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Factors determining the structure and distribution of benthic invertebrate assemblages in a tropical basin

Fatores que determinam a estrutura e distribuição das comunidades de invertebrados bentônicos em uma bacia hidrográfica tropical

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Abstract

We used the das Velhas River basin in southeastern Brazil as a study unit to evaluate the role of various physical and chemical variables and the state of conservation in determining the structure and distribution of benthic macroinvertebrate communities. The habitats were characterized through the use of a rapid evaluation protocol, the examination of the granulometric composition of the sediments, and the precipitation in the sub-basins of the segments studied. The taxonomic structure was determined, Shannon-Wiener and Simpson diversity indexes, taxonomic richness, % EPT and % Chironomidae for the benthic assemblages. The results corroborated the importance of habitats in spatial structuring, the importance of the hydrological regime in temporal structuring, and the state of conservation as the main structuring agents of benthic macroinvertebrate assemblages.

Key words: biological metrics, bioindicators, protected areas, environmental impact.

Resumo

Foi utilizada a bacia hidrográfica do Rio das Velhas, sudeste do Brasil, como unidade de estudo para avaliar o papel das variáveis físicas e químicas além do estado de conservação na determinação da estrutura e distribuição das comunidades de macroinvertebrados bentônicos. A caracterização dos habitats foi realizada através da utilização de um protocolo de avaliação rápida, da determinação da composição de granulométrica dos sedimentos e da precipitação nas sub-bacias hidrográficas dos segmentos estudados. Foi determinada a estrutura taxonômica das comunidades bentônicas através dos índices de diversidade de Shannon-Wiener e Simpson, além da riqueza taxonômica, % EPT e % Chironomidae. Os resultados encontrados corroboraram a importância dos habitats na estruturação espacial, do regime hidrológico na estruturação temporal e o estado de conservação como o principal agente de estruturação das comunidades de macroinvertebrados bentônicos.

Palavras-chave: parâmetros biológicos, bioindicadores, áreas de proteção ambiental, impacto ambiental.

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Introduction

The structure and spatial and temporal distributions of benthic macroinvertebrate assemblages are controlled by hydrology and habitat conditions. The river continuum concept (Vannote *et al.*, 1980) describes how longitudinal variations in geomorphology and energy change ecological attributes and aquatic assemblages along a river. Southwood (1977, 1988) reported that the distribution of assemblages along a river or within a river segment is largely influenced by habitat characteristics. Statzner *et al.* (1988) concluded that hydraulic characteristics determine the distribution of invertebrate assemblages from the headwaters to the river mouth and within a river segment.

In tropical regions, seasonal variations (Flecker and Feifarek, 1994), ecological interactions (Katano *et al.*, 2007; Schmera *et al.*, 2007), and land use (Hynes, 1975) are considered important. Despite 20 years of continuum studies, few unequivocal statements can be made about the main factors influencing aquatic assemblages.

Recently, the Neotropical region has been the subject of studies directed towards determining how these various factors influence benthic macroinvertebrate communities. Alterations of flow (Melo *et al.*, 2003; Silveira *et al.*, 2005; Bispo *et al.*, 2006) and degradation of water quality (Buss *et al.*, 2002; 2004; Soldner *et al.*, 2004; Moreno and Callisto, 2006) have been found important for determining macrobenthos structure and distribution, similarly to results from studies in temperate regions (Beavan *et al.*, 2001; Allan, 2004; Ortiz *et al.*, 2006; Ortiz and Puig, 2007). All these studies increase our ecological knowledge of the structure and functioning of lotic ecosystems. They also help us to understand how macroinvertebrates respond to anthropogenic disturbances that affect the chemical, physical, and hydraulic characteristics of a river. Aquatic benthic macroinvertebrates are important bioindicators of water quality (Cairns and Pratt, 1993; Rosenberg and Resh, 1993; Dale and Beyeler, 2001; Bailey *et al.*, 2005; Bonada *et al.*, 2006). Knowledge of the structure and distribution of these organisms relative to environmental variables has resulted in the development of quantitative biological indices. These indices can be used to compare the variance found in benthic assemblages from minimally disturbed environments with the variance found at altered sites (Reynoldson *et al.*, 1997; Bailey *et al.*, 2005; Stoddard *et al.*, 2006; Whittier *et al.*, 2007).

Study of benthic assemblages to understand the basic structuring factors will always be confounded to some degree by covarying anthropogenic impacts, and consequently it is important to find locales that retain natural characteristics, in order to facilitate understanding of these natural structuring factors. The most common stressors of Brazilian aquatic ecosystems are organic pollution and eutrophication, excessive sediment deposits, dams, overfishing, and alien species (Agostinho *et al.*, 2005). The das Velhas River basin in southeastern Brazil is affected by almost all these impacts. However, there are also several conservation units (national and state parks) that preserve natural variations in benthic assemblages within the basin (Paz *et al.*, 2008).

Our objectives were to evaluate macroinvertebrate and environmental data from the das Velhas River basin, in order to determine the main factors explaining the structure and distribution of the benthic fauna.

Study area

The das Velhas River basin is located in the central region of Minas Gerais state, between 17^o 15’and 20^o 25’ South and 43^o 25’ and 44^o 50’ West. It has an elongated north-south shape, is 761 km long, averages 38.4 Km wide, and drains an area of 30,000 Km^2 (Polignano *et al.*, 2001) (Figure 1). The local climate has well-defined wet and dry seasons, with the rainy season from October through April.

The basin is heavily urbanized, with 51 municipalities and a total population of 4.5 million (Polignano *et al.*, 2001). The headwaters region of the das Velhas River and its tributaries is located in the Quadrilátero Ferrífero (Iron Quadrant), a region known for its large iron ore deposits and mining industries. In addition, the metropolitan area of Belo Horizonte, with a population of 3 million, is located in the upper basin (Camargos, 2005). The Velhas River basin is a major tributary of the São Francisco River in regard to both water volume and pollution load (Camargos, 2005).

The Velhas River basin contains 21 conservation units, with a total area of 5,800 Km^2 encompassing 19% of the total basin area (SEMAD, 2007). Waters in the conservation units generally have lower conductivity, total P, total N, dissolved solids, and turbidity, sediments with less organic matter and silt load, and higher dissolved oxygen than altered areas in the basin (Pompeu *et al.*, 2005; França *et al.*, 2006).

Material and methods

We evaluated 19 sites in 16 streams in the basin, ranging from protected sites in conservation units to highly degraded sites in the metropolitan area. The streams are third through sixth order (Strahler, 1951).

We sampled from August 2004 to May 2006, with four visits during the dry season and four during the rainy season. We evaluated 16 environmental variables: habitat diversity; segment order; water electrical conductivity, Total P, Total N, dissolved oxygen, total dissolved solids, turbidity, pH, depth, current velocity, and temperature; substrate organic matter content and granulometric composition; and total precipitation.

We evaluated habitat diversity and conservation status at each site (Callisto *et al.*, 2002). We used YSI

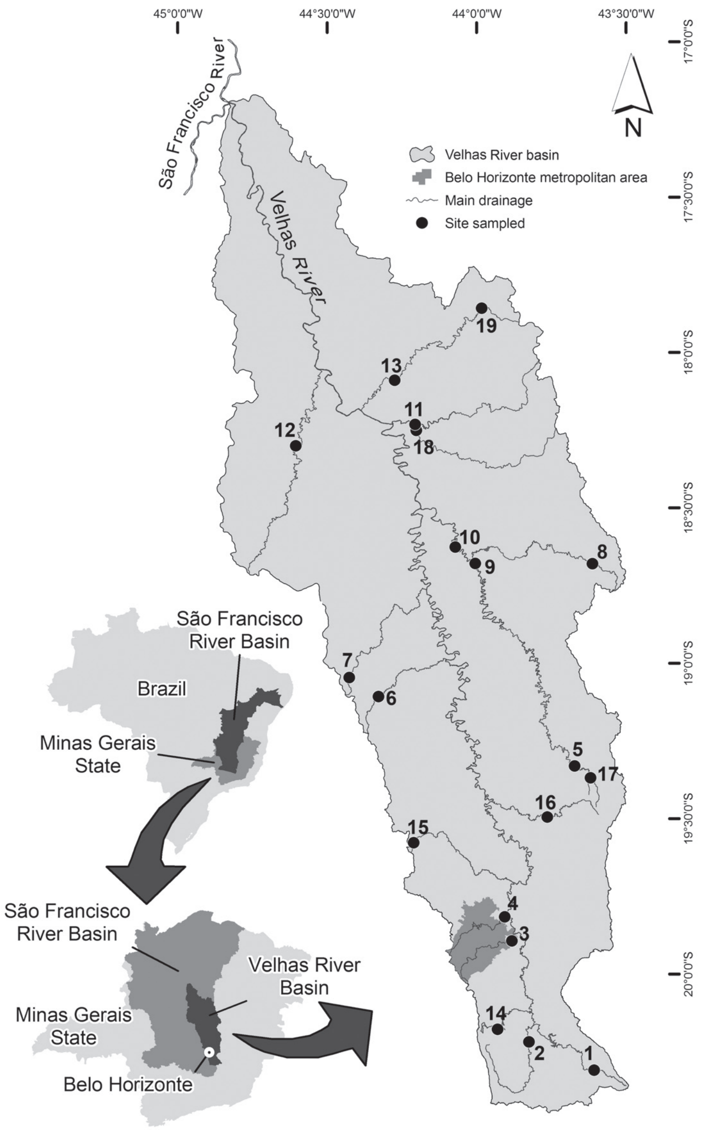

Figure 1. Sampling sites in the das Velhas River basin, MG, Brazil. MapBase: Projeto GeoMinas modified by Projeto Manuelzão/UFMG, 2004.

60 and 85 models (Yellow Springs, Ohio) to measure parameters *in situ*. We determined total nutrient content from protocols in Strickland and Parsons (1960) and Mackereth *et al.* (1978). Sediment organic matter and granulometric composition were determined following the protocol in Suguio (1973) as modified by Callisto and Esteves (1996).

For benthic communities study substrates were sampled using Surber collector (0.09 m^2). Three samples were collected at each site, and stored in plastic containers, which were taken to the laboratory. The samples were washed in sieves of 1, 0.50, and 0.25 mm mesh size, and the organisms retrieved were identified with the aid of a stereomicroscope. It was fixed in 70% ethanol, and stored in the Benthic Macroinvertebrate Reference Collection of the Biological Sciences Institute at UFMG, as described by Callisto *et al.* (1998) and França and Callisto (2007). The following metrics of assemblage structure were calculated, following Magurran (1991): Pielou's equitability index, Shannon-Wiener and Simpson diversity indexes, density (ind/m^2), taxonomic richness (number of families), and Margalef index. We also calculated the number of *taxa* of Ephemeroptera, Plecoptera, and Trichoptera (EPT); total EPT abundance (TEPT) and relative EPT abundance (%EPT); relative Chironomidae abundance (%CHI); relative Oligochaeta abundance (%OLI); relative abundance of collector-gatherers (%COG); relative abundance of shredders (%SHR); relative abundance of scrapers (%SCR); relative abundance of predators (%PRE); and relative abundance of collector-filterers (%COF) (Moya *et al.*, 2007). The designation of the trophic groups followed Merritt and Cummins (1998).

Using the values of taxonomic richness, organismal density, and Shannon-Wiener diversity index, we performed a factorial variance analysis (ANOVA) to evaluate the effect of (i) season, (ii) order, and (iii) protected area. In addition, we performed a SIMPER analysis (PRIMER software) to assess similarities between invertebrate assemblages inside and outside protected areas (Feio *et al.*, 2007).

The relationships among environmental factors and benthic macroinvertebrate assemblages were quantified by a Canonical Correspondence Analysis (CCA) using the PCOrd software. For these analyses, the biotic and abiotic matrixes (except pH) were log-transformed (Bispo *et al.*, 2006).

Results

The characterization of site habitat indicated a high degree of environmental preservation within the conservation units, and a high degree of degradation in the metropolitan area. Fourteen sites were classified as natural (#1; #5; #6; #7; #8; #9; #11; #13; #14; #15; #16; #17; #18; #19), three as altered (#2; #10; #12), and two as impacted (#3; #4). Only 35% of the habitat characteristics scored as suitable for the maintenance of life in urban water bodies. Low scores were obtained for habitat diversity and stability, substrate structure, availability of substrate and food resources, and maintenance of the hydraulic characteristics of the water body. As expected, the highest habitat scores occurred at sites located in protected areas.

In the benthic communities collected 94,502 organisms were identified belonging to 54 insect families (6 Coleoptera, 12 Diptera, 6 Ephemeroptera, 9 Heteroptera, 1 Megaloptera, 6 Odonata, 2 Plecoptera, and 12 Trichoptera) and Oligochaeta (Table 1). The highest family richness (31) and Margalef richness (2.94) were found at a 3rd order site during the dry season. Both density and diversity (Shannon-Wiener and Simpson) values were highest at 5th order sites (77,472 ind.m^{-2}, 2.23 and 0.87, respectively).

Highest TEPT values (18,989 individuals), %EPT (75%), %SHR (6%), %SCR (11%), %PRE (64%), and %COF (84%) occurred at 5th order sites. The highest EPT value (15) was obtained at a 3rd order site, and the highest %COG, %CHI, and %OLI values (100%) were found at 6th order sites (Table 2).

Significant differences in taxonomic richness ($F_{1;4}$ = 22.825, $p<0.005$), total density ($F_{1;4}$ = 9,504, $p<0.005$), and Shannon-Wiener diversity ($F_{1;4}$ = 15.648, $p<0.005$) were found between sites located inside and outside protected areas. There were also significant differences in taxonomic richness ($F_{1;4}$ = 3.986, $p<0.05$) and total density ($F_{1;4}$ = 6.759, $p<0.05$) between the wet and dry seasons. Finally, there were significant differences in taxonomic richness ($F_{1;4}$ = 4.631, $p<0.005$) and Shannon-Wiener diversity ($F_{1;4}$ = 7.991, $p<0.005$) among sites of different orders. Taxonomic richness was highest (22 to 31 *taxa*) at low-order sites, during the dry season, and at sites located in protected areas. The highest densities (53,000 to 77,500 ind.m^{-2}) were also found during the dry season and at sites located in protected areas. The highest values of the Shannon-Wiener index (1.80 to 2.23) were found in 3rd, 4th, and 5th order sites located inside protected areas.

During the dry season, there was greater similarity among the macroinvertebrate assemblages found in protected areas (SIMPER: 70.15), than among those in unprotected sites (SIMPER: 56.87), and the dissimilarity between these sites was 38.48. During the wet season there also was more similarity among sites located in protected areas than among those in unprotected areas (SIMPER: 71.06 and 55.25 respectively), and the dissimilarity between these sites was 39.71.

The total variance of the metrics describing the invertebrate assemblages explained by the CCA was 0.2432. The first three correlations between the biotic and abiotic matrixes were 0.889, 0.571, and 0.551 respectively. The first CCA axis accounted for 35.8% of the explanatory power for variation in the biological metrics. The Monte Carlo simulation demonstrated that the first three axes were significant.

The CCA indicated that habitat diversity, dissolved oxygen, and granulometric fractions of pebbles and gravel were negatively correlated with the first axis, and total dissolved solids and total nutrients were positively correlated with this axis. The %OLI was associated with higher values of nutrients and total dissolved solids, and the %COF and %SCR were associated with higher values of coarser substrates (Figure 2).

The total variance of the invertebrate assemblages explained by CCA was 1.5798. The first three correlations among data regarding the assemblages and the abiotic data were 0.807, 0.703, and 0.666, respectively, and the first two axes were significant. Total P was negatively correlated with the first axis; and habitat diversity, pebbles, and gravel were positively correlated with this axis. Total dissolved solids were positively correlated with the second axis. Most families of Ephemeroptera, Trichoptera, and Odonata were associated with highest habitat diversity and coarser substrates, while the majority of families of Diptera were associated with higher Total-P and total dissolved solids (Figure 3).

Discussion

Our results indicate the importance of natural factors (substrate and habitat diversity) in the structure and distribution of aquatic invertebrate assemblages in the Velhas River basin. These structuring factors reinforce the importance of maintaining extant habitats in the water bodies. With the exception of nutrient content, all other factors are direct or indirect measures of minimally disturbed riverine habitat, which is associated with high macroinvertebrate diversities (Dudgeon *et al.*, 2006). High nutrient concentrations were also associated with poor assemblage conditions in surveys of waters in the USA (Stoddard *et al.*, 2005, 2006).

The differences found in the taxonomic richness and Shannon-Wiener diversity values between 3rd and 6th order sites are also an important factor to be considered when analyzing assemblage structure. Although a strong altitude gradient was not observed, the differences can be explained by the transition river size described by Vannote *et al.* (1980), or by hydraulic differences that result in differences in assemblage structure (Nelson and Lieberman, 2002).

Seasonal hydrological variations are an environmental factor of great importance for benthic macroinvertebrate assemblages (Gibbins *et al.*, 2001). In tropical rivers, the rainfall plays an important role in the flood regime, and consequently in the structure of the aquatic assemblages (Junk *et al.*, 1989). Our results indicated that during the wet season, the assemblages had lower richness and organismal densities. The significant differences in these values can be explained by the reduced habitat stability caused by the wet season, as suggested by Death and Winterbourn (1995) coupled with less efficient sampling during high water.

Although our results concord with those from other studies of the importance of habitat diversity for spatial structuring (Southwood, 1977, 1988; Statzner *et al.*, 1997; Doisy and

Table 1. Total numbers of organisms found at each site in the Velhas River basin.

	Reaches outside of protected areas													Reaches in protected areas					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Order	**5**	**6**	**6**	**5**	**6**	**5**	**3**	**5**	**6**	**6**	**6**	**6**	**5**	**3**	**4**	**5**	**3**	**5**	**4**
Diptera	**2383**	**9441**	**1164**	**1101**	**4544**	**1845**	**5698**	**9790**	**2354**	**2957**	**2332**	**1131**	**562**	**5019**	**6611**	**10318**	**4712**	**10972**	**10308**
Canacidae																	14		
Ceratopogonidae	36	237	53	10	17	13	183	70	9	7	16	31	18	6	63	59	103	50	156
Chironomidae	1764	9127	681	1024	4406	1278	3867	2254	2307	1760	2283	881	452	3801	5301	6269	4129	8083	6746
Culicidae							13		1	1								1	6
Dolichopodidae				1				2											
Empididae	49	47			39	6	6	36	1	24	14	6	2	12	9	55	36	28	13
Muscidae			1									1							
Psychodidae	8	22	291	65			1			2		1		2	1	20	7		
Simuliidae	522	6			54	535	1617	7426	35	1160	19	196	85	1198	1233	3767	387	2782	3357
Stratiomyidae	2		109																
Tabanidae		2			12	3	9										4	2	1
Tipulidae	2		29	1	16	10	2	2	1	3		15	5		4	148	32	26	29
Trichoptera	**174**	**4**			**383**	**1978**	**120**	**316**	**119**	**496**	**47**	**123**	**618**	**142**	**977**	**1710**	**525**	**2683**	**1509**
Calamoceratidae	6														8	2	12	2	
Ecnomidae						2		1					7						
Glossosomatidae	1				6	10	8	2		3	2	4	108	10	12	33	50	21	4
Helicopsychidae	6				1	103				1	2	1	11		8		8		8
Hydrobiosidae	9				3		3	4								34	4	1	
Hydropsychidae	55	4			218	1424	38	259	69	444	18	83	184	128	715	420	120	680	561
Hydroptilidae	81				77	36	6	44		8	10	7	3	4	171	48	209	239	74
Leptoceridae	14				22		1	3	39	3	5	7	3		5	9	23	62	144
Odontoceridae					1					1			1		32	2	28		1
Philopotamidae					48	402	63	2	7	27	9	13	293		26	1151	37	1670	697
Polycentropodidae	2				7	1	1		4	9	1	8	8			11	34	8	14
Xiphocentronidae								1											6
Ephemeroptera	**827**	**199**			**1705**	**2234**	**735**	**881**	**419**	**472**	**169**	**786**	**474**	**44**	**1671**	**2890**	**956**	**3434**	**1952**
Baetidae	612	195			308	883	660	716	231	266	129	372	67	44	444	1617	360	1687	1138
Caenidae	14				6	1	3	10	15	2	3				6		53	18	74
Leptohyphidae	191	4			1275	608	19	67	56	99	13	167	175		1183	439	243	658	253
Leptophlebiidae	10				115	742	52	88	85	104	23	245	229		38	834	300	1071	486
Oligoneuriidae												1	1						1
Polymitarcyidae					1		1		32	1	1	1	2						
Plecoptera	**46**				**8**	**39**	**2**	**123**	**1**	**15**		**10**	**16**	**4**	**43**	**19**	**42**	**4**	**2**
Gripopterigidae	20																		
Perlidae	26				8	39	2	123	1	15		10	16	4	43	19	42	4	2
Coleoptera	**299**	**23**	**1**	**1**	**321**	**1299**	**58**	**858**	**134**	**190**	**42**	**54**	**91**	**26**	**1355**	**675**	**498**	**543**	**351**
Dytiscidae					6			37		1					2	11	36	1	
Elmidae	285	19		1	304	1294	57	757	133	189	21	53	81	26	1324	637	460	461	336
Gyrinidae	2	1				1		3							27	21	2	2	6
Hydrophilidae	12	2			9		1	60	1		21	1	7		1	6		79	7
Psephenidae						3		1					3						2
Staphylinidae		1	1		2	1									1				

Table 1. Continued.

Heteroptera	**33**	**3**			**94**	**55**	**190**	**37**	**34**	**8**	**29**	**35**	**11**	**2**	**19**	**82**	**35**	**100**	**86**
Belostomatidae						3	2				7							1	
Belostomidae						3			2		10								
Corixidae						2	143	5	4	1							2		
Gerridae	1				1		1		1					1			1		
Hebridae							2												
Naucoridae	32				86	47	32	24	5	6	12	26	9		18	64	16	98	78
Notonectidae							3		10	1							2		
Pleidae								1									3		1
Veliidae		3			7		7	7	12			9	2	1	1	18	11	1	7
Megaloptera	**3**	**7**			**9**	**69**	**5**	**30**		**5**		**5**	**1**	**4**	**32**	**16**	**5**	**24**	**15**
Corydalidae	3	7			9	69	5	30		5		5	1	4	32	16	5	24	15
Odonata	**33**	**14**			**34**	**29**	**58**	**38**	**90**	**40**	**18**	**41**	**48**	**23**	**54**	**113**	**155**	**213**	**146**
Aeshnidae	2					5									1		5	11	19
Calopterygidae	3							2	1				1	1	4	5	3		17
Coenagrionidae	1				3	9	10	8	4	2		20	4	1	21	12	49	9	38
Gomphidae	15	12			12	2	21		23	5	13	16	34	17	13	44	38	25	16
Libellulidae	10	2			19	13	26	28	62	33	5	5	8	4	14	48	56	168	55
Megapodagrionidae	2						1						1		1	4	4		1
Oligochaeta	**276**	**2811**	**10155**	**4207**	**47**	**218**	**401**	**226**	**176**	**107**	**2**	**119**	**92**	**541**	**1195**	**172**	**40**	**716**	**225**
Total	**4074**	**12502**	**11320**	**5309**	**7145**	**7766**	**7267**	**12299**	**3327**	**4290**	**2639**	**2304**	**1913**	**5805**	**11957**	**15995**	**6968**	**18689**	**14594**

Rabeni, 2001; Sandin, 2003; Ciesielka and Bailey, 2007) and of hydrological regimes for temporal structuring (Junk *et al.*, 1989; Gibbins *et al.*, 2001; Bunn and Arthington, 2002; Silveira *et al.*, 2006; Bonada *et al.*, 2007) of benthic macroinvertebrate assemblages, environmental degradation in the Velhas River basin was the most important main structuring agent observed. Sites 3 and 4 represented extremely degraded conditions, with high values for metrics indicating poor water quality (%CHI, %OLI, %COG, and density). These sites also had low dissolved-oxygen concentrations and high conductivity and total nutrients. Together these results indicated eutrophication, and demonstrate how anthropogenic activities have modified the structure of the benthic assemblages.

The TEPT, EPT, and %EPT metrics were the most sensitive to the environmental alterations observed in the basin, being strongly correlated with high levels of dissolved oxygen and low nutrient concentrations. EPT metrics are also commonly used indicators for assessing the biological condition of temperate waters (Barbour *et al.*, 1999). Thus, the structure and distribution of these three insect orders in the Velhas River basin offer important tools for evaluating water quality and environmental quality. In addition, these data provide baseline information for complementary studies that evaluate other Neotropical basins. However, there is a need for more studies focusing on bioindicator groups in tropical regions, because the ecology of tropical rivers is poorly known (Ribeiro and Uieda, 2005). Few Brazilian basins have so far been included in studies of this type. Some of the basins that have been studied are the Doce (Marques and Barbosa, 2001), Carmo (Melo and Froehlich, 2001), Almas (Bispo *et al.*, 2006), Macaé (Silveira *et al.*, 2006), and Guapimirim rivers (Buss and Salles, 2007).

There are several studies that demonstrate the importance of local factors (i.e., substrate, flow speed, riparian vegetation) (Doisy and Rabeni, 2001; Bispo *et al.*, 2006; Ortiz *et al.*, 2006) and factors acting over a large spatial extent (climate, stream order, geographical location, river sinuosity) (Allan, 1995; Sandin, 2003; Bonada *et al.*, 2007) on the structure and distribution of macroinvertebrate assemblages. However, we found that the main factors structuring macroinvertebrate assemblages were the degree of habitat preservation in the surrounding area and in the stream course, nutrient concentrations in the water, and sediment size. We believe that only through studying basins where both natural and anthropogenic variations occur, we will understand ecosystem functioning and

Table 2. Values of biological metrics (mean ± s.d.) of the benthic macroinvertebrate communities at sampling station at the Velhas River basin.

		TEPT	%EPT	EPT	%COG	%COF	%SHR	%PRE	%SCR	%CHI	%OLI	Richness	Density	Margalef Richness	Pielou Evenness	Shannon-Wiener Diversity	Simpson Diversity
Reaches outside of protected areas	**1**	1584 ± 1004	25 ± 14	7 ± 3	79 ± 11	11 ± 9	0.6 ± 1	6 ± 3	2 ± 3	42 ± 22	7 ± 10	17 ± 5	6730 ± 4034	1.84 ± 0.45	0.60 ± 0.13	1.69 ± 0.44	0.69 ± 0.17
	2	281 ± 512	2 ± 4	1 ± 1	92 ± 12	0.04 ± 0.07	0	7 ± 12	0	63 ± 30	25 ± 28	7 ± 5	20988 ± 25267	0.67 ± 0.45	0.41 ± 0.28	0.67 ± 0.37	0.36 ± 0.22
	3	0	0	0	98 ± 1	0	0	0.80 ± 0.88	0	9 ± 11	81 ± 16	4 ± 1	21570 ± 17646	0.36 ± 0.16	0.37 ± 0.28	0.51 ± 0.38	0.27 ± 0.22
	4	0	0	0	99 ± 1	0	0.06 ± 0.2	0.45 ± 0.8	0	30 ± 24	66 ± 27	3 ± 2	12649 ± 16714	0.26 ± 0.21	0.53 ± 0.33	0.56 ± 0.38	0.34 ± 0.24
	5	3249 ± 2839	25 ± 19	8 ± 4	89 ± 13	0.64 ± 0.86	0.3 ± 0.4	8 ± 14	0.92 ± 0.73	55 ± 23	6 ± 15	17 ± 8	11337 ± 7268	1.72 ± 0.74	0.51 ± 0.19	1.26 ± 0.35	0.55 ± 0.16
	6	6708 ± 5400	50 ± 20	6 ± 3	87 ± 8	6 ± 9	0.11 ± 0.1	5 ± 3	2 ± 3	16 ± 14	3 ± 4	15 ± 6	12322 ± 10017	1.62 ± 0.41	0.73 ± 0.10	1.92 ± 0.24	0.81 ± 0.05
	7	1406 ± 1902	12 ± 12	4 ± 3	63 ± 35	33 ± 37	0.02 ± 0.05	4 ± 4	0.17 ± 0.41	44 ± 30	6 ± 12	12 ± 7	12486 ± 13302	1.23 ± 0.70	0.46 ± 0.13	0.99 ± 0.51	0.47 ± 0.23
	8	2033 ± 1724	10 ± 6	6 ± 3	38 ± 18	45 ± 28	0.04 ± 0.12	17 ± 24	0.34 ± 0.54	18 ± 12	6 ± 12	16 ± 7	18997 ± 16165	1.58 ± 0.48	0.54 ± 0.20	1.34 ± 0.37	0.60 ± 0.17
	9	799 ± 730	20 ± 16	5 ± 2	93 ± 9	3 ± 8	0.01 ± 0.02	4 ± 3	0	50 ± 27	17 ± 30	12 ± 5	4958 ± 5615	1.36 ± 0.45	0.53 ± 0.20	1.28 ± 0.48	0.54 ± 0.23
	10	1714 ± 2635	22 ± 18	6 ± 3	61 ± 32	25 ± 24	0.06 ± 0.10	14 ± 35	0.26 ± 0.34	33 ± 24	2 ± 1	14 ± 6	6973 ± 6287	1.44 ± 0.53	0.59 ± 0.19	1.34 ± 0.37	0.62 ± 0.12
	11	340 ± 280	10 ± 5	5 ± 3	96 ± 6	0.52 ± 0.94	0	3 ± 5	0.65 ± 1.21	85 ± 10	0.09 ± 0.19	10 ± 6	4014 ± 3282	1.04 ± 0.65	0.33 ± 0.17	0.65 ± 0.45	0.26 ± 0.16
	12	1185 ± 1487	34 ± 24	6 ± 3	80 ± 15	10 ± 15	0.58 ± 1.13	9 ± 7	0.31 ± 0.59	34 ± 31	8 ± 14	13 ± 6	3318 ± 3975	1.56 ± 0.60	0.63 ± 0.16	1.59 ± 0.50	0.67 ± 0.19
	13	1547 ± 2722	35 ± 32	5 ± 4	84 ± 8	3 ± 5	0.33 ± 0.86	11 ± 11	2 ± 4	31 ± 22	15 ± 23	13 ± 6	2976 ± 3523	1.51 ± 0.69	0.70 ± 0.09	1.72 ± 0.54	0.72 ± 0.15
Reaches in protected areas	**14**	290 ± 262	8 ± 5	3 ± 1	77 ± 17	18 ± 18	0	4 ± 4	0.36 ± 0.76	62 ± 22	6 ± 8	9 ± 2	9617 ± 13842	0.94 ± 0.15	0.49 ± 0.21	1.01 ± 0.36	0.49 ± 0.20
	15	4231 ± 2476	21 ± 14	8 ± 4	82 ± 15	14 ± 16	0.41 ± 0.62	2 ± 2	1 ± 2	38 ± 18	9 ± 13	18 ± 8	20311 ± 14156	1.71 ± 0.76	0.62 ± 0.16	1.54 ± 0.41	0.69 ± 0.09
	16	7405 ± 7209	26 ± 15	8 ± 4	66 ± 29	16 ± 15	2 ± 2	3 ± 1	0.35 ± 0.27	32 ± 16	3 ± 6	18 ± 9	26204 ± 25989	1.76 ± 0.79	0.54 ± 0.24	1.62 ± 0.69	0.67 ± 0.28
	17	2705 ± 2482	23 ± 6	10 ± 4	83 ± 5	7 ± 6	1.25 ± 1.24	7 ± 2	3 ± 3	56 ± 7	1 ± 2	24 ± 7	12227 ± 10352	2.55 ± 0.45	0.55 ± 0.10	1.70 ± 0.22	0.65 ± 0.08
	18	9474 ± 6059	34 ± 19	8 ± 2	82 ± 8	13 ± 9	0.31 ± 0.44	3 ± 1	2 ± 3	39 ± 16	8 ± 17	20 ± 3	30752 ± 23708	1.86 ± 0.24	0.58 ± 0.09	1.72 ± 0.29	0.72 ± 0.10
	19	5942 ± 6551	20 ± 9	8 ± 3	70 ± 17	23 ± 20	0.29 ± 0.45	6 ± 6	0.72 ± 1.24	44 ± 14	3 ± 4	20 ± 5	24445 ± 24805	2.05 ± 0.42	0.56 ± 0.13	1.65 ± 0.31	0.68 ± 0.08

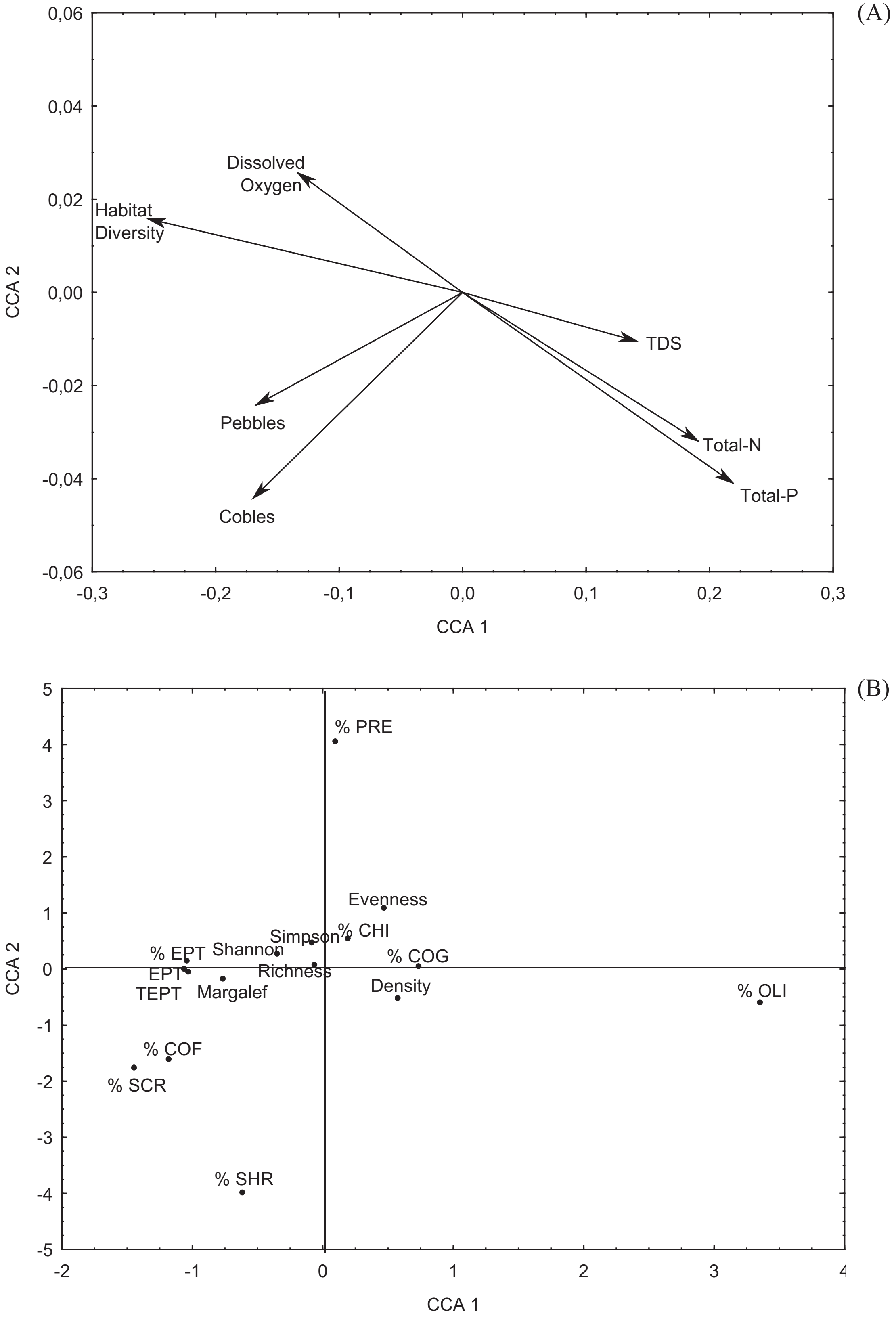

Figure 2. Results of Canonical Correspondence Analysis of environmental factors (A) and benthic macroinvertebrate metrics (B).

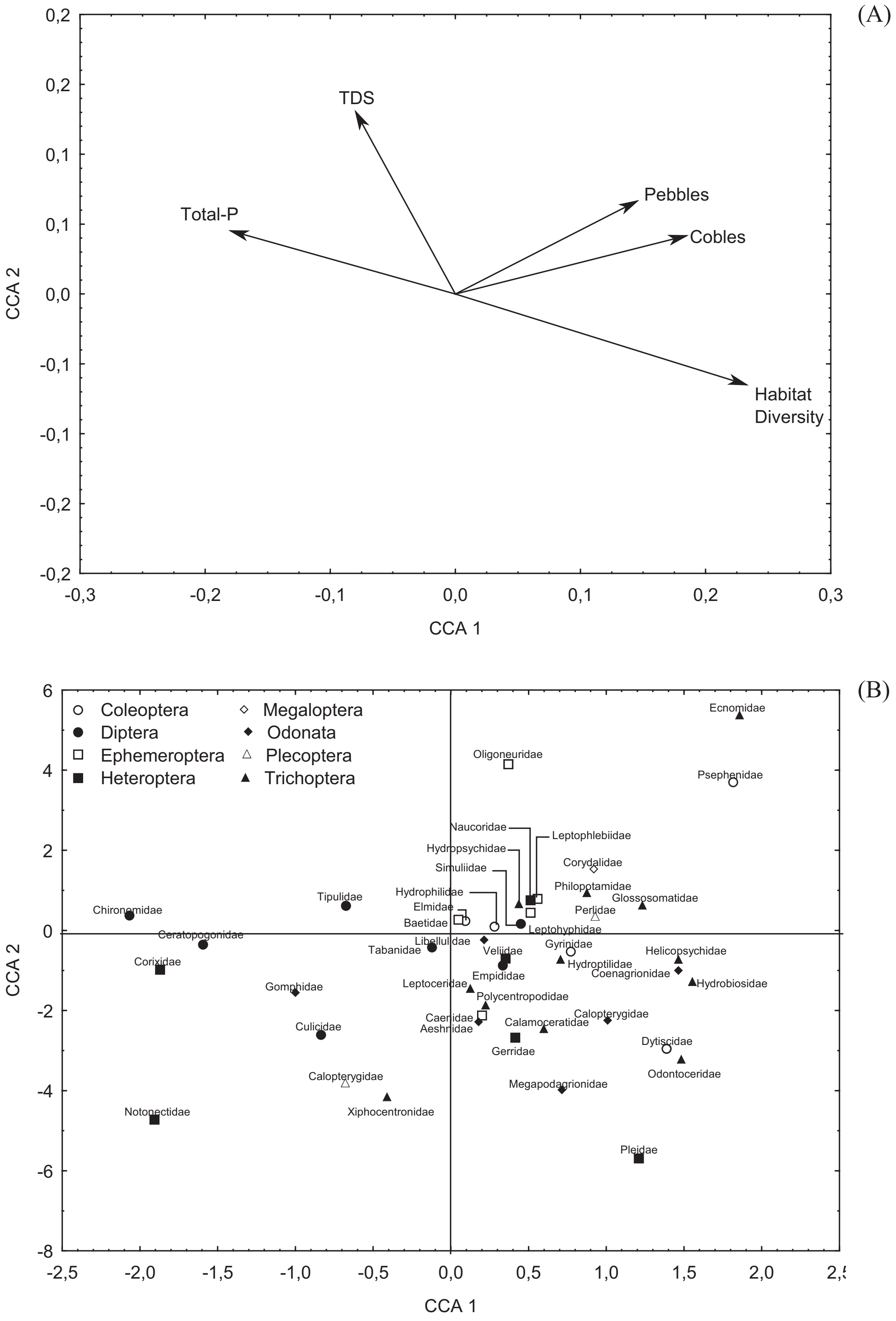

Figure 3. Results of Canonical Correspondence Analysis of environmental factors (A) and benthic macroinvertebrate *taxa* (B).

the effect of anthropogenic activities on the streams, and consequently be able to help propose measures for rehabilitation, conservation, and effective management of these Brazilian ecosystems.

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