Relationship between space distribution of the benthic macroinvertebrates community and trophic state in a Neotropical reservoir (Itupararanga, Brazil)

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Abstract: The purpose of this work was to verify the benthic macroinvertebrates community responses through environmental factors along a headwater tropical reservoir. Samplings were taken with a Van-Veen grab along the reservoir in littoral and profundal regions and in the headwater, next to the dam and the middle of the reservoir. Samples were taken during both wet and dry seasons. Dissolved oxygen concentrations, electric conductivity, temperature and pH near the sediment have been performed *in situ,* at every sampling station by using a multiprobe and Secchi disc. Total water phosphorus and chlorophyll *a* concentrations were analyzed to determine the trophic state index. Sediment's organic matter, total phosphorus, nitrogen concentrations and granulometric composition were measured. In order to verify which environmental variables would have more influence over the benthic macroinvertebrates community, a canonical correspondence analysis (CCA) was performed. The total number of recorded taxa was 28. Among them, the family Chironomidae (Diptera) was the richest group (19 taxa). It can be proposed that the benthic macroinvertebrates community may be influenced by environmental conditions such as nutrient and organic matter availability, as well as dissolved oxygen concentration. Macroinvertebrates are adequate bioindicators of water quality due to their sensibility to environmental changes mentioned before. *Chironomus* sp, *Limnodrilus hoffmeisteri* and *Branchiura sowerbyi* comprises a group that can be considered bio-indicators of eutrophic conditions. A second group can be considered as indicator of mesotrophic conditions. The presence of two or more members from that group which comprises Tanytarsini spp, *Fissimentum* sp, *Pelomus* sp and *Goeldichironomus* sp, like predominant taxa, may indicates mesotrophic conditions.
Keywords: *benthos, Chironomidae, Limnology, bioindicator, water quality.*

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Resumo: O objetivo deste trabalho foi verificar as respostas da comunidade de macroinvertebrados bentônicos a fatores ambientais ao longo de um reservatório tropical de cabeceira. As amostras foram coletadas com uma draga do tipo Van-Veen ao longo do reservatório nas regiões profunda e litorânea bem como na cabeceira, próximo à barragem e no meio do reservatório. Amostras foram coletadas tanto na estação seca quanto na estação chuvosa. Foram determinadas as concentrações de oxigênio dissolvido, condutividade elétrica, temperatura e pH próximos ao sedimento, *in situ*, em todas as estações amostrais com a utilização de um multisensor e disco de Secchi. Foram ainda determinadas as concentrações de fósforo e clorofila *a* da água para cálculo do índice de estado trófico. Com relação ao sedimento, foram determinados o teor de matéria orgânica, concentrações totais de fósforo e nitrogênio bem como a composição granulométrica. Para se verificar quais variáreis ambientais tiveram maior influência sobre a comunidade de macroinvertebrados bentônicos, uma análise de correspondência canônica (ACC) foi realizada. Foram registrados, ao todo, 28 táxons. Dentre estes, o grupo taxonômico com maior riqueza foi a família Chironomidae (Diptera) com 19 táxons. O estudo indicou que a comunidade de macroinvertebrados bentônicos respondeu às condições ambientais como disponibilidade de nutrientes e matéria orgânica, bem como às concentrações de oxigênio dissolvido. Assim sendo, os macroinvertebrados foram considerados bons indicadores da qualidade da água devido à sua sensibilidade frente às possíveis alterações ambientais supramencionadas. *Chironomus* sp, *Limnodrilus hoffmeisteri* e *Branchiura sowerbyi* formaram um grupo que pode ser considerado como bioindicador de condições eutróficas. Um segundo grupo pôde ser considerado como indicador de condições mesotróficas. A presença de dois ou mais membros deste grupo, que inclui os táxons Tanytarsini spp, *Fissimentum* sp, *Pelomus* sp e *Goeldichironomus* sp, como táxons dominantes, pode indicar tais condições.
Palavras-chave: *bentos, Chironomidae, Limnologia, bioindicadores, qualidade da água.*

Introduction

The water quality is a very important issue to the human life nowadays. Because of this, a wide variety of indicators have been employed to monitoring the water quality and the integrity of the aquatic ecosystems. There is not a unique indicator that may point to all the variations and impacts that a water body receives. Furthermore, variables like time, costs, skilled human resources, method's accuracy, extent of the answer, possibility of spatial and temporal identification and mainly what kind of disturbance is necessary to identify or to monitoring in the environment are factors that will determine which will be the more adequate indicator in each case.

The trophic state indices are usually the most used among the water quality indicators. The most traditional indices use phosphorus and chlorophyll concentrations in the water as its components (Carlson 1977, Lamparelli 2004). There are still those, among the biological ones, which show differentiated sensitivity to pollutants concentrations or other impacts such riparian forest suppression. The benthic macroinvertebrates are good examples of this as well as other organisms are as, for instance, the zooplankton (Brito et al. 2011) or fishes' communities (Terra & Araújo 2011). But, the first one, are better when the objective is to localize spatially the influence of the disturbance, due to their low mobility (Mandaville 2002), or is preferable when the goal is to measure the effects of impacts accumulation along the time as, for example, the nutrients or metals in the bottom (Arslan et al. 2010, Bettinetti et al. 2012).

The benthic macroinvertebrates are considered excellent bio-indicators because they can be found in most of the aquatic environments from temporary ponds to large rivers, lakes and deep reservoirs. Further, these animals present an elevated species richness. Since benthic macroinvertebrates, are mainly sedentary or has low mobility, the environmental disturbances can be easily localized. Furthermore, since they are in the sediment and have a long life cycle when compared to others bio-indicators like plankton organisms, the macroinvertebrates can indicate environmental conditions through the time providing long period recordings (Rosenberg 1998). Moreover, they are capable to react to both water column and sediment impacts which amplifies the response to environmental conditions spectrum, since the others indicators usually responses to one or another compartment (Carew et al. 2007).

Natural environmental conditions like sediment grain size, pH, temperature, currents, depth, oxygen as well as organisms interactions like predation, competition or food availability are relevant too and their influence will be according to the macroinvertebrates species populations multidimensional niches (Hutchinson 1965, Cowell & Rangel 2009) and so this influence must be considered in any environment that is being monitored by biological indicators.

Many works demonstrate that benthic macroinvertebrates community can also be altered in response to anthropogenic environmental changes, as land uses (Miserendino et al. 2011), riparian forest impacts and effluents loading (Baptista et al. 2007, Couceiro et al. 2007, Gamito & Furtado 2009, Sharma & Rawat 2009) and also by pollution by industrial effluents (Moreno & Callisto 2006). Several taxa from benthic macroinvertebrates community and a wide range of biological indexes and metrics have been widely employed as environmental indicators (Bode et al. 2002, Mandaville 2002, Fusari & Fonseca-Gessner 2006, Baptista et al. 2007, Baptista 2008, Angradi et al. 2009).

Our hypothesis is that the benthic macroinvertebrates communities' shows significative differences in abundance; distribution and composition when they are under diverging environmental conditions witch could be related to human impacts.

Moreover, there are few works that clearly demonstrates relationship between water and sediment environmental conditions and the benthic macroinvertebrates composition and distribution in the Neotropical region.

Hence, the aim of this work was to verify the responses of macroinvertebrates to environmental conditions and human impacts in a tropical reservoir. In that sense, the present research can provide tools for future studies and in monitoring or in restoring programs.

Materials and Methods

1. *Study area*

Itupararanga Reservoir is placed on Alto Sorocaba Basin (SP, Brazil), that corresponds to the main headwater of the left margin effluent of Tiete River (Figure 1).

The Itupararanga reservoir is located into an Environmental Preservation Area (EPA) created in 1998, with the main purpose to protect the water resources in the influenced area of the reservoir. More than 1/3 of the (EPA) is occupied by native vegetation fragments in a matrix of rural environment (Beu et al. 2011). The predominant vegetation can be classified as semideciduous forest (Almeida 2009). The EPA is located in the area of dense rainforests, but many of the original vegetation has been removed, and the majority of remaining plants are composed of secondary forest or pioneer formations (Almeida et al. 2011).

The region climate can be classified as Cwa according the Köppen classification. That classification is used to describe humid subtropical climates, with average temperatures in the warmest months of summer above 22 ° C. With respect to precipitation, there is characteristically a cold, dry season and a warm rainy season. The average annual rainfall in the Basin region of Alto Sorocaba is 1493 mm. The wettest month is January when the average rainfall is 248 mm. August is the driest one and average rainfall of its month is 43 mm (Salles et al. 2008).

The high Sorocaba basin is surrounded mainly by small cities. Those cities usually have the agriculture as their major economic resource (vegetable farming). Despite the forming rivers (Sorocabuçu, Sorocamirim and Una) of the reservoir drain peripheral regions of the Metropolitan Region of São Paulo, where a disordering marginal occupation is observed in almost every cities. The domestic effluents treatment is incipient and, as a consequence, sewage is discharged "in natura" in the forming rivers (Salles et al. 2008, Beu et al. 2011).

There are multiple uses for the water stored by that rivers damming. The main uses are energy supply for a large industry and the water supply for four cities (Votorantim, 2012) providing 85% of the treated water consumed by the city of Sorocaba that has approximately 600,000 habitants. Therefore, the water supply from this reservoir is given to about 850,000 people. In addition, this water body plays an important hydraulic regulatory role to Sorocaba River water, which crosses the metropolitan area of the city of Sorocaba.

The area of Itupararanga Reservoir is about 29.49 km^2 and its maximum capacity of water reaches 355×10^6 L of water. Its water is also used to some other activities like irrigation, recreation area and fishing (Beu et al. 2011).

2. *Collection and identification*

The samplings were taken in three distinct zones of the reservoir (Table 1) which were chosen in order to obtain samples longitudinally

Table 1. Geographic coordinates of the sample points.

Entrance	Profundal	23° 37' 3.8" S and 47° 13' 41.4" W
	Littoral	23° 37' 7.8" S and 47° 13' 39.8" W
Middle	Profundal	23° 37' 16.6" S and 47° 21' 30.5" W
	Littoral	23° 37' 16.6" S and 47° 21' 46" W
Dam	Profundal	23° 36' 44.6" S and 47° 23' 40.9" W
	Littoral	23° 36' 35.9" S and 47° 23' 16.9" W

along the reservoir. The first zone was near the headwater of the reservoir where there is higher turbulence, the edges are near each other and this is the closest region of the former rivers which receives many sewage discharges. The second was in the middle and can be considered as a transitional region and the last samples were taken close to the dam, far away from the impacted rivers and it is lentic as the middle region (Figure 2). The material was sampled twice: one profundal and another littoral in order to detect different degrees of terrestrial environment impact in the communities. All samplings were taken in December 2009 and in February 2010 (wet season) and in June and in August 2010 (dry season) during the day.

The measurements of water pH, dissolved oxygen content, temperature and electric conductance were performed *in situ*, near the sediment until 15m depth by using an YSI 556 model multiprobe. The water transparency was measured by a Secchi disk and the photic zone extension was calculated multiplying the disk lecture value by 2.27 (Padial & Tomaz 2008).

In order to calculate the trophic state index (TSI) of Carlson (1977) modified by Lamparelli (2004) (Table 2), the samplings taken in three reservoir zones in the central region near the surface to determine the total phosphorus (4500B (item 5) American... 2005) and chlorophyll *a* (Nush 1980).

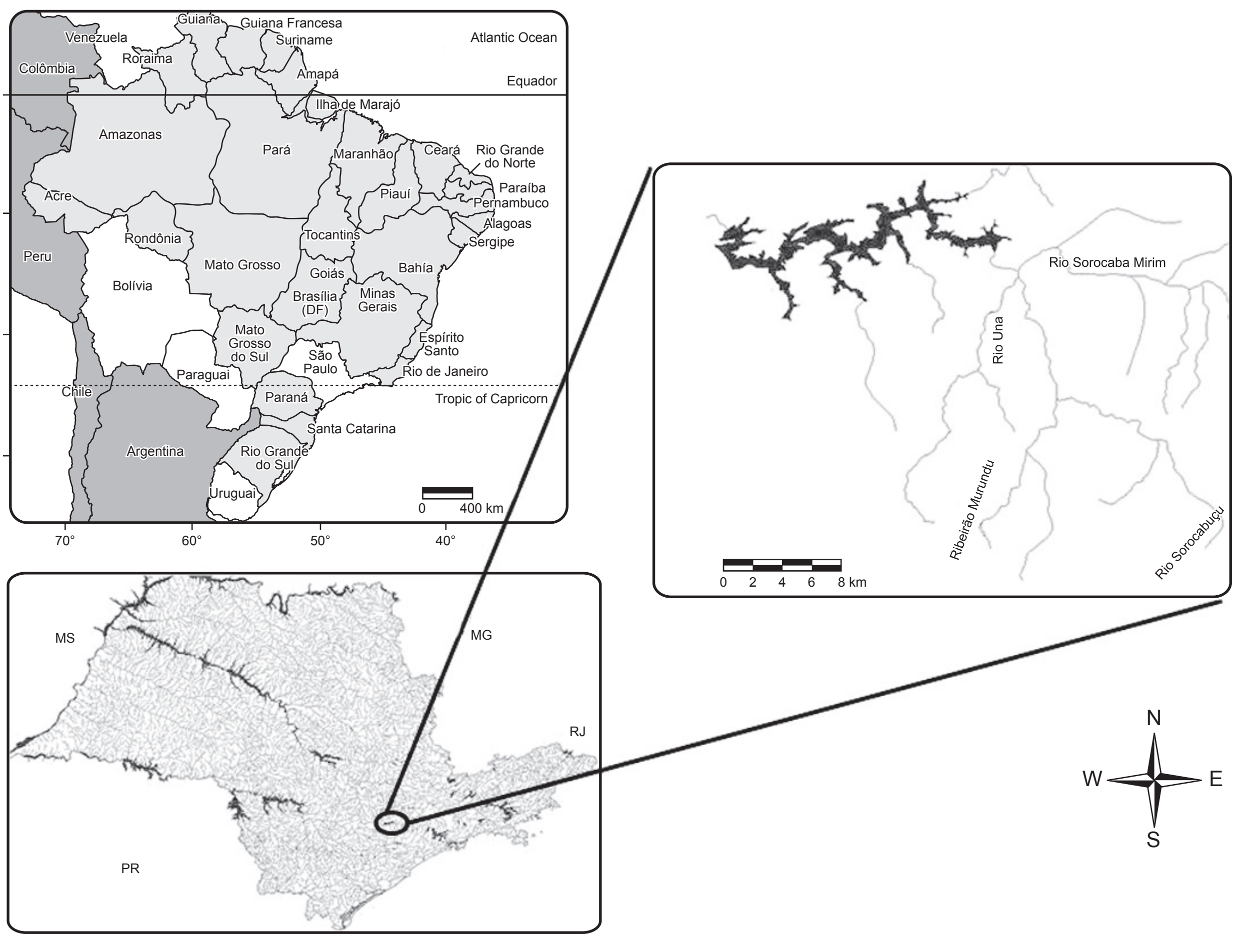

Figure 1. Map showing Itupararanga Reservoir location in the state of São Paulo. Modified from Environmental Information System – SinBiota – FAPESP. Available on http://sinbiota.cria.org.br/atlas/. Accessed January 14th, 2011.

Table 2. Water body classification according to the trophic state index of Carlson (1977) modified by Lamparelli (2004). TP = Total Phosphorus concentration; CL = Chlorophyll *a* concentration.

Classification	Range	Secchi – S (m)	TP (mg.m^{-3})	CL (mg.m^{-3})
Ultraoligotrophic	IET ≤ 47	S ≥ 2.4	P ≤ 8	CL ≤ 1.17
Oligotrophic	47 < IET ≤ 52	2.4 > S ≥ 1.7	8 < P ≤ 19	1.17 < CL ≤ 3.24
Mesotrophic	52 < IET ≤ 59	1.7 > S ≥ 1.1	19 < P ≤ 52	3.24 < CL ≤ 11.03
Eutrophic	59 < IET ≤ 63	1.1 > S ≥ 0.8	52 < P ≤ 120	11.03 < CL ≤ 30.55
Supereutrophic	63 < IET ≤ 67	0.8 > S ≥ 0.6	120 < P ≤ 233	30.55 < CL ≤ 69.05
Hypereutrophic	IET > 67	0.6 > S	233 < P	69.05 < CL

At each sample point, it was collected sediment samplings in order to determine the granulometric composition (Camargo et al. 2009), phosphorus (Andersen 1976) and nitrogen concentrations (4500 $N_{Org}C$; American... 2005), and organic matter proportion (Wetzel & Likens 2000).

The macroinvertebrates were collected with a Van Veen grab (0.045 m^2 sampling area); at each point three sampling units were taken, performing cumulative samples. The samplings were washed over a 212µm pore opening web, sorted and identified usually until genera or species level. The Chironomidae larvae were identified to genera level, because for species safe identification it is necessary to examine larva, pupa and imago and in the present work it was possible to take only larvae. The Tanytarsini tribe was not identified beyond the tribe level because the safe differentiation between *Caladomyia* and *Tanytarsus* requires the last instars larvae and most of them was first or second instars larvae. It was reached the species or genera level for Oligochaeta. The morphospecies concept was used to low representative taxa when the identification at genera level was not possible. The identification was performed in the laboratory by using stereomicroscope and optic microscope and it was also used the following identification keys and manuals: Brinkhurst (1971), Saether (1980), Brinkhurst & Gelder (2001), Hilsenhoff (2001), Pinho (2008), Epler (2011), Trivinho-Strixino (2011).

3. *Data analysis*

The total density per sampling was calculated by dividing the number of specimens sampled by the total sampled area at each point, resulting in the number of organisms per m^2.

Additionally, a matrix of Correspondence Canonical Analysis among the environmental variables and the density logarithm of the main taxa – considering only the taxa that had abundance higher than 10% in at least one sampling and frequency of, at least 30% – were performed and so, the variables that presented significant correlation with at least one of the analyzed taxa were selected to the Canonical Correlation Analysis (CCA).

The following variables had correlations with greater number of taxa: sediment phosphorus (six taxa) and nitrogen (five taxa); dissolved oxygen (five taxa) and organic matter in the sediment (four taxa). Depth, pH and sediment grain size also had some correlations but, in these cases with less than three taxa. The other environmental variables were omitted once that them had not shown any correlation with the main taxa.

The CCA significance was verified by a permutation test (1,000 permutations). After that, the groups and the main environmental variables that differentiate each one were identified. The softwares Multi Variate Statistical Package 3.12 (Kovach... 2001); Bioestat 5.0 (Ayres 2007) and Past 2.01 (Hammer et al. 2001) were employed to perform that analysis.

Two UPGMA (Unweighted pair-group average) cluster analysis, one for wet season and other for dry season, with binary data and a two-way ANOVA (similarity analysis) considering all samplings were performed in order to verify the spatial heterogeneity of the community based on species composition.

Results

According to the calculated TSI, Itupararanga Reservoir can be classified as meso – eutrophic water body. In general, the headwater of reservoir can be considered eutrophic, whereas the middle and dam are mesotrophic zones (Table 3). The mean water temperature during the wet season was 6.82° higher than during the dry season, the pH was usually neutral in both but higher during the dry season (Table 4). The electric conductivity can be considered intermediate and it was not recorded considerable variations between the seasons (Table 4). The oxygen concentrations were low and had great variation considering the spatial heterogeneity; the lowest values were recorded near the rivers entrance and in the profundal regions (Table 4).

The sediment nutrients concentrations were higher during the wet season. Average granulometric composition shows predominance of the finest grains in the sediment but, with great amplitude considering it was taken littoral and profundal samplings. The organic matter content remained similar in both seasons (Table 5).

A total of 2087 individuals were collected, belonging to 28 taxa (Tables 6 and 7). Densities varied from zero to 2963 $ind.m^{-2}$ for sampling. The mean density was 704 $ind.m^{-2}$ with a standard deviation of 756 including all samples. The recorded taxa number by period were 13, 12, 20 and 16 taxa, in December 2009, February 2010 (wet season), June and August 2010 (dry season), respectively. During the wet season 17 taxa were recorded, in contrast to the 25 taxa collected during the dry one.

The Tubificinae (Oligochaeta, Naididae) and Chironomidae (Diptera) were the most abundant taxonomic groups and was present in every sampling period and along all reservoir. The Tubificinae here is represented by four taxa: *Branchiura sowerbyi* Beddard; *Bothrioneurum* sp; *Limnodrilus hoffmeisteri* Brinkhurst; *Peloscolex* sp and one non identified taxa named here as Tubificinae sp1.When considering all reservoir, it was the more abundant taxa during the wet season and the Chironomidae, represented by 19 taxa, was the most abundant during the dry one.

The abundance was concentrated in the headwater during the wet season, while this distribution was more heterogenic during the

Figure 2. Schematic sampling points location in Itupararanga Reservoir, SP, Brazil showing the sampling stations adopted in this work (points) and the position of the dam and headwater in the reservoir.

Table 3. Calculated trophic state index of Carlson (1977) modified by Lamparelli (2004) (mean for each zone considered in this work) .TSI (TP) = TSI based on total Phosphorus concentration; TSI (CL) = TSI based on Chlorophyll *a* concentration. SD = standard deviation.

	Head	Middle	Dam
TSI (TP)	60.29	54.90	51.56
SD	2.36	3.85	0.98
TSI (CL)	59.29	58.72	59.42
SD	2.71	0.33	3.81
Secchi (m)	0.98	1.80	1.90
SD	0.21	0.41	0.61
TSI (mean)	61.04	57.26	55.72
SD	2.40	1.92	2.09
Category	Eutrophic	Mesotrophic	Mesotrophic

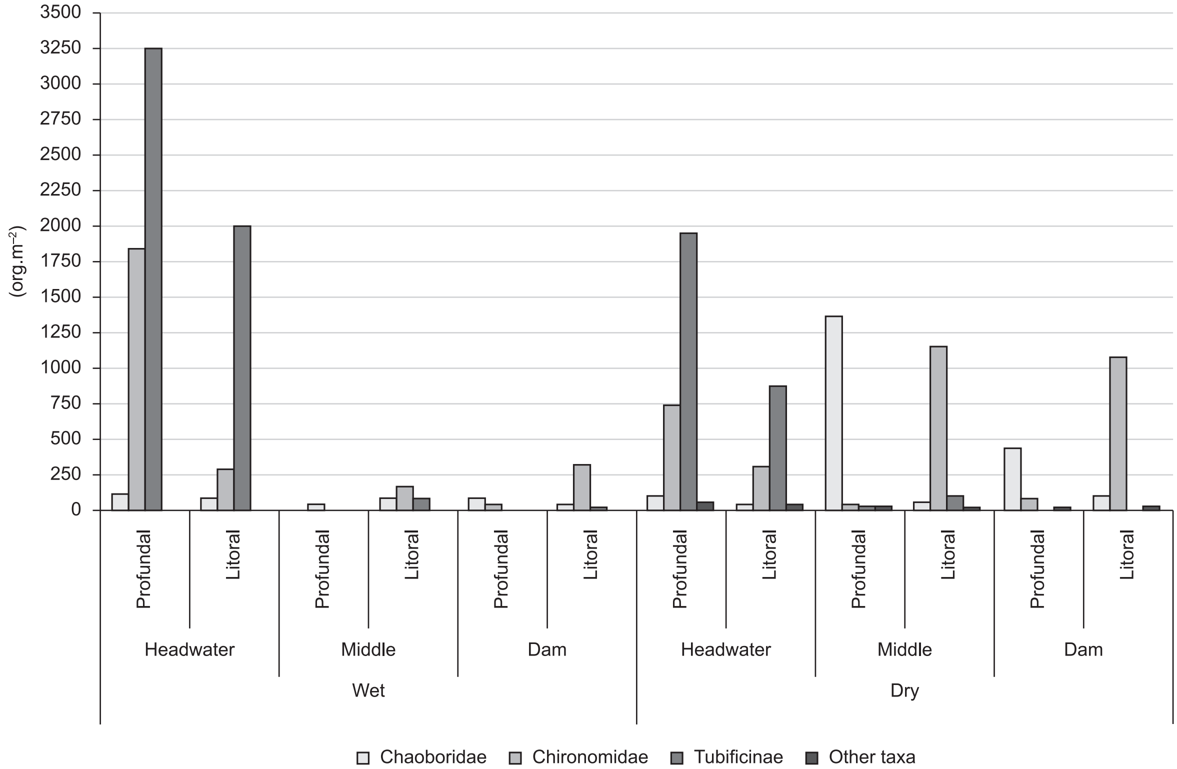

Figure 3. Densities (org.m^{-2}) for main taxonomic groups recorded by season in Itupararanga Reservoir, SP, Brazil.

Table 4. Mean, maximum, minimum, amplitude and standard deviation (SD) recorded for the abiotic variables of water of Itupararanga Reservoir, High Sorocaba Basin, SP, Brazil in wet season (December 2009, February, 2010) and in dry season (June 2010 and August 2010). Temp. = temperature; Cond. = electric conductance; DO = dissolved oxygen; Depth; Zeu = photic zone extension.

		Temp. (°C)	pH	Cond. (µS.cm^{-1})	DO (mg.L^{-1})	Depth (m)	Zeu (m)
Wet	Max	26.83	7.83	65.00	7.75	20.50	6.2
	Min	21.28	2.48	40.00	0.20	2.25	1.4
	Mean	23.46	5.84	51.33	4.10	9.23	3.6
	Amplitude	5.55	5.35	25.00	7.55	18.25	4.9
	SD	1.53	1.98	8.33	3.13	6.60	1.5
Dry	Max	17.80	7.39	97.00	9.05	20.00	4.1
	Min	14.45	5.15	40.00	3.07	2.50	1.8
	Mean	16.54	6.28	54.33	5.62	8.68	3.0
	Amplitude	3.35	2.24	57.00	5.98	17.50	2.3
	SD	0.99	0.70	17.42	1.71	6.04	0.8

Table 5. Mean, maximum, minimum, amplitude and standard deviation (SD) recorded for the abiotic variables of sediment of Itupararanga Reservoir, High Sorocaba Basin, SP, Brazil in wet season (December 2009, February, 2010) and in dry season (June 2010 and August 2010). Sand, Sil+Cl = fine sediment fractions (silt and Clay); P = total phosphorus, N = total nitrogen; OM = organic matter content.

		Sand (%)	Sil + Cl (%)	P (mg.g^{-1})	N (mg.g^{-1})	OM (%)
Wet	Max	85.10	99.70	8.48	2.67	18.00
	Min	0.30	12.47	0.18	0.00	2.00
	Mean	31.99	57.66	4.76	1.22	9.83
	Amplitude	84.80	87.23	8.30	2.67	16.00
	SD	30.23	35.89	2.59	0.99	5.98
Dry	Max	88.16	99.90	7.73	2.98	22.00
	Min	0.10	0.04	0.38	0.00	2.00
	Mean	26.51	52.26	3.57	0.87	9.92
	Amplitude	88.06	99.86	7.35	2.98	20.00
	SD	33.71	43.79	2.38	1.10	7.35

Table 6. Densities (org.m^{-2}) for each recorded taxa by sample point during the wet season in Itupararanga Reservoir, SP, Brazil. P = Profundal and L = Littoral. The Tanytarsini spp taxa represent *Caladomyia* sp and *Tanytarsus* sp larvae.

	Dec./09						Feb./10					
	Head		Middle		Dam		Head		Middle		Dam	
	P	L	P	L	P	L	P	L	P	L	P	L
Ablabesmyia sp	--	--	--	--	--	--	--	--	--	--	--	--
Asheum	--	--	7	--	--	--	--	--	--	--	--	--
Chironomus sp	630	7	--	7	--	--	1133	237	--	--	15	7
Coelotanypus sp	--	--	--	--	--	7	--	--	--	--	--	--
Corynoneura sp	--	--	--	--	--	--	--	--	--	--	--	--
Cricotopus sp	--	--	--	--	--	--	--	--	--	--	--	--
Fissimentum sp	--	--	--	7	--	30	--	--	--	--	--	119
Goeldichironomus sp	--	--	15	37	--	--	--	--	--	74	--	15
Nilothauma sp	--	--	--	--	--	--	--	--	--	--	--	--
Paralauterborniella sp	--	--	--	--	--	7	--	--	--	--	--	--
Pelomus sp	--	--	--	--	--	--	--	--	--	--	--	67
Pentaneurini sp1	--	--	--	--	--	--	--	--	--	7	--	--
Polypedilum sp	--	--	--	--	--	--	--	3--	--	--	--	--
Procladius sp	--	--	15	--	--	15	--	--	--	--	--	--
Stempellina sp	--	--	--	--	--	--	--	--	--	--	--	--
Saetheria sp.	--	--	--	--	7	--	--	7	--	--	--	--
Tanypus sp	--	--	--	--	--	--	67	--	--	--	--	--
Tanytarsini spp	--	--	--	15	--	52	--	--	--	--	7	--
Chaoborus sp	--	52	--	--	--	7	100	15	--	81	81	15
Ceratopogonidae sp1	--	--	--	--	--	--	--	--	--	--	--	--
Trichoptera sp1	--	--	--	--	--	--	--	--	--	--	--	--
B. sowerbyi	148	--	--	--	--	--	33	44	--	--	--	--
L. hoffmeisteri	2141	1296	--	37	--	15	933	644	--	37	--	--
Tubificinae sp1	--	--	--	--	--	--	--	--	--	--	--	--
Peloscolex sp	7	--	--	--	--	--	--	--	--	--	--	--
Bothrioneurum sp	--	--	--	--	--	--	--	--	--	--	--	--
Hirudinea sp1	--	--	--	--	--	--	--	--	--	--	--	--
Total abundance	2926	1355	37	103	7	133	2266	977	0	199	103	223
Total richness	4	3	3	5	1	7	5	6	0	3	3	5

dry one. The family Chaoboridae (Diptera) was also an abundant taxonomic group (Figure 3; Tables 6 and 7).

Ablabesmyia sp, *Corynoneura* sp, *Cricotopus* sp and *Nilothauma* sp. were found only in dry period on the other hand, 13 taxa were found only in wet period (Tables 6 and 7).

The CCA results indicate that water variables as dissolved oxygen and pH, as well as sediment variables as total nitrogen and phosphorus, organic matter content and granulometric composition may explain the high variation ($p < 0.0001$ and canonical $R = 0.9968$) in the distribution, abundance and structure of the benthic macroinvertebrates community (Table 8). Additionally, through CCA values, benthic macroinvertebrates could be separated in three groups compromising different taxa which are influenced by specific environmental conditions (Figure 4). Group I includes taxa which present tolerance to high sediment nutrient concentrations, as well as to lower dissolved oxygen water availability. Group II displays a higher heterogeneity and seems to be less tolerant to water hypoxia and more tolerant to low phosphorus, nitrogen and organic matter concentrations in the sediment. Group III correspond to the genera *Chaoborus* sp and *Procladius* sp. Only the first taxa showed significant correlation with the variables that were considered. *Chaoborus* sp was related to higher organic matter content in the sediment and to a higher proportion of fine granulometric fractions.

The spatial heterogeneity analyzes indicate that this occurs both transversely (littoral and profundal) and longitudinally (Figure 5). The *p* value for the ANOSIM was 0.049 for heterogeneity in the transverse direction and 0.009 for heterogeneity longitudinal sense.

Discussion

Some researches (Pamplin et al. 2006, Carew et al. 2007, Jorcin & Nogueira 2008, Buss & Vitorino 2010, Cortelezzi et al. 2011, Miserendino et al. 2011) have improved the knowledge of the bio-indicator potential of the benthic macroinvertebrates.

Carew et al. (2007) analyzed the response of Chironomidae taxa indicators to pollution, especially in the sediment. These authors identified taxa *Riethia stictoptera* Kieffer, *Tanytarsus inextentus* Skuse, *Coelopynia,* and *Chironomus februarius* Martin as potential low anthrophic pressure environment bio-indicators and *Chironomus duplex* Walter species as a high sediment pollution condition indicator.

In this study, Tubificinae and Chironomidae were the predominant taxa during both seasons reaching 66 and 29%, respectively, of the total organisms sampled during the wet season, and 35 and 40% during the dry one. Other studies suggest that these two groups, as well as most of macrobenthic components in lentic environments (including reservoirs) have some predominance variation due to both

Table 7. Densities (org.m^{-2}) for each recorded taxa by sample point during the dry season in Itupararanga Reservoir, SP, Brazil. P = Profundal and L = Littoral. The Tanytarsini spp taxa represent *Caladomyia* sp and *Tanytarsus* sp larvae.

	Jun./10						**Aug./10**					
	Head		**Middle**		**Dam**		**Head**		**Middle**		**Dam**	
	P	**L**	**P**	**L**	**P**	**L**	**P**	**L**	**P**	**L**	**P**	**L**
Ablabesmyia sp	--	--	--	--	--	--	--	--	--	--	--	7
Asheum	--	--	--	--	9	--	--	--	--	--	--	--
Chironomus sp	220	53	--	--	--	--	496	59	--	--	--	--
Coelotanypus sp	--	--	--	--	--	--	--	--	--	--	--	--
Corynoneura sp	--	--	--	--	9	--	--	--	--	--	--	--
Cricotopus sp	--	--	--	--	18	--	--	--	--	--	--	--
Fissimentum sp	--	--	--	53	--	35	--	--	--	22	--	7
Goeldichironomus sp	--	--	--	9	--	44	--	--	--	22	--	7
Nilothauma sp	--	--	--	--	--	9	--	--	--	--	--	--
Paralauterborniella sp	--	--	--	--	--	--	--	--	--	--	--	--
Pelomus sp	--	35	--	9	9	--	7	44	--	59	--	--
Pentaneurini sp1	--	--	--	--	--	--	7	--	--	--	--	--
Polypedilum sp	--	9	--	--	--	--	--	81	--	178	--	--
Procladius sp	--	--	--	9	9	--	--	22	30	119	22	--
Stempellina sp	--	--	--	--	--	--	--	--	--	--	--	15
Saetheria sp.	--	--	--	9	--	9	7	7	--	7	--	44
Tanypus sp	--	--	--	--	--	--	--	--	--	--	--	--
Tanytarsini spp	--	--	--	370	--	414	--	--	--	252	--	452
Chaoborus sp	26	--	802	9	168	97	67	37	563	37	259	--
Ceratopogonidae sp1	--	--	--	--	--	--	7	--	--	--	--	--
Trichoptera sp1	--	--	--	--	9	--	--	--	--	--	--	--
B. sowerbyi	26	--	18	--	--	9	--	7	--	--	--	--
L. hoffmeisteri	1517	115	18	--	--	--	407	726	--	104	--	--
Tubificinae sp1	35	--	--	--	--	--	--	--	--	--	--	--
Peloscolex sp	--	9	--	--	--	--	--	--	--	--	--	--
Bothrioneurum sp	--	18	--	--	--	--	--	--	--	--	--	--
Hirudinea sp1	--	18	9	--	--	--	7	--	--	7	--	--
Total abundance	1824	257	847	494	231	643	1005	983	593	807	281	532
Total richness	5	7	4	7	7	7	8	6	2	9	2	6

Table 8. Correlation matrix generated from canonical correspondence analysis. Only the variables with marked with an asterisk (*) had significative correlation with the correspondent taxon ($p < 0.05$). DO = dissolved oxygen; Ns = total sediment nitrogen; Ps = total sediment phosphorus; OM = organic matter sediment content; Cl+Sil = Clay + silt granulometric fractions. *Branchiura sowerbyi* = Bra; *Chironomus* spp – Chi; *Limnodrilus hoffmeisteri* = Lim; *Saetheria* sp = SAE; *Pelomus* sp = Pel; spp = Tant; *Fissimentum* sp = Fis; *Goeldichironomus* sp = Goe; *Chaoborus* sp = Cha; *Procladius* sp = Pro.

	pH	**DO**	**Depth**	**Ns**	**Ps**	**OM**	**Sand**	**Cl + Sil**
Cha	–0.35	–0.06	0.28	0.18	0.39	0.64*	–0.32	0.63*
Pro	0.07	0.39	0.18	–0.04	–0.10	0.09	–0.10	0.11
Bra	–0.06	–0.42*	–0.07	0.55*	0.48*	0.12	0.26	0.05
Chi	–0.13	–0.54*	–0.27	0.30	0.28	–0.08	0.40	–0.21
Lim	–0.00	–0.46*	–0.42	0.23	0.33	–0.07	0.45*	–0.16
Fis	0.49*	0.59*	–0.53*	–0.52*	–0.62*	–0.51*	0.16	–0.50*
Goe	0.19	0.62*	–0.39	–0.43*	–0.44*	–0.45*	0.15	–0.17
Pel	0.09	0.33	–0.38	–0.48*	–0.57*	–0.42	0.19	–0.47*
Sae	0.10	0.25	–0.31	–0.42	–0.46*	–0.48*	0.41	–0.51
Tant	0.27	0.41	–0.34	–0.43*	–0.48*	–0.38	0.11	–0.38

environmental conditions and historical factors (Callisto et al. 2005, Pamplin et al. 2006, Lucca et al. 2010).

The richness observed in Itupararanga Reservoir, which has eutrophic and mesotrophic conditions, suffering human impacts especially in the headwater, can be considered intermediate when compared with that described to other lentic environments in Neotropical Regions. Lucca et al. (2010) analyzed the benthic macroinvertebrates communities in an oligotrophic lake and recorded 23 taxa. Fusari & Fonseca-Gessner (2006) reported 20 and 34 taxa in an eutrophic and an oligotrophic reservoir, respectively. In the

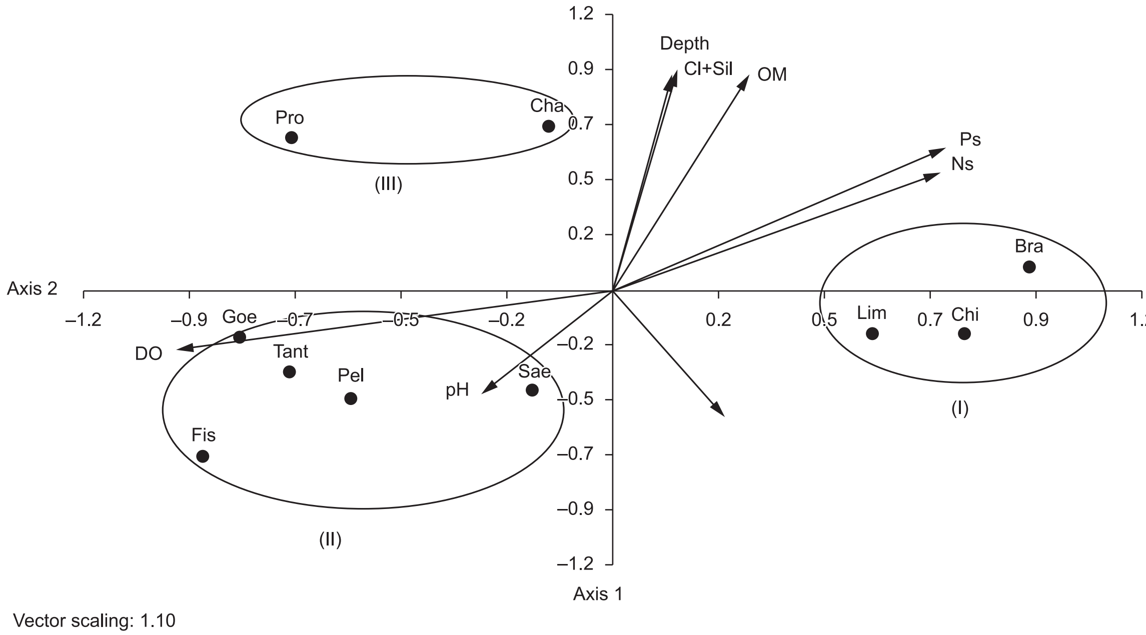

Figure 4. Correspondence Canonical Analysis considering the abundance and distribution of the benthic macroinvertebrates community and environmental variables from Itupararanga Reservoir, SP, Brazil, highlighting the relationship between the main taxa (*Branchiura sowerbyi* = Bra; *Chironomus* spp – Chi; *Limnodrilus hoffmeisteri* = Lim; *Saetheria* sp = SAE; *Pelomus* sp = Pel; spp = Tant; *Fissimentum* sp = Fis; *Goeldichironomus* sp = Goe; *Chaoborus* sp = Cha; *Procladius* sp = Pro) and the environmental variables (Ps = total sediment phosphorus; Ns = total sediment nitrogen; OM = sediment organic matter content; Cl+Si = fine sediment fractions (Clay + silt); Depth; Sand = sand sediment fractions; pH = water; DO = water dissolved oxygen concentrations. (I) = Group I, (II) = Group II and (III) = Group III.

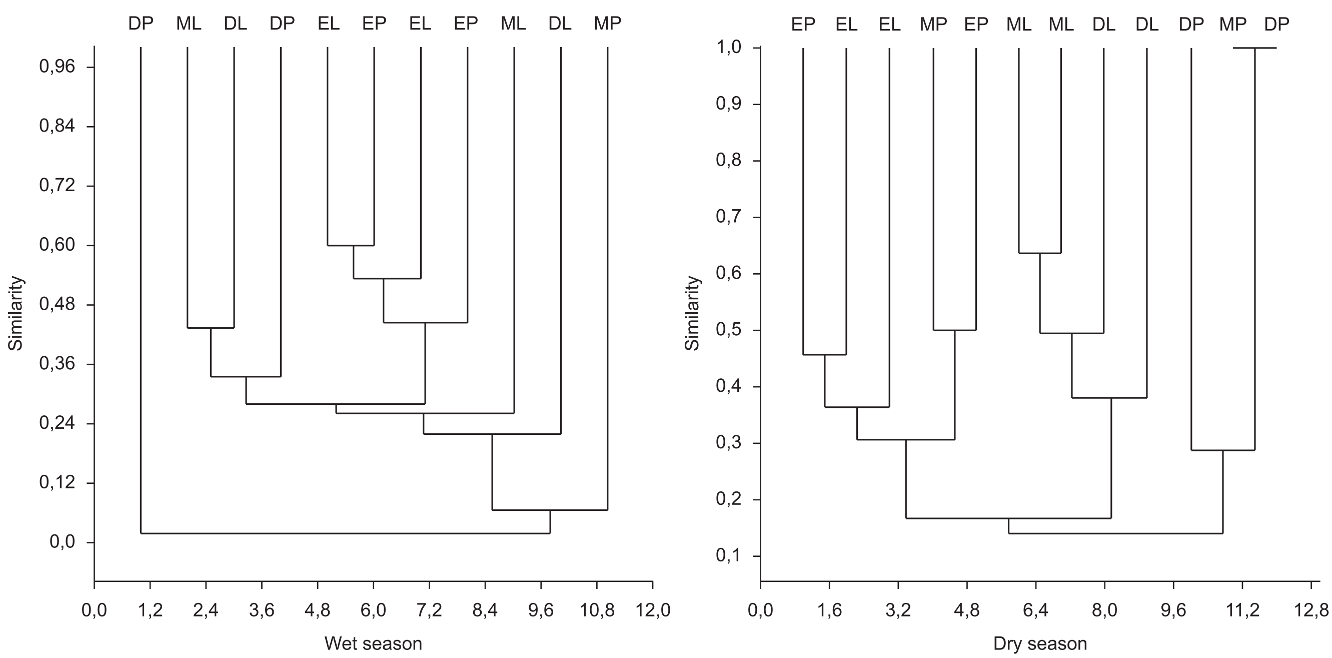

Figure 5. UPGMA Analysis for binary data (taxonomic composition) showing spatial heterogeneity. Letter E indicates samplings collected near the reservoir's entrance, letter M is for that collected in the middle of the reservoir and letter D represents the samplings near the dam. The letters P and L indicates respectively the profundal and littoral regions.

present study, we have recorded 19 Chironomidae among the 27 taxa identified. The major importance of that taxonomic group for the total richness may be understood as a standard for benthic macroinvertebrates when lentic environments or reservoirs are analyzed (Callisto et al. 2005, Fusari & Fonseca-Guessner 2006, Pamplin et al. 2006, Shostell & Williams 2007, Jorcin & Nogueira 2008, Lucca et al. 2010).

The benthic macroinvertebrates respond quickly and locally to the disturbances by changing the structure and the composition of the community, as well as altering the taxa distribution (Mandaville 2002). The abiotic analyses provided evidences that Itupararanga Reservoir is a heterogenic water body and that many relevant differences could be noticed. Because of this heterogeneity the reservoir can be analyzed as having at least three distinct areas as evidenced by ANOSIM and UPGMA analyses when considered together. The riverine (entrance) zone is evidenced as the most differing one in a longitudinal sense while in a transversal sense the heterogeneity is more pronounced in the middle of the reservoir and near the dam where the margins are farther each other.

In general, we could identify an eutrophicated zone that comprises the headwater profundal and littoral regions; a mesotrophic littoral one which comprises the middle and the near the dam areas in the littoral regions and a mesotrophic profundal zone with the profundal regions of the middle and near the dam areas.

In the present study, a significant correlation among environmental factors with the abundance and the distribution of the main taxa that formed the benthic macroinvertebrates communities of Itupararanga Reservoir was observed. These taxa can be divided into three groups according to their relationship with environmental factors. Group I has been formed by *L. hoffmeisteri*, *Chironomus* sp and *B. sowerbyi*; this group acts as an eutrophication bioindicator. *L. hoffmeisteri* is considered the Oligochaeta species that is the most tolerant to pollution according to Verdonschot (1989). High densities of them followed by the decrease of the diversity of other taxa may be seen as an organic enrichment indicator to continental water bodies (Dornfeld et al. 2006, Martins et al. 2008). In the same way, some studies pointed out the *Chironomus* genera as one of the most resistant benthic organisms to organic pollution (Adriansens et al. 2004, Simião-Ferreira et al. 2009). *B. sowerbyi* was reported in impacted environments (Suriani et al. 2007).

The relevant abundance of these organisms can be associated to high trophic level environmental conditions such as sediment nutrients accumulation and low dissolved oxygen concentrations in the water. This group has been recorded as predominant only in the headwater zone where it was present in every sampling. This zone was the only classified as eutrophic by TSI. Therefore, this data suggests that the group I is characteristic of impacted areas, then reflecting eutrophication of water and sediment.

Group II is a more diverse one. It comprises the Chironomidae *Fissimentum* sp, *Goeldichironomus* sp, *Pelomus* sp, *Saetheria* sp and *Tanytarsini* spp. The distribution of these animals is related to water conditions as well to the sediment. There is some preference for high oxygenated waters and low nutrient and organic matter content in the sediment. These organisms are also related to less clay and silt proportion in the sediment. Altogether, these conditions suggest that these organisms are indicators of oligo or mesotrophic environments, since nutrients or organic matter accumulation is not observed in littoral areas of the samples taken in the middle or near the dam zones. Group II organisms were recorded in mesotrophic littoraneous areas with, at least, two members in the same sample dominating the community. In general *Tanytarsini* spp. or *Goeldichironomus* sp. In contrast, this group are almost absent in the eutrophicated headwater – even in the deep or littoral region – and, when some group II member was recorded, it appears isolated from the other taxa that characterizes its group and never as predominant taxon. Moreover, the results point out that there are some more equitative taxa distributions, corroborating that metrics like richness or indexes like dominance and diversity may be considered as environmental quality indicators.

Finally, Group III is composed by *Chaoborus* sp and *Procladius* sp. While *Chaoborus* sp presented a significant correlation with sediment variables (higher organic matter content and finer sediments), it was not observed to *Procladius* sp. Considering that both taxa belong to the trophic guild of the predators, it can be suggested that prey availability, as well as the presence of the predators, regulate the distribution of these organisms that have migratory ability and a varied diet. *Chaoborus* sp eats mainly planktonic organisms and usually migrates daily in the water column (Castilho-Noll & Arcifa 2007) while *Procladius* sp eats as benthic organisms as rotifers, ostracods and cladocerans (Vodopich & Cowell 1984). Despite of the fact that these taxa were mainly recorded in mesotrophic areas, the groups have only two members and one of them was recorded in the eutrophicated headwater area too. So, it is more plausible that the main environmental factors that influenced their predominance were the depth and oxygen availability. So, this group can be considered more like a profundal specialists group that an indicator of other environmental conditions.

Pamplin et al. (2006), studying the benthic macroinvertebrates of Tropical Reservoir, Americana, SP, Brazil, observed that there was a strong correlation among fine sediment fractions (silt and clay) and high organic matter contents with *Chironomus decorus* Johansen and *Limnodrilus hoffmeisteri*. These results are different of that obtained in Itupararanga Reservoir. The Itupararanga Reservoir's data show also L. hoffmeisteri from group I associated with sediment granulometric composition but, here, the association is with sand fractions while the results from Pamplin et al. (2006) shown association of *Chironomus* sp and *L. hoffmeisteri* with the finest sediment fractions.

Some hypotheses can be considered when comparing these results: firstly, in Itupararanga Reservoir, sediment nitrogen and phosphorus concentrations were included in the analysis whereas in Americana Reservoir they were not included. So, it is plausible that when the sediment's nutrients are considered, the relative importance of the sediment granulometry loses some importance.

Another fact that must be mentioned is that in the present study, the *L. hoffmeisteri* group is composed in association with *Chironomus* sp and *B. sowerbyi* but in the Pamplin et al. (2006) research, the *L. hoffmeisteri* is associated with more three different taxa and *B. sowerbyi* is in another group, indicating that the communities structures are someway different.

On the other hand, *Chironomus* sp and *L. hoffmeisteri* were correlated in both reservoirs with high organic matter content and low oxygen conditions corroborating the hypothesis that these organisms are good indicators for these conditions, which usually are influenced by human activities.

Moreover, these authors demonstrated that other important factors that can influence macroinvertebrate composition and distribution are the depth and sand proportion in the sediments. The high density from the group I species is generally correlated to the water eutrophication (Martins et al. 2008, Simião-Ferreira et al. 2009).

Shostell & Williams (2007) analyzed the benthic macroinvertebrates community patterns in relation to the physical and chemical parameters in a shallow eutrophic reservoir (Lake Conway, AR, USA). In this study, spatial and seasonal variations in biomass, diversity and organisms' abundance were observed and the explanation was the proximity to the land environment corroborating with the Itupararanga Reservoir's data when considering the transversal heterogeneity separating communities from littoral and profundal regions as evidenced by CCA analysis.

In sum, this research demonstrated the influence of the environmental factors over the benthic macroinvertebrates community of Itupararanga Reservoir. Some of these factors (e.g., nutrient concentrations, organic matter content or the oxygen concentrations) may be greatly influenced by human activities. Therefore, anthropogenic actions can alter indirectly the composition and distribution of those organisms. The results provide strong evidences that groups I and II can be used as biological indicators. The record of the entire group is a more feasible indicator than analyzing only one member studied separately. However, it must be also emphasized the influence of some other non-anthropogenic impacts on benthic macroinvertebrates distributions, such as depth and mineral grains size of the sediment are. As a consequence, environmental peculiarities must be considered to perform a study with monitoring.

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