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Influence of water chemistry and environmental degradation on macroinvertebrate assemblages in a river basin in south-east Brazil

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Abstract

Benthic macroinvertebrate assemblages, water chemistry variables and environmental degradation were investigated in an Atlantic Forest region in Brazil. Seven sites of the Guapimirim river basin were studied during three sampling periods based on the rain regime: end of wet season (May 1998), dry season (August 1998), and wet season (January 1999). Four substrates were collected at each site: sand, stony substrates, litter in pool areas and litter in riffle areas. Relationships between macroinvertebrate assemblages, water chemistry variables and environmental degradation were examined using canonical correspondence analysis (CCA). According to CCA, concentrations of dissolved oxygen and chloride, and the environmental degradation, measured by the Riparian Channel Environment index, exhibited the strongest relationship to macroinvertebrate assemblages. Overall, the loss of community diversity measured by the Shannon Index along the degradation gradient was observed. Some taxa were shown to be sensitive to water pollution, especially among Plecoptera, Trichoptera, Coleoptera and some Ephemeroptera, while others such as Simuliidae, Odonata and molluscs were tolerant to moderate levels of pollutants. The Chironomidae were the only group tolerant to a high level of pollutants and degradation.

Introduction

Many problems such as accelerated deforestation, unplanned urban development and point source pollution, which involve conservation of freshwater resources in developing countries should be considered since the treatment of domestic wastes is scarce or absent (Dudgeon, 1992). Streams in agricultural and urban landscapes are affected by numerous natural and anthropogenic disturbances. These disturbances may affect resource quality and availability, physical and chemical conditions, ecological integrity as well as disrupt ecosystem processes and biotic structures (Resh et al., 1988). Alterations to the land-use adjacent to water courses, increased nutrient levels from point and non-point sources, organic enrichment from domestic and industrial sewage, among others are typical of urban areas. These factors play an important role in the stream physical characteristics and may affect macroinvertebrate assemblages (Hynes, 1970; Ward, 1992).

Most studies considering macroinvertebrates in South America have dealt with the Andean region (Turcotte & Harper, 1982; Flecker & Feifarek, 1994; Jacobsen & Encalada, 1998) or the Amazon River and its tributaries (Junk et al., 1989). However, the Atlantic Forest is one of the richest and most threatened ecosystems in the world (Dean, 1995). Also, the rivers and streams within the Atlantic Forest remnants are responsible for the water supply of more than 70% of the population in Brazil. Despite this, there are only a few studies on the macroinvertebrate fauna in this region (e.g., Baptista et al., 2001; Melo & Froehlich, 2001). In order to improve conservation of water resources in tropical areas, it is necessary to identify the factors influencing tropical freshwater communities which will enable the development of models that have been achieved in temperate regions (Jackson & Sweeney, 1995; Melo & Froehlich, 2001).

The aims of this study were: (1) to examine stream macroinvertebrate distributional patterns along an environmental and water chemistry gradient in the Guapimirim river basin, and (2) to identify which water chemistry and environmental variables are associated with the macroinvertebrate distribution pattern.

Description of sites

This study was carried out in the municipality of Guapimirim (22° 32′ 14″ S, 42° 58′ 55″ W), State of Rio de Janeiro, Brazil. This region is ecologically important due to its three areas of permanent conservation, Parque Nacional da Serra dos Órgãos, Estação Ecológica do Paraíso, and Área de Proteção Ambiental Guapimirim, all of which carry Atlantic Forest remnants. This river is also important due to its flow into the Guanabara Bay, which holds the largest mangrove ecosystem in the State. Accelerated deforestation and the absence of adequate wastewater treatment are the major environmental problems in the region. Most domestic wastes from the city of Guapimirim (around 32 000 inhabitants) enter untreated in the three main tributaries of the Guapimirim River.

Macroinvertebrates, as well as physical, chemical and environmental variables were sampled at seven sites on three tributaries of the Guapimirim River (Fig. 1). One site was inside a National Park (site A), upstream of Guapimirim, representing a well-preserved area. The other six sites received different concentrations of domestic waste. Three sites (B, C, D) were only slightly influenced by the urban area, exhibiting riparian forest (around 15 m wide) and natural mechanisms of retention such as rocks and logs. Two sites (E, F) were located in the urban area, receiving a higher concentration of domestic waste. At these sites the river was artificially channeled, silt was common, and the riparian vegetation was scarce, composed mainly by pioneer trees and shrubs. One site was located downstream from the city, received gross pollution, was channeled, had no riparian vegetation, and the river bed was dominated by silt and some rocks partially covered with fine sediments (site G).

All sites were located on a third order stream, except site G which was fourth order, although at about the same altitude (between 40 and 100 m a.s.l.) and with similar climatic conditions. The furthest distance between sites was 4.5 km. Another characteristic of all the sites was the occurrence of spates, mostly during summer – from December to April, because the headwaters have a high slope and are located at about 2000 m.a.s.l.

Materials and methods

Field and laboratory procedures

A Surber sampler (mesh size 125 μm, 0.09 m^2 area) was used to collect the benthic fauna. Four composite samples were collected (sand, stony substrates, litter in pool areas and litter in riffle areas) at each sampling site, except in site G, where litter substrates were absent. Each composite sample was formed by three pseudo-replicates of each substrate. In this study, site samples were pooled representing one sample per site.

In the field, samples were preserved immediately in 80% ethanol and packed for examination in the laboratory. Sampling was performed on three occasions, determined by the rain regime: end of the wet season (May 1998), dry season (August 1998) and wet season (January 1999).

Each time a biological sample was taken, field measurements of pH, water and air temperature, as well as mean values of width, water depth, and current velocity (using the flotation method at two transects 10 m distant from each other) were recorded. Also, water was sampled and frozen in order to measure further physical and chemical variables in laboratory: conductivity, alkalinity, hardness, NH_4-N, NO_3-N, PO_4-P, Cl^-, DO, and BOD_5.

An environmental assessment of each site was performed at each sampling period, based on the Riparian Channel Environment index (RCE) proposed by Petersen (1992). This index is calculated by choosing the best description that fits each of the 16 environmental characteristics such as land-use pattern, hydrological parameters, riparian and aquatic vegetation, then summing the scores and comparing the final result with a table that indicates the environmental condition of the site.

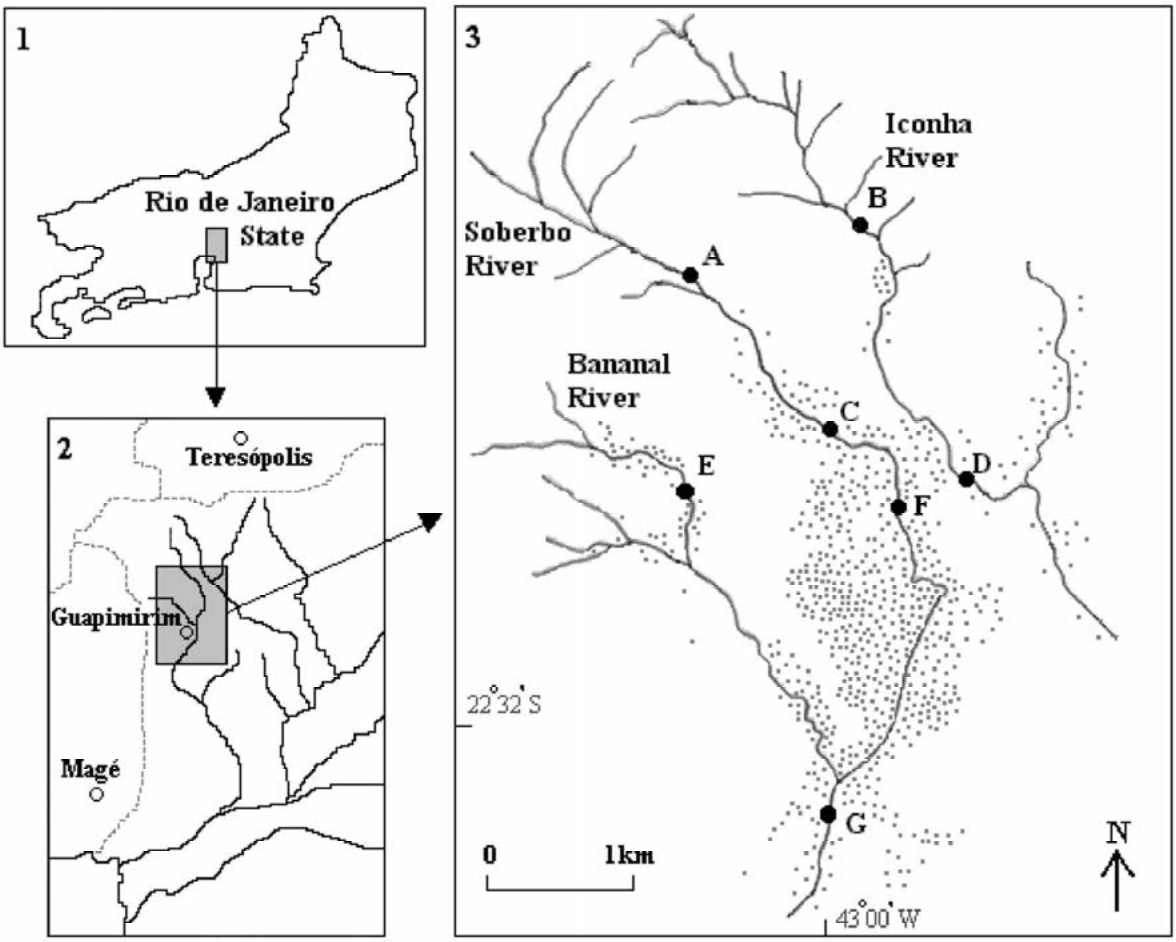

Figure 1. Section of the Guapimirim River basin, Rio de Janeiro State, indicating the sampling areas (A–G). Dots represent buildings according to 1:50 000 map.

In the laboratory, all biological samples were examined under a stereoscopic microscope. Macroinvertebrates were sorted, counted and identified mostly at genus level using the available taxonomic keys (Odonata-De Marmels, 1990; Nieser & de Melo, 1997; Plecoptera-Froehlich, 1984; Dorvillé & Froehlich, 1999; Trichoptera-Angrisano, 1995; Wiggins, 1996; Ephemeroptera-Dominguez et al., 1992; for common taxa – Merrit & Cummins, 1996), and the aid of specialists.

Data analysis

A Standardized Mantel Statistic (Manly, 1986; Sokal & Rohlf, 1995) was applied to test for matrix correspondence between the biological data and the RCE scores for each sampling period. The Mantel test evaluates the null hypothesis of no relationship between two dissimilarity (distance) or similarity matrices and a correlation index can be used as a measure of the strength of relationship between the two distance matrices. For each matrix, the Bray–Curtis distance index was calculated and the Pearson correlation was used as a measure of the strength of relationship between the paired distance matrices (see Smouse et al., 1986).

For each biological sample, number of taxa, abundance, Shannon Index of diversity, and the Pielou index of evenness were calculated according to Ludwig & Reynolds (1988).

Due to different taxonomic resolution, macroinvertebrate taxa were treated as operational taxonomic units (OTU). In this study, some taxa were excluded from Chironomidae which we treated separately as they are easily recognizable units and perform different feeding functions: subfamily Tanypodinae, gen-

Table 1. Chemical and environmental variables (mean, minimum, maximum) at the seven sites on the three sampling occasions

Mean values	Class 1		Class 2		Class 4		Class 5
	A	B	C	D	E	F	G
pH	7.2	7.1	7.2	7.1	7.1	7.3	6.8
	(7.1-7.2)	(6.9–7.2)	(7.1–7.2)	(6.9–7.2)	(7.0–7.2)	(7.2–7.4)	(6.7-06.9)
Dissolved Oxygen	9.6	9.3	8.9	9.3	9.0	9.2	5.2
(mg l^{-1})	(9.3–10.5)	(8.7–10.0)	(8.6–9.5)	(8.5–10.0)	(8.5–10.0)	(8.3–10.0)	(3.5–6.1)
BOD$_5$ (mg l^{-1})	0.7	1.1	1.4	3.6	3.8	1.8	12.1
	(0.2–1.5)	(0.5–1.6)	(0.9–2.2)	(0.3–7.5)	(2.4–6.0)	(1.5–2.4)	(4.9–19.5)
NH$_4$-N (mg l^{-1})	0.02	0.01	0.01	0.01	0.01	0.03	2.09
	(0–0.06)	(0–0.02)	(0–0.02)	(0–0.02)	(0–0.02)	(0.01–0.06)	(1.28–2.88)
NO$_3$-N (μg l^{-1})	1.3	1.5	1.3	1.8	2.0	1.8	2.0
	(1.3–1.3)	(1.3–1.8)	(0.9–1.8)	(0.9–2.7)	(1.3–3.5)	(1.3–2.7)	(1.3–3.5)
PO$_4$-P (mg l^{-1})	0.02	0.03	0.02	0.07	0.14	0.39	0.23
	(0.01–0.04)	(0.01–0.08)	(0.01–0.03)	(0.02–0.19)	(0.05–0.26)	(0.14–0.51)	(0.16–0.33)
Cl$^-$ (mg l^{-1})	1.6	2.3	1.7	3.3	3.8	2.8	5.0
	(0.9–2.2)	(1.5–3.4)	(1.5–2.1)	(2.4–4.4)	(2.4–5.4)	(0.9–5.4)	(2.4–8.3)
Alkalinity (mg l^{-1})	12.7	15.1	14.2	19.1	21.4	16.2	30.5
	(10.0–16.0)	(11.0–22.0)	(8.6–18.0)	(11.4–24.0)	(14.3–30.0)	(8.6–22.0)	(21.4–42.0)
Conductivity	14.5	17.0	20.5	25.4	32.5	25.0	61.2
(μS cm^{-1})	(8.5–25.0)	(10.0–30.0)	(9.0–40.0)	(11.2–35.0)	(12.5–45.0)	(10.0–35.0)	(40.0–100.0)
Hardness (mg l^{-1})	14.7	16.2	14.0	19.8	21.0	14.8	24.3
	(9.5–18.0)	(14.5–18.0)	(10.5–16.0)	(16.0–26.0)	(20.0–22.0)	(11.5–19.0)	(14.5–32.5)
RCE score	338	280	234	228	151	109	26

era *Stenochironomus* and *Xestochironomus* (subfamily Chironominae).

A canonical correspondence analysis (CCA) was performed to determine relationships between environmental variables and the respective biotic components. According to ter Braak (1986), CCA is a non-linear technique used to relate variation in biotic properties to measured variation of the environment. Environmental data were standardized by deducting each value from its mean and dividing it by its standard deviation, therefore reducing the effects of different scales in different characters (Manly, 1986). In addition, biological data were $\log_{10}(x + 1)$ transformed to approach the assumed conditions of normality and homocedasticity of the data (Sokal & Rohlf, 1995).

All macroinvertebrates were classified into functional feeding groups (FFG) based on Merrit & Cummins (1996), Angrisano (1995) and personal observations (Ephemeroptera, Plecoptera and Trichoptera, unpublished data). In some cases it was impossible to assign a single FFG to a taxon, so the total number of specimens of the taxon was divided among the FFGs.

Results

Physical, chemical and environmental data

The RCE scores classified sites into four classes: class 1 – excellent (site A); class 2 – very good (sites B, C, D); class 4 – regular (sites E , F); and class 5 – poor (site G). No site was assigned to 'good' classification.

The Mantel test indicated that in all three sampling periods the biological data were correlated with RCE score matrices (p<0.05, therefore rejecting the null hypothesis of no relationship). As this was an important factor in explaining macroinvertebrate distribution, we used this classification scheme in further analysis. Nutrient concentration increased with domestic and industrial effluents, reaching its maximum at site G (Table 1). High values of hardness and conductivity were found at sites of class 4, which were located in the urban area. The marked reduction in dissolved oxygen and the increase in BOD$_5$ at site G indicated organic enrichment.

Table 2. Values for total richness and diversity at the seven sites

	Class 1		Class 2		Class 4		Class 5
	A	B	C	D	E	F	G
Total richness	70	57	60	57	52	54	19
No. of individuals	3718	3613	11 803	6822	13 687	19 346	8107
Evenness (J)	0.611	0.527	0.420	0.428	0.483	0.408	0.056
Diversity (H')	2.60	2.13	1.72	1.73	1.91	1.63	0.16

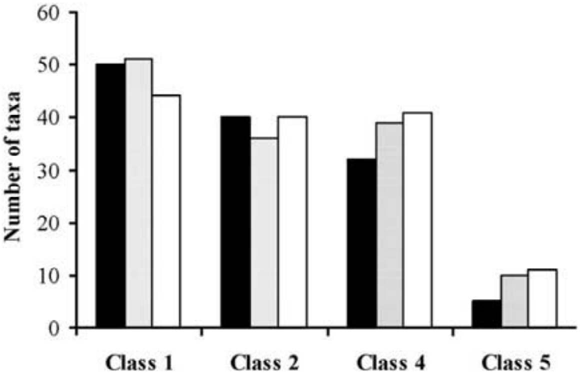

Figure 2. Number of taxa collected at the four classes of decreasing integrity at the end of wet season, dry season and wet season in the Guapimirim River basin. Class 2 refers to mean values for sites B, C and D (ranges: end of wet season, 39–41; dry season, 31-047; wet season, 38–42), and Class 4 refers to mean values for sites E and F (ranges: end of wet season, 33–35; dry season, 38–40; wet season 40–42). (Black – end of wet season; Grey – dry season; White – wet season).

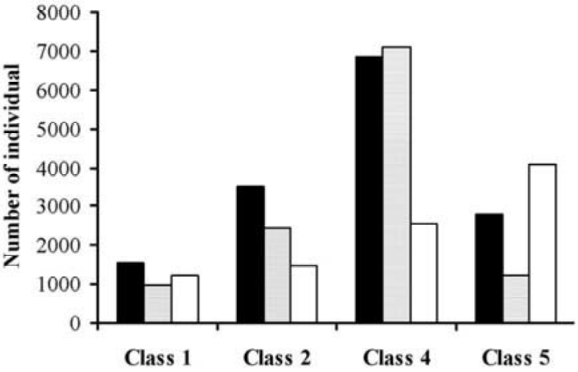

Figure 3. Number of individuals collected at the four classes of decreasing integrity at the end of wet season, dry season and wet season in the Guapimirim River basin. Class 2 refers to mean values for sites B, C and D (ranges: end of wet season, 1182–5627; dry season, 474–6314; wet season, 719–1854), and Class 4 refers to mean values for sites E and F (ranges: end of wet season, 971–12 808; dry season, 4571–9665; wet season, 1967–3105). (Black – end of wet season; Grey – dry season; White – wet season).

Biological data

A total of 67 096 specimens were collected, with 86 taxa identified belonging to 11 orders and 49 families. Overall, a decrease in taxonomic richness was observed from sites of class 1 to class 5. Site A had the highest richness (70 taxa), while site G had the lowest (19 taxa). Taxonomic richness exhibited a consistent pattern throughout the year, since site A always had the greatest richness (50, 51 and 44, respectively) and site G the lowest richness (5, 10 and 11, respectively) (Fig. 2). The Shannon Index exhibited the same pattern (2.60 in site A and 0.16 in site G) (Table 2).

Six invertebrate groups exhibited their highest richness at site A: Trichoptera (15 taxa), Coleoptera (14), Ephemeroptera (13), Diptera (12), Hemiptera (five) and Plecoptera (four). In intermediately degraded sites Mollusca (six taxa at class 4 sites) and Odonata (seven taxa at classes 2 and 4) occurred predominantly.

Considering the total number of individuals collected, site A had the lowest abundance (3718 specimens), while the highest abundance occurred at class 4 (33 033 individuals) (Fig. 3). Coleoptera, Diptera, Ephemeroptera, Mollusca, Odonata and Trichoptera were very abundant at class 4 sites, while Lepidoptera and Plecoptera were most abundant at site A. There was a marked dominance of Chironomidae and Simuliidae at all sites and periods, except for site E (dominated by Staphylinidae (in May) and *Melanoides* (in January)). The Chironomidae were present in higher numbers with increasing degradation, while the Simuliidae showed preference for sites with an intermediate degree of pollution (Table 3).

Ordination

The ordination results of the canonical correspondence analysis (CCA) on the relative importance of macroinvertebrate-environment variation are given in Table 4. All eigenvalues were low, indicating that

Table 3. CCA ordination codes, percentage composition, and total numbers of macroinvertebrates collected at each site in the Guapimirim river basin

Taxa	CCA codes	FFG	Class 1		Class 2		Class 4		Class 5	Total number
			A	B	C	D	E	F	G	
Blattaria	Bla	F	81.5	18.5	0	0	0	0	0	27
Dryopidae		R	100	0	0	0	0	0	0	1
Hexanchorus		CP/R	13.6	7.5	52.3	6.6	7.5	12.3	0.2	455
Heterelmis	Het	CP/R	8.9	11.9	14.9	17.7	32.3	14.2	0	2268
Macrelmis		CP/R	80.0	7.5	5.0	2.5	0	5.0	0	40
Microcylloepus		CP/R	22.6	9.4	41.5	5.7	20.8	0	0	53
Neoelmis		CP/R	5.7	5.7	10.4	17.0	54.7	6.6	0	106
Ordobrevia		CP/R	50.0	0	50.0	0	0	0	0	2
Phanocerus		CP/R	12.9	12.9	16.1	54.8	0	3.2	0	31
Xenelmis		CP/R	4.8	66.1	6.5	6.5	6.5	9.7	0	62
Elmidae sp1		CP/R	0	90.9	9.1	0	0	0	0	11
Gyrinidae	Gyr	P	50.0	50.0	0	0	0	0	0	4
Hydrophylidae		CP	81.1	0	5.4	2.7	0	0	10.8	37
Lutrochidae		CP	57.6	6.1	18.2	3.0	3.0	12.1	0	33
Psephenus		R	18.2	0	9.1	54.5	9.1	9.1	0	11
Staphylinidae		P	0.5	1.8	10.3	8.7	25.8	52.9	0	2666
Atrichopogon	Atr	P	20.0	0	0	20.0	0	0	60.0	5
Culicoides		P	6.2	27.7	9.2	32.3	6.2	18.5	0	65
Chironomidae		CP	5.1	6.9	10.2	11.6	6.5	28.9	30.9	25 533
Stenochironomus		F	17.6	13.5	28.4	6.8	21.6	12.2	0	74
Xestochironomus		F	16.7	16.7	16.7	16.7	16.7	16.7	0	1398
Tanypodinae		P	23.3	11.4	14.5	15.4	12.2	19.6	3.6	6
Dixidae	Dix	CP	50.0	33.3	16.7	0	0	0	0	6
Empididae		P	15.5	6.8	7.4	19.6	11.5	38.5	0.7	148
Maruina		CP/R	11.9	6.8	49.4	7.2	14.9	9.8	0	235
Pericoma		CP	0	0	0	0	100	0	0	1
Simuliidae		CF	2.1	1.5	26.4	9.3	27.9	32.3	0.5	23 682
Stratyomidae		CP	28.6	28.6	14.3	14.3	0	14.3	0	7
Tipulidae		CP/F	13.3	6.7	13.3	61.3	2.7	2.7	0	75
Baetis		R	6.7	13.5	3.4	37.1	4.5	21.3	13.5	89
Baetodes		R	9.0	5.1	34.5	4.4	29.8	17.2	0	1269
Camelobaetidius		R	14.9	1.8	66.7	0.9	10.5	5.3	0	228
Dactylobaetis	Dac	R	94.3	0	0	3.8	0	1.9	0	53
Cloeodes		R	15.2	10.1	17.7	17.3	4.0	35.0	0.7	277
Pseudocloeon		R	9.9	22.3	16.1	17.6	5.9	27.2	0.9	323
Caenis	Cae	R	100	0	0	0	0	0	0	3
Leptohyphes	Lep	CP	4.0	18.4	24.2	12.3	20.0	20.9	0.2	1086
Tricorythodes		CP	21.8	2.6	34.6	11.5	2.6	26.9	0	78
Askola		CP	100	0	0	0	0	0	0	2
Farrodes	Far	CP	45.8	11.0	8.8	15.9	11.5	7.0	0	227
Hylister		CF	0	0	0	100	0	0	0	1
Miroculis		CP	88.9	0	5.6	0	5.6	0	0	18
Thraulodes		CP	100	0	0	0	0	0	0	1
Cryphocricos		P	5.1	20.5	10.3	10.3	28.2	25.6	0	39
Limnocoris	Lim	P	66.7	0	0	33.3	0	0	0	3
Neotrephes		P	100	0	0	0	0	0	0	4
Notonecta		P	100	0	0	0	0	0	0	1
Rhagovelia		P	22.7	59.7	2.5	6.7	3.4	5.0	0	119

Continued on p. 131

Table 3. Continued

Taxa	CCA codes	FFG	Class 1		Class 2		Class 4		Class 5	Total number
			A	B	C	D	E	F	G	
Parapoynx		R	32.4	11.8	38.2	0	8.8	8.8	0	34
Petrophila		R	14.3	14.3	42.9	0	0	28.6	0	7
Corydalus		P	13.0	21.7	21.7	13.0	13.0	17.4	0	23
Ancylidae	Anc	R	0	0	0	0	89.2	10.8	0	74
Bivalvia	Biv	CF	0	0	3.6	3.6	80.4	12.5	0	56
Lymnaea		R	0	0	0	0	0	0	100	1
Physa	Phy	R	0	0.5	0.9	2.7	38.5	56.0	1.4	439
Biomphalaria	Bio	R	0	0	2.5	3.6	17.1	76.5	0.3	357
Melanoides	Mel	R	0	0	0.4	0.7	94.5	4.2	0.2	1648
Limnetron		P	0	20.0	0	0	80.0	0	0	5
Hetaerina		P	55.6	0	22.2	0	11.1	11.1	0	18
Argia	Arg	P	5.9	11.8	23.5	5.9	41.2	11.8	0	17
Cyanogomphus		P	0	0	50.0	50.0	0	0	0	2
Epigomphus		P	0	60.0	40.0	0	0	0	0	5
Gomphoides	Gom	P	0	22.2	11.1	0	44.4	22.2	0	9
Progomphus	Pro	P	0	7.7	7.7	7.7	76.9	0	0	13
Brechmorhoga		P	3.2	6.5	12.9	22.6	19.4	35.5	0	31
Elasmothemis	Ela	P	0	0	0	33.3	11.1	44.4	11.1	9
Gripopteryx		CP	100	0	0	0	0	0	0	3
Paragripopteryx	Par	CP	75.0	16.7	0	0	0	8.3	0	12
Anacroneuria	Ana	P	81.3	3.9	12.1	2.0	0.4	0.4	0	256
Macrogynoplax		P	100	0	0	0	0	0	0	2
Phylloicus		F	38.1	16.5	16.5	14.4	7.2	7.2	0	97
Protoptila		CF	68.1	12.8	10.6	6.4	2.1	0	0	47
Helicopsyche		R	19.5	3.7	4.0	0.3	27.1	45.3	0	892
Atopsyche	Ato	P	66.7	33.3	0	0	0	0	0	3
Barypenthus		CP	100	0	0	0	0	0	0	1
Leptonema		CP	3.4	3.4	44.8	13.8	17.2	17.2	0	29
Macronema		CP	100	0	0	0	0	0	0	1
Smicridea		CP	3.0	13.0	19.5	6.3	40.2	17.7	0.2	1798
Alisotrichia		CP	8.2	6.1	8.2	6.1	42.9	28.6	0	49
Ochrotrichia		CP	7.5	1.0	69.7	1.0	2.5	17.9	0.5	201
Nectopsyche	Nec	CP/F	60.0	20.0	13.3	3.3	0	3.3	0	30
Leptoceridae sp1.		CP	36.8	10.5	31.6	10.5	5.3	5.3	0	19
Triplectides		F	7.7	53.8	30.8	7.7	0	0	0	13
Marilia		P	100	0	0	0	0	0	0	2
Chimarra		CP	0	82.1	0	14.3	0	3.6	0	28
Polyplectropus		F	100	0	0	0	0	0	0	2

the total variation in taxon composition was low and the extracted environmental gradients were short. The CCA ordination explained 32.6% of the total variance on the first three axes.

The most important factors explaining the macroinvertebrate variation on the first axis of the CCA diagram were the RCE scores and chloride concentration, while the second axis displayed a gradient of dissolved oxygen and BOD (Table 5). There was no strong correlation between chemical variables and the third axis.

In the CCA diagram, sites were separated along the first axis by environmental degradation (Fig. 4a). Class 1 site (A1–3) and class 5 site (G1–3), were widely separated in the analysis and hence most different in character. Intermediately disturbed sites (class 2 sites

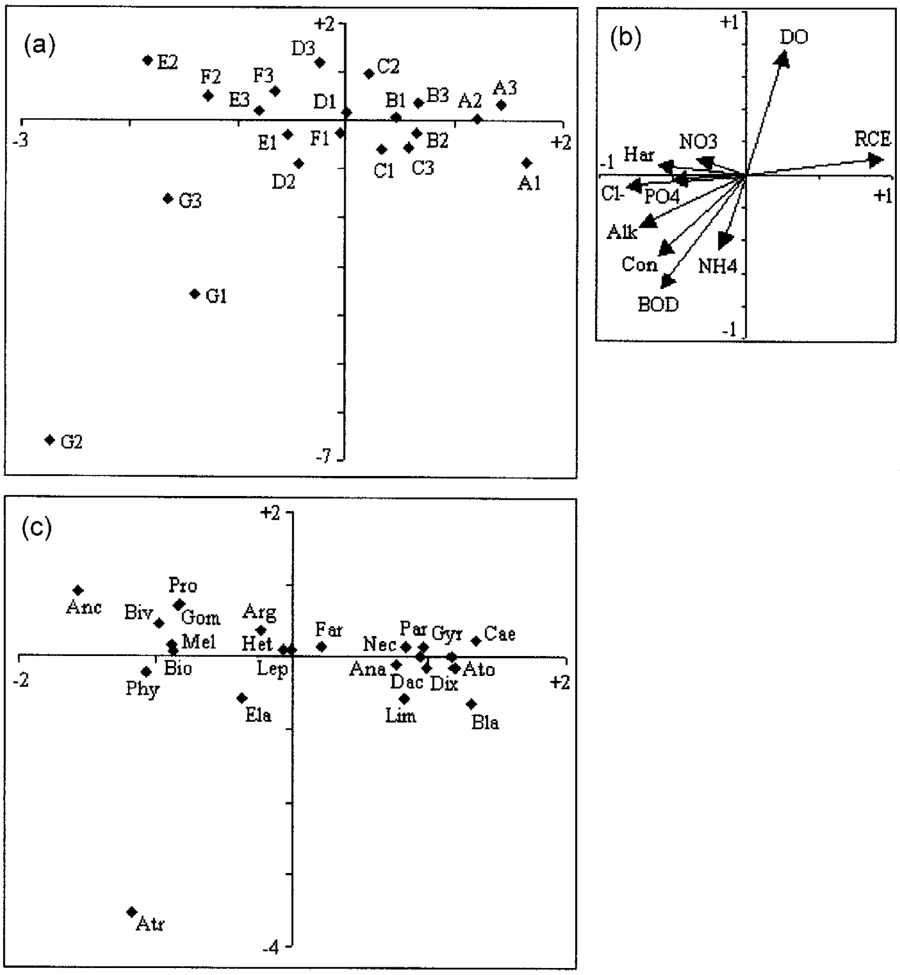

Figure 4. CCA ordination diagram of axes 1 and 2. (a) Sites, (b) environmental variables, and (c) species. Numbers after site codes represent sampling period (1, May; 2, August; 3, January). Species with position near the center or species with low contributions (<0.40) are not shown to avoid crowding the diagram. See text for environmental variables codes and Table 3 for species abbreviations.

B, C and D and class 4 sites E and F) were placed between those of classes 1 and 5. The second axis separated site G from the other sites. The temporal variation was less important since site samples were close to each other despite the sampling period.

In the CCA diagram, the orientation of the environmental arrow reflects the direction of maximum change of that variable (ter Braak, 1986). In Figure 4b, site A was positively correlated with RCE scores, while hardness was associated with sites of class 4. The CCA second axis showed site G associated with BOD, conductivity and NH_4-N and a strong negative correlation between this site and dissolved oxygen (Fig. 4b).

The CCA plot of taxa (Fig. 4c) showed some Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa associated with site A. Molluscs and Odonata taxa were associated with sites of class 4. Some genera of Ephemeroptera (*Caenis*, *Askola*, *Thraulodes*), Plecoptera (*Grypopteryx*, *Macrogynoplax*) and Trichoptera (*Barypenthus*, *Macronema*, *Marilia*, *Polyplectropus*) were exclusive of site A and other EPT taxa (*Farrodes*, *Dactylobaetis, Anacroneuria*, and *Nectopsyche*) were abundant at this site (Table 3). A decrease in EPT taxa was observed along the pollution gradient. At class 2 sites some groups of Trichoptera, Baetidae and Elmidae occurred with high abundance. These sites exhibited four exclusive taxa: two genera of Gomphidae (*Cyanogomphus* and *Epigomphus*), a leptophlebiid (*Hylister*) and an elmid (sp. 1). At class 4 sites, many groups had their highest abundance and Mollusca (Ancylidae, *Physa*, *Biomphalaria, Melanoides*, and Bivalvia), Odonata, Staphylinidae and Diptera were the most common.

Table 4. Eigenvalues, cumulative percent variance explained, and species-environment correlation coefficients for the first three CCA axes

	Axis 1	Axis 2	Axis 3
Eigenvalues	0.161	0.100	0.083
Cumulative percent variance explained by species data	15.2	24.7	32.6
Species–Environment Pearson Correlation coefficients	0.963*	0.954*	0.920*

*$p<0.001$.

Table 5. Pearson correlation coefficients between the first three CCA axes, chemical and environmental variables (n=21)

Chemical and environmental variables	CCA Axis 1	Axis 2	Axis 3
Dissolved oxygen	0.25	0.73	−0.46
BOD	−0.56	−0.65	−0.27
NH_4-N	−0.15	−0.37	0.17
NO_3-N	−0.29	0.09	0.02
PO_4-P	−0.48	−0.33	0.11
Cl^-	−0.79	−0.06	−0.53
Alkalinity	−0.67	−0.21	−0.20
Conductivity	−0.57	−0.47	0.14
Hardness	−0.56	0.05	−0.27
RCE scores	0.89	0.09	−0.25

The highest number of Simuliidae (66% of the 33 033 individuals) was found at these sites. Chironomidae was also very abundant, especially at site F (Table 3). At site G there were only few taxa, and Chironomidae showed a high dominance (97% of total individuals at this site). There was only one exclusive taxon, *Lymnaea*, with one individual found in January.

Functional feeding groups (FFG)

Collector–gatherer, predator and scraper groups comprised 28, 25, and 22 taxa, respectively, while shredder and collector–filterer groups were represented by seven and four taxa, respectively. Collector–gatherers were the most abundant group at sites of classes 1, 2 and 5 (Fig. 5) while collector–filterers dominated class 4 sites. The two sites of this class had different dominant taxa. Site E was dominated by scrapers in May and January, while site F (May) and E (August) by collector–filterers.

Collector–gatherers were dominant numerically at site G, but the highest taxonomic richness was found at site A (17 taxa). Also, predators, including many hemipteran genera exhibited the highest abundance and richness (20 taxa) at site A. Scrapers were most abundant at class 4 sites due to the abundance of molluscs. Shredders were rare in all sites and periods. However, when considering only this FFG, 56.8% of shredder abundance occurred at site A, 29.3% at class 2 sites, and 13.9% at class 4 sites, with no shredder at site G.

Discussion

The distribution of aquatic organisms is known to be influenced by their response to hydraulic conditions (Statzner et al., 1988), substrate composition (Rabeni & Minshall, 1977; Reice, 1980), and increase in nutrient loads (Haslam, 1990). In the present study, according to the CCA, RCE scores, chloride, alkalinity, conductivity, BOD, and hardness were significantly correlated with axis 1 ($p<0.01$). Although these factors can be related to the observed changes in the biota of the Guapimirim River basin, it is often difficult to isolate the influence of a particular factor. Overall, this combined effect created a gradient of environmental and water quality conditions that led to a reduction in taxon richness by exclusion of sensitive species, and an increase in the density of tolerant taxa densities, resulting in the decrease in community diversity indices.

Changes in the macroinvertebrate assemblages along the stream gradient indicate the ability of species to occupy different microhabitats and process organic material. From site of class 1–5 the replacement of taxa was observed from less to more pollution-tolerant ones. Species of Plecoptera showed clear preference for site A (with a scarce appearance at sites of class 2). Their sensitivity can be explained by their need for clean water with high dissolved oxygen and low siltation (McClelland & Brusven, 1980). A study on the effect of siltation and organic enrichment on the aquatic biota showed that accumulation of fine sand and inorganic silt on gills of Plecoptera and Ephemeroptera is a possible explanation for elimination of species from impacted areas (Lemly, 1982). The aquatic coleopterans also seemed to follow the integrity gradient, occurring predominantly at class 1 and 2 sites. According to Brown (1987) elmids drift to escape from poor environmental conditions such as low dissolved oxygen. Reliance upon plastron respir-

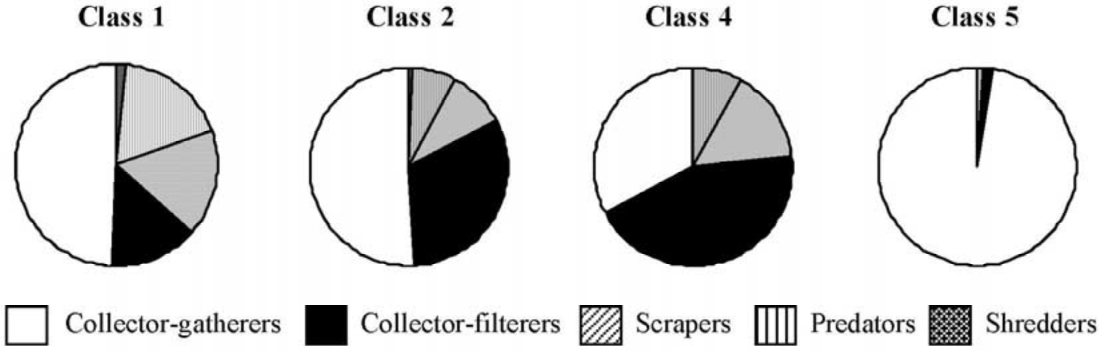

Figure 5. Functional feeding group composition found at sites of the four classes of integrity. Class 2 refers to mean values for sites B, C, and D, and Class 4 refers to mean values for sites E and F.

ation restricts most elmids to water nearly saturated with dissolved oxygen, hence to typically shallow, fast flowing, cool, or cold streams (Brown, op. cit.). Pollution by soaps and detergent is disastrous to adult elmids because such wetting agents make it impossible for the beetles to maintain either a plastron or a bubble. In this study, the reduction of oxygen concentrations was followed by the washing of clothes, especially at sites of class 4, which may explain the coleopteran distribution.

The highest taxonomic richness of Trichoptera and Ephemeroptera was also found at site A, but the highest abundance for both orders occurred at intermediately degraded areas. This was due to the high abundance of less sensitive families (Baetidae and Leptohyphidae in the Ephemeroptera, and Hydropsychidae in the Trichoptera). The most common trichopteran taxon, *Smicridea*, occurred predominantly at class 4 sites (1798 individuals). According to Oliveira & Froehlich (1997a), *Smicridea* present nets of large mesh size that would be more suited for sites subject to organic enrichment.

The Chironomidae showed higher abundance with increasing organic pollution despite their dominance at almost all sites. The Simuliidae, which were also abundant, showed a marked preference for moderately degraded areas (sites of class 4), where a greater amount of fine particulate organic nutrients was available.

Frequently, a positive relationship between molluscan species and hardness is found as they need calcium to build up their shells (Hynes, 1970). In this study, CCA ordination showed that hardness was associated with sites of class 4 and 5 and molluscan species (Fig. 4a–c). Markedly at site B, there was a high proportion of molluscs suggesting that the high hardness values found at this site influenced the distribution of this group. At site G, the virtual absence of algae explained by the high levels of pollutants and high proportion of suspended silt may be limiting mollusc species, once only a single specimen of *Lymnaea* was found.

Besides the effects of anthropogenic impacts, natural stress may also be regulating macroinvertebrate assemblage distribution such as the frequent spates that occur in this area. We agree with the discussion of Turcotte & Harper (1982), Flecker & Feifarek (1994), Rincón & Ladino (1997), and Jacobsen & Encalada (1998), all studies carried out in South American highland rivers, that abundance of macroinvertebrates in tropical streams is very dependent upon rainfall in the collecting period. In August (dry season), a heavy rain was observed before our collection at two sites, B and D (both class 2). All sites showed an increase in *taxa* richness from May (end of wet season) to August, except for these two sites, possibly due to macroinvertebrate flush out. Similar results were found in other areas of Brazil (Oliveira & Froehlich, 1997b; Kikuchi & Uieda, 1998).

The shredders, where present, showed a small numerical contribution to the invertebrate assemblage. The occurrence of spates in this river might be influencing this particular group as they are considered slow colonizers having long life-cycles (Wallace et al., 1986). Even at site A, where a higher amount of leaf packs should be found due to abundant riparian vegetation, litter substrates were difficult to find in all periods. The low retention capacity of this stream may have limited the shredder community, which seems to be a general pattern, because similar results were found for other unstable tropical and subtropical streams in New Zealand, New Guinea and Ecuador (Winterbourn et al., 1981; Dudgeon, 1994; Jacobsen & Encalada, 1998; respectively).

Overall, collector–gatherers and –filterers followed the trends of its two most abundant taxa (Chironomidae and Simuliidae, respectively). As they are rapid colonizers and due to their tolerance to anthropogenic stress, those taxa dominated almost all sites and periods.

In summary, the results obtained by the CCA indicated that the increase in chloride concentration, reduction in dissolved oxygen concentration (at site G) and the loss of environmental integrity were the most important factors in determining macroinvertebrate assemblages. Among other effects on the biota, there was a reduction in taxon richness, due to exclusion of sensitive species, and an increase in tolerant taxa, resulting in a marked decrease in community diversity. Some taxa showed sensitivity to water pollution especially plecopterans (both Perlidae and Gripopterygidae), trichopterans (with the exception of Hydropsychidae, Helicopsychidae and Hydroptilidae), coleopterans (most Elmidae) and some ephemeropterans (mainly Leptophlebiidae). On the other hand, some taxa proved to be tolerant to moderate levels of pollutants, such as Simuliidae, Odonata and molluscs. The Chironomidae seemed to be the only group tolerant to the high level of pollutants and degradation found in this study. These taxa may be helpful biological indicators of water quality in rivers of the type studied in southeastern Brazil.

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