of Rosana	1.7	2.1	32.2	60.8	438	364	6.8	6.9

* (mg L^{-1})

** (mg L^{-1})

The canonic correspondence analyses (Fig. 7) explained 37.8% of the data variance in the two first axes ($p < 0.05$). The scores showed a clear separation between the two sampling periods. In winter, the samplings were correlated with the higher values of dissolved oxygen and transparency and the lower values of conductivity. In summer, the samplings were associated with the higher values of temperature, total nitrogen and phosphorus and suspended matter. Notwithstanding the values of the biotic scores have not been significant, Chlorophyceae and Bacillariophyceae showed to be correlated with the winter points and Cryptophyceae, Cyanophyceae and others were associated with the summer points.

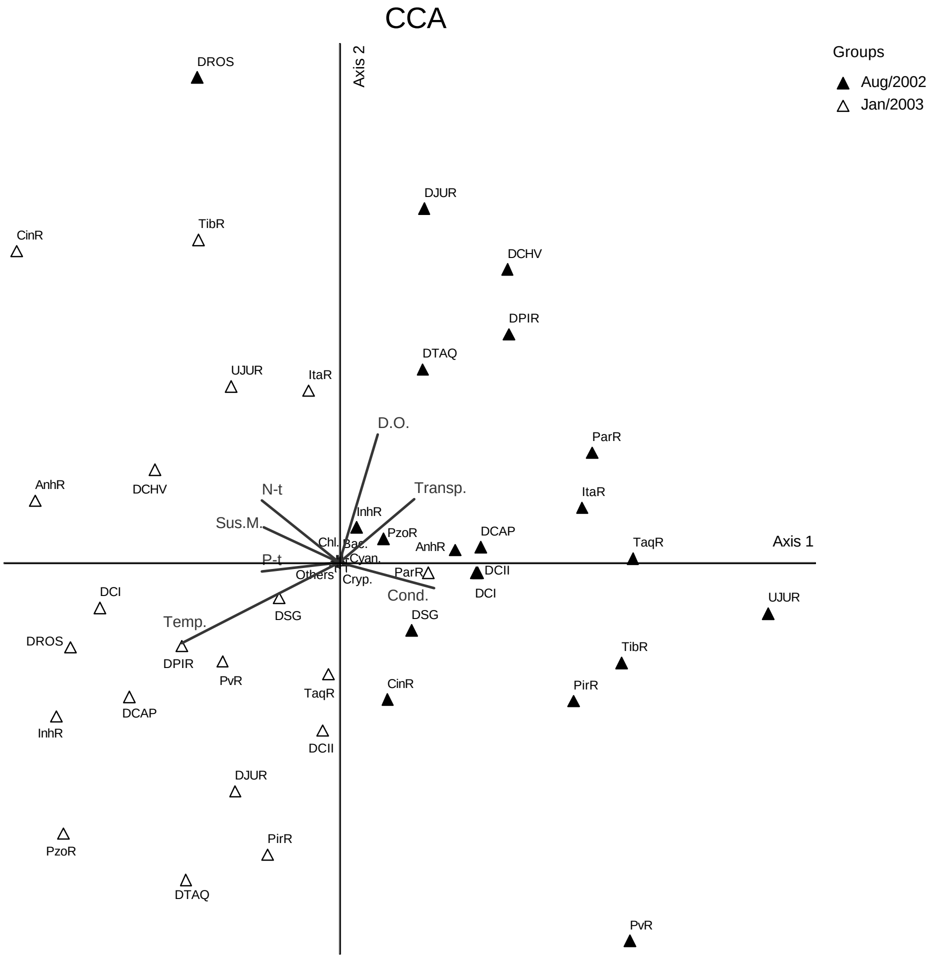


Figure 7: Canonic correspondence analyses using abiotic and biotic variables in the Paranapanema Basin obtained during two sampling periods.

Discussion

This study corroborated the idea that the evaluation of the limnological/water quality conditions of the rivers flowing into the reservoirs is an important tool for the detection of environmental impacts in the watershed and should be considered in management strategies.

A lower water quality, as indicated by the measured limnological variables, was observed in the tributaries when compared to the Paranapanema River itself. This pattern was more evident for the summer/ rainy period when abrupt changes (storm events) can produce an increase in the loads transportation of two or even threefold (Ferrareze et al., 2005).

A relatively high phytoplankton richness was found for the Paranapanema basin considering all the samples collected in the winter and summer periods. This result probably reflects the large spatial sampling scale (the whole basin) and the wide variety of environments – rivers of different orders and distinct watershed land uses, as well as the influence of several reservoirs representing a variety of lentic conditions.

For most sampling points, a higher number of taxa was observed in summer, rainy period, when compared to the winter. This fact indicates that, despite of the general decrease of the water transparency, the increase in the flow conditions and the input of nutrients into the rivers had a positive influence in the phytoplankton richness. The same pattern was observed in the upper Paraná River by Train & Rodrigues (1998). A positive correlation between richness and nutrient concentration was also verified by Branco & Senna (1996) and Santos & Rocha (1998), studying urban streams and reservoir. However, in contrast to our results, these authors found this relation for the dry period.

The sampling points located after the dams, in the Paranapanema River, were richer in species than the lateral tributaries. This fact was especially evident for Canoas I and Canoas II reservoirs, where it was observed around 100 different species in each point during summer. This could be associated to a moderate increase in the water retention time (about 4.5 to 7 days) in this river stretch (Nogueira et al., 2005) and also in the trophic conditions (mesotrophy) (Nogueira et al., 2002).

Lower phytoplankton richness was associated to poorer water-quality rivers. This is the case of the Pirapó and Anhumas Rivers, which had low transparency and high suspended solids concentration.

Considering the same points for both sampling periods, a higher similarity in the composition of the phytoplankton was seen in the Paranapanema River stretches, when compared to the tributaries. This must be related to the fact that in the reservoirs downstream, where there is an outflow control, the influence of the seasonal variation is lower, mainly related with the alternation between dry and rainy conditions. Thus, the regularization of the main river due to the construction of dams seems to attenuate the amplitude of the environmental variations resulting in a higher stability of the phytoplankton associations.

The abundance of the phytoplankton was higher in most sampling stations (15 points) during the summer. A similar result was found by De León & Chalar (2003) in Salto Grande Reservoir, Low Uruguay River (Uruguay/Argentina).

In general, a higher abundance of the phytoplankton was observed in the reservoirs downstream during the winter and the opposite occurred in the summer, with higher number of organisms in the tributaries. For the Reservoir of Jurumirim, the first one in the cascade, Nogueira (2000) had already verified a higher growth of the phytoplankton in the dry-winter season, when the retention-time tends to increase. For the tributaries the availability of nutrients in the rainy-summer season, is the main factor that stimulates the phytoplankton population growth. The same hypothesis is supported by the higher values of chlorophyll also observed in summer. The highest value of this variable occurred in the tributaries, reaching a maximum of 21.4 mL^{-1} in the Cinzas River (summer). Besides the Cinzas, other tributaries – Itararé, Pardo e Tibagi, showed chlorophyll a values near or superior to the maximum limit for Class 1 waters, according to the national water quality resolution (CONAMA, 2005).

The highest peaks of phytoplankton abundance were observed in the upstream of Jurumirim and in the Tibagi River during the winter, with 400,000 and 600,000 ind L^{-1}, respectively. These values can be considered high when compared with the maximum values observed in the oligotrophic reservoir of Jurumirim (Nogueira, 2000). Large phytoplankton populations, associated to more eutrophic punctual conditions along the basin, certainly acts as important inoculums to the rest of the system (Kiss & Kristiansen, 1994; Nogueira, 2000).

Certain tendency of a negative correlation between phytoplankton richness and abundance was observed for summer data, but it was not significant.

In August there was a predominance of Bacillariophyceae and Chlorophyceae in most sampling points. During this time Cryptophyceae also reached a high relative abundance in certain rivers (around 40% in Cinzas, Anhumas and Inhancá). In January there was a significant increase in the proportion of Cyanophyceae and Cryptophyceae.

For the cyanobacterias there was a remarkable increase in the Capivara downstream, due to growth of the Anabaena spiroides. This is related to more eutrophic conditions generated by the large entrance of nutrients with the rains combined to the relatively high water retention time in this reservoir, 130 - 150 days (Nogueira et al., 2005).

In case of the Cryptophyeae their growth could be explained by the high concentration of nutrients and high flow rate in certain stretches during summer. An increase of Cryptophyceae was also observed during the "high water" period (summer) in the upper Paraná River (Train & Rodrigues, 1998).

Among the diatoms the order Centrales was more abundant in winter, especially in the points directly influenced by the presence of reservoirs. In downstream of Jurumirim, their relative abundance reached

95% of the Bacillariophyceae, represented mainly by the filaments of Aulacoseira granulata. The dominance of the genus Aulacoseira in several kinds of reservoirs and in distinct geographic regions of South America has been attributed to the fact that this algae is a typical R-strategist organism (sensu Reynolds, 1988) which tolerate high turbulence and frequent changes in the environmental conditions (De León & Chalar, 2003).

In the same sampling point (downstream of Jurumirim), but in summer, the main diatom was the unicellular Discostella stelligera. This alternation in dominance among large and small diatoms is directly related to the mixture regime in the lacustrine zone of the reservoir – isothermal condition in autumn-winter and with the presence of thermocline in spring-summer (Henry, 1993; Nogueira et al., 1999).

The Pennales were better succeeded in the tributaries, where it was registered the maximum relative abundance of the order. They constituted more than 70% of diatoms in the Rivers Taquari, Pardo, Tibagi and Inhancá in the winter and Itararé and Tibagi in summer. In a previous study of the phytoplankton composition in the Tibagi River it was observed the dominance of diatom taxa during the dry period (Bittencourt-Oliveira, 2002).

The diversity of the phytoplankton assemblages in the Paranapanema basin was high. The only exception was observed in the Pirapó River, lower than 3 bits org^{-1}, due the dominance of M. cf. contortum. In general, the values of diversity were higher during the rainy period, following the same pattern observed for richness. It was also observed, for both periods, a tendency of diminution of the diversity into the lower stretches of the basin. It seems to be a consequence of a mixture between lake and river communities that prevail in the upper Paranapanema basin (great reservoirs and river stretches as well).

The cluster analysis and the canonic correspondence analysis showed the structure of the phytoplankton assemblages is directly influenced by the availability of light and nutrients, which determine variations in richness, diversity and, mainly, in the relative abundance of the distinct taxonomical groups (Reynolds, 1988).

The high turbulence in consequence of the increase of the flow conditions and lower penetration of light associated to excessive mineral turbidity limited the growth of some species, such as cyanobacterias, during the period of summer. These conditions favored the opportunist organisms, which are classified as C-strategists (Reynolds, op. cit.), with high rate of population growth, small size, and of high surface/volume relation. In this period, it was conspicuous the presence of Cryptomonas spp. in the different sampling stations of the Paranapanema basin. In the winter, the increment of light penetration, moderate concentrations of nutrient and lower washout effect promoted the development of Bacillariophyta and Chlorophyta species, resulting in an increase of the dissolved oxygen concentration.

The relative low abundance of cyanobaterias and low richness of this group in both periods of the year is probably related to the non eutrophic conditions that prevail in the basin and to the predominance of lotic conditions in the study environments, which impair their development.

The phytoplankton assemblages respond quickly the environmental changes (Reynolds, 1984). The information on phytoplankton assemblage structures showed to be a good indicator of the different conditions, in terms of spatial and temporal scales, of the Paranapanema Basin.

Finally, it is important to stress the necessity to consider the role of the tributary rivers for the limnological studies of large hydrographic basins and its biotic communities. Even in the river valleys characterized by the presence of cascade of reservoirs (longitudinal dimension), is fundamental to evaluate the lateral contribution of small and medium sizes rivers.

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