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Instituto de Biociências – Campus de Botucatu

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Tese de doutorado

Alterações limnológicas – físico-químicas e comunidades zooplanctônicas, decorrentes da construção de Pequenas Centrais Hidrelétricas: um estudo de caso no rio Sapucaí-Mirim (SP)

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Tese apresentada ao Instituto de Biociências da Universidade Estadual Paulista – UNESP, Campus de Botucatu, como parte dos requisitos para obtenção do Título de Doutor em Ciências Biológicas (Zoologia), Área de concentração: Ecologia Animal

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Sumário

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Apresentação

O alto rio Paraná, principal formador da bacia do Prata, corresponde à porção da bacia situada a montante dos saltos de Sete Quedas (agora inundados pelo reservatório de Itaipu) e incluí importantes tributários em território brasileiro, como os rios Grande, Paranaíba, Tietê e Paranapanema.

O rio Grande, um dos principais formadores da bacia do alto rio Paraná, nasce na Serra da Mantiqueira, nas regiões limítrofes dos Estados de São Paulo e Minas Gerais, a aproximadamente 1.500 m de altitude (22º15'S 44º34'W). Apresentando extensão total de 1.050 km (Ziesler & Ardizzone, 1979) e uma área de drenagem de aproximadamente 143 mil km² (CEMIG & CETEC, 2000). Deságua na confluência com o rio Paranaíba, formando o rio Paraná. O rio Sapucaí-Mirim, objeto do presente estudo, é um importante tributário do médio rio Grande.

Atualmente, a instalação de pequenas centrais hidrelétricas (PCHs) tem sido uma alternativa energética que se encontra em plena expansão, podendo apresentar vantagens em termos ambientais, sociais e econômicos, quando comparada à construção de grandes usinas hidrelétricas. Segundo dados obtidos na Agência Nacional de Energia Elétrica – ANEEL (sigel.aneel.gov.br), no Brasil existem 427 PCHs em operação, além de 1756 projetos previstos para implantação nos próximos anos. Contudo, apesar deste notável crescimento no número de instalações de PCHs, ainda são escassos os trabalhos que analisam as alterações limnológicas causadas por essas usinas de pequeno porte no Brasil, de forma individual ou através de efeitos cumulativos de um conjunto de empreendimentos numa determinada bacia hidrográfica.

Sendo assim, o presente estudo pretende avaliar os possíveis efeitos nas características limnológicas em um rio de médio porte, Sapucaí-Mirim no norte do Estado de São Paulo, decorrentes da construção de uma série em cascata de três Pequena Central Hidrelétricas.

Nosso trabalho está associado a outros já concluídos ou em andamento, contribuindo para a linha de pesquisa ecologia de reservatórios de hidrelétricas, nesse caso de PCHs, do Laboratório de Ecologia de Águas Continentais do Departamento de Zoologia da UNESP/Campus de Botucatu.

Cabe destacar que a experiência obtida através do estabelecimento da parceria entre empresas geradoras de energia e a universidade tem possibilitado o acesso a recursos para o desenvolvimento de pesquisa acadêmica de caráter mais aplicado, bem como a interação direta com o sistema de gestão do reservatório – empreendedor, comitê de bacia e órgãos ambientais públicos. Dessa forma, os resultados poderão contribuir para o aperfeiçoamento das práticas de monitoramento e de gestão ambiental na bacia hidrográfica do rio Sapucaí-Mirim, sobretudo tendo em consideração de que novos empreendimentos dessa natureza estão previstos no médio prazo.

Quanto a estrutura da tese, conforme normas previstas pelo programa de Pós-Graduação em Ciências Biológicas – Zoologia, apresenta-se um texto de formato compacto, em capítulos direcionados para a publicação de dois artigos científicos.

O primeiro capítulo contém as informações limnológicas físicas e químicas, procurando avaliar as alterações decorrentes dos barramentos, tanto as variações intra-reservatórios, como a possível transferência de efeitos – variações inter-reservatórios.

O segundo capítulo trás os resultados da análise do zooplâncton (Cladocera e Copepoda), com o mesmo enfoque em termos de análise da organização espacial do sistema – variabilidade intra e inter-reservatórios.

Capítulo 1.

Limnological changes in a small power plant reservoir cascade – physical and chemical factors

Abstract

The increasing demand for energy by society is one of the incentives for the construction of power plants. However, a comprehensive analysis of the associated environmental impacts is determinant for the implementation of new projects. In this sense, an alternative is to replace the model of large hydropower plants (HPP) by small hydropower plants (SHP). However, the knowledge about the physical and chemical changes caused by these hydropower projects in the aquatic environment is incipient. Thus, this study has the objective to analyze the limnological conditions in a series of three SHP reservoirs located in the Sapucaí-Mirim River, SP, Rio Grande basin. Six samplings campaigns, seasonally distributed (dry and rainy seasons), were carried out in 10 distinct points (upstream, transition and lacustrine zones of each reservoir). *In situ* measurements of transparency, depth and vertical profiles of water temperature, pH, oxidation-reduction potential, conductivity, turbidity, dissolved oxygen and total dissolved solids, and simultaneously collection of water samples for analysis of chlorophyll *a*, nitrogen and total phosphorus were performed. Despite the low water retention time it was evidenced the compartmentalization of the reservoirs through the results of a two-way ANOVA, for transparency, turbidity temperature, dissolved oxygen and total phosphorous. The sampling point more distinctive was the most upstream located, the only one without any dam influence. Therefore, the assumption that SHPs do not alter the limnological structure and functioning of the river stretches where they are built, was not confirmed. Ordination using principal component analysis evidenced the strong influence of seasonality - dry and rainy periods, on the limnological conditions, with homogenization caused by rains.

Keywords: limnological variables, dry season, rainy season, spatial organization, cascade system.

1. Introduction

The human society uses, and dependence of surficial water makes the management of this resource a complex task (Tundisi & Matsumura-Tundisi, 2003; Agostinho et al., 2007). Population growth and modernization of the society generate an increasing demand for water and energy. Energy is necessary for industry, transportation, domestic activity, heating, among other purposes. Currently, emerging and industrialized countries have total dependence on different sources of electricity generation (Tzimas et al., 2009).

In this context, the forms of energy production that have been implemented around the world vary according to the availability of regional resources and technologies. In Europe, for example, the energy matrix is based on the burning of fossil fuels (Valero, 2012); in North America as well as in South America the matrix of energy production has a high dependence on water resources (Agostinho et al., 2007). Hydroelectric plants are the main source of renewable energy, when compared to other technologies on a global scale, and they play a fundamental role in meeting current and future energy needs, offering an excellent alternative to fossil fuels (Valero, 2012; Zarfl et al., 2015).

In Brazil, most reservoirs were built in the southeast region, mainly in the 1970s, causing considerable environmental changes in landscapes and regional socioeconomy. In the 1990s, studies were intensified to understand the limnological structure and dynamics of reservoirs (e.g, Tundisi et al., 1991, Straskraba et al., 1993, Tundisi & Straškraba 1999).

Large reservoirs generally exhibit spatial and temporal compartments of major complexity (Thornton, 1990; Straškraba et al., 1993; Nogueira et al., 1999; Soares et al., 2008). The spatial variability occurs mainly along the main axis, in longitudinal gradients formed by velocity of flow, depth, width, particle sedimentation, transparency and light penetration, thermal stratification (Armengol et al., 1990; Henry & Maricatto 1996; Nogueira et al., 2006; De Filippo et al., 2007).

Because the physical magnitude, high cost and significant environmental impacts of large dams, operating as accumulation or run-of-river systems (Nogueira et al., 2012), exploitation initiatives are more and more directed to the development of small-scale projects – Small Hydropower Plants (SHPs) (Therrien et al, 2000).

In general, the production of a SHP is around 10 MW. In countries such as Brazil and Russia, the established limit capacity is up to 30 MW, in the USA between 5 and 100 MW and in India and China it varies from 25 MW to 50 MW (Valero, 2012).

Although there is considerable information on the environmental impacts associated to the construction of large reservoirs (Rollet, 2007), little is known about the limnological changes caused by SHPs (Malavoi, 2003, 2009, Warner, 2012 and Ibisate et al 2011; Ruocco et al., 2018; Brambilla et al., 2018). Thus, the present study intends to generate new information on the structure and functioning of a middle size fluvial environment due to the implantation of SHP reservoirs.

Our study aims to analyze (1) the spatial and temporal dynamics of the limnological and water quality characteristics in three SHP reservoirs located in the Sapucaí-Mirim, Rio Grande basin, Southeast Brazil, and (2) the reservoirs inter and intra limnological variability. Our two main hypotheses are: (1) there is an intra-reservoir spatial compartmentalization, following the models of large reservoirs, (2) there is a transference of inter-reservoir effects (or cumulative effects) along the cascade.

2. Materials and Methods

Study area and sampling sites

The study was performed in a cascade of three SHPs reservoirs constructed in the Sapucaí-Mirim River, North of São Paulo State. The most upstream SHP is named Palmeiras, the intermediate Anhanguera and the most downstream located is Retiro, which in this paper are denominated SHP A, SHP B and SHP C, respectively. We selected ten sampling sites for sampling (**Figure 1** and **Table 1**).

Table 1. Sampling sites denomination and geographic position and the main features of the studied SHP reservoirs.

Sites	Small Hydropower System	Geographical Coordinates	Reservoir Area (Km^2)	Maximum Length (Km)	Power Generation (MW)	Mean Depth(m)
1	A (Upstream)	20°34'20.6" S 47°46'58.4"O	2,6	7,5	16,5-	1,5
2	A (Transition)	20°34'06.4"S 47°47'43.9"O				4,0
3	A (Dam)	20°34'06.4"S 47°47'43.9"O				9,0
4	B (Upstream)	20°31'09.9" S 47°50'07.9" O	1,8	5,0	22,7	1,5
5	B (Transition)	20°30'37.1" S 47°51'23,3" O				6,0
6	B (Dam)	20°29'41,5" S 47°51'43" O				13
7	C (Upstream)	20°29'14.2" S 47°51'24.6" O	2,8	11,0	16,0	1,0
8	C (Upstream)	20°28'06.8" S 47°52'07.8" O				3,0
9	C (Transition)	20°26'54.8" S 47°52'44.3" O				7,0
10	C (Dam)	20°26'12.1" S 47°53'08.2" O				12

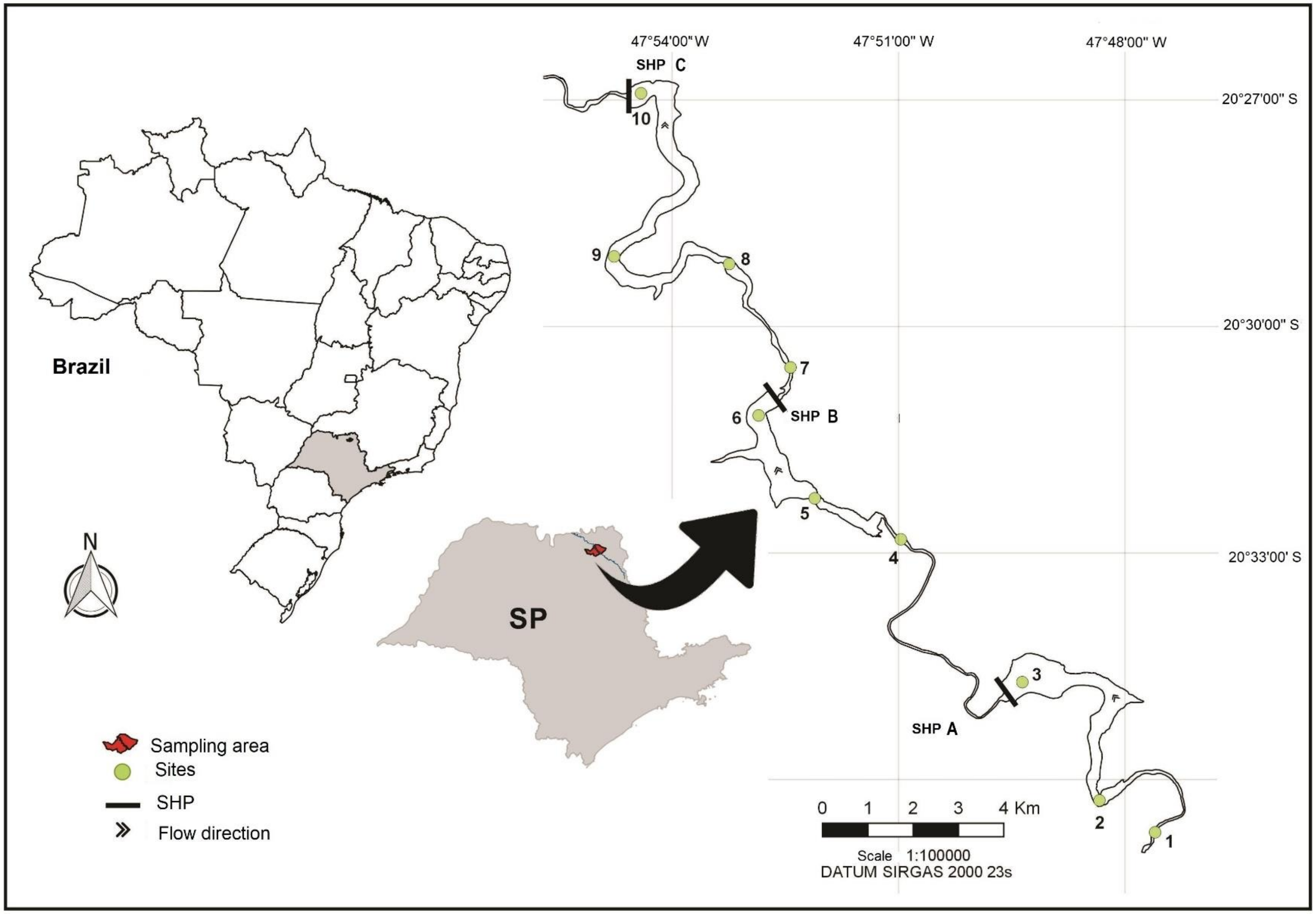


Figure 1. Geographic location of Sapucaí-Mirim River basin and the distribution of the sampling points.

The Sapucaí-Mirim River is a tributary of the Grande River (natural border between the states of São Paulo and Minas Gerais). The river extension is 290 km (Paiva, 1982), with a catchment area of 9.125 km², and the dam of SHP C is located at 83 km from the river mouth. Originally, the dominant type of vegetation in the region is the Semidecidual Seasonal Forest (source: http: //www.sigrh.sp.gov/cbhsmg/cbhsmg/apresentation – access at 28/03/2019). Along the studied SHPs there are few remaining of native forest, but the riparian vegetation has been recovered through plantation of native trees. The whole area is surrounded by intensive sugar-cane agriculture, for sugar and alcohol industrial production.

The sampling sites were selected along the main longitudinal axes of SHPs A, B and C, which started to operate in the years 2011, 2012 and 2013, respectively. All three SHPs are run-of-river systems, with about only two days of water retention time.

In order to evaluate the spatial structure, following models based on UHE reservoirs compartmentalization, water samples were taken in three different regions of each reservoir, intending to represent the upstream (lotic), transitional and dam (lentic) zones. An additional site was considered for sampling in SHP C, the largest reservoir.

Sampling and laboratory procedures

Samplings were taken in two periods of 2014: June (winter) and December (summer), and in four periods of 2015: March (autumn); June (winter); September (spring) and December (summer), in order to characterize the limnological conditions in distinct seasonal regimes of precipitation (**Figure 2**).

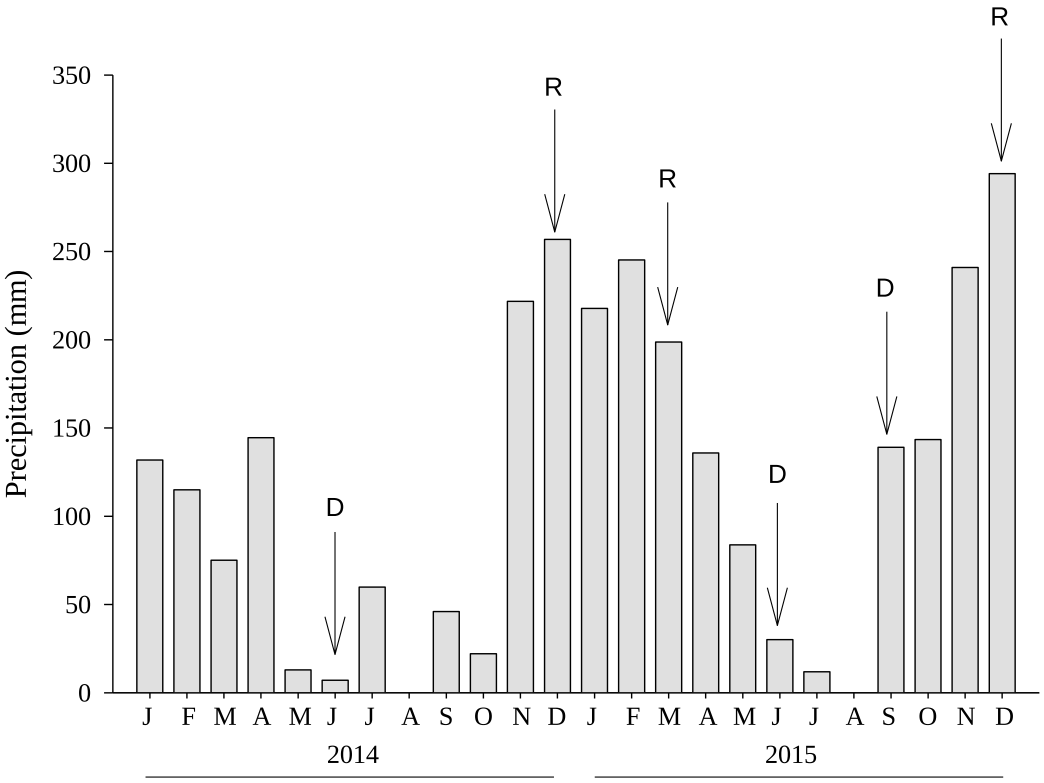


Figure 2. Precipitation values in the Sapucaí-Mirim River catchment during the studied period (National Institute of Meteorology). Arrows indicate the months when samplings were performed, D (Dry) and R (Rainy).

Vertical profiles (measurements every 1m depth) of water temperature (Temp.) (°C), pH, oxide-reduction potential (O.R.P.) (mV), electric conductivity (Cond.) (μS cm^{-1}), turbidity (Turb.) (NTU), dissolved oxygen (D.O.) (mg L^{-1}) and total dissolved solids (T.D.S.) (g L^{-1}), were taken using a water quality probe (Horiba U-52), daily calibrated. Water samples from surface, middle and bottom of the water column were taken with a Van Dorn bottle, integrated and aliquots separated for analyses of chlorophyll *a* (Chloro. *a*) (Golterman et al., 1978), total solids (T.S.) (gravimetry), total nitrogen (T.N.) (Strickland and Parsons, 1960) and total phosphorus (T.P.) (Mackreth et al., 1978). For both nutrient there was a previous chemical digestion of samples prior spectrophotometric determination (Valderama, 1981). It was also measured the Secchi disc transparency and the local depth using a SpeeedTech sonar.

Data analyses

For descriptive analyzes and application of statistical tests, data were separated in two major groups, Rainy and Dry seasons. We also considered subgroups, according to the sampling dates: December 2014 corresponds to Rainy 1; March 2015 to Rainy 2, and December 2015 to Rainy 3. Data from June 2014 corresponds to Dry 1, June 2015 to Dry 2 and September 2015 to Dry 3.

The mean value differences among reservoirs and sites were tested by a two way ANOVA. When differences were detected, the Holm-Sidak test was used for significance analyses ($p < 0.05$). Previously, Kolmogorov Smirnov test was used to check for data normality. All tests were performed using Sigma Plot 11 software.

For multivariate analyses, we used data of transparency and the mean values of the water columns of the following measurements: temperature; pH; conductivity; turbidity; dissolved oxygen; oxide-reduction potential; total dissolved solids; total nitrogen, total phosphorus and chlorophyll *a*. The analyzes were performed in the software PRIMER 6 and all data were transformed by log (x+1), except pH (Clarke and Gorley, 2006).

3. Results

Chemical and physical data (mean values and standard deviation for each region of each SHP) are presented in Table 2 (Dry) and Table 2 (Rainy).

Table2. Mean and standard deviation for environmental variables measured during Dry seasons. Superscript letters indicate statistical similarity (same letter) or statistical difference (different letters) according to ANOVA test followed by Holm-Sidak test.

	SHP A						SHP B						SHP C					
Variables	Upstream		Transition		Dam		Upstream		Transition		Dam		Upstream		Transition		Dam	
	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
Transp. (m)	$0,5^{ad}$	0,5	$0,6^{ad}$	0,4	$1,1^{ac}$	0,5	$1,0^{be}$	0,4	$1,6^{be}$	0,4	$1,7^{bf}$	0,4	$1,1^{bg}$	0,2	$1,8^{bg}$	0,2	$1,9^{bh}$	0,3
Water temp. (°C)	$19,4^{a}$	0,7	$19,2^{a}$	1,0	$20,0^{a}$	1,1	$19,8^{a}$	1,3	$20,0^{a}$	1,2	$20,1^{a}$	1,1	$20,2^{a}$	1,3	$20,3^{a}$	1,0	$20,6^{a}$	0,9
pH	$6,3^{a}$	0,2	$6,2^{a}$	0,2	$6,2^{a}$	0,3	$6,4^{a}$	0,4	$6,2^{a}$	0,4	$6,1^{a}$	0,4	$6,6^{a}$	0,5	$6,3^{a}$	0,7	$6,5^{a}$	0,9
O.R.P. (mV)	$371,5^{a}$	24,4	$372,3^{a}$	62,4	$378,0^{a}$	43,7	$354,8^{a}$	55,2	$372,7^{a}$	37,4	$384,1^{a}$	51,5	$332,5^{a}$	81,0	$344,0^{a}$	72,8	$374,3^{a}$	62,4
Cond. (µS cm^{-1})	$71,6^{a}$	11,2	$73,8^{a}$	14,1	$87,5^{a}$	17,0	$88,2^{a}$	17,3	$93,4^{a}$	13,7	$89,2^{a}$	13,3	$88,6^{a}$	14,0	$86,4^{a}$	12,8	$86,5^{a}$	13,1
Turb. (NTU)	$119,6^{a}$	91,0	$83,4^{a}$	77,1	$54,6^{a}$	77,2	$24,3^{b}$	17,5	$10,5^{b}$	4,6	$10,9^{b}$	5,0	$12,7^{b}$	5,3	$7,8^{b}$	3,5	$8,6^{b}$	4,1
D.O. (mg L^{-1})	$8,5^{a}$	0,7	$7,9^{a}$	0,6	$7,2^{a}$	0,3	$7,5^{a}$	0,9	$6,6^{a}$	0,9	$6,1^{a}$	0,9	$7,9^{a}$	0,9	$7,0^{a}$	1,6	$6,9^{a}$	1,7
T.D.S. (g L^{-1})	$0,05^{a}$	0,01	$0,05^{a}$	0,01	$0,06^{a}$	0,01	$0,06^{a}$	0,01	$0,06^{a}$	0,01	$0,06^{a}$	0,01	$0,06^{a}$	0,01	$0,06^{a}$	0,01	$0,06^{a}$	0,01
T.P. (mg L^{-1})	$1,8^{a}$	0,1	$1,3^{a}$	0,0	$1,1^{a}$	0,0	$0,5^{b}$	0,0	$0,5^{b}$	0,0	$0,4^{b}$	0,0	$0,1^{b}$	0,0	$0,3^{b}$	0,0	$0,4^{b}$	0,0
T.N. (mg L^{-1})	$2,4^{a}$	0,3	$1,4^{a}$	0,4	$3,5^{a}$	2,7	$1,8^{a}$	0,7	$1,2^{a}$	0,5	$2,2^{a}$	1,2	$2,4^{a}$	1,1	$1,7^{a}$	0,7	$1,6^{a}$	0,4
Chloro. *a* (µg L^{-1})	$6,8^{a}$	4,9	$4,2^{a}$	1,8	$3,6^{a}$	0,7	$3,3^{a}$	0,3	$8,5^{a}$	7,4	$10,8^{a}$	8,1	$11,9^{a}$	13,1	$11,2^{a}$	13,6	$10,5^{a}$	6,7

Table3. Mean and standard deviation for environmental variables measured during Rainy seasons. Superscript letters indicate statistical similarity (same letter) or statistical difference (different letters) according to ANOVA test followed by Holm-Sidak test.

	SHP A						SHP B						SHP C					
Variables	Upstream		Transition		Dam		Upstream		Transition		Dam		Upstream		Transition		Dam	
	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
Transp. (m)	0,3^a	0,2	0,3^a	0,2	0,5^a	0,2	0,3^a	0,1	0,5^a	0,2	0,6^a	0,2	0,6^a	0,3	0,6^a	0,3	0,7^a	0,3
Water temp. (°C)	23,3^a	0,8	23,4^a	0,7	23,8^a	1,6	24,5^b	0,6	24,9^b	1,5	24,5^b	1,3	24,5^b	0,8	25,2^b	1,0	25,5^b	0,9
pH	6,4^a	0,3	6,3^a	0,3	6,1^a	0,5	6,3^a	0,4	6,1^a	0,4	6,1^a	0,3	6,5^a	0,2	6,2^a	0,4	6,2^a	0,4
O.R.P. (mV)	382,5^a	14,8	391,5^a	25,4	418,7^b	36,4	345,3^c	25,1	389,9^c	32,9	402,0^d	38,5	376,5^e	21,6	400,5^e	35,4	399,5^f	34,2
Cond. (μS cm^{-1})	55,6^a	9,9	53,6^a	8,1	54,2^a	11,2	66,3^a	9,6	63,8^a	8,2	62,9^a	8,1	60,5^a	9,5	70,1^a	19,0	75,4^a	20,1
Turb. (NTU)	293,4^a	214,4	294,4^a	232,4	112,0^a	88,1	131,7^b	48,0	58,4^b	30,3	57,6^b	28,2	55,2^b	37,0	43,6^b	36,7	35,1^b	31,4
D.O. (mg L^{-1})	8,1^a	0,6	7,7^a	0,8	6,9^a	0,6	7,8^b	1,4	6,5^b	1,1	6,6^b	1,3	6,5^b	1,0	5,6^b	0,5	5,5^b	0,6
T.D.S. (g L^{-1})	0,04^a	0,01	0,03^a	0,01	0,04^a	0,01	0,04^a	0,01	0,04^a	0,01	0,04^a	0,01	0,04^a	0,01	0,05^a	0,01	0,05^a	0,0
T.P. (mg L^{-1})	3,6^a	0,2	5,4^a	0,3	3,8^a	0,0	1,0^a	0,0	2,0^a	0,0	15,4^a	0,4	0,9^a	0,0	1,7^a	0,0	1,6^a	0,0
T.N. (mg L^{-1})	1,5^a	0,8	1,4^a	0,5	1,3^a	0,1	1,6^a	0,3	1,9^a	0,7	1,3^a	0,3	1,2^a	0,2	1,6^a	0,3	1,6^a	0,3
Chloro. *a* (μg L^{-1})	3,3^a	0,4	3,2^a	0,2	3,3^a	0,4	2,3^a	0,9	3,7^a	1,0	3,2^a	0,3	1,9^a	1,0	4,2^a	1,6	2,5^a	0,6

Higher values of transparency were observed in the three reservoirs in the lacustrine zone. On the other hand, lower values were measured in the upstream zones of the three reservoirs.

Figure 3A shows the longitudinal gradient of water transparency in the reservoir cascade, showing an increasing tendency towards dam in all three reservoirs.

The water temperature profiles exhibit isothermal conditions in the upstream sites of all reservoirs. In the transitional sites, it is observed thermal stratification near the surface, probably due to daily effects. That same pattern occurred in the dam sites of the three reservoirs, with thermal stratification near the surface (**Figure 3B and 3C**).

The dissolved oxygen concentrations varied between 3.7 to 10.4 mg L^{-1} and SHP C presented marked differences between the sampling periods (**Figure 3D)**.

At the upstream sites of all three reservoirs, it was measured higher values of dissolved oxygen, probably due to intense flow conditions. In SHP A and SHP B transition sites, values varied between 5.9 mg L^{-1} (SHP B, Rainy 2) and 8.8 mg L^{-1} (SHP A, Dry 1). Values at SHP C, transition sites varied between 4.7 mg L^{-1} (Rainy 2) and 10.4 mg L^{-1} (Dry 3) and this major difference is probably influenced by high concentrations of chlorophyll *a* (**Figure 4D**). Among dam sites SHP B exhibited the lower value, 3.7 mg L^{-1} (bottom of water column during Dry 3) and SHP C the higher, 10.4 mg L^{-1} (Dry season 3).

The pH values, mean and standard deviation, remained around 6.0 or were slightly higher, slightly acidic (**Figure 3E)**.

The electrical conductivity in SHP A was lower than in the other two reservoirs. The variation was between 43 μS cm^{-1} and 108 μS cm^{-1} (**Figure 3F)**.

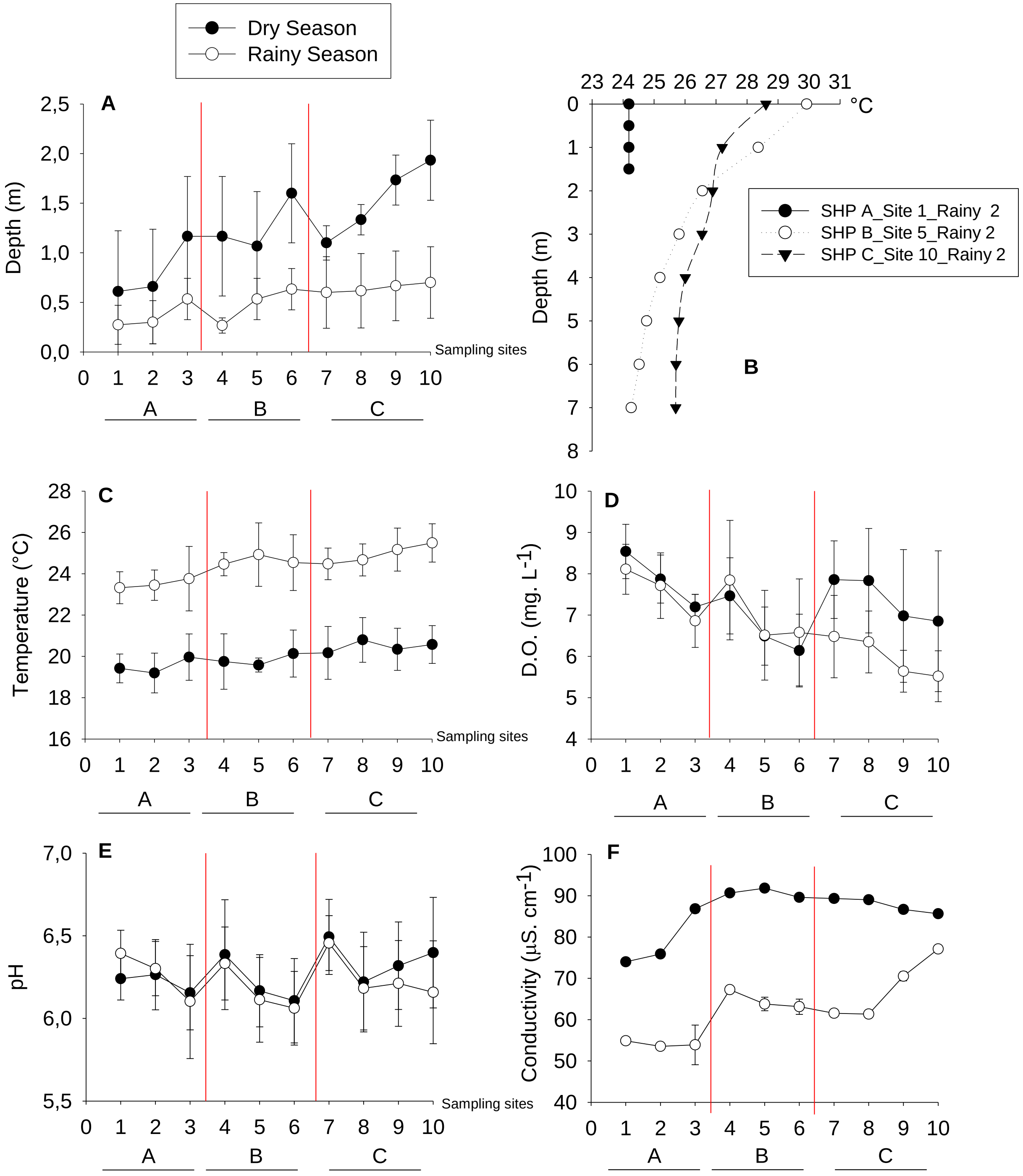


Figure 3. Variation of transparency (A), temperature (B) (C – selected profiles). dissolved oxygen (D), pH (E) and conductivity (F) (mean values and standard deviation) along the reservoir cascade during the Dry and Rainy periods. Reservoirs separated by red lines and letters (see text).

SHP A had higher values of turbidity, which ranged from 6.9 NTU to 617 NTU. SHP B from 4.2 NTU to 199 NTU and SHP C had lower values, from 3.3 NTU to 101 NTU (**Figure 4A**).

Higher values of total phosphorus were determined in SHP A during both dry and rainy seasons. Values ranged from 0.02 mg. L^{-1} to 0.91 mg. L^{-1}. Total phosphorus in SHP B ranged from 0.01 mg. L^{-1} to 0,12 mg. L^{-1} and SHP C exhibited lower values, from 0,01 mg. L^{-1} to 0,11 mg. L^{-1} (**Figure 4B)**.

Total nitrogen values in SHP A ranged from 0.54 mg. L^{-1} to 6.48 mg. L^{-1}. In SHP B ranged from 0.64 mg. L^{-1} to 3.62 mg. L^{-1} and in SHP C values ranged from 0,92 mg. L^{-1} to 3,64 mg. L^{-1} (**Figure 4C)**.

Chlorophyll *a* values in SHP A ranged from 3.0 μg L^{-1} to 20.4 μg L^{-1}. In SHP B from 1.23 μg L^{-1} to 21.5 μg L^{-1} and in SHP C from 1.3 μg L^{-1} to 48 μg L^{-1} (**Figure 4D)**.

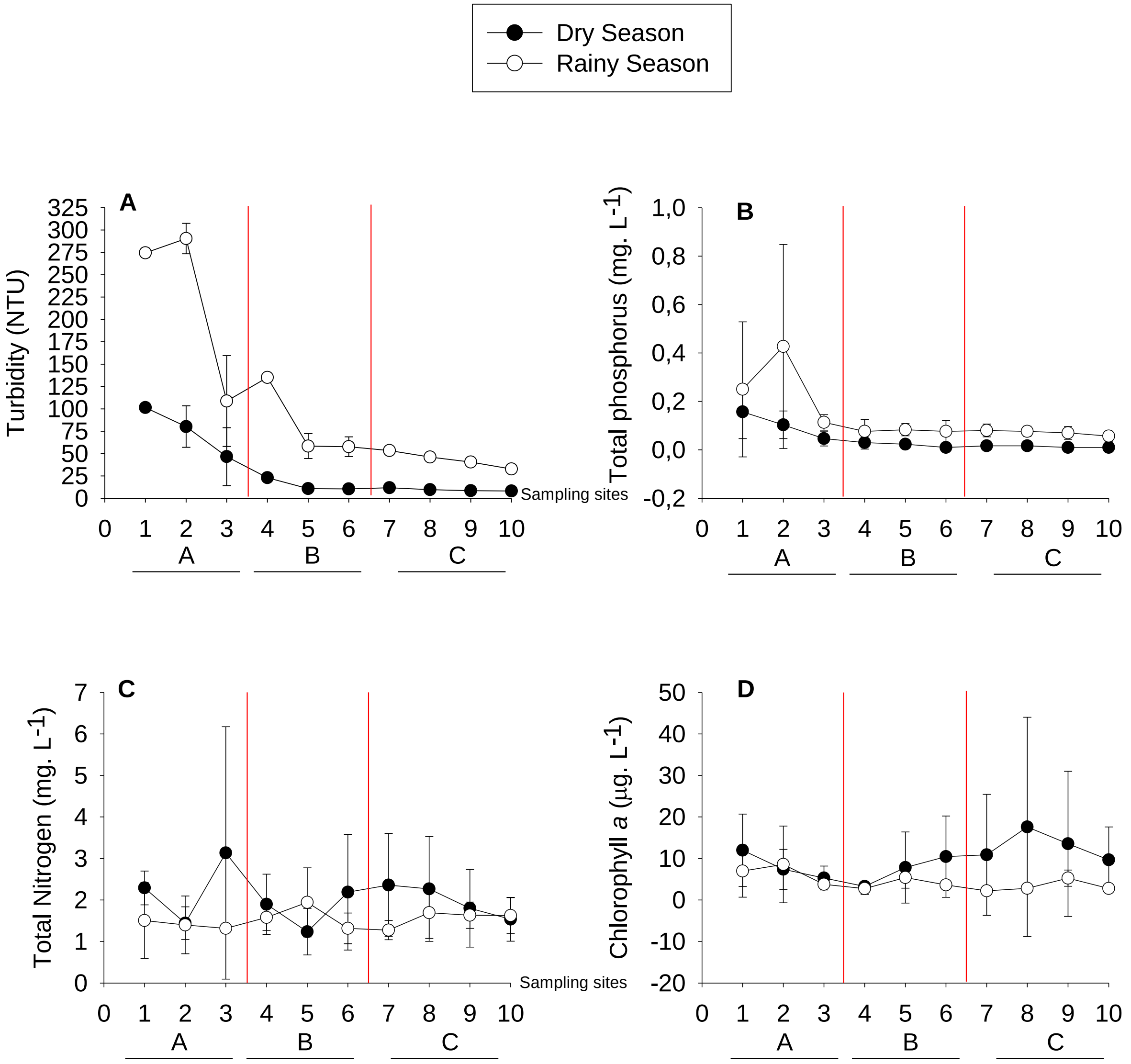


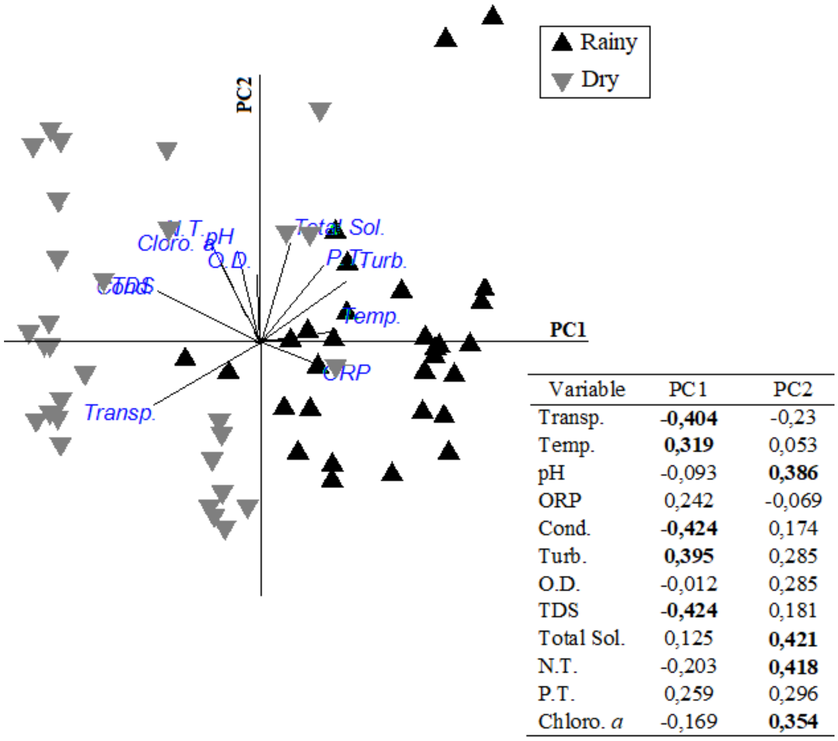
Figure 4. Variation of turbidity (A), total phosphorus (B), total nitrogen (C) and chlorophyll *a* (D) (mean values and standard deviation) along the reservoir cascade during the Dry and Rainy periods. Reservoirs separated by red lines and letters (see text).

The ANOVA two way based on dry periods data showed significant differences ($p<0,05$) for transparency, turbidity, and total phosphorus. Concerning inter-reservoirs variation, SHP A data were different from the other two reservoirs. Among regions (intra-reservoir), upstream was a site different from the dam within SHP A reservoir only for transparency data (**Table 2**).

For the rainy periods significant ($p<0,05$) differences were determined for temperature, oxidation-reduction potential, turbidity and dissolved oxygen. Along the cascade, SHP A was different from the other two reservoirs and among the sites, upstream region was different from dam in the three reservoirs in relation to redox potential data (**Table 3)**.

Principal components analysis

A PCA using the data set was performed in order to obtain an ordination of the results and the analysis showed a clear separation of two main groups - Dry and Rain (**Figure 5)**. The two first components explained 57.8% of data variability (PC1 35.9% and PC2 21.9%).

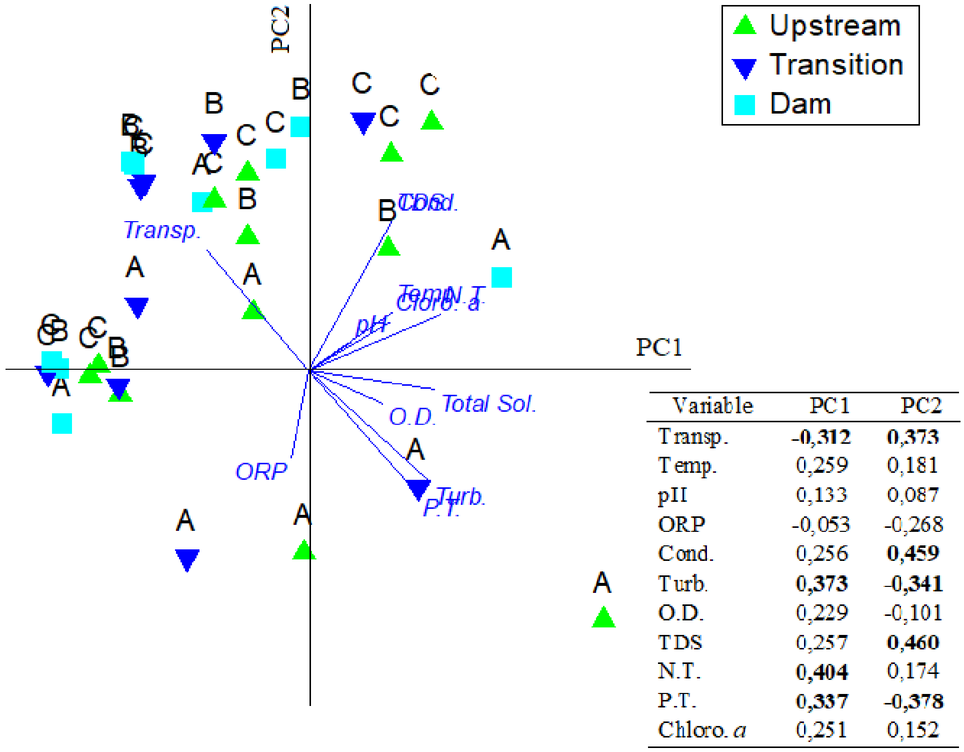


Variable	PC1	PC2
Transp.	**-0,404**	-0,23
Temp.	**0,319**	0,053
pH	-0,093	**0,386**
ORP	0,242	-0,069
Cond.	**-0,424**	0,174
Turb.	**0,395**	0,285
O.D.	-0,012	0,285
TDS	**-0,424**	0,181
Total Sol.	0,125	**0,421**
N.T.	-0,203	**0,418**
P.T.	0,259	0,296
Chloro. *a*	-0,169	**0,354**

Figure 5. Principal components analysis showing the distribution of the sampling sites in the rainy and dry condition, according to the limnological variables.

In order to better understand the intra and inter-reservoirs variation, we performed a PCA based on data from dry periods and a PCA based on data from rainy samplings, separately. **Figure 6** shows the graphical results for the dry campaigns. Data variability of 59.3% was explained, considering the PC1 (30.1%) and PC2 axis (29.2%).

Results revealed the main patterns of spatial distribution that occurred in the reservoir during the study period. Upstream and transition sites of SHP A differ from the other sites along the cascade, clearly separated by negative correlations of the axis 2 (total phosphorus and turbidity). The axis 1 data was positively correlated to total phosphorus, total nitrogen and turbidity, and in the negative side there was a correlation with transparency, which influenced the distribution of most SHP B and SHP C reservoirs sampling sites and one campaign in SHP A dam.

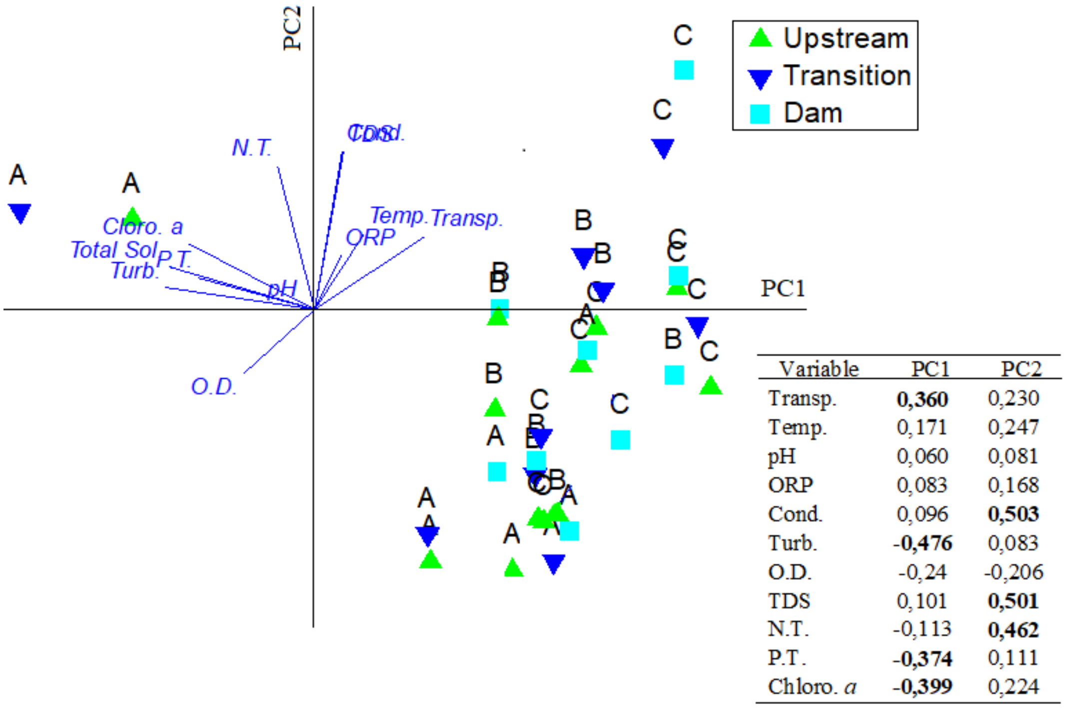


Variable	PC1	PC2
Transp.	**-0,312**	**0,373**
Temp.	0,259	0,181
pH	0,133	0,087
ORP	-0,053	-0,268
Cond.	0,256	**0,459**
Turb.	**0,373**	**-0,341**
O.D.	0,229	-0,101
TDS	0,257	**0,460**
N.T.	**0,404**	0,174
P.T.	**0,337**	**-0,378**
Chloro. *a*	0,251	0,152

Figure 6. Principal component analysis based on dry season samplings. SHPs represented by letters (see text).

Graphical PCA results based on samplings performed during rain periods are shown in **Figure 7**. Analysis explained 62.6% of data variability, considering the PC1 (35.1%) and PC2 axis (27.5%).

Rainy seasons data distribution was more homogeneous. Turbidity and chlorophyll *a* were better correlated with axis 1 (negatively). For axis 2 conductivity and total dissolved solids were positively correlated. SHP A upstream was the most segregated sampling point in the analysis.



Variable	PC1	PC2
Transp.	**0,360**	0,230
Temp.	0,171	0,247
pH	0,060	0,081
ORP	0,083	0,168
Cond.	0,096	**0,503**
Turb.	**-0,476**	0,083
O.D.	-0,24	-0,206
TDS	0,101	**0,501**
N.T.	-0,113	**0,462**
P.T.	**-0,374**	0,111
Chloro. *a*	**-0,399**	0,224

Figure 6. Principal component analysis based on rainy season samplings. SHPs represented by letters (see text).

4. Discussion

The water retention time is key factor in reservoirs ecological structure and functioning, determining temporal and spatial compartmentalization (Hejzlar & Straskraba 1989; Tundisi & Matsumura-Tundisi, 1990; Nogueira et al., 1999 2012). Nevertheless, despite the very short retention time of the SHP studied reservoirs, about 2 days, our results showed a complex spatial organization in those systems cannot be neglected.

Lower transparency (opposite for turbidity) in the upstream regions of the SHP reservoirs is directly associated with the high values of suspended solids transported under lotic conditions. However, despite the short distance from the upstream points to the points directly affected by the dams (reservoir conditions, properly), a clear longitudinal increase in transparency values, was observed. The same, even in lower amplitude of variation, was seen for other variables, such as nutrient and dissolved oxygen.

Concerning the inter-reservoirs observations, compartmentalization in SHP A was more evident. This first dam in the cascade receives, and retain, a higher load of sediments, turning the waters in the SHP B and SHP C reservoirs clearer.

Regarding the water column structure, vertical dimension, homogeneous profiles of temperature were observed at the SHP reservoirs upstream sites, what indicate frequent mixing. At transition and dam sites, near-surface thermal stratification occurs, probably due to daily effects of atmospheric heating. In turn, thermal stratification influences dissolved oxygen distribution.

Electric conductivity values can be directly related to the trophic condition of the environment (Nogueira & Pomari, 2019). In Sapucaí-Mirim River diminution of conductivity was associated to the rainy conditions, what can be explained by the dilution effect. Regarding turbidity values, as expected, had an opposite pattern, with higher values during the rainy samplings due to entrance of allochthonous material. Inter reservoirs effects are also evidenced for this variable, as turbidity decreased from SHP A to SHP B. The same for temperature, and also for chlorophyll during dry period samplings, with higher values in SHP C. Similar results are reported for large hydropower reservoirs in Paranapanema River (Jorcin & Nogueira, 2004).

Hydropower reservoirs downstream effects on river limnology are relatively well reported (Pourriot et al. 1997; Naliato et al 2009; Matsuura et al., 2015; Portinho e al., 2016). However, for a system of small reservoir cascade (SHPs), with low water retention time the understanding is scarce (Anderson et al., 2015).

Low or relatively low values of chlorophyll *a* predominated, but with certain increase in the dry samplings. Increase of chlorophyll during the dry period is common for large rivers and lakes of tropical/subtropical floodplains (Garcia de Emiliani, 1990; Neiff, 1990).

In the rainy period, the similarity between samples sites was higher, as shown by PCA results, because of considerable flow of water and transport of sediment and nutrient loads. The opposite occurs in the dry period when the homogenization process is less effective with a higher differentiation among habitats (Brambilla et al, 2018). Nogueira et al. (2012), studying Salto Grande Reservoir in the Paranapanema River, observed that the entire reservoir functions as a riverine system as result of the short water retention time.

Despite the scarcity of limnological studies in SHP reservoirs, the characteristic small size and low water retention time, the hypothesis of a homogeneous spatial structure could be assumed. Nevertheless, our study demonstrated that SHP reservoir internal compartmentalization do occurs during periods of low rain influence and that some limnological changes can even be transferred along reservoir cascade systems.

5. References

Agostinho, A.A.; Gomes, L.C. & Pelicice, F.M. 2007. Ecologia e manejo de recursos pesqueiros em reservatórios do Brasil. Maringá: Eduem, 501 p.

Anderson, D., Moggridge, H., Warren, P. and Shucksmith, J., 2015. The impacts of ‘run-of-river’ hydropower on the physical and ecological condition of rivers. Water and Environment Journal, vol. 29, no. 2, pp. 268-276. http://dx.doi.org/10.1111/wej.12101.

Armengol. J., Sabater F., Rieira J. L. & Mourgui J. A. 1990. Annual and longitudinal changes in the environmental conditions in three consecutive reservoirs of Guadiana River (W. Spain). Arch. Hydrobiol. Beih. Egebn Limnol. 33, 679–87.

Brambilla, E. M., Ruocco, A. M. C., & Nogueira, M. G. 2018. A contribution for the limnological knowledge of basaltic knickzones. Brazilian Journal of Biology, 78(2), 375-385.

Cemig & Cetec. 2000. Guia ilustrado de peixes da bacia do rio Grande. Companhia Energética de Minas Gerais e Fundação Centro Tecnológico de Minas Gerais, Belo Horizonte, 141 p.

De Filippo, R., Gomes, E. L., Lenz-César, J., Soares, C. B. P., & Menezes, C. F. S. 2007. As alterações na qualidade da água durante o enchimento do reservatório de UHE Serra da Mesa-GO. Ecologia de Reservatórios: Estrutura, função e aspectos sociais. São Paulo, FAPESP, FUNDIBIO, 321-346.

Esteves, F., 2011. Fundamentos de limnologia. 3. ed. Rio de Janeiro: Interciência. 826 p.

Ferrareze, M. F., M. G. Nogueira & L. P. Sartori, 2014. Limnology of a lateral lagoon system connected to a subtropical reservoir (SE, Brazil). Acta Scientiarum Biological Sciences 36: 197-207.

Garcia De Emiliani, M.O., 1990. Phytoplankton ecology of the middle Paraná River. Acta Limnologica Brasiliensia, vol. 3, pp. 391-417.

Golterman H. L., Clymo R. S. & Ohstad M. A. 1978. Methods for Physical & Chemical Analysis of Fresh Waters, 2nd edn. Blackwell Science, Oxford.

Hejzlar J. & Straskraba M. 1989. On the horizontal distribution of limnological variables in Rimov and others stratified Czechoslovak Reservoirs. Arch. Hydrobiol. Beih. Ergebn. Limnol. 33, 41–55.

Henry, R. & Maricatto, F. E. 1996. Sedimentation rates of tripton in Jurumirim reservoir (São Paulo, Brasil). Limnologica, 25: 15-25.

Ibisate, A., A. Ollero & E. Dı ´az, 2011. Influence of catchment processes on fluvial morphology and river habitats. Limnetica 30(2): 169–182.

Malavoi, J. R., 2003. Strategie d'intervention de L'agence de L'Eau sur les seuils en riviere. Agence de L'Eau LoireBretagne.

Malavoi, J. R., 2009. Ouvrages transversaux sur les cours d'eau: impacts hydromorphologiques et e cologiques et principes de restauration globale. 88e me congres de L'Astee. Nice, ONEMA.

Marckereth, F.I.H.; Heron, J. & Talling, J.F. 1978. Water analysis: some revised methods for limnologists. London: Freshwater Biological Association, 120p.

Matsuura, P., G. Perbiche-Neves, R. A. R. Ferreira, & M. G. Nogueira, 2015. Changes in the phytoplankton structure downstream a large reservoir: effects of tributaries on the assemblages attributes. Biologia Section Botany 70: 320–327.

Neiff, J.J., 1990. Aspect of primary productivity in the lower Paraná and Paraguay riverine system. Acta Limnologica Brasiliensia, vol. 3, pp. 77-113.

Nogueira, M. G.; Henry, R. & Maricatto, F. E. 1999. Spatial and temporal heterogeneity in the Jurumirim Reservoir, São Paulo, Brazil. Lakes & Reservoirs: Research and Management, 4: 107-120.

Nogueira, M.G.; Jorcin, A.; Vianna, N.C.; Britto, Y.C. 2006. Reservatórios em cascata e os efeitos na limnologia e organização das comunidades bióticas (fitoplâncton, zooplâncton e zoobentos): Um estudo de caso no rio Paranapanema (SP/PR). In:

Nogueira, M.G.; Henry, R. & Jorcin, A. (eds.). Ecologia de reservatórios: Impactos potenciais, ações de manejo e sistemas em cascata (2ª ed.). São Carlos: Rima, pp. 435-459.

Nogueira, M.G.; Perbiche-Neves, G.; Naliato, D.A.O. 2012. Limnology of two contrasting hydroelectric reservoirs (Storage and Run-of-River) in southeast Brazil. In: Samadi-Boroujeni, H. (eds) Hydropower-Practice and Application. Croatia: Tech. p.185-200.

Nogueira, M. G., & J. Pomari, 2019. Limnological Patterns in a Large Subtropical Reservoir Cascade. In Gokce, D. (ed.) Limnology (pp. 3–37). IntechOpen, London. p. 3-37.

Oliveira, M.D. & Calheiros, D.F., 2000. Flood pulse influence on phytoplankton communities of the south Pantanal floodplain. Hydrobiologia, vol. 427, no. 1, pp. 101-112.

Paiva, M. M., 1982. Grandes represas do Brasil. Brasília, DF: Editerra, 292 pp.

Portinho, J., G. Perbiche-Neves & M. G. Nogueira, 2016. Zooplankton community and tributary effects in free-flowing section downstream a large tropical reservoir. International Review of Hydrobiology 100: 1–9.

Pourriot R., Rougier C. & Miquelis A. (1997) Origin and development of riverzooplankton: example of the Marne. Hydrobiologia 345, 143–8.

Rollet, A.-J., 2007. Etude et gestion de la dynamique sedimentaire dun tronc¸on fluvial a L’aval dun barrage : Le cas de las basse valle e de L’Ain. Thesis doctoral: 305 pp.

Ruocco, A. M. C., Portinho, J. L., & Nogueira, M. G. 2018. Potential impact of small hydroelectric power plants on river biota: a case study on macroinvertebrates associated to basaltic knickzones. Brazilian Journal of Biology, (AHEAD).

Soares, M. C. S.; Marinho, M. M.; Huszar, V. L. M.; Branco, C. W. C. Azevedo, S. M. F. O. 2008. The effects of water retention time and watershed features on the limnology of two tropical reservoirs in Brazil. Lakes & Reservoirs: Research and Management 13: 257-269.

Straškraba, M.; Tundisi, J. G. & Duncan, A. 1993. State of the art of reservoir limnology and water quality management. In: Straskraba, M.; Tundisi, J. G.; Duncan, A., (eds) Comparative reservoir limnology and water quality management. Dordrecht, Kluwer Academic Publishers. 213-288.

Strickland, J. D. & Parsons, T. R. 1960. A manual of sea water analysis. Bull. Fish. Res. Bel. Can., 125: 1-185.

Therrien J, Bourgeois G. 2000. Fish passage at small hydro sites. Report by Genivar Consulting Group for CANMET Energy Technology Centre: Ottawa.

Thornton W. K. 1990. Perspectives on reservoir limnology. In: Reservoir Limnology: ecological perspectives. (eds K. W. Thornton, B. L. Kimmel & E. F. Payne) pp. 1-13. John Wiley & Sons, New York.

Truffer, B., C. Bratrich, J. Markard, A. Peter and A. Wüest, 2003: Green Hydropower: The contribution of aquatic science research to the promotion of sustainable electricity. – Aquat. Sci. 65: 99–110.

Tundisi J. G. & Matsumura-Tundisi T. 1990. Limnology and eutrophication of Barra Bonita Reservoir, S. Paulo State, Southern, Brazil. Arch. Hydrobiol. Beih. Ergebn. Limnol.

33, 661–76.

Tundisi, J.G. & Straškraba, M. 1999. Theoretical reservoir ecology and its applications. São Carlos: International Institute of Ecology/Brazilian Academy of Sciences. 585p.

Tundisi, J.G. & Matsumura-Tundisi, T. 2003. Integration of research and management in optimizing multiple uses of reservoirs: the experience of South American and Brazilian cases studies. Hydrobiologia, 500: 231-242.

Tzimas, E.; Georgakaki, A.; Peteves, S.D. 2009. Future Fossil Fuel Electricity Generation in Europe: Options and Consequence; Joint Research Center, European Commission: Petten, The Netherlands.

Valderrama, J. G. 1981. The simultaneous analysis of total nitrogen and phosphorus in natural waters. Marine Chemistry, 10: 109-122.

Valero. E. 2012. Characterization of the water quality status on a stretch of river lérez around a small hydroelectric power station. Water, 4, 815-834.

Warner, R. F., 2012. Environmental impacts of hydroelectric power and other anthropogenic developments on the hydromorphology and ecology of the Durance channel and the Etang de Berre, southeast France. Journal of Environmental Management 104: 35–50.

Zarfl, C., A. E. Lumsdon, J. Berlekamp, L. Tydecks & K. Tockner, 2015. A global boom in hydropower dam construction. Aquatic Sciences 77: 161-170.

Ziesler, R. & G. D. Ardizzone. 1979. The inland waters of Latin America. Copescal Technical Paper No. 1. Food and Agriculture Organization of the United Nations (FAO), Roma, 171p.

Capítulo 2.

Zooplankton in a reservoir cascade of small hydropower plants – spatial and temporal structure

Abstract

Cladocera and Copepoda assemblages from a reservoir cascade of three small hydropower plants (SHPs) were analyzed during 2014 e 2015. The reservoirs operate as run-of-river systems, with low water retention time (WRT) (2 days). The zooplankton was sampled in ten sites during dry and rainy seasons (6 sampling campaigns) through vertical hauls from the bottom to the surface with conical mesh net of 68 µm. In the upstream regions, due to the small depth (~ 1.50 m), samples were collected with a graduate bucket. Two hypotheses were postulated and partially confirmed through the data obtained (1) occurrence of an intra-reservoir spatial compartmentalization following the models of large reservoirs, (2) transference of inter-reservoir effects (or cumulative effects). Richness did not differ significantly among seasons, but abundance was clearly higher during dry season. Permanova analysis evidenced difference between upstream (reservoirs tail) and dam points (lacustrine zones) and between the first reservoir in the cascade from the two others downstream located. Therefore, our results demonstrate that effects on SHPs installation on biota should not be neglected, especially in a scenery of intense SHPs construction.

Keywords: Compartmentalization, rain season, dry season, cladocerans, copepods

1. Introduction

According to (Zarfl et al., 2015) approximately 8,600 dams primarily designed for hydropower generation are in operation, due to the increasing demand of an intensive population growth and lack of access to electricity of 1.4 million people. Projects for construction of hydropower plants (HPPs) involve large financial resources and considerable environmental impacts, so the construction of small hydropower plants (SHPs) has been considered as a viable alternative (Therrien et al, 2000).

The construction of reservoirs generally determines a remarkable reorganization process of the aquatic communities (Panarelli et al., 2003, Jorcin et al., 2009; Nogueira et al., 2010; Matsuura et al., 2015). In addition, it is not uncommon the construction of series of dams – cascade systems, especially in large rivers (Cella-Ribeiro et al. 2017; Nogueira et al., 2006).

Planktonic organisms play an important role in the aquatic food chains, transferring mass and energy from primary producers to higher trophic levels, and reflect directly changes in the limnological and water quality conditions (Odum, 2004; Pinto-Coelho, 1998). In case of river damming changes in the structure and functioning are immediate (Bicudo et al., 2006).

Alterations on biota as consequence of HPPs installation are well known, however the effects of SHPs are scarce (Premalatha et al., 2014).

Our study aims to analyze (1) the spatial distribution of the zooplankton assemblages in three SHP reservoirs located in the Sapucaí-Mirim, Rio Grande basin, Southeast Brazil, (2) the zooplankton structure variation along the internal longitudinal gradient of each SHP reservoirs. We presuppose (1) the occurrence of an intra-reservoir spatial compartmentalization following the models of large reservoirs, (2) and the transference of inter-reservoir effects (or cumulative effects).

2. Materials and Methods

Study area and sampling sites

The study was performed in a cascade of three SHPs reservoirs constructed in the Sapucaí-Mirim River, North of São Paulo State. The most upstream SHP is named Palmeiras, the intermediate Anhanguera and the most downstream located is Retiro, which in this paper are denominated SHP A, SHP B and SHP C, respectively. We selected ten sampling sites for samplings (**Figure 1** and **Table 1**).

Table 1. Sampling sites denomination and geographic position and the main features of the studied SHP reservoirs.

Sites	Small Hydropower System	Geographical Coordinates	Reservoir Area (Km^2)	Maximum Length (Km)	Power Generation (MW)	Mean Depth(m)
1	A (Upstream)	20°34'20.6" S 47°46'58.4"O	2,6	7,5	16,5-	1,5
2	A (Transition)	20°34'06.4"S 47°47'43.9"O				4,0
3	A (Dam)	20°34'06.4"S 47°47'43.9"O				9,0
4	B (Upstream)	20°31'09.9" S 47°50'07.9" O	1,8	5,0	22,7	1,5
5	B (Transition)	20°30'37.1" S 47°51'23,3" O				6,0
6	B (Dam)	20°29'41,5" S 47°51'43" O		-		13
7	C (Upstream)	20°29'14.2" S 47°51'24.6" O	2,8	11,0	16,0	1,0
8	C (Upstream)	20°28'06.8" S 47°52'07.8" O				3,0
9	C (Transition)	20°26'54.8" S 47°52'44.3" O				7,0
10	C (Dam)	20°26'12.1" S 47°53'08.2" O				12

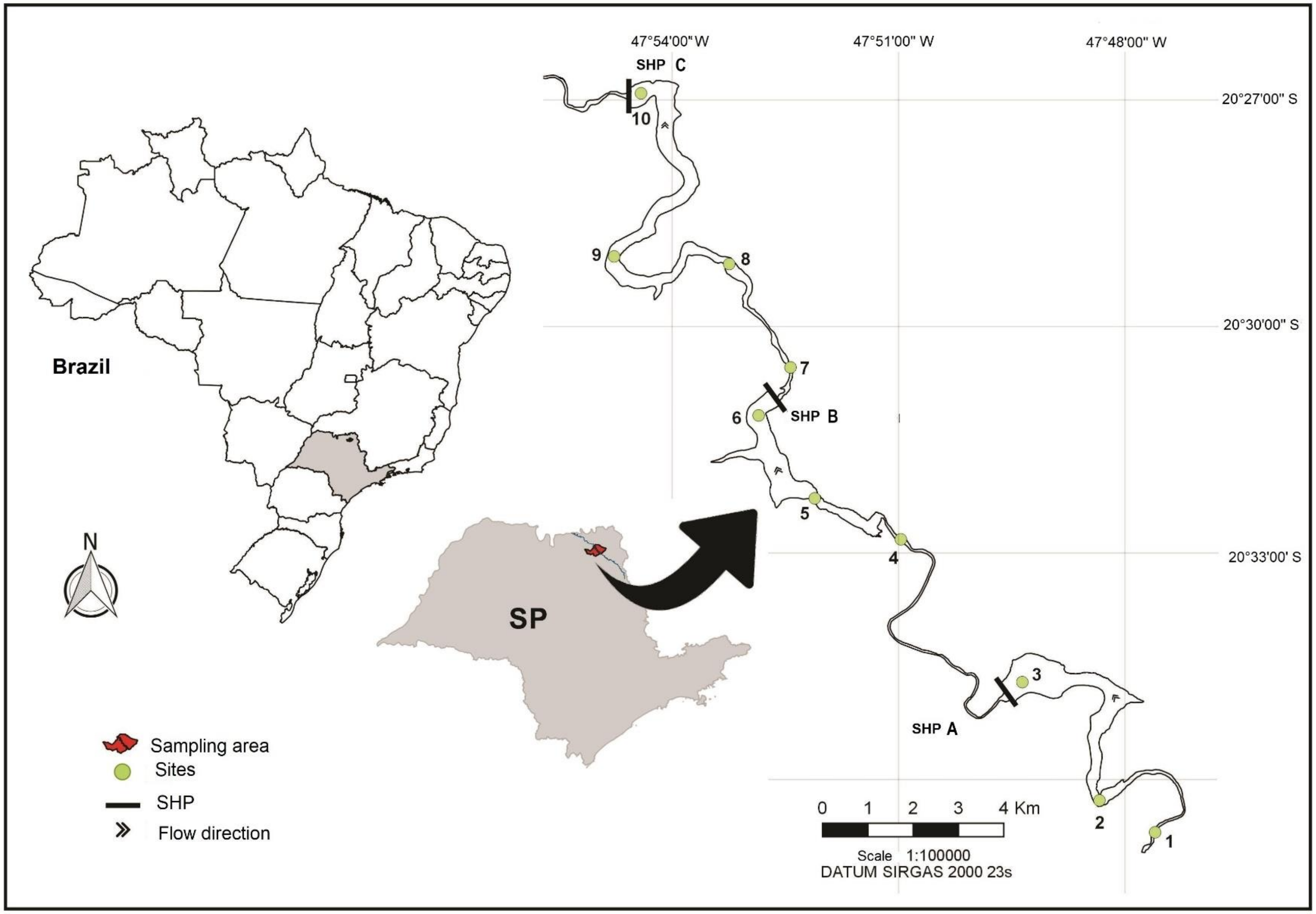


Figure 1. Geographic location of Sapucaí-Mirim River basin and the distribution of the sampling points.

Sampling and laboratory procedures

Samplings were taken in rain and dry periods: June (dry) and December (rainy) of 2014, except in SHP B, and in March (rainy), June (dry) September (dry) and December (rainy) of 2015.

The zooplankton was sampled in replicates in 2014 and in triplicate in 2015 through vertical hauls from bottom to the surface with a conical mesh net of 68 μm. In the upstream regions, organisms were collected with a graduate bucket, due to the small depth (~ 1.50 m), filtering a known volume of water between 150 and 200 L. Samples were fixed (8% formaldehyde) and used for qualitative (taxonomic composition) and quantitative (density) analyzes.

Larval stages of Copepoda were counted in Sedgwick–Rafter chambers, in optic microscope (at a magnification of × 100), copepodites and adult stages of Copepoda and Cladocera were counted using a stereo microscope (maximum magnification of × 120). At least 100 specimens were counted per sample.

The organisms were identified to the lowest taxonomic level based on specialized literature (Reid, 1985; Elmoor-Loureiro, 1997; Rocha, 1998; Paggi, 2001; Silva, 2003).

The samples are deposited in the plankton collection of the Departamento de Zoologia (Botucatu), Universidade Estadual Paulista (UNESP).

Data analyses

For descriptive and statistical analyzes, data were grouped in two major groups, Rainy and Dry, according to the sampling date.

Graphical results of abundance (individuals per m^{-3}) and richness, total and relative (Copepoda and Cladocera percentage), as well as Shannon–Wiener (H) diversity and Pielou’s equitability (J) (PAST software, Hammer et al., 2001), are presented.

To evaluate the differences in zooplankton structure considering reservoir compartments (intra reservoir) and the three SHP (inter reservoir) we applied a Non-Metric Multidimensional Scaling (NMDS) derived from Bray-Curtis similarity matrices using (log (x + 1)) transformed density data (Clarke and Warwick, 2001).

A Permutation Multivariate Analysis of Variance (PERMANOVA) (Anderson, 2001) based on the Bray-Curtis similarity matrix, derived from zooplankton abundance data transformed in log (x+1), was used to test for differences in assemblage between compartments (intra reservoir), SHP (inter reservoir) and the interaction between both factors. When the PERMANOVA pseudo-F is significant ($p < 0.05$).

3. Results

A total of 21 taxa of microcrustaceans was identified, as shown in **Table 2**. Cladocera was the richest group, with 14 taxa distributed in 8 genera. For Copepoda it was recorded 7 taxa, distributed in 5 genera.

Table 2. List of taxa found in the SHPs (see text) of Sapucaí-Mirim River.

COPEPODA
Família Cyclopidae
Mesocyclops longisetus (Thiébaud, 1912)
Mycrocyclops sp.
Thermocyclops minutus (Lowndes, 1934)
Thermocyclops decipiens (Kiefer, 1929)
Família Diaptomidae
Argyrodiaptomus furcatus (Sars G.O., 1901)
Notodiaptomus henseni (Dahl, 1894)
Notodiaptomus iheringi (Wright, 1935)
CLADOCERA
Família Bosminidae
Bosmina hagmanni (Stingelin, 1904)
Bosminopsis deitersi (Richard, 1895)
Família Chydoridae
Alona yara (Sinev & Elmoor-Loureiro, 2010)
Alona guttata (G.O. Sars, 1862)
Leydigia striata (Birabén, 1939)
Família Daphniidae

*Ceriodaphnia cornuta cornuta (*G.O. Sars, 1885)
Ceriodaphnia silvestrii (Daday, 1902)
Daphnia gessneri (Herbst, 1967)
Familia Macrothricidae
Macrothrix sioli (Smirnov, 1982)
Macrothrix squamosa (G.O. Sars, 1901)
Família Moinidae
Moina minuta (Hansen, 1899)
Família Sididae
Diaphanosoma birgei (Korinek, 1981)
Diaphanosoma fluviatile (Hansen, 1899)
Diaphanosoma spinulosum (Herbst, 1975)

Zooplankton total abundance (ind. m^{-3}), mean values for dry and rainy samplings, are shown in **Table 3**.

SHP A presented the highest value for richness (site 2, 11 taxa) (**Figure 2**), as well as the highest value of abundance (site 3; 5,866 ind. m^{-3} in dry season [mainly nauplii of calanoida: 2,783 ind. m^{-3} and *Ceriodaphinia silvestre*:1,344 ind. m^{-3}]) (**Table 3**, **Figure 3A** and **B**).

SHP B presented the lowest richness value (site 4, 3 taxa [*Ceriodaphinia silvestrii, Diaphanosoma birgei, Termocyclops minutus*], rainy sesason) (**Figure 2**). Regarding abundance, the maximum occurred in point 5 during dry season, 2,040 ind. m^{-3}, mainly Cladocerans (*Bosmina hagmani, Ceriodaphnia silvestre, Diphanosoma birgei, Diphanosoma fluviatile e Daphnia gessneri*) (**Table 3**, **Figure 3A** and **B**).

Seasonal differences (rainy and dry seasons) were lower for SHP C. The lowest richness occurred at site 7, during the rainy season, with 3 taxa (*Bosminopsis deitersi, Ceriodaphinia cornuta*, copepodito *Calanoida*, *Notodiaptumos henseni*). Maximum abundance was determined at site 9 during rainy season, 2,244 ind. m^{-3}. There was a predominance of Cladocera in dry season and increasing of Copepoda, mainly larval stages, in rainy season (**Figure 3A, B** and **C**).

Table 3. Zooplankton mean abundance (ind. m^{-3}) and standard deviation in SHPs of Sapucaí-Mirim River (see text) in dry and rainy seasons.

		Dry		Rainy	
	Sites	Mean	S. D.	Mean	S. D.
SHP A	1	277,9	84,6	505,2	237,7
	2	820,9	617,7	1105,0	601,1
	3	2997,8	2869,7	626,4	467,5
SHP B	4	832,0	943,3	136,8	14,4
	5	2040,8	2635,4	601,6	665,8
	6	663,7	815,1	185,9	189,1
SHP C	7	931,6	914,8	461,0	254,0
	8	1085,3	1617,7	439,6	298,1
	9	1851,0	1715,6	2244,1	2699,1
	10	1179,2	922,1	1704,6	786,9

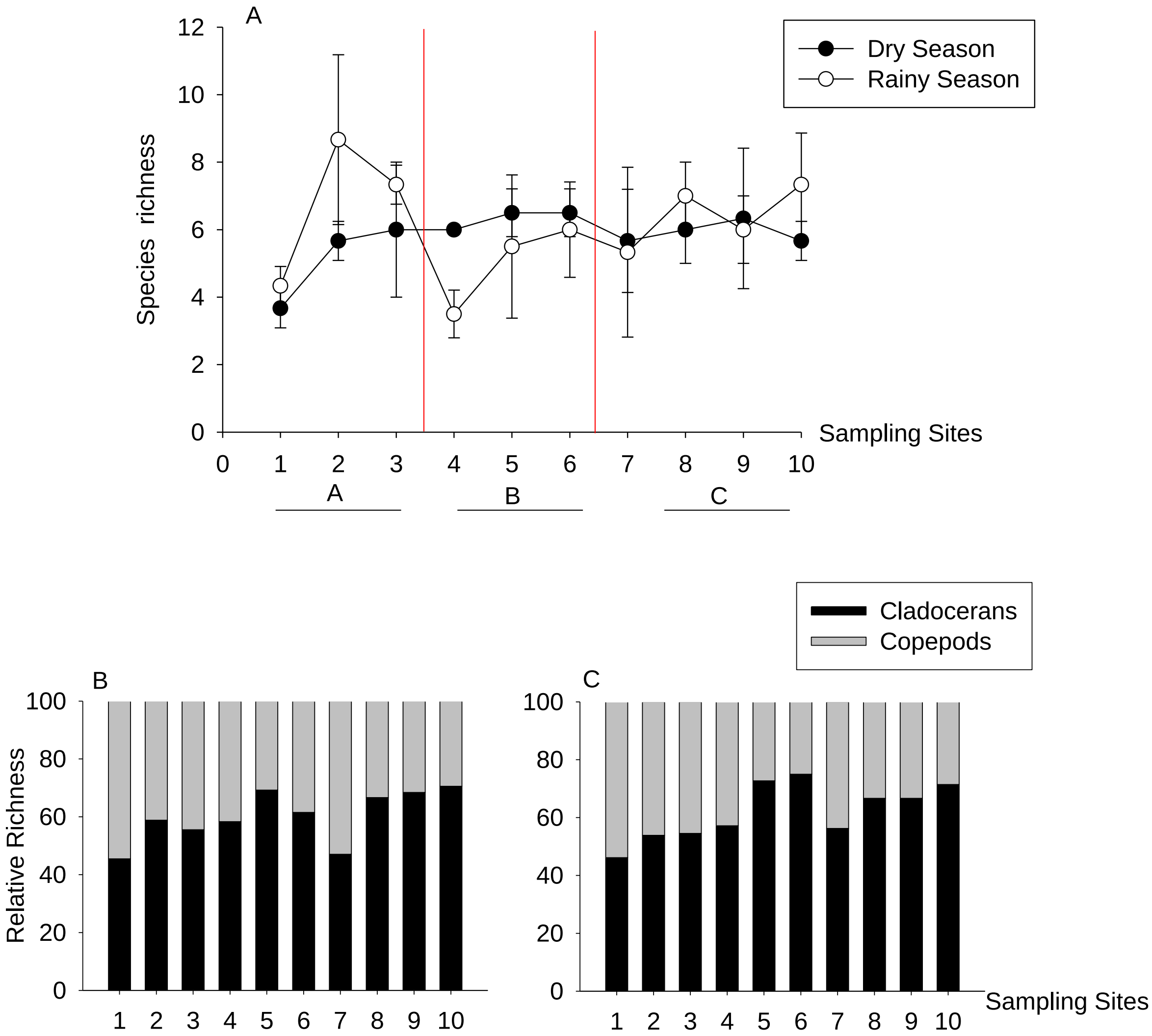


Figure 2. Zooplankton total species richness (A) and relative richness between cladocerans and copepods in the SHPs of Sapucaí-Mirim River (see text) during the Dry (B) e Rainy (C) seasons.

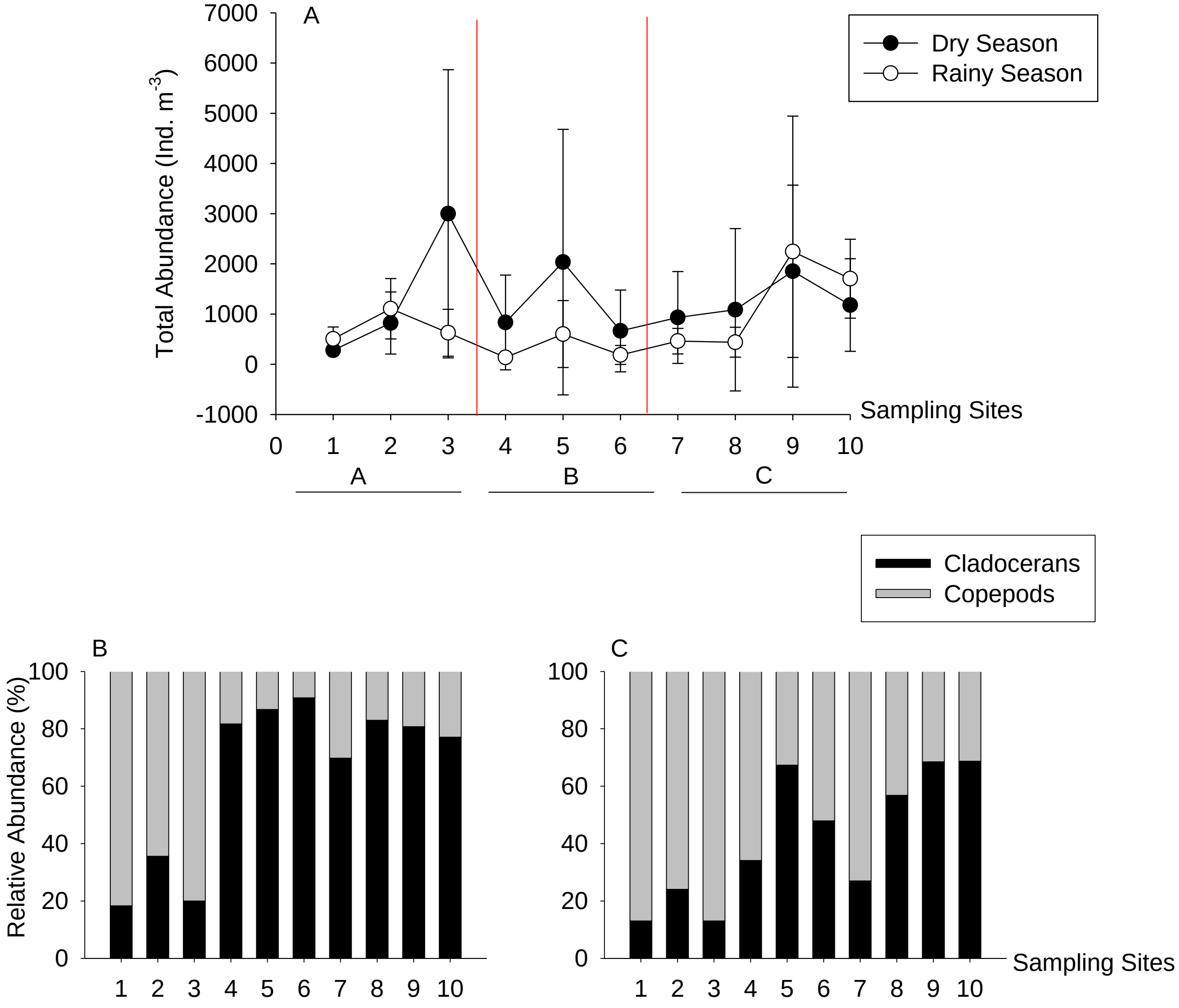


Figure 3. Zooplankton total abundance (A) and relative abundance between cladocerans and copepods in Dry (B) e Rainy (C) in the SHPs of Sapucaí-Mirim River (see text).

The results obtained for the diversity indexes demonstrate the occurrence of lower values for the dry season samplings comparing to the rainy season samplings. The opposite for equitability (**Fig. 4**).

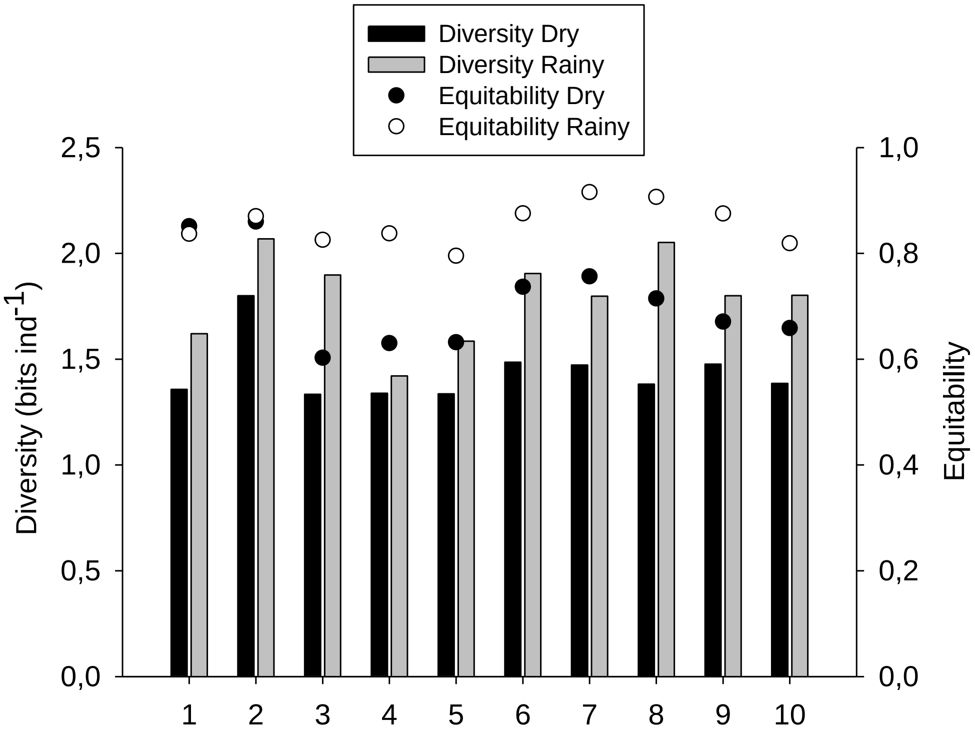


Figure 4. Diversity and equitability indexes (mean value) for the zooplankton taxa in the SHPs of Sapucaí-Mirim River (see text) during the dry and rainy seasons.

The ordination analysis (NMDS) applied to zooplankton abundance data did not indicated a structured pattern of spatial organization (**Figure 5**). However, the PERMANOVA showed differences in the zooplankton structure for the factor compartments (intra reservoirs) (pseudo-F = 1,78, p = 0,032) and SHPs (inter reservoirs) (pseudo-F = 2,46, p = 0,005), but not for interaction between both (pseudo-F =0,78, p = 0,76). In addition, the posteriori test (Pairwise Test) revealed differences between the dam and upstream compartments (p = 0,011) and between SHP A and SHP B (p = 0,011) and between SHP A and SHP C (p = 0,006).

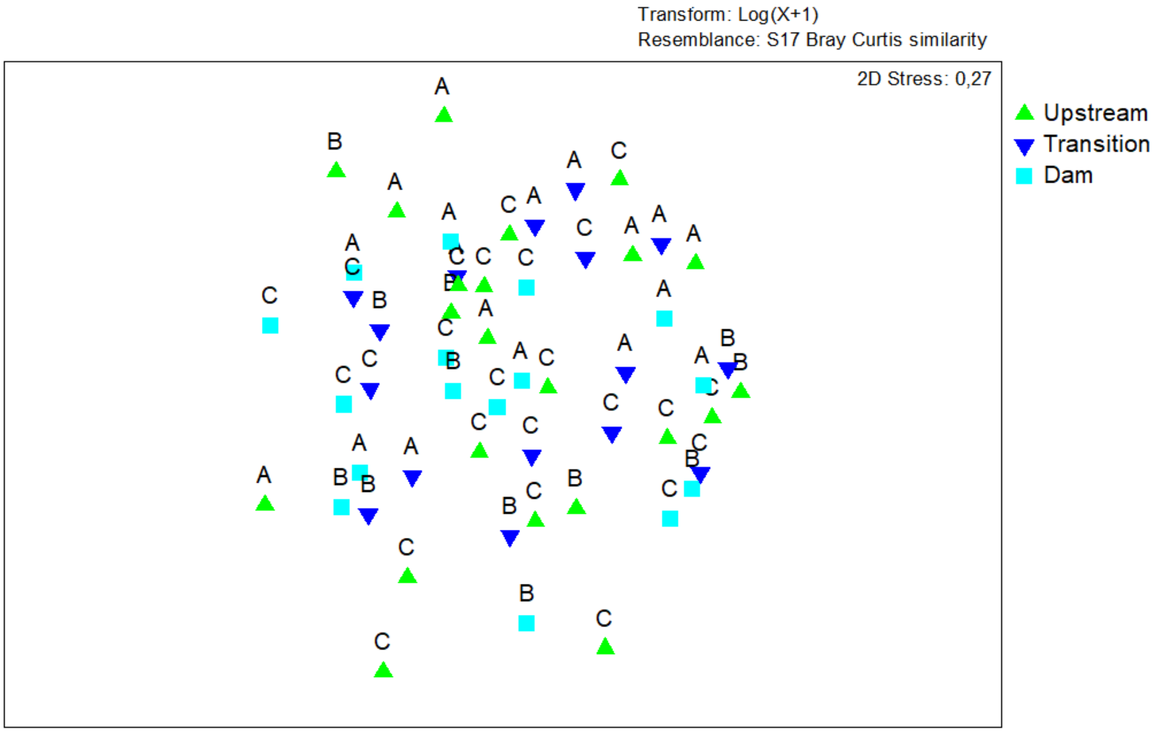


Figure 5. Non-metric multidimensional plots of the zooplankton abundance in the SHPs of Sapucaí-Mirim River (see text).

4. Discussion

The species composition of zooplankton, Cladocera and Copepoda, in Sapucaí-Mirim River is similar the ones found in the Alto Paraná river basin (Nogueira et. al. 2008, Lansac-Tôha, et al. 2009, Brito et al., 2011). The community structure weas influenced by both, temporal (dry and rainy) and spatial factors (intra and inter reservoirs).

Despite of the small size and very low water retention time of the studied SHPs reservoir cascade, contrasting results were seen between lotic and the intermediate/lentic sites, especially for the first reservoir (SHP A).

The typical richness increases along rivers longitudinal gradient (Vannote et al., 1980), regionally corroborated by fish (Carvalho et al., 1998), for instance, was not detected for microcrustaceans in the Sapucaí-Mirim River.

Considering intra-reservoir observations, SHP A shows an increase in the richness, even in a small extension. This trend was even more evident for total abundance from upstream (site 1) and the total for dam (site 3). Another interesting observation is the possible exportation of specimens from SHP A to SHP B upstream (site 4), evidenced through the analysis of relative abundance. The same was observed from SHP B (site 6) to upstream of SHP C (site 7) during the rainy season.

The inter-reservoir variation during the dry season shows that the zooplankton in SHP A is basically represented by Copepoda (mostly nauplii and juvenile stages). However, in the rest of the cascade Cladocera predominates, represented by *Diphanosoma birgei*, *Diphanosoma fluviatile* and *Moina minuta*. During the rainy season, there was an increase in copepod abundance throughout the entire cascade, showing the strong influence of seasonality in the structuring of the community.

These differences in the community structure were evidenced by Permanova analysis, which demonstrates compartmentalization effects (differentiation of upstream points) and a clear the difference of SHP A from the others downstream reservoirs.

In summary, despite not so evident as in larger hydropower reservoirs, the zooplankton in SHP reservoirs exhibits certain spatial structuration. The magnitude of changes when compared the rainy and dry seasons is also remarkable, showing that seasonal changes in middle size rivers may have a even higher relative importance.

5. References

Anderson, M. J. 2001. A new method for non-parametric multivariate analysis of variance. Austral Ecology 26 (1): 32-46.

Bicudo, D. C.; Ferragut, C.; Crossetti, L. O. & Bicudo, C. E. M. 2006. Efeitos do Represamento sobre a Estrutura da Comunidade Fitoplanctônica do Reservatório de Rosana, Baixo Rio Paranapanema, Estado de São Paulo. In: Nogueira, M. G.; Henry, R. & Jorcin, A. (eds.). Ecologia de reservatórios: Impactos potenciais, ações de manejo e sistemas em cascata (2ª ed.). São Carlos: Rima. 349-377p.

Brito, S. L.; Maia-Barbosa, P. M. & Pinto-Coelho, R. M. 2011. Zooplankton as an indicator of trophic conditions in two large reservoirs in Brazil. Lakes & Reservoirs: Research & Management 16 (4): 253-264.

Carvalho, E. D., Silva, V. F.; Fujihara, C. Y.; Henry, R. & Foresti, F..1998. Diversity of fish species in the River Paranapanema-Jurumirim M. (eds.): 1-28. Brazilian Academy of Sciences, International Institute of Ecology and Backhuys Publishers, Leiden.

Cella-Ribeiro A, Gianelli JD, Rodrigues C. 2017. Temporal fish community responses to two cascade run-of-river dams in the Madeira River, Amazon basin. Ecohydrology. 10:e1889.

Clarke, K. and Warwick, R.M., 2001. Change in marine communities: an approach to statistical analysis and interpretation. 2nd ed. Plymouth: PRIMER-E. 172 p.

Elmoor-Loureiro, L. M. A. (1997) Manual de Identificação de Cladóceros Límnicos do Brasil. Universa, Taguatinga. 156p.

Hammer, Ø., Harper, D.A.T. and Ryan, P.D., 2001 [viewed 23 July 2014]. PAST: paleontological statistics software package for education and data analysis. Palaeontologia Electronica [online], vol. 4, no. 1, pp. 4-9. Available from: http://palaeo-electronica. org/2001_1/past/issue1_01.htm

Jorcin, A.; Nogueira, M. G., Belmont, R. 2009. Spatial and temporal distribution of the zoobenthos community during the filling up period of Porto Primavera Reservoir (River Paraná, Brazil). Brazilian Journal of Biology 69 (1): 631 – 637

Lansac-Tôha, F. A., Bonecker, C. C., Velho, L. F. M., Simões, N. R., Dias, J. D., Alves, G. M., & Takahashi, E. M. (2009). Biodiversity of zooplankton communities in the Upper Paraná River floodplain: interannual variation from long-term studies. Brazilian Journal of Biology, 69(2): 539-549.

Legendre, P. & Legendre, L. 2012. Numerical Ecology. 2ed. Amsterdan, Elsevier. 853p.

Matsumura-Tundisi, T., 1986. Latitudinal distribution of Calanoida copepods in freshwater aquatic systems of Brazil. Revista Brasileira de Biologia 46 (3): 527–553.

Matsuura, P., Perbiche-Neves, G., FERREIRA, Rosa A R, NOGUEIRA, MARCOS G. 2015. Changes in the phytoplankton structure downstream a large reservoir: effects of tributaries on the assemblages attributes. Biologia (Bratislava) 70: p.1 – 8.

Nogueira, M. G.; Jorcin, A.; Vianna, N. C.; Britto, Y. C. 2006. Reservatórios em cascata e os efeitos na limnologia e organização das comunidades bióticas (fitoplâncton, zooplâncton e zoobentos): Um estudo de caso no rio Paranapanema (SP/PR). In: Nogueira, M. G.; Henry, R. & Jorcin, A. (eds.). Ecologia de reservatórios: Impactos potenciais, ações de manejo e sistemas em cascata (2ª ed.). São Carlos: Rima. 435-459.

Nogueira, M. G., P. C. Reis-Oliveira & Y. T. Britto, 2008. Zooplankton assemblages (Copepoda and Cladocera) in a cascade of reservoirs of a large tropical river (SE Brazil). Limnetica 27(1): 151–170.

Nogueira, M. G.; Ferrareze, M.; Moreira, M. L.; Gouvêa, R. M. 2010. Phytoplankton assemblages in a reservoir cascade of a large tropical -subtropical river (SE, Brazil). Brazilian Journal of Biology 70: 781 – 793.

Odum, E.P. 2004. Fundamentos de ecologia. Lisboa: Fundação Calouste Gulbenkian, 927 p.

Pinto-Coelho, R.M. 1998. Effects of eutrophication on seasonal patterns of mesozooplankton in a tropical reservoir: a 4-year study in Pampulha Lake, Brazil. Freshwater Biology 40: 159-173.

Paggi, J.C. 2001. Clarification of the taxonomic status of Notodiaptomus anisitsi (Daday, 1905) and related species, with description of a new species from Argentina (Crustacea: Copepoda: Diaptomidae). Hydrobiologia, 453/454: 549564.

Paiva, M. M., 1982. Grandes represas do Brasil. Brasília, DF: Editerra, 292 p.

Panarelli, E. A.; Casanova, S. M. C.; Nogueira, M. G.; Mitsuka, P. M. & Henry, R. 2003, A comunidade zooplanctônica ao longo de gradientes longitudinais no Rio Paranapanema/ Represa de Jurumirim (São Paulo, Brasil). In: Henry, R. (Ed.). Ecótonos nas interfaces dos ecossistemas aquáticos. RiMa, São Carlos. 129-160.

Premalatha, M., Tabassum-Abbasi., Abbasi, T. and Abbasi, S.A., 2014. A critical view on the eco-friendliness of small hydroelectric installations. The Science of the Total Environment, vol. 481, pp. 638-643. http://dx.doi.org/10.1016/j. scitotenv.2013.11.047. PMid:24332792.

Reid, J.W. 1985. Chave de identificação para as espécies continentais sulamericanas de vida livre da ordem Cyclopoida (Crustacea, Copepoda). Boletim de Zoologia, Universidade de São Paulo, 9: 17-143.

Rocha, C.E.F. 1998. New morphological characters useful for the taxonomy of genus Microcyclops (Copepoda, Cyclopoida). Journal Marine System., 15: 425-431.

Sartori, L. P., M. G. Nogueira, R. Henry & E. M. Moretto, 2009. Zooplankton fluctuations in Jurumirim Reservoir (Sa ˜o Paulo, Brazil): a three-year study. Brazilian Journal of Biology 69(1): 1–18.

Silva, W.M. 2003. Diversidade dos Cyclopoida (Copepoda, Crustacea) de água doce do Estado de São Paulo: taxonomia, ecologia e genética. Tese de doutorado, Universidade Federal de São Carlos, São Carlos, 170p.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell & C. E. Cushing. 1980. The river continuum concept. Can. J. fish. Aquat. Sci. 37: 130-137.

Therrien J, Bourgeois G. 2000. Fish passage at small hydro sites. Report by Genivar Consulting Group for CANMET Energy Technology Centre: Ottawa.

Zarfl, C., Lumsdon, A.E., Berlekamp, J., Tydecks, L. and Tockner, K., 2015. A global boom in hydropower dam construction. Aquatic Sciences, vol. 77, no. 1, pp. 161-170. http:// dx.doi.org/10.1007/s00027-014-0377-0.