

Environmental gradient in reservoirs of the medium and low Tietê River: limnological differences through the habitat sequence

Gradiente ambiental em reservatórios do médio e baixo Rio Tietê:
diferenças limnológicas ao longo da seqüência de habitats

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Abstract: Aim: The reservoirs of the medium and low Tietê River are disposed as a “cascade series”, in which time, physiographic features and influence from drainage basins present differences that determine variability in their dynamics. These reservoirs are submitted to different impacts from the urban centres which they drain, and also from agricultural activities. Considering these features, the aim of this work was to characterize the Medium and Low Tietê river stretches by limnological analysis (including water and sediments) considering dry and rainy seasons evaluating changes along the reservoirs sequence. **Methods:** Based on physical and chemical measurements on water and sediments from 16 points along the reservoirs and in the river mouth of the main tributaries, it was possible to make an environmental characterization of the study area. **Results:** This was performed focusing on water, sediment, habitat structure and time scale. Generally, the data showed a reduction in the values of the analyzed parameters along the reservoirs sequence. Moreover, it was possible to identify differences between the dry and rainy seasons for water and sediment parameters. Concerning habitat structure, there is a gradient along the river, which shows that the environmental quality improves from the river head to the river mouth. Differences in macrophyte composition, kind of sediments, transparency and habitats were also identified. **Conclusions:** Therefore, modifications were identified in the habitats general structure along the medium Tietê stretch: emerging macrophytes and muddy bottom predominate upstream; and submerging macrophytes and sandy bottom predominate downstream. The water characteristics should be taken into consideration, because they reflect the impacts upon the drainage basin of each reservoir.

Keywords: Tietê River, damming, limnology, cascade effect, habitat structure.

Resumo: Objetivo: Os reservatórios do médio e baixo Tietê compõem uma série em “cascata” cujas idades, características fisiográficas e influencia da bacia de drenagem apresentam diferenças determinando diferenças nas suas dinâmicas. Tais reservatórios são submetidos a diferentes impactos pelos centros urbanos as quais drenam e também pela atividade agrícola. Considerando essas características, este trabalho teve como objetivo caracterizar o médio e baixo Tietê através da análise limnológica (água e sedimento), considerando as épocas seca e chuvosa avaliando mudanças ao ao longo da seqüência de reservatórios. **Métodos:** Com base em amostragens físicas e químicas da água e sedimento em 16 pontos ao longo dos reservatórios e na foz dos principais tributários foi possível realizar uma caracterização ambiental da área de estudo focando a água, o sedimento, a estrutura de habitats e a escala temporal. **Resultados:** Os resultados mostraram de forma geral redução dos valores dos parâmetros analisados ao longo da seqüência de reservatórios. Além disso, foi possível identificar diferenças entre as épocas seca e chuvosa tanto para os parâmetros da água como de sedimento. Com relação a estrutura de habitats há um gradiente ao longo do rio mostrando melhora na qualidade ambiental no sentido montante-jusante e também diferenças na composição das macrófitas, tipo de sedimento,

transparência e habitats. **Conclusões:** Foram identificadas modificações na estrutura geral dos habitats ao longo do trecho médio Tietê: macrófitas emergentes e fundo lodoso predominam a montante enquanto macrófitas submersas e fundo arenoso predominam a jusante. As características da água deve ser levado em consideração, porque eles refletem os impactos sobre a bacia de drenagem de cada reservatório.

Palavras-chave: Tietê, represamento, limnologia, efeito cascata, estrutura do habitat.

1. Introduction

The most extensive period of dam construction was concentrated in 20th century (Mallik and Richardson, 2009; Li et al., 2012). Almost 60% of large river systems were affected by dams (Nilsson et al., 2005; Li et al., 2012). Large reservoirs are distributed all over the Brazil, but this number is particularly high in the Southeast region (Nogueira et al., 2010). A number of studies have demonstrated that the river can be remarkably impacted by damming, leading to habitat heterogeneity, declines in species richness and native species and exotic species invasion (Tealdi et al., 2011; Li et al., 2012). The changes in ecological processes associated with dam construction in both aquatic and terrestrial riparian ecosystems have become a key focus of river studies (Gordon and Meentemeyer, 2006).

In case of reservoir cascades, just a few efforts have been undertaken, to declines how their functioning affect the river ecological structure and functioning (Barbosa et al., 1999; Nogueira et al., 2010). It is necessary to learn the accumulated effect of cascade dams on hydrological characteristics, sediment and nutrient pollution discharge (Ouyang et al., 2011).

Many reservoirs built into rivers follow a cascade configuration, which means that two or more reservoirs are distributed along the watercourses. Cascading hydropower dams, defined as a series of dams from upstream to downstream (Fang and Deng, 2011)

The construction of reservoirs in sequence implies an interruption of the nature of water with typical behavior of river. However, the impact of modifying a river to a series of tanks have produced changes in the water system that are not yet fully known. Depending on the distance between the dams along the river, building a reservoir cascade systems has the potential to enhance the effects of damming the river in the biological composition and distribution (Callisto et al., 2005).

A pioneer survey of a series of connected reservoirs in Brazil, with a limnological integrated river basin approach, was carried out in the Tietê River, state of São Paulo by Tundisi et al. (1991).

Detailed investigations of the influence of Brazilian reservoir cascades on the biota aquatic and limnological factors are still scarce (Nogueira et al., 2010).

In reservoir cascades the alterations in water quality as well as in the biotic composition and distribution are the results of modifications in the lateral, vertical and longitudinal dimensions, as described in the Cascading Reservoir Continuum Concept (CRCC) (Barbosa et al., 1999).

Studies along 8 reservoirs in the Tietê river; 5 reservoirs in the Iguazu river, 3 reservoirs in the lower São Francisco river showed that phytoplankton, periphyton, macroinvertebrates, macrophytes and fish are highly affected by hydrodynamic changes (Padišák et al., 2000; Cavenaghi et al., 2003; Smith, 2004; Silva et al., 2005; Felisberto and Rodrigues, 2005; Callisto et al., 2005; Patesse et al., 2007; Jorcin and Nogueira, 2008).

The Tietê River, along its course, encounters various impacts such as pollution, damming and loss of riparian vegetation. In its medium and low stretches there are reservoirs created by damming, mainly for electrical energy generation. The dams of the medium and low Tietê River were built between the 1950s and 1990s. The first reservoir to be constructed was Barra Bonita (1964), followed by Bariri (1969), and Ibitinga (1969) reservoirs. The Promissão reservoir was constructed in 1975, the Nova Avanhandava in 1985, and the Três Irmãos in 1991 (Barbosa et al., 1999).

The damming of the river lead to changes in the lotic system (river), turning it to a lentic system (lake), which favors the creation of three different zones: the river zone, at the head, with faster flow and more intense processes in the horizontal axis; the transition zone, intermediary between the river and the lake; and the lacustrine zone, next to the dam, with slower flow and prevalence of processes in the vertical axis. According to Cooke et al. (1993), the river zone has a faster water flow and high concentration of suspended solids and nutrients; the transition zone has a slower flow, low concentration of suspended solids and nutrients, and high levels of photosynthesis; the lacustrine zone shows very

clear water, the lowest flow and concentration of suspended solids and nutrients.

In the Tietê system, the reservoirs are arranged as a cascade series, which reduces the river and the transition zones. Along the reservoirs sequence, changes in the system occur, such as reduction in turbidity, increase in transparency and alterations in biota composition (Barbosa et al., 1999). The cascade system improves the water quality, since part of the nutrients and pollutants are detained in the preceding reservoirs (Straškraba, 1994). In this way, the reservoir position is an important factor to be analyzed, associated with the unloading effect of the previous reservoir (Straškraba, 1994; Tundisi, 1996, 1999a).

The hydrodynamic of this complex system is also influenced by the tributaries, and by the floodgate opening and closing operational mechanisms, with great fluctuation on the water level, on the flow, and on the residential time. Other factors that also influence the hydrodynamic are the solar radiation, pluviometric precipitation, and wind, characterizing the majority of the reservoirs as polymitic (Barbosa et al., 1999).

Associated with this important system, which configures a great impact on the natural conditions of the river, there is also the intense loss of the riparian forest due to urban and rural expansion, as well as the discharge of pollutants from the cities placed on its bank and through its tributaries such as the Piracicaba and Jaú rivers, among others. The main

causes of degradation of the water quality are the punctual pollution sources (sewage and industrial effluents) and diffuse sources (urban and agricultural drainage), besides atmospheric precipitation (Lloyd, 1992). Considering these features, the aim of this work was to characterize the Medium and Low Tietê river stretches by limnological analysis (including water and sediments) considering dry and rainy seasons evaluating changes along the reservoirs sequence.

2. Material and Methods

2.1. Study area

The study area covers the Medium and Low Tietê River stretches, including sampling stations placed upstream from the beginning of the reservoirs cascade, six reservoirs and six tributaries (Figure 1). For water and sediment physical and chemical characterization, 8 sampling stations were selected (lacustrine zone); whereas for habitat description 16 stations were sampled (transitional and lacustrine zone) (Table 1). Riverine zone were not sampled because due to position of reservoirs in the cascade, the area is not present in most reservoirs reviews. Sampling events took place in July, 2000 (dry period), and January, 2001 (rainy period).

2.2. Sampling data

To characterize the sampling stations, physical and chemical variables were measured in the

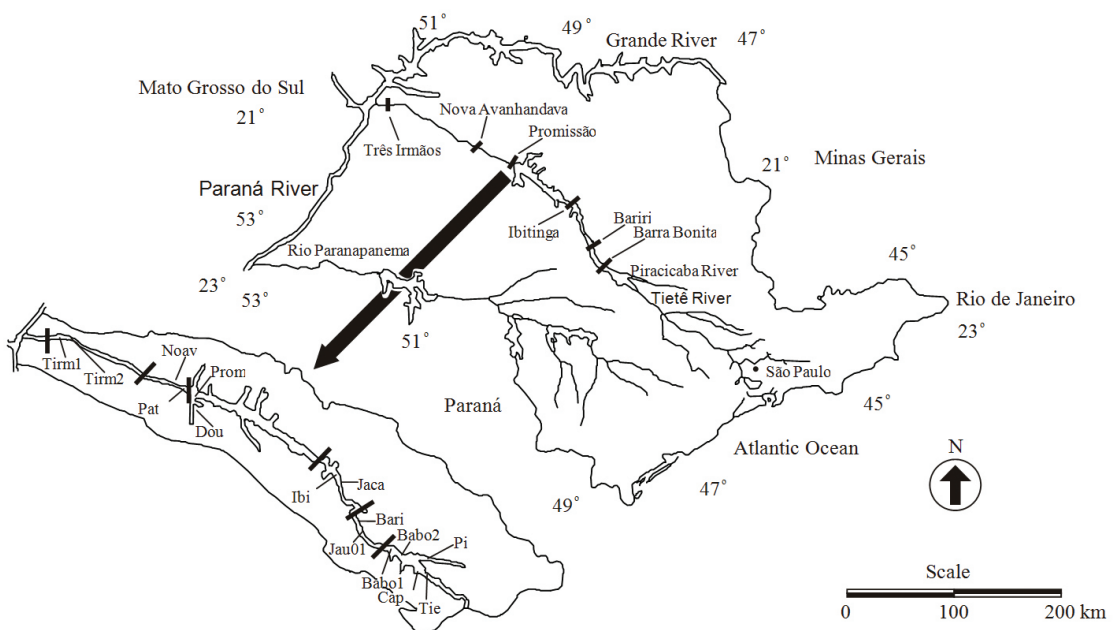


Figure 1. Location of the reservoirs, main tributaries and distribution of the sampling stations in the Tietê River, SP.

Table 1. Code, site, zone and geographic location of the sampling stations. *Sampling stations where water and sediment physical and chemical variables were analyzed.

Code	Site	Geographic location		
		Zone	South	East
tie*	Tietê River	transitional	22° 39' 54.4"	48° 9' 03.4"
cap	Capivara River, Tietê's tributary	transitional	22° 42' 40.8"	48° 22' 17"
pir*	Piracicaba River	transitional	22° 38' 27.1"	48° 09' 51"
babo*	Barra Bonita Reservoir	lacustrine	22° 31' 56.2"	48° 31' 05.4"
bari*	Bariri Reservoir	lacustrine	22° 09' 51.5"	48° 45' 36"
jau	Jaú River	transitional	22° 11' 45.5"	48° 40' 24.6"
ibi*	Ibitinga Reservoir	lacustrine	21° 52' 12.7"	48° 59' 05.9"
jaca	Jacaré-Guaçu River	transitional	21° 49' 58"	48° 54' 05.9"
iac	Iacanga River	transitional	21° 52' 12.7"	48° 59' 05.9"
prom*	Promissão Reservoir	lacustrine	21° 24' 12.6"	49° 42' 19.3"
dou	Dourado River	transitional	21° 24' 12.6"	49° 42' 13.3"
noav*	Nova Avanhandava Reservoir	lacustrine	21° 15' 43.2"	49° 51' 06.8"
pat	Dos Patos River	transitional	21° 17' 15.8"	49° 50' 29.2"
tirm*	Três Irmãos Reservoir	lacustrine	20° 40' 25.2"	51° 30' 06.8"
cot	Do Cotovelo River	transitional	20° 48' 24.5"	51° 04' 52.8"
ita	Tietê River	transitional	20° 39' 18.8"	51° 29' 25.8"

* Sampling stations where water and sediment physical and chemical variables were analyzed.

water, and some of these variables were related to each sampling station habitat structure. A single vertically integrated sample of water was collected with a suction pump from each sampling station. Temperature, pH, conductivity and dissolved oxygen were measured at 0.5 m depth using a Horiba U-10. Water samples were transferred to previously washed and dried plastic bottles and stored at 4 °C until the moment they were analyzed. Total organic nitrogen (Golterman et al., 1978), total phosphorous (APHA, 1995), total dissolved phosphate (Golterman et al., 1978), inorganic phosphate (Golterman et al., 1978), ammonia (Koroleff, 1976), nitrite and nitrate (Mackereth et al., 1978), chlorophyll (Nush, 1980), total lift material, inorganic and organic lift material (Fonseca, 1997), reactive silicate (Golterman et al., 1978), suspended material (Teixeira et al., 1978), total cadmium, chromium, copper and zinc (APHA, 1995) were analyzed.

Sediment samples were collected with an Eckman dredge and immediately stored in plastic containers inside styrofoam boxes containing ice until their analysis in the laboratory. Analyses of organic matter (Fonseca, 1997), granulometry (ABNT, 1968) and concentration of potentially bioavailable metals (Cd, Cr, Cu and Zn) (Tessier and Campbell, 1987) were made.

The variables *kind of substrate* and *submerged structures* were obtained using an echobathymeter Garmin (GPSMAP 135 model, besides direct observation), depth (measured in meters using a

graduated line), flow (obtained from the *Companhia Paulista de Força e Luz* (Power and Light São Paulo Company, Brazil), average resistance time (calculated from the monthly operational average volume, by the monthly effluent average flow), transparency (Secchi disk, with diameter of 30cm), presence or absence of submerged structures (trunks, rocks, etc.) and aquatic macrophytes (Platts et al., 1987). Marginal vegetation and sediment were evaluated using the following characterization: 0 (absence), 0.5 (presence in 50% of the area) and 1 (present in 100% of the area).

2.3. Data analysis

Data were evaluated through multivariate techniques. These techniques have been used to simplify data structure in ecological studies, by means of transformations, sampling classification, groups of individuals or variables, analysis of interdependency, and assistance in formulation of tests of hypothesis.

Principal Components Analysis was used to analyze the data. This is an ordination technique which aims to arrange samples in a lower number of dimensions by: keeping an essential percentage of information; getting rid of "noise"; emphasizing the greater variation patterns; and producing maximum information about the patterns and ecological similarities (Digby and Kempton, 1987). In this study, the correlation matrix was used.

The best results are obtained when the original variables are highly correlated (Manly, 1986). In this

work, the aim of this analysis was to help generating hypotheses (Digby and Kempton, 1987) with environmental data from each sampling station.

3. Results

3.1. *Water physical and chemical characterization*

Table 2 presents data for physical and chemical variables measured in water. There is a decrease in values from the first (Barra Bonita) to the last reservoir (Três Irmãos) of the cascade system, except for silicates (closest values). It was also verified that the values were generally higher for the sampling stations located before the cascade system, as well as for the first three reservoirs, than for the ones at the low course of the river. Besides, there were differences between results obtained in the dry and rainy seasons. In the dry season, higher values for conductivity and transparency were found, as well as higher nitrate and total organic nitrogen concentrations were detected. On the other hand, in the rainy season, higher concentrations of nitrite, total phosphorus, total dissolved phosphorus, inorganic phosphorus and suspended materials (considering both organic and inorganic fractions) were obtained. Considering dissolved oxygen, the greater concentrations occurred in the rainy season, in the upper stretches of the cascade system; they were, however, higher both in dry and rainy seasons in the sampling stations placed after Ibitinga reservoir.

Concerning metals, the values obtained for iron, manganese, magnesium, and zinc were greater in the rainy season; whilst the greatest lead concentrations occurred in the dry season. Generally, a reduction on metal concentration in water in the longitudinal axis of Tietê River was found, which shows the cascade effect in the sequence of reservoirs. The water quality improves from the first (Barra Bonita) to the last reservoir (Três Irmãos) of the system (Table 2).

3.2. *Sediment physical and chemical characterization*

Table 3 presents physical and chemical variables measured in sediment samples and the differences between dry and rainy seasons. The highest percentage contribution of organic material and nitrogen and total phosphorus concentrations were obtained for the first reservoirs, with a reduction in values along the cascade of reservoirs. Concerning sediment granulometry, there was a higher contribution of clay and sand fractions in Medium and Lower stretches of Tietê River, respectively. For

metals, the higher concentrations were found in the dry season. Chrome was an exception with higher values in the rainy season. Similar to the water compartment, there was found a decrease in metal concentration in the sediment along the sequence of reservoirs, again pointing to a cascade effect. The quality of both water and sediments improves from the first (Barra Bonita) to the last reservoir (Três Irmãos) of the system.

3.3. *Classification of the sampling stations*

With the data obtained for water and sediment physical and chemical variables, a Principal Component Analysis was performed. Only the first two components were considered since they together explained 56.48% of the total variance (Table 4).

The first principal component was responsible for 38.96% of the total variance. The main variables that contributed to form this axis were: conductivity, nitrite, ammonia, total dissolved phosphorus, inorganic phosphorus, chlorophyll, inorganic suspended materials, manganese, phosphorus in the sediments, organic materials in the sediments, thick sand, medium sand, clay and metals in the sediments (all with positive values), and dissolved oxygen, water transparency, lead and cadmium in water, inorganic materials in the sediments and fine sand (all with negative values). This component can be interpreted as the location of the sampling stations along the cascade of reservoirs.

The second principal component represented 17.52% of the variance. The more representative variables were: conductivity, nitrate, total nitrogen, and medium sand (all with positive values), temperature, dissolved oxygen, total suspended materials, iron, magnesium and zinc in water, and chrome in the sediments (all with negative values). This principal component was interpreted as the seasonal variation, that is, the differentiation between dry and rainy seasons.

Figure 2 shows the sampling stations arranged according to their scores in a continuous way. On the right side of the graphic are placed the upstream stations, which present, generally, higher values of conductivity, hardness, nitrite, ammonia, phosphate, and chlorophyll, and lower values of dissolved oxygen and water transparency, suggesting that these sites received a heavy load of effluents from diffuse and punctual pollution. On the left side of the graphic are placed the stations towards to the river mouth, which have lower values of conductivity, hardness, nitrite, ammonia,

Table 2. Abiotic variables of the collection stations water in rainy (r) and dry (d) seasons. Abbreviations used: cond = conductivity ($\mu\text{S}\cdot\text{cm}^{-1}$); temp = temperature ($^{\circ}\text{C}$); dox = dissolved oxygen; hard = hardness; TN = total nitrogen ($\mu\text{g/L}$); TP = total phosphorus ($\mu\text{g/L}$); total PO_4 = total dissolved phosphate ($\mu\text{g/L}$); inorg PO_4 = inorganic phosphate ($\mu\text{g/L}$); chloro = chlorophyll; TLM= total lift material ($\mu\text{g/L}$); ILM= inorganic lift material ($\mu\text{g/L}$); and OLM= organic lift material. The other variables are quantified in $\mu\text{g/L}$.

station	pH	cond	temp	dox	hard	Secchi	nitrate	nitrite	ammonia	TN	TP	total PO_4	inorg PO_4
tier	6.08	126	24.8	7.55	61	0.5	456.88	21.41	93.47	1.77	189.49	73.21	90.52
tied	6.98	407	22	2.71	60	1.3	1795.7	244.74	2389.6	5.32	148.67	79.58	277.53
pirr	6.27	62	24.3	7.58	20	0.1	236.12	46.56	14.1	0.47	86.96	56.99	44.81
pird	5.86	246	18.7	3.48	42	0.35	1187.3	6.28	16.05	1.54	750.37	12.33	22.17
babor	6.37	119	25.2	7.83	52	0.9	746.3	48.92	48.92	0.7	227.15	32.43	25.9
babod	6.92	219	20.4	5.77	48	0.5	1751.3	23.25	680.69	2.33	58.97	4.06	3.81
barir	7.13	175	28.3	7.16	36	1.9	712.92	15.54	0.91	0.28	56.13	18.32	5.45
barid	5.96	177	20.4	6.67	40	1	1749.1	6.56	7.08	1.31	42.748	4.8	2.84
ibir	5.52	116	26.1	7.49	34	1.5	640.54	6.23	3.33	0.09	103.48	27.7	12.78
ibid	6.1	73	20.3	10.1	40	3.8	859.62	4.36	9.02	1.59	26.07	2.33	1.16
promr	6.78	98	26.9	7.41	30	3	425.81	12.03	0.95	0.14	42.1	5.22	3
promd	7.06	115	21.56	8.5	38	4	603.39	4.8	10.4	1.77	8.98	1.22	2.19
noavr	6.86	82	28.3	7.06	32	3.5	282.99	8.21	3.77	0.05	32.33	14.8	12.79
noavd	6.43	123	21.2	8.44	32	6.4	471.35	3.33	18.61	0.23	18.02	14.83	1.52
tirmr	6.68	58	27.9	7.05	30	2.5	139.3	2.56	1.23	0.05	27.62	6.94	5.93
tirmd	6.84	56	22.7	8.36	34	8.3	277.03	2.86	1.1	1.21	22.24	11.24	1.54

silicate	chloro	TLM	ILM	OLM	cadmium	cobalt	copper	iron	manganese	magnesium	lead	zinc
5	27.9	5	2.56	2.44	0.0028	0.0256	0.0082	54.232	0.2606	37.688	0.05212	0.03574
5.33	40.45	7.06	4.25	2.81	0.0074	0.0248	0.0114	0.352	0.1742	3.695	0.006	0.01216
5.85	20.08	53.12	5.2	47.92	0	0.0026	0	50.562	0.1366	22.564	0.02732	121.526
6.68	8.37	6.87	1.85	5.02	0.0138	0.0574	0.0054	0.7204	0.0818	1.696	0.01	0.01524
4.6	17.02	7.99	4.9	4.9	0.0032	0.0004	0	20.152	0.1264	30.474	0.02528	0.08538
5.4	4.6	5.77	1.77	4	0.009	0.0292	0.0024	0.5616	0.0292	2.714	0.052	0.0142
3.19	27.9	10.18	2.82	2.82	0	0.0172	0	0.7982	0.0622	3.044	0.01244	0.04777
5.29	22.45	2.95	1.59	1.36	0.0058	0.0406	0.003	0.323	0.0396	27.523	0.192	0.0094
4.88	16.18	3.16	1.18	1.18	0	0.0194	0	10.264	0.0682	2.831	0.01364	0.0835
6.26	6.41	1.31	0.66	0.65	0.0044	0.08	0.0074	0.2132	0.0256	28.042	0.176	0.1666
5.08	13.95	2.32	0.44	0.44	0.0054	0.0612	0	0.2868	0.0064	22.584	0.00128	0.03668
6.69	12.13	1.55	1.48	0.07	0.0068	0.042	0	0.2262	0.0152	2.436	0.258	0.02226
4.96	8.09	1.88	0.15	0.15	0.0082	0.0574	0	0.559	0.0208	26.588	0.00416	0.0641
7.12	4.74	1.57	1.02	0.55	0.0064	0.0336	0.0002	0.3982	0.019	2.504	0.222	0.01606
6.56	2.65	2.05	0.75	0.75	0.0038	0.0574	0	0.2804	0.0244	26.052	0.00488	0.06964
7.32	3.77	0.38	0.55	0.38	0.0068	0.0138	0	0.19	0.0164	2.356	0.284	0.02506

• tic – Tietê River; pir – Piracicaba River; babo – Barra Bonita reservoir; bar – Bariri reservoir; ibi – Ibitinga reservoir; prom – Promissão reservoir; noav – Nova Avanhandava reservoir; tirm – Três Irmãos reservoir.

Table 3. Abiotic variables of the collection stations sediment in rainy (r) and dry (d) seasons. Abbreviations used: total N sed = total nitrogen in the sediment (g/Kg), total P sed = total phosphorus in the sediment (g/kg), OM sed = organic material in the sediment (g/kg), IM sed = inorganic material in the sediment (g/kg). The other variables are quantified in µg/L.

station	total N sed	total P sed	OM sed	IM sed	thick sand	medium sand	fine sand	silt	clay	gravel	cadmium
tier	21.79	73.75	13.92	86.08	5	2	11	12	70	0	0.004
tied	10.36	57.19	13.56	86.44	10	27	20	23	20	0	0.005
pirr	16.75	57.69	10.92	89.08	3	3	13	16	65	0	0.004
pird	22.12	37.47	11.47	88.53	3	13	29	30	25	0	0.008
babor	16.33	47.17	7.9	92.1	0	0	0	0	0	0	0.005
babod	5.69	27.39	2.32	97.67	2	10	75	13	0	0	0.007
barir	13.11	63.05	11.55	88.45	2	3	24	70	0	0	0.004
barid	1.45	49.1	0.3	99.7	0	20	79	0	1	0	0.007
lbr	29.91	44.97	11.13	88.67	0	2	26	72	0	0	0.004
lbid	44.38	45.68	13.65	86.35	6	10	31	33	20	0	0.012
promr	3.22	6.55	0.7	99.3	1	3	73	23	0	0	0.003
promd	4.53	10.53	4.07	95.93	0	0	80	17	3	0	0.011
noavr	1.59	6.2	0.1	99.9	0	0	0	0	0	0	0.002
noavd	1.84	32.31	5.83	94.17	0	0	77	12	11	0	0.012
tirmr	1.54	3.03	0.5	99.5	0	2	95	0	3	0	0.003
tirmd	1.54	4.13	0.5	99.5	0	2	94	3	1	0	0.015
cobalt	chrome	copper	iron	manganese	lead	magnesium	zinc				
0.09	0.031	0.08	20.212	7.132	0.1	14.141	0.3407				
0.184	0.035	0.187	72.808	8.896	0.29	23.922	0.6748				
0.115	0.057	0.114	23.492	5.533	0.05	29.627	0.3147				
0.159	0.019	0.135	73.812	3.752	0.31	29.776	0.4181				
0.106	0.052	0.186	46.614	7.925	0.07	22.562	0.2071				
0.164	0	0.088	5.915	2.409	0.29	16.019	0.0567				
0.067	0.034	0.16	22.654	7.369	0.06	17.187	0.133				
0.01	0	0.012	1.446	0.361	0.25	0.3701	0.007				
0.117	0.054	0.105	22.025	1.417	0.04	12.673	0.0172				
0.09	0	0.13	28.776	6.654	0.42	19.651	0.1042				
0.012	0.022	0.009	2.911	0.861	0.03	0.6838	0.0102				
0.119	0	0.037	3.695	0.763	0.43	18.472	0.0186				
0	0.028	0.004	1.12	0.534	0.02	0.2732	0.006				
0.12	0	0.162	10.167	1.559	0.43	29.973	0.0708				
0	0	0.006	2.207	0.041	0.03	0.2938	0.0067				
0.029	0	0.006	2.445	0.597	0.42	0.5402	0.0099				

• tie – Tierê River; pir – Pracicaba River; babor – Barra Bonita reservoir; bar – Bariri reservoir; ibi – Ibitiga reservoir; prom – Promissão reservoir; noav – Nova Avanhandava reservoir; tirm – Três Irmãos reservoir.

Table 4. Results from the Principal Component Analysis: values obtained for the abiotic variables of each principal component with the two greater percentages of variance.

Abiotic variables	PC1	PC2
pH	-0.238	0.278
Conductivity	0.675	0.630
Temperature	-0.105	-0.654
Dissolved oxygen	-0.562	-0.431
Hardness	0.581	0.454
Water transparency (Secchi)	-0.687	0.263
Nitrate	0.445	0.637
Nitrite	0.722	0.399
Ammonia	0.608	0.594
Total organic nitrogen (water)	0.564	0.727
Total phosphorus (water)	0.458	0.121
Total dissolved phosphorus (water)	0.823	-0.155
Inorganic phosphorus (water)	0.765	0.357
Silicate	-0.447	0.366
Chlorophyll	0.785	-0.012
Total suspended materials	0.449	-0.558
Inorganic suspended materials	0.804	-0.222
Organic suspended materials	0.379	-0.550
Cobalt (water)	-0.285	0.218
Iron (water)	0.494	-0.654
Manganese (water)	-0.840	-0.201
Magnesium (water)	0.090	-0.530
Lead (water)	-0.549	0.373
Zinc (water)	0.286	-0.615
Total nitrogen (sediment)	0.497	-0.201
Total phosphorus (sediment)	0.831	-0.185
Organic materials (sediment)	0.840	-0.103
Inorganic materials (sediment)	-0.839	0.104
Thick sand	0.786	0.322
Medium sand	0.501	0.634
Fine sand	-0.731	0.405
Silt	0.319	-0.124
Clay	0.590	-0.366
Cadmium (sediment)	-0.417	0.502
Cobalt (sediment)	0.695	0.330
Chrome (sediment)	0.655	-0.584
Copper (sediment)	0.759	0.074
Iron (sediment)	0.816	0.258
Manganese (sediment)	0.865	-0.057
Magnesium (sediment)	0.668	0.033
Lead (sediment)	-0.224	0.732
Zinc (sediment)	0.912	0.211
Percentage of variance by factor	38.96%	17.52%
Accumulated variance		56,48%

phosphate, and chlorophyll, and higher values of dissolved oxygen and water transparency, and thus present better conditions than the upstream stations.

When Figure 2 is analyzed considering factor 2, the separation of the stations in two seasons, dry (upper part) and rainy (lower part) can be observed.

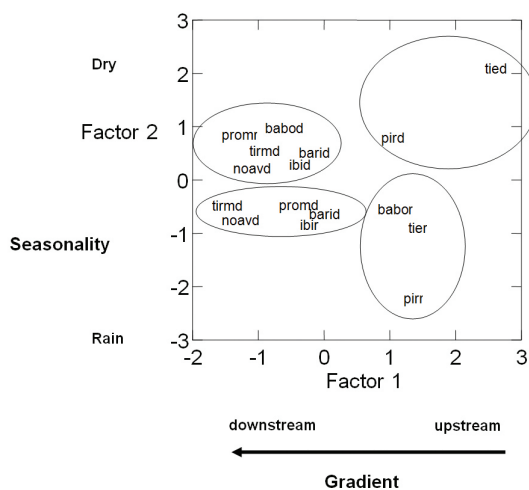


Figure 2. Representative diagram of the environmental analysis of the sampling stations located in Medium and Low Tietê River considering factor 1 (longitudinal gradient – cascade effect) and factor 2 (seasonal variation – dry and rainy seasons).

In the dry period, the values of conductivity, nitrate, and total nitrogen (in water), and medium sand, ammonia, cadmium, and lead (in the sediments) are higher, and the temperature, dissolved oxygen, total suspended materials, organic suspended materials, iron, magnesium, zinc, and chrome (in the sediments) are lower. The opposite occurs in the rainy season.

3.4. Characterization of the habitats

Table 5 depicts values for the abiotic variables related to habitat characterization for each sampling station in both dry and rainy seasons. From the data analysis, a gradient was verified along the Medium and Low Tietê River stretches. In the sampling stations located in the first reservoirs and tributaries, such as Tietê River (tie01), Barra Bonita (babo01), Piracicaba River (pira01), Bariri (bari01), and Jaú River (jau01), there higher values were obtained for conductivity, reduced water transparency, low concentration of dissolved oxygen and more acid pH. The bottom was muddy with great abundance of floating macrophytes, such as *Eichhornia* sp. and *Salvinia* sp.

In the sampling stations downstream of Ibitinga reservoir, such as Promissão (prom01), Nova Avanhandava (noav01), Três Irmãos (tirm01), and Itapura (ita01), there were the lowest values for conductivity, greater water transparency, higher concentration of dissolved oxygen and more neutral or basic pH. The bottom was sandy, with large occurrence of trunks, and higher abundance of submerged macrophytes.

Table 5. Average values for 12 abiotic variables, sampled during dry (d) and rainy (r) seasons. Legend: dep = depth (meters); pH = hydrogenic potential; cond = conductivity ($\mu\text{S}/\text{cm}$); dox = dissolved oxygen (mg/l); temp = water temperature ($^{\circ}\text{C}$); mud = muddy bottom; san = sandy bottom; maphy = macrophyte vegetation; and marg = marginal vegetation.

Station	dep (m)	pH	cond	dox (mg/l)	temp ($^{\circ}\text{C}$)	secchi	maphy	marg	gramineous	trunks	mud	san
tier	4	6.83	188	3.6	26.5	0.5	0	0.5	1	1	1	0
tied	6.5	7.03	445	1.78	19.5	0.5	0	1	0	1	0.5	0.5
capr	3	6.82	173.5	3.4	22	1.5	1	0	1	0	0	1
capd	1	7.7	248.7	10.9	20.2	0.5	0	1	1	1	1	0
pirr	1.9	6.38	111	3.69	24.2	0.3	1	1	1	1	1	0
pird	1.1	6.85	242	5.5	20	1	1	0	1	1	0	1
babor	5	6.5	122	7.32	26.2	1.6	1	1	1	0	1	0
babod	1.4	6.95	233.7	6.19	18.6	0.5	1	0	0	0	1	1
barir	4	6.17	119	7.36	25.3	1.9	1	1	0	0	0	1
barid	3.4	7	197	7.1	19.6	1	0	1	0	0	0	1
jeur	1.6	8.7	137	9.7	28.9	0.9	1	0	1	0	1	0
jeud	2.4	6.72	165.2	5.4	18.9	1	1	0	1	0	1	0
lbir	2.1	6.22	176	7.8	26.9	0.6	1	1	0	0	0	1
lbid	6.5	6.6	165	6.9	19.7	0.3	1	0	1	0	0	1
rijacr	0.6	6.6	41	3.75	27	0.4	1	0	0.5	0	0	1
rijacd	7.5	6.3	84	6.65	19.6	1	1	0	1	0	0.5	0.5
iacr	1.9	7	142	6.65	28.9	1.9	1	1	0	0	1	0
iacd	2.8	6.32	79	7.5	19.05	0.5	1	1	1	0	1	0
promr	3.5	7.63	153	8.57	28.6	2.35	0	0.5	1	1	0	1
promd	1	7.7	136	8.38	21.2	1	1	0	1	0	0	1
dour	3.7	7.67	138.5	9.25	28	0.5	0	0	1	1	1	0
dourd	3.5	7.97	127.5	9.5	22.3	1.5	1	1	1	1	1	0
noavr	6	7.5	150	8.1	27.3	3.5	1	0	0	1	0	1
noavd	1	8.2	138	9.2	21.5	1	1	0	0	1	0	1
patr	3.5	7.08	47	3.06	26.8	2	1	0	0	0	0	1
patd	1.2	6.02	58.7	3.3	20	1.5	1	0	0	0	1	0
tirmr	4.5	8.1	95	9.02	30.2	2.5	1	0.5	0	0	0	1
tirmd	1.5	6.76	101.7	8.6	21.9	1.5	1	0	1	0	0	1
cotr	3.4	7.05	104.3	4.04	30	1.7	1	0.5	1	1	0	1
cotd	2.4	7.6	112.6	7.2	23.1	2	1	1	1	1	0	1
itar	1.6	7.11	131.5	3.74	28	1.6	1	0.5	0	0.5	0	1
itad	1.5	6.7	93	7.79	22.2	1.5	1	1	0.5	0.5	0	1

• tie – Tietê River; cap – Capivara River; pir – Piracicaba River; babo – Barra Bonita; bar – Bariri; jaú – Jaú River; ibi – Ibitigá; jaca – Jacaré-Guaçu River; iac – Jacanga River; prom – Promissão; dou – dos Dourados River; noav – Nova Avanhandava; pat – dos Patos River; tirm – Três Irmãos; cot – do Cotovelo River; ita – Itapura.

The Principal Components Analysis was performed with the data obtained. The aim was to simplify the information and identify the most important variables for habitat characterization in each sampling station. Only the first two components, which together explained 39.9% of the total variance, were considered (Table 6).

The first principal component accounted for 22.9% of the total variance. The main variables that contributed to form this axis were: conductivity, presence of gramineous, and muddy bottom, with positive values; and water transparency, macrophytes, and sandy bottom, with negative values. This component can be interpreted as the type of environment (lentic or lotic). The environments characterized as lentic were the dams and the transition river-reservoir, and the ones characterized as lotics were the stations located in the river phase (tributaries). The second principal component represented 16.9% of the variance. The more representative variables were the pH, dissolved oxygen, temperature, water transparency, and presence of trunks, all with positive values. This component was interpreted as the water quality of the sampling stations.

The analysis has also indicated inverse relationships between the variables conductivity, presence of gramineous and muddy bottom, and the variables transparency, presence of macrophytes and sandy bottom. In this way, the stations with higher conductivity had also more gramineous and muddy bottom. The opposite was as well verified.

Figure 3 shows the sampling stations arranged according to their scores. The stations characterized as lotics can be found on the right, and the ones

characterized as lentic on the left. The lotic stations presented muddy bottom, higher abundance of gramineous and floating macrophytes, and increased conductivity values; whilst the lentic stations presented high abundance of submerged macrophytes, sandy bottom, and high values for water transparency.

In the vertical line, it was verified that the stations placed in the lower part of the graphic had lower values for pH, transparency, oxygen, and temperature, and had none or low density of trunks. The sampling stations placed in the upper part of the graphic presented high values for pH, transparency, oxygen, and temperature, and presented high density of trunks, important microhabitats for aquatic organisms. There were, also, segregation between the best tributaries with better environmental conditions, as Dourado River (dou01), and the worst ones, as Jaú River (jau01) and Iacanga (iac01). A scheme of changes in habitat characteristics along Medium and Low Tietê River is given in Figure 4.

4. Discussion

The environmental characterization of this work indicated that seasonality influences water and sediment variables with clear differences between dry and rainy seasons. A number of recent studies performed in reservoirs have also pointed to seasonal differences in physical and chemical parameters in water and sediment (Pagioro et al., 2005; Vieira et al., 2005; Rodgher et al., 2005; Pinto-Coelho et al., 2006; Soares and Mozeto, 2006; Ribeiro-Filho et al., 2011).

Table 6. Results from the Principal Component Analysis: values obtained for the abiotic variables of each principal component with the two greatest variance percentages.

Abiotic variables	PC1	PC2
Depth	0.087	0.144
pH	0.065	0.751
Conductivity	0.440	0.146
Dissolved oxygen	0.068	0.457
Temperature	-0.247	0.553
Water transparency (Secchi)	-0.545	0.538
Macrophyte vegetation	-0.602	-0.387
Marginal vegetation	0.302	0.301
Gramineous	0.469	-0.072
Trunks	0.403	0.601
Muddy bottom	0.814	-0.159
Sandy bottom	-0.814	0.159
Percentage of variance by factor	22.8%	17.2%
Accumulated variance		39.9%

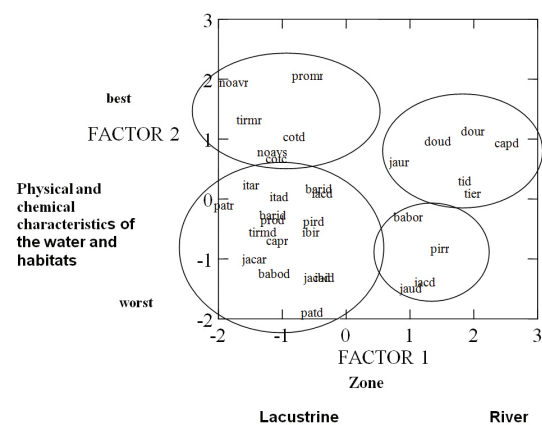


Figure 3. Diagram representing the types of environment and water quality for the sampling stations in Medium and Low Tietê River.

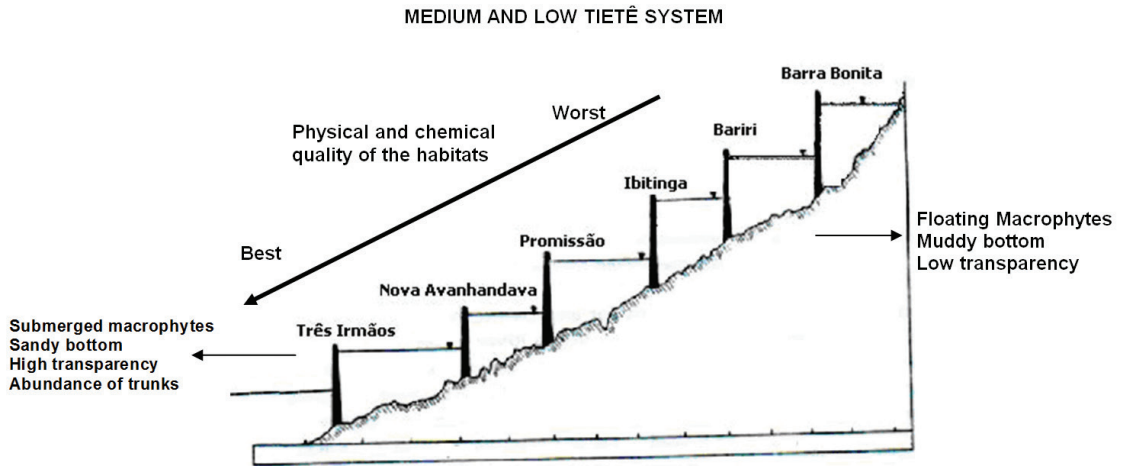


Figure 4. Gradient of habitats and water quality along the reservoirs cascade of the Medium and Low Tietê River stretches.

Water level fluctuation in reservoirs, due to operational procedures, has great influence on their physical, chemical and biological characteristics (Tundisi, 1996, 1999b). These characteristics are also regulated by seasonality. Thus, both factors (fluctuation and seasonality) are in great part responsible for the physical and chemical dynamics of water and sediment characteristics. According to Agostinho et al. (1999) total nitrogen, nitrate and turbidity did not display seasonal patterns.

In the reservoirs of Medium and Low Tietê River, high concentrations of suspended materials were verified in the rainy season. This was probably due to runoff. According to Pagioro et al. (2005), there is an increment of foreign material influx during the rainy season, which can be demonstrated by the variables of turbidity and total phosphorus. Considering another tropical reservoir, São Simão (MG/GO), clear seasonality in relation to transparency, turbidity, and total suspended solids was as well identified (Pinto-Coelho et al., 2006).

Moreover, during the rainy season, transparency diminished and the turbidity increased; this is in agreement with the findings of the present work. Cavenaghi et al. (2003) revealed higher turbidity in the rainy season in five Tietê River reservoirs. Vieira et al. (2005) have also verified differences between the rainy and dry seasons for total suspended solids and conductivity in the Ibitinga reservoir. These authors emphasized that the quality, kind and origin of suspended solids in the water were greatly influenced by the climate, landscape and geology of the drainage basin as well as by human actions. Ribeiro-Filho (2006, 2008) and Ribeiro-Filho et al. (2011) pointed to rain as an

important factor in relation to water transparency in the Itaipu Reservoir, with a negative correlation between both variables, and noted the importance of measuring these abiotic factors to estimate the productivity of aquatic systems.

High pluviosity contributes for the entry of organic and inorganic materials in the water bodies. The increase in the concentrations of nitrite, total phosphorus, total phosphate and inorganic phosphate, also in the rainy season, can be related to soil fertilization. This is carried out by farmers in crops, mostly sugar cane, placed on the edge of the reservoirs. In Ibitinga reservoir, agricultural activity was the hypothesis for the entry of limestone by means of surface drainage and lixiviating (Vieira et al., 2005). According to Fracácio et al. (2002), this situation is made worst by the lack of ciliar forest, which would retain a great part of the materials.

To Pagioro et al. (2005), water transparency increases in the direction of the dam due to sedimentation of solid particles. In the current work, a reduction in the values of suspended materials, nitrogen and phosphorus along the cascade of reservoirs was found. Barbosa et al. (1999) has also verified the same gradient in this study area: the values of total suspended organic and inorganic materials, turbidity, and phosphorus were reduced from Barra Bonita to Três Irmãos reservoir. Numerous studies have documented a reduction in the levels of phosphate, nitrogen, turbidity and solids along the Tietê river, finding higher values in Barra Bonita reservoir. Cavenaghi et al. (2003) reduction observed over the reservoirs for suspended solids, turbidity and conductivity. Roberto et al.

(2009) observed an increase in transparency of the water downstream from Porto Primavera Dam and the highest values of water transparency observed in recent years in Itaipu Reservoir, may be due to the cascading effect caused by the Porto Primavera Dam.

Agostinho et al. (1999) said that a major part of the phosphorous concentration is retained in upstream reservoirs, in the basin of the rivers Grande, Tietê and Paranapanema. Studies accomplished by Nogueira et al. (2005) (Paranapanema River) and Roberto et al. (2009) (Paraná River) showed that there is a phosphorous decreasing in cascade reservoirs. The nutrient retention in upstream reservoirs has long been considered the main process, which inhibits the acceleration of eutrophication in reservoirs lower in the Upper Paraná River (Tundisi et al., 1993).

Tundisi et al. (1991) found a reduction of nitrate, phosphate and conductivity values, and an increase of the photic zone along of the cascade of reservoirs. This fact can be one reason for differences among the biological communities, such as zooplankton, macrophytes, and fishes identified along the river. This is due to its influence upon physical biological and chemical aspects such as: increase in predator's visual ability; higher food offer; and differences in conductivity, turbidity, phosphorus and nitrogen.

A clear distribution of ecological groups in Rosana reservoir, with the dominance of submerged species next to the dam and free floating species next to the mouth of Paranapanema River, has previously been verified (Thomaz et al., 2005). Considering chains of reservoirs, submerged species of macrophytes tend to be more concentrated downstream and floating species upstream (Thomaz and Bini, 1999). The existence of this gradient, i.e. a difference in limnological conditions in the reservoirs downstream from Ibatinga, occurs due to the retention of part of the nutrients (mainly nitrogen and phosphorus). Therefore, the reservoirs operate as nutrient accumulators, holding up the eutrophication process downstream (Tundisi, 1993).

In relation to the sediment also decreased along the reservoir cascade of parameters. The same conclusion reached Cavenaghi et al. (2003) stating that higher values were obtained for Barra Bonita, Bariri and Ibatinga reservoirs and lower values for Promissão and Nova Avanhandava. Concerning metals, high concentrations potentially bioavailable (or weakly bonded) were found, mainly for cadmium, iron, copper and manganese. The higher

metal concentrations were detected in Tietê (before Barra Bonita) and Piracicaba rivers. These places are subjected to intense discharge of pollutants from different sources such as sewage, industrial effluents and pesticides. Moreover, a reduction in metal concentrations both in water and sediment along the cascade of reservoirs was found. The values decreased especially for iron, manganese and zinc, reflecting a reduction in the entry of these metals along the cascade. However, the same effect was not observed for cadmium and chrome, which increased along the cascade, indicating the presence of diffuse sources of pollution in the last reservoirs.

The Principal Component Analysis has shown, in a way, what happens along the cascade. It was possible to identify differences between the sampling stations along the river: upstream stations showed, generally, higher values of conductivity, hardness, nitrite, ammonia, phosphate, and chlorophyll, and lower values of dissolved oxygen and water transparency, which shows they are places that receive heavy load of effluents from diffuse and punctual pollution. Downstream are placed the stations with the lower values of conductivity, hardness, nitrite, ammonia, phosphate, and chlorophyll, and higher values of dissolved oxygen and water transparency, presenting better conditions than the ones placed upstream. This fact can be explained by the reduction in the entry of effluents, as well as the action of the reservoirs, which work as chemostats, keeping part of the pollutants.

In the present work, the variables related to habitat showed segregation between the sampling stations located in the reservoirs and tributaries concerning abiotic characteristics. The stations placed in the tributaries showed lower values of dissolved oxygen, pH and water transparency, and the opposite was found for the ones placed in the reservoirs. According to Pinto-Coelho et al. (2006), the tributaries present higher values of turbidity when compared to São Simão reservoir. This pattern can explain the low transparency of the tributaries as a consequence of the total solids transported by them to the reservoirs. Cavenaghi et al. (2003) obtained similar results on the same system, stressing that tributaries have higher values of turbidity and suspended solids and lower Secchi. The reservoirs located upstream from Promissão (Barra Bonita, Bariri and Ibatinga) present lower values of dissolved oxygen, pH, and transparency when compared to the ones downstream (Promissão, Nova Avanhandava and Três Irmãos). These results also suggest the existence of a gradient along the

reservoirs cascade: the reservoirs placed upstream have higher alterations in the limnological variables than the ones placed downstream. The first reservoirs receive the greater part of the pollutants, since they are located in more heavily populated and industrialized areas. As mentioned before, they decant part of the pollutants. Cavenaghi et al. (2003) said the pH is lower at the beginning of the cascade going to 8.0 at the end, which reinforces found and discussed by this study.

The analysis of the abiotic variables related to habitat indicated differences between the sampling stations. Such differences can be used as indicators of impacts, as well as explain the structure of fish community in these places. The tributaries and the Barra Bonita, Bariri and Ibitinga reservoirs have a physical habitat formed basically by emerging macrophytes, while Tietê, Piracicaba, and Dourado rivers and Promissão reservoir were markedly more influenced by the presence of trunks and rocks.

The sampling stations which presented macrophytes can be divided in two groups: the ones with predominant floating macrophytes, such as some of the tributaries and Barra Bonita, Bariri, and Ibitinga reservoirs; and the stations with predominant submerged macrophytes, as Nova Anhandava and Três Irmãos reservoirs. In the stations with lower concentrations of nutrients and higher water transparency, the submerged macrophytes (e.g. *Egeria sp.* – *Elodea*) predominated; whereas in the stations with greater concentration of nutrients and low water transparency more floating macrophytes occurred like *Eichhornia sp.* (water hyacinth), *Salvinia sp.* and *Pistia sp.* (water lettuce). Thomaz (2005) and Thomaz et al. (2005) had similar results, and also indicated that no submerged species was found in Barra Bonita whilst the ten more abundant species in Jupia reservoir were submerged. Besides, Cavenaghi et al. (2003) found that greater light penetration in the water column is related to the higher occurrence of aquatic plants emerged, such as those cited. These authors found this result in Promissão and Nova Avanhandava reservoirs. Thomaz and Bini (1999) presented a hypothetical tendency for aquatic macrophytes assembly structures. This shows that the growth of submerged macrophytes in oligotrophic or mesotrophic ecosystems is due to the high water transparency, lack of zooplanktivore fishes, or mechanisms directly related to submerged macrophytes, as reduction of water circulation.

Concerning data on habitats, the Principal Component Analysis also indicated the importance of the bottom type in the sampling stations, which

can be divided into two groups: the muddy bottom stations (tributaries) and the sandy bottom stations (Promissão, Nova Avanhandava, and Três Irmãos). The type of bottom can be associated with the higher or lower entrance of sediment and organic matter into the system, which will be retained in the first reservoirs by sedimentation. These materials come from the tributaries or Tietê and Piracicaba rivers, constituents of Barra Bonita reservoir, as well as from soil washing and by the lack of ciliar vegetation. The presence of marginal and floating plants is associated with the sedimentation process occurs in the margins and in areas of the tributaries entering the reservoir. Areas of intense sedimentation favors the occurrence of macrophytes, especially floating, as they reach the bottom (Cavenaghi et al., 2003). The bottom type is a determinant factor because it can influence the biological community abundance mostly in relation to diet.

Therefore, modifications were identified in the habitats general structure along the medium Tietê stretch: emerging macrophytes and muddy bottom predominate upstream; and submerging macrophytes and sandy bottom predominate downstream. The water characteristics should be taken into consideration, because they reflect the impacts upon the drainage basin of each reservoir.

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