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Primary Research Paper

Benthic macroinvertebrates in the watershed of an urban reservoir in southeastern Brazil

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Abstract

The Ibirité watershed is subject to several forms of environmental degradation such as the presence of a petroleum refinery industry, urbanization of its surrounding landscape, and non treated domestic sewage from over 135,000 inhabitants. Benthic macroinvertebrates represent a useful tool in the evaluation of environmental quality through studies of the structure of communities and their relationship to anthropic activities within the watersheds. The objective of this study was to evaluate the environmental impact to the Ibirité reservoir caused by the petroleum refinery industry, urbanization, and sulphatation. Degradation of the watershed was measured by using the richness, diversity, evenness, and density of benthic macroinvertebrates. Twelve sampling stations were established as follows: five stations on Pintados and Ibirité streams (upstream from the reservoir), six in the reservoir and one station downstream from the reservoir. From 2002 to 2003, during both the dry and rainy seasons (in the tributaries) and the stratified and non-stratified periods (in the reservoir) were evaluated. A total of 289,777 organisms were collected and the most abundant organisms found in the streams were Oligochaeta (60%), Chironomidae (*Chironomus*, *Goeldichironomus*, *Dicrotendipes*, *Cryptochironomus*, *Polypedilum*, *Parachironomus*, *Tanytarsus*, *Tribelos*, *Tanypus*, *Ablabesmyia*, *Cricotopus*, *Oliveriella*) (38%) and Gastropoda (*Biomphalaria straminea*, *Physa* sp., *Melanoides tuberculatus*, *Pomacea haustrum*) (2%). In the reservoir, the most abundant specimens were Chaoboridae (46%) and Chironomidae larvae (*Chironomus*, *Goeldichironomus*, *Tanypus*, *Coleotanypus*, *Labrundinia*) (17%), in addition to Oligochaeta (24%) and Gastropoda (*Melanoides tuberculatus*) (13%). Evaluation of the structure and distribution of benthic communities showed a rapid environmental degradation process within the studied aquatic systems, in which low values of richness and diversity and high densities of tolerant organisms were observed. This environmental degradation is a result of the intense discharge of domestic sewage into the streams, reducing water quality and contributing to rapid artificial eutrophication.

Introduction

The rapid urbanization and expansion of modern big cities have resulted, progressively, in deteriorating freshwater conditions. Urban watersheds have been studied to assess multiple environmental impacts in these surrounding areas. Different approaches have been used in environmental assessments in order to determine deteriorating conditions: chemical parameters (Meybeck, 1998; Daniel et al., 2002; Lim, 2003), aquatic invertebrates (Beavan et al., 2001; Marques & Barbosa, 2001; Timm et al., 2001; Buss et al., 2002; Gray, 2004), fish (Walters et al., 2003), biotic indexes (EPA, 2000;

Karr & Chu, 2000), geographic information system (Zandbergen, 1998; El-Raey et al., 2000), and strategies for conservation and environmental restoration (Davis, 1997; Helfield & Diamond, 1997; Walsh, 2000).

The degradation of water resources can result in eutrophication and a decrease in both the number and density of species, as well as a reduction in the amenities or services that these systems provide. Impairment of aquatic resources by eutrophication can thus have substantial ecological effects (Vitousek et al., 1997; Meybeck, 1998; Smith et al., 1999). The best studied effect caused by artificial eutrophication is cyanobacterial blooms. Excessive abundance or 'blooming' of cyanobacteria generally cause detrimental effects on domestic, industrial and recreational uses of water bodies and, in many cases, are a direct motivation for restoration measures (Dokulil & Teubner, 2000).

The Ibirité watershed is subject to several pollution sources such as a petroleum refinery industry, urbanization, and non treated domestic sewage from over 135,000 inhabitants. Consequently, cyanobacteria blooms are frequently observed in the Ibirité reservoir.

The frequent dominance of cyanobacteria in eutrophicated freshwater is an additional concern because these organisms have the capacity to produce toxins (Codd, 2000), thereby further degrading water resources. Water treatment companies in Brazil (e.g., COPASA, SABESP) have had to face the problem of cyanobacteria blooms and they have often employed the addition of copper sulphate to the water to reduce this problem. Copper sulphate ($CuSO_4$, $5H_2O$) has been used since 1904 to control algal growth but the ecological consequences to the quality of the water treated and the biota are not clear. In addition, aquatic plants and animals tend to tolerate only very low Cu concentrations. Furthermore, various studies regarding the toxicology of aquatic organisms subject to these conditions have found wide-ranging results (Haughey et al., 2000).

Ibirité watershed is a particularly good system for conducting these types of degradation studies due to the petroleum refinery and the unplanned urbanization and raw sewage discharge currently occurring.

An increased knowledge of how the biota is affected differently by human alterations measured at different spatial scales is critical for improving the ecological quality of running waters (Sandin, 2003). Benthic macroinvertebrates have been used for quite some time as indicators of water quality and are also the most commonly used biological indicator in most aquatic ecosystems (Rosenberg & Resh, 1993; Compin & Céréghino, 2003). Macroinvertebrate assemblages and taxonomical richness have been found, however, to respond to a multitude of environmental factors operating at different spatial scales. Nonetheless, studies including variables measured at several spatial scales are relatively scarce (Norris & Hawkins, 2000; Walsh, 2000; Sandin, 2003).

Using the benthic macroinvertebrate communities as indicators of human impacts on the Ibirité watershed (petroleum refinery industry, urbanization and sulphatation), the main objective of this study was to assess the contribution of these activities to the degradation of the Ibirité reservoir. Therefore, questions were asked in order to guide this study: (i) are there significant spatial-temporal differences in the structure of benthic communities between lotic environments, or between areas affected by petroleum refinery industry as opposed to urbanization? (ii) are there significant spatial-temporal differences in the structure of benthic communities comparing the Ibirité reservoir with its tributaries? (iii) did the sulphatation in the Ibirité reservoir affect the benthic communities?

Study area

The Ibirité reservoir (19° 07′ 00″–20° 02′ 30″ S; 44° 07′ 30″–44° 05′ 00″ W) belongs to the Paraopeba river watershed, an effluent of the São Francisco river in Minas Gerais State, southeastern Brazil. The watershed is composed by the subbasins of the Pintados, Retiro and Onça streams, giving rise to the Ibirité stream. The headwaters of the Ibirité stream are located in the Serra do Rola Moça State Park, and its main course drains urban areas. Pintados stream crosses the petroleum refinery industrial area (Fig. 1).

The Ibirité reservoir was constructed in the 60's (Fundação João Pinheiro, 2001). Ibirité is a warm-monomitic reservoir, characteristic of some tropical lakes/reservoirs (Hutchinson, 1957; Esteves, 1998). Thermal and chemical stratifications occur from September to March/April, and

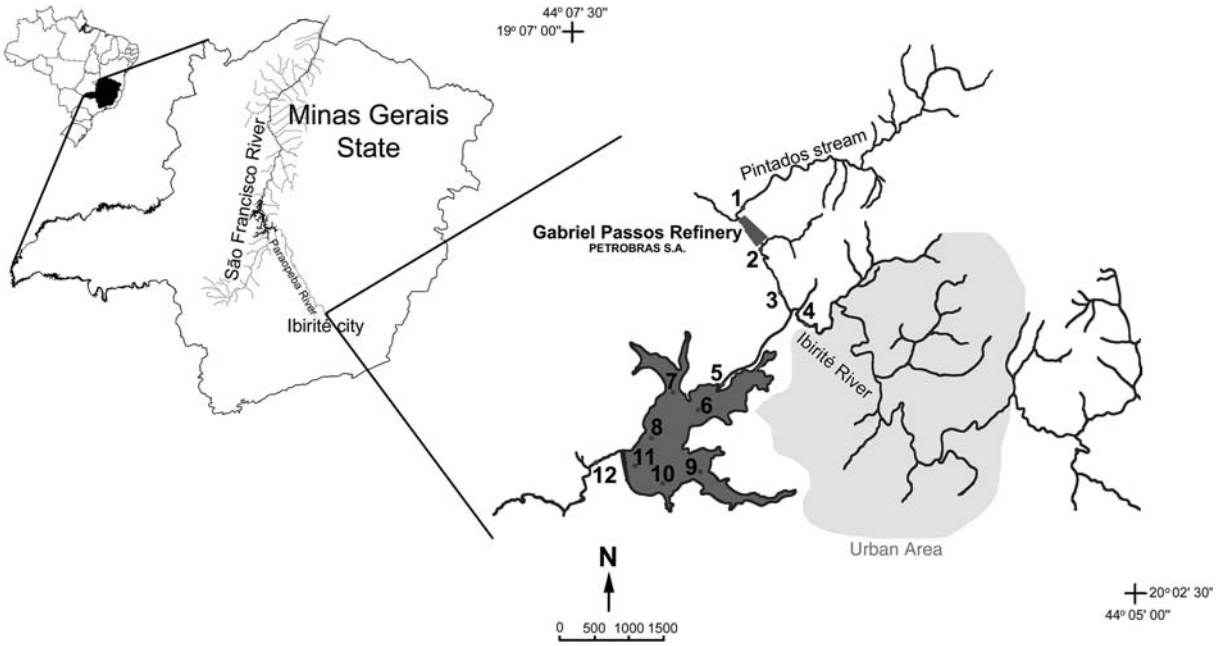

Figure 1. Study area showing the sampling stations.

destratifications from April/May to August. Climate in the region is tropical sub-humid (Cwb), with summer rains (November to April) and a dry winter (May to October). Average annual temperature is 20 °C (Christofoletti, 1974). Surrounding areas are densely occupied mostly by slums from which domestic raw sewage is released directly into the tributaries of the Ibirité reservoir.

Water quality is very low in these tributaries due to high fecal contamination. The granulometric composition is typically sandy with a prevalence of coarse and medium sized sand, which contributes to advanced streambed erosion and siltation. The reservoir is undergoing a process of rapid artificial eutrophication due to the population explosion of primary producers that use the excess nutrients and accumulated organic matter contained in raw sewage. In different periods of the year *Microcystis* spp and *Eichhornia crassipes* blooms occur.

Material and methods

Samples were collected monthly along the margins of the freshwater systems: five sampling stations on Pintados and Ibirité streams (upstream the reservoir), six sampling stations in the reservoir and one sampling station downstream from the reservoir. From 2002 to 2003, both the dry and rainy seasons (in the tributaries) and the stratified and non-stratified periods (in the reservoir) were evaluated (Fig. 1). To evaluate the ecological conditions of the sampling stations we used a rapid assessment protocol, as proposed by Callisto et al. (2002b), on the surrounding areas of Pintados and Ibirité streams.

Sediment collection for evaluation of benthic invertebrates was done monthly utilizing a Petersen sampler (0.0375 m^2) in the lotic environments and an Eckman-Birge dredge (0.0225 m^2) in the Ibirité reservoir. Five replicates were collected at each station in the Ibirité reservoir and three replicates in the lotic environments. Sediment samples were kept in plastic bags and taken to the laboratory where they were washed into sieves of 1.00, 0.50 and 0.25 mm mesh sizes, and screened with the help of a stereomicroscope. The organisms were fixed in 70% ethanol, taxonomically identified and deposited in The Benthic Macroinvertebrate Reference Collection of the Institute of Biological Sciences, Federal University of Minas Gerais.

Sampling collections were performed during 8 months in 2002 at Ibirité and Pintados streams (March–June during the dry period, August–November during the rainy period). In the Ibirité reservoir sampling occurred during 12 months: March–April and October–November, 2002 in stratified period; May–June and August–September, 2002 in non-stratified period; December 2002 and January–March 2003 after sulphatation.

As a remedial intervention, the petroleum company carried out the sulphatation treatment of the reservoir, by dispersing five tons of an aqueous solution (15% copper sulphate) in order to eliminate the phytoplanktonic communities.

Later collections were performed in an unpolluted zone (Serra do Rola Moça State Park) in preserved headwaters of the Ibirité watershed, minimally exposed to human stressors such as effluent discharges or land use changes, to compare the benthic macroinvertebrate communities (Bailey et al., 2004). In contrast to that reference condition zone, the study sampling stations at Ibirité watershed are exposed to the effects of petroleum refinery industry, urbanization and sulphatation. An adapted BMWP index (Junqueira et al., 2000) was used for comparisons between benthic communities among reference and impacted sample stations.

In order to evaluate the structure of the benthic macroinvertebrates, the Shannon–Wienner diversity and the Pielou evenness indices were calculated to each sample according to Magurran (1991). For each benthic sample the density of the organisms (individuals.m^{-2}), the dominance (% individuals), and the taxonomical richness (total number of taxa per sample) were estimated. Dominance results were calculated as the total number of organisms collected during each sampling period. Similarly, richness data were estimated as the total number of *taxa* found in each individual sampling period. Shannon–Wienner index values represent the maximum result in each sampling station during all study period.

Analysis of repeated measures (ANOVA) were used to test for benthic macroinvertebrate composition differences between Pintados and Ibirité streams, sampling periods, sample stations, and spatial-temporal differences in each studied ecosystem, followed by the Post Hoc Test (Tukey HSD test).

Results

Ecological conditions

The protocol for characterization of ecological conditions pointed to advanced environmental degradation in the Ibirité reservoir watershed, with direct consequences on habitat diversity, margin erosion, extinction of riparian vegetation, and water body siltation (see Callisto et al., 2005). The sampling stations #1 to #5 were classified as impacted stretches (scores between 16 and 31) and sampling station #12 was classified as a modified stretch (score 50). The waters of the Ibirité reservoir receive non-treated domestic sewage, agropasture effluents, and sediment carried along the watershed streams (Table 1).

Benthic macroinvertebrates

A total of 289,777 specimens belonging to 28 *taxa* were collected. From these, four were Gastropoda, one Platielmynthes, two Annelida, and 21 Insecta. The most abundant organisms found in the streams were Oligochaeta (60%), Chironomidae (*Chironomus*, *Goeldichironomus*, *Dicrotendipes*, *Cryptochironomus*, *Polypedilum*, *Parachironomus*, *Tanytarsus*, *Tribelos*, *Tanypus*, *Ablabesmyia*, *Cricotopus*, *Oliveriella*) (38%) and Gastropoda (*Biomphalaria straminea*, *Physa* sp., *Melanoides tuberculatus*, *Pomacea haustrum*) (2%). In the reservoir, the most abundant specimens were Chaoboridae (46%) and Chironomidae larvae (*Chironomus*, *Goeldichironomus*, *Tanypus*, *Coleotanypus*, *Labrundinia*) (17%), in addition to Oligochaeta (24%) and Gastropoda (*Melanoides tuberculatus*) (13%).

Comparing BMWP results between the reference streams and Ibirité sampling stations it was observed that the values of Ibirité were lower than the Serra do Rola Moça ones (Table 2). Besides, in the reference streams some typical *taxa* of good water quality were found (e.g., plecopteran Perlidae; trichopterans Helicopsychidae, Hydropsychidae, Hydroptilidae, Polycentropodidae; mayflies Leptohyphidae and Leptophebiidae; megalopteran Corydalidae; and the chironomids *Orthocladius*, *Djalmabatista, Larsia, Procladius, Thienemanniella, Cladopelma, Nilothauma*, and *Phaenopsectra*) and others related with the accumulation of leaf

Table 1. Results for characterization of stream's ecological conditions using Rapid Protocol by Callisto et al. (2002b)

Parameters	Sample Stations					
	Pintados stream			Ibirité stream		
	#1	#2	#3	#4	#5	#12
Types of edge occupation	Agriculture	Industry	Urban	Agriculture	Agriculture	Agriculture
Erosion	High	High	High	Moderate	Moderate	Moderate
Water odor	Absent	Absent	Sewage	Sewage	Sewage	Absent
Water oil presence	Absent	Absent	Absent	Absent	Absent	Absent
Water transparency	Transparency	Turbid	Opaque	Turbid	Opaque	Turbid
Sediment odor	Absent	Absent	Sewage	Sewage	Sewage	Absent
Sediment oil presence	Absent	Absent	Absent	Absent	Absent	Absent
Sediment deposition	Mud and sand	Mud and sand	Mud and sand	Mud and sand	Mud and sand	Rocks and gravel
Instream cover	Less than 10% mix of stable habitats; lack of habitat is obvious; substrate unstable or lacking					
Extension of riffles	Riffles or runs virtually nonexistent					
Frequency of riffles	Generally all flat water or shallow riffles; distance between riffles divided by the width of the stream is a ratio of >25					
Types of substrate	Sandy	Sandy	Muddy	Gravel and sand	Muddy	Gravel and sand
Mud deposition	>75%	>75%	>75%	>75%	>75%	25–50%
Channel alteration	40–80%	40–80%	>80%	<40%	40–80%	40–80%
Protective stream bank vegetation	Less than 50% for the stream bank surfaces covered by vegetation					
Bank stability	Moderately unstable; 30–60% of bank in reach has areas of erosion; high erosion potential during floods					
Riparian vegetative zone width	Width of riparian zone <6 meters; little or no riparian vegetation due to human activities					
Presence of aquatic vegetation	Absence of aquatic vegetation in the riverbed or great macrophytes banks					
Scores	26	29	16	31	29	50
Classification	Impacted	Impacted	Impacted	Impacted	Impacted	Modified

detritus in streambeds (e.g., trichopterans Leptoceridae with their organic cases, and detritus miner chironomids *Axarus, Beardius, Stenochironomus* and *Xenochironomus*).

The values of taxonomical richness varied from 3 to 20 taxa in Pintados stream, 4 to 14 taxa in Ibirité stream and 5 to 9 in Ibirité reservoir. The highest Shannon–Wienner diversity index value in the lotic environments was found in Pintados stream (1.345) while in the Ibirité reservoir we found the highest value (1.537) (Table 3).

Taxonomical richness and Shannon–Wienner diversity indices were significantly different between streams sample stations and sampling periods (ANOVA, Table 4). There were a significant interaction between sample stations and months in the density values (Table 4). Tukey test differed the sample stations during study period in three groups (#5 to #12; #1 to #2; and #3 to #4), evidencing benthic communities differences between streams.

In the Ibirité stream a higher density of organisms was found due to the large number of *Chironomus* larvae. When the values of each sampling station were analyzed individually, it was observed that in Pintados stream (#2 and #3) the taxonomical richness and diversity values were higher than those found in the Ibirité stream (#4) (Table 3).

In Ibirité reservoir, density, taxonomical richness, evenness, and Shannon–Wienner diversity indices were significantly different between sample stations and months, and associated interactions. Considering the distribution of organisms between

Table 2. Results of BMWP index at streams and Ibirité reservoir, and streams and reservoir of Serra do Rola Moça State Park

	Sample stations	BMWP score
Study area		
Pintados stream	1	3
	2	22
	3	18
Ibirité stream	4	3
	5	3
	12	7
Ibirité Reservoir	6	3
	7	3
	8	3
	9	7
	10	3
	11	3
Serra do Rola Moça State Park		
Streams	1	34
	2	37
	3	30
	4	19
	5	81
	7	68
Reservoirs	6	16
	8	8
	9	19

the sampling stations in the Ibirité reservoir it was observed that the benthic communities were significantly distinct in relation to their structure (Table 4). There were no significant differences between interactions (Tukey test) but there was evidence that sample station #6 (close to the inflow of the Ibirité stream) was different from the others. Higher taxonomical richness, evenness, diversity, and density of benthic organisms were found in station #6, while the lowest values were found at the limnetic station (# 8) (Table 3).

Seasonality and Sulphatation

Due to the influence of the seasonal rain and dry periods on the streams of the Ibirité reservoir basin, it was observed that in the rainy period there were significantly higher taxonomical richness (ANOVA, $F = 18.9553$, $p < 0.005$) and diversity values (ANOVA, $F = 5.6546$, $p < 0.05$) of benthic organisms, when compared to the dry period (Fig. 2a).

In the Ibirité reservoir, seasonality was marked by thermal stratification and destratification of the waters. The benthic community responded significantly to sulphatation in the Ibirité reservoir. There were significant differences between stratification, destratification, and sulphatation periods, whereas higher richness values (ANOVA, $F = 43.1924$, $p < 0.0005$) and diversity (ANOVA, $F = 22.7079$, $p < 0.0005$) were found in the destratification period (Fig. 2b).

A slight recolonization of benthic macroinvertebrates was observed after three months of sulphatation. There were significant differences of taxonomical richness from the repeated measures ANOVA of interactions between sampling stations and months richness (ANOVA: $F = 2.2412$, $p < 0.05$) and Shannon–Wienner diversity values (ANOVA, $F = 2.97166$, $p < 0.005$).

Discussion

Hydrographic basin

The benthic fauna found in all sampling stations was characterized as being poor in relation to taxonomical richness and diversity; comprised of pollution tolerant organisms that are typical of impacted environments. Karr & Schlosser (1978) suggested that the type of soil use influences riparian vegetation, food availability, and the type of sediment, which are reflected in the aquatic habitats structure. The homogenization of the sediment caused by the silting of the margins also affects the size of the benthic macroinvertebrate populations (Moss & Timms, 1989). It is believed that the simplified structure of the benthic community was due to the high degree of modification in the areas around the Ibirité hydrographic basin, where over 135,000 inhabitants live, causing silting and consequent homogenization of the sediment and loss of benthic habitats.

When compared to studies conducted in other impacted Brazilian systems (Marques & Barbosa, 2001; Buss et al., 2002) one can see that the benthic community structure found in the Ibirité reservoir basin is even more simplified, with lower values of richness and diversity. The low taxonomical

Table 3. Values for taxonomical richness, Pielou evenness and Shannon–Wienner diversity, and density (ind m^{-2}) for organisms found during the study period at Pintados and Ibirité streams and in the Ibirité reservoir

Sample Stations	Pintados stream			Ibirité stream			Ibirité Reservoir					
	1	2	3	4	5	12	6	7	8	9	10	11
Total richness	3	20	12	4	14	8	8	6	5	9	8	7
Total density	2484	27,675	18,576	5130	46,386	13,038	78,262	40,792	2722	34,550	16,408	3754
Evenness (J)	0.918	0.608	0.751	0.811	0.597	0.865	1.0	0.729	0	0.785	0.784	0.955
Shannon-Wienner Diversity (H')	0.637	1.335	1.345	0.562	0.961	0.950	1.099	1.173	0	1.263	1.405	1.537

richness and dominance of taxa resistant to pollution indicate poor water quality, where high densities of Oligochaeta, Chironomidae larvae (*Chironomus*, *Goeldichironomus*, *Dicrotendipes*, *Cryptochironomus*, *Polypedilum*, *Parachironomus*, *Tanytarsus*, *Tribelos*, *Tanypus*, *Coleotanypus*, *Labrundinia*, *Ablabesmyia*, *Cricotopus*, *Oliveriella*) and Gastropoda (*Melanoides tuberculatus* and *Biomphalaria straminea*) were found. These organisms are able to live in hypoxia conditions in the interface water-sediment; they are also detritivorous organisms, feeding on fine organic matter deposited in the sediment, which favors their adaptation to the current conditions in the

Table 4. Results of repeated measures ANOVA's predicting the structure of the benthic macroinvertebrates using taxonomical richness, Pielou evenness and Shannon-Wienner diversity, and density for organisms at streams and Ibirité reservoir

	Source	Effects	*F*	*p*
Streams	Density	Sample Stations	3,00505	0.054943
		Months	2,02505	0.061237
		Months vs. Sample Stations	2,13920	0.002444*
	Richness	Sample Stations	18,3000	0.000030*
		Months	8,4868	0.000000*
		Months vs. Sample Stations	3,9550	0.000000*
	Diversity	Sample Stations	9,21250	0.000853*
		Months	4,33086	0.000389*
		Months vs. Sample Stations	2,87891	0.000041*
	Evenness	Sample Stations	1,006849	0.454712
		Months	1,006132	0.432911
		Months vs. Sample Stations	1,002838	0.480429
Reservoir	Density	Sample Stations	43,0945	0.000000*
		Months	44,0821	0.000000*
		Months vs. Sample Stations	12,8941	0.000000*
	Richness	Sample Stations	24,8696	0.000000*
		Months	49,6691	0.000000*
		Months vs. Sample Stations	4,3285	0.000000*
	Diversity	Sample Stations	19,4243	0.000000*
		Months	32,1401	0.000000*
		Months vs. Sample Stations	5,4025	0.000000*
	Evenness	Sample Stations	21,1594	0.000000*
		Months	15,0503	0.000000*
		Months vs. Sample Stations	4,1759	0.000000*

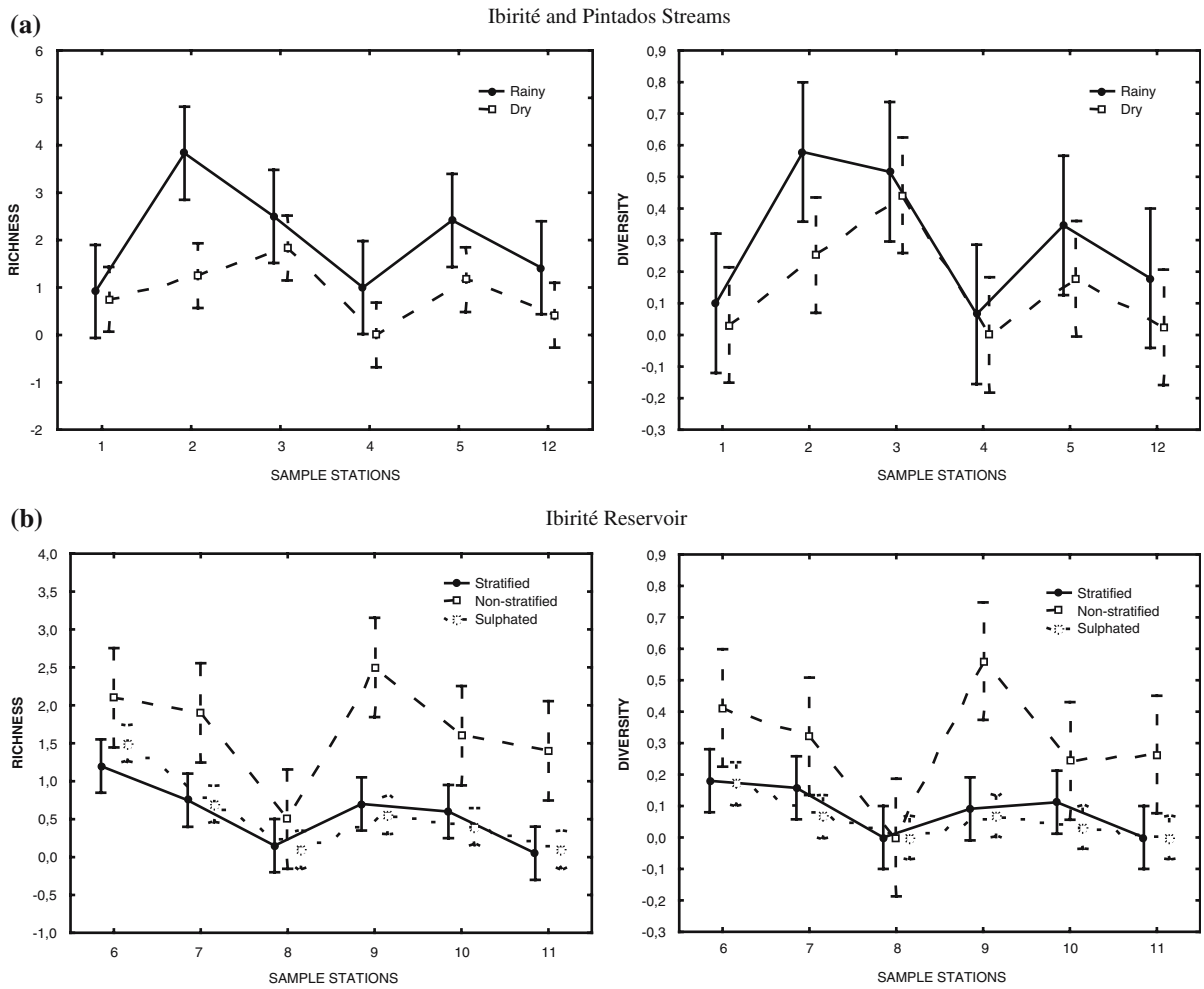

Figure 2. Results of repeated measures ANOVA's predicting the interactions between seasonality and sample stations on the streams (a) and Ibirité reservoir (b), with dependent variable being taxonomical richness and Shannon–Wienner diversity.

hydrographic basin of the Ibirité reservoir (Callisto et al., 2002a; Hooper et al., 2003).

Streams

Our results showed that the benthic macroinvertebrate community in the Ibirité stream was more affected than the Pintadoś community, showing lower values of taxonomical richness, evenness, and Shannon–Wienner diversity. This is probably related with the lower water quality of the Ibirité stream, due to the fact that this stream receives a great discharge of domestic sewage from urban areas. The Pintados stream exhibits an also simple but richer and more diverse community, taxonomically, than the Ibirité stream. Thus, our first question was answered as urbanization appears to be the main factor responsible for the degradation in this system as opposed to the petroleum refinery industry.

The high density of organisms found at the Ibirité stream was due to the high number of *Chironomus* larvae that probably fed on fine organic matter from domestic sewage discharged into the stream. High densities of *Chironomus* larvae have been regarded as excellent bioindicators of poor quality waters (Hooper et al., 2003), in which the increase in its density in response to

organic enrichment by antropic actions frequently eliminates all other Chironomidae genera (Stuijfzand et al., 2000; Marques & Barbosa, 2001).

The seasonal alterations in rainfall are an important environmental factor for community structure. In our study rain caused an increase in the volume of stream channels, increasing the amount of submersed substrates and consequently, increasing habitat diversity. This fact contributed to the idea that other organisms could be established, as opposed to what occured in the dry period, where lower values of taxonomical richness and, diversity of benthic organisms were found.

Ibirité reservoir

From the results found in the sampling stations at the Ibirité reservoir we can infer that the benthic macroinvertebrate communities showed reduced taxonomical diversity due to an impacted urban watershed. The availability of nutrients and accumulation of organic matter, due to the untreated domestic sewage in the Ibirité stream, are factors that favor the growth of aquatic macrophyte stands (*Typha domingensis* and *Echhornia crassipes*) close to the inflow of the Ibirité stream in the reservoir (#6). Thus, the sum of these characteristics favors a greater complexity in the structure of the benthic community in station #6, due to the higher availability of food and habitat diversity.

On the other hand, a simpler community structure was found in the limnetic region (#8) where the reservoir is 14 meters-deep and is comprised of a structurally simpler habitat also. In this station, only the larvae of *Chaoborus* (Chaoboridae, Diptera), organisms tolerant to eutrophicated environments, were found. These larvae have negative phototaxis, ability to migrate vertically in the water column, in addition to the ability to alternate from a planktonic to a benthic life habit. These characteristics allow them to easily relocate in the search for food or for better oxygen conditions (Callisto & Esteves, 1998; Scholz & Zerbst-Boroffka, 1998), which ensure their survival in hypoxia conditions.

Seasonality due to thermal stratification and destratification has an important role in the structuring of benthic communities in the Ibirité reservoir. The destratified period, where there is physical and chemical homogeneity of the water column, leads to oxygenation of the hypolimnion, favoring the maintenance of benthic macroinvertebrates (Henry, 1995); this can explain the high values for richness, evenness, diversity, and density obtained during that period.

The sulphatation treatment of the reservoir was dispersed causing the elimination as much of phytoplanktonic communities and, latter the benthic macroinvertebrates were also deleted. The effects of this sulphatation process have been well studied on algae (Garvey et al., 1991; Ma et al., 2003), aquatic macrophytes (Mal et al., 2002) and in humans (Araya et al., 2003). However, there have been very few studies on the effects of sulphatation on benthic organisms. The elimination of the benthic macroinvertebrate community demonstrated that this antropic impact caused a greater influence on the structure and composition of the communities than the seasonal thermal stratification and non stratification.

The elimination of these organisms can be explained by the high toxicity of copper, a metal that has the capacity of influencing the concentrations of dissolved organic carbon, pH, and alkalinity of the water where high amounts of its ions are found (Haughey et al., 2000). Nonetheless, a slight recolonization of benthic macroinvertebrates was observed as the toxicity concentration decreased during the following three months. According to Hullebusch et al. (2002), copper has the characteristic of reacting with several ligands such as carbonates, humic and fulvic acids, in addition to adsorbing colloidal and particulate components of the water column, becoming non-toxic when combined with organic matter. However, this management measure has been causing the acceleration of the deterioration process of already impacted waters, and can contribute to an even higher decrease in the benthic biodiversity in the Ibirité reservoir.

The evaluation of the structure and distribution of the benthic communities showed a rapid environmental degradation process of the studied aquatic systems, in which low values of richness and diversity and high densities of tolerant organisms were observed. This environmental degradation is a result of the intense discharge of domestic sewage into the streams, thereby, reducing water quality and contributing to rapid artificial eutrophication.

Urban growth in areas surrounding hydrographic basins causes a great depletion in the health of aquatic ecosystems (Walsh, 2000). Our results corroborate this statement, because comparisons of ideal conditions for streams at Serra do Rola Moça State Park to the Ibirité impacted watershed sampling stations evidenced different benthic macroinvertebrate communities of preserved to degraded freshwaters. Finding ways to restore and manage these environments is not easy, since interests other than scientific are at play, such as economical and political (Zandbergen, 1998). In some more populated regions, even if all sewage discharge were to be interrupted, it would take several years and much investing in ecotechnologies to recover these ecosystems (Deberdt, 2003).

Sanitary and sewage treatment measures can considerably increase the water quality at the Pintados and Ibirité streams. This would lead to a consequent improvement in the basin and in the reservoir, allowing a revitalization of the aquatic communities. In addition to these measures, it is important to establish a long term biological monitoring program that could bring about proposals for more efficient management, conservation, and environmental recovery. Finally, it is worth noting that, guaranteeing the quality of an ecosystem and its waters is of interest, not only to companies, governments, or local society, but in everyone's interest. The latter being a basic premise for sustainable development.

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