Composition and distribution of aquatic Coleoptera (Insecta) in low-order streams in the state of São Paulo, Brazil: influence of environmental factors.

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ABSTRACT: Composition and distribution of aquatic Coleoptera (Insecta) in low-order streams in the State of São Paulo, Brazil: Influence of environmental factors. A comparative study of the coleopteran fauna in low-order streams was carried out within six Conservation Units in São Paulo State, Brazil, in order to make an inventory and assess environmental influences. Twenty streams were sampled, between May and October 2005, with a Surber sampler. Some abiotic factors, such as temperature, stream velocity, electrical conductivity, pH and dissolved oxygen, were recorded at each collection site. Examination of 1,506 specimens of Coleoptera revealed 43 genera distributed in 13 families, one of these (Elmidae) representing 83.47% of all specimens. The abiotic data for the various streams were compared by principal component analysis (PCA) and canonical correspondence analysis (CCA) was employed to verify the influence of environmental variables on species composition and abundance in the sampled streams. The environmental variables indicated various differences among the streams and the distribution of coleopteran species in the streams was best explained by water temperatures and deforestation. Environmental and spatial variables jointly contributed with 20% to explain the variance in assemblage structure, so that the collection of sites analyzed here present low variation, and can be used as reference sites in biomonitoring programmes.
Key-words: aquatic insects, abiotic factors, conservation units, Neotropical region.

RESUMO: Composição e distribuição de Coleoptera aquáticos (Insecta) em córregos de baixa ordem no Estado de São Paulo, Brasil: Influência dos fatores ambientais. O presente trabalho foi realizado em seis Unidades de Conservação do Estado de São Paulo, Brasil, tendo como objetivo inventariar e comparar a fauna de coleópteros em córregos de baixa ordem. Foram amostrados vinte córregos entre os meses de maio e outubro em 2005, com amostrador tipo Surber. Alguns fatores abióticos, como temperatura, velocidade da corrente, condutividade, pH, oxigênio dissolvido da água foram registrados em todos os pontos de coleta. A análise dos 1506 exemplares de Coleoptera indicou a presença de 43 gêneros distribuídos em 13 famílias, das quais Elmidae representou 83,47% do total de indivíduos coletados. Para comparar os córregos em relação aos dados abióticos foi realizada uma Análise de Componentes Principais (PCA) e uma Análise Correspondência Canônica (CCA) para verificar a relação das variáveis ambientais com a composição e abundância das espécies, bem como os córregos amostrados. O conjunto de variáveis ambientais analisadas neste estudo evidenciou algumas diferenças entre os córregos e a temperatura da água bem como o desflorestamento foram as variáveis que melhor explicaram a distribuição das espécies de Coleoptera nos córregos amostrados. As variáveis espaciais e ambientais explicaram cerca de 20% da variância na estrutura das comunidades. Assim, os córregos amostrados aqui apresentaram baixa variação, e podem ser usados como áreas de referência em programas de biomonitoramento.
Palavras-chave: insetos aquáticos, fatores abióticos, unidades de conservação, Região Neotropical.

Introduction

Aquatic coleopterans comprise a group of insects widely distributed in freshwater ecosystems, which can be found in all kinds of aquatic and semiaquatic environments, inhabiting water bodies of all types and sizes that include special ecosystems such as brackish lagoons, temporary pools in hollow trees and bromeliads, marshes, high-altitude lakes, rapids and temporary puddles (Ribera et al., 2002; Merritt & Cummins, 1996).

Coleopterans play an important part in maintaining the ecological equilibrium in aquatic habitats, as these insects occupy niches at several trophic levels, from plant-eating scrapers up to predators (Merritt & Cummins, 1996; Costa et al., 2006). In fact, some species of the superfamily Dryopoidea are often used as diagnostic indicators of water quality (Brown, 1981; Hilsenhoff, 1977) and certain scientists incorporate the order Coleoptera into the EPT (Ephemeroptera, Plecoptera and Trichoptera) Index of water quality (Compin & Céréghino, 2003).

Around 350,000 species of insects are classified as coleopterans. About 6,000 of these species are aquatic or semiaquatic; these are distributed in 27 families (Hutchinson, 1957), of which 16 are known in Brazil (Costa et al., 1988).

The collecting of information on aquatic coleopterans in the Neotropical region is still at an early stage and most of the existing data is scattered in various publications on the taxonomy and ecology of the region (Benetti & Hamada, 2003; Benetti et al., 2003; Passos et al., 2003). No up-to-date list of genera found in Brazil is available, the two existing rarities being those compiled by Blackwelder (1944; 1957, neotropical distribution of coleopterans) and Brown (1981, world distribution of the Elmidae family).

In Brazil, the ever-growing impact of human activity on freshwater bodies, together with the scarcity of data on local coleopterans, has led to general concern on the part of researchers about the possible loss of species, probably including many as yet undescribed. Currently, around 22 species of aquatic coleopterans are named in the IUCN (International Union for the Conservation of Nature) red list of threatened species, under the heading "extinct", including two Brazilian dytiscid species, Megadytes ducalis and Rhantus orbignyi, (IUCN, 2006).

In view of the ecological importance and diversity of coleopterans, together with the lack of data on their occurrence in lotic water, especially in São Paulo State, Brazil, where historically the land has suffered large-scale substitution of the natural biota by sugarcane plantations and cattle ranches, so that only a few natural patches remain (in Conservation Units), this study was elaborated with the aim of listing and comparing the coleopteran fauna in low-order streams in Conservation Units in São Paulo State. The focus on low-order streams is based on the recorded presence of a unique community of insects in these habitats.

Material and methods

Study area

The field material was collected, between May and October 2005, from 20 low-order streams - orders 1 to 3 in Strahler´s hydrological classification (1957) - located in 6 Conservation Units in São Paulo State, in zones of the Atlantic Forest (semideciduous, mixed evergreen and dense evergreen rainforest) and the cerrado, two biodiversity hotspots regarded worldwide as priority conservation areas. The units visited were: Parque Estadual de Campos de Jordão (PECJ), Parque Estadual de Vassununga (PEV), Parque Estadual de Intervales (PEI), Parque Estadual do Morro do Diabo (PEMD), Estação Ecológica de Caetetus (EEC) and Parque Estadual de Furnas do Bom Jesus (PEFBJ).

Sampling and data analysis

In each stream, the main environmental features (presence of riparian vegetation and closed canopy) were noted and physicochemical properties of the water (dissolved oxygen content (D.O.), pH, electrical conductivity and temperature) were measured with a Horiba U-10 multiprobe. In addition, the depth of the water column and width of the stream were recorded and the average speed of the water current was calculated from float-test measurements (Wetzel & Likens, 1991).

The sampling effort employed was 6 sites per stream, including riffles and pools, within a single stretch of 100 m. Samples of the fauna were taken with a Surber sampler with a surface contact area of 30x 30 cm and a 250 mm mesh.

The samples were packed in labeled jars containing water from the same site and transported to the study centre of the conservation unit, where the material was sorted on a bottom-lit surface and chosen specimens were fixed and preserved in 70% ethanol. Later, in the laboratory, coleopterans were identified under stereoscopic low-power microscope and counted. Animals were identified with the help of taxonomic keys, by comparing with descriptions and drawings and, when possible, by a specialist. Some of the identified material was deposited in the aquatic insect collection of the Aquatic Entomology Laboratory of the Department of Hydrobiology at the Federal University of São Carlos (UFSCar, SP, Brazil) and some specimens in the São Paulo Zoology Museum (São Paulo).

To evaluate the relationships among sampling sites based on abiotic and environmental features, we used Principal Components Analysis (PCA) using the correlation matrix to extract the main axes.

To reveal any associations existing between the community structure (composition and taxon abundances) and both the environmental variables and the sampled streams, the data were subjected to canonical correspondence analysis (CCA). This resulted in the streams and the taxa being arranged on an ordination plot at positions that also related to the set of environmental variables. We deleted the variable "Cover" from this analysis, because it had the same variation as "Riparian vegetation". Each variable appears as a vector showing its gradient in ordination space (Ter Braak, 1995). The analysis was carried out with the computer program MVSP ver. 3.1 (Kovach, 2000). To evaluate if there was influence of spatial autocorrelation among sampled sites, we described the spatial structure of our data using eigenvectors generated through the principal coordinate of neighbor matrices (PCNM) method (Griffith & Peres-Neto, 2006). Eigenvectors were extracted using the SAM 2.0 software (Rangel et al., 2006). Variance partitioning between environmental and spatial variables was carried out with VarCan (see Peres-Neto et al., 2006 for a detailed description). We used 10,000 permutations for CCA correction, and the environmental and spatial fractions were compared with 10,000 permutations.

Results

The measurements of abiotic variable data revealed little variability among the sampled streams (Tab. I). Thus, the streams could be characterized as follows: shallow (maximum depth 30 cm), narrow (maximum width 2.7m) and slow flowing (mean speed 0.1-0.6m/s), with well-oxygenated (D.O. 5.9-10.8 $mg.L^{-1}$) water of low electrical conductivity (10-70$mS.cm^{-1}$) and near-neutral pH (4.35-7.12). The streams in the Parque Estadual de Intervales contrasted with the rest, having pH values from 8,8 to 8,3 and high conductivities (56-204 $mS.cm^{-1}$). The lowest water temperatures were recorded in streams in the PECJ (12.8°C), a park located at a high altitude (above 1500m), whereas in the other units the water temperature varied between 16.6 and 24.5°C.

Regarding vegetation, most of the streams in the sample were bordered by riparian forest that provided closed canopy over the river (gallery forest), the exceptions being three streams in the PEFBJ (Marins 1, Marins 2 and Necapedro).

The streams under study were characterized by principal components analysis (PCA), the first two components of which represented 61% of the total variability of the abiotic data. In Fig. 2, the streams are plotted on a graph produced by PCA, whose axes are the first two components. The first of these (36.22% of the variability) was associated positively with D.O. and negatively with electrical conductivity, pH and speed of flow (Tab. II). With respect to this component, the streams (Bocaína, Roda d´água and Cajado) with high conductivity and alkaline pH are clearly separated from the rest. The second component (24.68%) showed positive associations with riparian vegetation and canopy cover and a negative association with water temperature (Tab. II). On this axis, the warmer streams (especially Necapedro, Marins 1 and Marins 2, without vegetation) were separated from those with riparian vegetation and canopy cover. These three streams also showed large variation within PEFJB (Fig. 1), and were the most exposed to the influence of their surroundings.

The streams in the PEI were associated with high values of conductivity, pH and speed of flow, reflecting the region in which they are located. The analysis also shows that the streams in the PECJ are very similar to each other and are associated with riparian vegetation and a closed canopy. In the PEMD, the streams Taquara and Caldeirão were associated with raised D.O. levels, whereas Onça follows the pattern of the PECJ streams; the remaining streams exhibit intermediate values.

During the study, 1,506 coleopteran specimens were collected (larvae and adults). Among these, 43 genera were identified, belonging to 13 families, one of which, Elmidae (riffle beetles), was dominant in every system and represented 83.47% (1257 animals) of all the specimens. It was followed by Dryopidae (longtoed water beetles), Dytiscidae (predaceous diving beetles) and Psephenidae (water-penny beetles), respectively with 4.25% (64), 3.25% (49) and 2.66% (40) (Tab. III).

The most abundant genera were the elmids Heterelmis and Hexacylloepus, responsible for 33% and 22% of the coleopterans, respectively. Among the sampling sites, dominance alternated between these two genera, except in the Barreiro stream (EEC), where other taxa

Table I: Mean physicochemical properties of water and riparian characteristics of each stream in each conservation unit.

Units	Geographic Coord.	Streams	Riparian Veg.	Width (m)	Depth (cm)	Temp. (°C)	Conductivity	DO	pH	Speed (m/s)
PECJ										
1	22°43'07"S/45°27'26"W	Galharada 1	present	2.0	8.0	12.8	11.0	8.5	6.7	0.2
2	22°43'07"S/45°27'26"W	Galharada 2	present	1.5	9.6	15.2	11.4	8.3	6.6	0.5
3	22°14'53"S/45°29'19"W	Guarda	present	1.2	7.0	13.3	11.6	8.5	6.6	0.3
4	22°41'53"S/45°29'02"W	Meio	present	1.4	14.8	14.3	16.3	8.6	6.6	0.4
5	22°41'56"S/45°29'19"W	Sapucaí	present	1.0	11.0	14.0	12.1	8.5	6.6	0.3
PEV										
6	21°38'47"S/47°37'57"W	Pé Gigante	present	1.5	30.0	21.5	10.0	10.3	4.3	0.5
7	21°43'14"S/48°02'54"W	Gruta	present	1.0	10.0	20.8	10.0	10.2	6.7	0.2
PEI										
8	24°16'22"S/48°27'18"W	Bocaina	present	1.2	28.0	16.7	128.0	6.5	8.8	0.4
9	24°17'48"S/48°25'03"W	Rodadágua	present	0.8	20.0	18.1	204.0	6.3		0.6
10	24°16'20"S/48°25'25"W	Cajado	present	0.5	12.6	17.4	56.0	5.9	8.3	0.5
PEMD										
11	22°35'55"S/52°14'47"W	Taquara	present	2.7	5.2	18.4	10.0	10.3	6.3	0.3
12	22°36'17"S/52°18'02"W	Onça	present	1.1	8.6	16.6	30.0	10.4	6.8	0.6
13	22°28'35"S/52°20'34"W	Caldeirão	present	2.5	16.2	20.5	20.0	10.2	6.6	0.3
EEC										
14	22°23'11"S/49°41'10"W	Barreiro	present	0.6	10.0	16.7	70.0	10.8	7.1	0.1
PEFBJ										
15	20°12'55"S/47°26'32"W	Necapedro	absent	1.5	8.9	24.5	37.0	9.3	7.1	0.2
16	20°13'43"S/47°26'15"W	Marins 1	absent	0.4	11.5	20.9	46.0	8.3	6.7	0.2
17	20°13'36"S/47°26'25"W	Marins 2	absent	1.6	11.4	21.1	40.0	9.7	6.7	0.1
18	20°13'18"S/47°26'04"W	João Abib	present	1.1	10.2	21.3	33.0	9.3	6.3	0.1
19	20°12'07"S/47°24'59"W	Pedra	present	1.2	9.2	22.7	25.0	9.8	8.0	0.3
20	20°13'46"S/47°27'37"W	Fuminha	present	0.9	19.8	21.8	33	7.8	7.0	0.2

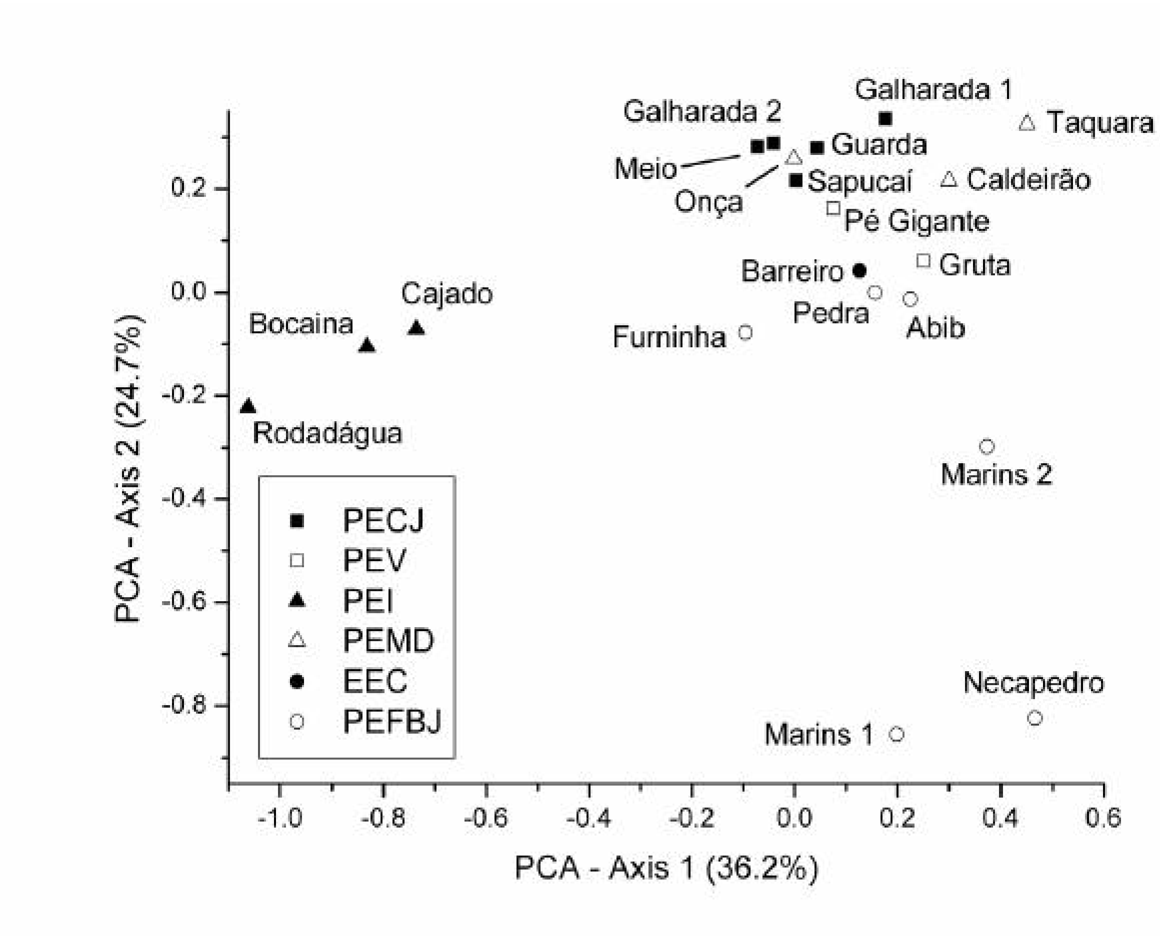

Figure 1: Ordination of streams by PCA, using the two main components (see Table II).

Table II: Correlation of environmental variables with the first two PCA axes and with the first two CCA axes.

Variables	**PCA Loadings**		**CCA Intraset Correlations**	
	Axis 1	**Axis 2**	**Axis 1**	**Axis 2**
Riparian Vegetation	-0.152	0.563	-0.294	0.134
Vegetation Cover	-0.199	0.557	-0,199	0,557
Average Width	0.261	0.270	0.436	0.344
Average Depth	-0.295	-0.050	0.036	0.406
Water Temperature	0.170	-0.414	0.706	-0.265
Electrical Conductivity	-0.431	-0.237	-0.230	-0.319
DO	0.457	0.144	0.497	-0.323
pH	-0.481	-0.149	-0.359	-0.681
Average Speed	-0.357	0.163	0.068	0.322

(dryopid Helichus and dytiscid Desmopachria) dominated (Tab. III).

The highest total abundance (571 specimens) and taxon richness (25 genera) were observed in the PECJ, where Hexacylloepus represented 17.69% and Heterelmis 16.11%. In the PEV, the 245 specimens collected were distributed in 13 genera, of which Heterelmis represented 81.22% (and the highest abundance of any genus in one stream, 194) and Hexacylloepus 9.79%. In the PEFBJ, the 216 specimens were rich in taxa (23 genera), with 40.74% in Heterelmis and 14.35% in Hexacylloepus. In the PEMD, 212 specimens were collected in 19 genera; here, Heterelmis (39.15%) shared the dominance with another elmid, Macrelmis (31.13% total specimens). In the PEI, 142 specimens in 8 genera were collected, 54.22% of which belonged to Hexacylloepus. In the EEC, 120 specimens were taken, the most abundant genera being Helichus (38.33%) and Desmopachria (19.17%).

Both environmental and spatial variables had a low influence on assemblage composition among reference sampling sites. Variance partitioning indicated that 80.0% of the

Table III: Number of water beetles in each taxon recorded in each stream (grouped by conservation units). For stream names, see Table I.

	PECJ					PEV		PEI			PEMD			EEC	PEFBJ					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Chrysomelidae sp1															1					
Dryopidae																				
Helichus	1				1									46						3
Pelonomus					3		2		1	1				6						
Dytiscidae																				
Bidessonotus																	1			
Desmopachria	1													23			1			
Ilybius												1			1					
Laccodytes						3														
Laccophilus												1		5						
Liodessus												1		1						
Rhantus																			1	
Elmidae																				
Austrolimnius	45	22	8	8	2						1									
Cylloepus	19	2	2	3	1	2						1	2	3		11	1	2		
Heterelmis	31	3	24	12	22	5	194	6	3	8	25	48	10	20		27		11	20	30
Hexacylloepus	36	5	65	46	29		24	33	3	41		4		4	1	4				26
Huleechius	4															1				
Macrelmis	1	2			1						5	48	13			4	1	4		4
Macronychus						1														1
Microcylloepus	9	1		3	2			4	2	1		1		1		1		1		
Neoelmis	15	9	9	10	4	2		8	1			1							15	
Ordobrevia	1																			
Phanocerus		1	2	1	2			5		5				6						
Promoresia	2		2		1															
Stegoelmis	1	3	2																	
Stenelmis			1		1	3												5		
Xeneimis	6		39	8	4	2														9
Zaitzevia												1								

Table III: Cont.

	PECJ					PEV		PEI			PEMD			EEC	PEFBJ					
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Gyrinidae																				
Gyretes						2					14	2	4							
Hydraenidae																				
Hydraena																			2	
Hydrophilidae																				
Anacaena		1	2	6										2						
Berosus																1	1	1		
Derallus												1								
Helocombus												1		1						
Laccobius													1							
Tropisternus							2					1								1
Lampyridae sp1				1																
Lutrochidae																				
Lutrochus			1					3		3		2	3	2					1	
Noteridae																				
Hydrocanthus																3				
Suphisellus											2									
Psephenidae																				
Ectopria			9																	
Psephenus	4	2		2	4							18			3	2		3	2	
Ptilodactylidae																				
Anchytarsus							2			14									9	
Scirtidae																				
Prionocyphon					1															
Scirtes						1														
Total	**176**	**51**	**166**	**100**	**78**	**21**	**224**	**59**	**10**	**73**	**47**	**132**	**33**	**120**	**6**	**54**	**5**	**27**	**50**	**74**

variance was unexplained, 7.1% was only due to environmental variables (p › 0.05), 3.7% only due to spatial structure (p › 0.05), and 9.1 due to the joint effect of environmental and spatial variables. There was no difference in the contribution of environmental and spatial fractions (p = 0.65). Thus, environmental variables contributed with 14.2% of the variance. In the analysis of all the data by CCA, there was influence of D.O., vegetation, electrical conductivity, stream width and speed of flow on the ordination of the streams along the first axis, while temperature is the main influence along the second (Tab. II).

When CCA was applied to the distribution of the coleopteran taxa, clear evidence was found of a separation of the elmid specimens from those in other families. The same was seen for the streams of the PEI and the PECJ, and both were related to the presence of vegetation and canopy cover (Fig. 2). Other taxa, such as Bidessonotus (Dytiscidae), Berosus (Hydrophilidae) and type I Chrysomelidae, were strongly correlated with high water temperature and the absence of vegetation and canopy, features that distinguished the Necapedro, Marins 1 and Marins 2 streams from others in the PEFBJ. In this unit, the CCA results (Fig.2) indicated significant variation among the streams, while those in the PECJ and PEI exhibited very little variation.

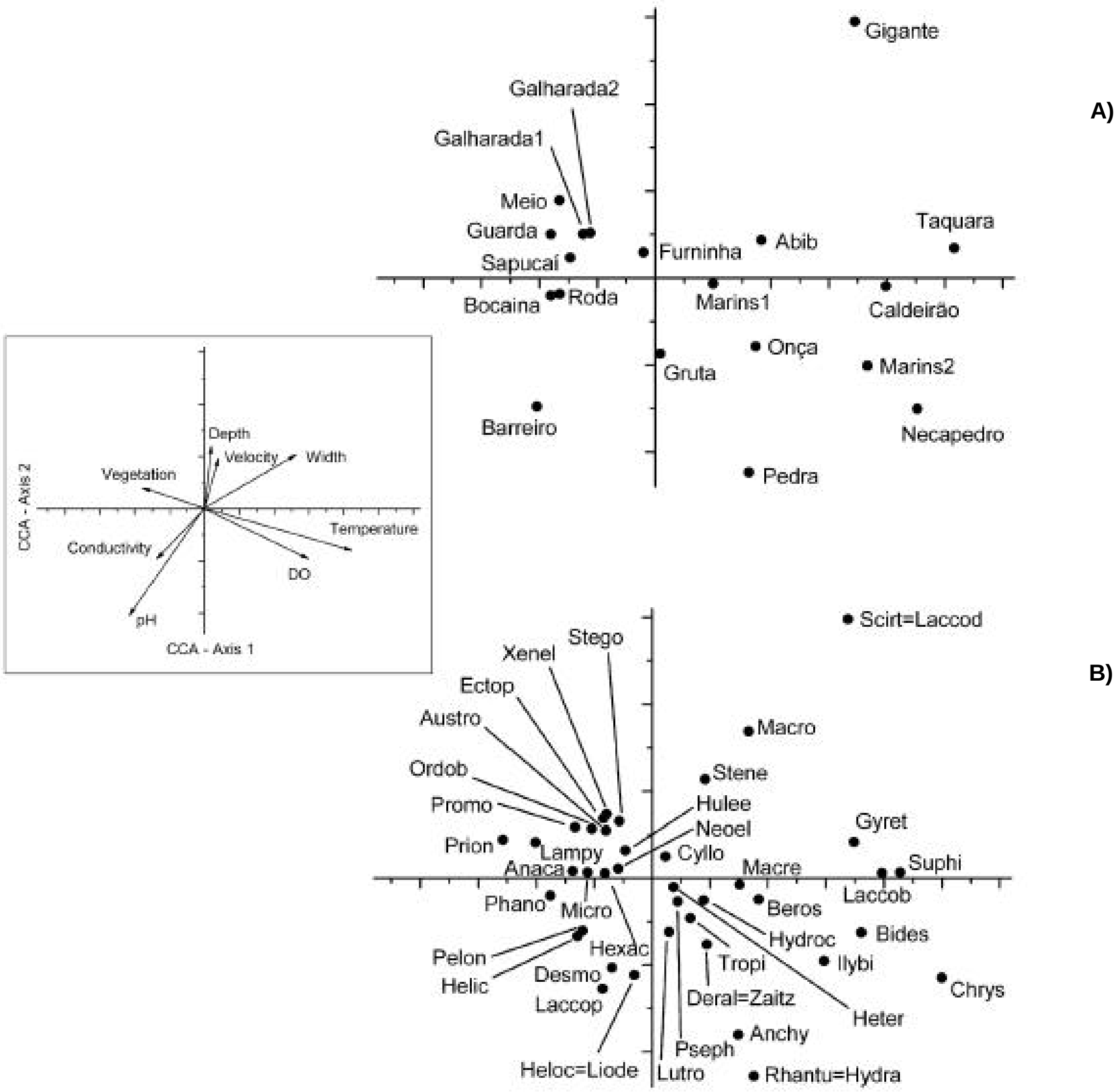

Figure 2: Canonic correspondence analysis (CCA): ordination diagrams for (A) streams and (B) coleopteran genera, based on the numerical distributions of 44 genera sampled in 20 streams in the 9 recorded environmental variables, whose correlations with the axes are visualized as arrows and given in the Table II Taxon names are abbreviated; see Table III for complete names.

Discussion

In general, environmental factors regulate the occurrence, amount and distribution of aquatic invertebrates. In the streams under study, within the six units, the abiotic factors in question did not differ greatly. Exceptions were found in the pH of the Pé de Gigante stream (PEV) and in the electrical conductivity and pH of the water in the PEI streams.

Hutchinson (1957) points out that the pH and electrical conductivity of river water can be determined by the soil composition in the drainage basin of the river. The acidic water in the Pé de Gigante stream reflects the predominance of acid soils in the region of this park (Batalha, 1997). In general, lotic water in Brazil tends to be neutral or acid (Maier, 1978).

The high values for conductivity and pH recorded in the PEI streams also reflect the type of soil in the Serra Paranapiacaba, which is typically karstic with outcrops of limestone (Mantovani, 1994). The latter contributes a high concentration of bicarbonate ions, reflected in high electrical conductivity and alkaline pH. In natural water, several bicarbonates may be found, arising from carbonate rocks dissolved in weakly acid water, and these determine the physicochemical characteristics of the water (Allan, 1995).

The analysis of riverside vegetation and closed canopy cover shows a clear difference between the Necapedro, Marins 1 and Marins 2 streams (PEFBJ), which lack such vegetation, and all the others. These three streams are exactly those that suffer the strongest effects from their surroundings. It should be emphasized that large cattle farms threaten the physical integrity of the streams near the borders of the park, as the animals come into the park in search of food and water. The best-conserved vegetation is restricted to the remoter areas inside the park. Preservation of a riparian zone of forest alongside a river is crucial to the stable form of the water channel and the containment of bank erosion, apart from increasing the amount of allochthonous leaves, wood and fruit carried on the current. Such material adds to the heterogeneity of the environment and hence increases the amount of food and niches available for colonization (Kikuchi & Uieda, 1998; Hynes, 1970).

The taxon richness and abundances observed in this study of aquatic coleopterans were consistent with published descriptions of low-order lotic habitats, in which several authors point to the Elmidae as the most commonly found and numerous family in such streams (Brown, 1987; Spangler, 1981). The large number of elmid beetles in the streams can be explained by their numerous adaptations to the physical limits imposed by the lotic ecosystem, which include: physiological (respiration from plastron air bubble), morphological (developed tarsal claws; small size) and behavioral (wide dispersal and selection of microhabitats) adaptations. Other aquatic beetle families such as the Psephenidae are also restricted to flowing water habitats and depend on a firm surface on which to attach; psephenid larvae thus have a strongly depressed body (Brown, 1987; Ward, 1992). Other families of coleopterans less associated with low-order lotic systems, such as Hydrophilidae (water scavenger beetles) and Noteridae (burrowing water beetles), were found in these streams, generally in pools.

The particular abundance of the elmid genera Heterelmis and Hexacylloepus can also be explained by their preference for streams with hard beds of rocks and pebbles and sunken foliage (Brown, 1987; Hynes, 1970). On the other hand, the genera Helichus (scrapers) and Desmopachria (predators) should appear where fragments of wood and fruit have collected, along the sampled stretches, as in the EEC. Thus, the dominance pattern observed in the streams can be understood in terms of their environmental features, the availability of food sources and the feeding types of the aquatic beetles.

The low variability of the coleopteran fauna in relation to spatial and environmental variables suggest that water beetles are an interesting group to include in biomonitoring studies. Sánchez-Fernández et al., (2006) showed that Coleopteran species richness is strongly correlated with total macroinvertebrate species richness, and that both genera and families can be used as biodiversity surrogates in a Mediterranean region. Further, coleopteran fauna could be included in more traditional indexes of water quality, as already used by Compin & Céréghino (2003) in France. Although more studies are necessary, our study indicates that water beetle data from the reference sites studied could be used to evaluate different impacts at different locations in São Paulo state.

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