Composition and distribution of benthic macroinvertebrates in Americana Reservoir (SP, Brazil).

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ABSTRACT: Composition and distribution of benthic macroinvertebrates at Americana Reservoir (SP, Brazil). The structure of benthic community at the Americana Reservoir was studied in two distinct periods of one year comprised between 1997-1998. Field sampling was conducted in dry and rainy periods in 15 and 13 sites, respectively. Nutrient (nitrate, nitrite, ammonium, total phosphorus and orthophosphate) analyses revealed that the reservoir is in advanced eutrophication process. Bottom fauna of the reservoir was composed by 19 invertebrate taxa, belonging to the following faunistic groups: Gastropoda, Oligochaeta, Hirudinea, Diptera (Chaoboridae, Chironomidae, Ceratopogonidae and Stratiomyidae) and Ephemeroptera. Chironomidae was the richest group, being represented by 6 taxa. The majority of species showed low densities, being that the oligochaetes formed the most important components of benthos densities, and Limnodrilus hoffmeisteri was the dominant taxa, representing almost 50% of total benthos. Comparing both periods, major densities were registered in dry season for most taxa. Cluster analysis revealed a longitudinal gradient with total densities decreasing from riverine portion towards the dam. The actual structure of benthic community at the Americana Reservoir is probably a consequence of the advanced state of environmental degradation. In addition, the existence of exotic species, represented by the gastropod Melanoides tuberculata and the leech Barbronia weberi, can also be contributing to the biodiversity losses in this community.
Key-words: benthic macroinvertebrates, eutrophication, biodiversity, exotic species.

RESUMO: Composição e distribuição de macroinvertebrados bentônicos na represa de Americana (SP, Brasil). A estrutura da comunidade bentônica da represa de Americana foi estudada em dois períodos distintos. As coletas foram realizadas nos períodos seco e chuvoso, respectivamente, em 15 e 13 estações de amostragem. A análise da concentração de nutrientes (nitrato, nitrito, amônia, fósforo total e ortofosfato) revelou que a represa encontra-se em avançado processo de eutrofização. A fauna de macroinvertebrados bentônicos da represa foi composta por 19 taxons, pertencentes aos seguintes grupos: Gastropoda, Oligochaeta, Hirudinea, Diptera (Chaoboridae, Chironomidae, Ceratopogonidae e Stratiomyidae) e Ephemeroptera. Chironomidae foi o grupo com maior riqueza, estando representado por seis táxons. A maioria dos táxons ocorreu em baixas densidades. Os oligoquetos formaram o maior componente da fauna bentônica e Limnodrilus hoffmeisteri foi o táxon dominante, representando cerca de 50% do bentos total. Comparando ambos os períodos amostrados, as maiores densidades foram registradas no período seco para a maioria dos táxons. A análise de cluster revelou um gradiente longitudinal, com a densidade total da fauna bentônica diminuindo da região lótica em direção à barragem. A estrutura atual da comunidade bentônica na represa de Americana é provavelmente uma conseqüência do adiantado estado de degradação ambiental. A ocorrência de espécies exóticas representadas nesse reservatório pelo gastrópode Melanoides tuberculata e pelo hirudíneo Barbronia weberi, pode estar também contribuindo para a perda de diversidade nesta comunidade.
Palavras-chave: macroinvertebrados bentônicos, eutrofização, biodiversidade, espécies exóticas.

Introduction

Freshwater ecosystems are inhabited by great variety of organisms. Zoobenthos is characterized as a group of invertebrates, which spend at least part of their life cycle at the bottom substrate in the water bodies. In many reservoirs, benthic community is represented by three main groups: chironomid larvae, oligochaetes and mollusks. Kajak (1988) and Covich et al. (1999) have pointed out the importance of these organisms in the cycling of nutrients and in the energy transfer trough aquatic food-chains. Additionally, they have been described as good indicators of water quality (Saether 1979; Lang & Reymond 1996).

According to Schindler & Scheuerell (2002), lentic ecosystems (including reservoirs) are complex and composed by distinct habitats. As a consequence the composition, abundance and distribution of benthic organisms can be determined by a set of biotic and abiotic factors, e. g. competition, predation, food availability, substrate type, oxygen concentration and others (Prat et al., 1992; Jónasson, 1996).

In Brazil, a country reservoir-oriented (Tundisi et al., 1993), much limnological information (both abiotic and biotic aspects) has been published, especially in the last two decades. On the other hand, studies concerning benthic community are still scarce in reservoirs (Valenti & Froehlich, 1988; Moretto et al., 2003), probably by difficulties in sampling procedures and taxonomic identification, to be solved in the future, with equipment development and publication of appropriate taxonomical manuals.

In spite of this situation, some knowledge regarding the bottom fauna of Americana Reservoir has been provided (Strixino, 1971; Rocha, 1972; Shimizu, 1978; 1981; Valenti & Froehlich, 1986; 1988), although much of these results were unpublished.

The present study is part of an extensive environmental and limnological research in Americana Reservoir carried out in the last decade. We analyzed the composition, abundance and distribution of macroinvertebrate benthic assemblages in Americana Reservoir in two distinct periods.

Study Area

Americana Reservoir (22°44´S and 47°19'W; 530 m a.s.l.) is located in the central-east region of São Paulo State (Fig. 1).

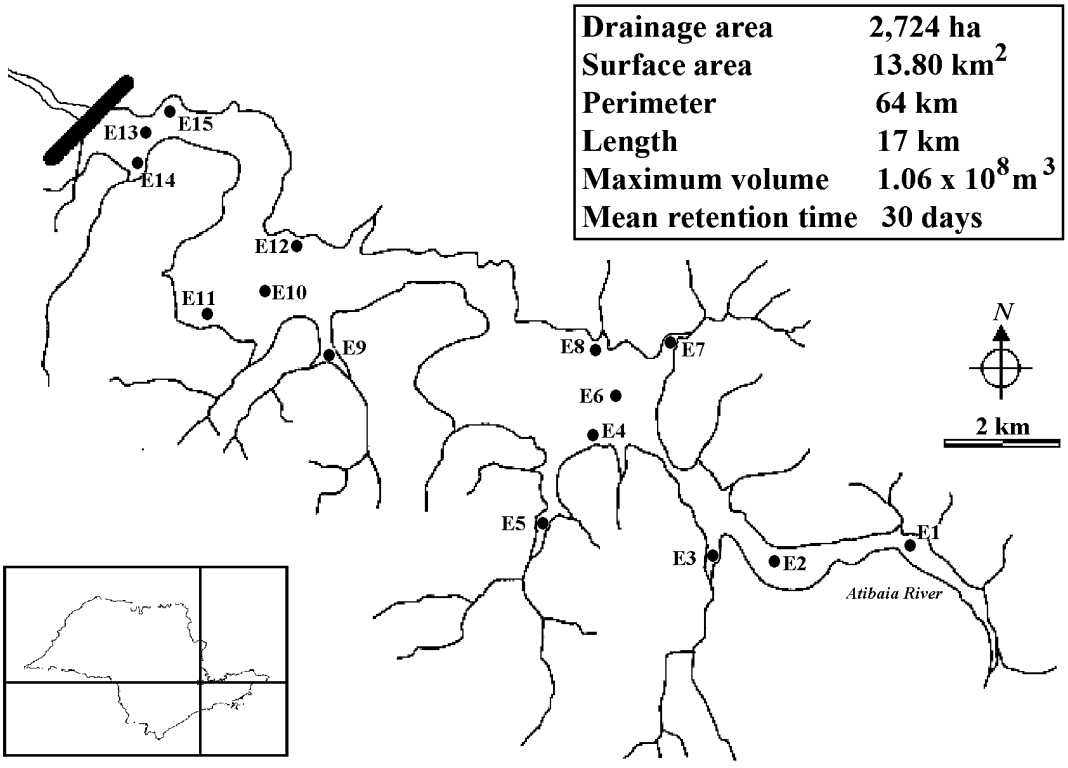

Figure 1: Map of Americana Reservoir (SP, Brazil), showing of the sampling stations and some morphometric features

Covering an area of 13.8 km^2 and with a maximum volume of 106 x 10^6 m^3, the reservoir is placed in the Atibaia River. It was constructed at the end of the forties in the last century for multiple purposes, including hydroelectricity generation, recreation, fishery, irrigation and water supply.

Placed in a region with high population density and heavy industrial development, both accelerating natural resources degradation, particularly that of the aquatic ecosystems. The surroundings of Americana Reservoir are occupied by sugarcane plantations on the right margin and by urban settlements in the opposite side, and natural vegetation is restricted to some fragments. Regarding the climate, there are two distinct periods: dry winter (April – September) and rainy summer (October – March) with an average monthly precipitation 51.5 ± 13.1 mm and 163.3 ± 43.4 mm, respectively (Coelho, 1993). More detailed information regarding the region and the reservoir can be found in Espíndola et al. (2004).

Material and methods

Three sediment samples were collected using an Ekman-Birge grab (15 x 15 cm) in 15 sampling stations in two periods: July/1997 and January/1998. In the last period, the large and dense macrophyte stands prevented sampling at stations E14 and E15. The material was washed through a sieve with 210 mm-mesh aperture and preserved on 10% formalin.

In the laboratory, the organisms were sorted, identified and counted. Oligochaetes and chironomids larvae were slide-mounted with Hoyer solution to evidence some morphological characteristics of taxonomic interest. Organisms were identified down to genus or species level, was based in guides and keys of Brinkhurst & Marchese (1991) for Oligochaeta, Trivinho-Strixino & Strixino (1995) and Epler (1995) for Diptera-Chironomidae, and Merritt & Cummins (1996) for other insect groups. Density and relative abundance were calculated.

Additional sediment samples were collected to determine organic matter content (loss ignition after 6 hours at 550ºC) and granulometry (adapted from Suguio, 1973). Water temperature, pH, conductivity and dissolved oxygen concentration were also measured at each site using a multisensor apparatus HORIBA U-10 model. Nutrient concentrations (nitrate, nitrite, ammonium, total phosphorus and orthophosphate) from surface water were quantified as described in Koroleff (1976), Golterman et al. (1978) and Mackereth et al. (1978). Water transparency was determined by Secchi disk disappearance.

The existence of significant differences among water or sediment variables between the sampling periods was tested by Mann-Whitney test (Zar, 1998). Canonical Correspondence Analysis (CCA) was performed in order to reveal probable relationships of macroinvertebrates assemblages and environmental variables (depth, sand, clay+silt, and organic matter content in the sediment). Significance of canonicals axis and variables were verified by Mantel test (Ter Braak, 1986; Legendre & Legendre, 1998). Only taxa with relative abundance greater than 1%, in at least one sampling period, were used in the CCA analysis (10 of 19 taxa). Biological data were previously transformed by squared root, whereas data from abiotic variables were not transformed.

Results

Limnological features of Americana Reservoir are summarized in Tab. I. Only Secchi disk readings and the concentrations of nitrate, ammonium and total phosphate were significantly different (Mann-Whitney test) among the periods. The values of pH indicated a slightly acid condition in the dry period; in the rainy period, both acid and alkaline conditions were found, with pH values ranged from 5.99 to 9.30. The minimum conductivity registered in the reservoir was 82 $mS.cm^{-1}$ and the maximum value was 240 $mS.cm^{-1}$, revealing an environment rich in nutrients. In general, the highest nutrient concentrations were registered in the dry season (Tab. I). Nitrate concentrations varied from 1217 $mg.L^{-1}$ to 1945 $mg.L^{-1}$ in the dry period, and from 564 $mg.L^{-1}$ to 1409 $mg.L^{-1}$, in the rainy season. Nitrite concentrations ranged from 44 $mg.L^{-1}$ to 275 $mg.L^{-1}$ and 32 $mg.L^{-1}$ to 179 $mg.L^{-1}$ in the dry and rainy periods, respectively. For ammonium, the concentration varied from 164 $mg.L^{-1}$ to 1520 $mg.L^{-1}$ in dry period and from 35 $mg.L^{-1}$ to 744 $mg.L^{-1}$ in the rainy. This pattern was also followed by the total phosphorus and orthophosphate, although mean concentrations were still high in the rainy period.

Table I: Limnological features of water and sediment from Americana Reservoir (SP, Brazil). Significant differences (Mann-Whitney test) between both periods are indicated by asterisk (* p< 0.05; ** p< 0.001).

	Dry Period				Rainy Period				Mann-Whitney test	
	n	Mean ± S.E.	Min	Max	n	Mean ± S.E.	Min	Max	U value	p
Water variables										
Secchi Disk (m)	12	1.66±0.14	0.80	2.20	13	0.33±0.04	0.20	0.70	0.0	< 0.0001**
pH	16	6.89±0.04	6.34	7.00	13	7.59±0.26	6.99	9.30	42.5	0.0120*
Conductivity ($\mu S.cm^{-1}$)	16	146.17±16.72	80.00	240.00	13	124.23±13.00	66.00	189.00	73.0	0.2737
Ammonium ($\mu g.L^{-1}$)	16	640.27±106.96	163.63	1619.90	13	330.11±68.07	36.44	743.87	48.0	0.0222*
Nitrate ($\mu g.L^{-1}$)	16	1482.94±61.61	1217.40	1944.80	13	1160.87±63.11	663.74	1409.10	11.0	< 0.0001**
Nitrite ($\mu g.L^{-1}$)	16	120.86±19.41	43.62	274.76	13	97.46±12.30	32.28	178.71	86.0	0.6360
Total Phosphorus ($\mu g.L^{-1}$)	16	96.66±16.46	36.00	244.22	13	103.74±4.16	86.43	140.67	66.0	0.0620
Total Phosphate ($\mu g.L^{-1}$)	16	49.24±9.18	24.22	146.87	13	76.61±4.44	46.84	113.62	29.0	0.0010**
Dissolved Oxygen ($mg.L^{-1}$)	16	0.96±0.42	0.00	6.00	13	3.16±0.90	0.00	9.20	62.5	0.1109
Sediment variables										
Organic matter (%)	16	14.69±1.22	6.66	23.76	13	11.86±1.36	1.40	18.69	66.0	0.1423
Sand (%)	16	66.83±3.78	36.19	81.30	13	64.38±6.76	27.96	96.16	82.0	0.4966
Clay + Silt (%)	16	44.16±3.78	18.70	66.61	13	46.62±6.76	3.86	72.04	82.0	0.4966

A complex thermal structure with several micro-stratifications was observed in Americana Reservoir, especially in the rainy period (Fig. 2). Water temperature ranged from 17.80°C to 20.70°C in dry period; while in the rainy period, it varied from 25.60°C to 32.10°C. In both sampling periods, anoxia was observed in the reservoir, especially in the dry period (Fig. 2). The highest concentrations of dissolved oxygen were 5.37 $mg.L^{-1}$ and 14.94 $mg.L^{-1}$ in dry and rainy periods, respectively.

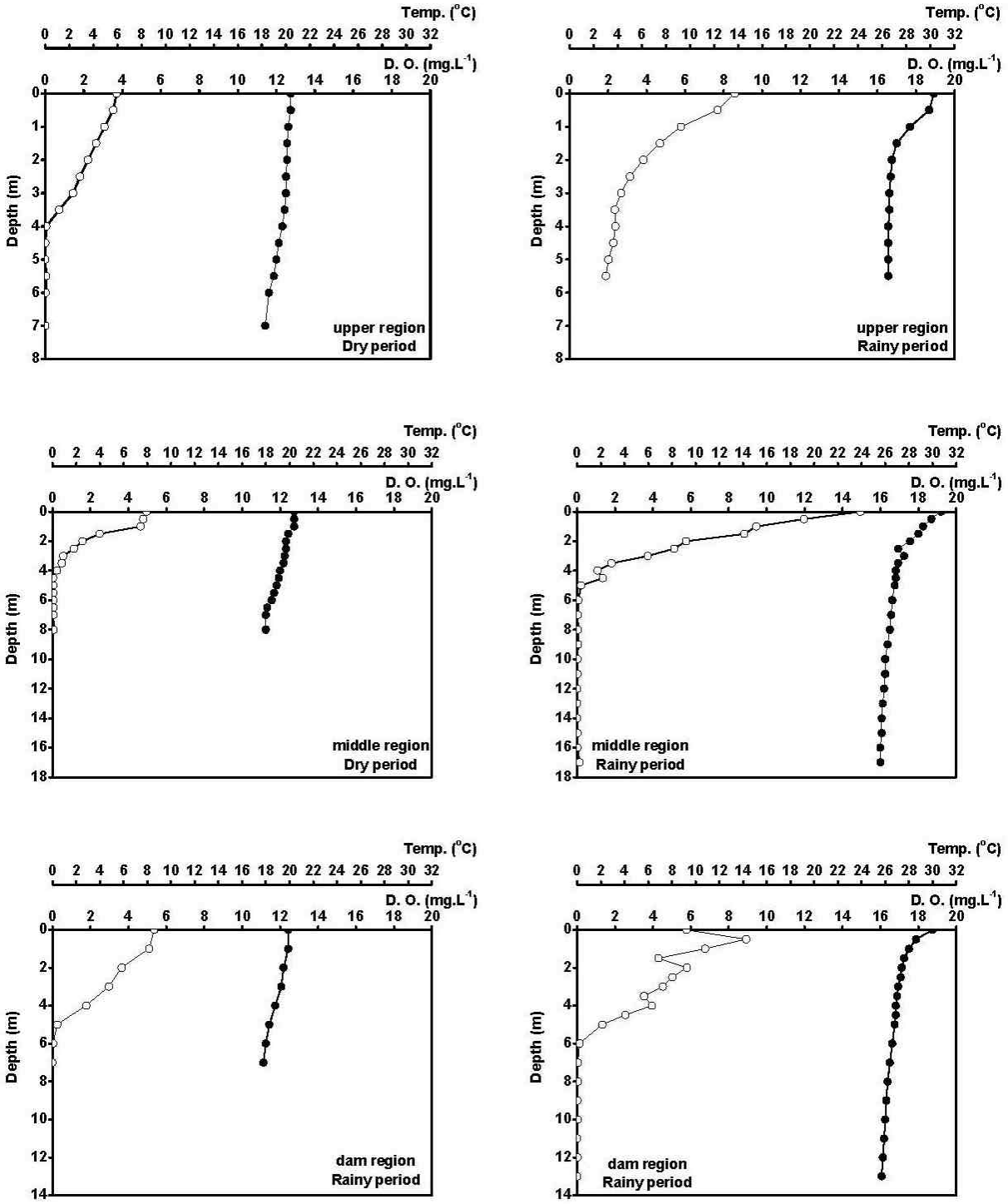

Figure 2: Profiles of temperature (full circle) and dissolved oxygen concentration (empty circle) in Americana Reservoir (SP, Brazil). The profiles correspond to sampling stations E6 (upper region), E10 (middle region) and E13 (dam region) in both periods.

Considering all samples taken, a total of 5119 benthic invertebrates were counted for the sediment of Americana Reservoir. The benthic fauna consisted of 19 invertebrate taxa, as shown in Tab. II. Diptera was the group with the highest species richness being represented by 9 taxa, 6 belonging to the Chironomidae family. Both Hirudinea and Oligochaeta were represented by 4 taxa each, while only one taxon was collected for Ephemeroptera (Insecta) and Gastropoda (Mollusca), in this reservoir. The mean densities in the dry and rainy seasons were 4256 ± 6300 ind.m^{-2} and 2475 ± 2714 ind.m^{-2}, respectively (Tab. II). Tubificid Limnodrilus hoffmeisteri, was the main species, corresponding to 49.9 % of total benthos, while Branchiura sowerbyi and Dero (Aulophorus) sp. represented about of 10.5 % each. Other taxa found in

Table II: Composition, mean density and abundance of benthos community in Americana Reservoir (SP, Brazil), sampled in July 1997 (dry season) and January 1998 (rainy season).

	mean density ± s.d. (ind.m^{-2})		Relative Abundance (%) in this study
	Dry Season	Rainy Season	
GASTROPODA			
Melanoides tuberculata	11 ± 50	138 ± 232	1.7
HIRUDINEA			
Helobdella stagnalis	386 ± 1038	51 ± 135	7.5
Helobdella brasiliensis	16 ± 50	2 ± 6	0.3
Gloiobdella obscura	314 ± 623	3 ± 12	5.7
Barbronia weberi	164 ± 623	-	3.2
OLIGOCHAETA			
Branchiura sowerbyi	616 ± 1038	209 ± 56	10.5
Limnodrilus hoffmeisteri	1899 ± 5791	1212 ± 2787	49.9
Opystocysta funiculus	86 ± 278	65 ± 120	1.9
Dero (Allophorus) sp.	333 ± 278	35 ± 674	10.5
INSECTA - EPHEMEROPTERA			
Campsurus sp	246 ± 517	26 ± 74	3.5
INSECTA - DIPTERA			
Stratiomyidae			
Labostigmina cf. fenestrata	-	2 ± 6	‹ 0.1
Chaoboridae			
Chaoborus sp	34 ± 80	8 ± 14	0.5
Ceratopogonidae			
Culicoides sp	9 ± 39	21 ± 74	0.4
Chironomidae			
Ablabesmya annulata group	28 ± 69	10 ± 73	0.5
Aedokritus sp	68 ± 264	-	0.9
Chironomus decorus group	28 ± 39	178 ± 499	2.4
Goeldichironomus pictus	13 ± 22	9 ± 25	0.3
Polypedilum sp	3 ± 11	-	‹ 0.1
Tanypus stellatus	1 ± 6	7 ± 25	0.1
Mean density	**4256 ± 6300**	**2475 ± 2714**	
Richness	**18**	**16**	

Americana reservoir had relative abundances lower than 3.5 %, except leeches Helobdella stagnalis and Gloiobdella obscura, with 7.5 % and 5.7 % of the total, respectively.

Oligochaeta was the main group, representing 69.12 % and 81.63 % in the dry and rainy periods, respectively (Fig. 3). Hirudinea occurred mainly in the dry period, being the second group with 22.72 % of total benthos. Gastropod Melanoides tuberculata was practically absent in the dry period (0.22 %), but increasing to 5.59 % in the rainy period. In this period, a high percentage of Chironomidae was also

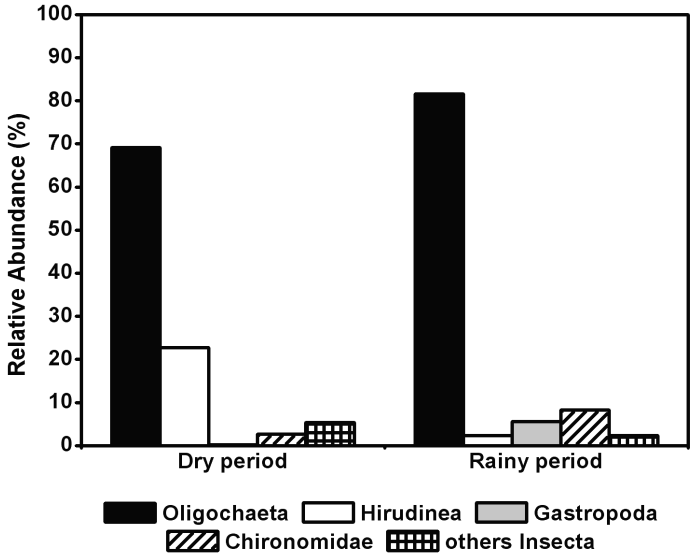

Figure 3: Relative abundance of the main benthic macroinvertebrate groups in Americana reservoir (SP, Brazil), sampled in July 1997 (dry period) and January 1998 (rainy period).

registered, representing 8.22 % of the total, against 2.64 % in the other period.

In both sampling periods, high total densities were recorded in the riverine region, decreasing towards the dam (Fig. 4). This pattern was mainly influenced by the densities of Oligochaeta and Hirudinea. In the dry period, mean density declined from 17733 ind.m^{-2} in the riverine zone (E1 and E2) to 1481 ind.m^{-2} near the dam; while in the rainy period, mean density at the riverine region was 7844 ind.m^{-2} and 15 ind.m^{-2} near

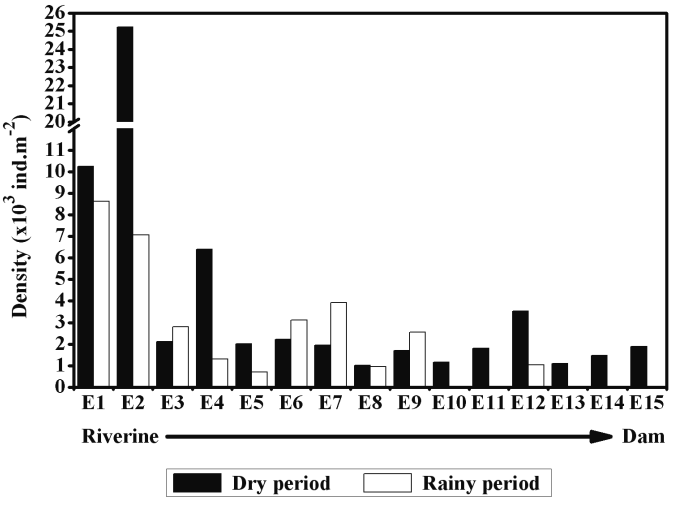

Figure 4: Longitudinal distribution of total benthic macroinvertebrates density in Americana Reservoir (SP, Brazil),; sampled in July 1997 (dry period) and January 1998 (rainy period).

the dam. In the dry period, Gastropoda densities were almost similar in all sampling stations (mean density of 11 ind.m^{-2}); while in the rainy period, major densities (up to 133 ind.m^{-2}) were registered in sampling stations located close to the riverine zone. Regarding the Chironomidae, densities accounted were below 250 ind.m^{-2}, except in sites E12 (dry period) and E3 (rainy period) where the densities were 2266 ind.m^{-2} and 1422 ind.m^{-2}, respectively.

Canonical Correspondence Analysis (CCA) the two first axes accounted for 24.5% of the variance on the species composition, of which 86% was explained by the environmental variables (Table III). Sand (F_{cal}=4.11; p=0.005), depth (F_{cal}= 1.90; p=0.07) and organic matter (F_{cal}=1.84; p=0.075) were significant variables. In canonical analysis, three major groups were pointed out as shown in Fig. 5). The first association (Group I) was determined negatively by axis 1, while association 2 (Group II) and 3 (Group III) were defined positively and negatively by axis 2, respectively. Group I gathered riverine stations (E1 and E2) and had a major correlation with fine sediment fraction

Table III: Results from Canonical Correspondence Analysis of species composition and environmental variables (sand, clay+silt, organic matter, and depth). Accumulated percentages of explained variations of axes 1 and 2 and environmental variables.

	Axes 1	**Axes 2**
Accumulated percentage of species	16.5	24.5
Accumulated percentage of variables	57.8	86.1
F calculated – Mantel's test	4.152	2.092
Mantel's test p	0.020	0.025

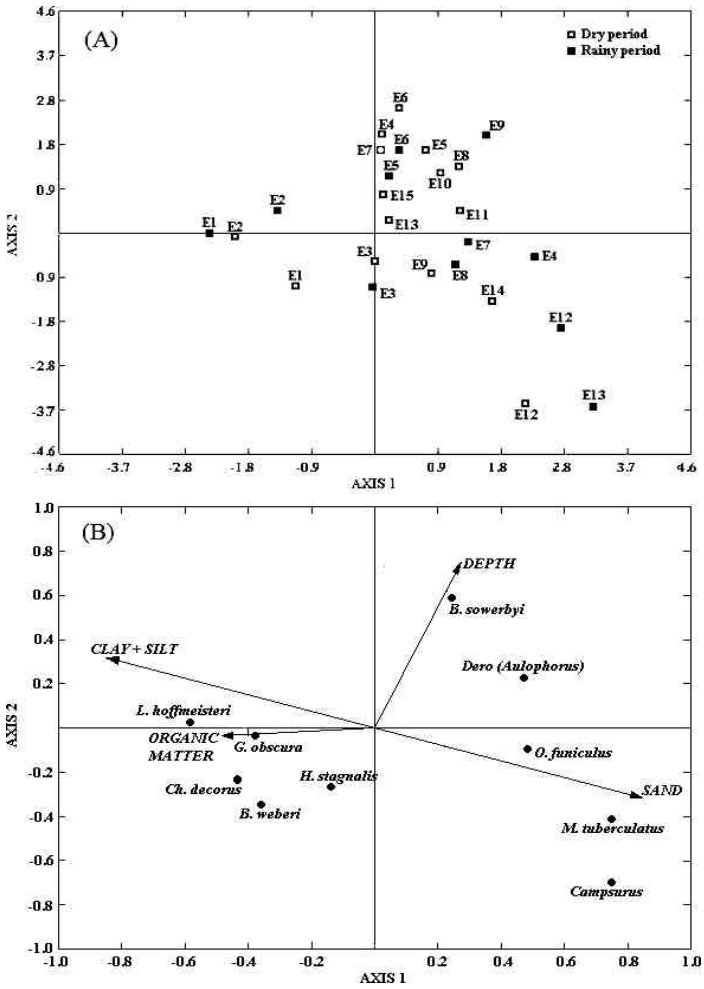

Figure 5: Ordination diagram of benthic macroinvertebrates in Americana Reservoir (SP, Brazil) based on a canonical correspondence analysis (a) sampling station and time score representation; and (b) species score representation. Arrows represents the environmental variables.

(clay+silt) and organic matter. This group was related to the abundance of Limnodrilus hoffmeisteri, Chironomus decorus, Barbronia weberi and Gloiobdella obscura. At the Group II, depth was the major variable and the Branchiura sowerbyi was the main species. The mayfly Campsurus characterized the Group III, that was formed by E12 (both periods) and E13 (only in the rainy period), and was associated with the sand sediment fraction.

Discussion

According to Ravera (1996), the structure of aquatic communities depends on a setting of environmental variables and on the species adaptation to specific environments. Water analysis of Americana Reservoir reveals that the reservoir is an eutrophic ecosystem in accelerated process of degradation. This fact can probably be pointed out as the major cause of significant modifications in the structure and dynamics of the benthic fauna of that reservoir, as found in Kuibyshev Reservoir, Russia (Zinchenko, 1992) and in Pawnee Reservoir, United States (Popp & Hoagland, 1995).

Reservoirs have generally a reduced diversity of benthic fauna as compared with natural lakes (Lindergaard, 1995). In Americana Reservoir, the community structure of benthic macroinvertebrates was very simple, had few faunistic groups, low species number in each group and the majority of the species occurring with very low abundance. The dominant species, Limnodrilus hoffmeisteri, is an organic-tolerant species, worldwide distributed. High organic matter content (up to 10% in the majority of sites) and a poor-oxygenated environment near the sediment contributed to its high densities as evidenced by canonical analysis. Gong & Xie (2001) observed that the abundance of L. hoffmeisteri in a Chinese shallow lake was positively correlated with the eutrophication degree. According to Milbrink (1994) and Lang (1997), some aquatic oligochaetes (including of L. hoffmeisteri) are able to survive for prolonged periods of anoxia and high organic loadings.

In previous studies in Americana Reservoir, Shimizu (1978) and Valenti & Froehlich (1988) registered the relative abundance of oligochaetes as 56.52 % and 67.18 % of total benthos (excluding microcrustaceans, rotifers and bryozoans), respectively. The tendency of increase in oligochaetes abundance was verified in our study, where they represented 72.77 % of bottom fauna. In contrast, chironomids and mollusks populations drastically declined along the time. Shimizu (1978) reported that the relative abundance of chironomids and mollusks were of 19.85 % and 10,31 %; while in our study the percentage decreased to 4.57 % and 1.74 %, respectively.

Considering the insects, although at low densities, they formed the highest richnest group, especially well represented by Chironomidae. This dipteran family together with the oligochaetes, are in fact the most conspicuous and relevant components of benthic communities in almost all freshwaters. In addition to the environmental degradation, it is possible that the low abundance of insects found in sediment of Americana Reservoir is due to the preference of these organisms for the free floating vegetation banks, especially of Eichhornia crassipes, Pistia stratiotes, Salvinia auriculata and Polygonum spp (Tavares et al., 2004), which provide diversified habitats for them, with wide food resources, breeding places and refugia against predators (Bechara, 1996).In Anhumas Reservoir, Corbi & Trivinho-Strixino (2002) registered higher richness and densities of macrobenthic fauna in places rich in aquatic vegetation. The predominance of mayfly Campsurus in station E12 (especially, in dry period) was probably related to low depth, predominance of sand, low organic matter content and high dissolved oxygen concentration.

Rocha (1972) and Shimizu (1978) recorded the presence of gastropods Ancylidae and Planorbiidae, and bivalves Sphaeridae, in Americana Reservoir. However, they practically disappeared at the end of 70's decade (Shimizu, 1981). Valenti & Froehlich (1988) only registered the presence of gastropods, but did not refer the families. In our study, the unique species of gastropod found was Melanoides tuberculata, although in low densities. This exotic species might have contributed, together environmental degradation, for the disappearance of those native species of mollusks. This afro-asiatic Thiaridae has been introduced in many countries, especially in the Caribbean area, as a competitor for native mollusks that are

vectors of disease (Pointier et al., 1993). In Brazil, it was firstly registered in middle sixties in the city of Santos, São Paulo State (Vaz et al, 1986), from which rapidly dispersed to other localities, being currently found in many Brazilian regions (Simone, 1999).

Longitudinally, the majority of the invertebrates of the Americana reservoir preferentially inhabited well oxygenated areas, riverine zone and upper reservoir section. In the middle and near the dam, where anoxic condition in the bottom were registered in both sampling periods, densities were lower and many taxa were absent. This result corroborated with other studies on benthic fauna that pointed out depth, dissolved oxygen and substrate, as the main factors controlling their spatial distribution (Petridis & Sinis, 1993; Di Giovanni et al., 1996; Moretto et al., 2003). In Americana Reservoir, spatial heterogeneity was also demonstrated for phytoplankton (Falco & Calijuri, 2002) and zooplankton (Zanata & Espíndola, 2002). For the former, Chlorophyceae (mainly Monoraphidium griffithii) dominated riverine zone; while in the dam region, Cyanophyceae (principally Microcystis aeruginosa) had major abundance (Falco & Calijuri, 2002). Regarding the zooplankton, Zanata & Espíndola (2002) have found that the density of rotifers decreased from upstream towards the dam, while the densities of microcrustaceans (copepods and cladocerans) increased. As previously mentioned, the existence of dense stands of macrophytes in the middle and near dam areas of Americana reservoir created new habitats for the bottom fauna.

In summary, we concluded that the structure (composition and abundance) of benthic community in Americana Reservoir has been highly impacted as a consequence of human activities, especially by eutrophication and organic pollution. According to Zinchenko (1992) and Popp & Hoagland (1995) anthropogenic impacts in freshwaters ecosystems, especially the increasing load of materials, is a major factor correlated with species loss, particularly of insects. The reduction and even extinction of many bottom invertebrates can compromise the whole ecological functioning of an aquatic ecosystem, affecting the energy transfer through the trophic food chain, and the nutrient cycling both by nutrient excretion and material suspending to the water column.

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