UNIVERSIDADE ESTADUAL PAULISTA – UNESP
INSTITUTO DE BIOCIÊNCIAS DE BOTUCATU
Programa de Pós-Graduação em Ciências Biológicas: Zoologia

Avaliação do uso de índices de qualidade de água e bioindicadores – zooplâncton e fitoplâncton, em um programa de monitoramento dos Reservatórios em Cascata no rio Paranapanema (SP/PR – Brasil)

Juliana Pomari

Orientador: Prof. Dr. Marcos Gomes Nogueira

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Tese apresentada ao Instituto de Biociências da Universidade Estadual Paulista "Júlio de Mesquita Filho" – UNESP, Campus de Botucatu, como parte dos requisitos para obtenção do Título de Doutor em Ciências Biológicas - Zoologia.

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Palavras-chave: Reservatórios em cascata; Zooplâncton; Índice de estado trófico (IET); Índice de integridade biótica (IBI); Índice de qualidade de água (IQA).

"Imagination is more important than science, because science is limited, while imagination encompasses the whole world."

Albert Einstein

"The whole history of Science has been the gradual realization that events do not happen in an arbitrary way, but reflect a basic order, which may or may not be divinely inspired."

Stephen Hawking

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Presentation

The construction of dams modifies rivers into a complex of ecological systems. These new environments are exposed to multiple uses and integrated to a complex generation system which can, while providing a relatively clean and renewable energy source, cause major socio-environmental changes and interfere with the ecological structure and functioning of river basins (Tundisi et al., 1993; Tundisi and Matsumura-Tundisi, 2003; Nogueira et al., 2006; Agostinho et al., 2007; Nogueira et al, 2012).

The Paranapanema River is one of the main tributaries of the Paraná River (La Plata basin), located between the coordinates 22° - 26° S and 47° - 54° W, on the tropical/subtropical boundary (Southeast/South Brazil). The river is under Federal jurisdiction because is the natural border between the States of Paraná and São Paulo, with a length of 929 km. The river is known for its "good water quality" and for presenting eleven hydropower plants, which have been constructed along the main course of the river.

In 2011, a systematic Physical, Chemical and Biotic (Phytoplankton and Thermotolerant coliforms)[1] Monitoring Program started in eight cascade reservoirs of the Paranapanema River reservoir cascade system (Jurumirim, Chavantes, Salto Grande, Canoas II, Canoas I, Capivara, Taquaruçu and Rosana). This initiative resulted from a partnership between the company in charge of the hydropower generation and researchers of the São Paulo State University (UNESP), Campus of Botucatu. At that time, I participated in this program as a research trainee supported by a scholarship from FUNDIBIO (Fundação do Instituto de Biociências – UNESP Botucatu).

Aiming to deep explore the monitoring results and use the academic knowledge on the complexity of these ecosystems in order to improve the technical protocols of the Monitoring Program, in 2013 we proposed the development of this PhD Thesis entitled:

"Evaluation to the use of water quality indexes and bioindicators - zooplankton and phytoplankton, in a monitoring program of Paranapanema River Reservoirs Cascata (SP / PR - Brazil)" ("Avaliação do uso de índices de qualidade de água e

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[1] Zooplankton was additionally sampled - it was not part of the monitoring protocols.

bioindicadores – zooplâncton e fitoplâncton, em um programa de monitoramento dos Reservatórios em Cascata no rio Paranapanema (SP/PR – Brasil)" (in Portuguese).

The Thesis was partitioned into four distinct, but complementary, Chapters. Since the themes are reasonably connected, some repetitions are inevitable.

The title of Chapter 1 is **"Identifying limnological patterns in a large subtropical reservoir cascade – Paranapanema River, Brazil"**. The objective is to discriminate the main limnological tendencies and recurrent patters along the Paranapanema River cascade. Analyses based on the reservoirs morphometric characteristics, operation type, water retention type, physical, chemical and biological variables and trophic status. In this chapter were considered eight reservoirs, Jurumirim (JR), Chavantes (CH), Salto Grande (SG), Canoas II (CII), Canoas I (CI), Capivara (CP), Taquaruçu (TQ) e Rosana (RS), arranged in a cascade system with a total of 37 sampling sites and two sampling seasons (wet and dry). We analyze water transparency, depth, temperature, pH, condutivity, dissolved oxygen, biochemical oxygen demand, total solids, suspended solids, total nitrogen, total phosphorus, chlorophyll *a* and thermotolerant coliforms as limnológicas variables and also some ecologically important morphometric characteristics.

The Chapter 2 is entitled **"Application of multiple-uses indices to assess water quality emphasizing the zooplankton community and focus on biomonitoring and management purposes".** Here we indeed to apply and compare the results of different types of water quality indices for multipurpose uses, such as water supply, trophy levels evaluation and protection of aquatic communities. The selected indexes were Water Quality Index (WQI), Trophic State Index (Carlson, 1977 and some derived modified models), Phytoplankton Community Index (FCI), Zooplankton Community Index (ZCI) and the Planktonic Index of Biotic Integrity (P-IBI) - a new tool that has been recently developed. The objective is to generated new insights on this theme in order to improve the present water quality monitoring program at a regional scale - a relatively large watershed from Southeast Brazil.

The Chapter 3 is entitled **"Zooplankton community composition and structure as potential indicators of water quality and trophic state conditions in the Paranapanema River reservoir cascade".** The main goal of this study is to explore information on the structure of the zooplankton sampled in the Paranapanema River reservoir cascade (eight reservoirs), focusing on the potential of this community to evaluate changes in water quality and trophic level - biomonitoring purposes. Information on the structure and functioning of planktonic communities in reservoir ecosystems provide opportunities to investigate patterns of responses to cyclical variations and episodic disturbances and can be useful to evaluate the resilience in this kind of system to limnological changes in relatively short periods.

Finally, the Chapter 4 is entitled **"A new tool to assess ecosystem health in large subtropical reservoirs: development and validation of a Planktonic Index of Biotic Integrity (P-IBI)".** We developed and validated a Planktonic Index of Biotic Integrity (P-IBI) following Kane et al. (2009) with the purpose of effectively assess the ecosystem health of subtropical reservoirs. The study is based on a reservoir cascade system located in Southern Brazil and includes metrics of the plankton community – phyto and zooplankton. In contrast to traditional water quality approaches, the P-IBI is an aggregative indicator that can not only capture aquatic trophic status but also identify variations in the aquatic ecosystems associated to the biota. The development and application of a viable Planktonic Index of Biotic Integrity (P-IBI) for subtropical reservoirs can be useful for management purposes – stakeholder's decision processes, improvement of monitoring protocols, and expansion of scientific knowledge.

We hope this thesis can bring new insights to the research line on Ecology of Reservoirs and that some ideas and obtained results may support better management resolutions too.

Summary

Chapter 1 - Identifying limnological patterns in a large subtropical reservoir cascade – Paranapanema River, Brazil

Identifying limnological patterns in a large subtropical reservoir cascade – Paranapanema River, Brazil

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Abstract

The present study aims to identify limnological patterns in the Paranapanema River cascade as a system based on the morphometric characteristics, operation type, water retention time, physical, chemical and biological variables and trophic status on behalf of management purposes. The Paranapanema River is one of the main tributaries of the high Paraná River (La Plata basin) and is the natural border between the States of Paraná and São Paulo, Southern Brazil. The study was carried out in eight reservoirs, Jurumirim (JR), Chavantes (CH), Salto Grande (SG), Canoas II (CII), Canoas I (CI), Capivara (CP), Taquaruçu (TQ) e Rosana (RS), arranged in a cascade system. A total of 37 sites were sampled in two seasons (dry and wet). We analyzed the following limnological and water quality variables: water transparency, depth, temperature, pH, conductivity, dissolved oxygen, biochemical oxygen demand, total solids, suspended solids, total nitrogen, total phosphorus, chlorophyll *a* and thermotolerant coliforms. Additionally, it was calculated the trophic state index for tropical/subtropical reservoirs, the water retention time and some important morphometric characteristics of each reservoir. Data analyzes focused on spatial (longitudinal and vertical dimensions) and seasonal (late summer-wet and late spring-dry periods) variation. The reservoir operational design (storage or run-of-river) is a major factor influencing on limnological structure and functioning. It was concluded that the influence of the land use intensification in the Paranapanema River middle stretches is also determinant and comparable to the influence of the river damming.

Resumo

O presente estudo tem como objetivo identificar padrões limnológicos na cascata de reservatórios do rio Paranapanema como um sistema, baseado nas características morfométricas, tipo de operação, tempo de retenção de água, variáveis físicas, químicas e biológicas, além do estado trófico, para fins de manejo. O rio Paranapanema é um dos principais afluentes do Alto Rio Paraná (Bacia do Prata) e é a fronteira natural entre os Estados do Paraná e São Paulo, no sul do Brasil. O estudo foi realizado em oito reservatórios, Jurumirim (JR), Chavantes (CH), Salto Grande (SG), Canoas II (CII), Canoas I (CI), Capivara (CP), Taquaruçu (TQ) e Rosana (RS), dispostos em cascata. Foram amostrados um total de 37 estações em dois períodos (seca e chuva). As seguintes variáveis limnológicas e de qualidade da água foram analisadas: transparência da água, profundidade, temperatura, pH, condutividade, oxigênio dissolvido, demanda bioquímica de oxigênio, sólidos totais, sólidos suspensos, nitrogênio total, fósforo total, clorofila a e coliformes termotolerantes. Além disso, foi calculado o índice de estado trófico para reservatórios tropicais/subtropicais, o tempo de retenção de água e algumas características morfométricas importantes de cada reservatório. As análises dos dados focaram variações espaciais (dimensões longitudinal e vertical) e sazonais (verão tardio - úmido e final da primavera). O tipo de operação do reservatório (acumulação ou fio d´água) é um fator importante que influencia a estrutura limnológica e o funcionamento dos mesmos. Podemos concluir que a influência da intensificação do uso da terra nos trechos médios do rio Paranapanema é determinante e comparável à influência do represamento do rio.

Key words: Limnological patterns, reservoir cascade system, trophic state, spatial variability, temporal variability.

Introduction

In Brazil, a major modification produced on rivers is the construction of dams, which substantially alter the flow condition, the storage capacity and all chemical and biological process associated to these important physical characteristics. For the South American continent, there is an estimative of about 1,000 installed reservoirs (Agostinho et al., 2007).

Most large reservoirs in the country are primarily projected for production of electricity. Brazil's water potential is one of the largest in the world, where hydropower plants have produced about 90% of the energy consumed in recent years (ca. 70,000MW). Presently there are at least 190 large hydropower plants (individual production higher than 30 MW) and 420 small ones (individual production lower than 30 MW) (www.aneeel.gov.br). Additionally, a number of 1,000 different sites have been inventoried for new projects (potential 107,000 MW) (Kelman et al., 2006).

For the first decades of this new century, it is expected the construction of the 3,700 dams worldwide, what could increase the global hydropower production by 73 %. This would correspond to intensification in the exploitation of the technically feasible hydropower potential from 22 % to 39% (International Commission on Large Dams, 2011). However, the role of hydropower in total global electricity production will rise only slightly from 16 % in 2011 to 18 % until 2040 because of the concurrent increase in global energy demand (Zarfl et al., 2015).

Hydroelectric dams are an integrated and complex generation system that provide a relatively clean and renewable energy type. However, they can cause major socio-environmental changes and interfere with the ecological structure and functioning of river basins (Tundisi et al., 1993; Tundisi and Matsumura-Tundisi, 2003; Nogueira et al., 2006; Agostinho et al., 2007).

The construction of dams in the rivers transforms lotic stretches into lentic or semi-lentic systems, promoting significant attenuations in current velocity and increase in depth. The reservoirs, especially those of large size, are generally systems of great spatial and temporal complexity (Thornton, 1990; Straskraba et al., 1993; Tundisi et al., 1993; Nogueira et al., 1999).

In terms of the operational design and engineering concept, reservoirs can be classified as accumulation (storage) or run-of-river systems (Kelman et al., 1999). The accumulation systems are larger in size and volume, with high water retention time. The distinctiveness between accumulation and run-of-river systems, in terms of physical dimensions and functioning, affects the physical and chemical limnology of these environments as well as the aquatic communities organization (Nogueira et al., 2008; Perbiche-Neves and Nogueira, 2010; Tundisi and Matsumura-Tundisi, 2003; Nogueira et al. 2012; Perbiche-Neves and Nogueira, 2013).

The accumulated limnological knowledge on reservoirs limnology promoted a growing understanding of these environments as an exclusive class of lakes (e.g. Tundisi, 1988, Thornton, 1990; Straškraba, et al., 1993; Henry, 1999, Tundisi and Straškraba, 1999). Despite of the structural and functional similarity between lakes and large reservoirs some particularities have been pointed out. For instance, Lind et al. (1993) discussed the differences between lakes and reservoirs related to the application of trophic state indexes. According to the authors, one of the main factor that affect the application of these indices is the conspicuous spatial heterogeneity that occurs in reservoirs.

Classical studies on reservoirs, including Thornton (1990) and Wetzel (2001), distinguish three areas in a reservoir: the region with strong influence of the incoming river - lotic region; an intermediate - transition region and finally a region considered similar to a lake, located near the dam. However, it is now known that in large tropical reservoirs, this zonation is multidimensional, greatly influenced by the input of secondary tributaries and also by the differential residence time of each reservoir arm (Nogueira et al., 1999, Nogueira, 2000; 2001; Pinto-Coelho et al., 2006). These distinctive areas in reservoir ecosystem may also change seasonally, in a complex dynamics (Thornton et al., 1990; Henry and Maricatto, 1996; Nogueira et al., 1999; Pagioro and Thomaz, 2002).

The large-scale variability of reservoirs along the main axis is determined by longitudinal gradients of flow velocity, depth, width, particle sedimentation, transparency and light penetration, and thermal stratification (Armengol et al. 1999; Henry and Maricatto, 1996; Paggioro and Thomaz, 2002). In comparison with lakes, reservoirs exhibit high watersheds area/water body area, shorter but varying retentions times, a rapid ageing process related to watershed uses, high capability to retain organic and inorganic matter (Straskraba, 1998; Straskraba and Tundisi, 1999).

The limnological conditions and the water quality of the rivers, lakes and reservoirs are greatly influenced by the drainage network, due to the biogeophysical characteristics of the basin, land uses and the state of conservation of the ecosystems. Thus, differences in the concentration of total dissolved solids or particulates in water, for example, reflect variations of geological nature, soil use and occupation, and precipitation/evaporation rate. The characteristics of riparian vegetation along watercourses, in turn, may be responsible for differences in water temperature and in the quantity and size distribution of the organic particles transported (Rice et al., 2001; Jorcin and Nogueira, 2005).

However, there are still many gaps in the understanding of these ecosystems. In case of cascaded reservoirs, efforts have been undertaken to determine how their operation affects the ecological structure and organization of rivers or how cumulative effects spread throughout the system (Barbosa et al., 1999; Matsumura-Tundisi and Tundisi, 2003; Nogueira et al., 2006; 2008; Jorcin and Nogueira, 2008; Naliato et al., 2009; Nogueira et al., 2012; Perbiche-Neves and Nogueira, 2013). In Brazil, new cascades of reservoirs have been built or planned, including rivers under international jurisdiction, such as Paraná and Uruguay.

An integrated approach, including measurements and experimentation, is required for the understanding of the problems and working mechanisms of reservoir ecosystems, giving their inherent complexity, with many components and subsystems that interact intensively in space and time (Tundisi, 2008).

The Paranapanema River is one of the main tributaries of the Paraná River (La Plata basin), located between the coordinates 22° - 26° S and 47° - 54° W, on the tropical/subtropical boundary (Southeast/South Brazil). The river, with a length of 929 km, is under Federal jurisdiction, because it is the natural border between the states of Paraná and São Paulo. According to the CEEIPEMA (Executive Committee for Integrated Studies of the Paranapanema River Basin) in 1980 the Paranapanema River was classified as Class 1 (CONAMA Resolution 357/2005) from the headwaters to the confluence of the Turvo River and as Class 2 from the confluence of the Turvo River to its mouth on the Paraná River. These classifications intended "to preserve the natural balance of aquatic communities".

Aiming to provide technical-scientific information on behalf of management purposes, the present study intended to identify limnological tendencies or patterns of variation in the Paranapanema River reservoir cascade. We considered the morphometric characteristics, operation type, water retention time, physical, chemical and biological variables and the trophic status. We hypothesized that: 1) the Paranapanema River reservoir cascaded is highly influenced by the intensification of the agriculture land use towards the middle basin; 2) The reservoir operation is determinant in establishing reservoirs limnological patterns.

Study area

The Paranapanema River is the natural border between the states of Paraná and São Paulo, with a length of 929 km. Since the 1950's, eleven hydropower plants were constructed in the main course of the river. Ongoing studies have being carried out in eight of the reservoirs by researchers of the São Paulo State University, Campus of Botucatu, as part of a Limnological and Water Quality monitoring program of the Paranapanema River reservoir cascade. Three of the reservoirs, Jurumirim, Chavantes and Capivara are storage systems (i.e. with high water retention times), whereas the others, Salto Grande, Canoas II, Canoas I, Taquaruçu and Rosana are run-of-the-river systems.

The selected reservoirs for study purposes are Jurumirim (JR), Chavantes (CH), Salto Grande (SG), Canoas II (CII), Canoas I (CI), Capivara (CP), Taquaruçu (TQ) and Rosana (RS), arranged in a cascade (upstream → downstream) system. Information were obtained at 37 sampling sites (Fig. 1), whose distribution intended to cover the longitudinal gradient between the lotic (Paranapanema River entrance) and lentic (dam) areas of each reservoir, as well as the entrance of important secondary tributaries. At least three up to six sites in each reservoir were selected. Table 1 presents the geographic coordinates as well as the altitude data of the sampling sites, obtained with a Garmin Etrex Vista H GPS.

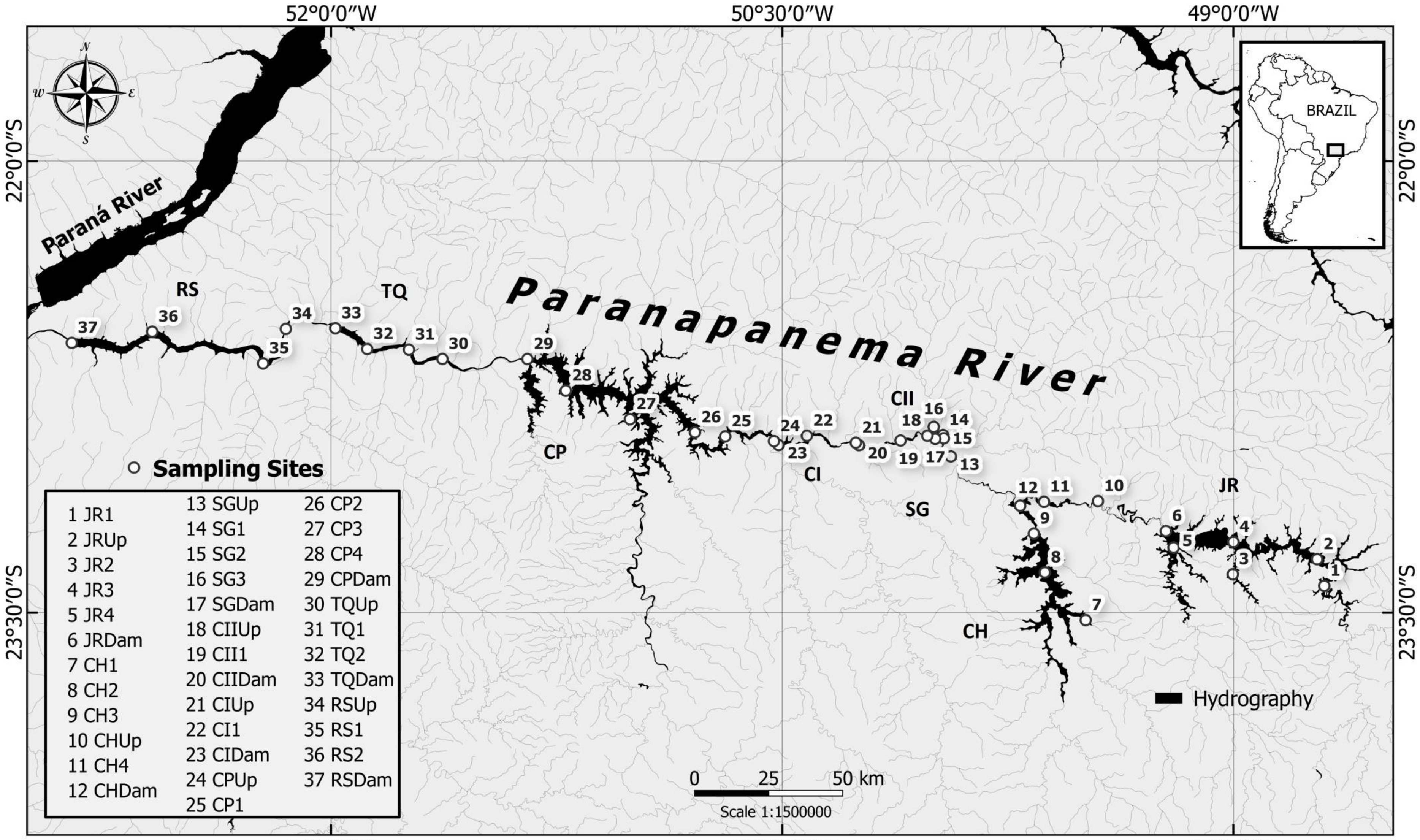

Figure 1 – Geographic location of Paranapanema River reservoirs cascade and the selected sampling sites.

Table 1 - Geographic coordinate and elevation of the sampling sites along the reservoir cascade.

Reservoir	**Sampling sites**	**Coordinates**		**Altitude (m) (a.s.l.)**
Jurumirim	JR1	23°24'39.40"S	48°41'53.80"O	565
	JRUp	23°19'21.90"S	48°43'19.00"O	568
	JR2	23°22'20.80"S	49° 0'7.80"O	567
	JR3	23°15'55.40"S	49° 0'1.10"O	560
	JR4	23°17'1.90"S	49°11'56.80"O	570
	JRDam	23°13'44.80"S	49°13'29.20"O	563
Chavantes	CH1	23°31'29.50"S	49°29'29.30"O	469
	CH2	23°21'58.90"S	49°37'37.90"O	471
	CH3	23°14'15.00"S	49°39'48.60"O	467
	CHUp	23° 7'46.20"S	49°27'2.30"O	468
	CH4	23° 7'55.10"S	49°37'47.30"O	477
	CHDam	23° 8'41.70"S	49°42'32.40"O	473
Salto Grande	SGUp	22°58'52.60"S	49°56'22.10"O	383
	SG1	22°54'43.60"S	49°57'57.20"O	383
	SG2	22°54'49.60"S	49°58'0.30"O	389
	SG3	22°53'3.20"S	49°59'40.40"O	385
	SGDam	22°53'56.00"S	49°59'27.00"O	389
Canoas II	CIIUp	22°55'5.50"S	49°59'31.50"O	368
	CII1	22°55'42.50"S	50° 6'24.00"O	364
	CIIDam	22°56'36.80"S	50°14'42.80"O	367
Canoas I	CIUp	22°56'8.60"S	50°15'19.70"O	348
	CI1	22°54'44.40"S	50°25'5.40"O	348
	CIDam	22°56'35.90"S	50°30'43.10"O	354
Capivara	CPUp	22°55'49.30"S	50°31'38.90"O	329
	CP1	22°54'52.60"S	50°41'22.10"O	326
	CP2	22°54'4.50"S	50°47'24.50"O	322
	CP3	22°51'26.80"S	51° 0'22.00"O	335
	CP4	22°45'45.80"S	51°13'10.40"O	332
	CPDam	22°39'27.90"S	51°20'49.80"O	325
Taquaruçu	TQUp	22°39'27.00"S	51°37'46.00"O	277
	TQ1	22°37'36.20"S	51°44'27.00"O	273
	TQ2	22°37'28.00"S	51°52'46.60"O	273
	TQDam	22°33'19.80"S	51°59'7.90"O	271
Rosana	RSUp	22°33'27.50"S	52° 8'59.90"O	260
	RS1	22°40'20.30"S	52°13'32.80"O	268
	RS2	22°34'1.10"S	52°35'38.60"O	251
	RSDam	22°36'14.30"S	52°51'42.10"O	241

Material and methods

Sampling campaigns for physical, chemical and biological measurements were carried out in the eight reservoirs JR, CH, SG, CII, CI, CP, TQ and RS (Fig. 1) in two periods of the year March (late summer-wet season) and October (late spring-dry season) of 2011.

The limnological variables measured *in situ* and respective methodologies are shown in Table 2.

Table 2 - Limnological variables measured *in situ*.

Parameters	**Methodology**
Water transparency	Secchi disk depth
Air temperature	Mercury thermometer
Water temperature	Eureka multi-parameter probe - vertical profile
Dissolved oxygen	Eureka multi-parameter probe - vertical profile
pH	Eureka multi-parameter probe - vertical profile
Conductivity	Eureka multi-parameter probe - vertical profile

Water samples were collected with a Van Dorn bottle in three depths corresponding to the surface, middle and bottom (about 0,5 to 1,0 m above sediments) of the water column for nutrient analysis (total nitrogen and phosphorus), total solids, suspended solids, turbidity, chlorophyll *a*, biochemical oxygen and thermo tolerant coliforms. For this last variable 100 mL of sample was collected with sterilized gloves to avoid contamination and formerly wrapped in a sterile plastic envelope.

Samples for total nitrogen and total phosphorus were previously digested (Valderrama, 1981) and then determined spectrophotometrically (Strickland and Parsons, 1960). Turbidity was measured in a turbidimeter Tecnopon MS and total solids were analyzed according to the amount of remaining residues in a beaker after total evaporation of a sample and subsequent oven drying at a set temperature (100 ° C) (APHA, 2005).

The determination of suspended solids followed the gravimetric method according to the principle described in Cole (1979). Millipore AP40 membranes and vacuum filtration pump were used for the retention of particulate material in suspension in a known volume of water (500 to 1000 ml). The filters were pre-dried (450 °C for 1h) and weighed on the Denver Instrument analytical balance (0.00001g precision). After filtration in the field, the filters were again dried and weighed to obtain the total suspended material (50 °C / 24h). Subsequently, the same filters were taken to an oven type Mufla (Fanen brand model 413) at 450 °C for 1 hour to discriminate the organic and inorganic fractions.

The biochemical oxygen demand was determined by the Incubation Method (20 °C, 5 days) (APHA, 1998) and thermo tolerant coliforms quantitative determination was performed according to the NMP technique, recommended by APHA (2005).

Total chlorophyll *a* concentration was determined after vacuum filtration (Millipore AP40 membranes) of 0.5 to 1 L of water from each sampling depth, depending on the concentration of particulate material on the water sample. For pigments extraction, cold acetone (90%) and manual maceration were used (Talling and Driver, 1963; Golterman et al., 1978).

The shore line development index was calculated according methodology proposed by Häkanson (2005) and using data collected from Duke Energy International Paranapanema Generation (ABC da Energia). The theoretical residence time (days) was defined as the ratio of reservoir volume and the flow calculated using the formula: TRT = V / (Q x 86,400), where V = reservoir volume (m^3); Q = mean flow (m^3 s^{-1}) and 86,400 = number of seconds contained in a day. Input data are available at the government agency website (http://sar.ana.gov.br).

The trophic state index was determined in accordance with Cunha et al. (2013) for tropical/subtropical reservoirs (TSItsr), which include six categories: (U) Ultraoligotrophic (≤51.1), (O) Oligotrophic (51.2 -53.1), (M) Mesotrophic (53.2-55.7), (E) Eutrophic (55.8-58.1), (S) Supereutrophic (58.2-59) and (H) Hypereutrophic (≥ 59.1), respectively.

The studied parameters were compared with the references standards established by CONAMA Resolution 357/2005 (conditions of water quality categories for Brazilian aquatic systems) for *Class 1* waters – the better condition in which the Paranapanema River is framed of. See Table 3.

Table 3 – Standard references established by CONAMA Resolution 357/2005 (conditions for water quality categories for Brazilian aquatic ecosystems) for Class 1 waters.

Parameter	Reference
pH	6 up to 9
Turbidity	< 40 NTU
Dissolved Oxigen	> 6 mg l^{-1} O^{2}
Biochemical oxygen demand	< 3 mg l^{-1} O^{2}
Total Solids	< 500 mg l^{-1}
Total Nitrogen	< 1.27 mg l^{-1} lentic systems
	> 2.18 mg l^{-1} lotic systems
Total Phosphorus	< 0.020 mg l^{-1} lentic systems
	< 0.025 mg l^{-1} Intermediate systems*
Chlorophyll *a*	< 10 µg l^{-1}
Thermo tolerant coliforms	< 200 NMP/100 ml

* Water retention time between 2 and 40 days.

A Principal Component Analysis (PCA) was performed to summarize variation tendencies or patterns for limnological variables during both sampling periods, using the PRIMER v6 statistics package for Windows (Plymouth Routines in Multivariate Ecological Research, www.primer-e.com).

Results

The studied reservoirs have distinct features in terms of morphometric dimensions, operation and trophy degrees, for instance, which are very important for the limnological structure and functioning. Table 4 systematize the reservoirs main characteristics.

Table 4 – General characteristics of the study reservoirs.

	JR	**CH**	**SG**	**CII**	**CI**	**CP**	**TQ**	**RS**
Type (*modis operandi*)*	**S**	**S**	**R**	**R**	**R**	**S**	**R**	**R**
Area (km^2)	449	400	12	22.51	30.85	576	80.1	220
Perimeter (km)	1,286	1,085	81	103	120	1,550	301	433
Volume (hm^3)	7,702	9,410	63.22	158	220	11,743	754.17	1,942
Shore line development index	17.1	15.3	6.6	6.1	6.1	18.2	9.5	8.2
Water retention time (days)	400	335	2	4	6	115	7	17
Z_{max} (m)	32	79	10	15	25	40	26	27
Altitude (m) (a.s.l)	563	473	389	367	354	325	271	241
Age	54	45	56	17	17	38	27	29
T.S.I.$_{tsr}$**	U - O	U	U - E	U -O	U - E	U - M	U	U - M

*** Reservoir operation S - Storage; R - Run-off River**

**** Trophic State Index $_{\text{tropical/subtropical reservoir}}$**

The appendixes 1 and 2 contain the water column mean values for each measured variable per sampling station and seasonal period.

Jurumirim reservoir

Jurumirim reservoir is a 449 km^2 storage system, very dendritic (17.1 shore line development index) and with a large water retention time, about 400 days (Table 4). The depths measured in Jurumirim reservoir varied between 5.1 m (JR1) and 32 m (JRDam) in the wet season and between 4.7 m (JR1) and 29 m (JRDam) in the dry season.

A variation of about 2 m in the reservoir water level was observed along the studied year. The lowest value occurred in January (monthly average of 565.1 m) and the highest in April (monthly average of 567.2 m) and the highest outflow occurred in February, mean of 342 m^3 s^{-1}, while lower values occurred in April (mean of 184 m^3 s^{-1}) and August (mean of 181 m^3 s^{-1}) (Fig. 2.)

During the wet season lower values of water transparency were observed at station JR1 and JRUp (0.65 m) and higher at JR4 (2.3 m) and JRDam (3 m). In the dry season lowest values occurred at the sites JR1 (0.4 m), JRUp (0.5) and JR2 (0.6) and higher at JR4 (3.45 m) and JRDam (3.5 m) (Fig. 2). A clear longitudinal gradient increase (upstream to dam), was observed both in wet (4.6 X) and dry (8.7 X) seasons.

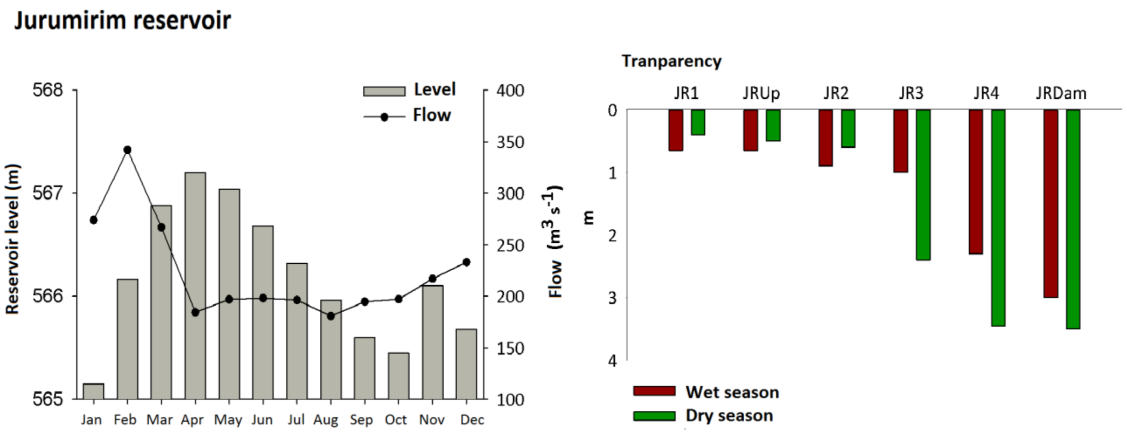

Figure 2 – Reservoir level and flow variation throughout the year (monthly averages) and water transparency at the Jurumirim reservoir sampling sites in the 2011 wet and dry seasons.

Temperature profiles along the water column are shown in Figure 3. In the wet season different conditions were found along the reservoir. In the central region of the reservoir – station JR3, the temperature profile was practically isothermal while at JR1 and JR4 sites decreasing gradients were observed. Slightly stratification occurred at dam (JRDam) and upstream (JRUp) areas and more structured stratification occurred at JR2. Higher values of temperature were observed at the surface, varying between 25 and 26.5 ^{o}C, and the lower at the bottom, between 23 and 24 ^{o}C. The amplitude of variation between surface and bottom was higher at stations JR2 and JRUp, approximately 3 ^{o}C.

The dry season was characterized by superficial stratifications – at JR1, JRUp and JR2, and isothermal condition at JRDam and JR4. At JR4 there was a decrease in the temperature near to the bottom, bellow 21 m, and a small surface decrease was observed at JRDam.

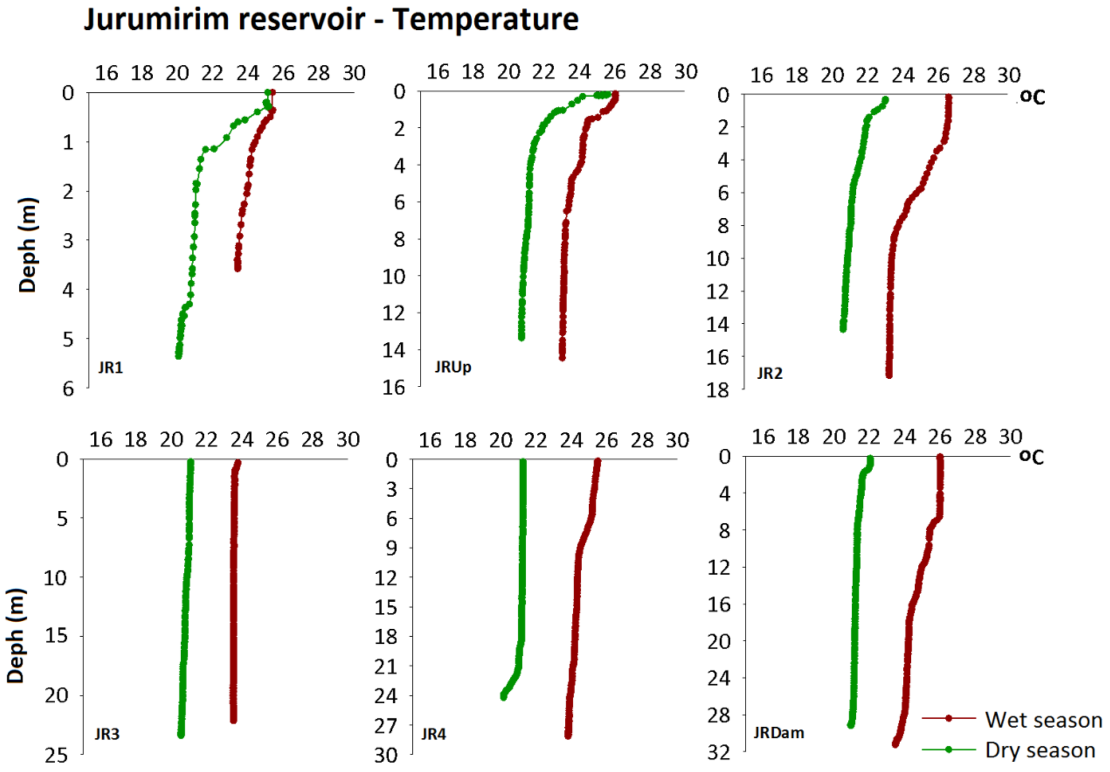

Figure 3 - Temperature profiles at the sampling sites of the Jurumirim reservoir in the 2011 wet and dry seasons.

The concentrations of dissolved oxygen in the water column were high in both periods (Fig. 4). Profiles averages ranged from 8.6 mg l^{-1} at JRDam to 9.3 mg l^{-1} in JR2, in the wet season, and were higher in the dry period, between 10.28 mg l^{-1} at JR4 and 11.45 mg l^{-1} at JRUp. In summer it was observed a considerable diminution of oxygen in the deepest layer of the water column at the dam zone (<5mg l^{-1}). At others sampled sites, moderate decreases, around 2 mg l^{-1}, occurred with increasing depth (JR4 and JR2) or values remained practically homogeneous (JR3, JR1 and JRUp). During the dry period, there was a small oxygen increase at the surface region of stations JR1, JRUp and JR2 and a bottom decrease at station JR4.

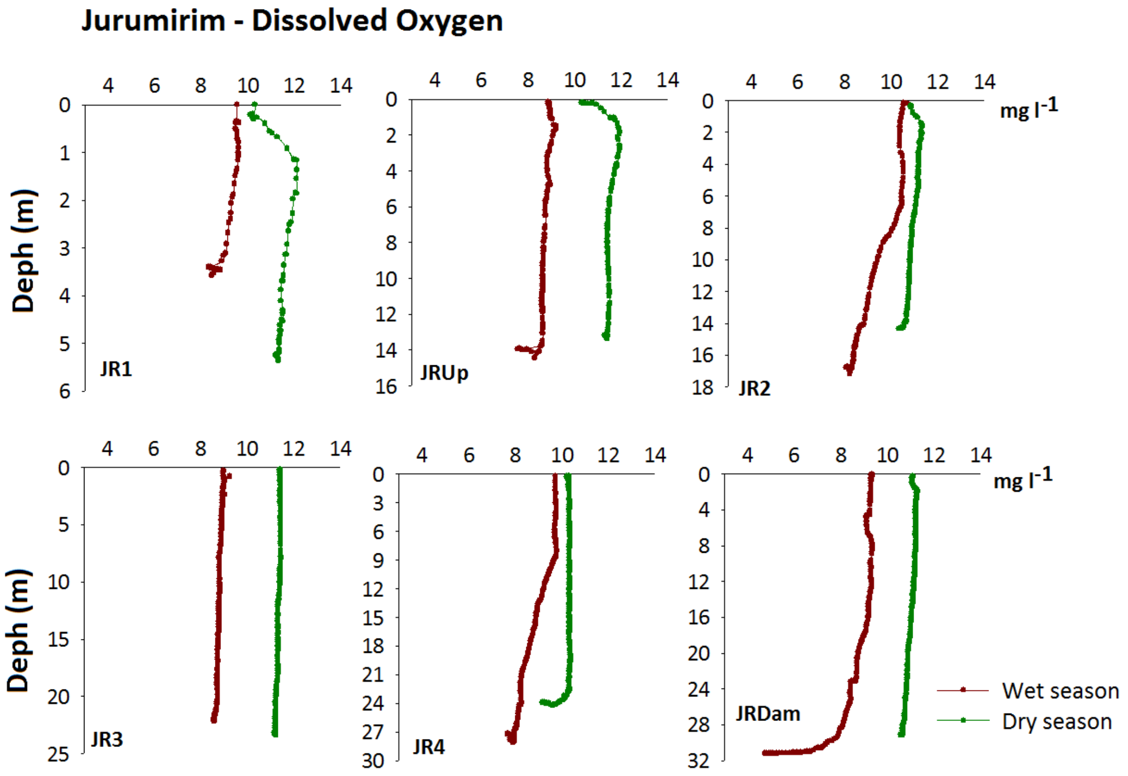

Figure 4 - Dissolved oxygen profiles at the Jurumirim reservoir sampling sites in the 2011 wet and dry seasons.

The values of conductivity, pH, turbidity, total and suspended solids, biochemical oxygen demand, total nitrogen, total phosphorus, thermo tolerant coliforms and chlorophyll *a* for Jurumirim reservoir are shown in Figure 5.

The conductivity ranged from 44 µS cm^{-1} (JRUp) to 60 µS cm^{-1}(JR2) in the wet season and between 50.38 µS cm^{-1}(JRUp) and 57.26 µS cm^{-1}(JR2) in the dry season.

For pH neutral or slightly alkaline values were measured in the wet season, ranging from 7 (JR1) to 8 (JRDam), while in the dry season acid values predominated, between 4.64 (JR4) and 6.49 (JRUp).

The highest turbidity was observed during the wet season at JRUp, 42.98 NTU. For the other sites, the values varied between 1.73 NTU, JRDam, and 25.69 NTU, JR1. In the dry season it ranged between 3.85 NTU, JR1, and 36.28 NTU, JR2.

In the wet season lower values of total solids occurred at JR1, 53.3 mg l^{-1}, and JRDam, 68.3 mg l^{-1}, and higher at JR3, 89.6 mg l^{-1}, and JR2, 97 mg l^{-1}. For dry season, the lowest value was observed at JR4, 51.7 mg l^{-1}, and higher at JRUp, 85.7 mg l^{-1}, and JR2, 89.3 mg l^{-1}.

Higher values of suspended solids were registered at JR1, 12.70 mg l^{-1}, and JRUp, 10.51 mg l^{-1}, in wet season, and in JR1, 9.86 mg l^{-1}, during dry season. The lowest concentrations (<2) were observed at stations JR4 in wet season, and JRDam in dry season. The inorganic matter fraction prevailed over organic, except at JRDam and JR4 in the wet season and at JR4 in dry season, where the organic fraction predominated.

Total nitrogen concentration in the water showed the highest values at JRUp, in both, wet (424.5 µg l^{-1}) and dry (604.63 µg l^{-1}) seasons. Values were relatively low in others sites, ranging from 283.1 µg l^{-1}, JRDam, to 382.7 µg l^{-1}, JR1, in the wet season and from 214.68 µg l^{-1}, JRDam, and 404, 33 µg l^{-1}, JR1, during the dry season.

The total phosphorus concentrations ranged from 11.2 to 24 µg l^{-1}, in wet season and from 3.13 to 17.57 µg l^{-1}, in dry season. Higher mean values occurred at JRUp, 24 µg l^{-1}, and at JR1, 20.71 µg l^{-1}, in wet season and at JRUp and JR2, both with 17.57 µg l^{-1}, in dry season. Lower values were observed at JR4, 11.2 µg l^{-1}, in wet season and at JRDam, 3.13 µg l^{-1}, in dry season.

Among the sampled sites, the lowest values of biochemical oxygen demand were observed at station JR4, with 0.2 mg l^{-1} O_2 (wet season) and 0.6 mg l^{-1} O_2 (dry season). Higher values occurred at JR3, 1.6 mg l^{-1} O_2, JR1, 1.3 mg l^{-1} O_2 and JR2, 1.2 mg l^{-1} O_2 (wet) and at JR1 and JRUp, both with 1.6 mg l^{-1} O_2 (dry season).

Thermo tolerant coliforms ranged from 4 NMP/100ml at JR3, JR2 and JRUp, to 93 MNP/100ml, at JR1, in wet season, and between 9.1 NMP/100ml, at JR1, and 43 NMP/100ml, at JRdam, during dry season.

The chlorophyll *a* concentration ranged from 0.85 µg l^{-1} at JR4 to 2.94 µg l^{-1} at JR2, in wet season, and between 0.73 µg l^{-1}, at JR3, and 3.48 µg l^{-1}, at JR2, in dry season.

The trophic status showed good water quality with Ultraoligotrophic and Oligotrophic states in the reservoir (Table 4). Except for pH (JR1 – 5.11 and JR4 – 4.64, wet season), turbidity (42.98 NTU, dry season) and phosphorus (JR1 – 20.72 µg l^{-1} and JRUp – 24.07 µg l^{-1}, dry season) all parameters values were in agreement with CONAMA Resolution 357/2005 standards for Class 1 (Table 4).

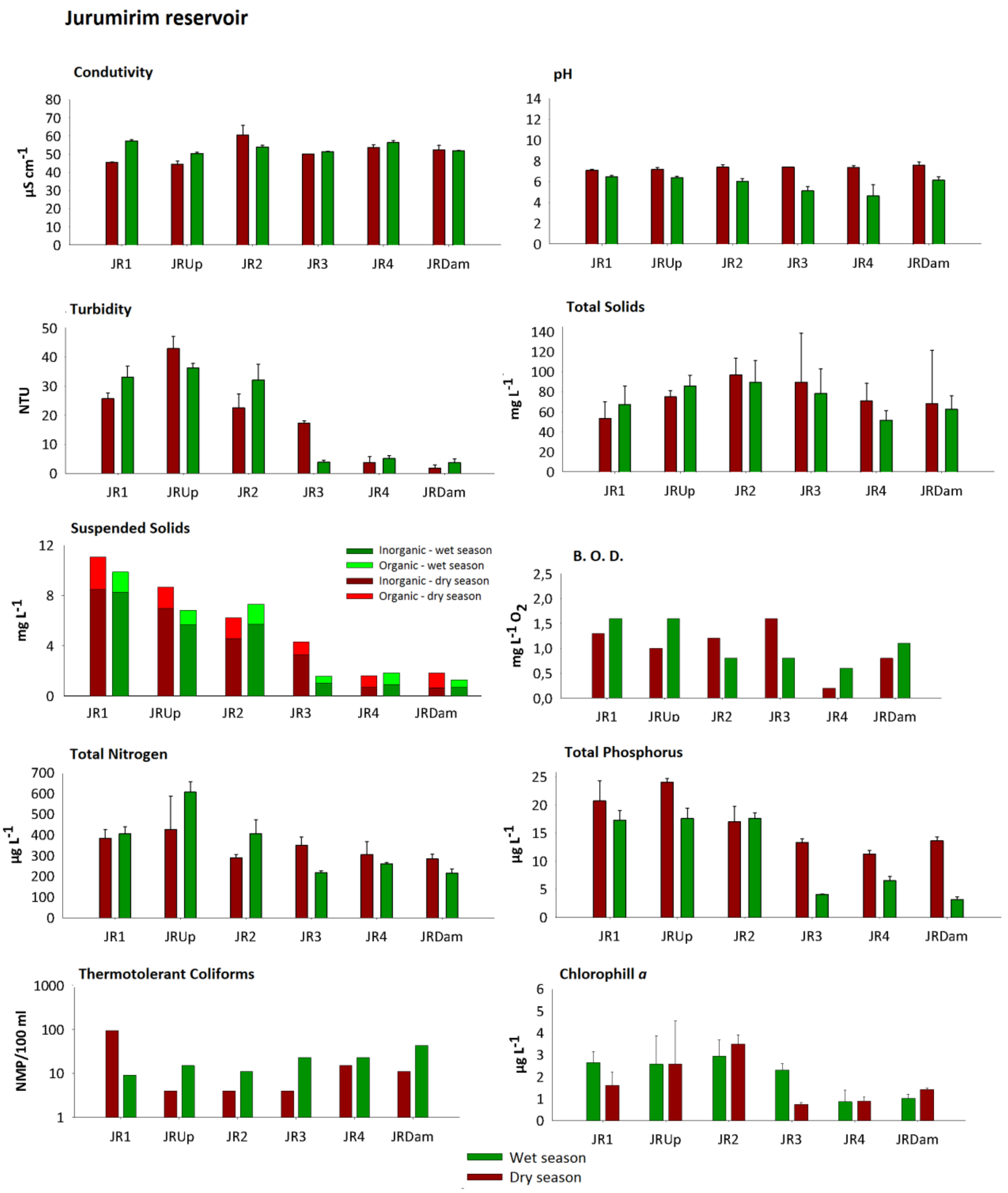

Figure 5 - Values (Mean, +S.D.) of conductivity, pH, turbidity, total and suspended solids, biochemical oxygen demand, total nitrogen, total phosphorus, thermo tolerant coliforms and chlorophyll *a* at the Jurumirim reservoir sampling sites in the 2011 wet and dry seasons.

Chavantes reservoir

Chavantes reservoir is a 400 km^2 storage system, very dendritic (15.3 shore line development index) and with about 335 days of water retention time (Table 4). The depths measured in the Chavantes reservoir varied between 10 m (CHUp) and 74.4 m

(CHDam) in the wet season and between 15 m (CH1) and 79.2 m (CHDam) in the dry season.

Figure 6 shows the variations of the reservoir level and flow throughout the year, as well as the variation of the water transparency at the different sampling sites. A variation of 3.5 m in the reservoir water level was observed during the year with the lowest value in January (average of 470 m) and higher in April (average of 473.5 m). The highest flow occurred in December, average of 416 m^3 s^{-1}, while lower values occurred in April, average of 236 m^3 s^{-1}.

Lower values of water transparency were observed at station CH1, even in wet (0.8 m) and in dry period (0.9 m). CHDam exhibited the highest values, 5.5 m (wet season) and 4.2 (dry season). A clear longitudinal gradient increase (upstream to dam), was observed both in wet (6.9 X) and dry (8.7 X) seasons.

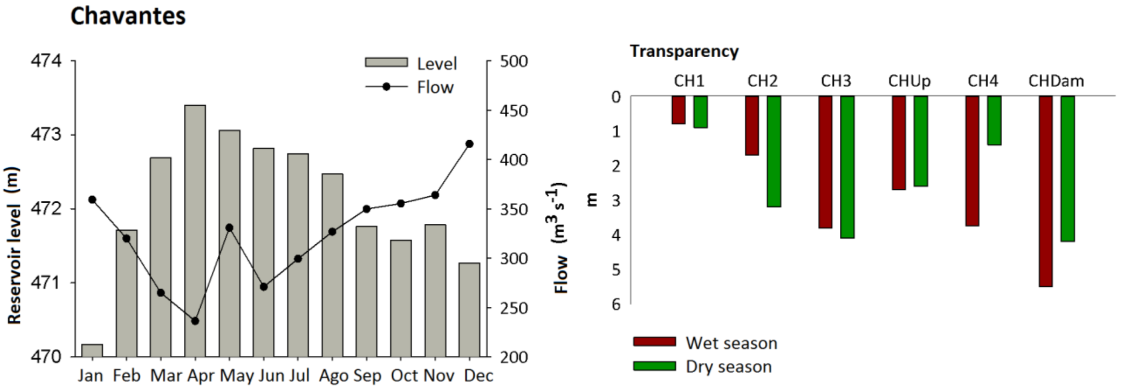

Figure 6 – Reservoir level and flow variation throughout the year (monthly averages) and water transparency at the Chavantes reservoir sampling sites in the 2011 wet and dry seasons.

The water temperature profiles (Fig. 7) were homogeneous or relatively homogeneous only at the CHUp, with water column values varying from 25-26 °C, in wet season, and from 20-22 °C, in dry season. Thermal stratifications of different amplitudes occurred in the others sampling stations. At CHDam, CH3 and CH4 the stratifications were accentuated, especially in summer, with a difference between the surface and bottom up to 10 °C. In CH1 and CH2 the amplitude was lower, with 3-4 °C decline towards the bottom.

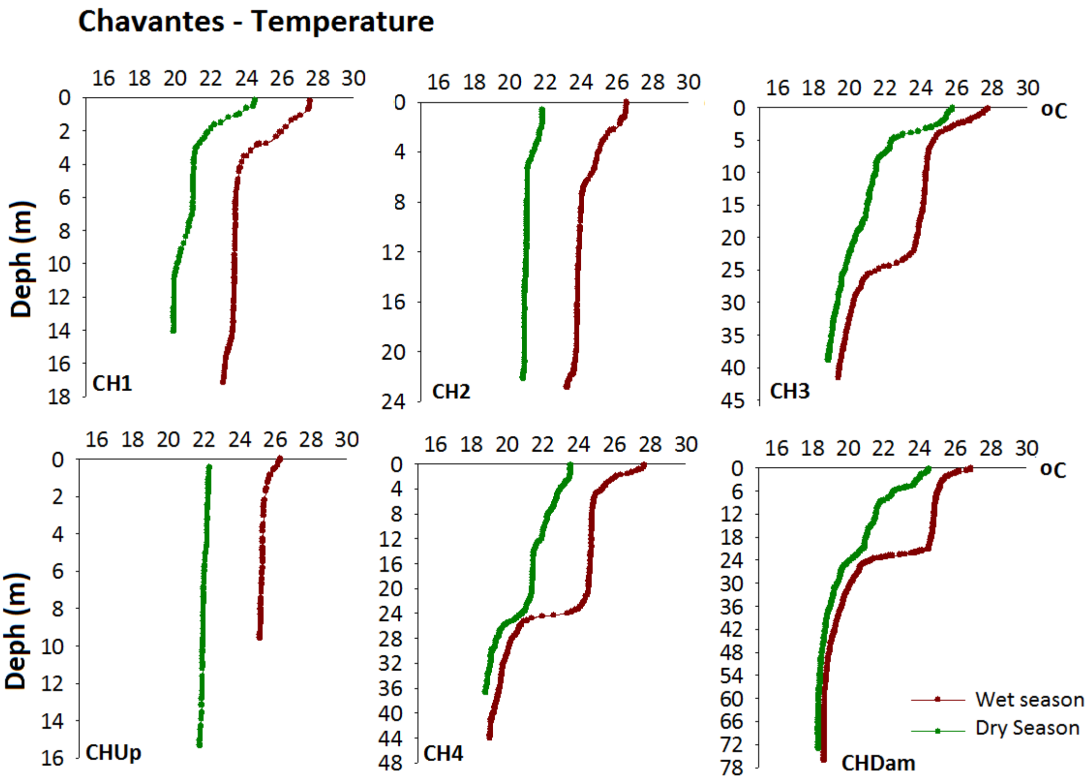

Figure 7 - Temperature profiles at the sampling sites of the Chavantes reservoir in the 2011 wet and dry seasons.

The concentrations of dissolved oxygen (Fig. 8) in the wet and dry seasons exhibited a small increase in the sub-superficial layers and a decreasing trend towards the bottom, except for CHUp. At this site, the values were practically homogeneous along the water column, with an average value of 10.07 mg l^{-1} in wet and 8.95 mg l^{-1} in dry season. At CHDam, CH3 and CH4 sites, in the wet period, there was a drop in oxygen concentrations (2 or 3 mg l^{-1}) from 25 meters deep, with a gradual decrease to the bottom. Mean values ranged from 7.65 mg l^{-1} in CHDam to 10.07 mg l^{-1} in the CHUp in wet season and between 7.51 mg l^{-1}, CH4 and CHDam, and 10.83 mg l^{-1}, in CH2, in dry season.

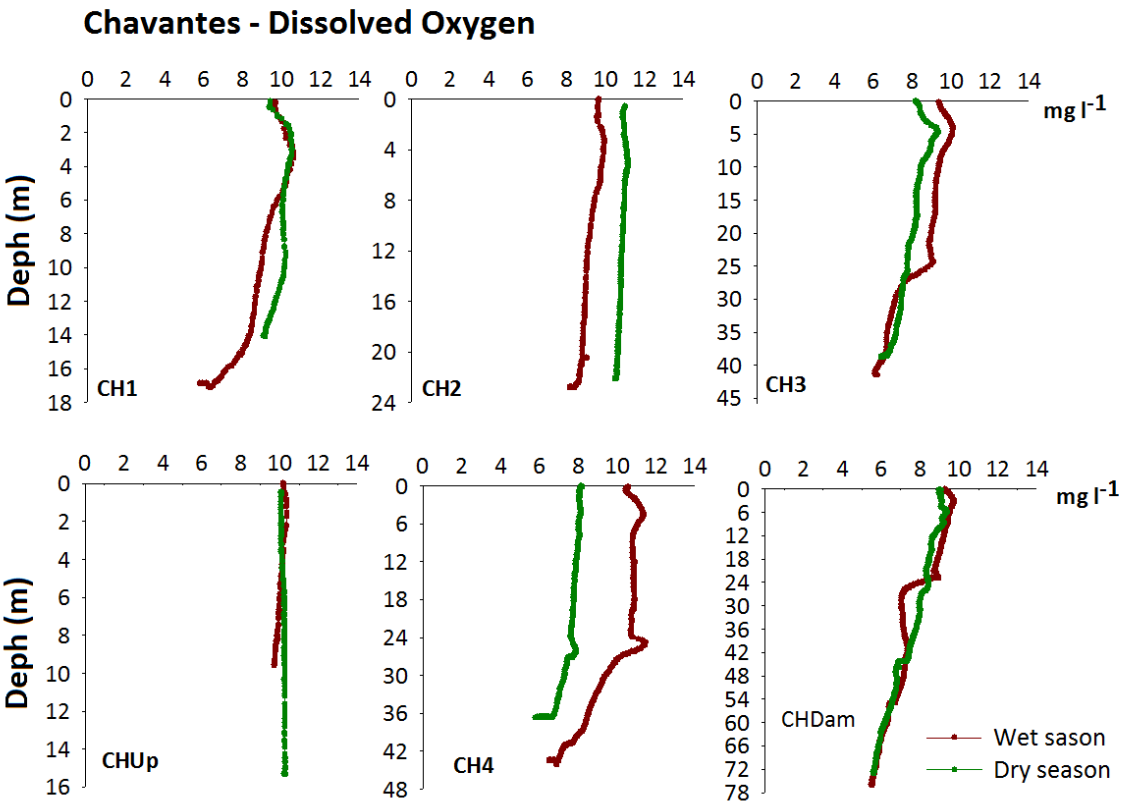

Figure 8 - Dissolved oxygen profiles at the Chavantes reservoir sampling sites in the 2011 wet and dry seasons.

The values of conductivity, pH, turbidity, total and suspended solids, biochemical oxygen demand, total nitrogen, total phosphorus, thermo tolerant coliforms and chlorophyll *a* for Chavantes reservoir are shown in Figure 9.

The conductivity ranged from 50.74 µS cm^{-1} (CHUp) to 54.86 µS cm^{-1}(CH1) in the wet season and between 50.77 µS cm^{-1}(CHUp) and 56.06 µS cm^{-1}(CH2) in the dry season.

The pH values showed a great seasonal variation, tending to a more basic condition in the wet season (between 7 and 8) and intermediate in the dry period (between 6 and 8).

Higher turbidity was observed in the wet season at CH1, 28.51 NTU, and CH2, 14.85 NTU, and the lower values at CHUp, 1.98 NTU, and CH4, 2.48 NTU. The values measured in the dry season ranged from 5.39 NTU (CH3) to 21.62 NTU (CH1).

The values of total solids determined in the wet season varied from 11.3 mg l^{-1}, CH4, to 56.3 mg l^{-1}, CH2. Higher values occurred during the dry season, between 61.3 mg l^{-1}, CH2, and 72.7 mg l^{-1}, CHDam.

Higher suspended solids values were found at stations CH1, Itararé axis upstream site, and CHDam. Suspended solids in wet season ranged between 0.39 mg l^{-1}, CH41 and 0.61 mg l^{-1}, CHDam to 4.37 mg l^{-1}, CH1. In dry season the highest concentration was found at CHDam 15.77 mg l^{-1} and lower concentrations (<2) were observed at CH2 and CH3. The inorganic matter fraction exceeds the organic fraction in all the Itararé axis sampled sites (CH1, CH2 and CH3). At the Paranapanema axis sampled sites (CHUp, CH4 and CHDam), the organic fraction was higher than the inorganic fraction, except for CHDam during the wet season.

Total nitrogen concentration in the water showed the highest values in the CH3 (392.98 µg l^{-1}) and CH2 sites (406.03 µg l^{-1}), in the wet season and at CH1 (302.05 µg l^{-1}) in dry season. The lower values occurred at CH4, 301.88 µg l^{-1} (wet) and 197.87 µg l^{-1} (dry season).

The total phosphorus concentrations ranged from 12.81 (CH4) to 39.76 µg l^{-1} (CHDam) in the wet season. The CHDam high value is probably due to the high concentration found in the depth of 35 meters (86.67 µg l^{-1}), just below the formation of the thermocline, where an increase of turbidity was detected too. In the dry period, the values were much lower ranging from 5.34 µg l^{-1}, CHDam and 9.05 µg l^{-1}, CH1.

Among the sampled sites, the lowest values of biochemical oxygen demand were observed at station CHUp, with 0.5 mg l^{-1} O_2 (wet season) and CH3, 0.6 mg l^{-1} O_2 (dry season). The highest values occurred in CH3, 1.3 mg l^{-1} O_2 (wet) and 1.6 mg l^{-1} O_2 (dry season).

Thermo tolerant coliforms ranged from <3 NMP/100ml (CH1 and CH2) to 43 MNP/100ml at CHUp, wet season and between <3 NMP/100ml, CH4 and 23 NMP/100ml, CHup during dry season.

The chlorophyll *a* concentration ranged from 0.44 µg l^{-1} (CH3) to 1.07 µg l^{-1} (CH1) in wet season, and between 0.53 µg l^{-1} (CH4) to 1.96 µg l^{-1} (CHDam) in dry season.

The trophic status show excellent water quality with Ultraoligotrophic state for all sampled sites in the reservoir. Except for one isolated value of high total phosphorus (CHDam – 39.76 µg l^{-1}, wet season) all parameters were in agreement with CONAMA Resolution 357/2005 standards for Class 1 (Table 4).

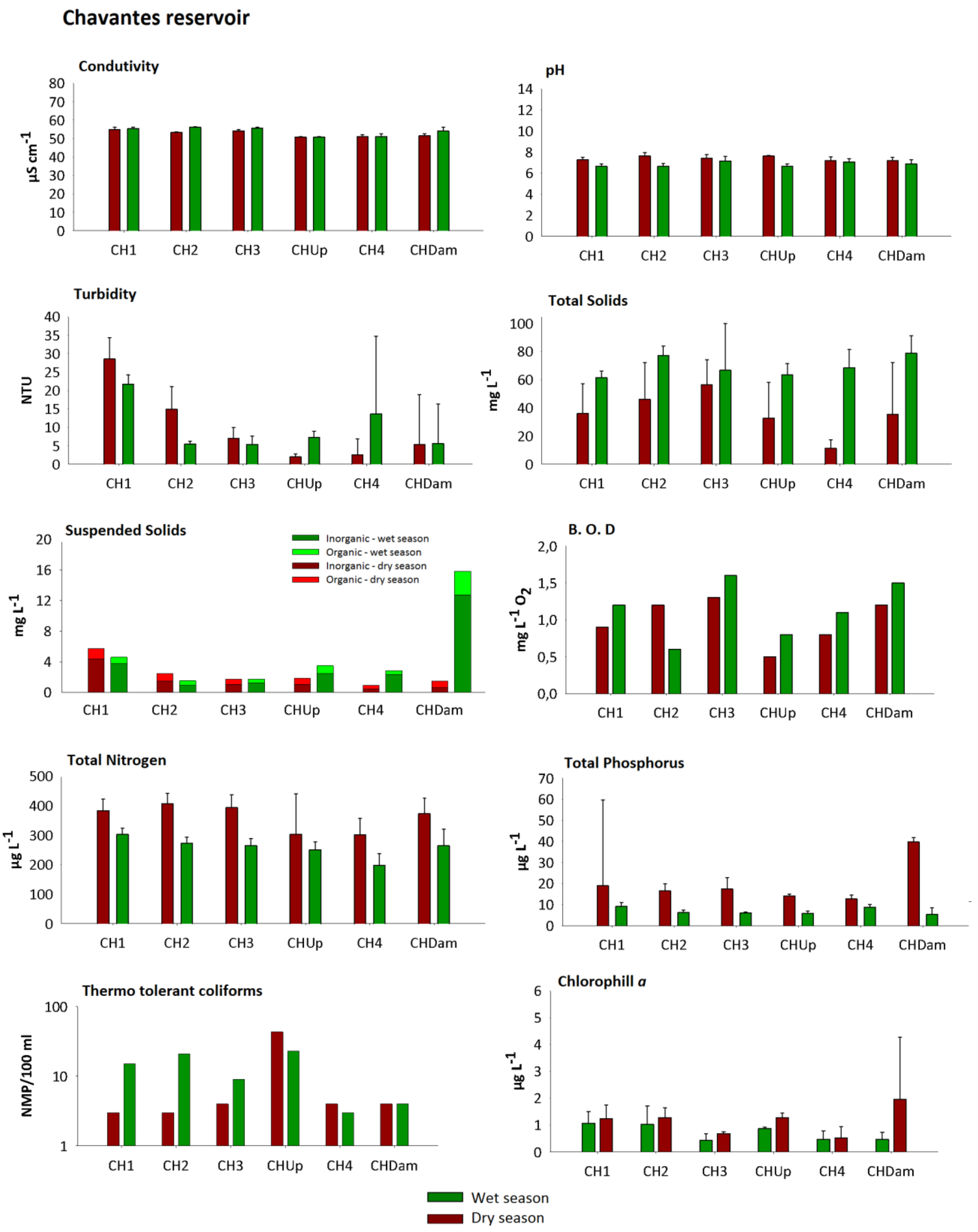

Figure 9 - Values (Mean, +S.D.) of conductivity, pH, turbidity, total and suspended solids, biochemical oxygen demand, total nitrogen, total phosphorus, thermotolerant coliforms and chlorophyll *a* at the Chavantes reservoir sampling sites in the 2011 wet and dry seasons.

Salto Grande reservoir

Salto Grande reservoir is a 12 km^2 run-off-river system, not dendritic (6.6 shore line development index) and with about 2 days retention time (Table 4).The depths measured in the Salto Grande reservoir varied between 3.5 m (SGUp) and 10.2 m (SGDam) in the wet season and between 2.3 m (SGUp) and 10.7 m (SGDam) in the dry season.

Figure 10 shows the variations of the reservoir level and flow throughout the studied year and also the variation of the water transparency in the different sampling sites. There was a minor variation in the level of the reservoir during the year (< 0.5 m). The highest flow occurred in January, approximately 357 m^3 s^{-1}, while lower values occurred in April, 380 m^3 s^{-1}, and June, 384 m^3 s^{-1}.

The lowest values of water transparency were observed in SG1 (0.25 m, wet and 0.55 m dry season). The highest values in SG2, with 3.5 m (wet season) and 3.4 (dry season) and SGUp, 3.5 m (wet season).

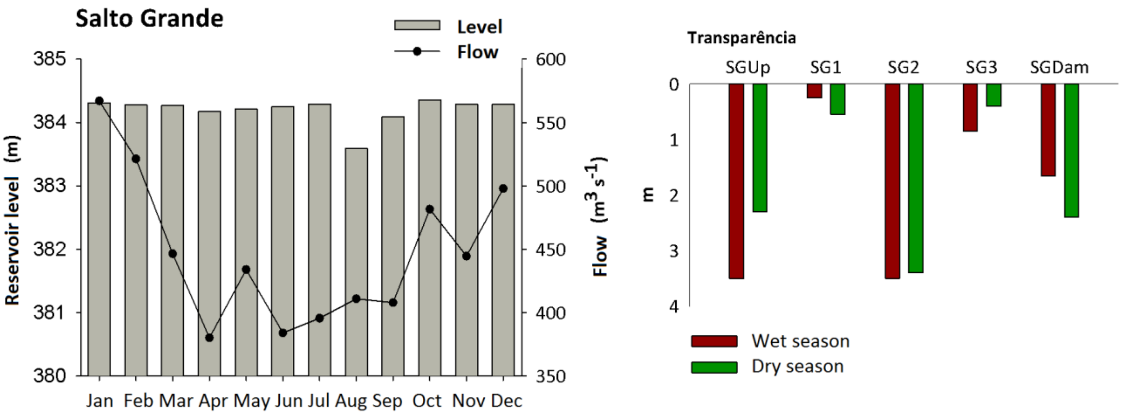

Figure 10 – Reservoir level and flow variation throughout the year (monthly average) and water transparency at the Salto Grande reservoir sampling sites in the 2011 wet and dry seasons.

The water temperature profiles (Fig. 11) showed isotherm condition in wet season at SGUp, SG2 and SG1 sites, with values between 24 and 26 °C. In SG3, a superficial stratification was observed in the first meter of depth, with a difference of up to 4 °C between surface and bottom. At the SGDam, stratification near the surface of 1 °C was observed, indicating a daily phenomenon. During the dry season all sampled sites showed isothermal condition, or small decreasing gradients. The water temperature varied between 22.42 ^{o}C in the SGUp and 24.25 ^{o}C in the SG1 (Fig. 11).

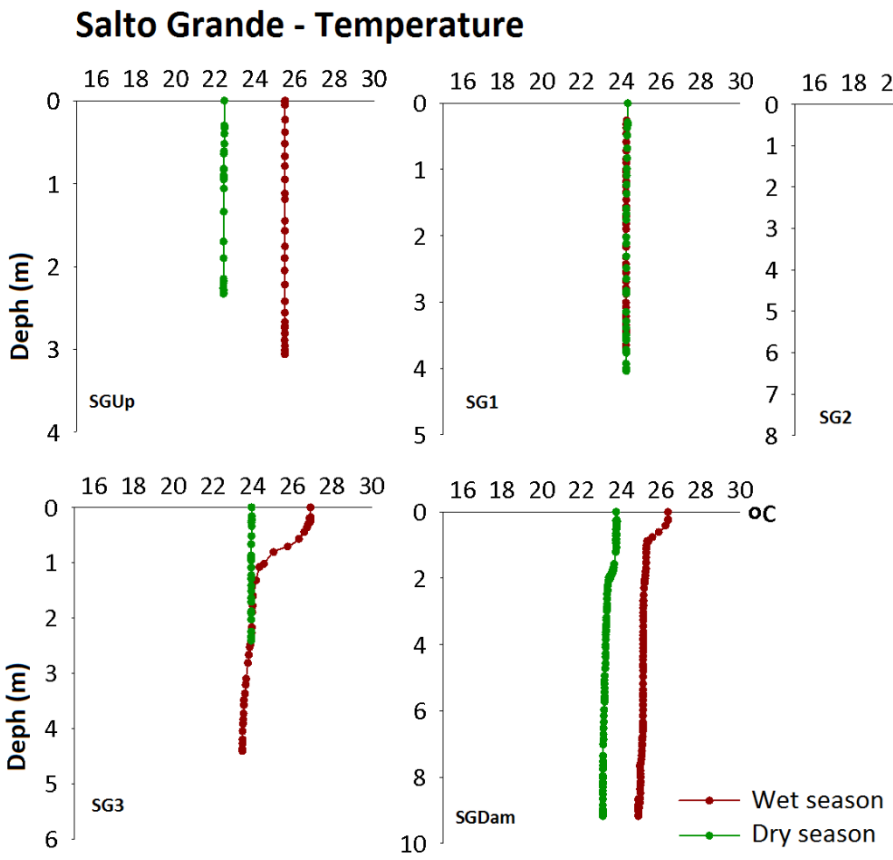

Figure 11 - Temperature profiles at the sampling sites of the Salto Grande reservoir in the 2011 wet and dry seasons.

The concentrations of dissolved oxygen (Fig. 12), showed a variation tendency similar to that observed for water temperature. In wet season, the values remained relatively homogeneous along the water column at SGUp, SG2 and SG1 and exhibited small variations near the surface in SGDam and SG3. Mean values of oxygen ranged from 9.19 mg l^{-1} (SG2) to 10.19 mg l^{-1} (SG1) in the wet season and between 7.83 mg l^{-1} (SG1) and 9.87 mg l^{-1} (SG2) in the dry season.

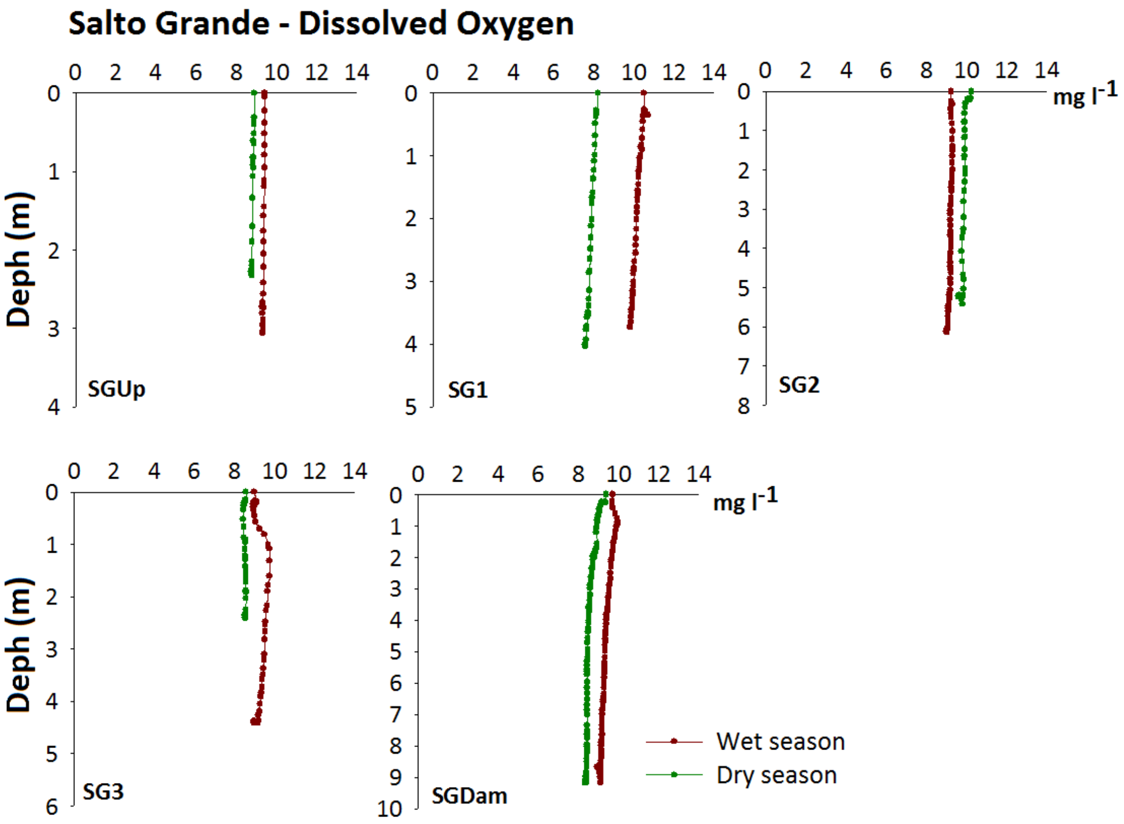

Figure 12 - Dissolved oxygen profiles at the Salto Grande reservoir sampling sites in the 2011 wet and dry seasons.

The values of conductivity, pH, turbidity, total and suspended solids, biochemical oxygen demand, total nitrogen, total phosphorus, thermo tolerant coliforms and chlorophyll *a* are shown in Figure 13.

The conductivity ranged from 47.98 µS cm^{-1} (SG3) to 62.68 µS cm^{-1} (SG2) in the wet season and between 52.91 µS cm^{-1} (SG3) and 67.93 µS cm^{-1} (SG1) in the dry season.

The pH showed basic condition in the wet season (between 7 and 8) and slightly lower values (between 6.8 and 7.5) in the dry period.

The highest turbidity values was observed in the wet season at SG3 station, 85.41 NTU, and the lowest at SG2 and SGUp (1.43 and 2.30 NTU, respectively). The values measured in the dry season ranged from from 3.11 NTU, SGUp, to 53.23 NTU SG1.

The values of total solids obtained in the wet season varied from 42.3 mg l^{-1}, SG1, and 73 mg l^{-1}, SGDam, and between 43.7 mg l^{-1}, SG2 and 90.3 mg l^{-1}, SGDam, during the dry season.

In the wet season the highest value of suspended solids was observed in SG1 (39.62 mg l^{-1}) and the lowest value in SG2 (0.50 mg l^{-1}). The highest value in dry season was observed again in SG1, 26,43 mg l^{-1}, and the lowest in SGUp (1,031 mg l^{-1}) and SG2 (1,492 mg l^{-1}). The inorganic fraction exceeded the organic fraction in all sampled sites.

Total nitrogen concentration in the water showed the highest values at SGDam (418.82 µg l^{-1}) and SG1 (449.05 µg l^{-1}), in the wet season, and at SG1 (428.01 µg l^{-1}) in dry season. Lower values occurred at SG3, 263.67 µg l^{-1} (wet season) and SG2, 190.77 µg l^{-1} (dry season).

The total phosphorus concentrations ranged from 17.70 µg l^{-1} (SG2) to 36.90 µg l^{-1} (SG1) in the wet season and from 5.17 µg l^{-1} (SGUp) to 27.2 µg l^{-1} (SG1) in the dry season.

The lowest values observed for biochemical oxygen demand occurred at SGDam (0.8 mg l^{-1} O_2) and SGUp (0.9 mg l^{-1} O_2) in the wet season and at SGUp (0.6 mg l^{-1} O_2) in the dry season. The highest values were observed at SG2 season, 2.8 mg l^{-1} O_2 (wet), and at SG1, 1.9 mg l^{-1} O_2 (dry season).

Thermo tolerant coliforms values in the wet period were lower than 200 NMP/100ml only at the SGDam and SG3, with 43 and 93 NMP/100ml, respectively. In the dry season all values were below 200 NMP/100ml, ranging from <3 NMP/100ml, at SGDam, and 23 NMP/100ml, at SG1 and SG3.

In the wet season the lowest concentrations of chlorophyll *a* were observed at SG3 (0.58 µg l^{-1}) and SGDam (0.69 µg l^{-1}), while the highest value occurred at SG1 (10.30 µg l^{-1}). In the dry season, the lowest value occurred at SGUp (1.06 µg l^{-1}) and the highest at SG3 (6.07 µg l^{-1}).

The trophic status in Salto Grande reservoir showed a diversified range of water quality conditions, from Ultraoligotrophic to Eutrophic. Two total phosphorus values (SG1 – 36.9 µg l^{-1}, wet, and 27.2 µg l^{-1}, dry season) and three values of thermo tolerant coliforms (SGUp, SG1 and SG2, >1100 NMP/100 ml, wet season) were above the limits of CONAMA Resolution 357/2005 for Class 1 (Table 4).

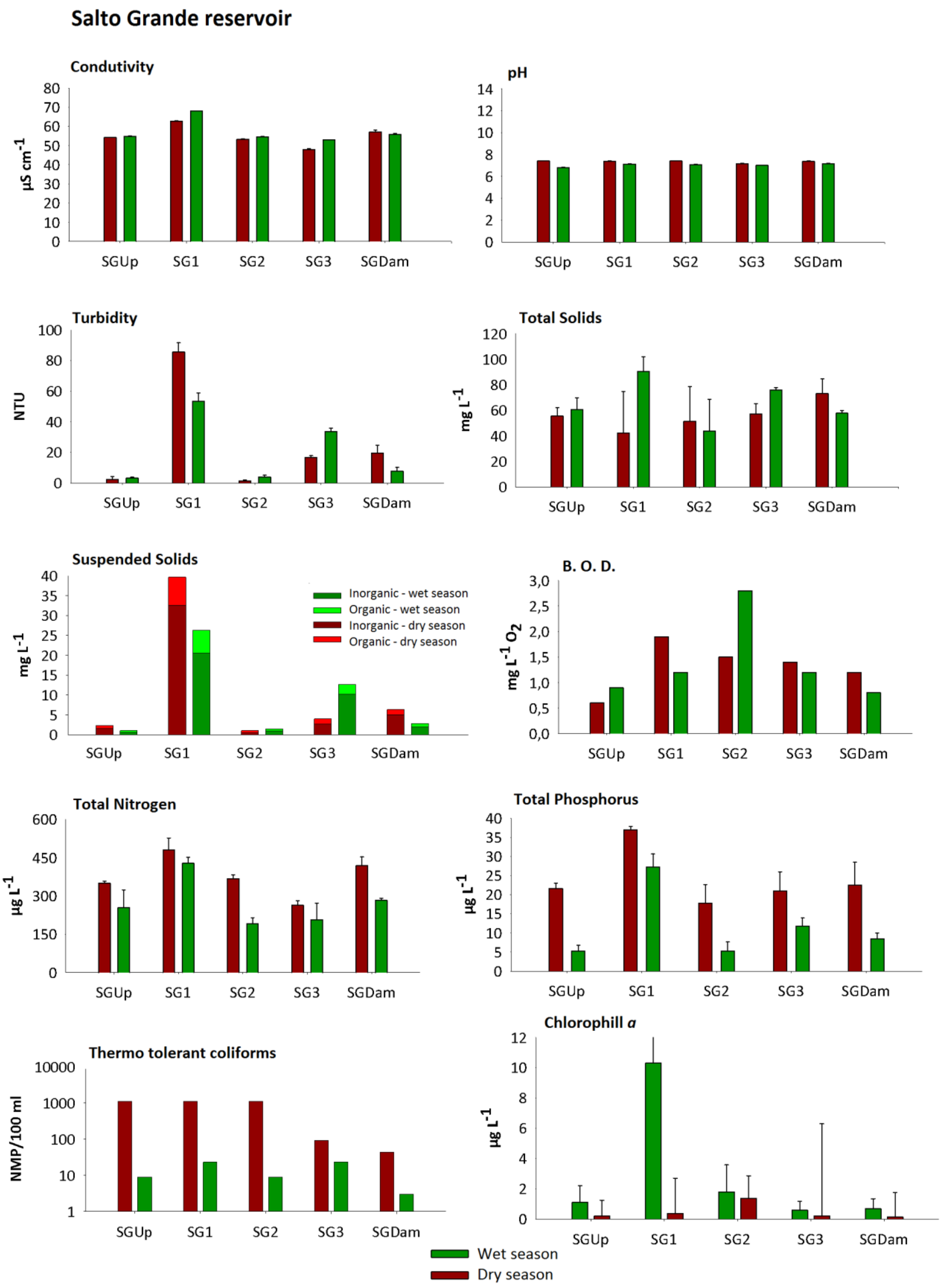

Figure 13 - Values (Mean, +S.D.) of conductivity, pH, turbidity, total and suspended solids, biochemical oxygen demand, total nitrogen, total phosphorus, thermotolerant coliforms and chlorophyll *a* at the Salto Grande reservoir sampling sites in the 2011 wet and dry seasons.

Canoas II reservoir

Canoas II reservoir is a 22.5 km^2 run-off-river system, not dendritic (6.1 shore line development index) and with about 4 days retention time (Table 4). The depths measured in the Canoas II reservoir varied between 8 m (CIIUp) and 13 m (CIIDam) in the wet season and between 9.5 m (CIIUp) and 15.5 m (CIIDam) in the dry season.

Figure 14 shows the variations of the reservoir level and flow throughout the year and also the variation of the water transparency in the different sampling sites. There was no significant variation in the reservoir level during the year. The highest flow occurred in January, approximately 565 $m^3 s^{-1}$, while lower values occurred in July (373 $m^3 s^{-1}$) and June (374 $m^3 s^{-1}$).

Water transparency varied between 1.3 and 1,7 in wet season and between 1.7 and 3.2 in dry season. Lower values were registered at CIIUp and higher at CIIDam, in an increasing longitudinal gradient.

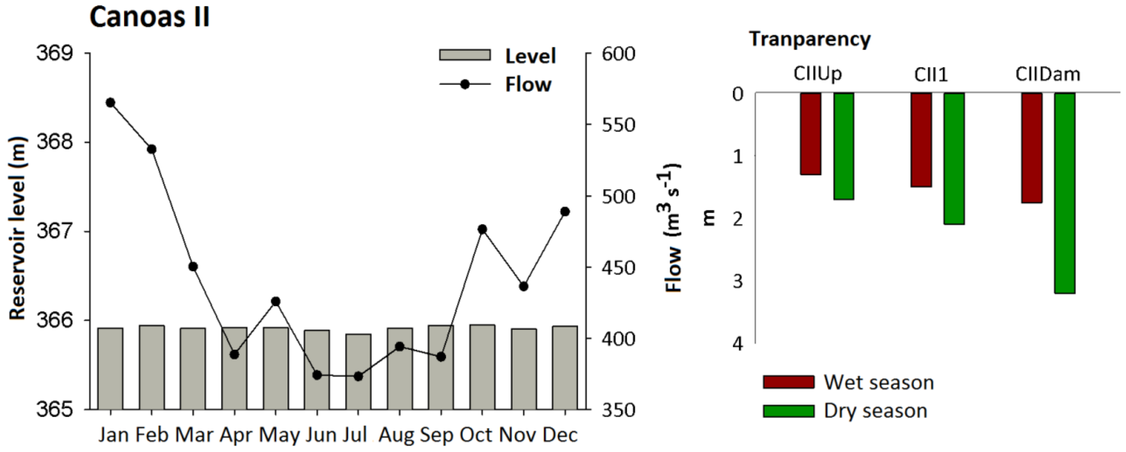

Figure 14 – Reservoir level and flow variation throughout the year (monthly average) and water transparency at the Canoas II reservoir sampling sites in the 2011 wet and dry seasons.

Temperature profiles along the water column (Fig. 15) show isothermal conditions, or slight gradual decrease with depth. The mean values for the water column varied between 25-26 °C in the wet season and between 22.5 and 23.2 °C in the dry season. A heat accumulation tendency in the dam region (CIIDam) was verified during the dry season, where the average temperature of the water column was slightly warmer than in the other sampled sites, mainly due to higher values on surface (up to 5 m).

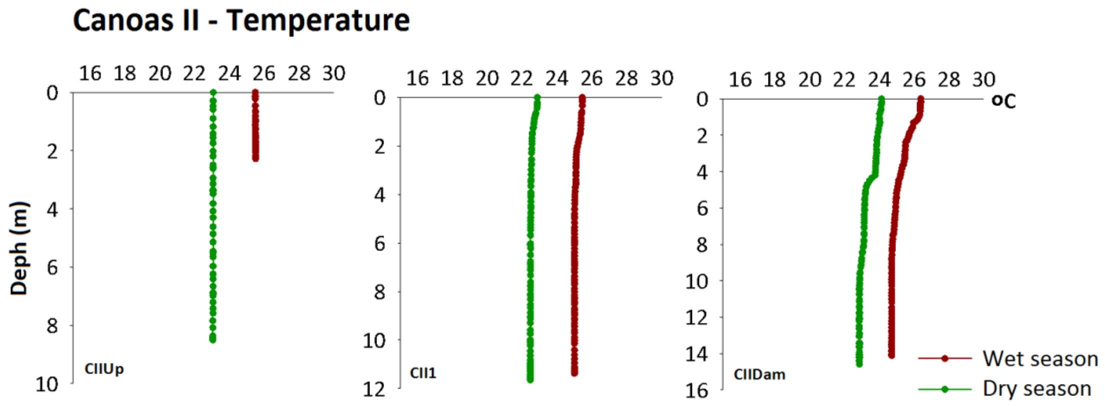

Figure 15 - Temperature profiles at the sampling sites of Canoas II reservoir in the 2011 wet and dry seasons.

High dissolved oxygen concentrations were observed in Canoas II reservoir (Fig. 16). The vertical profiles had a similar pattern to that observed for the water temperature, with relatively homogeneous values along the water column or presenting small gradients. Mean values ranged from 8.97 mg l^{-1} at CIIUp station to 9.13 mg l^{-1} at CIIDam in the wet season and from 8.78 mg l^{-1} at CII1 to 9.13 mg l^{-1} at CIIUp in dry season.

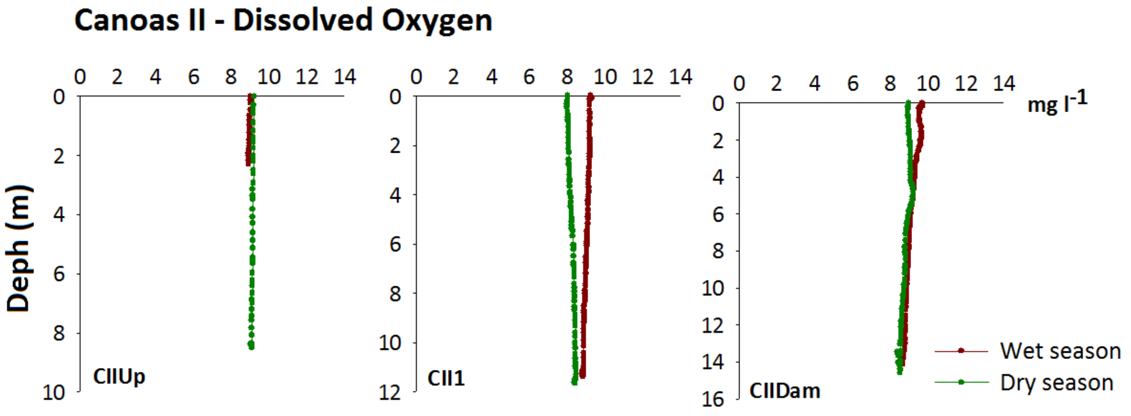

Figure 16 - Dissolved oxygen profiles at the Canoas II reservoir sampling sites in the 2011 wet and dry seasons.

The values of conductivity, pH, turbidity, total and suspended solids, biochemical oxygen demand, total nitrogen, total phosphorus, thermo tolerant coliforms and chlorophyll *a* for the reservoir of Canoas II are shown in Figure 17.

The conductivity varied between 56.21 µS cm^{-1} (CIIUp) and 57.39 µS (CIIDam) cm^{-1} in the wet season and between 56.23 µS cm^{-1} (CIIUp) and 57.41 µS cm^{-1} (CIIDam) in the dry season.

The pH values tended to be more basic in the wet season and intermediate in the dry season ranging between 7 and 8.

The turbidity ranged from 7.59 NTU at CIIDam to 10.70 NTU at CIIUp in wet season and between 3.02 NTU at CIIDam and 9.21 NTU at CIUp in dry season.

The lowest values of total solids were measured at CII1, 23 mg l^{-1} in the wet and 24.7 mg l^{-1} in the dry season. The highest values occurred at CIIDam, 110.7 mg l^{-1} in wet and 61.7 mg l^{-1} in dry season.

The suspended solids highest value was found at CIIUp (3.82 mg l^{-1}), followed by CII1 (3.29 mg l $^{-1}$) and CIIDam (2.87 mg l^{-1}), in wet season, and at CIIUp (5.9 mg l^{-1}), CII1 (3.65 mg l^{-1}) and CIIDam (1.25 mg l^{-1}), in dry season. The inorganic fraction exceeded the organic fraction at all sampling sites, except at the CIIDam in dry season, where organic fraction was greater.

Similar values of total nitrogen concentration were observed among the sampling sites. The concentrations ranged from 414.38 µg l^{-1}, CIIUp, and 432.20 µg l^{-1}, CII1, in the wet season and between 308.76 µg l^{-1} at CIIUp and 346.80 µg l^{-1} at CIIDam in dry season.

The total phosphorus concentrations ranged ranged from 21.71 µg l^{-1}, CIIDam, and CII1, and 21.79 µg l^{-1}, CIIUp, in the wet seanson and from 12.15 µg l^{-1}, CIIDam, and 15.36 µg l^{-1}, CII1, in the dry season.

The biochemical oxygen demand observed ranged from 0.6 mg l^{-1} O_2, CII1, to 1.0 mg l^{-1} O_2, CIIUp, in wet season and from 0.8 mg l^{-1} O_2, CIIUp and CIIDam, to 0.9 mg l^{-1} O2, CII1, in dry season.

Thermo tolerant coliforms concentrations in wet season were much higher and ranged from 93 MNP/100ml, CII1 and CIIUp, and >1100 MNP/100ml at CIIDam. The concentrations were lower than 3 NMP/100ml in all sampling sites during the dry season.

The chlorophyll *a* concentrations varied from 0.66 µg l^{-1}, CIIDam, to 1.76 µg l^{-1}, CII1, in wet season and between 0.69 µg l^{-1}, CII1, and 0.96 µg l^{-1}, CIIUp and CIIDam, in dry season.

The trophic status show good water quality with Ultraoligotrophic and Oligotrophic conditions in the reservoir. Except for one measurement of thermo tolerant coliform (CIIDam >1100 NMP/100 ml, wet season) all parameter are in agreement with CONAMA Resolution 357/2005 standards for Class 1 (Table 4).

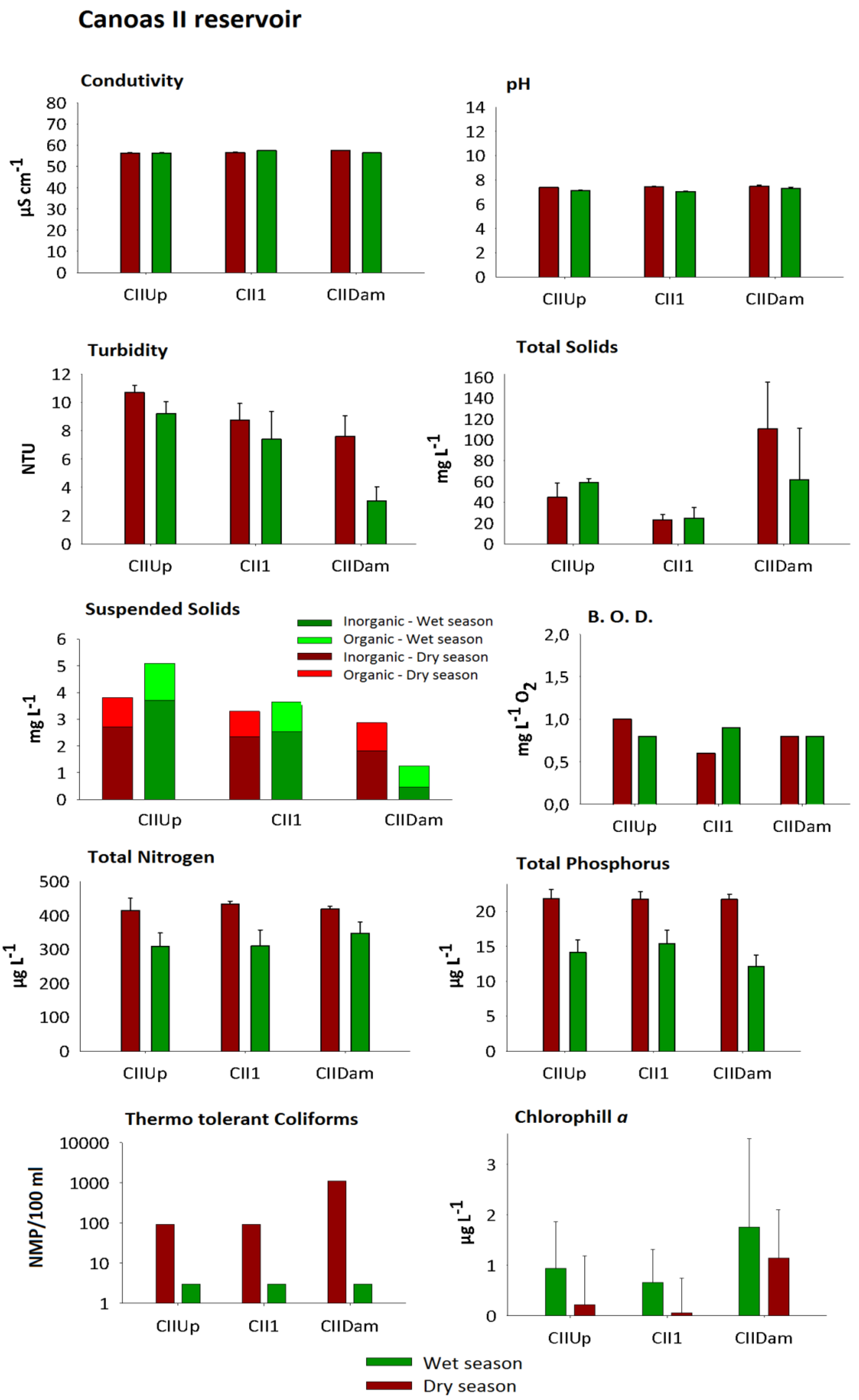

Figure 17 - Values (Mean, +S.D.) of conductivity, pH, turbidity, total and suspended solids, biochemical oxygen demand, total nitrogen, total phosphorus, thermotolerant coliforms and chlorophyll *a* at the Canoas II reservoir sampling sites in the 2011 wet and dry seasons.

CANOAS I reservoir

Canoas I reservoir is a 30.85 km^2 run-off-river system, not dendritic (6.1 shore line development index) and with about 6 days retention time (Table 4). The depth varied between 4 m (CIUp) and 14.2 m (CIdam) in wet season and between 2 m (CIUp) and 25.2 m (CIDam) in dry season.

Figure 18 shows the variations of reservoir level and flow throughout the year and also the water transparency in the different sampled sites. We can observe that there was no change in the reservoir level during the year. The highest flow occurred in January, approximately 609 m^3 s^{-1}, while lower ones occurred in June (413 m^3 s^{-1}).

A considerable increase of transparency was observed and dry season, compared to wet. In March, The lowest value of water transparency was observed in CIDam, 1.4 m (wet season), and at CIUp, with 2 m (dry season), while the highest was observed at CI1, 2.3 m (wet) and 3.6 m (dry).

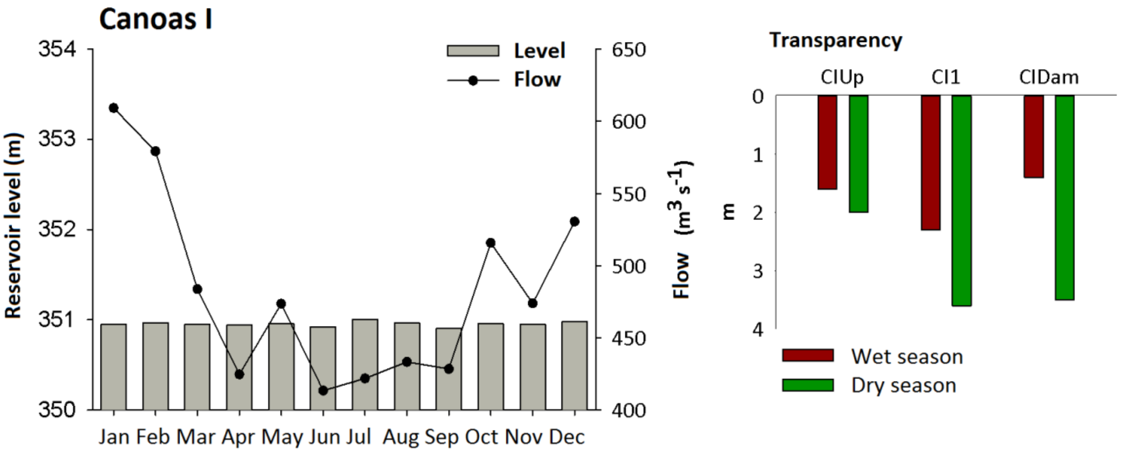

Figure 18 – Reservoir level and flow variation throughout the year (monthly average) and water transparency at the Canoas I reservoir sampling sites in the 2011 wet and dry seasons.

The temperature profiles along the water column show isothermal conditions in both sampled periods (Fig. 19), with values around 25-26 °C (wet) and 22-24 °C (dry season). At CIDam and C1, a higher average temperature was observed in relation to CIUp, probably due to a tendency of heat accumulation in the more lentic zone - less advective transport, deeper and of greater volume. Close to surface micro-stratification trends were observed in wet season, whit a small decrease in temperature (1 ^{o}C) in the first 2 m depth at CIDam and CI1. It is a daily phenomenon of surface heating, and in the dry season, the same was observed in CIDam, with lower amplitude of variation, 0.5 ^{o}C.

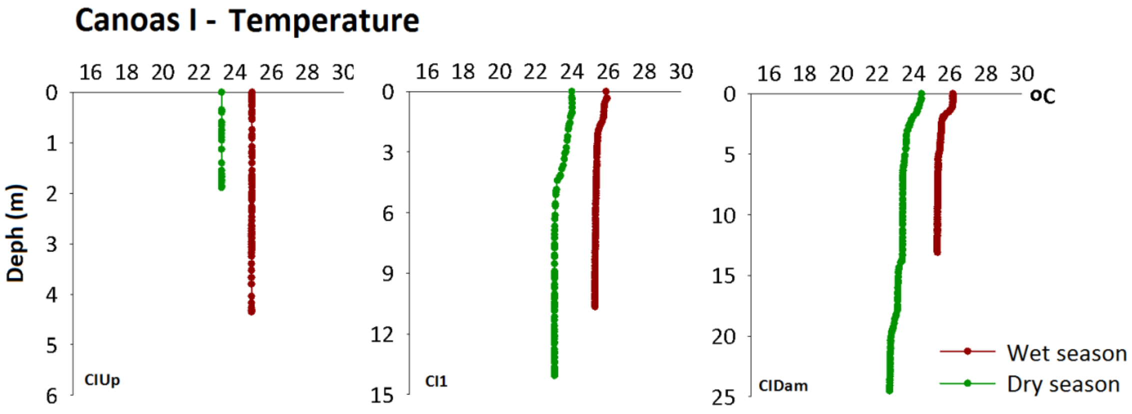

Figure 19 - Temperature profiles at the Canoas I reservoir sampling sites in the 2011 wet and dry seasons.

The dissolved oxygen concentrations in Canoas I reservoir are high and homogeneously distributed, or with a slightly decrease (CI1 and CIDam in the dry season), along the water column (Fig. 20). Mean values of oxygen ranged from 8.61 mg l^{-1}, CIDam, to 9.30 mg l^{-1}, CIUp, in wet season and between 8.31 mg l^{-1}, CIDam, and 8.87 mg l^{-1}, CIUp, in dry season.

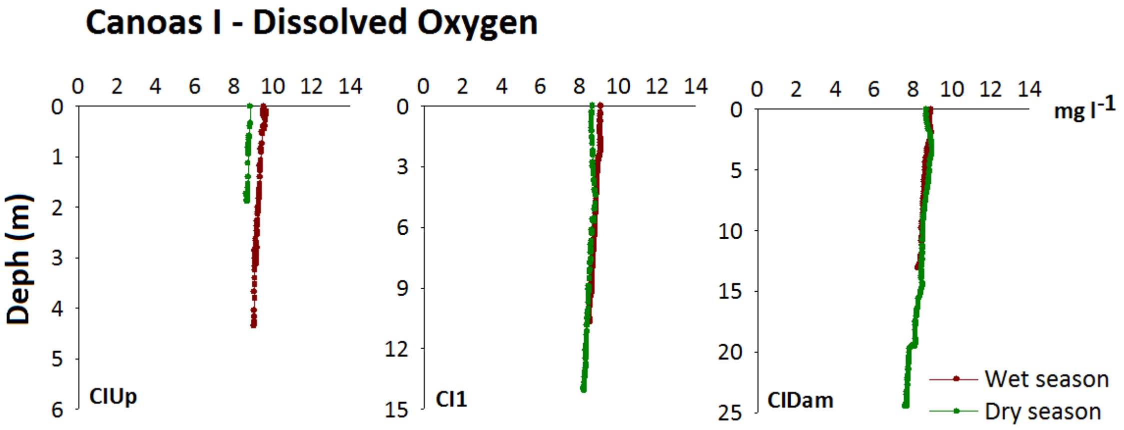

Figure 20 - Dissolved oxygen profiles at the Canoas I reservoir sampling sites in the 2011 wet and dry seasons.

The values of conductivity, pH, turbidity, total and suspended solids, biochemical oxygen demand, total nitrogen, total phosphorus, thermo tolerant coliforms and chlorophyll *a* for Canoas I reservoir are shown in Figure 21.

Minor variation between the sampling stations were observed for conductivity. In the wet season values ranged from 55.55 µS cm^{-1}, CIDam, to 57.34 µS cm^{-1}, CIUp, and in dry season from 56.34 µS cm^{-1}, CIUp, to 57.51 µS cm^{-1}, CIDam.

The pH values were slightly basic and homogeneous in both periods varying between 7 and 8.

Turbidity was higher in wet season ranging from 5.21 NTU, CI1, to 11.19 NTU, CIDam. The average values varied between 1.71 NTU, CIDam, and 3.11 NTU, CIUp, in the dry season.

The lowest value of total solids was measured at CIUp, 23.7 mg l^{-1}, in dry season and in turn, the highest values occurred in CIDam in the wet season, 74.7 mg l^{-1}.

Suspended solids concentrations varied between 0.74 mg l^{-1}, CIDam, and 1.75 mg l^{-1}, CIUp, in wet season and between 1.03 mg l^{-1}, CIUp, and 1.77 mg l^{-1}, CIDam, in dry season. The inorganic fraction exceeded the organic fraction, except for the prevalence of the organic fraction at CIUp and CIDam in the dry season.

Total nitrogen concentration ranged from 434 µg l^{-1}, CIUp, to 484.98 µg l^{-1}, CIDam, in wet season and from 278.61 µg l^{-1}, CIUp to 306.95 µg l^{-1}, CIDam, in dry season.

Total phosphorus concentrations ranged from 23.94 µg l^{-1}, CI1, to 27.06 µg l^{-1}, CIUp, in the wet season and from 8.17 µg l^{-1}, CI1, to 9.66 µg l^{-1}, CIDam, in the dry season.

The lowest values of the biochemical oxygen demand were measured in samples from CIUp, 0.3 mg l^{-1} O_2 (wet) and 0.6 mg l^{-1} O_2 (dry season). The highest value occurred at CIDam, 2.0 mg l^{-1} O_2 (wet season).

The concentration s of thermo tolerant coliforms were low in the dry season, varying between 3 NMP/100ml, CIDam, and 9 NMP/100ml, CIUp. In the wet season the CIDam site had a relatively low value, 93 MNP/100 ml, while in the others (CI1 and CIDam) concentrations were around 1,000 MNP/100 ml.

The chlorophyll *a* concentrations ranged from 0.51 μg l^{-1} (CIDam) to 1.30 μg l^{-1} (CI1), in the wet season and from 1.40 μg l^{-1} (CIUp) to 2.20 μg l^{-1} (CIDam), in the dry season.

The trophic status show a diversified range of water quality with Ultraoligotrophic up to Eutrophic conditions in the reservoir. Except for two total phosphorus values (CIUp – 27.06 μg l^{-1} and CIDam – 26.10 μg l^{-1}, wet season – for intermediate system with 2 up to 40 water retention days) and one thermo tolerant coliforms value (CIUp and CI1 NMP/100ml, wet season) all parameter are in agreement with CONAMA Resolution 357/2005 standards for Class 1 (Table 4).

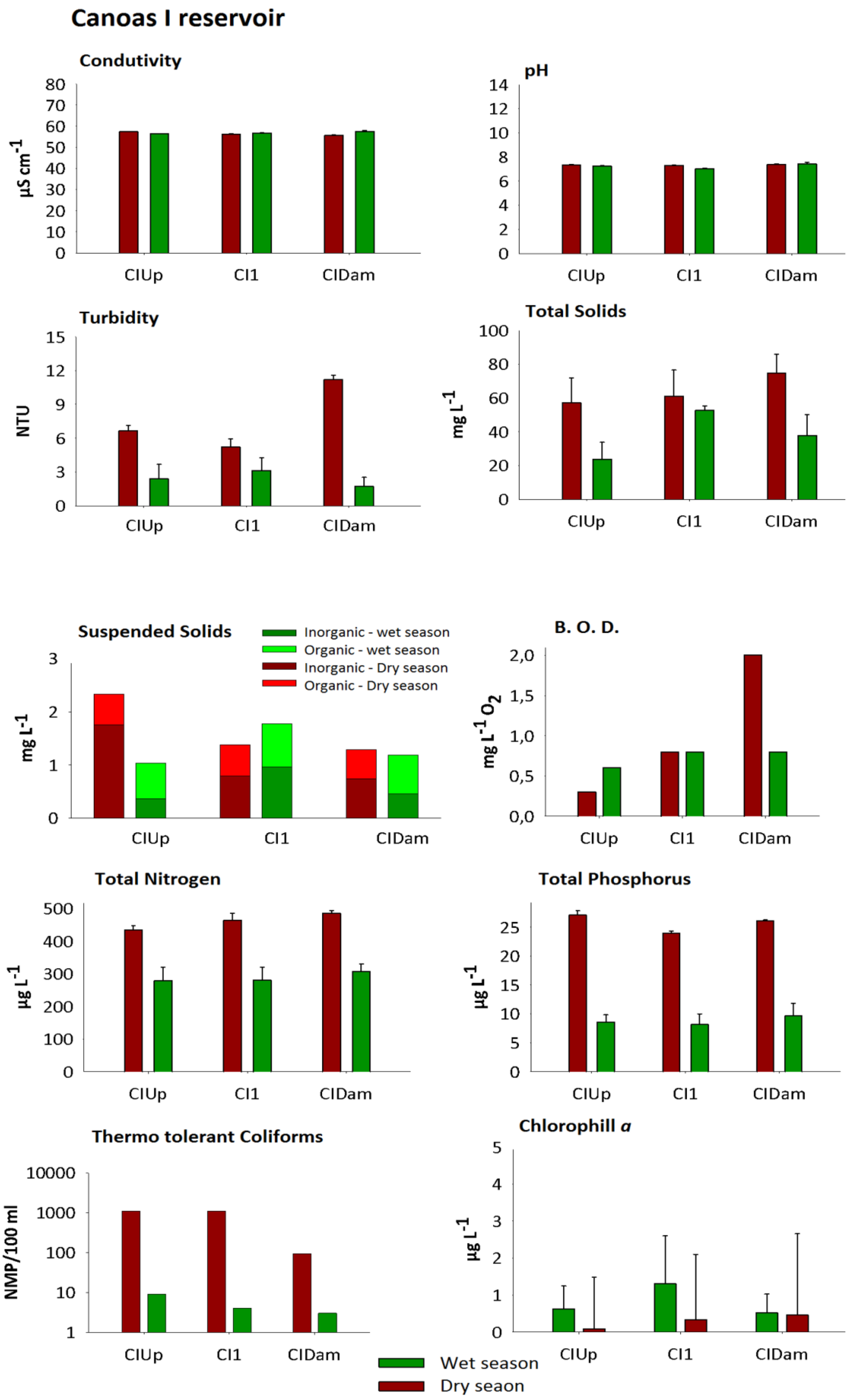

Figure 21 - Values (Mean, +S.D.) of conductivity, pH, turbidity, total and suspended solids, biochemical oxygen demand, total nitrogen, total phosphorus, thermo tolerant coliforms and chlorophyll *a* at the Canoas I reservoir sampling sites in the 2011 wet and dry seasons.

CAPIVARA reservoir

Capivara reservoir is a 576 km^2 storage system, very dendritic (18.2 shore line development index) and with about 115 days retention time (Table 4). The depth measurements varied between 3 and 42 m in the wet season and between 2.7 m and 29.5 m in the dry season with the lowest depth observed at CPUp and the highest at CPDam.

Figure 22 shows the variations of reservoir level and flow throughout the year and also the water transparency at the sampled sites. We can observe that there was a variation of 4 m in the reservoir level during the year with the lowest value in January (330 m) and higher during the months of April and May (334 m). The highest flow occurred in October, approximately 1442 m^3 s^{-1}, while the lowest in May (893 m^3 s^{-1}).

During the wet season the transparency values were lower, from 0.8 m at CP2 to 2,7 m at CPDam. In the dry season most sampling sites exhibited higher values, with maximum of 3.3 m at CPDam. However, very low values occurred at CP1 (0.18 m) , and CP2 (0.2 m).

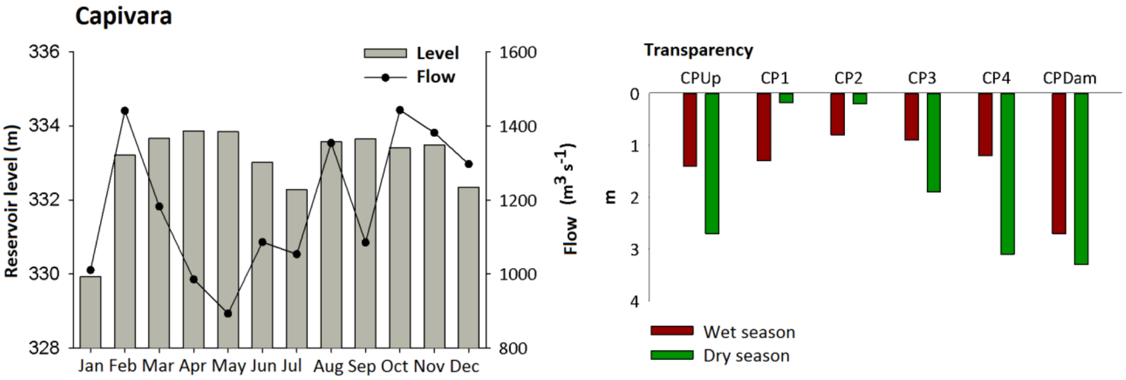

Figure 22 - Reservoir level and flow variation throughout the year (monthly average) and water transparency at the Capivara reservoir sampling sites in the 2011 wet and dry seasons.

The temperature profiles (Fig. 23) show different conditions along the reservoir. In the wet season, decreasing gradients of temperature toward the bottom(CP1, CP and CP3) and stratification (CP4 and CPDam) were observed, with a range of thermal variation of approximately 2 ^{o}C between surface and bottom. In the dry season, all stations showed isothermal condition along the water column, except for station CP2 that showed a gradual decrease of approximately 2 °C between depths 12 and 20 m. During this season, there was also a slight decrease in temperature, 1 °C, at the bottom of CPDam. Seasonal difference in temperature was low (2 to 3 °C).

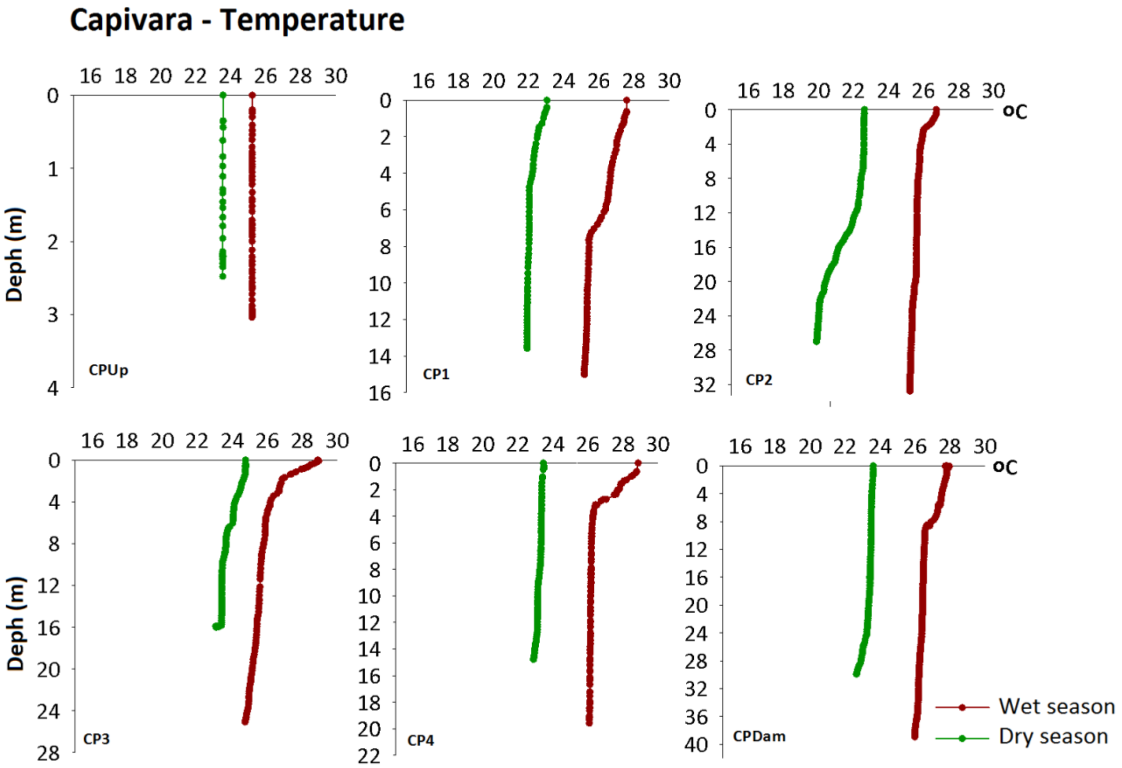

Figure 23 - Temperature profiles at the Capivara reservoir sampling sites in the 2011 wet and dry seasons.

The concentrations of dissolved oxygen in Capivara reservoir were high (Fig. 24). The averages varied between 8.03 mg l^{-1}, CP1, and 10.03 mg l^{-1}, CPUp, in the wet season and between 9.55 mg l^{-1}, CPUp, and 10.02 mg l^{-1}, CP4, dry season. At CPDam (wet) there was an increase in oxygen concentration along the water column and, subsequently, an abrupt decrease in the 30 m deep region (about 3 mg l^{-1}). At the other sampled sites, during wet season, there was a small increase in the first few meters of depth, followed by moderate decreases. In general, there was a gradual small decrease in oxygen concentrations along the water column in the dry season.

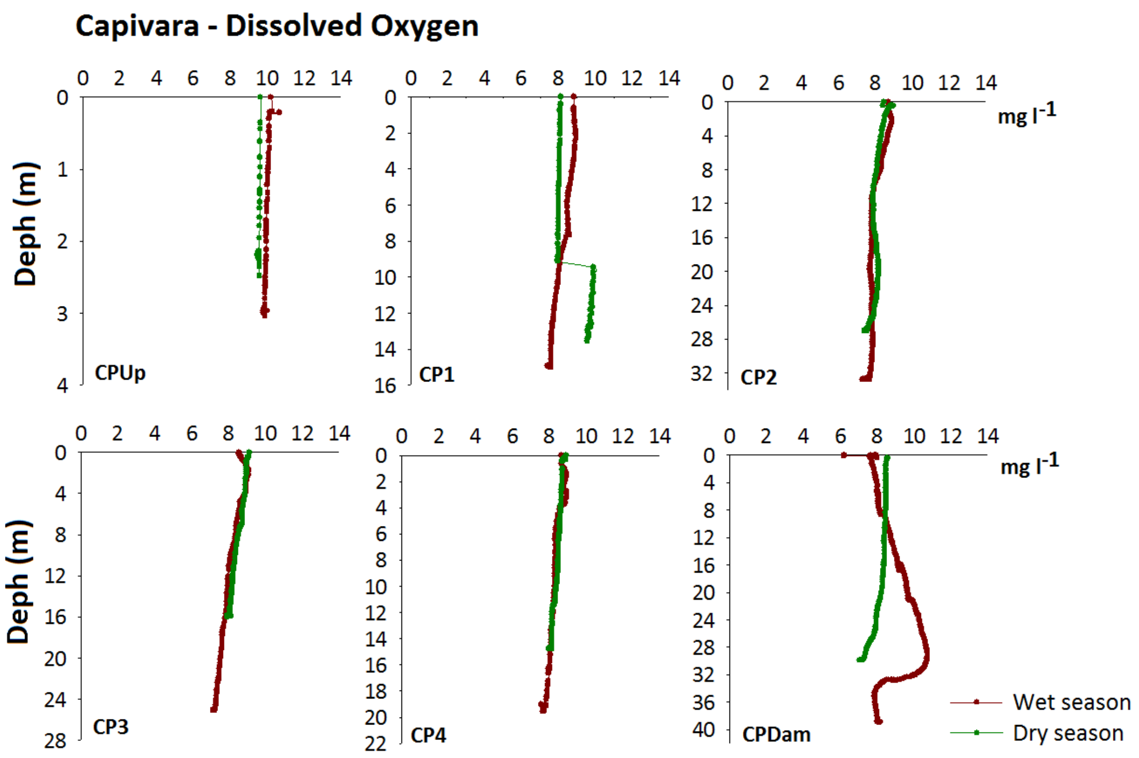

Figure 24 - Dissolved oxygen profiles at the Capivara reservoir sampling sites in the 2011 wet and dry seasons.

The values of conductivity, pH, turbidity, total and suspended solids, biochemical oxygen demand, total nitrogen, total phosphorus, thermotolerant coliforms and chlorophyll *a* for Capivara reservoir are shown in Figure 25.

The mean values of conductivity varied between 48.22 µS cm^{-1}, CP3, and 63.89 µS cm $^{-1}$, CP1, in the wet season and between 48.35 µS cm^{-1}, CP3, and 58.31 µS cm^{-1}, CP2, in the dry season.

Slightly basic pH values, ranging from 7 to 8, were observed in all sampled sites in both, wet and seasons.

During the wet season, higher turbidity occurred at CP2, 25.20 NTU, and CP3, 18.76 NTU, while the lowest value was observed at CPDam 8.90 NTU. In the dry season CPDam, 2.82 NTU, and CPUp, 2.84 NTU, showed the lowest values, while the highest ones occurred in CP2, 88.66 NTU, and CP1 144.48 NTU.

The lowest average value of total solids was obtained at CPUp, 69.7 mg l^{-1}, and the highest at CP4, 104.3 mg l^{-1}, in the wet season. In dry season values varied between 56 mg l^{-1}, CPUp, and 174.7 mg l^{-1}, CPDam.

The highest value of suspended solids in the wet season was observed at CP4 (5.32 mg l^{-1}) and the lowest values at CPDam and CPUp, below 2 mg l^{-1}. The concentration of suspended solids in the dry season was higher at CP1, 44.24 mg l^{-1}, and CP2, 19.96 mg l^{-1}, and lower than 2 mg l^{-1} at the others sampled sites. In the wet season, the inorganic fraction exceeded the organic fraction, except for CPUp, and in the dry season the inorganic fraction exceed organic fraction at stations CP1, CP2 and CP3.

The total nitrogen concentration in the water showed, in the wet season, the occurrence of higher values at CP3, 834.67 µg l^{-1} and lower at CPUp, 468.52 µg l^{-1}, and CP4, 638.73 µg l^{-1}. In the dry season values ranged from 343.24 µg l^{-1}, CPDam, to 818.67 µg l^{-1}, CP3.

Total phosphorus concentrations in water ranged from 21.07 µg l^{-1}, CPDam, to 40.17 µg l^{-1}, CP2, in the wet season and from 9.82 µg l^{-1}, CP4, to 67.18 µg l^{-1}, CP2, in the dry season.

The lowest values of the biochemical oxygen demand in the wet season occurred at stations CP4 (0.4 mg l^{-1} O_2) and CP3 (0.6 mg l^{-1} O_2), while the highest at CP2 (1.3 mg l^{-1} O_2), CP1 and CPUp (both, 1.2 mg l^{-1} O_2). In the dry season values varied between 0.4 mg l^{-1} O_2, CPDam, and 1.9 mg l^{-1} O_2, CP1.

The lowest values of thermo tolerant coliforms, <3 NMP/100ml, were observed at CPDam and CP1, in the wet season, as well as at CPUp, CP4 and CPDam, in the dry season. The highest value, 43 MNP / 100 ml, occurred at CP4 in the wet season.

The chlorophyll *a* concentrations ranged from 0.64 µg l^{-1}, CPUp, to 2.58 µg l^{-1}, CP4, in wet season and from 1.01 µg l^{-1}, CPUp, to 7 µg l^{-1}, CP1, in the dry season.

The trophic status show distinct water quality characteristics, from Ultraoligotrophic to Mesotrophic conditions in the reservoir of Capivara. Values of total phosphorus (all stations in the wet season and CP1 – 42.41 µg l^{-1} and CP2 – 67.18 µg l^{-1}, dry season) and turbidity (CP1 – 144.48 NTU and CP2 88.66 NTU, dry season) were above the standards of CONAMA Resolution 357/2005 for Class 1 (Table 4).

Capivara reservoir

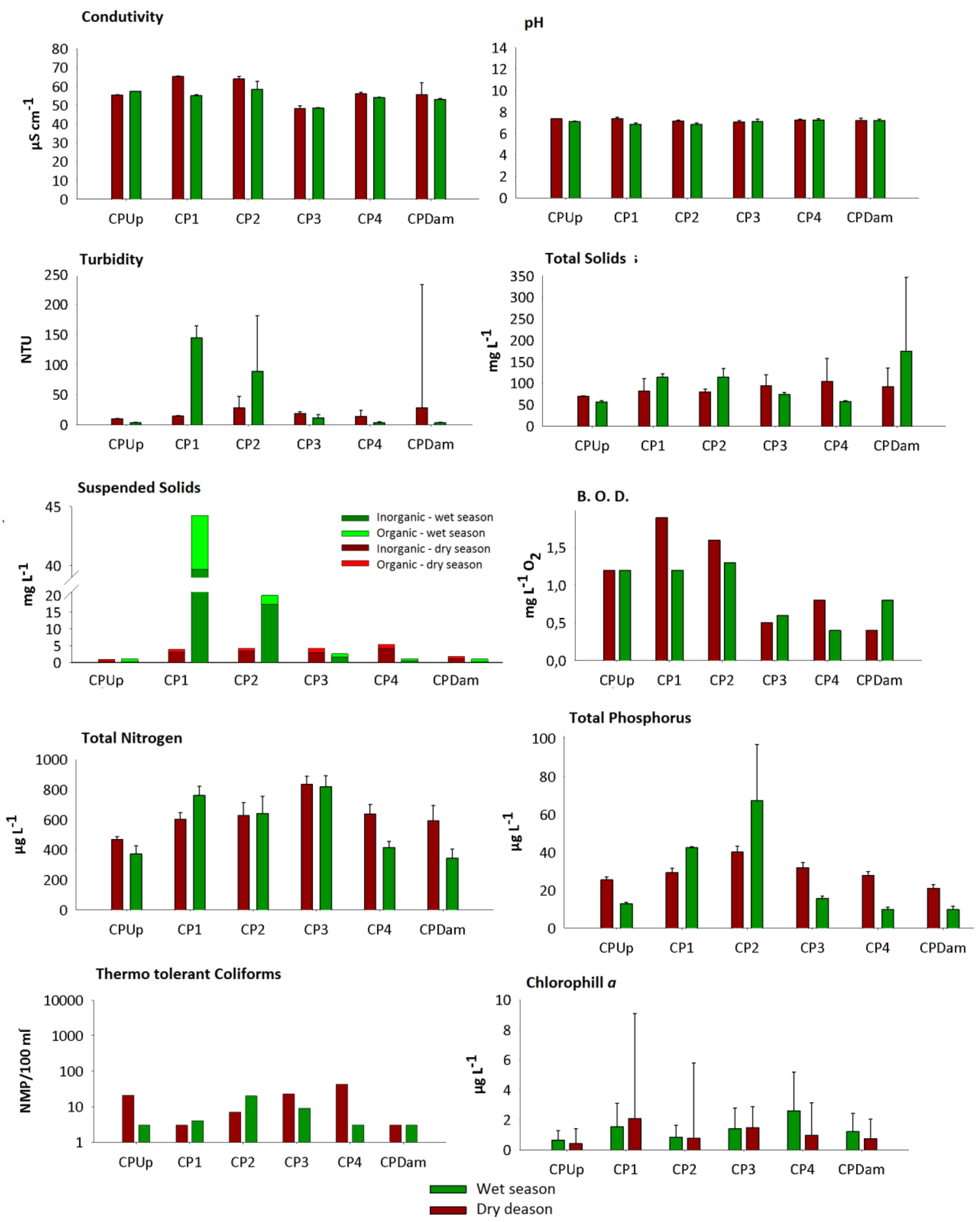

Figure 25 - Values (Mean, +S.D.) of conductivity, pH, turbidity, total and suspended solids, biochemical oxygen demand, total nitrogen, total phosphorus, thermotolerant coliforms and chlorophyll *a* at the Capivara reservoir sampling sites in the 2011 wet and dry seasons.

TAQUARUÇU reservoir

Taquaruçu reservoir is an 80.1 km^2 run-off-river system, not dendritic (9.5 shore line development index) and with about 7 days of water retention time (Table 4). The depth measured in the wet season varied between 9.5 m (TQUp) and 26 m (TQDam) and in the dry season between 9.5 m (TQUp) and 16 m (TQDam).

Figure 26 shows the variations of the reservoir level and flow throughout the year and also the variation of the water transparency in the different sampled sites. There was no significant variation in the reservoir level during the year. The highest flow occurred in February, approximately 1508 $m^3 s^{-1}$, while lower values occurred in May (914 $m^3 s^{-1}$).

Water transparency ranged from 1.8 m (TQUp) to 2.15 m (TQ1) in wet season and from 1.9 m (TQ2) to 2.2 m (TQDam) in dry season.

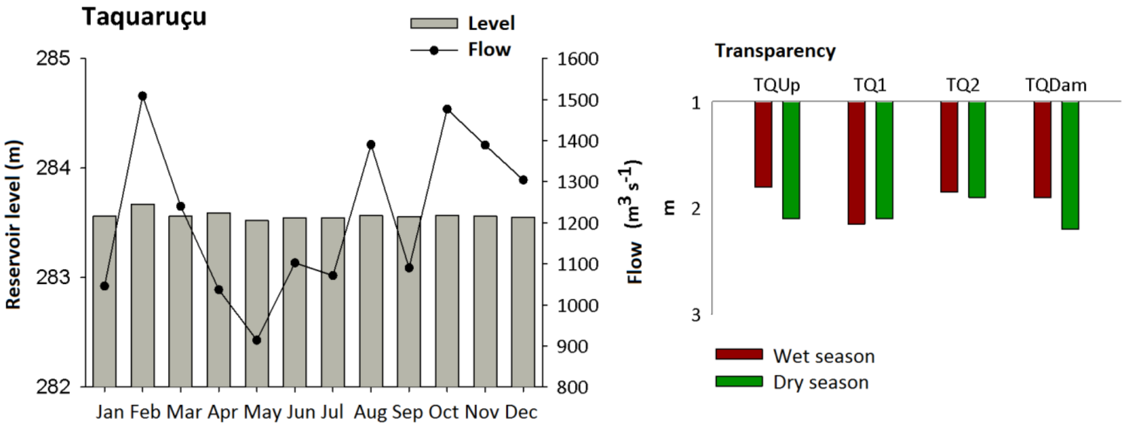

Figure 26 - Reservoir level and flow variation throughout the year (monthly average) and water transparency at the Taquaruçu reservoir sampling sites in the 2011 wet and dry seasons.

The temperature profiles (Fig. 27) show isotherm condition or small decreasing gradients in the different sampled sites along the reservoir in the wet and dry season. Mean values were around 27 °C, wet, and 23 °C, dry season.

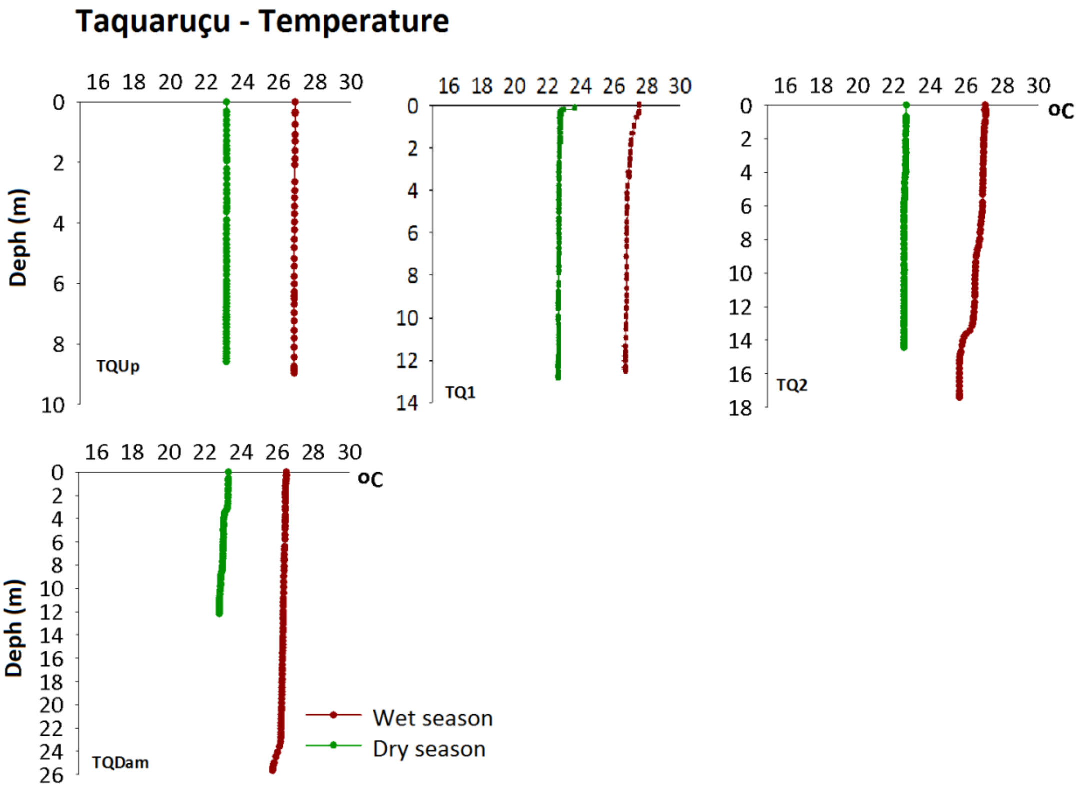

Figure 27 - Temperature profiles at the Taquaruçu reservoir sampling sites in the 2011 wet and dry seasons.

The concentrations of dissolved oxygen in Taquaruçu reservoir are high and homogeneously distributed along the water column (Fig. 28). Values ranged from 8.09 mg l^{-1}, TQUp, to 10.26 mg l^{-1}, TQ2, in the wet season and from 8.53 mg l^{-1}, TQ1, to 11.35 mg l^{-1}, TQUp, in the dry season.

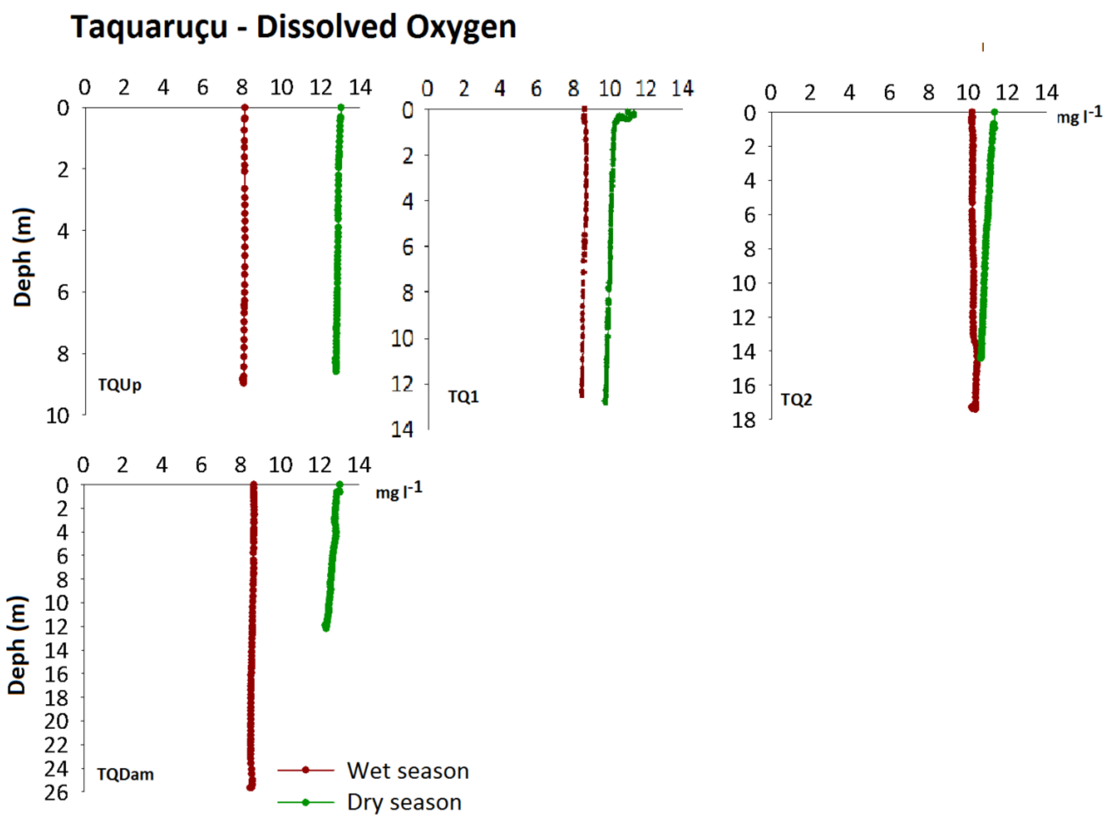

Figure 28 - Dissolved oxygen profiles at the Taquaruçu reservoir sampling sites in the 2011 wet and dry seasons.

The values of conductivity, pH, turbidity, total and suspended solids, biochemical oxygen demand, total nitrogen, total phosphorus, thermo tolerant coliforms and chlorophyll *a* for Taquaruçu reservoir are shown in Figure 29.

The mean values of conductivity were relatively homogeneous between the sampled sites and slightly higher in the wet season. The mean values were around 55 µS cm^{-1} and only at station TQ1, dry season, data along the water column exhibited some variation.

Neutral or slightly basic pH values, ranging from 7 to 7.5, predominated in both seasons, ranging from 6.78, TQDam ,to 7.35, TQ1, both in dry season.

The turbidity varied between 6.40 NTU, TQDam, and 9.78 NTU, TQUp, during the wet season. In the dry season a peak of 53.04 NTU was observed at TQ1, while the others sampled sites had lower values, ranging from 7.92 NTU, TQUp, to 9.50 NTU.

Total solids in the wet season ranged from 36 mg l^{-1}, TQ2, to 58.3 mg l^{-1}, TQ1, and in the dry season from 19.7 mg l^{-1}, TQDam, to 92.7 mg l^{-1}, TQ2.

Suspended solids were lower in wet season, reaching 1.51 mg l^{-1} at TQUp highest and 1.28 mg l^{-1} atTQ1. In the dry season the maximum was 7.82 mg l^{-1} at TQ1. The inorganic fraction exceeded the organic fraction, except for TQDam in the wet season.

The total nitrogen concentration showed the highest values in the wet season with averages ranging from 551.90 µg l^{-1}, TQ1, to 686.30 µg l^{-1}, TQUp. Values varied between 395.33 µg l^{-1}, TQDam, to 494.78 µg l^{-1}, TQUp, in the dry season.

Total phosphorus concentration ranged from 22.43 µg l^{-1}, TQDam, to 25.30 µg l^{-1}, TQUp, in the wet season and from 8.05 µg l^{-1}, TQUp, to 10.76 µg l^{-1}, TQ2, in the dry season.

The biochemical oxygen demand ranged from 0.4 mg l^{-1} O_2, TQ1, to 1.2 mg l^{-1} O_2, TQ2 in the wet season and from 0.8 mg l^{-1} O_2, TQ1, to 1.3 mg l^{-1} O_2, TQ2, in the dry season.

For thermo tolerant coliforms the values ranged from 4 NMP/100ml (TQDam and TQ1) to 15 MNP/100ml (TQ2) in the wet season and from 3 NMP/100ml (TQDam) to 4NMP/100ml in the others sampled sites in the dry season.

The chlorophyll *a* concentrations were slightly higher in the dry season, compared to wet season, except in TQ2. Values ranged from 0.35 µg l^{-1}, TQUp, to 0.71 µg l^{-1}, TQDam in wet season and from 0.62 µg l^{-1}, TQ2, to 1.68 µg L^{-1}, TQ1 in dry season.

The trophic status showed good water quality with Ultraoligotrophic conditions in the reservoir. Except for two values of total phosphorus (TQUp – 25.30 µg l^{-1} and TQ1 – 25.22 µg l^{-1}, wet season for intermediate system with 2 up to 40 water retention days) all parameter are in agreement with the standards of CONAMA Resolution 357/2005 for Class 1 (Table 4).

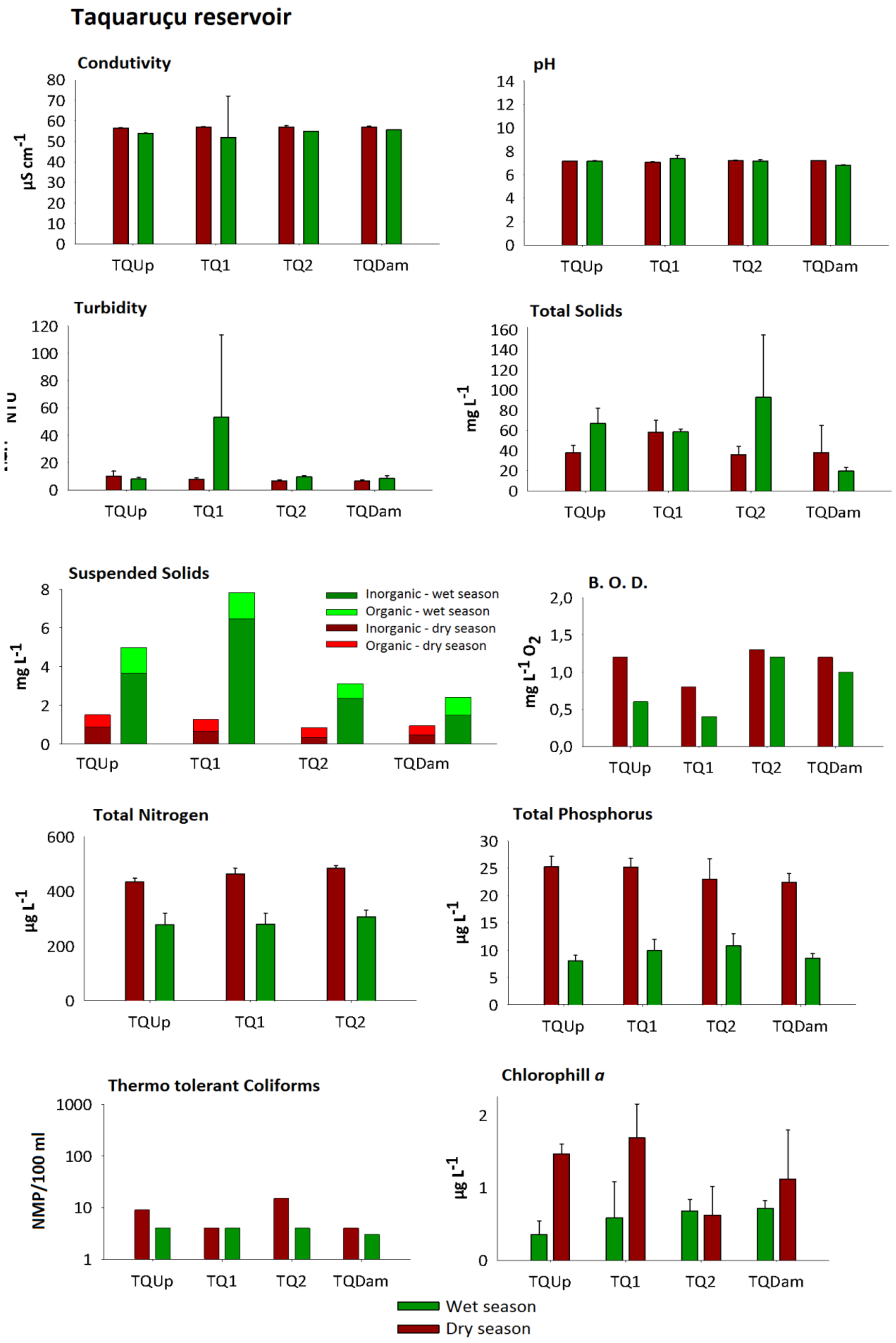

Figure 29 - Values (Mean, +S.D.) of conductivity, pH, turbidity, total and suspended solids, biochemical oxygen demand, total nitrogen, total phosphorus, thermo tolerant coliforms and chlorophyll *a* at the Taquaruçu reservoir sampling sites in the 2011 wet and dry seasons.

ROSANA reservoir

Rosana reservoir is a 220 km^2 run-off-river system, not dendritic (8.2 shore line development index) and with about 17 days of water retention time (Table 4).The depth ranged from 8.5 m (RS1) to 27 m (RS2) in the wet season and from 7 m (RS1) to 25.9 m (RSDam) in the dry season.

Figure 30 shows the variations of the reservoir level and flow throughout the year and also the water transparency in the sampled sites. We can observe that there was no significant variation in the reservoir level during the year. The highest flow was observed in February, approximately 1679 m^3 s^{-1}, while lower values occurred in the period of May (1014 m^3 s^{-1}).

The water transparency values were similar in all sampled sites in the wet season, varying between 1.3 m (RS2) and 1.6 m (RS1 and RSUp). However, in the dry season differences were much higher, between 0.3 m, RS1, and 2.8 m, RS2.

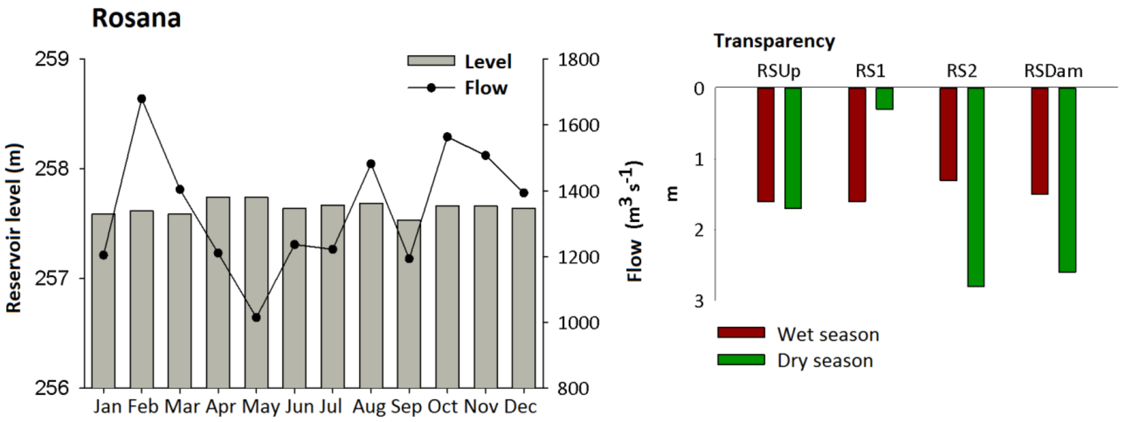

Figure 30 - Reservoir level and flow variation throughout the year (monthly average) and water transparency at the Rosana reservoir sampling sites in the 2011 wet and dry seasons.

The temperature profiles (Fig. 31) show that a homogeneous tendency prevailed in the wet season, with values around 26.5 °C, except for RSDam, where the temperature in the surface region was very high, near 28 °C. In the dry season it was observed isotherm conditions with temperature values around 23-24 °C along the water column. At RS2 and RSDam, dry season, it was observed only a small decrease of 1 °C towards the bottom.

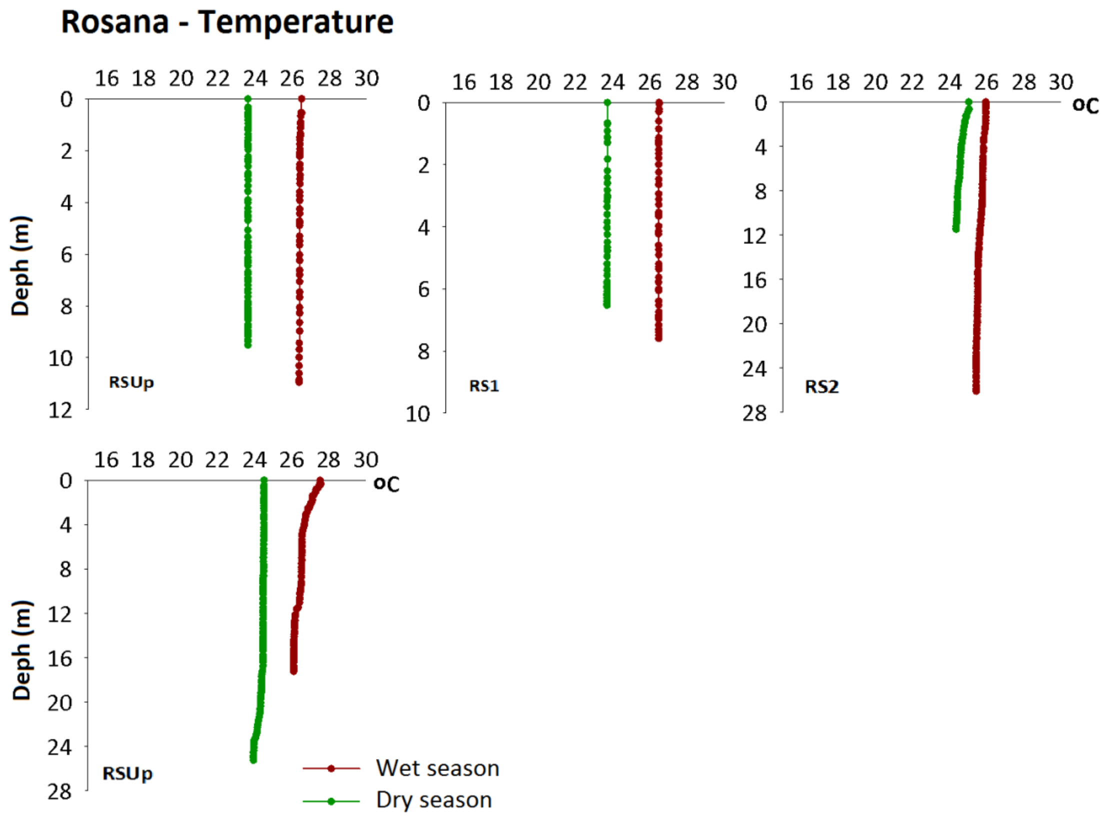

Figure 31 - Temperature profiles at the Rosana reservoir sampling sites in the 2011 wet and dry seasons.

The concentrations of dissolved oxygen in water are shown in Figure 32. High values were observed throughout the year with water column means ranging from 8.56 mg l^{-1}, RSUp, to 9.63 mg l^{-1}, RSDam, in the wet season and from 8.68 mg l^{-1}, RS2, to 11.11 mg l^{-1}, RSUp, in the dry season. Comparatively, the lowest concentrations occurred in the wet season, certainly influenced by the high water temperatures. The concentrations were practically homogeneous along the water column or showed a slight variation with depth.

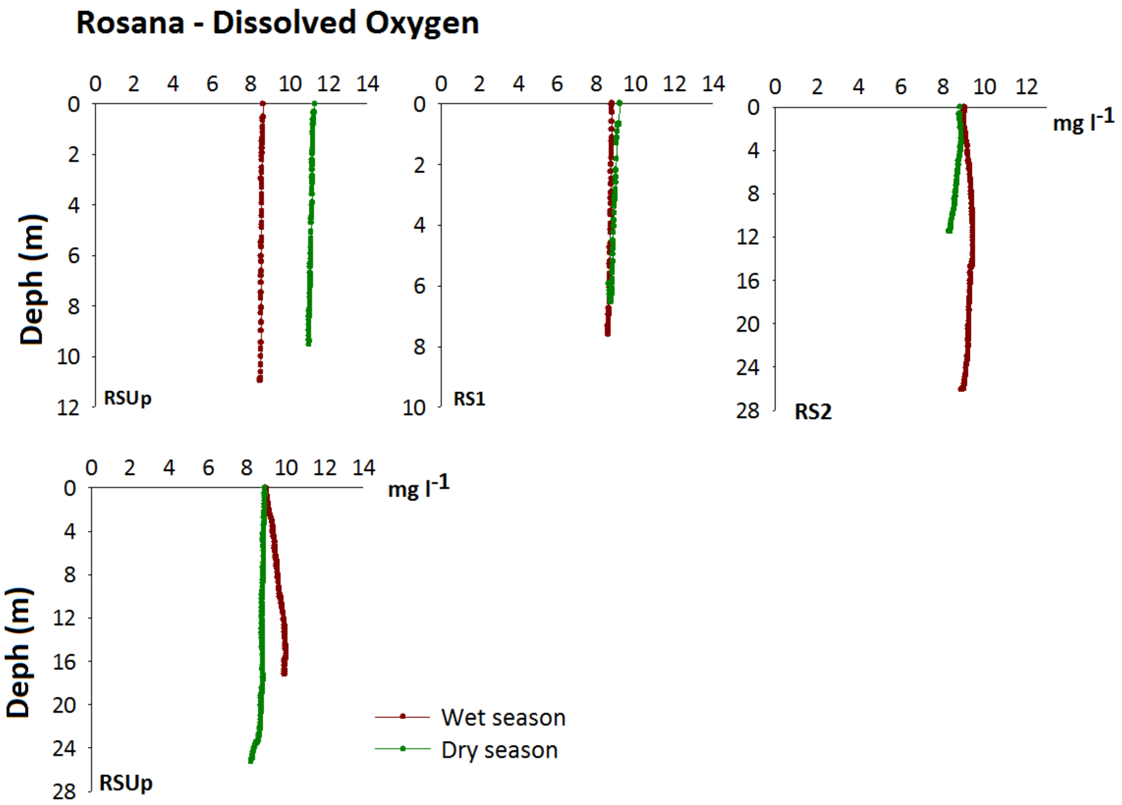

Figure 32 - Dissolved oxygen profiles at the Rosana reservoir sampling sites in the 2011 wet and dry seasons.

The values of conductivity, pH, turbidity, total and suspended solids, biochemical oxygen demand, total nitrogen, total phosphorus, thermo tolerant coliforms and chlorophyll *a* for Rosana reservoir are shown in Figure 33.

The conductivity variation was very similar in wet and dry seasons, ranging from 55.43 µS cm^{-1}, RS2, to 59.69 µS cm^{-1}, RSUp (wet), and from 55.34 µS cm^{-1}, RSUp, to 57.66 µS cm^{-1}, RSDam (dry season).

Slightly basic pH values ranging from 7 to 8 were observed in all sampled sites in both wet and dry seasons.

Turbidity values ranged from 8, 99 NTU, RSDam, to 14.03 NTU, RS2, in the wet season and from 3.94 NTU, RSDam, to 154.79 NTU, RS1, in the dry season. The high value observed in the dry season is atypical and is due to the effect of a large rainfall occurring at the time of sampling.

Total solids ranged from 64 mg l^{-1}, RS2, to 78.7 mg l^{-1}, RS1, in the wet season and from 64.3 mg l^{-1}, RSUp, to 99.3 mg l^{-1}, RS2, in dry season.

The suspended solids ranged from 1.40 mg l^{-1}, RSDam, to 5.99 mg l^{-1}, RSUp, in the wet season and from 1.4 mg l^{-1}, RS2, to 58.89 mg l^{-1}, RS1, in the dry period. The inorganic fraction exceeded the organic fraction, except for RSDam, in the wet season, and the inorganic fraction exceeded the organic fraction at RSUp and RS1 in the dry period.

Homogeneous values of total nitrogen concentration among the sampled sites occurred in the same season. Mean values were higher in the wet season, approximately 700 µg l^{-1}, compared to dry season, 470 µg l^{-1}.

The total phosphorus concentrations in the water ranged from 20.27 µg l^{-1} (RSDam) to 25.30 µg l^{-1} (RS1) in the wet season and from 6.83 µg l^{-1} (RSDam) to 22.16 µg l^{-1} (RS1) in the dry season.

The biochemical oxygen demand ranged from 0.8 mg l^{-1} O_2 (RSUp and RS1) to 1.3 mg l^{-1} O_2 (RSDam) in wet season and from 0.8 mg l^{-1} O_2 (RS1) and 1.9 mg l^{-1} O_2 (RSDam) in dry season.

The thermo tolerant coliforms values varied between <3 NMP/100ml, (RSDam, (wet and RS2, dry season) and 21 MNP/100ml, (RS1, wet and RS2, wet and dry season).

The chlorophyll *a* concentrations varied between 1.03 µg l^{-1}, RS1, and 1.52 µg l^{-1}, RSDam, in wet season and in the dry season between 1.71 µg l^{-1}, RSUp, and 7.50 µg l^{-1}, RS1.

The trophic status showed varied water quality with Ultraoligotrophic to Mesotrophic conditions in the reservoir of Rosana. Except for one turbidity value (RS1 - 154.79 NTU, dry season) and two total phosphorus values (RSUp – 25.22 µg l^{-1} and RS1 – 25.30 µg l^{-1}, wet season) all parameter are in agreement with CONAMA Resolution 357/2005 standard for Class 1 (Table 4).

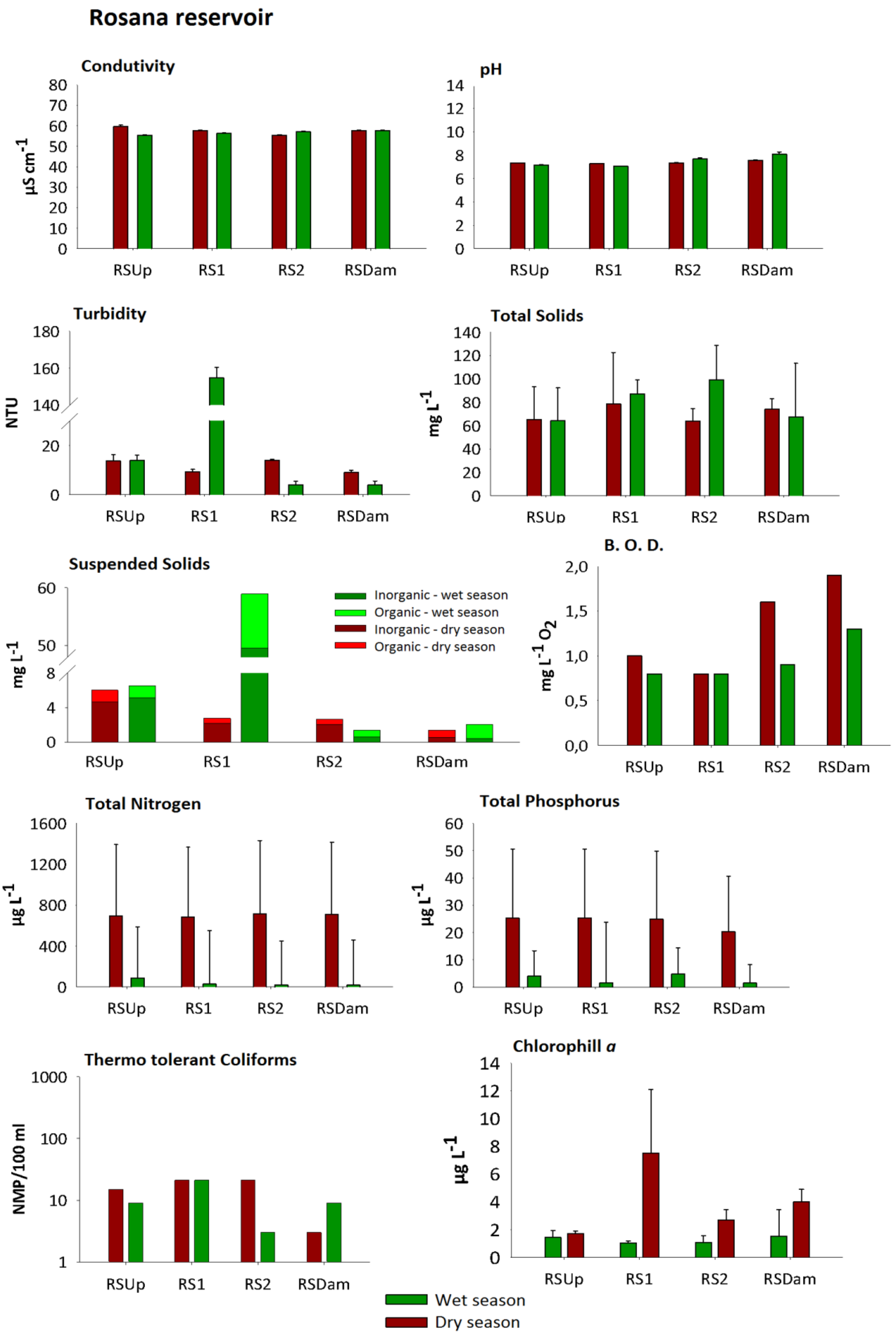

Figure 33 - Values (Mean, + S.D.) of conductivity, pH, turbidity, total and suspended solids, biochemical oxygen demand, total nitrogen, total phosphorus, thermotolerant coliforms and chlorophyll *a* at the Rosana reservoir sampling sites in the 2011 wet and dry seasons.

The first two axes (PC1 and PC2) of the principal component analysis corresponded to 48.3% of the ordering of the sampled sites in relation to the limnological variables (Table 5; Fig. 34).

In the first axis (PC1) the transparency, turbidity, inorganic suspended solids, organic suspended solids and chlorophyll a were the variables with greater influence on the ordering of the points. In axis two (PC2) the distribution was mainly influenced by temperature, pH, dissolved oxygen, total nitrogen and total phosphorus (Table 5; Fig. 34). The analysis demonstrates the strong influence of seasonality in the cascade of Paranapanema reservoirs.

Table 5 - Principal Component Scores for Paranapanema River reservoir cascade considering the first two Components.

Limnological Variables	**PC1 (30,7%)**	**PC2 (17,6%)**
Transparency	-0.405	-0.020
Deph	-0.125	0.052
Temperature	0.061	-0.545
pH	0.022	-0.420
Condutivity	0.100	-0.184
Turbidity	0.403	0.095
Dissolved Oxygen	-0.048	0.251
Biochemical Oxygen Demand	0.143	0.124
Total Solids	0.199	0.061
Inorganic Suspended Solids	0.415	0.191
Organic Suspended Solids	0.390	0.165
Total Nitrogen	0.225	-0.372
Total Phosphorus	0.284	-0.381
Chlorophill *a*	0.343	0.184
Themo tolerant Coliforms	0.089	-0.130

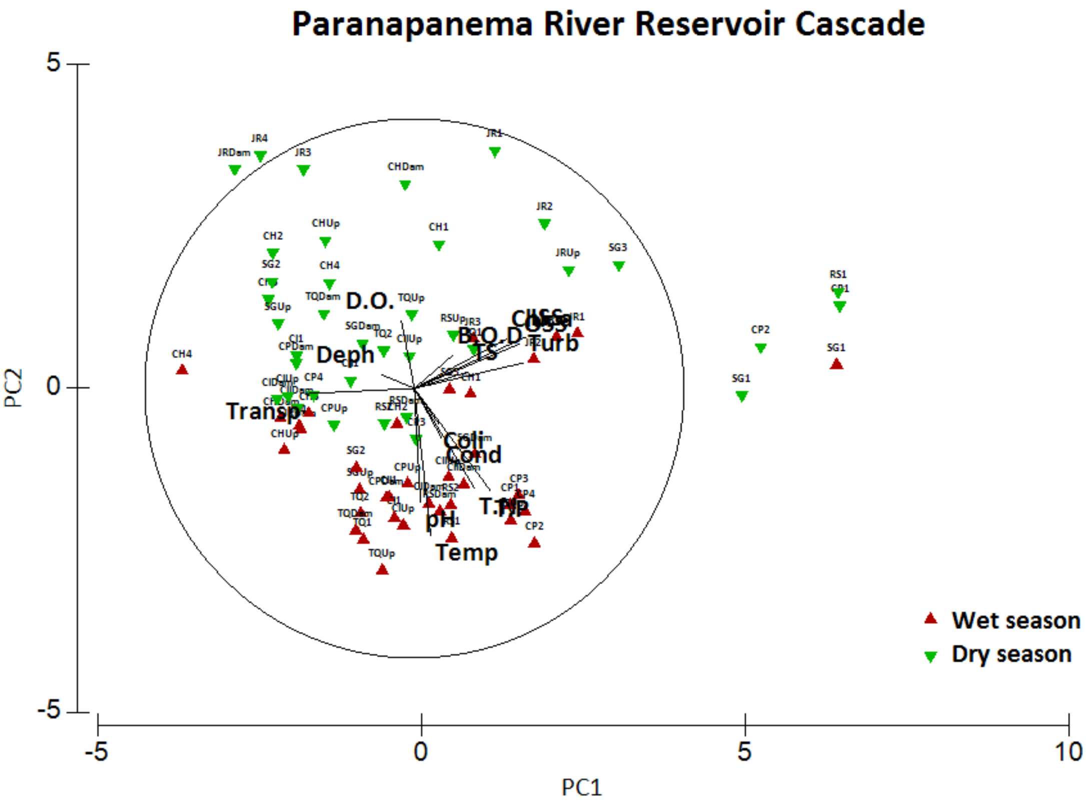

Figure 34 - Principal Component Analysis of Paranapanema River reservoir cascade considering the first two Components PC1 and PC2 and using the seasonality as the factor or ordination.

Discussion

Jurumirim reservoir

The Jurumirim reservoir exhibit a spatial organization pattern typical of large reservoirs, where gradual changes (gradient) of physical, chemical and biological conditions occur along the main axis established between the upstream (lotic zone) and the dam (lentic zone). For example, it was observed a clear increasing tendency, approximately 5 times, of transparency towards the dam for both seasons, and the opposite for turbidity and suspended solids. The reservoir showed a stratification tendency in the wet-warmer period (late summer – March), which has a strong influence on the limnology of the system. Oxygen values, for example, were high along the water column, except for the deep zone of the dam region during the wet season (<5mg l^{-1}), certainly due to an extended period of summer stratification. The pH, as well as the temperature, also presented a considerable seasonal variation, with more basic values in the wet season and neutral or slightly acid in the dry season. Only at the

JR2 station, a slightly higher value of chlorophyll (around 3.0 μg l^{-1}) was recorded, as a function of the local hydrodynamics, since this is an arm with little circulation of the water.

Chavantes reservoir

Initially, it is important to consider that the sampling design for Chavantes reservoir is based on the existence of two "longitudinal axes": one of them formed along the Itararé River Valley (CH1, CH2 and CH3), with lateral insertion into the Paranapanema River, and the other corresponding to the Paranapanema River channel, properly (CHUp, CH4 and CHDam). The analysis of the limnological characteristics of Chavantes reservoir corroborates the occurrence of these two large distinct compartments. In general, variables such as turbidity, suspended solids, total nitrogen and total phosphorus (in this case only for wet season) exhibited lower values in the Paranapanema axis, compared to the Itararé axis.

In both spatial axes a longitudinal pattern of increase of water transparency towards the dam was also observed, with the highest values in the Paranapanema axis (CHUp, CH4 and CHDam). Unlike the upper areas of the reservoir, the transparency in the lacustrine zone is less affected by the summer heavy rains.

Due to its large size, and by the fact that it is operated as a storage system, there is a large seasonal variation of the water level. The pH values observed in the Chavantes reservoir showed a high seasonal variation, tending to a more acidic condition in the dry season and more basic in wet season. However, the influence of important factors associated with the annual variation of precipitation (e.g. sediment supply) is limited to upstream zones, mainly on the Itararé axis.

With the exception of the CHUp, the Chavantes reservoir had a well defined thermal stratification, mainly in the central channel and lacustrine zone near the dam.

The variation of dissolved oxygen corroborates the temperature patterns, in general, decreasing with depth in the wet and dry season. Low oxygen values were measured in the deep zones of the lentic region. This shows that this compartment, due to the high depth, has a limited vertical circulation. A good indicator of the reservoir water quality condition is the low chlorophyll *a* values (maximum around 2 μg l^{-1}).

Salto Grande reservoir

Although it is a relatively small reservoir, there is a wide spatial and temporal variation of the limnological conditions and water quality in Salto Grande reservoir. The study demonstrates the influence of seasonality and compartmentalization on the physical, chemical and biological characteristics of water. The importance of the contribution of the tributary rivers to the central body of the reservoir is also an extremely relevant factor. The transparency of water, for example, is high in the upstream region (SGUp) influenced by the waters of the Chavantes reservoir (Paranapanema River) located upstream, and low at the mouth of the Pardo River (SG1). The opposite pattern of variation, as expected, was verified for turbidity and suspended solids. In the case of turbidity values <5 NTU occurred in the SGUp and SG2 (wet and dry seasons) and >80 NTU in SG1 (wet season).

It is a reservoir where isothermal conditions prevail, with continuous and complete mixing of the water column (high oxygen values). Tendency for surface stratification (microstratification) during the wet season in the lentic region was detected. The pH values observed in the Salto Grande reservoir showed a significant seasonal variation, with more neutral values in the wet season and slightly basic ones in the wet season.

The highest concentrations of total nitrogen were observed at SG1 9Pardo river mouth) and SGDam, also under the influence of Pardo River. The same occurred for total phosphorus and chlorophyll *a*.

Canoas II reservoir

The results for Canoas II reservoir demonstrate the existence of a moderate spatial gradient between the upstream zone and the dam zone. Seasonally important changes in the dynamics of the system were observed. There was an increasing trend of transparency towards the dam (lentic environment). Likewise, a decreasing longitudinal gradient of the turbidity and suspended solids concentration was observed.

In terms of thermal structure, there was a prevalence of isothermal conditions or a slightly gradual decrease of temperature with depth. The concentrations of dissolved oxygen were high and had a vertical distribution pattern similar to that observed for temperature, with relatively homogeneous values along the water column or with small gradients. The pH values showed a considerable variation temporal variation, tending to a more basic condition in the wet season and intermediate values in the dry season. The concentrations of nutrients (nitrogen and phosphorus) were similar between the different regions of the reservoir for the same season.

Canoas I reservoir

The Canoas I reservoir is highly influenced by the seasonal variations. Spatially (longitudinal), it presented a moderate compartmentalization. A considerable reduction of water transparency was observed during the wet season period. Longitudinally there was an increase in transparency, with lower values at CIUp and higher values at CI1. The inverse, that is, a decreasing gradient towards the dam, was verified for suspended solids (wet season).

Much higher concentrations of nutrients (nitrogen and total phosphorus) in water occurred in the wet season and lower in the dry season.

During both season predominated isothermal profiles or micro stratification tendencies close to the surface in CI1 and CIDam. This thermal structure indicates a continuous circulation of the water mass in the system, resulting in a homogeneous or relatively homogeneous distribution of the others physical and chemical variables along the water column. An increasing gradient of chlorophyll *a* towards the dam zone occurred in the dry season.

Capivara reservoir

The results obtained in the Capivara reservoir demonstrate the great influence of both spatial compartmentalization and seasonal variation on the physical and chemical characteristics. An increasing longitudinal gradient of transparency evidences the highest light penetration in the lacustrine zone. The temperature profiles show different conditions along the reservoir. In the wet season it was seen increasing gradients of temperature and superficial stratifications, contrasting to more isothermal conditions in the dry season. This variability in the thermal structure influenced the distribution of oxygen. In general, the concentrations were high, although slightly lower in summer due to the higher temperatures.

The spatial compartmentalization of the system was also indicated by variations in the conductivity values between the different sampling sites.

The pH values remained close to neutrality or were slightly basic. This variable is also an indicator of the spatial complexity of the system.

In the dry season, there was a wide variation of the suspended solids concentration, up to 20 times, according to the sampling site. During this period there was a decreasing trend toward the dam.

The concentrations of nutrients (nitrogen and phosphorus) varied widely among the different compartments of the reservoir. The nutrients and chlorophyll *a* concentrations can be considered relatively high when compared to the other reservoirs of the Paranapanema River.

Taquaruçu reservoir

The results obtained in the Taquaruçu reservoir show a limited spatial compartmentalization. However, there was considerable seasonal changes.

Although transparency values were higher in the dam area during dry season, a longitudinal gradient from the upstream was not evident. The same was observed for the suspended solids.

Isothermal condition or small decreasing gradients of temperature, was observed at the different sampled sites along the reservoir. The continuous mixing condition of the water column causes the oxygen values to be high in both seasons. The pH was close to neutrality or slightly basic in the dry and wet season. The concentrations of nutrients were much higher in the rainy season.

Rosana reservoir

The results obtained in the Rosana reservoir show a moderate influence of the spatial compartmentalization on the physical and chemical characteristics of the water. However, the effects of seasonality are clear.

Water transparency, for example, showed lower values in the wet season and turbidity data were higher in both seasons There was no recurring tendency of increase or decrease in transparency along the main axis of the reservoir. However, a longitudinal decrease of the suspended material was verified for the wet season.

In both seasons and sites the vertical profiles of temperature are homogeneous or have small decreasing gradients. This pattern determines the homogeneous distribution of oxygen throughout the water column. Comparatively, lower concentrations of oxygen occurred in the wet season, certainly due to the negative influence of higher temperatures.

The pH was slightly basic in the wet season and intermediate in the dry season.

The RS1 station is located in the river-reservoir transition zone of the reservoir, after a sharp curve of the river, where the sedimentation of particles is intense resulting in higher concentrations of nutrients and suspended solids, and also hlorophyll *a* (dry season).

Nutrient concentrations (nitrogen and phosphorus) were higher in the wet season compared to dry season.

Based on the limnological characteristics of each reservoir we can verify the distinctiveness of the two types of hydropower reservoirs defined in terms of functioning: storage and run-of-river systems. Both exhibit riverine, intermediate, and lentic compartments, but better discriminated in storage systems. In run-of-river reservoirs (short water retention time), the shape is generally simpler and shallower, and the water level variation has of low amplitude and high frequency (daily) as seen in Salto Grande, Canoas II, Canoas I, Taquaruçu and Rosana. Conversely, Jurumirim, Chavantes and Capivara are typical storage reservoir, with dendritic shapes, greater physical stability, depth, volume, area, and variation in water level, and also seasonal thermal stratification. Such patterns have been previously demonstrated in Brazil by

Soares et al. (2008), Nogueira et al. (2012) and Perbiche-Neves et al. (2013) and supports the second hypothesis proposed by this work.

In a comparative study of Chavantes and Salto Grande Perbiche-Neves et al., (2013) detected that due to the longer water retention time and larger area, compartmentalization in Chavantes Reservoir was more evident. There was contrasting conditions between the lotic region and the intermediate/lentic one. The author also pointed out for Salto Grande that the lateral variability was proportionally more important with a clear influence of the Pardo River entrance, and also a certain degree of separation of Novo River entrance (correspond to our 16 site – SG3), especially due to the influx of water with lower transparency and higher concentrations of suspended solids.

The rainfall pattern is similar along the cascade reservoirs, with higher values in summer (December-February) and lower in autumn/winter (April to September). This seasonal regime had already been identified as an important factor influencing the limnological functioning of the distinct Paranapanema River reservoirs (Nogueira et al., 2002, 2006; Jorcin and Nogueira, 2005; Pagioro et al., 2005; Henry et al., 2006; Nogueira et al., 2012).

According to Cunha et al. (2013) the prediction of trophic state may be more complex in tropical/subtropical freshwaters because there are more environmental constraints controlling nutrient dynamics and the phytoplankton responses in such water bodies. The main reason for establishing a specific index for tropical/subtropical reservoirs different from the Carlson’s one is that this classical model only considers the highest productive seasons in temperate lakes (spring and summer), whilst tropical/subtropical systems may have high primary production through the year (e.g. Calijuri and Santos, 2001). High rainfall in tropical/subtropical regions may increment the nonpoint sources from urban or agricultural areas and unbalance the biogeochemical cycles (Qin et al., 2010; Thothong et al., 2011; Cunha et al., 2013). High temperatures increase evaporation rates (Freire et al., 2009) and possibly affect the circulation movements in the reservoirs water column.

The increasing trophic gradient observed along the cascade of Paranapanema River reservoirs is evidenced by differences in the concentration of total dissolved solids or particulates in water, reflecting variations of geological nature, soil use and occupation, and precipitation/evaporation rate (Jorcin and Nogueira, 2005). Therefore, our first hypothesis is corroborated. The influence of the intensification of the land use in the Paranapanema River middle stretches is a determinant process, comparable to the influence of the river damming.

The proper discrimination of the main tendencies of limnological variability and recurrent patterns could be useful to improve the programs of reservoirs environmental management as well as the water quality monitoring protocols.

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Appendix 1 - Limnological variables (mean values for the water column) measured in the Paranapanema River reservoir cascade in the wet season.

Wet season	Secchi disc	Deph	Temp.	pH	Cond.	Turb.	D.O.	B.O.D	T.S.	Inorg. S.S.	Org. S.S	T.N	T.P	S.R.P	Chl. *a*	Thermo Coli
	(m)	(m)	(°C)		(µS cm^{-1})	(NTU)	(mg l^{-1})	(mg l^{-1} O^{2})	(mg l^{-1})	(mg l^{-1})	(mg l^{-1})	(µg l^{-1})	(µg l^{-1})	(µg l^{-1})	(µg l^{-1})	(NMP/100 ml)
JR1	0.65	5.1	24.06	7.11	45,46	25.69	9.13	1.3	53.3	8.49	2.57	382.71	20.71	19.65	2.65	93
JRUp	0.65	15	23.71	7.19	44,40	42.98	8.70	1,0	75.0	6.95	1.72	424.51	24.07	30.34	2.56	4
JR2	0.9	18	24.12	7.41	60,57	25.53	9.36	1.2	97.0	4.57	1.65	288.88	17.01	14.05	2.94	4
JR3	1.00	23.3	23.54	7.42	49,85	17.31	8.81	1.6	89.7	3.28	1.03	349.38	13.30	20.96	2.31	4
JR4	2.3	28.8	24.29	7.35	53,62	3.74	8.69	0.2	71.0	0.71	0.90	304.65	11.20	6.16	0.85	15
JRDam	3.00	32	24.79	7.59	52,29	1.73	8.62	0.8	68.3	0.66	1.18	283.17	13.63	5.17	1.01	11
CH1	0.8	17.8	23.73	7.25	54,86	28.51	8.73	0.9	36.0	4.37	1.31	382.63	19.05	15.86	1.07	<3
CH2	1.7	24	24.33	7.62	53,22	14.85	9.18	1.2	46.0	1.49	0.96	406.03	16.59	10.76	1.03	<3
CH3	3.8	48	22.63	7.39	54,12	7.03	8.29	1.3	56.3	1.01	0.71	392.98	17.47	5.66	0.44	4
CHUp	2.7	10	25.44	7.62	50,74	1.98	10.07	0.5	32.7	1.01	0.82	303.33	14.19	11.42	0.86	43
CH4	3.75	45	22.31	7.21	51,04	2.48	9.62	0.8	11.3	0.39	0.54	301.88	12.82	10.93	0.48	4
CHDam	5.5	74.4	21.44	7.18	51,57	5.39	7.75	1.2	35.3	0.61	0.88	372.22	39.76	5.17	0.47	4
SGUp	3.5	3.5	25.49	7.41	54,20	2.30	9.37	0.9	55.3	1.63	0.74	349.92	2.,62	8.95	1.10	>1100
SG1	0.25	4.4	24.24	7.39	62,68	85.41	10.19	1.2	42.3	32.53	7.10	480.55	36.90	64.56	10.30	>1100
SG2	3.5	6.4	25.71	7.41	53,31	1.43	9.19	2.8	51.3	0.51	0.59	367.05	17.70	11.25	1.79	>1100
SG3	0.85	4.9	24.98	7.16	47,98	16.67	9.23	1.2	57.0	2.67	1.31	263.37	20.90	18.82	0.59	93
SGDam	1.65	10.2	25.12	7.38	57,06	19.56	9.36	0.8	73.0	4.98	1.34	418.82	22.42	37.42	0.68	43
CIIUp	1.3	8	25,48	7.37	56,21	10.70	8.97	1,0	44.7	2.71	1.11	414.38	21.79	10.27	0.93	93
CII1	1.5	12,4	25.09	7.42	56,48	8.76	9.04	0.6	23.0	2.36	0.94	432.2	21.71	13.89	0.66	93
CIIDam	1.75	13	25.22	7.48	57,39	7.59	9.13	0.8	110.7	1.82	1.05	418.47	21.71	100.60	1.76	>1100
CIUp	1.6	4	24.91	7.34	57,34	6.66	9.30	0.3	57.0	1.75	0.58	434.00	27.06	13.89	0.62	>1100
CI1	2.3	9	25.37	7.29	56,15	5.21	8.80	0.8	61.0	0.78	0.59	463.77	23.94	7.97	1.30	>1100
CIDam	1.4	14.2	25.51	7.37	55,55	11.19	8,61	2,0	74.7	0.74	0.55	484.98	26.10	7.31	0.51	93
CPUp	1.4	3	25.22	7.35	55,35	9.84	10.03	1.2	69.7	0.42	0.50	468.52	25.47	13.23	0.64	21
CP1	1.3	16	25.60	7,14	63,89	14.17	8.03	1.2	81.7	3.04	0.96	602.18	29.30	12.41	1.54	<3
CP2	0.8	33	25.91	7.38	65,17	25.20	8.20	1.3	79.7	3.41	0.89	626.1	40.17	10.60	0.82	7

Wet season	**Secchi disc**	**Deph**	**Temp.**	**pH**	**Cond.**	**Turb.**	**D.O.**	**B.O.D**	**T.S.**	**Inorg. S.S.**	**Org. S.S**	**T.N**	**T.P**	**S.R.P**	**Chl. *a***	**Thermo Coli**
	(m)	**(m)**	**(°C)**		**(µS cm^{-1})**	**(NTU)**	**(mg l^{-1})**	**(mg l^{-1} O^{2})**	**(mg l^{-1})**	**(mg l^{-1})**	**(mg l^{-1})**	**(µg l^{-1})**	**(µg l^{-1})**	**(µg l^{-1})**	**(µg l^{-1})**	**(NMP/100 ml)**
CP3	0.9	26	25.92	7.05	48,22	18.76	8.09	0.6	94.3	2.90	1.33	834.67	31.86	7.97	1.39	23
CP4	1.2	20	26.39	7.26	56,08	12.61	8.29	0.4	104.3	4.16	1.16	638.73	27.70	6.49	2.58	43
CPDam	2.7	40	26.58	7.22	55,48	8.90	8.91	0.8	92.0	1.12	0.61	592.95	21.07	5.66	1.21	<3
TQUp	1.8	9.5	26.85	7.14	56,38	9.78	8.09	0.6	37.7	0.87	0.64	686.3	25.30	4.51	0.35	9
TQ1	2.15	13	26.88	7,07	56,86	7.71	8.61	0.4	58.3	0.66	0.61	551.9	25.22	4.51	0.59	4
TQ2	1.85	18	24.41	7.22	56,96	6.65	10.26	1.2	36.0	0.34	0.51	624.3	22.99	4.51	0.68	15
TQDam	1.9	26	26.29	7.17	56,91	6.40	8.56	1,0	38.0	0.46	0.49	634.43	22.43	7.14	0.71	4
RSUp	1.6	11	26.40	7.31	59,69	13.73	8.56	0.8	65.3	4.61	1.38	696.43	25.22	7.31	1.44	15
RS1	1.6	8.5	26.46	7.17	57,63	9.39	8.71	0.8	78.7	2.17	0.59	683.13	25.30	8.13	1.03	21
RS2	1.3	27	25.61	7.34	55,43	14.03	9.24	0.9	64.0	2.04	0.64	716.05	24.91	11.42	1.08	21
RSDam	1.5	18	26.49	7.56	57,70	8.99	9.63	1.3	74.0	0.51	0.90	707.25	20.27	6.49	1.52	<3

Appendix 2 - Limnological variables (mean values for the water column) measured in the Paranapanema River reservoir cascade in the dry season.

Dry season	**Secchi disc**	**Deph**	**Temp.**	**pH**	**Cond.**	**Turb.**	**D.O.**	**B.O.D**	**T.S.**	**Inorg. S.S.**	**Org. S.S**	**T.N**	**T.P**	**S.R.P.**	**Chl. *a***	**Thermo Coli**
	(m)	**(m)**	**(°C)**		**(µS cm^{-1})**	**(NTU)**	**(mg l^{-1})**	**(mg l^{-1} O^{2})**	**(mg l^{-1})**	**(mg l^{-1})**	**(mg l^{-1})**	**(µg l^{-1})**	**(µg l^{-1})**	**(µg l^{-1})**	**(µg l^{-1})**	**(NMP/100 ml)**
JR1	0.4	4.7	20.78	5.11	51.20	3.85	11.29	1.6	67.3	8.24	1.62	404.33	17.28	16.85	1.60	9.1
JRUp	0.5	13	21.48	6.49	57.26	33.08	11.45	1.6	85.7	5.67	1.16	60.63	17.57	11.42	2.58	15
JR2	0.6	18	21.52	6.38	50.38	36.28	10.90	0.8	89.3	5.73	1.58	404.80	17.57	16.69	3.48	11
JR3	2.4	25	21.19	6.03	53.93	32.07	11.33	0.8	78.3	1.01	0.56	217.28	4.07	6.98	0.73	23
JR4	3.45	25	21.11	4.64	56.34	5.07	10.28	0.6	51.7	0.91	0.93	259.43	6.50	5.17	0.88	23
JRDam	3.5	29	21.33	6.14	51.91	3.68	11.2	1.1	62.7	0.70	0.59	214.68	3.13	10.27	1.41	43
CH1	0.9	15	20.96	6.64	55.34	21.62	9.82	1.2	77.3	3.70	0.88	302.05	9.05	11.59	1.25	15
CH2	3.2	23	21.02	6.63	56.06	5.45	10.83	0.6	61.3	0.92	0.59	271.74	6.23	19.48	1.28	21
CH3	4.1	40	20.55	7.13	55.63	5,39	7.79	1.6	66.7	1.20	0.53	264.09	6.00	5.00	0.69	9
CHUp	2.6	16	22.03	6.66	50.77	7.21	10.22	0.8	63.3	2.42	1.05	249.41	5.90	5.66	1.28	23
CH4	1.4	37.8	20.95	7.08	51.09	13.62	7.51	1.1	68.3	2.30	0.51	197.87	8.83	4.68	0.53	3
CHDam	4.2	79.2	19.72	6.86	54.13	5.61	7.51	1.5	78.7	12.69	3.09	264.01	5.34	5.00	1.96	4
SGUp	2.3	2.3	22.42	6.80	54.85	3.11	8.83	0.6	60.7	0.57	0.47	254.22	5.17	4.51	1.06	9
SG1	0.55	4	24.25	7.12	67.93	53.23	7.83	1.9	90.3	20.55	5.70	428.01	27.20	33.96	2.34	23
SG2	3.4	5.8	22.75	7.08	54.63	3.88	9.87	1.5	43.7	0.96	0.53	190.77	5.23	4.51	1.48	9
SG3	0.4	2.7	23.92	7.00	52.91	33.60	8.53	1.4	76.0	10.15	2.47	206.87	11.76	16.03	6.07	23
SGDam	2.4	10.7	23.33	7.15	55.77	7.70	8.66	1.2	57.7	2.00	0.82	283.10	8.49	5.33	1.61	<3
CIIUp	1.7	9.5	23.05	7.14	56.23	9.21	9.13	0.8	58.7	3.71	1.38	308.76	14.14	12.90	0.96	<3
CII1	2.1	12.6	22.52	7.04	57.41	7.39	8.27	0.9	24.7	2.53	1.12	310.05	15.35	15.21	0.69	<3
CIIDam	3.2	15.5	23.22	7.31	56.36	3.02	8.78	0.8	61.7	0.45	0.80	346.80	12.15	13.13	0.96	<3
CIUp	2	2	23.23	7.23	56.34	2.38	8.87	0.6	23.7	0.36	0.67	278.61	8.61	6.98	1.40	9

Dry season	**Secchi disc**	**Deph**	**Temp.**	**pH**	**Cond.**	**Turb.**	**D.O.**	**B.O.D**	**T.S.**	**Inorg. S.S.**	**Org. S.S**	**T.N**	**T.P**	**S.R.P.**	**Chl. *a***	**Thermo Coli**
	(m)	**(m)**	**(°C)**		**(µS cm^{-1})**	**(NTU)**	**(mg l^{-1})**	**(mg l^{-1} O^{2})**	**(mg l^{-1})**	**(mg l^{-1})**	**(mg l^{-1})**	**(µg l^{-1})**	**(µg l^{-1})**	**(µg l^{-1})**	**(µg l^{-1})**	**(NMP/100 ml)**
CI1	3.6	14.9	23.20	7.03	56.61	3.11	8.51	0.8	52.7	0.96	0.81	279.00	8.17	4.51	1.76	4
CIDam	3.5	25.2	23.22	7.40	57.51	1.71	8.31	0.8	37.7	0.46	0.73	306.95	9.66	7.31	2.20	<3
CPUp	2.7	2.7	23.55	7.09	57.28	2.84	8.05	1.2	56.0	0.21	0.88	371.42	12.87	4.68	1.01	<3
CP1	0.18	12.5	22.13	6.97	55.01	144.48	8.37	1.9	113.7	39.71	4.53	760.66	42.41	26.06	7.00	4
CP2	0.2	27.3	21.26	6.83	58.31	88.66	8.06	1.6	113.7	17.29	2.58	640.69	67.18	20.64	5.04	20
CP3	1.9	16.5	23.80	7.12	48.35	10.98	8.52	0.5	74.0	1.67	0.94	818.67	15.63	4.84	1,39	9
CP4	3.1	16.8	23.20	7.26	53.99	3.17	8.44	0.8	57.3	0.46	0.64	413.80	9.82	5.83	2,17	<3
CPDam	3.3	29.5	23.30	7.18	53.09	2.82	9,63	0.4	174.7	0.26	0.78	343.25	9.77	4.68	1,34	<3
TQUp	2.1	9.5	23.10	7.16	53.83	7.92	11.35	1.2	67.0	3.66	1.33	494.78	8.05	10.11	1,47	4
TQ1	2.1	12.8	23.04	7.35	51.67	53.04	8.53	0.8	58.7	6.46	1.36	450.05	9.93	10.27	1.68	4
TQ2	1.9	15	22.58	7.16	54.78	9.50	9.40	1.3	92.7	2.37	0.76	403.89	10.76	7.64	0.62	4
TQDam	2.2	16	23.02	6.78	55.53	8.32	11.14	1.2	19.7	1.49	0.93	395.33	8.49	8.79	1.12	<3
RSUp	1.7	11.9	23.59	7.17	55.34	13.88	11.11	1.0	64.3	5.14	1.36	498.56	9.32	9.94	1.71	9
RS1	0.3	7	23.69	7.01	56.32	154.79	8.87	0.8	87.3	49.53	9.37	521.77	22.16	22.44	7.50	21
RS2	2.8	13.4	24.60	7.67	57.02	4.00	8.68	1.6	99.3	0.60	0.81	429.19	9.55	5.66	2.69	<3
RSDam	2.6	25.9	24.37	8.10	57.66	3.94	8.75	1.9	67.7	0.44	1.58	443.63	6.83	4.51	3.99	9

Chapter 2 - Application of multiple-uses indices to assess water quality emphasizing the zooplankton community and focus on biomonitoring and management purposes

Application of multiple-uses indices to assess water quality emphasizing the zooplankton community and focus on biomonitoring and management purposes

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Abstract

In this study we indeed to apply, and compare the results, different types of water quality indices for multipurpose uses, such as water supply, trophy levels evaluation and aquatic communities protection. The selected indexes were Water Quality Index (WQI), Trophic State Index (Carlson, 1977 and some derived modified models), Phytoplankton Community Index (FCI), Zooplankton Community Index (ZCI) and the Planktonic Index of Biotic Integrity (P-IBI) - a new tool that has been recently developed. The Paranapanema River is one of the main tributaries of the high Paraná River (La Plata basin) and is the natural border between the states of Paraná and São Paulo, Southern Brazil. The study was carried out in eight reservoirs, Jurumirim (JR), Chavantes (CH), Salto Grande (SG), Canoas II (CII), Canoas I (CI), Capivara (CP), Taquaruçu (TQ) e Rosana (RS), arranged in a cascade system considering a total of 37 sampling sites and two seasons. The objective is to generated new insights on this theme in order to improve the present water quality monitoring programs and to validate new useful protocols at the regional scale – a relatively large watershed from Southeast Brazil. The Water Quality Index ranged from “Good” to “Excellent” demonstrating the good quality of water. The original model of Carlson (1977) shows an overestimation by sensitively increasing the levels of eutrophication of the reservoirs while TSI models proposed by Carlson modified by Toledo and CETESB, (2006) for reservoirs are more suitable for tropical and subtropical environments, and TSI for tropical/subtropical reservoirs is the most sensitive. The Communities Indices

FCI, ZCI, P-IBI can fairly represent water quality standards which were reinforced, especially for zooplankton, through correlations made in this study.

Resumo

Neste estudo, aplicamos e comparamos os resultados de diferentes tipos de índices de qualidade de água para múltiplos usos, como abastecimento de água, avaliação de níveis tróficos e proteção de comunidades aquáticas. Os índices selecionados foram: o Índice de Qualidade da Água (WQI), o Índice de Estado Trófico (Carlson, 1977 e alguns modelos modificados), o Índice de Comunidade Fitoplanctônica (FCI), o Índice de Comunidade Zooplanctônica (ZCI) e o Índice Planctônico de Integridade Biótica (P-IBI) - uma nova ferramenta que foi recentemente desenvolvida. O Rio Paranapanema é um dos principais afluentes do Alto Rio Paraná (bacia do Prata) e é fronteira natural entre os estados do Paraná e São Paulo, no sul do Brasil. O estudo foi realizado em oito reservatórios, Jurumirim (JR), Chavantes (CH), Salto Grande (SG), Canoas II (CII), Canoas I (CI), Capivara (CP), Taquaruçu (TQ) e Rosana), dispostos em cascata e considerando um total de 37 locais de amostragem em duas estações. O objetivo é gerar novos *insights* sobre esse tema para melhorar os atuais programas de monitoramento da qualidade da água e validar novos protocolos úteis à escala regional – em uma bacia hidrográfica relativamente grande do Sudeste do Brasil. O Índice de Qualidade da Água variou entre "Bom" e "Excelente" demonstrando a boa qualidade da água. O modelo original proposto por Carlson, (1977) do Índice de Estado Trófico (TSI) mostra uma superestimação ao aumentar sensivelmente os níveis de eutrofização dos reservatórios enquanto que os modelos propostos por Carlson modificados por Toledo e CETESB, (2006) para reservatórios, são mais adequados para ambientes tropicais e subtropicais, enquanto o TSI para tropicais/subtropicais se mostrou o mais sensível para os ambientes estudados. Os índices de comunidades FCI, ZCI, P-IBI podem representar adequadamente padrões de qualidade da água, reforçada neste estudo, especialmente para a comunidade zooplanctônica, através de correlações desta com as variáveis limnológicas e os índices de qualidade de água e estado trófico.

Key words: Reservoir cascade system, Water Quality Index (WQI), Trophic State Index Phytoplankton Community Index (FCI), Zooplankton Community Index (ZCI), Planktonic Index of Biotic Integrity (P-IBI).

Introduction

As complex ecological systems with multiple uses, reservoirs present a hierarchy of functions, mechanisms of feedback, regulation, and control (Tundisi, 2008). In order to assess such complex systems, the use of integrated indices and indicators are frequently used in environmental monitoring programs and are generally based on selected abiotic factors or community structure indicators (Thomaz, 2000).

Environmental indices and indicators emerged as result of the growing social concern for the environmental aspects of socioeconomic development, a process that requires a large number of information organized in distinct degrees of complexity (CETESB, 2015). The main goal of indices is to assess the present condition of the environment and monitor trends over time. They can provide an early warning signal of changes in the environment and they be used to diagnose the causes of environmental problems (Dale and Beyeler, 2001).

Environmental indicators should represent key information about structure, function, and composition of the ecosystem (Dale and Beyeler 2001). They need to capture the ecosystem complexities but remain simple enough to be easily and routinely monitored and have the following criteria: be easily measured, be sensitive to stresses on the system, respond to stress in a predictable manner, be anticipatory, predict changes that can be averted by management actions, be integrative, have a known response to disturbances, anthropogenic stresses, and changes over time, and have low variability in response (Dale and Beyeler 2001).

The most challenging problem on selection of environmental indices and indicators is to understand the fundamental principles of ecology, also the inherent complexity of environmental problems and the limitations of using just a single indicator or indices that integrate information across a range of attributes and/or different levels of biological organization (Thornton and Kennedy, 1999; Wetzel, 2001).

Appropriate water quality indices can be useful for management purposes – stakeholder's decision processes, improvement of monitoring protocols, and expansion of scientific knowledge, as well as to disseminate the results of the analyses to citizens (Kane at al., 2009) and to make it possible is inherent to take into account that a proper choice of an index or indicators must be intrinsically related to the studied environment and will often present such regional character, which means that they will probably need some adaptation, but always taking into account the thought on which this was based.

In São Paulo State (Brazil), the official environmental agency called Companhia de Tecnologia de Saneamento Ambiental (CETESB), has monitored the water bodies for almost three decades, always focused on public supply requirements. Nevertheless, most surficial water ecosystems of this State are considered as Class 1 and 2 (Decree No. 10,755) (São Paulo, 1977), which are equivalent to Special Class and Class 1 of the federal CONAMA Resolution 357 (Brazil, 2005). This legislation predicts a more comprehensive set of uses including "to preserve the balance natural of aquatic communities". Therefore, it is important that the water quality monitoring programs also consider the biota composition and structure.

According to this, the Special Class is destined: a) to the supply for human consumption, with disinfection; B) the preservation of the natural balance of aquatic communities; and (c) the preservation of aquatic environments in fully protected conservation units, while Class 1 may be destined for: (a) supply for human consumption after simplified treatment; (b) protection of aquatic communities; (c) recreation of primary contact, such as swimming, water skiing and diving, (d) irrigation of raw vegetables and fruits that grow on the ground and are eaten raw without film removal; and (e) the protection of aquatic communities in Indigenous lands.

Although there is not an ideal model to measure environmental impacts, there are available options for selection and development of indices and indicators. More applied approaches have been requested by engineers and managers who work in the management of reservoirs, in order to complement the basic limnological studies performed by academic institutions (Tundisi and Matsumura-Tundisi, 2003; Tundisi, 2006).

Based on a study carried out in the 1970’s by the National Sanitation Foundation of United States, CETESB adapted and developed a regional Water Quality Index (WQI) to assess the water quality with the purpose of public supply. The WQI consider nine parameters: water temperature, pH, dissolved oxygen, biochemical oxygen demand, thermotolerant coliforms, total nitrogen, total phosphorus, total solids, and turbidity). The WQI is a widely accepted index and commonly used in water quality monitoring and the proposal was based on an opinion survey (Delphi method) with specialists in water quality. They were argued about the variables to be evaluated, the relative weight and the condition with which each parameter is presented, mainly in order to evaluate the contamination of the water bodies caused by the discharge of domestic sewage (CETESB 2006).

A trophic state index for temperate lakes was proposed by Carlson (1977), considering empirical relationships among Chlorophyll *a* (Chl *a*), Total Phosphorus (TP) and Secchi disk depth (SDD). This index has frequently been applied by researchers and government institutions to, indirectly, estimate the algal biomass and indicate lake trophic status. However, it is known that the relationships and the equations for calculating the index should be adapted when applied to aquatic systems different from those studied by Carlson. Otherwise results of the index application can lead to misclassification of the trophic status of a water body (Cunha et al., 2013).

Currently, in Brazil, there are modifications of Carlson original model´s based on the prediction that the trophic state may be more complex in tropical/subtropical freshwaters because there are more environmental constraints controlling nutrient dynamics and phytoplankton responses in such water bodies (Cunha et al., 2013). These modifications take into account the same reasoning, but they present changes in the calculation, in the number of variables analyzed and also in the weighting given to each one of them.

Although the previously mentioned indices are widely recognized and used, in 1998, the SMA[1]-65 Resolution (São Paulo, 1998) established a working group to revise the Water Quality Index (WQI) in order to consider the aquatic biota and develop other assessment methods, which consider biological indicators integrated with to eutrophication indexes. This technical group was composed of experts from CETESB,

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[1] São Paulo State Environmental Secretary – Secretaria de Meio Ambiente, in Portuguese.

Universities and Research Institutes that generated a first version for biological indexes based on phytoplankton, zooplankton, benthos and fish communities (CETESB, 2006). We selected two of the proposed indices, the Phytoplankton Community Index (FCI) and the Zooplankton Community Index (ZCI) for reservoirs, for our study.

In this study we applied, and compared, different types of water quality indices that are considered to be appropriated for assessment of aquatic ecosystems for multipurpose uses (e.g. water supply, hydropower generation, aquaculture, recreation, irrigation, aquatic community's protection). Our case study is focused on the Paranapanema River Reservoir Cascade. The following indexes were selected: Water Quality Index (WQI), Trophic State Index (Carlson, 1977 and three regionally modified models), Phytoplankton Community Index (FCI), Zooplankton Community Index (ZCI) and the Planktonic Index of Biotic Integrity (P-IBI) - a new tool that has been recently developed (see more details in Chapter 4).

The objective of the study is to get new insights on this subject, contributing for the evaluation and improvement of the water quality monitoring program carried out in a large hydrographic basin from Southeast Brazil.

Additionally, we present an exploratory analysis on plankton, mainly zooplankton, responses to water quality and trophic conditions variability in the Paaranapanema basin. The perspective is to incorporate available academic information on practical protocols for environmental evaluation and management. Phytoplankton and zooplankton samples are regularly sampled and analyzed as part of the regional water quality monitoring program sponsored by the hydropower generation company.

Study area

The study was carried out in the Paranapanema River Reservoirs Cascade considering the same eight reservoirs and 37 sampling sites described in Chapter 1 (Fig. 1; Tables 1 and 2).

Materials and methods

The Water Quality Index (WQI) was calculated using nine variables: water temperature, pH, dissolved oxygen, biochemical oxygen demand, thermotolerant coliforms, total nitrogen, total phosphorus, total solids, and turbidity. The methodologies concerning each individual variable (sampling and analysis) are detailed in Chapter 1. The WQI calculation was performed according to CETESB (2006) methodology and the results, which can range from 0 to 100 (the higher the value the better the water quality), were classified according to Table 1, also a CETESB (2006) methodology recommendation.

Table 1 – Water Quality Index (WQI) classification.

WQI Classification	
Category	**Rating**
Excellent	79 < WQI ≤ 100
Good	51 < WQI ≤ 79
Regular	36 < WQI ≤ 51
Poor	19 < WQI ≤ 36
Very Poor	WQI ≤ 19

For the Trophic State Indices four variables were used: Secchi disc transparency, total phosphorus, reactive soluble phosphorus and chlorophyll *a*. Sampling methods and analysis for each variables are also detailed in Chapter 1. To calculate the indices we used the original model proposed by Carlson (1977) and the Carson Index modified by Toledo (1983) (*apud* Mercante and Tucci, 1999), by CETESB (2009) - Trophic State Index for reservoirs and by Cunha et al. (2013) - Trophic State Index for tropical/subtropical reservoirs. The classification is in accordance with each method, which has variations in the rating values and categories (in this case, the lower the value the better the water quality), but, to facilitate comparison, the similar classifications were represented in the same colors (Table 2).

Table 2 – Classes of Trophic State Index.

TSI Classification	**TSI Carlson**	**TSI Carlson mod. Toledo**	**TSI Reservoir**	**TSI_{TSR}**
Ultraoligotrophic	<20		TSI < 47	≤ 51.1
Oligotrophic	21-41	TSI < 44	47 < TSI ≤ 52	51.2 - 53.1
Mesotrophic	41-50	44< TS I>54	52 < TSI ≤ 59	53.2 - 55.7
Eutrophic	51-60	TSI >54	59 < TSI ≤ 63	55.8 - 58.1
Supereutrophic			63 < TSI ≤ 67	58.2 - 59.0
Hypereutrophic	>61		TSI > 67	≥ 59.1

The Phytoplankton Community Index for Reservoirs (FCI) and the Zooplankton Community Index for Reservoirs (ZCI) were both calculated according to CETESB (2006). For the FCI Index it is considered the proportion of the main community groups and/or the density of the organisms and the concentration of chlorophyll *a* or TSI (Chl *a*). However, the numerically dominant group of phytoplankton in the Paranapanema River reservoirs cascade, Cryptophyceae, is not considered in the model. Therefore, for this analysis we used the total density (org. ml^{-1}) instead of the phytoplanktonic dominant groups, as well as the Trophic State Index, Carlson modified by Toledo model for Chlorophyll *a*. For the ZCI it is considered the presence of the three main zooplankton groups (Rotifers, Copepods and Cladocerans), Calanoida/Cyclopoida ratio and TSI. (Carlson modified by Toledo) (see CETESB, 2006).

For phytoplankton qualitative analysis, an integrated sample was collected (entire water column) at each sampling station through vertical net hauls (20 µm of mesh size) and immediately preserved in 2% formalin. The net samples were observed in an optical microscope (maximum magnification of 1000×) for taxonomical identification and determination of the assemblage total richness. For phytoplankton quantitative analysis, three unfiltered samples were collected (van Dorn bottle) at the subsurface (ca. 0.2 m), middle of the water column and near to the bottom (ca. 1 m above the sediment). The samples were fixed and preserved with Lugol's solution. After sedimentation, the organisms (cell, colony, and filament) were counted using inverted microscopy (*sensu* Utermöhl) at a magnification of 400×. At least 120 optical fields distributed in parallel transects were examined, and at least 150 organisms were counted per sample. A mean value for the water column was calculated for further use in the FCI index. Since the dominant phytoplankton group (Cryptophyceae) in

Paranapanema River reservoirs cascade does not appear in the CETESB classification table, we use only the organisms' density and the trophic state.

The zooplankton samples were collected using a conical net (30 cm mouth diameter and 50 µm mesh size) for vertical hauls from near bottom (ca. 1 m) to the surface. In each site we collected to identical samples, one for qualitative and the other for quantitative purpose. Samples were fixed and preserved in 4 % formaldehyde. For the quantitative analyses, most organisms were counted at species level. Rotifera, and nauplii of Copepoda were counted in Sedgwick–Rafter chambers, under optic microscope Zeiss Standard 25 (at a magnification of × 200); and Cladocera, copepodites and adult stages of Copepoda were counted using a stereo microscope Zeiss Stemi SV 6 (maximum magnification of × 120). At least 150 specimens were counted per subsample. Additional sub-samples, or even the entire sample, were analyzed when the density of organisms was low (generally less than 100 organisms per 5 ml of sample, in case of Cladocera and Copepoda, and less than 100 organisms per 1 ml of sample, in case of Rotifera).

Both phytoplankton and zooplankton were sampled during wet/summer (March/2011) and dry/spring (October/2011) seasons.

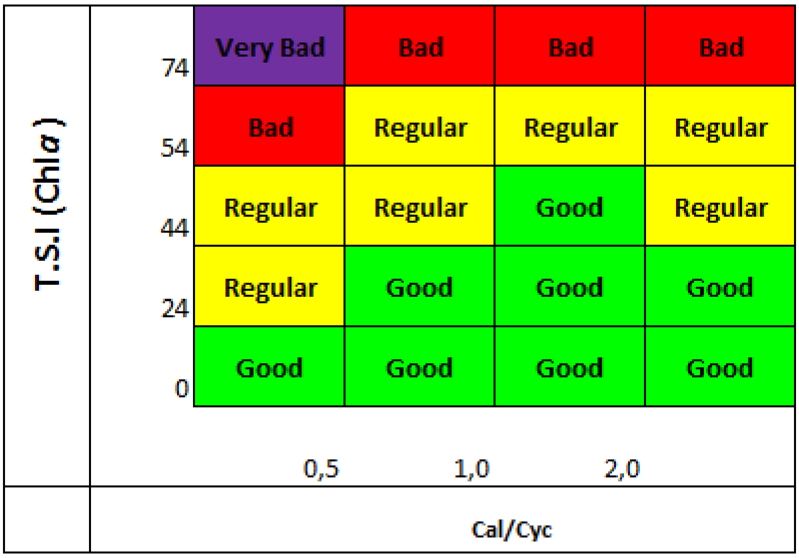
The Planktonic Index of Biotic Integrity (P-IBI) was calculated according to methodology detailed in Chapter 4. As this index is derived from a proposal developed for natural large lakes, it was only used for the Paranapanema storage reservoirs (theoretical water retention time higher than 100 days) (Jurumirim, Chavantes and Capivara).

To facilitate comparisons, the classification rating was also showed in term of corresponding colors, equivalent for similar categories of the distinct indices. The FCI for reservoir and P-IBI is according to Table 3 (with the lower the value of the classification corresponding to the better the water quality) and ZCI for reservoirs Table 4.

Table 3 – FCI for reservoir and P-IBI classification.

Classification	FCI_{Res}	P-IBI
Excellent	1	Excellent
Good	2	Good
Regular	3	Fair
Bad	4	Poor
Very Bad		Very Poor

Table 4 – ZCI for reservoir classification based on T.S.I. (Chl*a*) and Calanoida/Cyclopoida ratio.



T.S.I (Chl*a*)	74	Very Bad	Bad	Bad	Bad
	54	Bad	Regular	Regular	Regular
	44	Regular	Regular	Good	Regular
	24	Regular	Good	Good	Good
	0	Good	Good	Good	Good
		0,5	1,0	2,0	
		Cal/Cyc			

Adapted from CETESB, (2006)

In order to reinforce the potential of the zooplankton as bioindicator of water quality and corroborate the effectiveness of the Zooplankton Community Index for Reservoirs (ZCIres) and Plankton Index of Biotic Integrity (P-IBI), we performed an exploratory analysis using the Pearson correlation (Pearson, $p<0,05$) Statistic v. 7.0 (Statsoft, 2002).

The following genera or species of zooplankton were settled on as indicators of trophic state from a selected literature review: *Brachionus* sp., *Collotheca* sp. and *Filinia* sp. among Rotifers; *Argyrodiaptomus* sp., *Notodiaptomus iheringi*, *Thermocyclops decipiens*, and *Thermocylops minutus*, among the Copepods; and *Bosmina* sp. and *Daphnia* sp. among Cladocerans. Additionally we considered the total abundance and richness of Rotifera, Cladocera and Copepoda (with and without nauplii) and the relation Calanoida/Cyclopoida + Cladocera. Zooplankton data were correlated with the limnological variables (transparency, dissolved oxygen, biochemical oxygen demand, conductivity, chlorophyll, total phosphorus, soluble reactive phosphorus, total nitrogen, total suspended solids, organic suspended solids, inorganic suspended solids) (Chapter 1) and with the quantitative results of WQI and modified Carlson T.S.Is indexes for reservoirs (CETESB, 2006) and for tropical and subtropical reservoirs (Cunha et al., 2013). We selected some results for graphical presentation.

All data, except pH, were log-transformed and the parametric distributions was verified in the software Statistic v. 7.0 (Statsoft, 2002).

The selection of zooplankton metrics is based on published information which was carried out using a selected literature review, focused on the studied environment and which have regionalized characteristics of the occurrence and distribution of the organisms in the Paranapanema River reservoirs and in São Paulo State reservoirs with different trophic states as well as some classical related literature that showed the potential indicator of this community. The accumulated experience of our research group can be found in Sendacz et al., (1985); Panarelli et al., (2001); Nogueira, (2001); Sampaio et al., (2002); Matsumura-Tundisi and Tundisi,(2003); Casanova and Henry, (2004); Lansac-Toha et al., (2004); Matsumura-Tundisi and Tundisi, (2005); Landa et al., (2007); Nogueira et al., (2008); Tundisi, (2008); Silva, (2008); Sartori et al., (2009); Perbiche-Neves and Nogueira, (2010); Perbiche-Neves et al., (2016) and Nogueira and Naliato, (2016).

For all index calculations were used the mean value for the water column for the limnological variables, except transparency.

Results

The Water Quality Index (CEYESB 2006) for the Paranapanema River reservoirs cascade resulted in only two distinct classifications, Good and Excellent (Table 5, Appendix I). Among the 74 determinations the Excellent condition widely prevailed (64 times) over the Good condition (10 times). The index evidences a decrease in the water quality condition during the wet season. In this period the proportion of sampling stations considered Excellent corresponded to 81.1 % and in the dry season it was 91.9 %.

In order to facilitate comparison among the different models of Trophic State Index applied for the Paranapanema River reservoirs cascade all the results are showed in Table 6. Lower levels of trophy were obtained when used the Carlson Index (1977). Results ranged from Hypereutrophic (SG1) to Oligotrophic (CH3, CH4 and CHDam) in the wet season and from Hypereutrophic (CP1 and CP2) to Oligotrophic (JR3, JRDam and CHDam) in the dry season. Most sampling sites (70.3 % considering both seasons) were classified as Mesotrophic according to this index. The same number (8 times) of lower trophic conditions (Hypereutrophic/Eutrophic) was found in wet and dry seasons.

For the Carlson Trophic State Index modified by Toledo (Mercante and Tucci, 1999), the Eutrophic condition was determined four times (SG1, wet season; CP1, CP2 and RS1, dry season). All others classifications varied between Oligo (71.6 %) and Mesotrophic (21.6 %) conditions, during both wet and dry seasons (Table 6). Following the original Carlson Index this model also indicates a decrease in the water quality during the rainy season.

The results of the Trophic State Index for Reservoirs proposed by CETESB (2006) are similar to the ones of Carlson modified by Toledo, showing the predominance of Oligotrophic and Mesotrophic conditions, 29.7 and 59.5% of the determinations, respectively (Table 6). The stations with the best trophic conditions according to this model were JR3, JRDam and CH3, which were classified as Ultraolithotrophic during the dry season when was detected an improvement of the water quality.

The most recent model of Trophic State Index proposed for tropical and subtropical reservoirs (Cunha et al., 2013) indicated predominance of Ultraoligotrophic conditions, corresponding to 77.0 % of the sampling sites (Table 6), followed by Oligotrophic condition (17.6 %). The index was also sensitive to poor condidition in wer season, when one sites was classified as Eutrophic (SG1). The total results of the TSI models presented here are shown in Appendices II, III, IV and V.

The use of Phytoplankton Community Index for reservoir (FCI) resulted in similar proportion of Good and Excellent conditions, 47.3 and 51.3 % of the determinations, respectively (Table 7). Only one Regular condition was detected (SG1, wet season). Differently, for the Zooplankton Community Index (ZCI) the condition Excellent was not determined. Most sites were classified as Good (72.9 %) or Regular

(21.6 %), which could be observed in most sampled sites for both seasons (Table 7). The sites SG1 and SG3 were classified as Bad conditions in both wet and dry seasons, according to the ZCI. Both plankton indices were not sensitive to the seasonal variation.

The Planktonic Index of Biotic Integrity (P-IBI) showed that most sites are in Excellent conditions (75 %) and the others are Good (25 %). Regular, Bad and Very Bad conditions were not detected. Jurumirim reservoir exhibited a higher number of sampled sites with "Good" conditions when compared with the others (Table 8). There was no remarkable difference between wet and dry season.

Three hundred and ninety nine correlations among distinct zooplankton metrics and environmental variables/integrated indices were performed (Appendix IV). Some variables that had significant correlations with zooplankton were also evidenced in the Principal Component Analysis (PCA) shown in Chapter 1 (e.g. transparency, turbidity, inorganic and organic suspended solids, total nitrogen, total phosphorus, chlorophyll a, temperature, pH and dissolved oxygen).

We selected for graphical representation a set of significant correlations ($p < 0.05$) (Figure 1). Conversely, although significant some correlations were not considered either because its amplitude of variation was not sensitive to capture environmental distinctiveness for the Paranapanema River reservoirs cascade (e.g. dissolved oxygen that also exhibits high values) (Chapter 1) or because the particular variable (e.g. temperature) is not directly related to water quality.

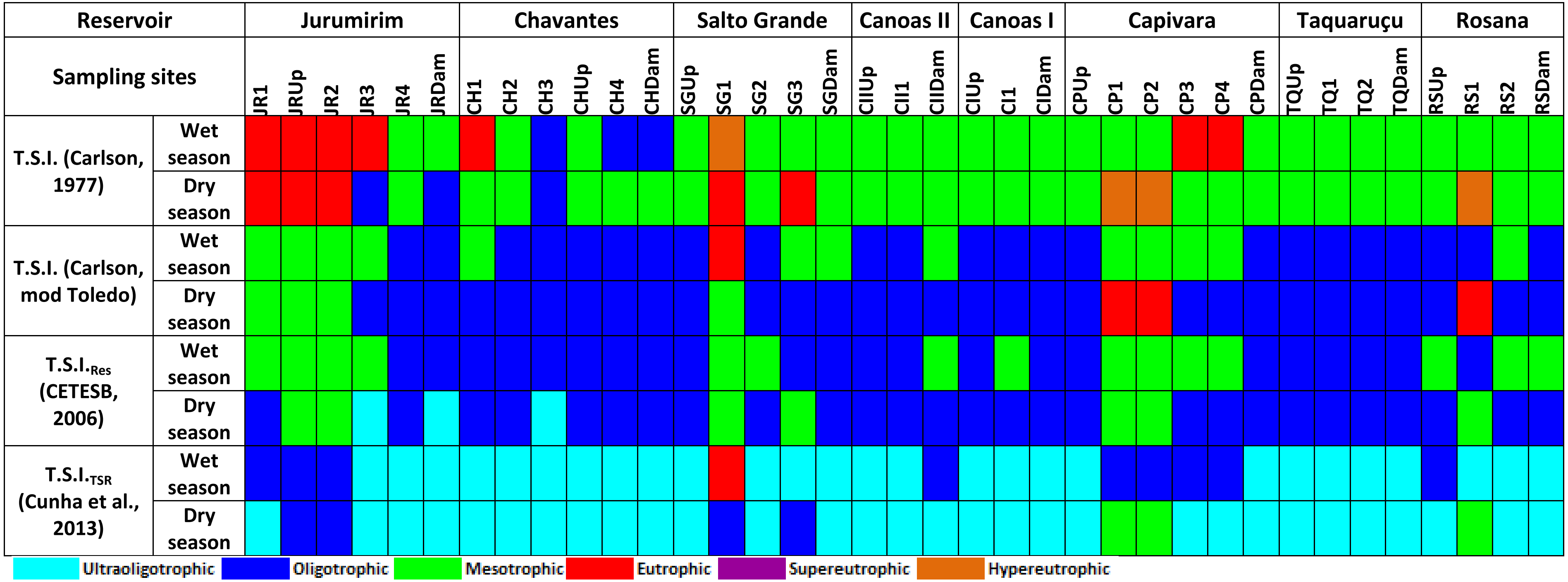
Among rotifers the genera *Brachionus* sp. and *Filinia* sp. were correlated with trophic increase (water quality decrease), while the genus *Collotheca* sp. exhibited an opposite tendency. For microcrustaceans we observed that Calanoida was correlated with good water quality and low trophic levels as well as for Cladocerans, and the opposite, was observed for Cyclopoida. For lower microcrustacean taxonomic level it can mention the inverse relationship of *T. minutus* with total phosphorus and the inverse relationship of *Daphnia* with TSI mod. Toledo and positive with WQI (Figure 1 and Appendix IV).

Table 5 – WQI classification for Paranapanema River reservoirs cascade during the wet and dry season.

Reservoir		Jurumirim						Chavantes						Salto Grande					Canoas II			Canoas I			Capivara						Taquaruçu				Rosana			
Sampling sites		JR1	JRUp	JR2	JR3	JR4	JRDam	CH1	CH2	CH3	CHUp	CH4	CHDam	SGUp	SG1	SG2	SG3	SGDam	CIIUp	CII1	CIIDam	CIUp	CI1	CIDam	CPUp	CP1	CP2	CP3	CP4	CPDam	TQUp	TQ1	TQ2	TQDam	RSUp	RS1	RS2	RSDam
WQI	Wet season	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟦	🟦	🟦	🟦	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	Dry season	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦

🟦 Excellent 🟩 Good 🟨 Regular 🟥 Bad 🟪 Very Bad

Table 6 – Comparison of the different Trophic State Index models and respective classification for Paranapanema River reservoirs cascade during the wet and dry season.



Reservoir		Jurumirim						Chavantes						Salto Grande					Canoas II			Canoas I			Capivara						Taquaruçu				Rosana			
Sampling sites		JR1	JRUp	JR2	JR3	JR4	JRDam	CH1	CH2	CH3	CHUp	CH4	CHDam	SGUp	SG1	SG2	SG3	SGDam	CIIUp	CII1	CIIDam	CIUp	CI1	CIDam	CPUp	CP1	CP2	CP3	CP4	CPDam	TQUp	TQ1	TQ2	TQDam	RSUp	RS1	RS2	RSDam
T.S.I. (Carlson, 1977)	Wet season	🟥	🟥	🟥	🟥	🟩	🟩	🟥	🟩	🟦	🟩	🟦	🟦	🟩	🟧	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Dry season	🟥	🟥	🟥	🟦	🟩	🟦	🟩	🟩	🟦	🟩	🟩	🟩	🟩	🟥	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟧	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟧	🟩	🟩
T.S.I. (Carlson, mod Toledo)	Wet season	🟩	🟩	🟩	🟩	🟦	🟦	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟥	🟦	🟩	🟩	🟦	🟦	🟩	🟦	🟦	🟦	🟦	🟩	🟩	🟩	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟦
	Dry season	🟩	🟩	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟥	🟥	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟥	🟦	🟦
T.S.I.$_{Res}$ (CETESB, 2006)	Wet season	🟩	🟩	🟩	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟦	🟦	🟦	🟦	🟩	🟦	🟩	🟦	🟦	🟩	🟩	🟩	🟩	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟩	🟩
	Dry season	🟦	🟩	🟩	🩵	🟦	🩵	🟦	🟦	🩵	🟦	🟦	🟦	🟦	🟩	🟦	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟦	🟦
T.S.I.$_{TSR}$ (Cunha et al., 2013)	Wet season	🟦	🟦	🟦	🩵	🩵	🩵	🩵	🩵	🩵	🩵	🩵	🩵	🩵	🟥	🩵	🩵	🩵	🩵	🩵	🟦	🩵	🩵	🩵	🩵	🟦	🟦	🟦	🟦	🩵	🩵	🩵	🩵	🩵	🟦	🩵	🩵	🩵
	Dry season	🩵	🟦	🟦	🩵	🩵	🩵	🩵	🩵	🩵	🩵	🩵	🩵	🩵	🟦	🩵	🟦	🩵	🩵	🩵	🩵	🩵	🩵	🩵	🩵	🟩	🟩	🩵	🩵	🩵	🩵	🩵	🩵	🩵	🩵	🟩	🩵	🩵

🩵 Ultraoligotrophic 🟦 Oligotrophic 🟩 Mesotrophic 🟥 Eutrophic 🟪 Supereutrophic 🟧 Hypereutrophic

Table 7 – Comparison between Phytoplankton Community Index (FCI) and Zooplankton Community Index (ZCI) for reservoirs and respective classification for Paranapanema River reservoirs cascade during the wet and dry season.

Reservoir		Jurumirim						Chavantes						Salto Grande					Canoas II			Canoas I			Capivara						Taquaruçu				Rosana			
Sampling sites		JR1	JRUp	JR2	JR3	JR4	JRDam	CH1	CH2	CH3	CHUp	CH4	CHDam	SGUp	SG1	SG2	SG3	SGDam	CIIUp	CII1	CIIDam	CIUp	CI1	CIDam	CPUp	CP1	CP2	CP3	CP4	CPDam	TQUp	TQ1	TQ2	TQDam	RSUp	RS1	RS2	RSDam
FCI$_{Res}$	Wet season	🟩	🟩	🟩	🟩	🟦	🟩	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟨	🟦	🟩	🟩	🟦	🟦	🟩	🟦	🟩	🟦	🟦	🟩	🟩	🟩	🟩	🟩	🟦	🟦	🟦	🟦	🟩	🟩	🟦	🟩
	Dry season	🟩	🟩	🟩	🟦	🟦	🟦	🟩	🟦	🟦	🟦	🟦	🟩	🟦	🟩	🟦	🟩	🟦	🟦	🟦	🟩	🟦	🟦	🟩	🟦	🟩	🟩	🟩	🟩	🟩	🟦	🟦	🟦	🟦	🟦	🟩	🟩	🟩
ZCI$_{Res}$	Wet season	🟨	🟨	🟨	🟨	🟨	🟨	🟩	🟩	🟩	🟨	🟨	🟩	🟩	🟥	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	Dry season	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟩	🟨	🟩	🟩	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟨

🟦 Excellent 🟩 Good 🟨 Regular 🟥 Bad 🟪 Very Bad

Table 8 – P-IBI classification for selected reservoirs in the Paranapanema River cascade during the wet and dry season.

Reservoir		Jurumirim						Chavantes						Capivara					
Sampling sites		JR1	JRUp	JR2	JR3	JR4	JRDam	CH1	CH2	CH3	CHUp	CH4	CHDam	CPUp	CP1	CP2	CP3	CP4	CPDam
P-IBI	Wet season	🟩	🟦	🟩	🟦	🟩	🟩	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	Dry season	🟩	🟩	🟦	🟦	🟩	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟦

🟦 Excellent 🟩 Good 🟨 Regular 🟥 Bad 🟪 Very Bad

Figure 1 – Correlations between zooplankton metrics with limnological variables, WQI and T.S.Is indexes- Carlson modified by Toledo (Mercante and Tucci, 1999), Cetesb (2006) for reservoirs and Cunha et al. (2013) for tropical and subtropical reservoirs).

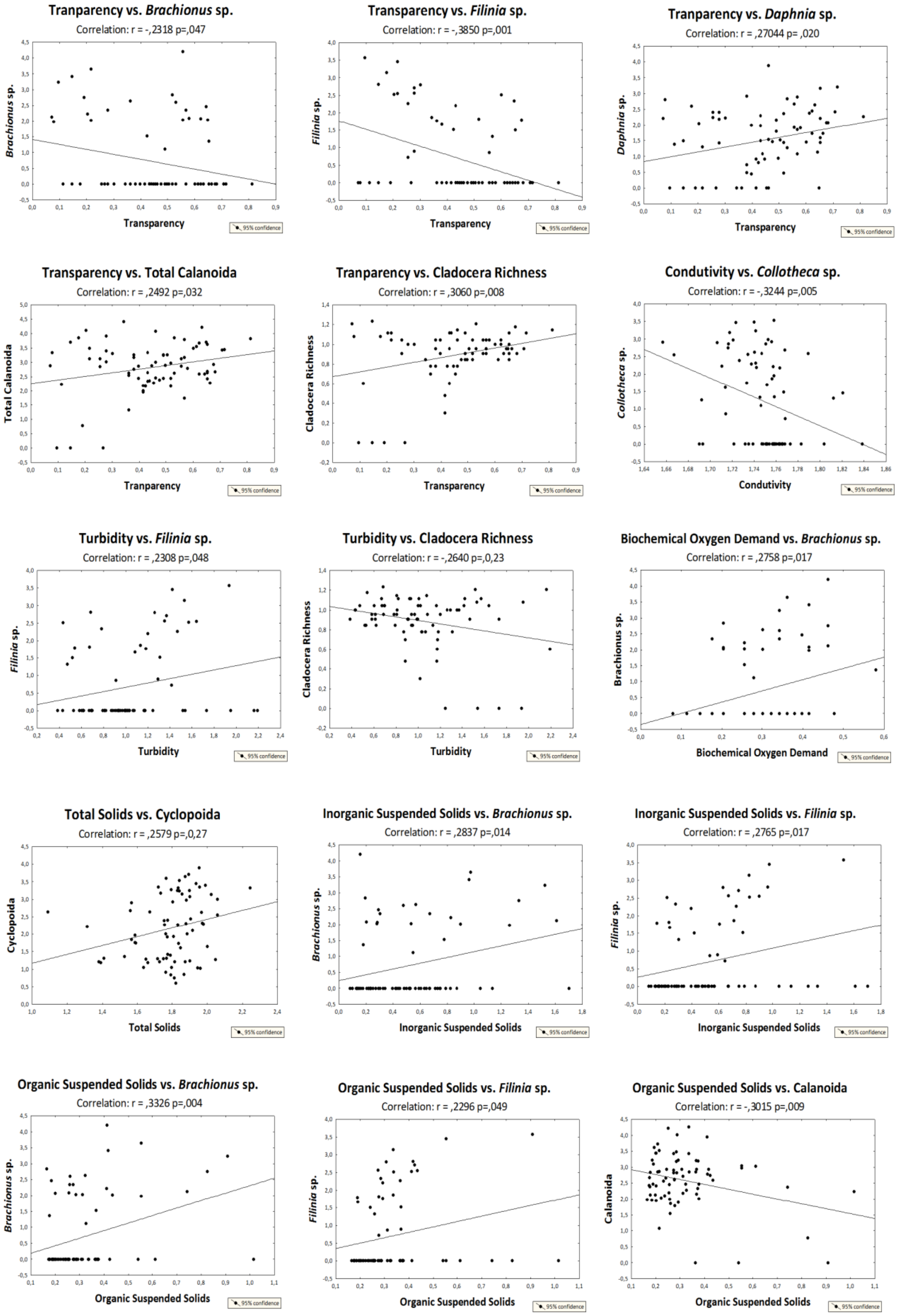


Figure 1 – continued.

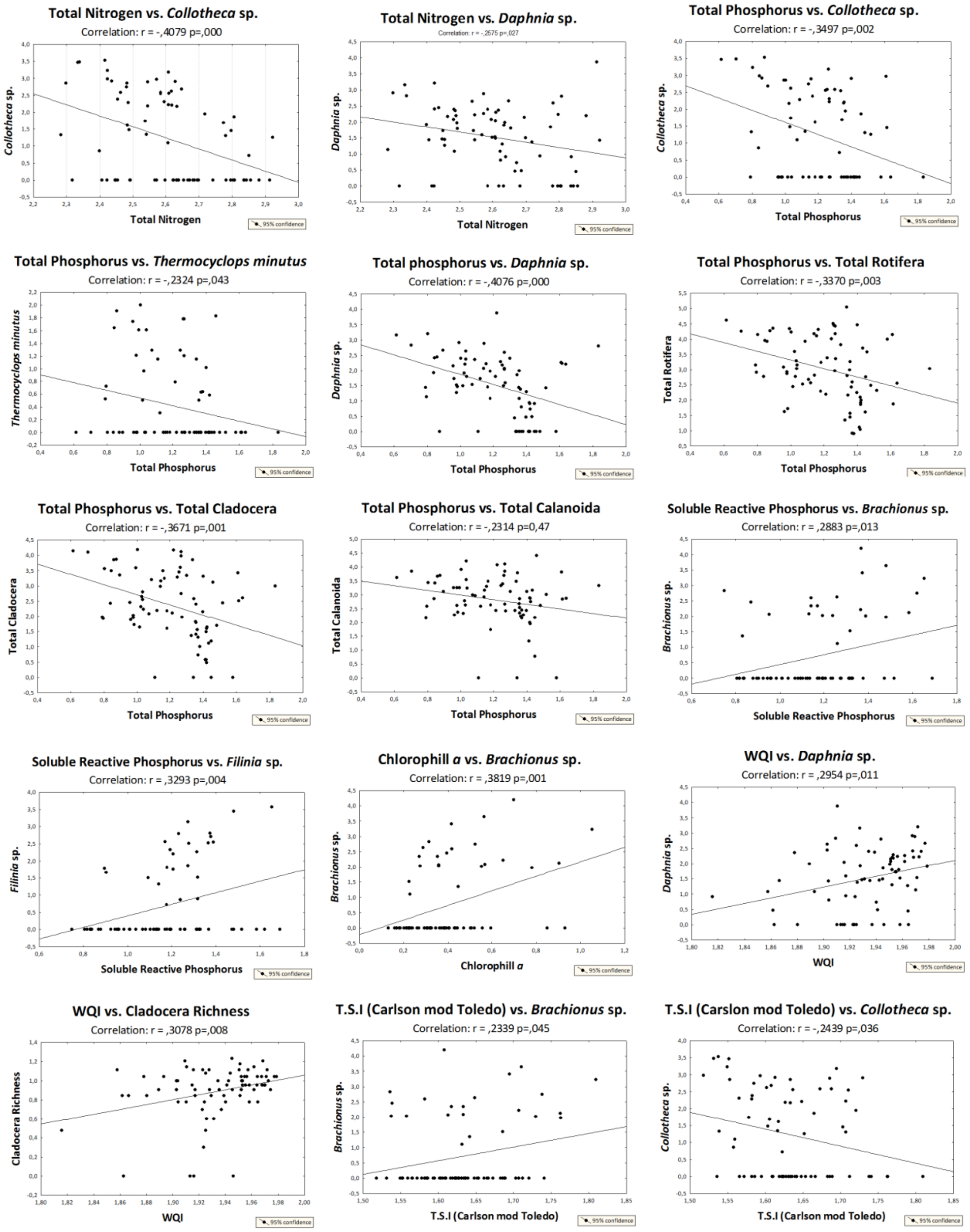
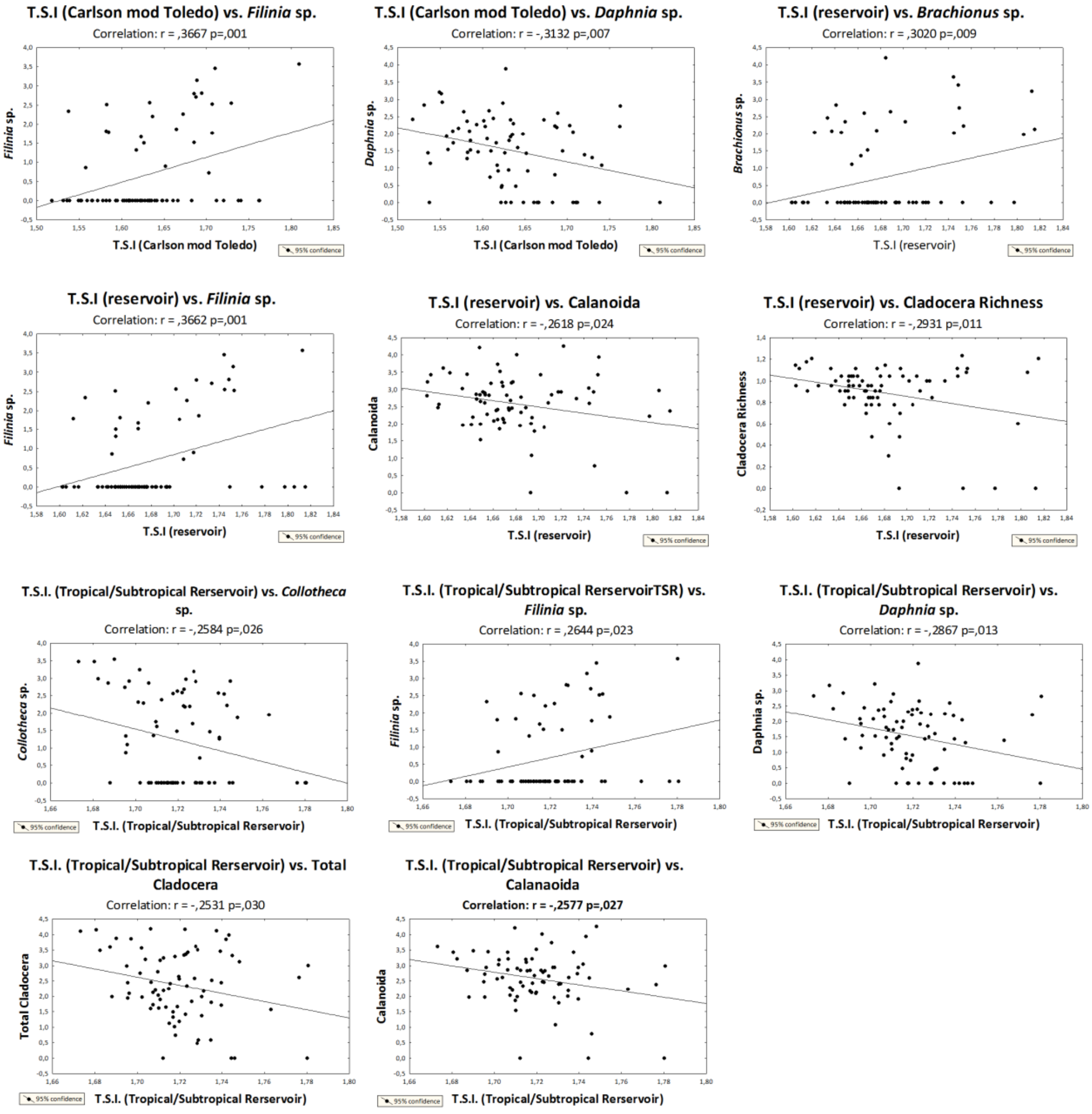


Figure 1 – continued.



Discussion

The environmental complexity of problems and the limitations of using a single indicator have prompted the development and application of indicators that integrate information across a range of attributes of environmental systems and/or different levels of biological organization (Thornton and Kennedy, 1999). In order achieve a more accurate assessment of ecosystem "health" and adjust to a multiple uses perspective, it is essential to conduct sensitive and robust biomonitoring programs. Results should provide an integrated view of the operating natural processes, as well as the effects of human actions and a rich variety of signals, which can be used to diagnose environmental degradation (Karr, 2006; Kanne et al., 2009; Nogueira and Naliato, 2016).

The application of different water quality/trophic state indices in the Paranapanema River reservoirs cascade exhibited different responses. For a better interpretation it is imperative to consider that water quality concept is not absolute; the terms “good” or “poor” water quality have definite meaning only in relation to the use of water and the assessment of the user (Parparov et al., 2010).

For monitoring programs to select the appropriate indicators and to provide information that contributes for management decisions, it is critical that the management questions and required information be clearly articulated and understood (Thornton and Kennedy, 1999). In this way, the Water Quality Index (WQI) has been regularly used in monitoring programs and it is considered a robust and reliable index once it is composed of physical, chemical and biological variables previously established by experts to detect the quality of water for public supply purposes. In addition to these, it is essential to consider that when the results are compared to those described in a more traditional limnological studies (i.e., Chapter 1), they are fairly adequate in describing environmental conditions.

According to Thornton and Kennedy, (1999) limnologists have long used broadly defined terms to describe complex changes associated with eutrophication i.e., eutrophic lakes are characterized as having high nutrients and algal abundance, while the opposite is true for oligotrophic lakes

Parparov et al. (2010) showed that water quality assessed with the Trophic State Index (TSI) is more suitable for needs of natural water resources management, if eutrophication is a major threat. Contrastingly, the WQI allows accounting for several water resource uses and therefore it is a more robust and comprehensive tool for water quality quantification and thus for sustainable water resources management.

In the last decades we have faced a discussion related to the misuse of the original TSI model proposed by Carlson (1977) for tropical/subtropical regions and regardless of the type of environment system (i.e. lakes, rivers, reservoirs, flooded areas). Carlson (1977) developed the Trophic State Index (TSI) for temperate lakes. It integrates information about nutrient (phosphorus) concentration, chlorophyll, and transparency (Secchi disk depth). The purpose of the trophic status index is to classify water bodies into different degrees of trophy, i.e. to assess water quality changes related to nutrient enrichment (Zagatto et al., 1999), and a number of studies were carried out proposing modifications, or minor adaptations to better meet the criteria and purposes of this index for particular habitat/regional characteristics.

An important consideration is that temperate and tropical/subtropical aquatic systems have specific sensitivities to eutrophication (Huszar et al., 2006), because they are exposed to different stressors magnitude concerning climatological attributes and land use shifts, with corresponding changes in physical, chemical and biological characteristics of the aquatic ecosystem (Ortiz- Jimenez et al., 2006). The prediction of trophic state may be more complex in tropical/subtropical freshwaters because there are more environmental constraints controlling nutrient dynamics and the phytoplankton responses in such water bodies (Cunha et al., 2013).

According to Cunha et al., (2013) the main reason for establishing a specific index for tropical/subtropical regions is that the Carlson´s model only considers the highest productive seasons in temperate lakes (spring and summer), whilst tropical/subtropical systems may have high primary production through all the year (Calijuri and Santos, 2001).

The TSIs comparative analyses are easier to be interpreted if one has solid information on the limnological structure and functioning of considered environment and of the methodological development of the selected models. In case of the Paranapanema River reservoirs cascade if we compare the limnological data presented in Chapter 1, with the results of the original proposal of Carlson (1977), we observed that this model overestimates the trophic condition - most sampling sites were classified as Mesotrophic or even Eutrophic and Hypereutrophic.

The Carlson TSI models modified by, Toledo 1983 (*apud* Mercante and Tucci, 1999) and by CETESB (2006) for reservoirs showed to be more appropriated for tropical and subtropical environments. In case of the first modified model around 70 % of the Paranapanema reservoirs determinations resulted in Oligotophic conditions, followed by Mesotrophic, 27 %. For the second it was around 60 and 30 %, for Oligotrophic and Mesotrophic, respectively. These results are more realistic if considered the low concentrations of nitrogen, phosphorus and chlorophyll commonly found in the Paranapanema reservoirs (Chapter 1; Henry, 2014; Nogueira et al., 2006;

Perbiche-Neves et al., 2011; Nogueira et al., 2014l). These models were also sensitive to the seasonal changes, capturing the water quality decrease during the rainy season (higher input of sediments/nutrients). A difference to be considered between both models is that the first does not take into account the type of environment, such as the reservoir ecosystem particularities that are considered in the second.

The TSI for tropical/subtropical reservoirs is the most recent proposed model (Cunha et al., 2013). It considered relevant ecological aspects for an appropriate assessment, including geographic positioning (tropical/subtropical region) and it was tested in a large number of reservoirs in the São Paulo State for validation purpose. The results of its application showed to be a sensitive model with most classifications resulting as Ultraoligotrophic (77 %) followed by Oligotrophic (17.6 %) which can be associated with the truly lower concentration of nutrients. Seasonality was not detected, as well. Similar results were obtained for WQI, but in this case, seasonality was better captured, resulting Excellent for 70 % of the determinations during the wet season and 95 % in the dry season.

The incorporation of aquatic biota information, biomonitoring programs, associated with the conventional study of abiotic variables, is a strategy that possibilities better environmental diagnosis in order to generate concrete subsidies for the water resources management. Monitoring based on physical and chemical parameters, even including microbiological determinations, may be insufficient for a conclusive analysis of the diverse ecological dimensions of an aquatic system (Nogueira and Naliato, 2016).

Organisms integrate time and space in a more conservative manner than physical and chemical variables and the incorporation of information on aquatic biota into water monitoring programs is a necessary strategy for alignment with the most advanced regulations (Nogueira and Naliato, 2016). By studying the ecological attributes (presence/absence, richness, abundance, dominance, equitability, taxonomic and functional diversity) of aquatic communities, it is possible to cover the wide range of environmental conditions in the watershed and their potential effects on the aquatic biota (CETESB, 2006; Bonada et al., 2006; Nogueira and Naliato. 2016).

In our study, we have tried to use the available information on plankton communities of the Paranapanema reservoirs cascade in a water quality approach.

Based on the application of the Communities Indices for reservoirs (FCI and ZCI) proposed by CETESB (2006) we can assume that they have a good potential to represent water quality standards when compared to the already established WQI and TSI indices. The FCI resulted classified the studied sites in only two categories, Excellent (52 %) and Good (48 %). The ZCI resulted to be more sensitive to trophic increase, with 73 % of the determinations as Good, 22 % as Regular and 5 % as Bad. However, it is important to mention that the lack of data and published results from these plankton indices applications, fundamental for comparison, is a difficulty that certainly can not be ignored.

The Planktonic Index of Biotic (P-IBI) is a new tool for evaluation of lake integrity (Kane et al., 2009). The first Index of Biotic Integrity (IBI) proposed by Karr et al. (1986) recognizes the importance of interactions among five classes of main factors to the aquatic biota: energy, chemical constituents, habitat structure, hydrology, and interactions between organisms. The U. S. Environmental Protection Agency developed a guidance for establishing biological criteria and biologically assessing for lakes and reservoirs (Thornton and Kennedy, 1999).

Chapter 4 deals specifically with the development and validation of the P-IBI proposal for Paranapanema River large reservoirs (Jurumirim, Chavantes and Capivara). The application of this index resulted in only two categories, Excellent, 75% of the determinations, and Good, 25 % of the determinations. This was similar to the FCI classifications and, as also observed for the FCI and ZCI indices, the P-IBI was not sensitive to seasonal changes.

In addition to the indices application in the present work we put some effort trying to understand the zooplankton responses to the environmental variability, concerning water quality and trophic state differences.

The zooplankton is a fundamental component of the pelagic food web in lakes, linking primary producers to higher consumers, and the limnological research has a long tradition in investigating the mechanisms that govern zooplankton diversity and species succession (Obertegger et al., 2007).

The successful use of the zooplankton community as a potential bioindicator of environmental quality in freshwater has already been reported (Pace and Orcutt, 1981; Ferdous and Muktadir, 2009), especially when analyzing some ecological attributes of the community (richness, abundance, dominance, diversity). The association of species to altered (eutrophic) or preserved (oligotrophic) environments, even for the Paranapanema basin, are cited in the scientific literature (Nogueira et al., 2008). Furthermore, Perbiche-Neves et al. (2016) studies showed that zooplankton abundance (generally dominated by few species) is positively correlated to high values of chlorophyll and nutrients (especially N and P) and negatively to conductivity and dissolved oxygen. Besides these general trends, individual response of each species is less known but would be desirable to simplify biomonitoring schemes by using a smaller number of species with the best response to eutrophication processes.

The simultaneous application and comparison of distinct water quality and trophic state indices (WQI, TSI and TSI modifications, FCI, ZCI and P-IBI) is a new approach for the relatively well known, in terms of limnological features, Paranapanema River reservoirs cascade. Results demonstrate the potential of using integrated indices and plankton, mainly zooplankton, metrics as robust, as well sensitive, environmental indicators. For some models (e.g. FCI, ZCI, P-IBI) would be challenging to incorporate a higher volume of data set to confirm the identified trends, and perhaps establish the new protocols for achieving a better management of these water resources.

Environmental indicators, when properly applied, provide valuable insight into complex environmental problems and can be used to effectively support the management-decision process (Thornton and Kennedy, 1999). However, indicators are based on simplifications and prudent choices must be made in data selection, application, and interpretation. Managers must ensure that indicators are relevant to management issues and target appropriate attributes of the environment.

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Appendix I – Water Quality Index (WQI) scores for Paranapanema River reservoir cascade in the wet and dry seasons.

Sampled sites	Season	W.Q.I.	Classification	Season	W.Q.I.	Classification
JR1	**Wet**	80	Excellent	**Dry**	83	Excellent
JRUp		89	Excellent		79	Excellent
JR2		87	Excellent		83	Excellent
JR3		88	Excellent		82	Excellent
JR4		88	Excellent		86	Excellent
JRDam		89	Excellent		83	Excellent
CH1	**Wet**	91	Excellent	**Dry**	83	Excellent
CH2		90	Excellent		84	Excellent
CH3		89	Excellent		87	Excellent
CHUp		83	Excellent		86	Excellent
CH4		91	Excellent		91	Excellent
CHDam		89	Excellent		88	Excellent
SGUp	**Wet**	73	Good	**Dry**	90	Excellent
SG1		70	Good		76	Good
SG2		72	Good		88	Excellent
SG3		79	Excellent		84	Excellent
SGDam		81	Excellent		89	Excellent
CIIUp	**Wet**	80	Excellent	**Dry**	90	Excellent
CII1		81	Excellent		91	Excellent
CIIDam		73	Good		91	Excellent
CIUp	**Wet**	73	Good	**Dry**	89	Excellent
CI1		74	Good		91	Excellent
CIDam		80	Excellent		91	Excellent
CPUp	**Wet**	84	Excellent	**Dry**	90	Excellent
CP1		89	Excellent		85	Excellent
CP2		87	Excellent		82	Excellent
CP3		84	Excellent		87	Excellent
CP4		83	Excellent		88	Excellent
CPDam		89	Excellent		87	Excellent
TQUp	**Wet**	88	Excellent	**Dry**	87	Excellent
TQ1		90	Excellent		91	Excellent
TQ2		84	Excellent		90	Excellent
TQDam		90	Excellent		88	Excellent
RSUp	**Wet**	85	Excellent	**Dry**	84	Excellent
RS1		85	Excellent		85	Excellent
RS2		84	Excellent		89	Excellent
RSDam		88	Excellent		87	Excellent

Appendix II – Carlson, (1977) Trophic State Index (TSI) scores for Paranapanema River reservoir cascade in the wet and dry seasons.

		Prof. Secchi (m)	F. T. (µg l^{-1})	Cl. *a* (µg l^{-1})	TSI (Secchi)	TSI (PT)	TSI (Chla)	TSI (tsr)	Trophic State Category
JR1	**Wet**	0.65	20.72	2.65	66.21	57.30	40.12	55	Eutrophic
JRUp		0.65	24.07	2.56	66.21	57.68	39.81	55	Eutrophic
JR2		0.9	17.01	2.94	61.52	56.72	41.14	53	Eutrophic
JR3		1	13.30	2.31	60.00	55.80	38.77	52	Eutrophic
JR4		2.3	11.20	0.85	47.98	55.02	29.01	44	Mesotrophic
JRDam		3	13.63	1.01	44.15	55.90	30.64	44	Mesotrophic
JR1	**Dry**	0.4	17.28	1.60	73.22	56.77	35.18	55	Eutrophic
JRUp		0.5	17.57	2.58	70.00	56.82	39.88	56	Eutrophic
JR2		0.6	17.57	3.48	67.37	56.82	42.80	56	Eutrophic
JR3		2.4	4.07	0.73	47.37	46.26	27.52	40	Oligotrophic
JR4		3.45	6.50	0.88	42.13	51.41	29.31	41	Mesotrophic
JRDam		3.5	3.13	1.41	41.93	42.14	33.94	39	Oligotrophic
CH1	**Wet**	0.8	19.05	1.07	63.22	57.07	31.23	51	Eutrophic
CH2		1.7	16.59	1.03	52.34	56.63	30.82	47	Mesotrophic
CH3		3.8	17.47	0.44	40.74	56.80	22.51	40	Oligotrophic
CHUp		2.7	14.19	0.86	45.67	56.06	29.10	44	Mesotrophic
CH4		3.75	12.82	0.48	40.93	55.64	23.29	40	Oligotrophic
CHDam		5.5	39.76	0.47	35.41	58.60	23.16	39	Oligotrophic
CH1	**Dry**	0.9	9.05	1.25	61.52	53.83	32.72	49	Mesotrophic
CH2		3.2	6.23	1.28	43.22	51.03	33.01	42	Mesotrophic
CH3		4.1	6.00	0.69	39.64	50.69	26.88	39	Oligotrophic
CHUp		2.6	5.90	1.28	46.21	50.53	33.01	43	Mesotrophic
CH4		1.4	8.83	0.53	55.15	53.67	24.28	44	Mesotrophic
CHDam		4.2	5.34	1.96	39.30	49.54	37.18	42	Mesotrophic
SGUp	**Wet**	3.5	21.62	1.10	41.93	57.42	31.49	44	Mesotrophic
SG1		0.25	36.90	10.30	80.00	58.49	53.45	64	Hypereutrophic
SG2		3.5	17.70	1.79	41.93	56.84	36.28	45	Mesotrophic
SG3		0.85	20.91	0.59	62.34	57.33	25.33	48	Mesotrophic
SGDam		1.65	22.42	0.68	52.78	57.51	26.73	46	Mesotrophic
SGUp	**Dry**	2.3	5.17	1.06	47.98	49.20	31.16	43	Mesotrophic
SG1		0.55	27.20	2.34	68.62	57.95	38.89	55	Eutrophic
SG2		3.4	5.23	1.48	42.34	49.32	34.44	42	Mesotrophic
SG3		0.4	11.76	6.07	73.22	55.25	48.27	59	Eutrophic
SGDam		2.4	8.49	1.61	47.37	53.42	35.25	45	Mesotrophic
CIIUp	**Wet**	1.3	21.79	0.93	56.21	57.44	29.90	48	Mesotrophic
CII1		1.5	21.71	0.66	54.15	57.43	26.48	46	Mesotrophic
CIIDam		1.75	21.71	1.76	51.93	57.43	36.11	48	Mesotrophic
CIIUp	**Dry**	1.7	14.14	0.96	52.34	56.05	30.18	46	Mesotrophic
CII1		2.1	15.36	0.69	49.30	56.36	26.88	44	Mesotrophic
CIIDam		3.2	12.15	0.96	43.22	55.40	30.18	43	Mesotrophic

		Prof. Secchi (m)	F. T. (µg l^{-1})	Cl. *a* (µg l^{-1})	TSI (Secchi)	TSI (PT)	TSI (Chla)	TSI (tsr)	Trophic State Category
CIUp	**Wet**	1.6	27.06	0.62	53.22	57.94	25.92	46	Mesotrophic
CI1		2.3	23.94	1.30	47.98	57.67	33.15	46	Mesotrophic
CIDam		1.4	26.10	0.51	55.15	57.86	24.02	46	Mesotrophic
CIUp	**Dry**	2	8.61	1.40	50.00	53.51	33.85	46	Mesotrophic
CI1		3.6	8.17	1.76	41.52	53.16	36.13	44	Mesotrophic
CIDam		3.5	9.66	2.20	41.93	54.22	38.29	45	Mesotrophic
CPUp	**Wet**	1.4	25.46	0.64	55.15	57.81	26.21	46	Mesotrophic
CP1		1.3	29.30	1.54	56.21	58.09	34.83	50	Mesotrophic
CP2		0.8	40.17	0.82	63.22	58.61	28.67	50	Mesotrophic
CP3		0.9	31.86	1.39	61.52	58.25	33.81	51	Eutrophic
CP4		1.2	27.70	2.58	57.37	57.98	39.88	52	Eutrophic
CPDam		2.7	21.07	1.21	45.67	57.35	32.43	45	Mesotrophic
CPUp	**Dry**	2.7	12.87	1.01	45.67	55.66	30.64	44	Mesotrophic
CP1		0.18	42.41	7.00	84.74	58.68	49.65	64	Hypereutrophic
CP2		0.2	67.18	5.04	83.22	59.17	46.43	63	Hypereutrophic
CP3		1.9	15.63	1.39	50.74	56.43	33.81	47	Mesotrophic
CP4		3.1	9.82	2.17	43.68	54.31	38.18	45	Mesotrophic
CPDam		3.3	9.77	1.34	42.78	54.28	33.42	43	Mesotrophic
TQUp	**Wet**	1.8	25.30	0.35	51.52	57.79	20.29	43	Mesotrophic
TQ1		2.15	25.22	0.59	48.96	57.79	25.33	44	Mesotrophic
TQ2		1.85	22.99	0.68	51.12	57.57	26.75	45	Mesotrophic
TQDam		1.9	22.43	0.71	50.74	57.51	27.27	45	Mesotrophic
TQUp	**Dry**	2.1	8.05	1.47	49.30	53.06	34.32	46	Mesotrophic
TQ1		2.1	9.93	1.68	49.30	54.38	35.69	46	Mesotrophic
TQ2		1.9	10.76	0.62	50.74	54.81	25.92	44	Mesotrophic
TQDam		2.2	8.49	1.12	48.62	53.42	31.66	45	Mesotrophic
RSUp	**Wet**	1.6	25.22	1.44	53.22	57.79	34.15	48	Mesotrophic
RS1		1.6	25.30	1.03	53.22	57.79	30.86	47	Mesotrophic
RS2		1.3	24.91	1.08	56.21	57.76	31.33	48	Mesotrophic
RSDam		1.5	20.27	1.52	54.15	57.24	34.69	49	Mesotrophic
RSUp	**Dry**	1.7	9.32	1.71	52.34	54.01	35.83	47	Mesotrophic
RS1		0.3	22.16	7.50	77.37	57.48	50.33	62	Hypereutrophic
RS2		2.8	9.55	2.69	45.15	54.15	40.27	47	Mesotrophic
RSDam		2.6	6.83	3.99	46.21	51.83	44.14	47	Mesotrophic

Appendix III – Carlson modified by Toledo Trophic State Index (TSI) scores for Paranapanema River reservoir cascade in the wet and dry seasons.

		Prof. Secchi (m)	**T.P. (µg l^{-1})**	**Cl. *a* (µg l^{-1})**	**S.R.P (µg l^{-1})**	**TSI (Secchi)**	**TSI (PT)**	**TSI (SRP)**	**TSI (Chla)**	**TSI (tsr)**	**Trophic State Category**
JR1	**Wet**	0.65	20.72	2.65	19.65	59.81	40.45	58.59	47.36	50	Mesotrophic
JRUp		0.65	24.07	2.56	30.34	59.81	42.62	64.86	47.04	53	Mesotrophic
JR2		0.9	17.01	2.94	14.05	55.12	37.61	53.75	48.40	48	Mesotrophic
JR3		1	13.30	2.31	20.96	53.60	34.06	59.52	45.98	48	Mesotrophic
JR4		2.3	11.20	0.85	6.16	41.58	31.58	41.84	36.00	37	Oligotrophic
JRDam		3	13.63	1.01	5.17	37.75	34.41	39.32	37.67	37	Oligotrophic
JR1	**Dry**	0.4	17.28	1.60	16.85	66.82	37.84	56.37	42.31	49	Mesotrophic
JRUp		0.5	17.57	2.58	11.42	63.60	38.07	50.76	47.11	48	Mesotrophic
JR2		0.6	17.57	3.48	16.69	60.97	38.07	56.23	50.10	50	Mesotrophic
JR3		2.4	4.07	0.73	6.98	40.97	16.96	43.65	34.48	33	Oligotrophic
JR4		3.45	6.50	0.88	5.17	35.73	23.73	39.32	36.31	33	Oligotrophic
JRDam		3.5	3.13	1.41	10.27	35.53	13.17	49.23	41.05	35	Oligotrophic
CH1	**Wet**	0.8	19.05	1.07	15.86	56.82	39.24	55.50	38.27	46	Mesotrophic
CH2		1.7	16.59	1.03	10.76	45.94	37.25	49.90	37.85	42	Oligotrophic
CH3		3.8	17.47	0.44	5.66	34.34	37.99	40.64	29.36	36	Oligotrophic
CHUp		2.7	14.19	0.86	11.42	39.27	34.99	50.76	36.10	40	Oligotrophic
CH4		3.75	12.82	0.48	10.93	34.53	33.52	50.12	30.16	37	Oligotrophic
CHDam		5.5	39.76	0.47	5.17	29.01	49.86	39.32	30.03	38	Oligotrophic
CH1	**Dry**	0.9	9.05	1.25	11.59	55.12	28.50	50.97	39.80	42	Oligotrophic
CH2		3.2	6.23	1.28	19.48	36.82	23.10	58.47	40.09	40	Oligotrophic
CH3		4.1	6.00	0.69	5.00	33.24	22.58	38.86	33.83	32	Oligotrophic
CHUp		2.6	5.90	1.28	5.66	39.81	22.32	40.64	40.09	35	Oligotrophic
CH4		1.4	8.83	0.53	4.68	48.75	28.14	37.88	31.17	35	Oligotrophic
CHDam		4.2	5.34	1.96	5.00	32.90	20.89	38.86	44.35	34	Oligotrophic
SGUp	**Wet**	3.5	21.62	1.10	8.95	35.53	41.07	47.25	38.55	41	Oligotrophic
SG1		0.25	36.90	10.30	64.56	73.60	48.78	75.75	60.99	64	Eutrophic
SG2		3.5	17.70	1.79	11.26	35.53	38.18	50.55	43.44	43	Oligotrophic
SG3		0.85	20.91	0.59	18.83	55.94	40.58	57.97	32.24	45	Mesotrophic
SGDam		1.65	22.42	0.68	37.42	46.38	41.59	67.88	33.67	48	Mesotrophic
SGUp	**Dry**	2.3	5.17	1.06	4.51	41.58	20.43	37.36	38.21	33	Oligotrophic
SG1		0.55	27.20	2.34	33.96	62.22	44.38	66.48	46.10	54	Mesotrophic
SG2		3.4	5.23	1.48	4.51	35.94	20.59	37.36	41.55	34	Oligotrophic
SG3		0.4	11.76	6.07	16.03	66.82	32.28	55.65	55.69	51	Oligotrophic
SGDam		2.4	8.49	1.61	5.33	40.97	27.59	39.78	42.39	37	Oligotrophic
CIIUp	**Wet**	1.3	21.79	0.93	10.27	49.81	41.18	49.23	36.92	43	Oligotrophic
CII1		1.5	21.71	0.66	13.89	47.75	41.13	53.58	33.42	43	Oligotrophic
CIIDam		1.75	21.71	1.76	100.60	45.53	41.13	82.15	43.26	54	Mesotrophic
CIIUp	**Dry**	1.7	14.14	0.96	12.90	45.94	34.94	52.52	37.21	42	Oligotrophic
CII1		2.1	15.36	0.69	15.21	42.90	36.13	54.89	33.83	42	Oligotrophic
CIIDam		3.2	12.15	0.96	13.23	36.82	32.75	52.88	37.21	40	Oligotrophic

		Prof. Secchi (m)	T.P. (µg l^{-1})	Cl. *a* (µg l^{-1})	S.R.P (µg l^{-1})	TSI (Secchi)	TSI (PT)	TSI (SRP)	TSI (Chla)	TSI (tsr)	Trophic State Category
ClUp	**Wet**	1.6	27.06	0.62	13.89	46.82	44.30	53.58	32.85	44	Oligotrophic
Cl1		2.3	23.94	1.30	7.97	41.58	42.54	45.56	40.23	43	Oligotrophic
ClDam		1.4	26.10	0.51	7.31	48.75	43.78	44.32	30.90	41	Oligotrophic
ClUp	**Dry**	2	8.61	1.40	6.98	43.60	27.77	43.65	40.95	38	Oligotrophic
Cl1		3.6	8.17	1.76	4.51	35.12	27.02	37.36	43.28	36	Oligotrophic
ClDam		3.5	9.66	2.20	7.31	35.53	29.44	44.32	45.50	39	Oligotrophic
CPUp	**Wet**	1.4	25.46	0.64	13.23	48.75	43.43	37.88	33.14	44	Oligotrophic
CP1		1.3	29.30	1.54	12.41	49.81	45.45	62.66	41.96	47	Mesotrophic
CP2		0.8	40.17	0.82	10.60	56.82	50.00	59.29	35.66	47	Mesotrophic
CP3		0.9	31.86	1.39	7.97	55.12	46.66	38.37	40.92	46	Oligotrophic
CP4		1.2	27.70	2.58	6.49	50.97	44.64	41.05	47.11	46	Mesotrophic
CPDam		2.7	21.07	1.21	5.66	39.27	40.69	37.88	39.50	40	Oligotrophic
CPUp	**Dry**	2.7	12.87	1.01	4.68	39.27	33.58	52.88	37.67	37	Oligotrophic
CP1		0.18	42.41	7.00	26.06	78.34	50.79	51.96	57.11	60	Eutrophic
CP2		0.2	67.18	5.04	20.64	76.82	57.42	49.68	53.81	60	Eutrophic
CP3		1.9	15.63	1.39	4.84	44.34	36.39	45.56	40.92	39	Oligotrophic
CP4		3.1	9.82	2.17	5.83	37.28	29.68	42.60	45.38	39	Oligotrophic
CPDam		3.3	9.77	1.34	4.68	36.38	29.60	40.64	40.51	36	Oligotrophic
TQUp	**Wet**	1.8	25.30	0.35	4.51	45.12	43.33	48.99	27.10	37	Oligotrophic
TQ1		2.15	25.22	0.59	4.51	42.56	43.29	49.23	32.24	38	Oligotrophic
TQ2		1.85	22.99	0.68	4.51	44.72	41.95	44.95	33.70	39	Oligotrophic
TQDam		1.9	22.43	0.71	7.14	44.34	41.59	46.98	34.23	41	Oligotrophic
TQUp	**Dry**	2.1	8.05	1.47	10.11	42.90	26.82	37.36	41.43	40	Oligotrophic
TQ1		2.1	9.93	1.68	10.27	42.90	29.85	37.36	42.83	41	Oligotrophic
TQ2		1.9	10.76	0.62	7.64	44.34	31.00	37.36	32.85	37	Oligotrophic
TQDam		2.2	8.49	1.12	8.79	42.22	27.59	43.99	38.71	38	Oligotrophic
RSUp	**Wet**	1.6	25.22	1.44	7.31	46.82	43.29	48.76	41.26	44	Oligotrophic
RS1		1.6	25.30	1.03	8.13	46.82	43.33	60.51	37.90	43	Oligotrophic
RS2		1.3	24.91	1.08	11.42	49.81	43.11	40.64	38.38	45	Mesotrophic
RSDam		1.5	20.27	1.52	6.49	47.75	40.14	37.36	41.82	42	Oligotrophic
RSUp	**Dry**	1.7	9.32	1.71	9.94	45.94	28.93	44.32	42.97	41	Oligotrophic
RS1		0.3	22.16	7.50	22.44	70.97	41.42	45.86	57.80	56	Eutrophic
RS2		2.8	9.55	2.69	5.66	38.75	29.27	50.76	47.51	39	Oligotrophic
RSDam		2.6	6.83	3.99	4.51	39.81	24.45	42.61	51.47	38	Oligotrophic

Appendix IV – CETESB, (2006) Trophic State Index (TSI) for reservoirs scores for Paranapanema River reservoir cascade in the wet and dry seasons.

		F. T. **(µg l^{-1})**	**Cl. *a*** **(µg l^{-1})**	**TSI (PT)**	**TSI (Chla)**	**TSI (tsr)**	**Trophic State Category**
JR1	**Wet**	20.72	2.65	52.83	55.57	54	Mesotrophic
JRUp		24.07	2.56	53.74	55.42	55	Mesotrophic
JR2		17.01	2.94	51.63	56.08	54	Mesotrophic
JR3		13.30	2.31	50.15	54.90	53	Mesotrophic
JR4		11.20	0.85	49.11	50.02	50	Oligotrophic
JRDam		13.63	1.01	50.29	50.84	51	Oligotrophic
JR1	**Dry**	17.28	1.60	51.73	53.11	52	Oligotrophic
JRUp		17.57	2.58	51.83	55.45	54	Mesotrophic
JR2		17.57	3.48	51.83	56.92	54	Mesotrophic
JR3		4.07	0.73	42.96	49.27	46	Ultraoligotrophic
JR4		6.50	0.88	45.81	50.17	48	Oligotrophic
JRDam		3.13	1.41	41.37	52.49	47	Ultraoligotrophic
CH1	**Wet**	19.05	1.07	52.32	51.13	52	Oligotrophic
CH2		16.59	1.03	51.48	50.92	51	Oligotrophic
CH3		17.47	0.44	51.80	46.77	49	Oligotrophic
CHUp		14.19	0.86	50.54	50.06	50	Oligotrophic
CH4		12.82	0.48	49.92	47.16	49	Oligotrophic
CHDam		39.76	0.47	56.78	47.10	52	Oligotrophic
CH1	**Dry**	9.05	1.25	47.81	51.88	50	Oligotrophic
CH2		6.23	1.28	45.54	52.02	49	Oligotrophic
CH3		6.00	0.69	45.32	48.96	47	Ultraoligotrophic
CHUp		5.90	1.28	45.21	52.02	49	Oligotrophic
CH4		8.83	0.53	47.66	47.65	48	Oligotrophic
CHDam		5.34	1.96	44.62	54.10	49	Oligotrophic
SGUp	**Wet**	21.62	1.10	53.09	51.26	52	Oligotrophic
SG1		36.90	10.30	56.33	62.24	59	Mesotrophic
SG2		17.70	1.79	51.88	53.66	53	Mesotrophic
SG3		20.91	0.59	52.89	48.18	51	Oligotrophic
SGDam		22.42	0.68	53.31	48.88	51	Oligotrophic
SGUp	**Dry**	5.17	1.06	44.42	51.10	48	Oligotrophic
SG1		27.20	2.34	54.48	54.96	55	Mesotrophic
SG2		5.23	1.48	44.49	52.73	49	Oligotrophic
SG3		11.76	6.07	49.40	59.65	55	Mesotrophic
SGDam		8.49	1.61	47.43	53.14	50	Oligotrophic
CIIUp	**Wet**	21.79	0.93	53.14	50.47	52	Oligotrophic
CII1		21.71	0.66	53.11	48.76	51	Oligotrophic
CIIDam		21.71	1.76	53.11	53.57	53	Mesotrophic
CIIUp	**Dry**	14.14	0.96	50.51	50.61	51	Oligotrophic
CII1		15.36	0.69	51.02	48.96	50	Oligotrophic
CIIDam		12.15	0.96	49.59	50.61	50	Oligotrophic

		F. T. (µg l^{-1})	Cl. *a* (µg l^{-1})	TSI (PT)	TSI (Chla)	TSI (tsr)	Trophic State Category
ClUp	**Wet**	27.06	0.62	54.45	48.48	51	Oligotrophic
Cl1		23.94	1.30	53.71	52.09	53	Mesotrophic
ClDam		26.10	0.51	54.23	47.52	51	Oligotrophic
ClUp	**Dry**	8.61	1.40	47.51	52.44	50	Oligotrophic
Cl1		8.17	1.76	47.19	53.58	50	Oligotrophic
ClDam		9.66	2.20	48.20	54.66	51	Oligotrophic
CPUp	**Wet**	25.46	0.64	54.08	48.62	51	Oligotrophic
CP1		29.30	1.54	54.93	52.93	54	Mesotrophic
CP2		40.17	0.82	56.84	49.85	53	Mesotrophic
CP3		31.86	1.39	55.44	52.42	54	Mesotrophic
CP4		27.70	2.58	54.59	55.45	55	Mesotrophic
CPDam		21.07	1.21	52.93	51.73	52	Oligotrophic
CPUp	**Dry**	12.87	1.01	49.94	50.84	50	Oligotrophic
CP1		42.41	7.00	57.17	60.34	59	Mesotrophic
CP2		67.18	5.04	59.96	58.73	59	Mesotrophic
CP3		15.63	1.39	51.12	52.42	52	Oligotrophic
CP4		9.82	2.17	48.31	54.61	51	Oligotrophic
CPDam		9.77	1.34	48.27	52.22	50	Oligotrophic
TQUp	**Wet**	25.30	0.35	54.04	45.66	50	Oligotrophic
TQ1		25.22	0.59	54.02	48.18	51	Oligotrophic
TQ2		22.99	0.68	53.46	48.89	51	Oligotrophic
TQDam		22.43	0.71	53.31	49.15	51	Oligotrophic
TQUp	**Dry**	8.05	1.47	47.10	52.67	50	Oligotrophic
TQ1		9.93	1.68	48.38	53.36	51	Oligotrophic
TQ2		10.76	0.62	48.86	48.48	49	Oligotrophic
TQDam		8.49	1.12	47.43	51.34	49	Oligotrophic
RSUp	**Wet**	25.22	1.44	54.02	52.59	53	Mesotrophic
RS1		25.30	1.03	54.04	50.94	52	Oligotrophic
RS2		24.91	1.08	53.95	51.18	53	Mesotrophic
RSDam		20.27	1.52	52.70	52.86	53	Mesotrophic
RSUp	**Dry**	9.32	1.71	47.99	53.43	51	Oligotrophic
RS1		22.16	7.50	53.24	60.68	57	Mesotrophic
RS2		9.55	2.69	48.13	55.65	52	Oligotrophic
RSDam		6.83	3.99	46.11	57.59	52	Oligotrophic

Appendix V – Cunha et al., (2013) Trophic State Index (TSI) for tropical/subtropical reservoirs scores for Paranapanema River reservoir cascade in the wet and dry seasons.

		F. T. (µg l^{-1})	**Cl. *a* (µg l^{-1})**	**TSI (TP)**	**TSI (Chla)**	**TSI (tsr)**	**Trophic State Category**
JR1	**Wet**	20.72	2.65	52.9	51.38	52.1	Oligotrophic
JRUp		24.07	2.56	53.5	51.26	52.4	Oligotrophic
JR2		17.01	2.94	52.1	51.75	51.9	Oligotrophic
JR3		13.30	2.31	51.1	50.88	51.0	Ultraoligotrophic
JR4		11.20	0.85	50.4	47.27	48.9	Ultraoligotrophic
JRDam		13.63	1.01	51.2	47.88	49.6	Ultraoligotrophic
JR1	**Dry**	17.28	1.60	52.2	49.55	50.9	Ultraoligotrophic
JRUp		17.57	2.58	52.2	51.29	51.8	Oligotrophic
JR2		17.57	3.48	52.2	52.37	52.3	Oligotrophic
JR3		4.07	0.73	46.4	46.72	46.6	Ultraoligotrophic
JR4		6.50	0.88	48.3	47.38	47.8	Ultraoligotrophic
JRDam		3.13	1.41	45.4	49.09	47.2	Ultraoligotrophic
CH1	**Wet**	19.05	1.07	52.6	48.09	50.3	Ultraoligotrophic
CH2		16.59	1.03	52.0	47.94	50.0	Ultraoligotrophic
CH3		17.47	0.44	52.2	44.87	48.5	Ultraoligotrophic
CHUp		14.19	0.86	51.4	47.31	49.3	Ultraoligotrophic
CH4		12.82	0.48	51.0	45.16	48.1	Ultraoligotrophic
CHDam		39.76	0.47	55.5	45.11	50.3	Ultraoligotrophic
CH1	**Dry**	9.05	1.25	49.6	48.64	49.1	Ultraoligotrophic
CH2		6.23	1.28	48.1	48.75	48.4	Ultraoligotrophic
CH3		6.00	0.69	48.0	46.49	47.2	Ultraoligotrophic
CHUp		5.90	1.28	47.9	48.75	48.3	Ultraoligotrophic
CH4		8.83	0.53	49.5	45.52	47.5	Ultraoligotrophic
CHDam		5.34	1.96	47.5	50.29	48.9	Ultraoligotrophic
SGUp	**Wet**	21.62	1.10	53.1	48.19	50.6	Ultraoligotrophic
SG1		36.90	10.30	55.2	56.30	55.8	Eutrophic
SG2		17.70	1.79	52.3	49.96	51.1	Ultraoligotrophic
SG3		20.91	0.59	52.9	45.91	49.4	Ultraoligotrophic
SGDam		22.42	0.68	53.2	46.43	49.8	Ultraoligotrophic
SGUp	**Dry**	5.17	1.06	47.4	48.07	47.7	Ultraoligotrophic
SG1		27.20	2.34	54.0	50.92	52.5	Oligotrophic
SG2		5.23	1.48	47.4	49.28	48.3	Ultraoligotrophic
SG3		11.76	6.07	50.6	54.39	52.5	Oligotrophic
SGDam		8.49	1.61	49.3	49.58	49.5	Ultraoligotrophic
CIIUp	**Wet**	21.79	0.93	53.1	47.60	50.4	Ultraoligotrophic
CII1		21.71	0.66	53.1	46.34	49.7	Ultraoligotrophic
CIIDam		21.71	1.76	53.1	49.89	51.5	Oligotrophic
CIIUp	**Dry**	14.14	0.96	51.4	47.71	49.5	Ultraoligotrophic
CII1		15.36	0.69	51.7	46.49	49.1	Ultraoligotrophic
CIIDam		12.15	0.96	50.8	47.71	49.2	Ultraoligotrophic

		F. T. (µg l^{-1})	Cl. *a* (µg l^{-1})	TSI (TP)	TSI (Chla)	TSI (tsr)	Trophic State Category
ClUp	**Wet**	27.06	0.62	54.0	46.13	50.0	Ultraoligotrophic
Cl1		23.94	1.30	53.5	48.80	51.1	Ultraoligotrophic
ClDam		26.10	0.51	53.8	45.43	49.6	Ultraoligotrophic
ClUp	**Dry**	8.61	1.40	49.4	49.06	49.2	Ultraoligotrophic
Cl1		8.17	1.76	49.2	49.90	49.5	Ultraoligotrophic
ClDam		9.66	2.20	49.9	50.70	50.3	Ultraoligotrophic
CPUp	**Wet**	25.46	0.64	53.7	46.24	50.0	Ultraoligotrophic
CP1		29.30	1.54	54.3	49.42	51.9	Oligotrophic
CP2		40.17	0.82	55.5	47.15	51.3	Oligotrophic
CP3		31.86	1.39	54.6	49.05	51.8	Oligotrophic
CP4		27.70	2.58	54.1	51.29	52.7	Oligotrophic
CPDam		21.07	1.21	53.0	48.54	50.8	Ultraoligotrophic
CPUp	**Dry**	12.87	1.01	51.0	47.88	49.4	Ultraoligotrophic
CP1		42.41	7.00	55.8	54.90	55.3	Mesotrophic
CP2		67.18	5.04	57.6	53.71	55.6	Mesotrophic
CP3		15.63	1.39	51.8	49.05	50.4	Ultraoligotrophic
CP4		9.82	2.17	49.9	50.66	50.3	Ultraoligotrophic
CPDam		9.77	1.34	49.9	48.90	49.4	Ultraoligotrophic
TQUp	**Wet**	25.30	0.35	53.7	44.05	48.9	Ultraoligotrophic
TQ1		25.22	0.59	53.7	45.91	49.8	Ultraoligotrophic
TQ2		22.99	0.68	53.3	46.44	49.9	Ultraoligotrophic
TQDam		22.43	0.71	53.2	46.63	49.9	Ultraoligotrophic
TQUp	**Dry**	8.05	1.47	49.1	49.23	49.2	Ultraoligotrophic
TQ1		9.93	1.68	50.0	49.74	49.9	Ultraoligotrophic
TQ2		10.76	0.62	50.3	46.13	48.2	Ultraoligotrophic
TQDam		8.49	1.12	49.3	48.25	48.8	Ultraoligotrophic
RSUp	**Wet**	25.22	1.44	53.7	49.17	51.4	Oligotrophic
RS1		25.30	1.03	53.7	47.96	50.8	Ultraoligotrophic
RS2		24.91	1.08	53.6	48.13	50.9	Ultraoligotrophic
RSDam		20.27	1.52	52.8	49.37	51.1	Ultraoligotrophic
RSUp	**Dry**	9.32	1.71	49.7	49.79	49.8	Ultraoligotrophic
RS1		22.16	7.50	53.2	55.15	54.2	Mesotrophic
RS2		9.55	2.69	49.8	51.43	50.6	Ultraoligotrophic
RSDam		6.83	3.99	48.5	52.86	50.7	Ultraoligotrophic

Appendix VI – Correlation scores for Paranapanema River reservoir cascade in the wet and dry seasons.

	Brachionus sp.	*Collotheca* sp.	*Filinia* sp.	*Argyrodiaptomus* sp.	*Notodiaptomus iheringi*	*Thermocyclops decipiens*	*Thermocyclops minutus*	*Bosmina* sp.	*Daphnia* sp.	Rotifera total	Copepoda total	Cladocera total	Calanoida total	Calanoida s/nauplii	Cyclopoida total	Cyclopoida s/nauplii	Cal/(Cyc+Rot)	Richness Rotifera	Richness Copepoda	Richness Cladocera	Richness Rot+Cop+Clad
Transp	-.2318	.2212	-.3850	.1026	.2106	-.1702	-.0850	.0914	.2704	.0056	-.0259	.1795	.2492	.2466	-.1314	-.0459	.1956	-.0869	.2065	.3060	.1266
	p=.047	p=.058	p=.001	p=.384	p=.072	p=.147	p=.472	p=.438	p=.020	p=.963	p=.827	p=.126	p=.032	p=.034	p=.264	p=.698	p=.095	p=.461	p=.077	p=.008	p=.282
Temp.	-.2193	-.4500	-.0792	.1514	.0704	-.2137	-.3185	-.5862	-.5979	-.5771	-.4531	-.6138	-.3760	-.2955	-.4312	-.5081	.3785	-.2870	-.0877	-.3934	-.4099
	p=.060	p=.000	p=.502	p=.198	p=.551	p=.068	p=.006	p=.000	p=.000	p=.000	p=.000	p=.000	p=.001	p=.011	p=.000	p=.000	p=.001	p=.013	p=.458	p=.001	p=.000
pH	-.2070	-.2765	-.1989	.1119	.0623	-.2186	-.1827	-.4223	-.0702	-.2879	-.3722	-.3676	-.2928	-.2720	-.3610	-.3973	.1975	-.2103	-.1331	-.1798	-.2480
	p=.077	p=.017	p=.089	p=.343	p=.598	p=.061	p=.119	p=.000	p=.552	p=.013	p=.001	p=.001	p=.011	p=.019	p=.002	p=.000	p=.092	p=.072	p=.258	p=.125	p=.033
Cond.	-.0402	-.3244	-.2004	-.1352	-.0309	-.3488	-.1542	-.3589	-.2158	-.3989	-.4206	-.3828	-.2715	-.2592	-.4041	-.4086	.2171	-.4751	-.1323	-.3063	-.4948
	p=.734	p=.005	p=.087	p=.251	p=.794	p=.002	p=.189	p=.002	p=.065	p=.000	p=.000	p=.001	p=.019	p=.026	p=.000	p=.000	p=.063	p=.000	p=.261	p=.008	p=.000
Turb.	.1294	-.1244	.2309	-.0166	-.1492	.1827	.0748	-.0303	-.1108	.0625	.0818	-.0842	-.1482	-.1270	.1580	.1026	-.1637	.0185	-.2188	-.2640	-.1463
	p=.272	p=.291	p=.048	p=.889	p=.205	p=.119	p=.527	p=.798	p=.347	p=.597	p=.488	p=.476	p=.207	p=.281	p=.179	p=.385	p=.163	p=.876	p=.061	p=.023	p=.214
D.O.	.1744	.0526	.2484	.0022	-.0858	-.0435	.1937	.1213	-.0056	.1697	.1389	.1261	.1026	.1346	.0841	.0784	.0355	.1569	.1694	.0620	.1751
	p=.137	p=.656	p=.033	p=.985	p=.467	p=.713	p=.098	p=.303	p=.962	p=.148	p=.238	p=.284	p=.384	p=.253	p=.476	p=.507	p=.764	p=.182	p=.149	p=.600	p=.136
B.O.D	.2759	.0166	.0479	-.2738	-.1649	.0900	.1513	.0432	.0318	.2402	.0004	-.0143	-.1053	-.1760	.0781	.0306	-.2422	.1069	-.0906	-.0061	.0790
	p=.017	p=.888	p=.685	p=.018	p=.160	p=.446	p=.198	p=.715	p=.788	p=.039	p=.997	p=.904	p=.372	p=.134	p=.508	p=.796	p=.038	p=.365	p=.443	p=.959	p=.504
T.S.	.0362	.0791	.0414	.2127	-.2205	.1607	.0425	.1976	.0917	.1087	.2321	.1296	.1811	.1938	.2061	.2579	.0043	-.0567	-.0923	-.0074	-.0724
	p=.759	p=.503	p=.726	p=.069	p=.059	p=.171	p=.719	p=.091	p=.437	p=.356	p=.047	p=.271	p=.123	p=.098	p=.078	p=.027	p=.971	p=.631	p=.434	p=.950	p=.540
Inorg. S.S.	.2837	-.0746	.2765	-.0651	-.1418	.1092	.0723	.0031	-.0981	.1507	.0303	-.0986	-.2246	-.2274	.1302	.0263	-.2239	.0719	-.1752	-.2836	-.1151
	p=.014	p=.527	p=.017	p=.582	p=.228	p=.355	p=.540	p=.979	p=.406	p=.200	p=.798	p=.403	p=.054	p=.051	p=.269	p=.824	p=.055	p=.543	p=.136	p=.014	p=.329
Org. S.S	.3326	-.0366	.2296	-.0140	-.1188	.0448	-.1049	-.0285	-.1020	.1670	-.0065	-.1415	-.2942	-.3015	.0881	-.0458	-.2457	.0215	-.2116	-.3284	-.1623
	p=.004	p=.757	p=.049	p=.906	p=.313	p=.705	p=.374	p=.809	p=.387	p=.155	p=.956	p=.229	p=.011	p=.009	p=.455	p=.699	p=.035	p=.856	p=.070	p=.004	p=.167

	Brachionus sp.	*Collotheca* sp.	*Filinia* sp.	*Argyrodiaptomus* sp.	*Notodiaptomus iheringi*	*Thermocyclops decipiens*	*Thermocyclops minutus*	*Bosmina* sp.	*Daphnia* sp.	Rotifera total	Copepoda total	Cladocera total	Calanoida total	Calanoida s/nauplii	Cyclopoida total	Cyclopoida s/nauplii	Cal/(Cyc+Rot)	Richness Rotifera	Richness Copepoda	Richness Cladocera	Richness Rot+Cop+Clad
T.N	-.1440	-.4079	-.0316	.3635	-.0198	.1820	-.1210	-.2012	-.2575	-.4369	-.1752	-.2544	.0124	.0724	-.2036	-.1611	.3552	-.2977	.1223	-.1028	-.2287
	p=.221	p=.000	p=.789	p=.001	p=.867	p=.121	p=.304	p=.086	p=.027	p=.000	p=.135	p=.029	p=.916	p=.540	p=.082	p=.170	p=.002	p=.010	p=.299	p=.383	p=.050
T.P	-.0674	-.3497	.1597	-.0720	.0385	.0517	-.2324	-.3144	-.4076	-.3370	-.1733	-.3671	-.2314	-.2235	-.0973	-.2019	.1023	-.0351	-.1363	-.2527	-.1868
	p=.568	p=.002	p=.174	p=.542	p=.745	p=.662	p=.046	p=.006	p=.000	p=.003	p=.140	p=.001	p=.047	p=.056	p=.410	p=.085	p=.386	p=.767	p=.247	p=.030	p=.111
S.R.P	.2883	.0134	.3293	.0310	-.0593	.1467	-.0529	.0628	-.0223	.2245	.1268	-.0003	-.1537	-.1817	.1664	.0614	-.2004	.1220	-.1294	-.1835	-.0114
	p=.013	p=.910	p=.004	p=.793	p=.616	p=.212	p=.654	p=.595	p=.851	p=.055	p=.282	p=.998	p=.191	p=.121	p=.157	p=.603	p=.087	p=.300	p=.272	p=.118	p=.923
Chl. *a*	.3819	-.0182	.2224	.0797	-.1866	.0870	-.0648	.1152	.0008	.2132	.0916	-.0151	-.1650	-.1944	.1518	.0420	-.2510	.0628	-.0922	-.1934	-.0423
	p=.001	p=.878	p=.057	p=.500	p=.111	p=.461	p=.583	p=.328	p=.994	p=.068	p=.438	p=.898	p=.160	p=.097	p=.197	p=.723	p=.031	p=.595	p=.435	p=.099	p=.721
Thermo Coli	.1469	-.1973	.1155	-.2181	-.1124	-.3266	-.1675	-.2251	-.3770	-.0526	-.2174	-.2875	-.3395	-.2539	-.1547	-.3361	-.0611	.1062	-.3235	-.3386	-.1814
	p=.212	p=.092	p=.327	p=.062	p=.340	p=.005	p=.154	p=.054	p=.001	p=.656	p=.063	p=.013	p=.003	p=.029	p=.188	p=.003	p=.605	p=.368	p=.005	p=.003	p=.122
WQI	-.0038	.1870	-.1100	-.0384	.0414	.2648	.1681	.1569	.2954	.1423	.1072	.2096	.1890	.0779	.0924	.2179	-.0561	-.0066	.1860	.3078	.2181
	p=.974	p=.111	p=.351	p=.746	p=.726	p=.023	p=.152	p=.182	p=.011	p=.226	p=.363	p=.073	p=.107	p=.510	p=.434	p=.062	p=.635	p=.956	p=.113	p=.008	p=.062
T.S.I (Cmd)	.2339	-.2439	.3667	-.1499	-.1336	.0475	-.1223	-.1760	-.3132	-.0717	-.0861	-.2647	-.3282	-.3334	.0240	-.1107	-.1615	.0886	-.2104	-.3321	-.1375
	p=.045	p=.036	p=.001	p=.202	p=.257	p=.687	p=.299	p=.134	p=.007	p=.544	p=.466	p=.023	p=.004	p=.004	p=.839	p=.348	p=.169	p=.453	p=.072	p=.004	p=.243
T.S.I (CTB)	.3020	-.2048	.3662	-.0244	-.2045	.1648	-.0055	-.0615	-.2209	.0314	.0305	-.1658	-.2467	-.2618	.1312	.0170	-.2034	.0729	-.1615	-.2931	-.1139
	p=.009	p=.080	p=.001	p=.836	p=.081	p=.161	p=.963	p=.603	p=.059	p=.790	p=.797	p=.158	p=.034	p=.024	p=.265	p=.886	p=.082	p=.537	p=.169	p=.011	p=.334
T.S.I. (TSR)	.1923	-.2584	.2644	.0222	-.0986	.1016	-.2030	-.1508	-.2867	-.1074	-.0652	-.2531	-.2419	-.2577	.0187	-.1163	-.0653	.0101	-.1325	-.2814	-.1522
	p=.101	p=.026	p=.023	p=.851	p=.403	p=.389	p=.083	p=.200	p=.013	p=.362	p=.581	p=.030	p=.038	p=.027	p=.875	p=.324	p=.581	p=.932	p=.260	p=.015	p=.195

Chapter 3 - Zooplankton community composition and structure as potential indicators of water quality and trophic state conditions in the Paranapanema River reservoir cascade

Zooplankton community composition and structure as potential indicators of water quality and trophic state conditions in the Paranapanema River reservoir cascade

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Abstract

Hydropower represents more than two-thirds of Brazil's energy supply and several rivers have a series of dams along their course forming reservoir cascade systems, which create longitudinal discontinuities. The understanding of structure and functioning of plankton communities in reservoir ecosystems provide opportunities to investigate patterns of responses to cyclical variations and episodic disturbances. The purpose of this study is to improve the knowledge on zooplankton community structure of the Paranapanema River reservoir cascade, with a special focus on detecting patterns and species with indicative potential to evaluate environmental changes. The zooplankton community structure and ecological attributes were evaluated for eight reservoirs, Jurumirim, Chavantes, Salto Grande, Canoas II, Canoas I, Capivara, Taquaruçu and Rosana, considering 37 sampling sites and two seasons, wet and dry. To analyze zooplankton species as potential indicator of water quality and trophic state we considered only storage (higher water retention time) reservoirs (Jurimirm, Chavantes and Capivara). Zooplankton data was correlated with total phosphorus, chlorophyll *a* and with the quantitative results of Water Quality Index. and Trophic State Index for tropical/subtropical reservoirs. A multivariate analyses was also performed using non-metric multidimensional scaling (NMDS) together with SIMPER analyses to examine the contribution of each variable to average resemblances between groups. The zooplankton community was composed by 112 taxa distributed among the main groups, Rotifera (65), Copepoda (14) and Cladocera (33). The potential of a set of species as biondicators was evidenced, but there was no remarkable species replacement by tolerant forms. This could be attributed to inherent variety of transient conditions involving hydrological, limnological, and biological features, typical of reservoir ecosystems. Other point to be considered is that in this basin the range of trophic conditions is still not too variable. Zooplankton is valuable as indicators on changes in water quality and trophic conditions and can give us signs that the environment is undergoing changes before it's become drastic or irreparable.

Resumo

Hidrelétricas representam mais de dois terços do suprimento de energia do Brasil e vários rios possuem uma série de barragens ao longo do curso formando sistemas de cascata de reservatórios, que criam descontinuidades longitudinais. A compreensão da estrutura e do funcionamento das comunidades planctônicas em ecossistemas de reservatórios proporciona oportunidades para investigar padrões de respostas a variações cíclicas e perturbações episódicas. O objetivo deste estudo é aprimorar o conhecimento sobre a estrutura da comunidade do zooplâncton da cascata do reservatório do rio Paranapanema, com foco especial na detecção de padrões e espécies como potencial indicador para avaliar as mudanças ambientais. A estrutura da comunidade zooplanctônica e atributos ecológicos foram analisados em oito reservatórios, Jurumirim, Chavantes, Salto Grande, Canoas II, Canoas I, Capivara, Taquaruçu e Rosana, considerando 37 pontos de amostragem e duas estações, seca e chuva. Para analisar as espécies do zooplâncton como potencial indicador de qualidade da água e estado trófico consideramos apenas reservatórios de acumulação (maior tempo de retenção de água) (Jurumirim, Chavantes e Capivara). Os dados do zooplâncton foram correlacionados com fósforo total, clorofila *a* e com os resultados quantitativos do Índice de Qualidade da Água e Índice de Estado Trófico para reservatórios tropicais/subtropicais. Realizou-se também uma análise de ordenação utilizando escalonamento multidimensional não-métrico (NMDS) juntamente com análise SIMPER para examinar a contribuição de cada variável para semelhanças médias entre os grupos. A comunidade zooplanctônica foi composta por 112 táxons distribuídos entre os principais grupos, Rotifera (65), Copepoda (14) e Cladocera (33). Um conjunto de espécies com potencial para bioindicador foi evidenciado, mas não houve nenhuma substituição espécies notável por formas tolerantes. Isso pode ser atribuído à variedade inerente de condições transitórias envolvendo características hidrológicas, limnológicas e biológicas, típicas dos ecossistemas de reservatórios. Outro ponto a ser considerado é que nessa bacia a faixa de condições tróficas ainda não é muito variável. O zooplâncton é valioso como indicador de mudanças na qualidade da água e condições tróficas e pode nos dar sinais de que o ambiente está passando por mudanças antes destas se tornarem drásticas ou irreparáveis.

Key words: Rotifers, copepods, cladocerans, bioindicators, reservoir monitoring.

Introduction

The resources provided by river damming and regulation of rivers flow are fundamental for local and regional economies. Access to energy is a fundamental driver of economic growth, and during the next two decades, rivers around the world, including many currently free flowing rivers, are predicted to undergo development of hydropower plants that could double current global capacity (Opperman et al., 2015).

Hydropower accounts for more than two-thirds of Brazil’s energy supply (Winemiller et al., 2015). Hydropower plants seems to be an attractive technology for many countries because: 1) use of low-carbon source of energy; 2) In addition to direct generation, support a set of energy-related services, including renewable energy, such as wind and solar power; 3) is relatively low-cost domestic source of power that can be exploited with proven technology and 4) can provide and support multiple uses, from storage to navigation (Opperman et al., 2015).

In Brazil, several rivers have a series of dams along their course forming reservoir cascade systems (Barbosa et al., 1999; Nogueira et al., 2006). This human interference creates a series of alternating lotic and lentic stretches, discontinuities that results in longitudinal shifts of riverine characteristics (Ward and Stanford 1983). These shifts, which can be considered both negative (upstream) and positive (downstream), are also applied to the physical and chemical characteristics as well as the attributes of biotic communities (Kennedy 1998).

Studies on the structure and functioning of planktonic communities in reservoir ecosystems provide opportunities to investigate patterns of responses to cyclical variations and episodic disturbances The understanding of plankton dynamics can be useful to evaluate the resilience of this kind of ecosystem too, which can present deep changes in limnological conditions in relatively short periods (Nogueira, 2001).

The use of zooplankton community characteristics as a tool for bioindication has been considered for a long time with low informative value (Andronikova, 1996). However, zooplankton indices based on taxonomic composition, size distribution, trophic levels, spatial patterns of distribution, functional characteristics and quantitative data may be of high informative potential, and should not be overlooked in monitoring studies (Gannon and Stemberger, 1978; Andronikova, 1996; Ferdous and Muktadir, 2009).

Zooplankton plays an important role in food web by linking the primary producers, by consuming phytoplankton, bacterioplankton and even small zooplankton organisms, to higher trophic levels (Ferdous and Muktadir, 2009). Zooplankton respond quickly to environment changes and act as an effective indicator of alterations in water quality, been more valuable as indicator of trophic conditions than has generally been considered (Gannon and Stemberger, 1978).

The structure and dynamics of the zooplankton community result from interactions between fertility rates, mortality and dispersion of their populations. A large number of environmental variables constantly influences the zooplankton functional characteristics, directly and indirectly. Examples can include the effects of temperature, quantity and frequency of precipitation, wind episodes, nutrient availability, food quality and quantity, intra and interspecific competition and predation (Nogueira and Matsumura-Tundisi, 1996; Serafim-Júnior et al., 2005).

Modifications in the structure and dynamics of freshwater zooplankton, which is represented mainly by protozoans, rotifers, cladocerans and copepods, can spread alterations in the trophic structure (lower and higher levels), and, therefore, are relevant for the entire ecosystem metabolism (Lansac-Tôha, et al., 2004). These organisms have a high growth rate, responding quickly to the impacts that alter the physical and chemical conditions of the water (Sendacz et al., 1985; Matsumura-Tundisi, 1999; Nogueira 2001; Serafim-Júnior et al., 2003).

In these sense, the incorporation of information on aquatic biota, including the zooplankton community, in biomonitoring programs associated to the conventional study of abiotic variables can be a strategy that enlarges the possibilities of diagnosis in order to generate concrete subsidies for an integrated management of surface water resources as pointed out by Nogueira and Naliato (2016). The authors also said that monitoring based on physical and chemical parameters, and even including direct and indirect microbiological determinations, may be insufficient for a conclusive diagnosis of the different ecological dimensions of river systems. That is because of the risk of reflecting only momentary condition of the evaluated water system.

The potential use of the zooplankton community as successful water quality bioindicator has been reported (Pace and Orcutt, 1981; Ferdous and Muktadir, 2009). Especially when analyzing some communities attributes, such as richness, abundance, dominance and diversity, associated to other aquatic biota data, the set of information may contribute to a comprehensive strategic planning that must be applied at the basin scale, with the goal of finding balance between exploitation of hydropower potential and sustainability of key natural resources (Winemiller et al., 2015).

In the Paranapanema River reservoirs, the zooplankton assemblages have been intensively studied, including analyses of faunal composition and diversity, effects of spatial compartmentalization, and seasonal cycles (e.g. Nogueira, 2001; Sampaio et al., 2002; Nogueira et al., 2008; Sartori et al., 2009; Perbiche-Neves and Nogueira, 2010; Perbiche-Neves and Nogueira, 2013). The first reservoir (Jurumirim) concentrates most information on zooplankton distribution and dynamics (Nogueira 2001; Casanova and Henry 2004; Mitsuka and Henry 2002; Panarelli et al. 2003; Sartori et al. 2009). Sampaio et al. (2002) and Nogueira et al. (2008) also reported the zooplankton variation along the reservoir cascade of the Paranapanema River.

The main goal of this study is to explore information on the structure of the zooplankton sampled in the Paranapanema River reservoir cascade (eight reservoirs), focusing on the potential of this community to evaluate changes in water quality and trophic level - biomonitoring purposes.

In the analysis of the zooplankton versus water quality and trophic state using lower taxonomical levels (species) as potential indicators it was considered only the three larger storage reservoirs (Jurumirim, Chavantes and Capivara). The premise is that they have water retention time higher than a hundred days what make possible the development of a proper plankton community (reduced limitation by intensive flow).

Study area

The study was carried out in the Paranapanema River Reservoirs Cascade considering, for zooplankton community structure and ecological attributes, the same eight reservoirs and 37 sampling sites described in Chapter 1 (Fig. 1; Tables 1 and 2).

Material and methods

The zooplankton samples were collected during wet/summer (March/2011) and dry/spring (October/2011) seasons using a conical net (30 cm mouth diameter and 50 µm mesh size) for vertical hauls from near bottom (ca. 1 m) to the surface. In each site we collected two identical samples, one for qualitative and other for quantitative purpose. Samples were fixed and preserved in 4 % formaldehyde. For the quantitative analyses, most organisms were counted at species level. Rotifera and nauplii of Copepoda were counted in Sedgwick–Rafter chambers, under optic microscope Zeiss Standard 25 (at a magnification of × 200); and Cladocera, copepodites and adult stages of Copepoda were counted using a stereo microscope Zeiss Stemi SV 6 (maximum magnification of × 120). At least 150 specimens were counted per subsample. Additional sub-samples, or even the entire sample, were analyzed when the density of organisms was low (generally less than 100 organisms per 5 ml of sample, in case of Cladocera and Copepoda, and less than 100 organisms per 1 ml of sample, in case of Rotifera). The collected specimens are deposited in the Freshwater Invertebrate Collection of the Department of Zoology, Biosciences Institute (campus of Botucatu) of the São Paulo State University.

The specimens of main zooplankton groups (Rotifer, Copepod and Cladocera) were analyzed at the lowest taxonomic level, by specialized literature. The density of the organisms were calculated from the volume of water filtered and the size of each sub sample, and expressed as numbers of individuals per cubic meter. The structure of the zooplankton community was determined through species composition (list of taxa and respective occurrence) and ecological attributes: richness, total and relative density, Shannon-Wienner diversity (H ') and evenness (J').

For the analysis of the zooplankton species as potential indicator, data on individual densities were correlated with total phosphorus, chlorophyll *a* and with the quantitative results of Water Quality Index (WQI) and Carlson Trophic State Index modified and for tropical and subtropical reservoirs (T.S.Is) (Chapter 2). All data were previously log-transformed and significant correlations ($p < 0.05$) were retained. The software Statistic v. 7.0 (Statsoft, 2002) was used.

In order to evidence community similarity among trophic status levels (T.S.I. for tropical and subtropical reservoirs) we used a multivariate analyses - non-metric multidimensional scaling (NMDS) derived from a Bray–Curtis similarity matrix with log (X+1) transformed data. Through SIMPER analyses, we examined the contribution of each variable to average resemblances between groups. PRIMER v6.0 was used.

Results

The zooplankton community of the Paranapanema River reservoir cascade was composed of 112 taxa represented by Rotifera with 65 taxa (58%), Copepoda with 14 taxa (12.5%) and Cladocera with 33 taxa (29.5%). The list of taxa, as well as the spatial and seasonal occurrence, is presented in Table 1. The most frequent species were *Conochilus unicornis* (88%), *Collotheca* spp. (81%), *Euchlanis dilatata* (81%) and *Synchaeta stylata* (75%) among the rotifers; *Notodiaptomus henseni* (100%) and *N. iheringi* (75%) among Copepoda Calanoida and *Thermocyclops decipiens* (100%), *T. minutus* (75%) and *Microcyclops anceps* (75%) among Copepoda Cyclopoida and the cladocerans *Ceriodaphnia cornuta* f. *tipica* (100%), *Daphnia gessneri* (100%), *Bosmina hagmanni* (94%), *C. cornuta* f. *rigaudi* (88%), *C. silvestrii* (88%), *Bosmina freyi* (81%), *Diaphanosoma spinulosum* (81%), *D. birgei* (75%) and *Moina minuta* (75%).

The highest values for richness were found in JR, 59 taxa during the dry season, followed by JR, CH and CP in the wet season, all with 51 taxa each. Conversely, the lowest values were found in TQ, 21 taxa (wet) followed by CI, 24 taxa (dry), CI (wet) and RS (dry), both with 25 taxa each (Fig. 1).

The total density highest values were observed in JR, CH and CP, being higher in JR with densities > 45,000 ind. m^3 in both seasons. Lower values occurred in RS (wet) 217 ind. m^3, followed by TQ (wet) 715 ind. m^3, CI and CII (dry) with 807 and 854 ind. m^3, respectively (Fig. 2). The highest densities values were found for the species

Conochilus unicornis, *Polyarthra* spp., *Synchaeta* spp. and *Synchaeta stylata* among rotifers; *Notodiaptomus henseni* (calanoid) and *Thermocyclops decipiens* (cyclopoid) among copepods and *Ceriodaphnia cornuta* f. *rigaudi*, *Moina minuta*, *Daphnia gessneri*, *C. cornuta* f. tipica, *C. silvestrii* and *Diaphanosoma spinulosum* among cladocerans.

The relative abundance among the zooplankton groups are presented in Figure 3a (wet season) and Figure 3b for dry season. During the wet season Rotifera predominated in the upstream portion of the river cascade – JR, CH, SG reservoirs and also at CIIUp site, while Copepoda predominance was observed from CIIDam towards downstream river. In the dry season, the dominance of Rotifera and Copepoda remained in the upper and lower portions of the river course, but there was an increase of Cladocera representation.

The Shannon-Wienner diversity (H´) and evenness (J´) values were calculated per zoological group (Rotifer, Cladocera and Copepoda) and season (wet and dry). Rotifer highest diversity values, greater than 3 bits. ind^{-1}, occurred at JR1 and CHUp (wet) and at CP1 and TQUp (dry) while the lowest values occurred at TQ1 (wet) and SG1 (dry), both with 0 bits. ind^{-1}. The highest evenness values, equal to 1, were found at CIUp, TQ2, RSUp (wet) and CII1, CIUp, TQUp, TQ2, RSUp and RSDam (dry), while the lowest values were observed at CP2 (wet) 0.437 and TQ1 (dry), equal to 0 (Fig. 4a and 4b). For Copepoda, the highest diversity values occurred at TQ2, 2.44 bits. ind^{-1} and CHDam, 1.99 bits. ind^{-1} (wet) and in JR1, 2.02 bits. ind^{-1} and CP4 2.31 bits. ind^{-1} (dry) while the lowest values occurred at SG1, SG3 and CIUp (wet) all with 0 bits. ind^{-1} and CIIUp, 0.59 bits. ind^{-1}, CP2, 0.64 bits. ind^{-1} and CHUp, 0.69 bits. ind^{-1} (dry). The highest evenness values were found at JR4, 0.996, CHUp, 0.985, TQ2, 0.945 (wet) and SG1, 1 (dry) while the lowest values were observed at SG1, SG3 and CIUp, equal to 0 (wet) and at TQDam, 0.356, CIIDam 0.357 and CI1, 0.399 (dry) (Fig. 4c and 4d). For Cladocera, the highest diversity values occurred at CH4, 3.30 bits. ind^{-1}, CPUp and CHDam, both with 3.19 bits. ind^{-1} (wet) and at JR2, 2.98 bits. ind^{-1} and CP1 2.94 bits. ind^{-1} (dry) while the lowest values, equal to 0 bits. ind^{-1}, occurred in SG1, SG3 and RS1 (wet) and SG1 (dry). The highest evenness values, equal to 1, were found at CPUp, RSUp and RS2 (wet) and CH3 e CHUp (dry) while the lowest values, equal to 0, were observed at SG1, SG3 and RS1 (wet) and at SG1 and SG3 (dry) (Fig. 4e and 4f).

Table 1 – List of zooplankton taxa sampled in the Paranapanema River reservoir cascade during the wet and dry seasons.

List of taxa	Jurumirim		Chavantes		Salto Grande		Canoas II		Canoas I		Capivara		Taquaruçu		Rosana	
	Wet	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**
ROTIFERA																
Class Bdelloidea																
Bdelloidea Hudson, 1884			+		+		+	+					+		+	+
Class Monogononta																
Order Collothecaceae																
Family Collothecidae																
Collotheca Harring, 1913	+	+	+	+	+	+		+		+	+	+		+	+	+
Family Conochilidae																
Conochilus coenobasis (Skorikov, 1914)	+	+	+	+	+	+					+	+		+		
Conochilus natans Seligo, 1900	+	+	+								+	+				
Conochilus unicornis Rousselet, 1892	+	+	+	+	+	+	+	+		+	+	+		+	+	+
Family Filiniidae																
Filinia longiseta (Ehrenberg, 1834)	+	+	+	+	+				+		+					
Filinia opoliensis (Zacharias, 1898)	+	+	+	+	+											
Filinia terminalis (Plate, 1886)					+		+				+					
Family Flosculariidae																
Ptygura cf. *pedunculata* Edmondson, 1939					+											
Sinantherina Bory de St. Vincent, 1826			+								+					
Family Hexarthridae																
Hexarthra Schmarda, 1854	+	+	+	+	+	+						+				
Family Testudinellidae																
Pompholyx complanata Gosse, 1951	+	+	+								+					
Testudinella mucronata (Gosse, 1886)				+										+		
Testudinella patina (Hermann, 1783)					+	+		+			+					
Testudinella patina trilobata (Anderson et Shephard, 1892)					+	+					+					
Testudinella Bory de St. Vincent, 1826	+															
Order Ploima																
Family Asplanchnidae																
Asplanchna Gosse, 1850						+										

List of taxa	Jurumirim		Chavantes		Salto Grande		Canoas II		Canoas I		Capivara		Taquaruçu		Rosana	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Asplanchnopus Guerne, 1888					+		+						+	+		+
Family Brachionidae																
Anuraeopsis Lauterborn, 1900	+	+														
Brachionus angularis Gosse, 1851	+	+	+	+	+	+	+									
Brachionus calyciflorus Pallas, 1766					+	+										+
Brachionus dolabratus Harring, 1914		+														
Brachionus falcatus (Zacharias, 1989)	+	+			+							+				
Brachionus mirus Daday, 1905	+	+						+				+				
Kellicottia bostoniensis (Rousselet, 1908)	+	+	+				+									
Keratella americana Carlin, 1943	+	+	+	+	+						+	+				
Keratella cochlearis (Gosse, 1851)	+	+	+		+		+		+		+	+				
Keratella cochlearis tecta Gosse, 1851	+		+								+					
Keratella tropica (Apstein, 1907)	+	+	+		+				+							
Platyias quadricornis (Ehrenberg, 1832)					+	+		+					+	+		
Family Dicranophoridae																
Dicranophorus Nitzsch, 1827							+									
Family Epiphanidae																
Epiphanes Ehrenberg, 1832					+	+					+					
Family Euchlanidae																
Dipleuchlanis De Beauchamp, 1910												+				
Euchlanis dilatata Ehrenberg, 1832	+	+	+		+	+	+	+			+	+	+	+	+	+
Family Gastropodidae																
Ascomorpha ecaudis Perty, 1850	+		+						+							
Ascomorpha ovalis Carlin, 1943		+	+													
Family Lecanidae																
Lecane bulla (Gosse, 1851)		+				+	+	+			+					
Lecane cf. *hamata* (Stokes, 1896)													+			
Lecane curvicornis (Murray, 1913)						+	+				+		+	+	+	
Lecane flexilis (Gosse, 1886)											+					
Lecane leontina (Turner, 1892)		+						+								
Lecane ludwigii (Eckstein, 1883)					+		+				+				+	

List of taxa	Jurumirim		Chavantes		Salto Grande		Canoas II		Canoas I		Capivara		Taquaruçu		Rosana	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Lecane lunaris (Ehrenberg, 1832)					+							+			+	
Lecane lunaris cf. *perplexa* (Ahlstrom, 1938)									+							
Lecane papuana (Murray, 1913)					+	+		+								
Lecane signifera (Jennings, 1896)	+															
Lecane Nitzsch, 1827	+		+												+	
Lecane stenroosi (Meissner, 1908)							+					+				
Family Lepadellidae																
Colurella Bory de St. Vincent, 1824	+	+	+		+											
Lepadella Bory de St. Vincent, 1826		+														
Family Notommatidae																
Cephalodella Bory de St. Vincent, 1826					+		+									
Family Synchaetidae																
Ploesoma truncatum (Levander, 1894)	+	+	+	+							+	+				
Polyarthra Ehrenberg, 1834	+	+	+	+	+		+		+		+	+			+	
Synchaeta pectinata Ehrenberg, 1832	+	+		+	+				+	+					+	
Synchaeta Ehrenberg, 1832	+	+	+	+	+			+	+		+	+			+	+
Synchaeta stylata Wierzejski, 1893	+	+	+	+	+	+		+	+	+	+	+				+
Family Trichocercidae																
Trichocerca capucina (Wierzejski & Zacharias, 1893)		+														
Trichocerca cf. *bicristata* (Gosse, 1887)							+				+					
Trichocerca cf. *parvula* Carlin, 1939													+			
Trichocerca chattoni de Beauchamp, 1907	+	+	+		+											
Trichocerca similis(Wierzejski, 1893)	+	+			+		+									
Trichocerca Lamarck, 1801	+	+							+							
Family Trichotriidae																
Trichotria Bory de St. Vincent, 1827											+					
Trichotria tetractis (Ehrenberg, 1830)								+		+				+		
Rotifera n. id.							+		+	+					+	

List of taxa	Jurumirim		Chavantes		Salto Grande		Canoas II		Canoas I		Capivara		Taquaruçu		Rosana	
	Wet	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**
COPEPODA																
Order Calanoida																
Family Diaptomidae																
Argyrodiaptomus azevedoi (Wright S., 1938)											+	+	+	+	+	+
Notodiaptomus cf. *deitersi* (Poppe, 1891)	+			+	+	+			+							
Notodiaptomus cf. *spinuliferus* Dussart, 1986		+	+									+		+		
Notodiaptomus henseni (Dahl F., 1894)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Notodiaptomus iheringi (Wright S., 1935)	+	+	+	+			+	+		+	+	+	+		+	+
Order Cyclopoida																
Family Cyclopidae																
Eucyclops Claus, 1893				+	+	+										
Mesocyclops ogunnus Onabamiro, 1957	+	+	+	+		+					+		+		+	
Metacyclops Kiefer, 1927			+								+					
Microcyclops anceps (Richard, 1897)		+	+			+	+	+	+	+	+		+	+	+	+
Paracyclops chiltoni (Thomson, 1883)	+	+	+		+	+	+	+		+		+		+		
Thermocyclops decipiens (Kiefer, 1929)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Thermocyclops inversus (Kiefer, 1936)		+										+				
Thermocyclops minutus (Lowndes, 1934)	+	+	+	+	+	+	+	+			+		+	+		+
Order Harpacticoida																
Harpacticoida Sars, 1903				+	+	+		+		+						
CLADOCERA																
Order Anomopoda																
Family Bosminidae																
Bosmina freyi De Melo & Hebert, 1994	+	+	+	+	+	+	+	+	+	+	+	+				+
Bosmina hagmanni Stingelin, 1904	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+
Bosmina tubicen Brehm, 1953										+		+				
Bosminopsis deitersi Richard, 1895	+	+	+	+				+	+	+	+	+				+
Family Chydoridae																
Acroperus Baird, 1843														+		
Alona cf. *setigera* Brehm, 1931														+		

List of taxa	Jurumirim		Chavantes		Salto Grande		Canoas II		Canoas I		Capivara		Taquaruçu		Rosana	
	Wet	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**
Alona cf. *yara* Sinev & Elmoor Loureiro, 2010								+								
Alona glabra Sars, 1901							+				+					
Alona intermedia Sars, 1862			+			+									+	
Alona Baird, 1843														+		
Alona verrucosa Sars, 1901											+	+	+		+	
Camptocercus australis Sars, 1896.							+								+	
Chydorus Leach, 1816						+										
Chydorus pubescens Sars, 1901	+							+			+	+		+		
Coronatella poppei Richard, 1897							+									
Leydigia striata Birabén, 1939		+									+	+			+	
Notoalona sculpta (Sars, 1901)		+														
Family Daphnidae																
Ceriodaphnia cornuta f. *tipica* Sars, 1886	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Ceriodaphnia cornuta f. *rigaudi* Sars, 1886	+	+	+	+	+	+	+	+	+	+	+	+	+	+		
Ceriodaphnia silvestrii Daday, 1902	+	+	+	+	+	+	+	+		+		+	+	+	+	+
Daphnia ambigua Scourfield, 1947		+	+								+					+
Daphnia cf. *laevis* Birge, 1878								+		+						
Daphnia gessneri Herbst, 1967	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Simocephalus serrulatus Koch, 1841		+									+					
Family Ilyocryptidae																
Ilyocryptus spinifer Herrick, 1882	+		+		+			+		+	+	+				
Family Macrothricidae																
Macrothrix squamosa Sars, 1901		+									+	+				
Macrothrix elegans Sars, 1901							+	+						+		
Family Moinidae																
Moina micrura Kurz, 1874		+	+	+		+		+				+				
Moina minuta Hansen, 1899	+	+	+	+		+	+	+	+	+	+	+				+
Order Ctenopoda																
Family Sididae																
Diaphanosoma birgei Korinek, 1981	+	+	+	+			+		+	+	+	+	+	+		+
Diaphanosoma brevireme Sars, 1901		+	+	+	+		+	+	+		+	+			+	

List of taxa	Jurumirim		Chavantes		Salto Grande		Canoas II		Canoas I		Capivara		Taquaruçu		Rosana	
	Wet	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**
Diaphanosoma fluviatile Hansen, 1899	+	+	+				+	+	+							+
Diaphanosoma spinulosum Herbst, 1967	+	+	+	+	+	+	+	+			+	+		+	+	+

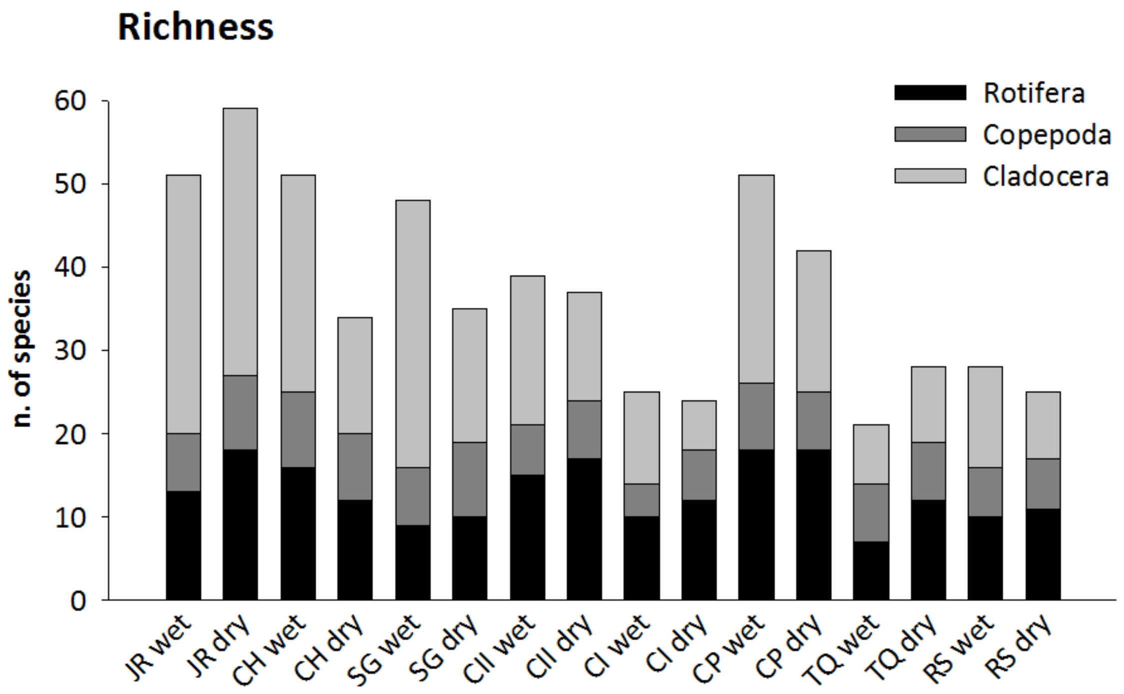

Figure 1 – Zooplankton species richness in the Paranapanema River reservoir cascade during the wet and dry season.

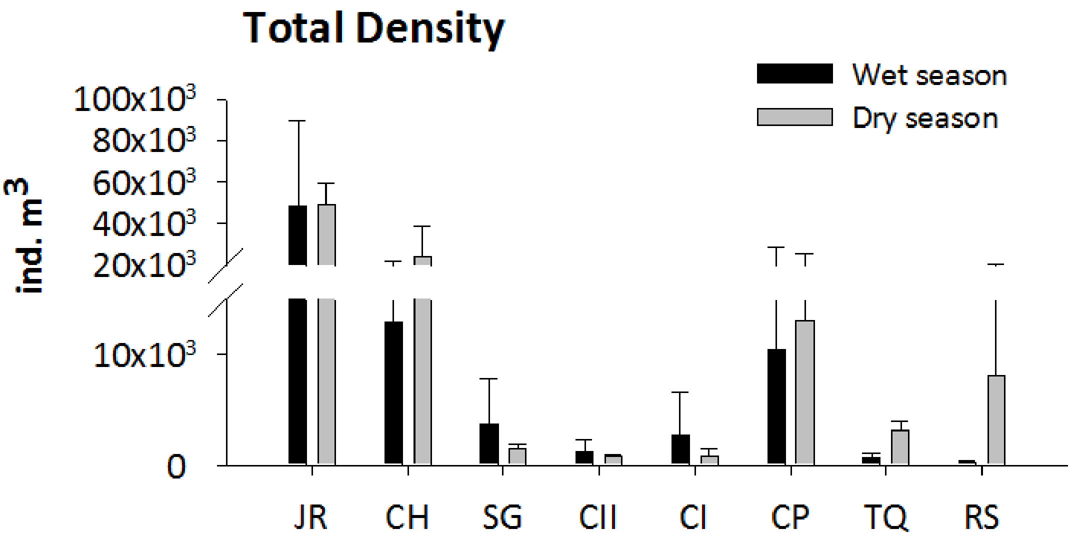

Figure 2 - Zooplankton total densities in the Paranapanema River reservoir cascade during the wet and dry season.

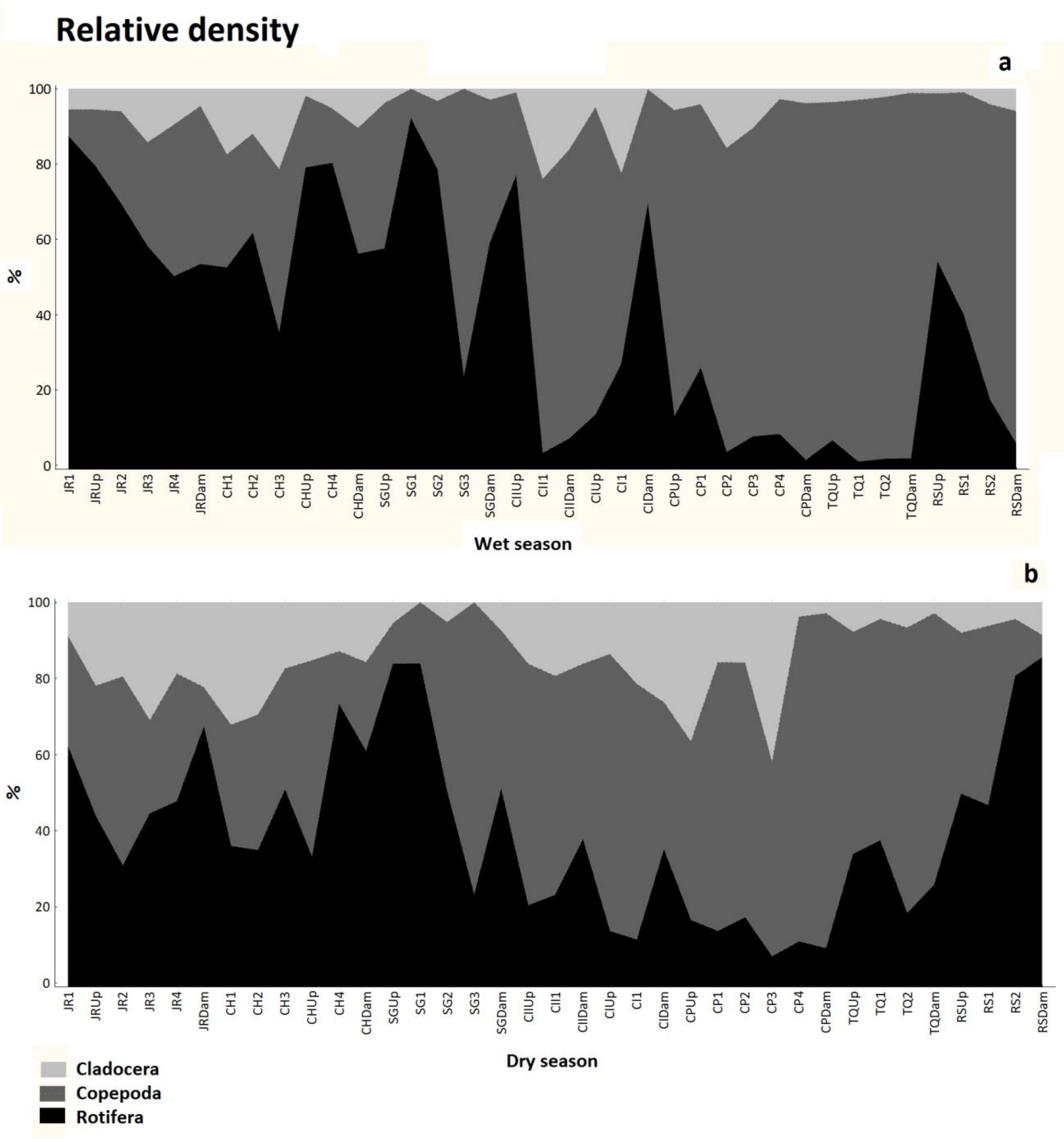

Figure 3 - Zooplankton relative densities in the Paranapanema River reservoir cascade during the a) wet and b) dry season.

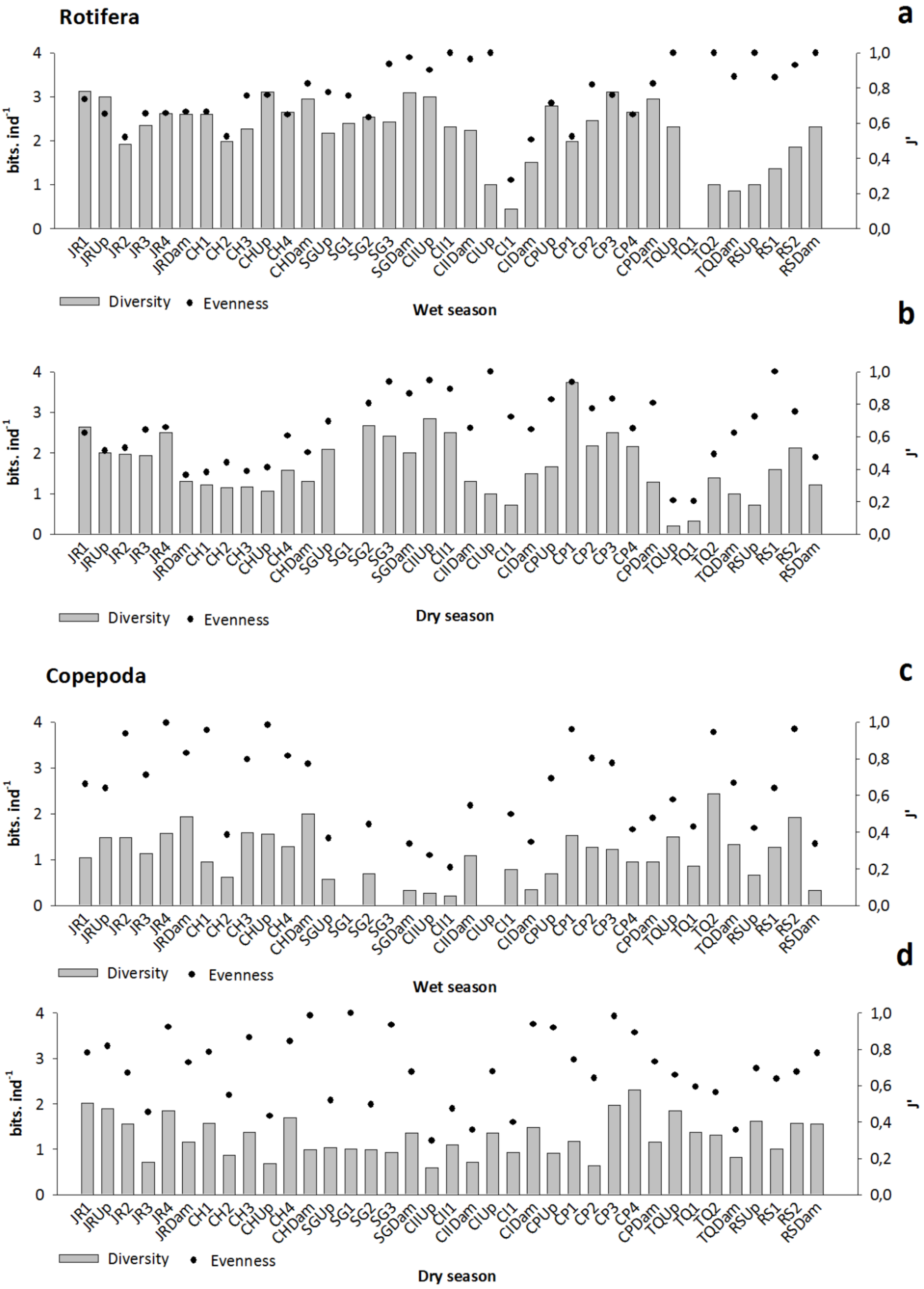

Figure 4 - Zooplankton Shannon-Wiener diversity and evenness in the Paranapanema River reservoir cascade: a) Rotifera wet season; b) Rotifera dry season; c) Copepoda wet season; d) Copepoda dry season.

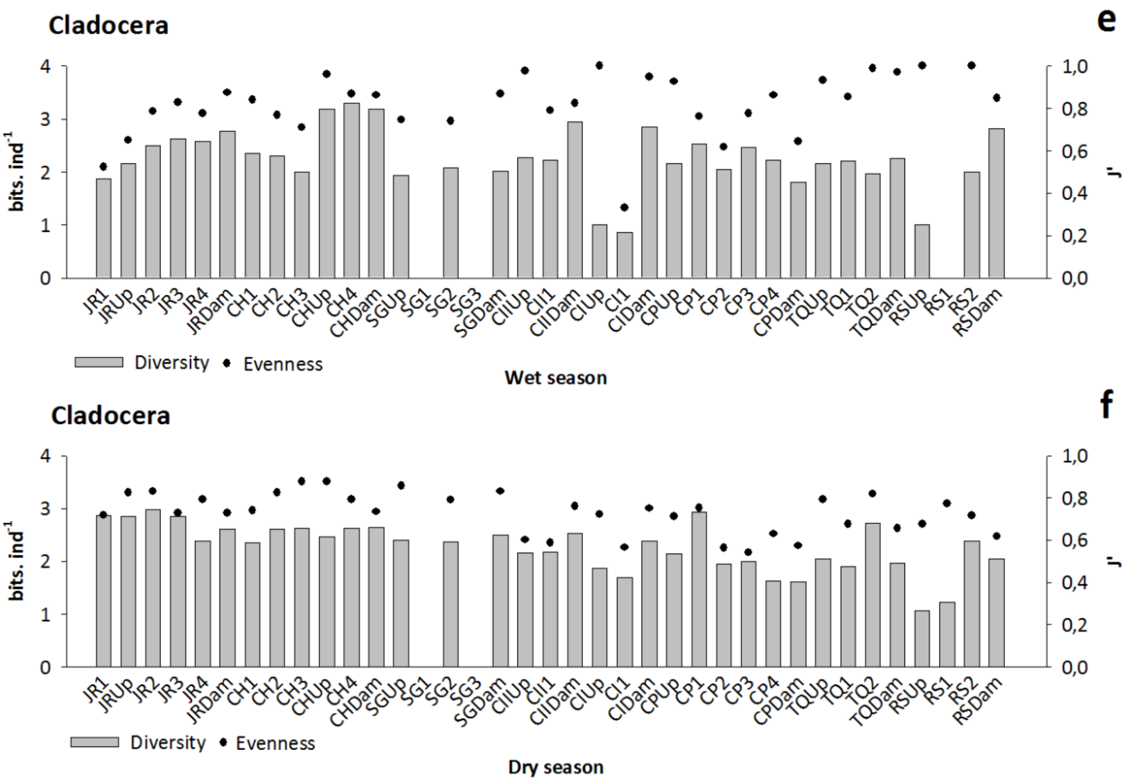

Figure 4 – Continued. Zooplankton Shannon-Wiener diversity and evenness in the Paranapanema River reservoir cascade: e) Cladocera wet season and f) Cladocera dry season.

Significant correlations ($p < 0.05$) with at least one of the selected parameters were found for 15 species of rotifers, 3 of copepods and 10 of cladocerans (Table 2). Among the rotifers, the species with the highest number of correlations were *Brachionus mirus* positively correlated with Chl *a*, T.S.I. (cmd) and T.S.I. (tsr); *Collotheca* spp. negatively related with T.P., T.S.I. (cmd) and T.S.I. (tsr); *Dipleuchlanis* spp. positively correlated with T.P., Chl *a*, T.S.I. (cmd) and T.S.I. (tsr) and *Lecane lunaris* positively correlated with Chl *a*, T.S.I. (cmd) and T.S.I. (tsr). Among the copepods *Thermocyclops inversus* was positive correlated with Chl *a* and negatively with W.Q.I. and among cladocerans *Alona verrucosa was* positively correlated with Chl *a*, T.S.I. (cmd) and T.S.I. (tsr) and *Macrothrix squamosa* positively correlated with T.P., Chl *a*, T.S.I. (cmd) and T.S.I. (tsr).

The multivariate analyses of communities performed using non-metric multidimensional scaling (NMDS) and SIMPER analyses showed the distribution of the species in relation to T.S.I. (Tsr) and respective sampling sites (Fig. 5, 6 e 7). The species that most contributed in this analysis were: *Collotheca* spp., *Conochilus coenobasis*

Conochilus unicornis and Polyarthra spp. (Ultra-Oligotrophic), *Filinia longiseta* (Oligotrophic) and *Hexarthra* spp. (Mesotrophic) among the rotifers; *Thermocyclops minutus* (Ultraoligotrophic) *Notodiaptomus henseni* and *Thermocyclops decipiens* (Ultra-Oligotrophic) and *Thermocyclops inversus* (Mesotrophic) among copepods and *Ceriodaphnia cornuta* f. *cornuta*, *Ceriodaphnia cornuta* f. *rigaudi*, *Ceriodaphnia silvestrii* and *Diaphanosoma spinulosum* (Ultra-Oligotrophic), *Daphnia gessneri* (Oligo-Mesotrophic), *Bosmina hagmanni* (Oligotrophic), *Bosmina freyi*, *Moina minuta*, *Bosminopsis deitersi* and *Diaphanosoma birgei* (Mesotrophic) among cladocerans.

Table 2 – Zooplankton species of Jurumirim, Chavantes and Capivara reservoirs that exhibited significant correlations (p <0.05) with water quality and trophic status parameters.

	T.P		**Chl *a***		**W.Q.I.**		**T.S.I. (cmd)**		**T.S.I. (tsr)**	
	r	**p**	**r**	**p**	**r**	**p**	**r**	**p**	**r**	**p**
Rotifer										
Brachionus angularis					-,4627	0,004				
Brachionus falcatus			,3629	0,030						
Brachionus mirus			,4007	0,015			,4375	0,008	,3629	0,030
Collotheca spp.	-,5303	0,001					-,4066	0,014	-,5227	0,001
Conochilus natans					,3493	0,037				
Conochilus unicornis	-,5447	0,001							-,3572	0,032
Dipleuchlanis spp.	,3889	0,019	,3884	0,019			,3383	0,044	,4244	0,010
Filinia longiseta							,4335	0,008		
Kellicottia bostoniensis					-,4243	0,010				
Keratella cochlearis tecta							,3510	0,036		
Keratella tropica					-,4059	0,014				
Lecane lunaris			,5097	0,001			,3366	0,045	,3950	0,017
Lecane spp.					-,3799	0,022				
Trichocerca capucina					-,4116	0,013				
Trichocerca chattoni					,3338	0,047				
Copepoda										
Microcyclops anceps					-,3583	0,032				
Notodiaptomus henseni	-,3505	0,036								
Thermocyclops inversus			,3378	0,044	-,4006	0,015				
Cladocera										
Alona verrucosa			,4859	0,003			,3402	0,042	,4231	0,010
Bosmina hagmanni					-,3518	0,035				
Ceriodaphnia cornuta f. *rigaudi*	-,5458	0,001							-,4157	0,012
Ceriodaphnia cornuta f. *tipica*	-,3894	0,019								
Ceriodaphnia silvestrii	-,4281	0,009								

	T.P		Chl *a*		W.Q.I.		T.S.I. (cmd)		T.S.I. (tsr)	
	r	p	r	p	r	p	r	p	r	p
Daphnia gessneri	-,3702	0,026					-,3309	0,049		
Diaphanosoma brevireme	-,3411	0,042							-,3588	0,032
Diaphanosoma spinulosum	-,4606	0,005								
Macrothrix squamosa	,4051	0,014	,4143	0,012			,4748	0,003	,4711	0,004
Moina minuta	-,2597	0,126			-,3300	0,049				

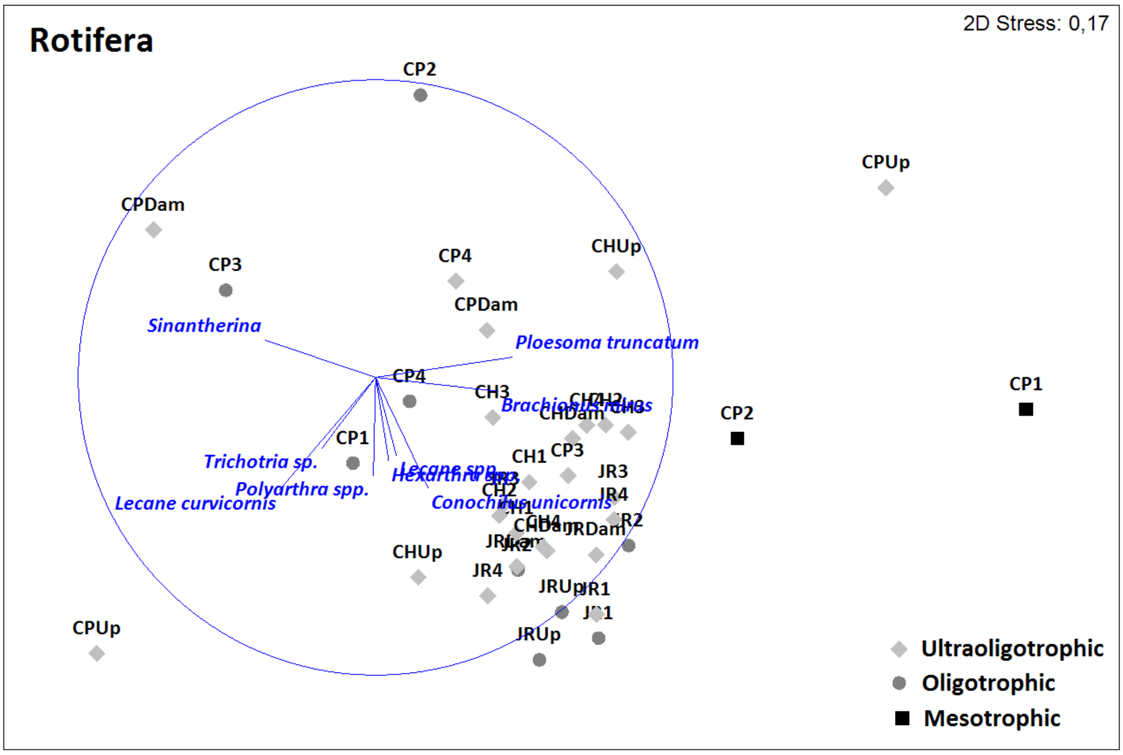

Figure 5 – NMDS plot showing the spatial distribution of Rotifera related to the Trophic State Status in Jurumirim, Chavantes and Capivara reservoirs sampling sites during the wet and dry seasons and the main taxa which contributed to this distribution.

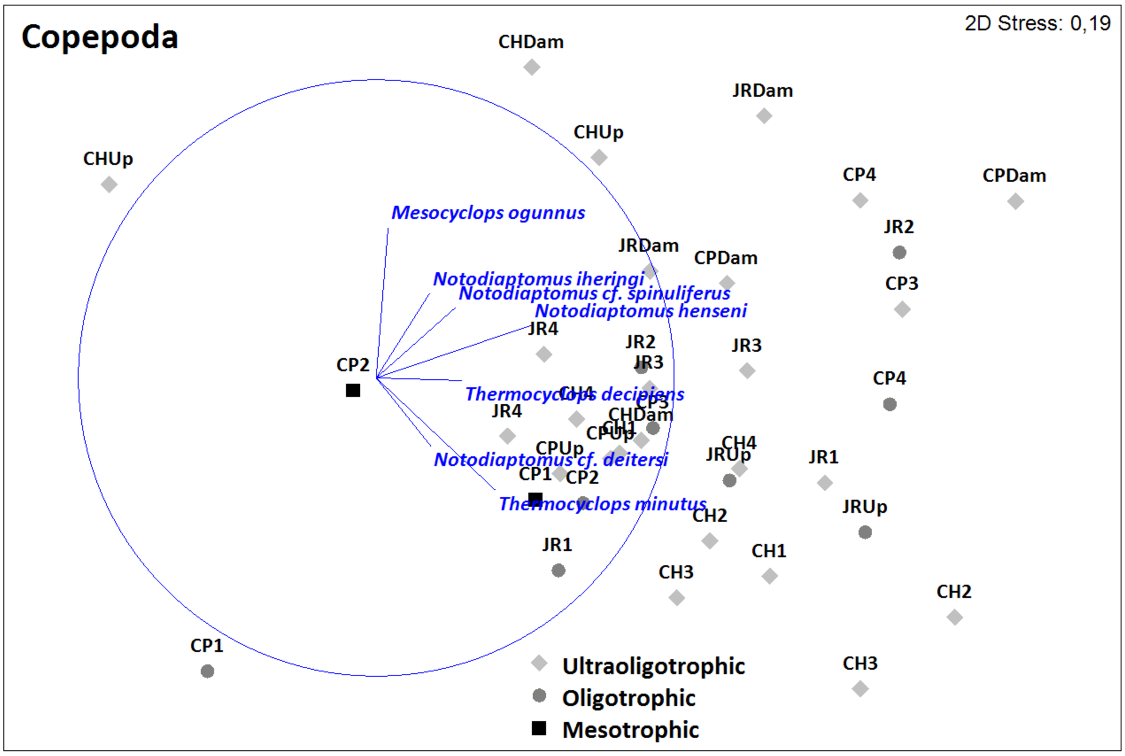

Figure 6 – NMDS plot showing the spatial distribution of Copepoda related to the Trophic State Status in Jurumirim, Chavantes and Capivara reservoirs sampling sites during the wet and dry seasons and the main species which contributed to this distribution.

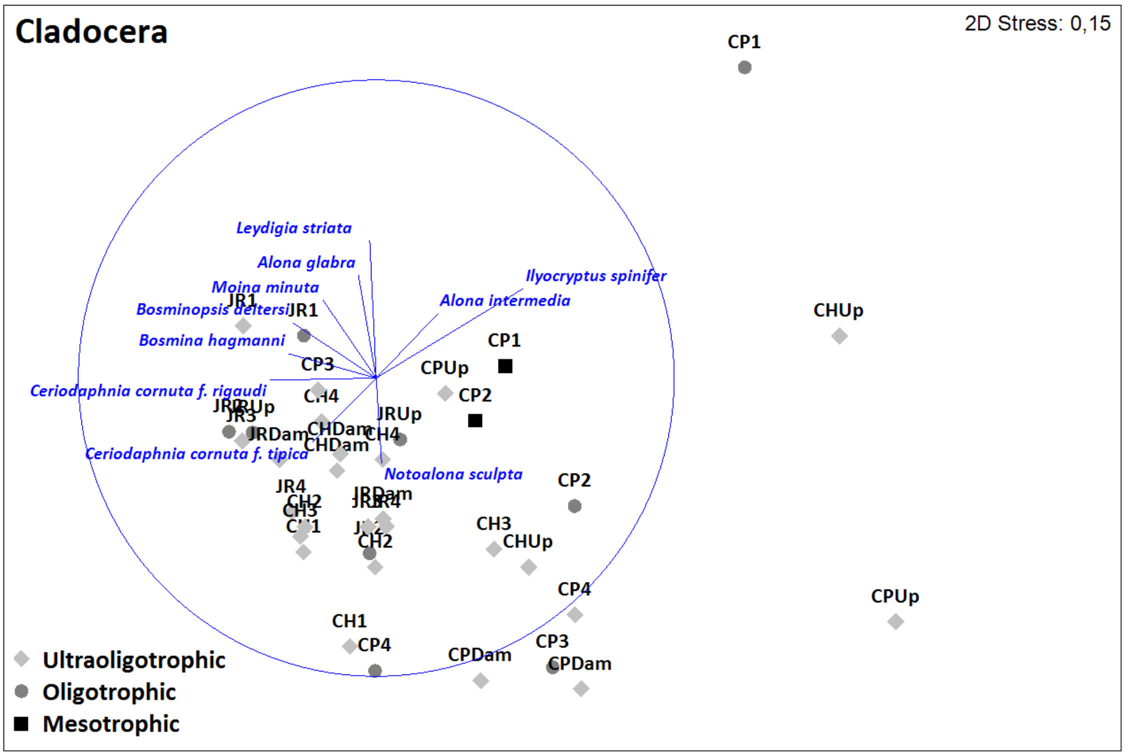

Figure 7 – NMDS plot showing the Cladocera spatial distribution related to the Trophic State Status in Jurumirim, Chavantes and Capivara reservoirs sampling sites during the wet and dry seasons and the main species which contributed to this distribution.

Discussion

The zooplankton community composition includes species with different development strategies, related to reproduction and feeding, allowing the colonization of environments with different physical and chemical properties (Lansac-Tôha et al., 2003). The Paranapanema River reservoirs cascade is composed, in terms of the operational design and engineering concept, by two types of reservoirs: accumulation (storage) and run-of-river systems. The distinctiveness of reservoirs in terms of dimensions and functioning, accumulation and run-of-river systems, affects the physical and chemical limnology of these environments (see Chapter 1) and also the structure and dynamics of the aquatic communities (Tundisi and Matsumura-Tundisi, 2003; Nogueira et al., 2008; Perbiche-Neves and Nogueira, 2010; Nogueira et al. 2012; Perbiche-Neves and Nogueira, 2013; Ferrareze et al., 2014).

In this study the zooplankton community of Paranapanema River reservoir cascade was composed of 112 taxa distributed among the main groups Rotifera (65), Copepoda (14) and Cladocera (33). These results are similar to the ones Sampaio et al.

(2002) that found by 108 taxa, Rotifera (76), Copepoda (7) and Cladocera (26). The similarities between both studies is also comparable in terms of the most frequent species. Although we found similarities in the composition and frequency, the species abundance and distributional patterns in each studied reservoir was quite variable (Sampaio et al., 2002).

Other studies carried out in Paranapanema River reservoir cascade along the last two decades, considering microcrustaceans (Copepoda and/or Cladocera) in the series of reservoirs and/or reservoirs individually reveal a set of common species and similar frequency of occurrence (Panarelli et al., 2001; Nogueira, 2001; Casanova and Henry, 2004; Nogueira et al., 2008; Sartori et al., 2009; Perbiche-Neves and Nogueira, 2010; Perbiche-Neves et al., 2016 and Nogueira and Naliato, 2016). This means that, in some way, in this reservoirs system there is a reasonably well established zooplankton community.

Species composition in natural lakes lake, with a few exceptions, remains quite constant for many decades, perhaps even centuries (Gannon and Stemberger, 1978) while reservoirs represent more complex and dynamics ecosystems, because of their interactions with the watershed and the influx of tributaries (Straškraba, 1997; Straškraba and Tundisi, 1999). Therefore, while in natural lakes plankton composition, species richness, and abundance of organisms are dependent on various factors such as lake origin, trophic state, colonization processes, and presence or absence of toxic substances or pollutants, in reservoirs the influence of spatial and temporal heterogeneity on plankton richness and diversity is even higher (Matsumura-Tundisi and Tundisi, 2005).

The high number of species in reservoirs and the reported variability can be related to distinct factors such as reservoir ageing, residence time, trophic state, biological interactions, water basin endemism, and even to sampling designs and the expertise of researchers (Matsumura-Tundisi, 1999; Rocha et al., 1999).

In our study the group of Rotifera, with the highest number of taxa (65) and numerically dominant, had greater species richness in the middle to lower course of the river - CII, CI, CP, TQ and RS reservoirs during the dry season. Cladocera showed greater richness in the upper portion of the river - JR, CH and SG reservoirs in the both sampled seasons (wet and dry), and also in the middle course of the river - CII, CI, CP and RS in the wet season. In terms of density, Rotifera showed highest values occurring in practically all reservoirs of the cascade, lower than Copepoda only in SG (dry season), CP (wet and dry) and RS (wet season). Cladocera is a very important group in terms of species richness but its occurrence is always observed in low densities.

The zooplankton community density was higher in the accumulation reservoirs (storage system - JR, CH and CP), as expected (Nogueira et al., 2008). The relative density among groups showed the predominance of rotifers in the upper course of the river in most sampled sites of JR, CH, SG during the wet and dry seasons. Conversely, the predominance of copepods was observed in the middle and lower course of the river - CII, CI, CP, TQ and RS. An increase of cladocerans occurred during the dry season.

The diversity and evenness results have no recognized pattern of variation along the reservoir cascade. Probably because of the intra reservoir variability, such as water masses compartmentalization and tributaries influence, and their differential effects on different groups (Rotifera, Copepoda and Cladocera).

Despite the great effort with the purpose of understanding the structure and dynamics of the zooplankton in Paranapanema River reservoir cascade (Panarelli et al., 2001; Nogueira, 2001; Sampaio et al., 2002, Matsumura-Tundisi and Tundisi, 2003; 2005; Casanova and Henry, 2004; Nogueira et al., 2008; Sartori et al., 2009; Perbiche-Neves and Nogueira, 2010; Perbiche-Neves et al., 2016), there are only few analyses that includes the whole cascade, as a system, and all the main groups of zooplankton community together.

In terms of regional zooplankton fauna, it is very important to consider the studies of Matsumura-Tundisi and Tundisi (2003) on the composition and distribution of the Calanoida species in 21 reservoirs of São Paulo State by, carried out from 1979 onwards. Results show a considerable change in species composition. For instance, frequent species such as *Notodiaptomus conifer* in the majority of the reservoirs of the Middle Tietê and Paranapanema River basins disappeared completely, being substituted by other ones. In case of Paranapanema River probably it was replaced by *N. henseni*, currently the most frequent, widely distributed and numerically more abundant. According to Gannon and Stemberger, (1978), perturbations that change physicochemical milieu or alter the balance of competition can cause extermination of some species populations and allow the appearance of others.

The eutrophication of freshwaters causes great changes in the structure of zooplankton communities and one of the main difficulties in studying loss of biodiversity due to eutrophication is the absence of previous records of species composition and/or misclassification of species, prior to eutrophication (Sampaio et al., 2002, Matsumura-Tundisi and Tundisi, 2003; 2005). In case of São Paulo State reservoirs, a pioneer typological study on 23 reservoirs during late 1970's established a base line, comprising a seasonal study of their main physical, chemical and biological characteristics (Tundisi, 1981).

In the composition of the zooplankton community of the Paranapanema River reservoirs during the late 1970's, typical eutrophic bioindicators, such as *Brachionus calyciflorus*, rarely occurred (Sampaio et al., 2002). Changes in community structure are expected during the process of eutrophication (Hellawell, 1978). In case of Paranapanema reservoirs, the zooplankton is presently characterized by variation in the proportions of the different species, but without any severe species replacement by tolerant forms. The accumulated information based on studies carried out in more than three decades that clearly show the appearance, gradual and in low abundance, of trophic indicator species.

The results of the correlation and NMDS/SIMPER analyses (Table 2; Fig. 5, 6 and 7) clearly indicated the potential of using the zooplankton as biondicators in the Paranapanema River Basin. Nevertheless, results also indicated the need to find statistically more consistency relationships. Perhaps this a problem that could be solved if we increase our data set. In this sense, there is a good perspective through the use of information from the ongoing long term monitoring program of the Paranapanema River reservoir cascade.

Nevertheless, we also have to take into account the fact that reservoirs are aquatic ecosystems subject to a set of conditions (human impacts, weather variability, operational engineering, etc.) which create a variety of transient situations affecting limnological and biological features. The reservoir steady state is frequently disturbed and requires some time to reestablish (Matsumura-Tundisi and Tundisi, 2003). The physical and chemical dynamics is intense and underlies a kind of organized chaos which the biological components survive through adaptive strategies based on the mechanisms of species tolerance - capability to respond either to a certain environmental factor or to an assemblage that act synergistically on the organisms (Matsumura-Tundisi and Tundisi, 2003).

According to Naselli-Flores et al. (2003), quite a number of ecological concepts have been using terms such as ecological equilibrium, stability, steady-state, climax, stable state, etc. The term equilibrium was supposed to better depict the dynamic nature of a community when it is, or seems to be, persistent. Actually the persistency is only related to the temporal scale of the observer. The term stable state was proposed by Scheffer (1998) to describe the alternative stages in shallow lake ecosystems. The need for a clear definitions and the necessity for clarifying terms was openly addressed in Rojo and Álvarez-Cobelas (2003).

Occasionally, surprisingly large shifts occur in ecosystems. Theory suggests that such shifts can be attributed to alternative stable states and it implies that gradual changes in temperature or other factors might have little effect until a threshold is reached at which a large shift occurs, which might be difficult to reverse (Scheffer and Carpenter, 2003). Even a tiny incremental change in certain conditions can trigger a large shift in some systems if a critical threshold known as ‘catastrophic bifurcation’ is passed (Kusnetsov, 1995).

Zooplankton is a valuable as indicators of water quality and trophic conditions than has been under considered. It give us signs that the environment is undergoing changes before these changes become drastic or irreparable. More attention must also be given to eutrophication rate process so we can determine when natural rates are being accelerated by man’s activities (Gannon and Stemberger, 1978). It is important to reinforce that this information is critically needed for wise management of aquatic ecosystems and indicator organisms may be useful not only for trophic state assessment but to reflect minor changes in water quality as well.

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Chapter 4 - A new tool to assess ecosystem health in large subtropical reservoirs: development and validation of a Planktonic Index of Biotic Integrity (P-IBI)

A new tool to assess ecosystem health in large subtropical reservoirs: development and validation of a Planktonic Index of Biotic Integrity (P-IBI)

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Abbreviations list

P-IBI - Planktonic Index of Biotic Integrity

TSItsr - Trophic State Index for tropical/subtropical reservoirs

Abstract

We developed and validated a Planktonic Index of Biotic Integrity (P-IBI) for subtropical reservoirs to assess their ecosystem health. We have analyzed the phytoplankton and zooplankton communities and determined the reservoirs' trophic status in the Paranapanema River. This is one of the main tributaries of the high Paraná River (La Plata basin) and is the natural border between the states of Paraná and São Paulo, Southern Brazil. During the last half of twentieth century, eleven hydropower plants were constructed in the main course of the river. Three of the reservoirs are accumulation systems (i.e. high water retention times), whereas the others are run-of-river dams. For the study the three larger reservoirs (Jurumirim, Chavantes and Capivara) were selected. Physical, chemical and biological (phytoplankton and zooplankton) data were obtained in two sampling campaigns carried out in March (wet season) and October (dry season) of 2011. For each reservoir we sampled six stations, which were arranged in a gradient established between the lotic (Paranapanema River entrance) and lentic (dam) areas. According to the trophic state index for tropical/subtropical reservoirs (TSItsr), the sampling stations were categorized between ultraoligotrophic and mesotrophic, exhibiting low concentrations of phosphorus and chlorophyll. Four metrics achieved significant discrimination, in a set of twenty analyzed by discriminant analysis. The individual metric scores were summed to provide a P-IBI score, which ranged as Mesotrophic (4-9), Oligotrophic (10-14) and Ultraoligotrophic (15-20) and corresponded with the classification of fair, good and excellent, respectively. Following the longitudinal sequence, Jurumirim was classified as Oligotophic (qualitative category Good) and both Chavantes and Capivara as Ultraoligotrophyc (qualitative category Excellent).

Resumo

Desenvolvemos e validamos um Índice Planktônico de Integridade Biótica (P-IBI) para reservatórios subtropicais para avaliar a “saúde” de seus ecossistemas. Analisamos as comunidades fitoplanctônica e zooplanctônica e determinamos o estado trófico dos reservatórios no rio Paranapanema. Este é um dos principais afluentes do Alto Rio Paraná (bacia do Prata) e é fronteira natural entre os estados do Paraná e São Paulo, no sul do Brasil. Durante a última metade do século XX, onze usinas hidrelétricas foram construídas no curso principal do rio. Três dos reservatórios são sistemas de acumulação (isto é, apresentam tempo de retenção de água elevado), enquanto que os outros são do tipo fio d´água (baixo tempo de retenção da água). Foram selecionados, neste estudo, os três maiores reservatórios (Jurumirim, Chavantes e Capivara). Os dados físicos, químicos e biológicos (fitoplâncton e zooplâncton) foram obtidos em duas campanhas de amostragem realizadas em março (estação chuvosa) e outubro (estação seca) de 2011. Para cada reservatório foram amostradas seis estações, disposta em um gradiente estabelecido entre a região lótica (entrada do Rio Paranapanema) e lêntica (barragem). De acordo com o índice de estado trófico para reservatórios tropicais/subtropicais (TSItsr), as estações de amostragem foram categorizadas entre ultraoligotróficas e mesotróficas, apresentando baixas concentrações de fósforo e clorofila *a*. Quatro métricas obtiveram discriminação significativa, em um conjunto de vinte analisadas por análise discriminante. Os escores métricos individuais foram somados para fornecer uma pontuação P-IBI, que variou como Mesotrófico (4-9), Oligotrófico (10-14) e Ultraoligotrófico (15-20) e correspondeu com a classificação de suficiente, boa e excelente, respectivamente. Seguindo a sequência longitudinal, Jurumirim foi

classificado como Oligotópico (categoria qualitativa Boa) e ambos Chavantes e Capivara como Ultraoligotrófico (categoria qualitativa Excelente).

Introduction

Brazil is a reservoir-orientated country, where most electricity production comes from dammed rivers. According to The World Bank (2014), 32 countries, including Brazil, use hydropower to produce more than 80 % of their electricity requirements. Further, at least 3,700 major dams, each one with a capacity of more than 1 MW, are either planned or under construction in countries with emerging economies (Zarfl et al., 2015).

The construction of large reservoirs for hydropower generation during the last decades is common all over the country (about 200 dams in operation and 200 under construction). These human-designed environments are particularly common in the Southeast region, present in most rivers and have deeply changed the surrounding landscapes. Besides the relatively clean and renewable energy production, additional positive aspects related to reservoirs are the strategic water storage, flood control, recreation for local residents, tourism and other economic opportunities, such as fisheries and aquaculture (Tundisi and Matsumura-Tundisi, 2003). Among the negative impacts it can be mentioned the considerable changes in the rivers' biota (Agostinho et al., 2008; Nogueira et al., 2008; Nogueira et al. 2010).

Studies on reservoir limnology indicate that they constitute a particular class of aquatic environment due to the dynamic interaction between riverine and lacustrine compartments (Thornton et al., 1990; Armengol et al., 1999; Kennedy et al., 2003). This distinctive pattern of spatial organization has been evidenced for several large Brazilian reservoirs (Nogueira et al., 1999; Pinto-Coelho et al., 2006; Soares et al., 2008; Perbiche-Neves et al., 2011). The temporal and spatial complexity is even higher in the case of reservoir cascades. Despite some accumulated ecological information (Barbosa et al., 1999; Jorcin and Nogueira, 2005a, b; Nogueira et al., 2008; Naliato et al., 2009; Nogueira et al., 2010; Nogueira et al., 2012; Perbiche-Neves et al., 2011; Matsuura et al., 2015), research efforts are still necessary to understand the limnological changes along the river continuum (Vannote et al., 1980), including the structure and function after construction of series of dams - upstream and downstream *transference effects (i.e*. downstream exportation of low oxygenated water (deep located turbines), exportation of algae biomass, upstream nutrient and solids retention, etc. (Matsuurra et al., 2015; Portinho et al., 2016).

Integrity of a given ecosystem can be assessed through the diagnosis of biological attributes or indicators, which ideally are sensitive to a range of stresses, able to distinguish stress-induced variation from natural variation, relevant to society concerns, and easy to measure and interpret. The complexity of biotic systems dictates that integrity assessments should incorporate a variety of indicators (including elements and processes) from multiple organizational levels and spatiotemporal scales (Angermeier and Karr, 1994).

The Index of Biotic Integrity (IBI) (Karr, 1981) is an ecologically based multi-metric index for assessing the biological integrity of surface waters. It considered distinct biotic attributes, ranging from individual to ecosystem-level properties. The IBI was originally developed in the 1980s and used to assess fish assemblages as an indicator of aquatic ecosystem health (Karr, 1981; Karr et al., 1986). This tool has been adapted and modified in order to evaluate aquatic ecosystem health worldwide. A variety of organisms have been used like littoral zone plants (Rothrock et al., 2008), benthic macroinvertebrates (Fore et al., 1996, Li et al., 2010), aquatic insects (Silva et al., 2010), benthic diatom communities (Wu et al., 2012a), phytoplankton (Gómez et al., 2012; Wu et al., 2012b; Li et al., 2013), zooplankton (Carpenter et al., 2006) and combined phyto- and zooplankton (Kane et al., 2009; Kane et al., 2015). IBIs have been applied to different aquatic environments such as rivers (Karr, 1981; Wu et al., 2012a; Cassati et al., 2009; Esteves and Alexandre, 2011), estuaries (Carpenter et al., 2006; Gómez et al., 2012), lakes (Kane et al., 2009), reservoirs (Wu et al., 2012a) and reservoir cascades (Li et al., 2013) as well.

Although IBIs have been used for many purposes, there is a unique study focusing on the impact of cascading dams construction, which includes metrics related to phytoplankton assemblages (Li et al., 2013). The index values agreed with the pattern of increased abundance and biomass of phytoplankton assemblages in reservoir areas and provided evidence of aquatic ecosystem degradation (as compared with natural riverine stretches).

All components of reservoirs functioning can be influenced in major ways by the dynamics of the phytoplankton and zooplankton once their abundances are related to nutrient/trophic status (i.e. total phosphorus and chlorophyll *a* concentrations - eutrophic-oligotrophic gradients). Therefore, phytoplankton and zooplankton dynamics have a large impact on aquatic ecosystem and, as a consequence, on humans who interact with these environments (Kane et al., 2009).

With the purpose of effectively assessing the ecosystem health of subtropical reservoirs, we developed and validated a Planktonic Index of Biotic Integrity (P-IBI) for these systems, following Kane et al. (2009). The study is based on a reservoir cascade system located in Southern Brazil and includes metrics of the entire plankton community – phyto and zooplankton. In contrast to traditional water quality approaches, the P-IBI is an aggregative indicator that can not only capture aquatic trophic status but also identify variations in the aquatic ecosystems associated to the biota. The development and application of a viable Planktonic Index of Biotic Integrity (P-IBI) for subtropical reservoirs can be useful for management purposes – stakeholder's decision processes, improvement of monitoring protocols, and expansion of scientific knowledge.

Following Kane at al. (2009), our study included five goals: 1) to develop and implement sampling protocols; 2) to develop a multimetric Planktonic Index of Biotic Integrity (P-IBI) for subtropical reservoirs; 3) to validate the P-IBI for subtropical reservoirs statistically; 4) to apply the P-IBI for subtropical reservoirs using plankton selected data sets (2011 – March and October) from a Water Quality Monitoring Program carried out in the Paranapanema River reservoirs cascade and 5) to disseminate the results of the analyses to citizens and policy makers.

Methods

Study area and site locations

The Paranapanema River is one of the main tributaries of the Paraná River (La Plata basin), located between the coordinates 22° - 26° S and 47° - 54° W, on the tropical/subtropical boundary (Southeast/South Brazil). The river is the natural border between the states of Paraná and São Paulo (Fig. 1), with a total length of 929 km. Since the 1950's, eleven hydropower plants have been constructed in the main river course. Three of the reservoirs are accumulation systems (i.e. with high water retention times), whereas the others are run-of-the-river systems. For this study the three larger storage (accumulation) reservoirs (Jurumirim, Chavantes and Capivara) were selected, based on the criteria that they are more lake like which allows succession of plankton assemblages. These three reservoirs have high shoreline development (> 15), high retention time ($\geq$ 150 days), and are relatively deep (> 30 m near to the dam) (Table 1).

For each reservoir we considered six sampling stations including the main spatial compartments identified from previous studies (Nogueira et al., 1999; 2012), which are arranged in a gradient established between the lotic (Paranapanema River entrance) and lentic (dam) areas (Fig. 1).

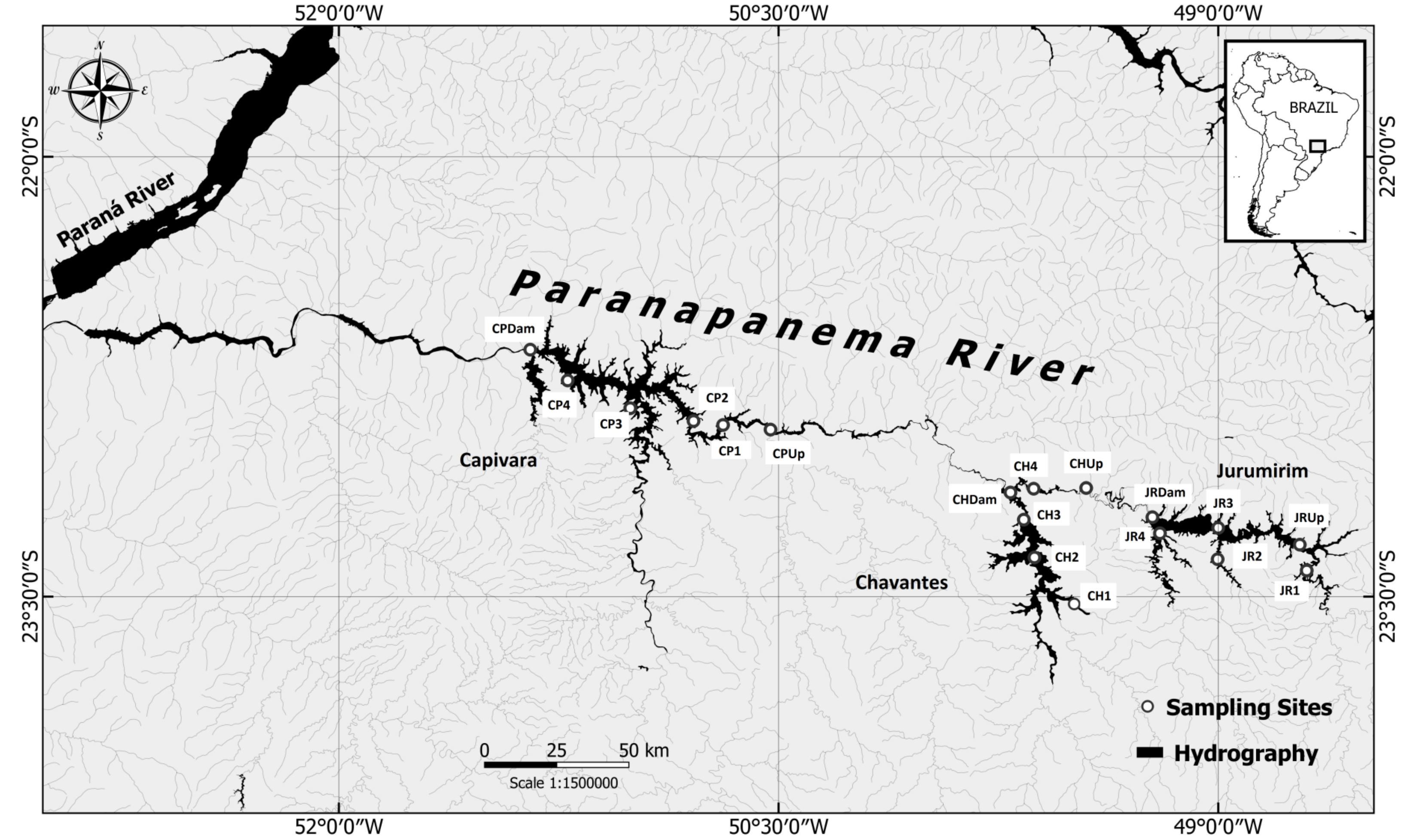

Figure 1 - Geographic location of Paranapanema River showing the entire eleven reservoirs cascade and the selected ones highlighted with sampling sites.

Table 1. Characteristics of the studied Paranapanema River reservoirs.

	Jurumirim	**Chavantes**	**Capivara**
Area (km^2)	449	400	576
Perimeter (km)	1286	1085	1550
Volume (hm^3)	7.2	9.4	10.54
Shore line development index	17.1	15.3	18.2
Retention time (days)	323	418	150
Z_{max} (m)	32	79	40
Altitude of water level (m) (a.s.l)	563	473	325

Sampling methods

Sampling campaigns for physical, chemical and biological (phytoplankton and zooplankton) measurements were carried out during two periods of the year, March 2011, corresponding to the end of the wet season, and October 2011 corresponding to the end of the dry season – the most contrasting seasonal periods.

Limnological analyzes and Trophic State Index calculation

Water samples for total phosphorus and chlorophyll *a* analysis were collected with a Van Dorn bottle in three depths: surface, middle and bottom of the water column. Samples for total phosphorus were previously digested (Valderrama, 1981) and then anlyzed spectrophotometrically (Strickland and Parsons, 1960). Total chlorophyll *a* concentration was determined in replicates after vacuum filtration (Millipore AP40 membranes) of 1 L of water from each considered depth. For pigments extraction it was used cold acetone (90%) after manual maceration were used (Talling and Driver, 1963; Golterman et al., 1978).

The trophic state index was determined according to Cunha et al. (2013) for tropical/subtropical reservoirs (TSItsr), which consider six categories: (U) Ultraoligotrophic (≤51.1), (O) Oligotrophic (51.2 -53.1), (M) Mesotrophic (53.2-55.7), (E) Eutrophic (55.8-58.1), (S) Supereutrophic (58.2-59) and (H) Hypereutrophic (≥ 59.1). For both, TP and Chl *a*, average values among depths of each sampling station was used to calculate the trophic state index.

Phytoplankton and Zooplankton samples

For phytoplankton, at each sampling station, an integrated sample was collected (entire water column) through vertical net hauls (20 µm of mesh size) and immediately preserved in 4% formalin. The net samples were observed in an optical microscope (maximum magnification of 1000×) for taxonomical identification and determination of assemblage total richness. For phytoplankton quantitative analysis, three unfiltered samples were collected (van Dorn bottle) at the subsurface (ca. 0.2 m), middle of the water column and near to the bottom (ca. 1 m above the sediment). The samples were fixed and preserved with Lugol's solution. After sedimentation, the organisms (cell, colony, and filament) were counted using inverted microscopy (*sensu* Utermöhl) at a magnification of 400×. At least 120 optical fields distributed in parallel transects were examined, and at least 150 organisms were counted per sample. The quantitative data were expressed as mean values for the water column.

The zooplankton samples were collected using a conical net (30 cm mouth diameter and 50 µm mesh size) and vertical hauls from near bottom (*ca.* 1 m) to the surface. In each site/campaign an additional sample for qualitative analysis was collected. Samples were fixed and preserved in 4 % formaldehyde. For the quantitative analyses, most organisms were counted at species level using sub-samples. Rotifera, and nauplii of Copepoda were counted in Sedgwick–Rafter chambers, by optic microscope Zeiss Standard 25 (at a magnification of × 200); and Cladocera, copepodites and adult stages of Copepoda were counted using a stereo microscope Zeiss Stemi SV 6 (maximum magnification of × 120). At least 150 specimens were counted per subsample. Additional sub-samples, or even the entire sample, were analyzed when the density of organisms was low (generally less than 100 organisms per 5 ml of sample, in case of Cladocera and Copepoda, and less than 100 organisms per 1 ml of sample, in case of Rotifera).

Developing a planktonic index of biotic integrity (P-IBI) for subtropical reservoirs

Metric selection and statistical validation

A number of plankton characteristics are directly related to the assemblage's structure and composition and reflect the status of a range of environment attributes. It is well known from scientific studies carried on along more than a century worldwide that plankton features are susceptible to anthropogenic influences and can indicated distinct levels of eutrophication. Based on previous experience on developing the P-IBI (Kane et al., 2009) as well as on the accumulated regional knowledge (e.g. Nogueira et al., 2008; Nogueira et al., 2009; Perbiche et al., 2011; Perbiche et al., 2016) 20 candidate metrics were considered and included in the discriminant analysis to be used for the multimetric index for tropical and subtropical reservoirs: total calanoid density; total cyclopoid density; total cladocera density; total rotifer density; total crustacean density; zooplankton ratio calanoid/cladocera + cyclopoid; zooplankton ratio calanoid/cyclopoid; zooplankton richness; zooplankton diversity; zooplankton equitability; total phytoplankton density; % cyanobacteria; abundance of the most common Cyanobacteria genera *Anabaena* (*Dolichospermum*)*, Aphanizomenon,* and *Microcystis*; % of *Anabaena* (*Dolichospermum*), *Aphanizomenon* and *Microcystis*; edible phytoplankton density; inedible phytoplankton density; abundance of the invasive species *Ceratium* cf. *furcoides*; phytoplankton richness; phytoplankton diversity and phytoplankton equitability.

Total phosphorus concentrations (µg L^{-1}), and total chlorophyll *a* concentrations (µg L^{-1}) were used to classify the sites trophic status (from ultraoligotrophic to hypereutrophyc as proposed by Cunha et al., 2013).

Discriminant analysis (DA) was used to evaluate the ability of plankton metrics to distinguish among levels of degradation. DA discriminates among pre-specified groups of samples based on a set of variables to find gradients among groups of samples, then variation among groups is maximized, while within group variation is minimized (McGarigal et al., 2000). Discriminant analysis has been identified as an acceptable statistical method for the development of Indices of Biotic Integrity and can be used to identify variables that discriminate between levels of degradation (USEPA, 1998). We performed discriminant analyses (Statistica, version 7.0) to give a broad range of conditions in both trophic status and in the candidate metrics. All 20 metrics and sites were included in the discriminant analysis.

Four out 20 metrics were selected on through the discriminant analysis. In order to calculate individual metric scores we constructed ‘’boxplots’’ of the significant individual plankton metrics frequency distributions. We used the 95th percentile as the upper boundary and zero as the lower boundary (Karr et al., 1996) and trisected each of the final individual metrics included in the multimetric P-IBI for subtropical reservoirs (based on significance in the discriminant analyses) into ranges that were assigned a score of 1, 3, or 5 to match those values assigned to the trophic status condition. A 5, represented the better environmental condition (ultraoligotrophic) range of trisection, while a 1, was the most degraded (mesotrophic) range of the trisection. The statistically significant metrics for each site were summed to provide a P-IBI score and a classification applicable for subtropical reservoirs, in this case, ranging from fair to excellent, or Mesotrophic (4-9), Oligotrophic (10-14) and Ultraoligotrophic (15-20), respectively.

We performed two steps to calculate the P-IBI: 1) Use cutoff scores for each variable to calculate individual metric values and 2) Estimate a subtropical reservoir mean metric score.

P-IBI was computed through:

$$\mathrm{P-IBI} = \frac{1}{\mathrm{R}} \sum_{\mathrm{k}=1}^{\mathrm{R}} \square \frac{1}{\mathrm{S}} \sum_{\mathrm{j}=1}^{\mathrm{S}} \square \frac{1}{\mathrm{M}} \sum_{\mathrm{i}=1}^{\mathrm{M}} \square \, (\mathrm{CA}_{\mathrm{ijk}} + \mathrm{CYijk} + \mathrm{PRijk} + \mathrm{PDijk})$$

Where: CA_{ijk}= Total Calanoid density metric score; Cy_{ijk}= Total Cyclopoid density metric score; PR_{ijk}= Phytoplankton richness metric score; PD_{ijk}= Phytoplankton diversity metric score; M = number of metrics; S = number of sites and R = number of reservoirs.

Finally, a weighted Cohen’s Kappa statistic (k) (Cohen, 1960) was calculated in order to judge the accuracy of classification. Cohen’s Kappa is a statistical measure of the agreement of two raters or two rating methods. In our case, we compared the trophic status determined by TSItsr and the developed P-IBI for subtropical reservoirs. Significance for the weighted Cohen’s Kappa was judge α=0.05 or hypothesis testing. A

Cohen’s Kappa of 1 indicates perfect agreement between the raters and 0 indicates that any agreement is totally due to chance. There is no clear-cut agreement on what constitutes good or poor levels of agreement, although a common set of criteria is: <0,00 = poor, 0,00-0,20 = slight, 0,21-0,40 = fair, 0,41-0,60 = moderate, 0,61-0,80 = substantial, 0,81-1,00 almost perfect (Landis and Kock, 1977).

Comunication

An important goal of IBI development is to communicate the biotic integrity results to a variety of different groups of stakeholders (Karr and Chu, 1997). This group ranges from scientists and managers to citizens and policy makers who all have a stake on management of lakes/reservoirs water quality.

Further, we graphed the data as simple bar plots of P-IBI scores and also determined qualitative categories of the P-IBI for subtropical reservoirs that reflect the level of degradation scoring system (i.e., poor, fair, good, excellent) and are effective for summarizing reservoirs biological integrity.

Results

Reservoirs trophic state condition and plankton richness

The selected Paranapanema River reservoirs exhibited low or relatively low concentrations of TP (varying from 3,1 µg L^{-1} in Jurumirim to 67,2 µg L^{-1} in Capivara) and Chl *a* (varying from 0,4 µg L^{-1} in Chavantes to 7,0 µg L^{-1} in Capivara) (Fig. 2). The observed concentrations limited the range used on developing P-IBI from ultraoligotrophic to mesotrophic status (Table 2), restricting the final classification from fair to excellent.

The plankton community richness seems to correspond to the trophic conditions of the selected reservoirs. In general, phytoplankton richness ranged between 116 (Chavantes) and 147 species (Jurumirim) in March, and between 112 and 137 species in October, also in Chavantes and Jurumirim, respectively. Zooplankton was represented by Rotifera, Cladocera and Copepod and the highest richness was found in Jurumirim (58 species) in October and the lowest was in Chavantes (34 species) also in October. The total richness (number of taxa) for phytoplankton during the entire period was 176 in Jurumirim, 158 in Chavantes and 180 in Capivara and for zooplankton it was 68 in Jurumirim, 58 in Chavantes and 64 in Capivara.

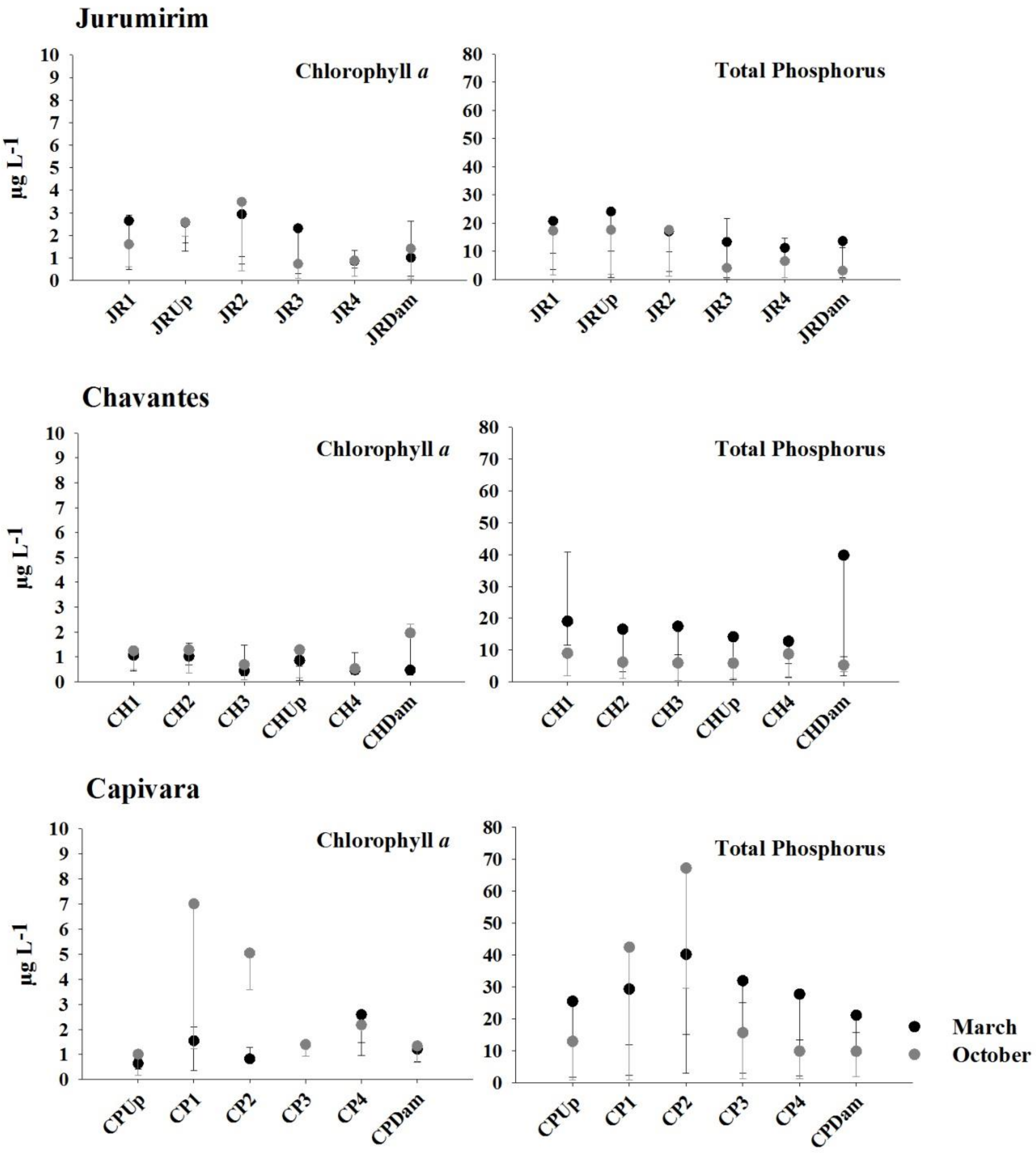

Figure 2 - Total Phosphorus and Total Chlorophyll *a* concentrations in the cascade reservoir of the Paranapanema River during the study period.

Table 2. Total phosphorus, chlorophyll and Trophic State Index (Tropical/Subtropical reservoirs) values and categories in the studied Paranapanema River reservoirs.

Trophic state Index (Cunha et al., 2013)			**T.P. (µg l^{-1})**	**Chl*a* (µg l^{-1})**	**TSI (TP)**	**TSI (Chl*a*)**	**TSI (tsr)**	**TSI Category**
Jurumirim	**JR1**	**March**	20.7	2.6	52.9	51.3	52.1	**O**
	JRUp		24.0	2.5	53.5	51.2	52.4	**O**
	JR2		17.0	2.9	52.1	51.7	51.9	**O**
	JR3		13.3	2.3	51.1	50.8	51.0	**U**
	JR4		11.2	0.8	50.4	47.2	48.9	**U**
	JRDam		13.6	1.0	51.2	47.8	49.6	**U**
	JR1	**October**	17.2	1.6	52.2	49.5	50.9	**U**
	JRUp		17.5	2.5	52.2	51.2	51.8	**O**
	JR2		17.5	3.4	52.2	52.3	52.3	**O**
	JR3		4.0	0.7	46.4	46.7	46.6	**U**
	JR4		6.5	0.8	48.3	47.3	47.8	**U**
	JRDam		3.1	1.4	45.4	49.0	47.2	**U**
Chavantes	**CH1**	**March**	19.0	1.0	52.6	48.0	50.3	**U**
	CH2		16.5	1.0	52.0	47.9	50.0	**U**
	CH3		17.4	0.4	52.2	44.8	48.5	**U**
	CHUp		14.1	0.8	51.4	47.3	49.3	**U**
	CH4		12.8	0.4	51.0	45.1	48.1	**U**
	CHDam		39.7	0.4	55.5	45.1	50.3	**U**
	CH1	**October**	9.0	1.2	49.6	48.64	49.1	**U**
	CH2		6.2	1.2	48.1	48.75	48.4	**U**
	CH3		6.0	0.6	48.0	46.49	47.2	**U**
	CHUp		5.9	1.2	47.9	48.75	48.3	**U**
	CH4		8.8	0.5	49.5	45.52	47.5	**U**
	CHDam		5.3	1.9	47.5	50.29	48.9	**U**
Capivara	**CPUp**	**March**	25.4	0.6	53.7	46.2	50.0	**U**
	CP1		29.3	1.5	54.3	49.4	51.9	**O**
	CP2		40.1	0.8	55.5	47.1	51.3	**O**
	CP3		31.8	1.3	54.6	49.0	51.8	**O**
	CP4		27.7	2.5	54.1	51.2	52.7	**O**
	CPDam		21.0	1.2	53.0	48.5	50.8	**U**
	CPUp	**October**	12.8	1.0	51.0	47.8	49.4	**U**
	CP1		42.4	7.0	55.8	54.9	55.3	**M**
	CP2		67.1	5.0	57.6	53.7	55.6	**M**
	CP3		15.6	1.3	51.8	49.0	50.4	**U**
	CP4		9.8	2.1	49.9	50.6	50.3	**U**
	CPDam		9.7	1.3	49.9	48.9	49.4	**U**

The results of the P-IBI Score highlight the good water quality in the Paranapanema River, considering the selected reservoirs (Fig. 3-A). All of them feature ultraoligotrophic condition except for Jurumirim in March, which obtained oligotrophic condition. These results fairly represent the values obtained through the Trophic State Index for tropical/subtropical reservoirs as presented in Table 2. There is also a good correspondence with the classification proposed by the P-IBI for subtropical reservoirs, with scores ranging from Good in Jurumirim reservoir and Excellent in the Chavantes and Capivara reservoirs.

Figure 3 (B to D) shows the P-IBI for subtropical reservoirs for each one of the selected reservoirs and sampling sites. Variations between seasons and also sampled sites support the spatial complexity of reservoirs. The score values ranged between Good and Excellent in the distinct reservoirs and were higher and more homogeneous in Chavantes (Fig. 3-C) followed by Capivara (Fig. 3-D) and then Jurumirim (Fig. 3-B) with the highest spatial and temporal variation.

When we confronted our results (P-IBI) with the TSItsr, using the Cohen´s kappa statistic (k = 0,067) (Table 3), there was a slight agreement (*sensu* Landis and Kock, 1977).

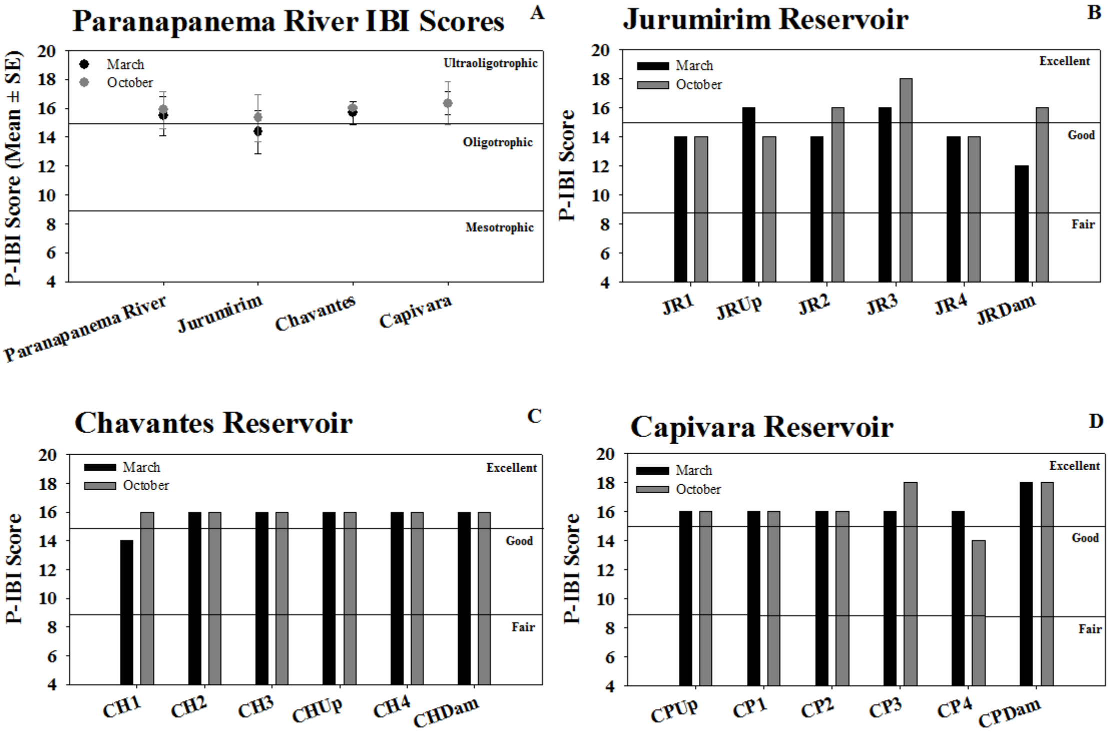

Figure 3 – A. Paranapanema River (mean values of Jurumirim, Chavantes and Capivara) Planktonic Index of Biotic Integrity (P-IBI) score for March and October/2011; B. Jurumirim reservoir P-IBI score for March and October/2011; C. Chavantes reservoir P-IBI score for March and October/2011; D. Capivara reservoir P-IBI score for March and October/2011.

Table 3. P-IBI validation using Cohen's kappa statistic.

	TSI (tsr)			
TSI (IBI)	Mesotrophic	Oligotrophic	Ultraoligotrophic	Total
Mesotrophic	0	0	0	0
Oligotrophic	0	3	6	9
Ultraoligotrophic	2	6	19	27
Total	2	9	25	36
Agreement	0	3	19	22
By Chance	0	2,25	18,75	21,00
Kappa	**0,067**			

Discussion

Large scale reservoir construction have economic and social consequences, in addition to environmental impacts (Redman et al., 2004), justifying studies focusing on water quality and ecosystem health assessments.

The development and application of a viable Planktonic Index of Biotic Integrity (P-IBI) can be useful for monitoring protocols and management purposes of the Paranapanema River reservoirs. These reservoirs are considered as strategic for the environmental policy of the State of São Paulo, the most populous and industrialized in the country where deterioration of inland waters resources is critical.

The Paranapanena River has been considered as a fluvial system that preserves a relatively good "water quality" condition, with frequent classification of its reservoirs as oligotrophic or oligo-mesotrophic (Jorcin and Nogueira 2005a, b; Nogueira et al., 2008; Jorcin and Nogueira, 2009; Nogueira et al., 2010; Henry, 2014).

The use of plankton assemblages as integrative indexes for assessment of regional environmental variability is promising. Studies carried on along the Paranapanema River reservoir cascade have shown that phytoplankton and zooplankton abundances are positively associated along the cascade. It has also been demonstrated that their composition and structure, even in major taxonomical categories, can be good indicators of distinct trophic conditions in the reservoirs cascade (Nogueira et al., 2008, Sartori et al., 2009; Nogueira et al., 2010; Perbiche-Neves and Nogueira 2010).

The determination of the trophic state index (TSI) is a traditional approach for evaluation of the water quality in freshwater systems. The TSI based on limnological variables that are relatively simple to measure, easy to calculate, and simple to understand and explain. In our study we adopted the regional proposal of Cunha et al. (2013) for tropical/subtropical reservoirs (TSItsr), which is a modified version of the original Carlson TSI (1997). Despite the fact that the TSIsr proposes the use of annual geometric mean based on 4 seasonal samplings (we have 2) and is recommended for lacustrine conditions (we have also sampled the upstream zones of reservoirs – river-reservoir transition), this index allows for comparison with the P-IBI in the case subtropical reservoirs. Further, our sampling limitations can be overcome in the future, as additional data have been and will be collected under the auspices of the hydropower generation company.

The following considerations helps to justify the choose of TSItsr in our study: (i) the trophic state criterion may help the decision making process when managing reservoir eutrophication and estimating the risk of phytoplankton blooms; (ii) trophic state criteria developed for temperate systems may overestimate the enrichment condition of tropical/subtropical reservoirs; (iii) comparison with previous investigations (e.g. Lamparelli, 2004) and with the official monitoring protocol of the environment agency of São Paulo State (iv) the use of the TSItsr in other studies has been encouraged, based on the perspective that is more representative for tropical/subtropical freshwaters (Cunha et al., 2013).

The spectrum of variation resulting from the TSItsr for the selected Paranapanema River reservoirs was relatively low. The classification varied between ultraoligotrophic and mesotrophic, with the prevalence of the first condition (Table 2). These results are in accordance with other studies carried this watershed (see above), and also with the P-IBI we have developed. In our study the reservoir scores (mean values) were very close and comprised the categories meotrophic, oligotrophic and ultraoligotrophic and the reservoirs were classified either as ultraoligotrophic or oligotrophic (qualitative categories Excellent or Good) (Figure 3).

The agreement between the two considered methodological approaches, TSItsr and the developed P-IBI, was slight (Cohen's Kappa statistic) (Table 3). This fact is probably because of the low number of samples collected in a single year. Nevertheless, there is a feasible possibility to enhance the P-IBI consistency in further analyses, as systematic monitoring of Jurumirm, Chavantes and Capivara reservoir continue.

Previous to our study, the phytoplankton IBI was developed for a reservoir cascade in the Lancang-Mekong River, Southwest China (Li et al. 2013). The index was developed using phytoplankton metrics (but not zooplankton metrics) and the results corroborated the known longitudinal spatial pattern. Variability was mainly related to increasing abundance and biomass of phytoplankton assemblages in reservoir areas.

Despite using data of only two sampling periods, it is important to consider that the selected periods (March and October 2011) are representative of the regional environmental variability, as they correspond to the most contrasting seasonal periods - end of summer/rainy season and end of winter/dry season, respectively. The type of data used to develop our P-IBI is comparable with those of Kane et al., (2009) and other authors who developed IBI's (i.e. Carpenter et al., (2006), Rothrock et al., (2008), Cassati et al., (2009), Li et al., (2010), Silva et al., (2010), Esteves and Alexandre, (2011), Gómez et al., (2012), Wu et al., (2012a), Wu et al., (2012b), Ruaro et al., (2013), Li et al., (2013), Kane et al., (2015)).

Multimetric indices have been criticized because they reduce data into a single number (Wu et al., 2012b). However, agreeing with Ruaro et al. (2013), we believe that an integrative and simple index may be a fast and efficient tool to monitor aquatic environments. The advantages of using a multimetric system over a univariate assessment include: (1) they measure different responses to multi-stressors occurring within the region of interest, since metrics represent various taxonomic and functional groups within the assemblages (biotic integrity) (Zalack et al., 2010); (2) they compare habitats both within and among regions (Barbour et al., 1999), and (3) they compensate for erratic responses of a few metrics, and (4) they incorporate metrics related to multiple ecological attributes that are valued by decision makers (Wang et al., 2005).

Moreover, the ideas proposed by Karr (1981) have contributed to the management of water resources and biological conservation (Ruaro et al., 2013). The original Karr IBI is one of the most frequently used and one of the most efficient in the assessment of freshwater ecosystems integrity. It allows the identification of priority sites for conservation (Lyons et al., 1995), integrates measurements of biological condition and associated resources that are easily understood by public and official agencies, and allows the comparison of both individual and cumulative effects of a variety of human activities (Karr and Chu, 2000).

Final considerations

This study demonstrated that the P-IBI is a potential tool for monitoring and management of large subtropical reservoirs, and reflects differences in ecosystem health over space and time. The use of metrics associated with plankton assemblages is appropriated, once the organisms are sensitive to environmental changes and integrates distinct time and space scales.

P-IBI scores can be understood and used by nonscientists involved in the making, planning, and management decisions at an appropriate level for the multiple uses of subtropical reservoirs. This P-IBI generally agrees with previous evaluations of the study reservoirs and can be easily integrated into the water quality monitoring program of the Paranapanema River reservoir cascade.

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