# Aquatic macroinvertebrate diversity and composition in streams along an altitudinal gradient in Southeastern Brazil

***Ana Lucia Henriques-Oliveira[1,2] & Jorge Luiz Nessimian[1]***

*[1]Laboratório de Entomologia, Instituto de Biologia, Universidade Federal do Rio de Janeiro – UFRJ, Ilha do Fundão, Cidade Universitária, CP 68044, CEP 21944-970, Rio de Janeiro, RJ, Brasil*
*[2]Corresponding author: Ana Lucia Henriques-Oliveira, e-mail: anahenri@biologia.ufrj.br*

HENRIQUES-OLIVEIRA, A.L. & NESSIMIAN, J.L. **Aquatic macroinvertebrate diversity and composition in streams along an altitudinal gradient in Southeastern Brazil**. Biota Neotrop. 10(3): http://www.biotaneotropica.org.br/v10n3/en/abstract?article+bn02010032010.

***Abstract:*** Aquatic macroinvertebrate diversity and composition in streams along an altitudinal gradient in Southeastern Brazil. A study concerning taxonomic richness and composition of the aquatic insect fauna in streams within the same catchment basin along an altitudinal gradient in Southeast Brazil, was conducted to test the hypothesis that there is a faunal discontinuity in the biocenotic composition, related to differences in altitude and latitude. In Southeastern Brazil, around latitude 22°, this faunal transition from rhithron to potamon biocenosis should occur at 500 m above sea level. Eighteen tributaries of the Mambucaba River, at Serra da Bocaina National Park, SP-RJ, Brazil, were studied. The streams were separated into 6 altitudinal zones (zone 1: above 1500 m; zone 2: 1200-1300 m; zone 3: 900-1000 m; zone 4: 400-700 m; zone 5: 100-300 m; and zone 6: 0-100 m) each including three streams. The aquatic insects were identified at the lowest possible taxonomic level. The highest richness was observed in altitudes between 1200-1300 m, while the lowest occurred in altitudes below 100 m. The Indicator Value method indicated taxa characteristic for four of the six altitudinal zones considered in this paper. Sorensen's Index and CCA results showed that distribution and composition of aquatic insect fauna of Serra da Bocaina National Park was influenced primarily by altitude and temperature rather than stream size. The absence of indicator species and the lower abundance in altitudes between 400-700 m suggest a transition from rhithral to potamal fauna, which is distinct at 200 m.
***Keywords:*** *altitudinal distribution, spatial distribution, taxonomic richness, benthic macroinvertebrates.*

HENRIQUES-OLIVEIRA, A.L. & NESSIMIAN, J.L. **Riqueza de macroinvertebrados aquáticos em riachos ao longo de um gradiente altitudinal no Sudeste do Brasil**. Biota Neotrop. 10(3): http://www.biotaneotropica.org.br/v10n3/pt/abstract?article+bn02010032010.

***Resumo:*** Riqueza de macroinvertebrados aquáticos em riachos ao longo de um gradiente altitudinal no Sudeste do Brasil. Um estudo da riqueza e composição da fauna de insetos aquáticos de uma bacia hidrográfica com ênfase no gradiente altitudinal foi conduzido com o objetivo de testar a hipótese de que existe uma descontinuidade na composição da fauna relacionada à altitude e latitude. Na região Sudeste do Brasil, próxima à latitude 22°, a transição da fauna ritral-potamal deveria ocorrer em torno de 500 m. Com este objetivo central foram estudados 18 afluentes do Rio Mambucaba, Parque Nacional da Serra da Bocaina, SP-RJ, divididos em 6 faixas altitudinais (faixa 1: acima de 1500 m; faixa 2: 1200-1300 m; faixa 3: 900-1000 m; faixa 4: 400-700 m; faixa 5: 100-300 m e faixa 6: 0-100 m), sendo amostrados três riachos por faixa de altitude. Os insetos aquáticos foram identificados até o menor nível taxonômico possível. A maior riqueza foi observada nas altitudes entre 1200-1300 m, enquanto a menor riqueza ocorreu em altitudes inferiores a 100 m. O teste de espécies indicadoras mostrou táxons característicos para quatro das seis zonas altitudinais consideradas no presente trabalho. Os resultados do índice de Similaridade de Sorensen e da CCA mostraram que a comunidade de insetos aquáticos do Parque Nacional da Serra da Bocaina foi influenciada primariamente pela altitude e temperatura mais do que o tamanho do rio. A ausência de táxons indicativos, associada a menor riqueza de táxons e menor abundância entre as altitudes de 400-700 m sugerem uma zona de transição da fauna ritral para a fauna potamal, a qual parece ser distinta a 200 m.
***Palavras-chave:*** *distribuição altitudinal, distribuição espacial, riqueza taxonômica, macroinvertebrados bentônicos.*

## Introduction

The Atlantic Rain Forest, like most other tropical forests, has been damaged due to deforestation and other human activities. Nowadays, only mountainous areas keep parts of the Atlantic Rain Forest less damaged, as they are areas of higher altitude where water courses still keep their original features. There are few intact water bodies in low altitudinal areas where human occupation causes destruction in several ways. One of the most important problems arising from the intensification of human occupation in Southeastern Brazil, besides the loss of the remnants of Atlantic Rain Forest, is the degradation of the river network. Therefore, make it indispensable studies on taxonomy and ecology of benthic macroinvetebrates to the knowledge of the biological heritage. Althought few, ecological studies on macroinvertebrates in Atlantic Forest rivers have increased and improved during the last years (e.g. Baptista et al. 2001a, b, Callisto et al. 2001, Melo & Froehlich 2001, Egler 2002, Moulton & Magalhães 2003, Roque et al. 2003, Buss et al. 2004, Silveira et al. 2006, Crisci-Bispo et al. 2007).

Patterns in species richness along environmental and geographical gradients are fascinating topics in ecology (Jacobsen 2004). According to Palmer et al. (1994), the role of slope and elevation has been mentioned, but not so explicitly emphasized as it is in vegetation ecology, where it has long been recognized as a surrogate for a range of environmental gradients which strongly influence the composition of vegetation. Illies (1964, 1969) studying the macroinvertebrate benthic fauna in the Huallaga River tributaries, Andes Mountains, verified a change in the faunal biocenotic composition in relation to the altitude of each sampling station. In his studies, Illies classified benthic community according to its altitudinal distribution in Oligostenothermal fauna (animals adapted to low temperatures and high oxygen contents, normally found in the rhithral section of a stream) and Polistenothermal (animals adapted to stable high temperature of the water, and low oxygen contents, represented by families with wide geographic distribution). According Illies, differences between the river fauna zonation occur in relation to local geographical conditions and latitude. The typical oligostenothermal fauna exist at different elevations. In the tropics, near to Equator, it is restricted to high-andine localities above 3000 m a.s.l.; towards the south it occurs at medium elevations; and in Patagonia it exist in waters of the flat plain. In the southeast region of Brazil, near latitude 22°, this faunal transition from rhithron to potamon biocenosis should occur at 500 m above sea level.

According to Jacobsen (2004), stream biologists have shown interest in altitudinal patterns of macroinvertebrate richness, although their results diverge and no consensus or a general pattern has been reached. Patterns of macroinvertebrate distribution along altitudinal gradients were analyzed in South American Rivers, especially in the Andes (e.g. Illies 1964 in Peru; Jacobsen et al. 1997, Monaghan et al. 2000, Sites et al. 2003 and Jacobsen 2004 in Ecuador; Dominguez & Ballesteros-Valdez 1992 and Miserendino 2001 in Argentina; Ramirez et al. 2004 in Colombia). However, there is not any study about richness or structure of aquatic macroinvertebrate communities related to altitudinal gradient in Southeastern Brazil. The knowledge of distribution patterns related to altitude may be important to conservation policy proposals and to the understanding of geographical distribution of many genera and species of insects as well as their local diversity.

The goal of this study was to test the effect of the altitude on diversity and composition of aquatic macroinvertebrates in a catchment basin in Southeastern Brazil.

## Material and Methods

### *1. Study area*

The study was carried out in 18 tributaries of the Mambucaba River at different altitudes in Serra da Bocaina National Park (22° 40'-23° 25' S and 44° 20'-45° 00' W; Oliveira & Santos, 2001), between the cities of São José do Barreiro, State of São Paulo and Angra dos Reis, State of Rio de Janeiro (Figure 1), Brazil. The altitudinal range was divided into 6 zones, containing three streams each with similar characteristics: Zone 1: above 1500 m a.s.1. (S1, S2, S3), Zone 2: 1200-1300 m a.s.1. (S4, S5, S6), Zone 3: 900-1000 m a.s.1. (S7, S8, S9), Zone 4: 400-700 m a.s.1. (S10, S11, S12), Zone 5: 100-300 m a.s.1. (S13, S14, S15) and Zone 6: 0-100 m a.s.1. (S16, S17, S18). All streams sampled presented riparian vegetation composed of mature tropical rain forest or forest in regeneration, with grass and fruit trees mixed. The streams presented well-oxygenated clear water, riverbeds composed of rocks, gravel and sand with the presence of moss-covered rocks and leaf packs accumulations in pool areas with or without silt deposited.

### *2. Sampling*

Two sampling events were performed, both in winter dry season (August, 2003 and 2004). The dry season was chosen because it presents the highest environmental stability and, consequently, the highest biota stability. It is also the safest and easiest period to access stream sites. According to Guimarães et al. (2000), the highest rain precipitation levels in PNSB occur during the highest temperature periods (December-February). This period is followed by a marked decrease of the rainfall in the cold months of the year (June-August). Four substrate types were sampled in each stream: litter in riffle areas, litter in pool areas, stones and gravel. Three samples of each substrate were taken with a Surber sampler (0.09 $m^2$ area and mesh size 185 µm). All samples formed a single representative sample of each stream.

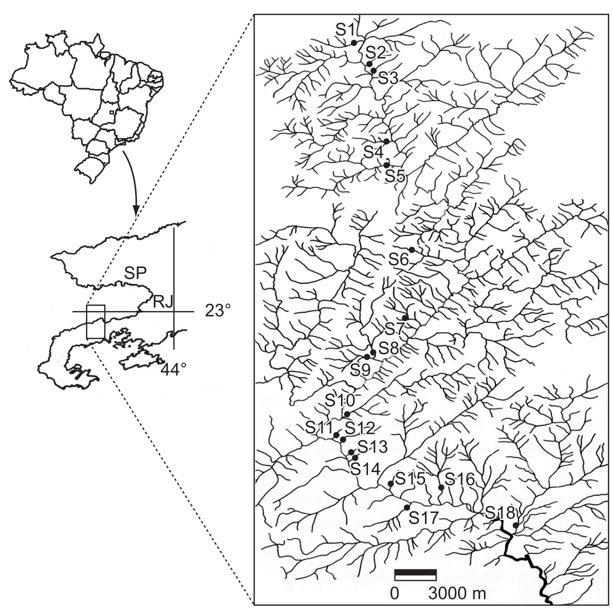


**Figure 1.** Map of Mambucaba River basin, showing the eighteen (•) sampling sites.

The following environmental parameters were measured at each site in the two sampling events: water temperature (°C), acidity (pH), electric conductivity (CE, $\mu S.cm^{-1}$), depth (m), width (m), current velocity (m/s) and discharge ($m^3/s$). Water temperature was recorded with a mercury thermometer. The pH values were taken using a portable pHmeter PH-TEK 100 and the electric conductivity were measured using a portable conductivimeter CORNING CD 55. The mean width (in meters) per stream was determined from two sections (10 m apart) perpendicular to the main stream flow. The current velocity was estimated by the head rod method (Waterwatch Australia Steering Committee 2002), using a stainless steel ruler. In each section, we measured the depth of the stream in meters, (D1, with the thin edge of the ruler into the flow), and (D2, with the flat side faces into the flow, creating a standing wave or 'head'). These measures were taken at every 30 cm across the stream section. The difference between D1 and D2 is the head. The average head (h) were calculated from these measurements. The average velocity of the stream was determined by the formula: $V(m/s) = \sqrt[2]{(2 \times 9.81 \times h)}$, where 9.81 is the gravitational constant. The current velocity of each stream was the average of velocities measured in each sampling year.

Samples were preserved in 80% ethanol. Insects were identified to the lowest taxonomic level, except for Diptera (family level), using keys or taxonomic descriptions (Carvalho 1989, Belle 1992, Angrisano 1995, Merritt & Cummins 1996, Wiggins 1996, Nieser & Melo 1997, Carvalho & Calil 2000, Carvalho et al. 2002, Da-Silva et al. 2003, Olifiers et al. 2004, Salles et al. 2004, Pes et al. 2005, Dias et al. 2006, Passos et al. 2007) and with the aid of specialists.

### *3. Data analysis*

The diversity was evaluated using the taxonomic richness (S), Shannon's Diversity (H') and Pielou Evenness indexes (Elliott 1977, Ludwig & Reynolds 1988). These indexes were analyzed at local (per stream) and zonal (for 1 to 6 altitudinal zones) levels. Taxonomic richness comparisons between streams were made using a rarefaction method (Gotelli & Colwell, 2001) using the program Past version 1.40 (Hammer et al. 2001).

Simple-linear regression analysis was performed to test relationships between the estimated taxonomic richness, observed family richness and environmental variables with the altitude, using the program Statistica 6.0 (StatSoft 2001).

A standardized Mantel Test (Sokal & Rohlf 1995) was applied to examine the altitudinal effect on the composition of macroinvertebrate community. One general matrix was constructed (sites × taxa) and two matrices hypothesis (altitude and geographic distance) were compared, using quantitative and qualitative data. The geographic distance matrices were constructed using the highest site as point zero in relation to orthers sites.

Characteristic groups of each altitudinal zone were determined through Indicator Value Method (IndVal; Dufrêne & Legendre 1997). This method matches information on species abundance and frequency of occurrence among groups. A Monte Carlo permutation test was employed to test significant associations of taxa and group of sites ($p < 0.05$).

A Canonical Correspondence Analysis (CCA) was used as ordination technique to determine the main factors that might be influencing the structure of the aquatic insect communities in streams. In this way, it was possible to infer the relation between environmental factors and the presence of some aquatic insect taxa and its distribution. The total abundance data of all streams was Log 10 (n + 1) transformed. Environmental variables included were: altitude, water temperature, pH, electric conductivity, width, depth, current velocity and discharge. This analysis and Indicator Value Method were performed using PC-ORD program version 4.14 (McCune & Mefford 1999).

Sorensen's Index was used for analyzing similarities between taxonomic composition based on a presence–absence matrix for the aquatic insect fauna of each stream. The Sorensen's Index matrix was submitted to cluster analysis through the average association method (UPGMA) in the program NTSYS version 1.70 (Rohlf 1992). The distortion was evaluated using the cophenetic correlation coefficient, which was obtained correlating the original similarity matrix with the matrix obtained from the dendrogram ($r \geq 0.8$).

Gerridae, Mesoveliidae, and Veliidae were excluded of the analysis because these taxa are not associated to the substrates sampled. Chironomidae was excluded of the Rarefaction and Fisher's Alpha tests, because this family is very abundant and diverse.

## Results

### *1. Environmental features and richness patterns*

The environmental parameter values measured are presented in Table 1. Only two variables correlated significantly with altitude: water temperature ($r = -0.832$, $p < 0.0000$) and stream width ($r = -0.508$, $p < 0.0315$). Sites S14 and S8 showed the lowest pH values 5.0 and 5.1 respectively, and the highest pH values were measured at Sites S11 (8.1) and S18 (8.2). Electric conductivity values were higher at Site S5 (0.90 $\mu S.cm^{-1}$) and the lower values were measured at S1 (0.03 $\mu S.cm^{-1}$). The streams located above 1250 m a.s.l. presented temperatures lower than 14.5 °C, while the streams below 200 m showed values higher than 19.0 °C. Overall the lowland streams were more wide than its relatives in highland.

We collected 83,526 individuals of aquatic insect belonging to 216 taxa distributed in the orders Ephemeroptera, Odonata, Plecoptera, Hemiptera, Megaloptera, Coleoptera, Trichoptera, Lepidoptera and Diptera (Table 2). The order Diptera presented the largest number of individuals (48,187), being the Chironomidae the most abundant group (30,109 individuals), more than 35% of the total aquatic insects collected. Among the orders of Insecta identified below the family level, the richest groups were Trichoptera (15,582 individuals in 65 taxa of 14 families), Coleoptera (7,824 individuals, 57 taxa, 13 families) and Ephemeroptera (6,702 individuals, 33 taxa, 6 families). The most abundant taxa were *Paragripopteryx*, *Anacroneuria*, *Heterelmis* sp.1, *Smicridea* sp.1, *Grumichella*, *Nectopsyche* sp.1, *Notalina*, *Triplectides* and *Grumicha* sp.2.

Zones at higher altitudes showed higher number of families ($r = 0.619$, $p < 0.0061$). Zone 1 (above 1500 m) presented 55 families, while Zone 6 (0-100 m) presented 46 families. Local and zonal values of taxonomic richness (rarefaction), Fisher's alpha and abundance are shown in Table 3. The richness was standardized for 820 individuals by the rarefaction method. This value represents the stream with lower abundance (S1). Among the streams studied, the highest values of taxonomic richness and Fisher diversity index were found at Sites S2 (87.58 and 25.01, respectively), S5 (82.12 and 23.66) and S6 (80.44 and 23.33) and the lowest richness and diversity was found in S17 (38.44 and 10.38). The highest total abundance occurred at Sites S16 (6,872 ind.), S17 (6,602 ind.) and S6 (6,196 ind.), while the lowest values occurred at S11 (1,896 ind.). Among the altitudinal zones, the highest total abundance occurred at Zone 6 (0-100 m) with 18,480 ind., and the lowest values at Zone 4 (700-400 m) 7,674 ind. The highest values of taxonomic richness and Fisher diversity index were found at Zone 2 (142.28 and 27.03, respectively) and the lowest values at Zone 6 (90.99 and 16.92).

### *2. Taxa composition in the altitudinal gradient*

The Indicator Value analysis carried out to zones as group ($p < 0.05$) showed representatives to four altitudinal zones (Table 4). The Zone 1 (above 1500 m) and Zone 4 (400-700 m) did not present

**Table 1.** Localization and values of environmental parameters of the 18 streams sampled in Mambucaba River basin, Serra da Bocaina National Park, SP-RJ.

| Sites | Stream | Latitude (S) | Longitude (W) | Altitude m a.s.l. | T (°C) | pH | C.E. µS.cm$^{-1}$ | Width (m) | Depth (cm) | Discharge (m$^3$/s) | Current (m/s) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| S1 | unknown name | 22° 42’ 46.7” | 44° 38’ 14.2” | 1645 | 14.0 | 7.5 | 0.03 | 1.62 | 10.75 | 0.038 | 0.213 |
| S2 | unknown name | 22° 43’ 47.4” | 44° 37’ 04.9” | 1550 | 13.0 | 7.6 | 0.06 | 1.50 | 6.08 | 0.019 | 0.252 |
| S3 | unknown name | 22° 44’ 05.6” | 44° 36’ 58.4” | 1520 | 12.0 | 7.1 | 0.05 | 1.50 | 9.46 | 0.030 | 0.239 |
| S4 | Córrego das Posses | 22° 46’ 06.6” | 44° 36’ 36.0” | 1270 | 13.0 | 7.5 | 0.09 | 1.56 | 9.29 | 0.044 | 0.136 |
| S5 | Ribeirão da Prata | 22° 46’ 48.9” | 44° 36’ 40.4” | 1200 | 14.5 | 7.4 | 0.90 | 2.98 | 19.30 | 0.164 | 0.300 |
| S6 | unknown name | 22° 49’ 22.6” | 44° 35’ 52.0” | 1200 | 18.0 | 7.4 | 0.07 | 1.50 | 4.84 | 0.017 | 0.372 |
| S7 | Córrego Barra Branca | 22° 51’ 09.9” | 44° 36’ 07.4” | 1040 | 18.0 | 7.1 | 0.12 | 1.50 | 13.27 | 0.076 | 0.458 |
| S8 | Córrego do Moinho | 22° 52’ 18.9” | 44° 36’ 58.2” | 940 | 18.0 | 5.1 | 0.34 | 3.55 | 17.97 | 0.212 | 0.391 |
| S9 | Córrego São Gonçalo | 22° 52’ 29.2” | 44° 37’ 05.8” | 920 | 17.0 | 7.7 | 0.26 | 2.46 | 12.75 | 0.075 | 0.282 |
| S10 | Córrego da Memória | 22° 54’ 16.8” | 44° 37’ 43.6” | 720 | 15.0 | 7.8 | 0.16 | 4.07 | 15.66 | 0.251 | 0.402 |
| S11 | unknown name | 22° 54’ 41.4” | 44° 37’ 52.0” | 586 | 17.5 | 8.1 | 0.36 | 1.50 | 2.52 | 0.005 | 0.176 |
| S12 | Córrego Maitaca | 22° 54’ 58.3” | 44° 37’ 47.2” | 550 | 16.5 | 7.5 | 0.12 | 2.74 | 6.38 | 0.060 | 0.351 |
| S13 | unknown name | 22° 55’ 31.2” | 44° 37’ 31.2” | 318 | 18.0 | 7.8 | 0.24 | 1.50 | 2.88 | 0.009 | 0.250 |
| S14 | Córrego do Forno | 22° 55’ 34.3” | 44° 37’ 24.8” | 318 | 18.0 | 5.0 | 0.21 | 1.80 | 5.61 | 0.009 | 0.194 |
| S15 | Córrego do Pontilhão | 22° 56’ 22.5” | 44° 36’ 31.5” | 116 | 19.0 | 7.5 | 0.05 | 1.91 | 9.08 | 0.120 | 0.169 |
| S16 | Rio Cachoeira da Cruz | 22° 56’ 41.6” | 44° 35’ 21.1” | 87 | 19.0 | 7.9 | 0.23 | 4.48 | 13.35 | 0.150 | 0.245 |
| S17 | unknown name | 22° 56’ 45.5” | 44° 26’ 01.4” | 68 | 22.0 | 7.8 | 0.14 | 3.30 | 12.46 | 0.183 | 0.289 |
| S18 | Córrego Itapetininga | 22° 57’ 44.4” | 44° 33’ 13.2” | 46 | 21.0 | 8.2 | - | 8.34 | 22.09 | 0.359 | 0.275 |

any indicator taxon. Zone 2 showed 10 indicator taxa: *Austrolimnius laevigatus* (Grouvelle, 1888), *Hagenulopsis diptera* Ulmer, 1920, *Heterelmis* sp.1, *Heterelmis* sp.4, *Kempnyia, Marilia* sp.1, *Neoelmis* sp.2, *Paracloeodes*, *Paragripopteryx* and *Smicridea* sp.4; Zone 3 showed 3 indicatives taxon: *Promoresia* sp.2, *Tupiperla* and *Xenelmis* sp.2; Zone 5 showed only 2 taxa: *Caenis* and *Phylloicus* sp.2 and Zone 6 showed 5 indicator taxa: *Camelobaetidius*, *Chimarra*, *Grumicha* sp.2, *Miroculis frohelichi* Savage & Peters, 1983 and *Metrichia* sp.4.

Some taxa were present in only one zone, even with few individuals. Zone 1: *Rhagovelia* sp.1, Polycentropodidae sp.1, Sericostomatidae sp.1; Zone 2: *Coleopterocoris hungerfordi* De Carlo, 1968, *Guaranyperla*, *Limnocoris siolli* De Carlo, 1966, *Marilia* sp.3, *Marilia* sp.5, *Stegoelmis*; Zone 3: *Askola* sp. 2, *Berosus*, *Macrothemis*, *Nectopsyche* sp.5; Zone 4: *Derallus*, *Epigomphus*, *Oocyclus, Suphisellus*; Zone 5: *Enitharoides brasiliensis* (Spínola, 1836), *Leptonema* sp.3, *Metrichia* sp.5, *Nectopsyche* sp.6, *Platynectes*, *Progomphus* sp.1, and Zone 6: *Brachimetra albinervis* Amyot & Serville, 1843, *Camelobaetidius*, *Cyanogomphus*, *Mesovelia*, *Rhagovelia itatiaiana*, Drake, 1953.

The Mantel test, considering qualitative data, indicated that assemblages from the studied streams are influenced by altitude ($r = 0.566$, $z = 0.1033$, $p = 0.001$), the streams present communities with differents taxa composition. However, analysis of quantitative data, indicated that assemblage structures no significant differences in relation to altitude ($r = 0.241$, $z = 0.6814$, $p = 0.068$).

The Cluster Analysis based on Sorensen’s Similarity Index matrix (Figure 2) grouped the streams through an altitudinal gradient. Site S1, with higher altitude, was separated from all other streams that formed two groups. Group A was formed by streams at altitudes below 200 m (S15, S16, S17 and S18) and group B was formed by all remaining streams. Group B was divided by two groups: b1 - formed by sites 10 and 11, streams of altitude higher than 300 m; b2 split into two groups: b21 - formed by streams at altitudes above 1000 m, and b22 - formed by streams at altitudes between 300 and 900 m.

The CCA ordination performed on the abundance of taxa and environmental variables showed clear distinction among sites by altitude (Figure 3). The first axis (16.6% of total variance, eigenvalue 0.181) corresponded to an altitudinal gradient. There is a clear distinction between streams of high altitudes (above 900 m) with cold water and streams with altitudes below 700 m and warmer water. In one side of axis we can observe two groups formed: one formed by streams in altitudes below 200 m and more large, and an other group formed by streams (S11, S12, S13 and S14) with altitude intermediate among 300 and 600 m and with smaller width. The second axis (9.1% of the total variance, eigenvalue 0.099) separated streams by size. On the upper portion of the ordination, streams with higher values of discharge, depth, width and order, while on the lower portion, small streams with lower values of discharge.

The streams of high altitudes were characterized by taxa as *Anastomoneura*, *Askola,* Elmidae tipo 2, cf. *Laccornelus*, *Massartela alegrettae* Ulmer, 1943, *Massartela brieni* (Lestage, 1924), *Melanemerella brasiliana* Ulmer, 1920, *Notalina, Nectopsyche* sp.3, *Paragripopteryx, Tupiperla* and *Xenelmis* sp.1 (Figure 4). The streams from at altitudes between 300 and 900 m were characterized by taxa with wide distribution that presented higher abundance and/or occurrence in streams at this altitude. The streams of lower altitudes were characterized by taxa related to regions of warm waters as: *Caenis,* which presented its highest abundance in rivers at zone 5, *Chimarra, Grumicha* sp.2, *Macronema*, *Miroculis froehlichi* Savage & Peters, 1983*, Thraulodes* and *Triplectides,* besides *Camelobaetidius, Cryphocricos, Metrichia* sp.4.

## Discussion

### *1. Environmental features and richness patterns*

As expected, the values of water temperature varied according to the altitude. Although the range altitudinal of Serra da Bocaina National Park is small, our results showed decrease of the temperature

**Table 2.** Aquatic insect taxa collected in 18 streams in Mambucaba River basin, Serra da Bocaina National Park, SP-RJ.

| Taxa | | Above 1500 (m) | 1200-1300 (m) | 900-1000 (m) | 400-700 (m) | 200-300 (m) | 0-100 (m) |
|---|---|---|---|---|---|---|---|
| | | Zone 1 | Zone 2 | Zone 3 | Zone 4 | Zone 5 | Zone 6 |
| EPHEMEROPTERA | | | | | | | |
| Baetidae | *Americabaetis* | X | X | X | - | X | X |
| | *Baetodes* | X | X | X | X | X | X |
| | *Camelobaetidius* | - | - | - | - | - | X |
| | *Cloeodes* | X | - | X | - | X | X |
| | *Paracloeodes* | X | X | - | - | X | X |
| | *Zelusia principalis* Lugo-Ortiz & McCafferty, 1995 | X | X | X | - | - | X |
| Caenidae | *Caenis* | - | - | - | - | X | X |
| Euthyplociidae | *Campylocia* cf. *bocainensis* Pereira & Da-Silva, 1990 | - | X | X | X | X | - |
| Leptohyphidae | *Leptohyphes* | X | X | X | X | X | X |
| | *Leptohyphodes* | X | X | X | X | X | X |
| | *Traverhyphes* | X | X | X | X | X | X |
| | *Tricorythopsis* | X | X | X | X | - | X |
| | *Tricorythodes* | X | X | X | X | X | X |
| Leptophlebiidae | *Askola froehlichi* Peters, 1969 | X | X | X | - | - | X |
| | *Askola* sp.1 | X | X | - | - | - | - |
| | *Askola* sp.2 | - | - | X | - | - | - |
| | *Farrodes carioca* Domínguez, Molineri & Peters, 1996 | X | X | X | X | X | X |
| | *Hagenulopsis diptera* Ulmer, 1920 | X | X | X | X | X | X |
| | *Homothraulus* | X | X | - | - | - | X |
| | *Hylister plaumanni* Domínguez & Flowers, 1989 | - | X | X | X | - | - |
| | *Massartella alegrettae* Ulmer, 1943 | X | X | X | - | - | - |
| | *Massartella brieni* (Lestage, 1924) | X | X | X | - | X | - |
| | *Massartella* sp.1 | X | X | - | X | - | - |
| | *Massartella* sp.2 | - | - | - | X | X | - |
| | *Miroculis froehlichi* Savage & Peters, 1983 | X | X | X | X | X | X |
| | *Needhamella* | - | X | X | - | - | X |
| | aff. *Perissophlebiodes* | - | - | X | - | - | X |
| | *Thraulodes itatiajanus* Traver & Edmunds, 1967 | X | X | X | X | X | X |
| | *Thraulodes* sp.1 | X | X | - | - | - | X |
| | aff. *Thraulodes* | X | X | X | - | X | - |
| | *Ulmeritoides* sp.1 | X | X | X | - | - | - |
| | *Ulmeritoides* sp.2 | X | X | X | X | - | - |
| Melanemerellidae | *Melanemerella brasiliana* Ulmer, 1920 | X | X | X | X | - | - |
| ODONATA | | | | | | | |
| Aeshnidae | *Limnetron debile* Karsch, 1891 | X | X | X | - | X | - |
| | *Limnetron* sp.1 | - | X | X | X | X | - |
| Calopterygidae | *Hetaerina* | X | X | X | X | X | X |
| Coenagrionidae | *Argia* | X | - | X | - | X | X |
| Corduliidae | *Neocordulia* | X | X | X | X | X | - |
| Gomphidae | *Cyanogomphus* | - | - | - | - | - | X |
| | *Epigomphus* | - | - | - | X | - | - |
| | *Progomphus gracilis* Hagen in Selys, 1854 | X | X | X | X | X | - |
| | *Progomphus* sp.1 | - | - | - | - | X | X |
| Libellulidae | *Brechmorhoga* | X | X | X | X | X | X |
| | *Macrothemis* | - | - | X | - | - | - |
| Megapodagrionidae | *Heteragrion* | X | X | X | X | X | X |
| PLECOPTERA | | | | | | | |
| Gripopterygidae | *Gripopteryx* | X | X | X | X | X | X |
| | *Guaranyperla* | - | X | - | - | - | - |
| | *Paragripopteryx* | X | X | X | X | X | X |
| | *Tupiperla* | X | X | X | | - | - |
| Perlidae | *Anacroneuria* | X | X | X | X | X | X |

**Table 2.** Continued...

| Taxa | | Above 1500 (m) | 1200-1300 (m) | 900-1000 (m) | 400-700 (m) | 200-300 (m) | 0-100 (m) |
|---|---|---|---|---|---|---|---|
| | | Zone 1 | Zone 2 | Zone 3 | Zone 4 | Zone 5 | Zone 6 |
| | *Kempnyia* | X | X | X | X | X | X |
| | *Macrogynoplax* | X | - | X | - | X | - |
| HEMIPTERA | | | | | | | |
| Gerridae | *Brachymetra albinervis* Amyot & Serville, 1843 | - | - | - | - | - | X |
| Helotrephidae | *Neotrephes jackzewskii* China, 1940 | X | X | X | X | X | X |
| | *Neotrephes* sp.1 | X | X | - | - | - | - |
| Mesoveliidae | *Mesovelia* | - | - | - | - | - | X |
| Naucoridae | *Cryphocricos* | X | - | X | X | X | X |
| | *Limnocoris asper* Nieser & Lopez-Ruf, 2001 | - | X | X | - | - | - |
| | *Limnocoris brasiliensis* De Carlo, 1941 | - | X | - | - | X | - |
| | *Limnocoris intermedius* Nieser & Lopez-Ruf, 2001 | X | X | - | - | - | - |
| | *Limnocoris pauper* Montandon, 1897 | - | X | X | X | X | - |
| | *Limnocoris siolii* De Carlo, 1966 | - | X | - | - | - | - |
| Notonectidae | *Enitharoides brasiliensis* (Spínola, 1836) | - | - | - | - | X | - |
| Potamocoridae | *Coleopterocoris hungerfordi* De Carlo, 1968 | - | X | - | - | - | - |
| Vellidae | *Microvelia costaiana* Drake & Hussey, 1951 | X | - | X | X | - | X |
| | *Rhagovelia accedens* Drake, 1957 | X | X | - | - | - | - |
| | *Rhagovelia agra* Drake, 1957 | - | X | - | - | - | X |
| | *Rhagovelia itatiaiana* Drake, 1953 | - | - | - | - | - | X |
| | *Rhagovelia lucida* Gould, 1931 | - | X | X | X | X | X |
| | *Rhagovelia tijuca* Polhemus, 1997 | - | X | - | X | X | - |
| | *Rhagovelia* sp.1 | X | - | - | X | - | - |
| MEGALOPTERA | | | | | | | |
| Corydalidae | *Corydalus* sp.1 | X | X | X | X | X | - |
| | *Corydalus* sp.2 | X | X | X | | X | - |
| COLEOPTERA | | | | | | | |
| Curculionidae | | X | X | - | - | - | - |
| Dryopidae | | X | X | X | X | X | - |
| Dytiscidae | *Laccophilus ovatus* Sharp, 1882 | - | - | - | X | - | - |
| | cf. *Laccornelus* | X | X | - | - | - | - |
| | *Platynectes* | - | - | - | - | X | - |
| Elmidae | *Austrolimnius formosus* (Sharp, 1882) | X | X | X | X | X | - |
| | *Austrolimnius laevigatus* (Grouvelle, 1888) | X | X | X | - | X | X |
| | *Austrolimnius pilulus* (Grouvelle, 1888) | X | - | X | - | X | - |
| | *Cylloepus* | X | X | X | - | - | - |
| | *Gyrelmis* | X | X | X | X | X | - |
| | *Heterelmis* sp.1 | X | X | X | X | X | X |
| | *Heterelmis* sp.2 | X | X | X | X | X | X |
| | *Heterelmis* sp.3 | - | X | X | X | X | X |
| | *Heterelmis* sp.4 | X | X | X | X | X | X |
| | *Heterelmis* sp.5 | X | X | X | X | X | - |
| | *Heterelmis* sp.6 | - | X | X | X | X | X |
| | *Hexacylloepus* | X | X | X | X | X | X |
| | aff. *Hexacylloepus* | X | X | X | X | X | X |
| | *Hexanchorus* sp.1 | - | X | - | X | - | X |
| | *Hexanchorus* sp.2 | - | - | X | X | - | - |
| | *Macrelmis granosa* (Grouvelle, 1896) | - | X | X | X | X | - |
| | *Macrelmis* sp.1 | X | X | X | X | - | X |
| | *Macrelmis* sp.2 | X | X | X | X | X | X |
| | *Macrelmis* sp.3 | X | X | X | X | X | X |
| | *Microcylloepus* sp.1 | X | X | X | X | X | X |
| | *Microcylloepus* sp.2 | X | X | X | X | X | X |
| | *Microcylloepus* sp.3 | X | X | X | X | - | - |

**Table 2.** Continued...

| Taxa | | Above 1500 (m) | 1200-1300 (m) | 900-1000 (m) | 400-700 (m) | 200-300 (m) | 0-100 (m) |
|---|---|---|---|---|---|---|---|
| | | **Zone 1** | **Zone 2** | **Zone 3** | **Zone 4** | **Zone 5** | **Zone 6** |
| | *Neoelmis* sp.1 | X | X | X | X | X | X |
| | *Neoelmis* sp.2 | X | X | X | - | X | X |
| | *Neoelmis* sp.3 | - | X | - | - | - | X |
| | aff. *Neoelmis* | X | X | - | - | X | - |
| | *Phanocerus clavicornis* Sharp, 1882 | X | X | X | X | X | X |
| | *Promoresia* sp.1 | X | X | X | X | X | - |
| | *Promoresia* sp.2 | - | X | X | X | - | X |
| | *Stegoelmis* | - | X | - | - | - | - |
| | *Xenelmis* sp.1 | X | X | X | - | - | X |
| | *Xenelmis* sp.2 | X | X | X | X | X | X |
| | *Xenelmis* sp.3 | - | X | X | X | X | X |
| | Elminae tipo 1 | X | X | X | X | X | X |
| | Elminae tipo 2 | X | X | - | - | - | - |
| | Elminae tipo 3 | X | X | - | - | - | - |
| | Elminae tipo 4 | - | X | X | - | - | - |
| Gyrinidae | *Gyretes* | X | X | X | X | X | |
| Hydraenidae | *Hydraena* | X | X | X | X | X | X |
| Hydrophilidae | *Berosus* | - | - | X | - | - | - |
| | *Chasmogenus* | - | - | - | X | X | - |
| | *Derallus* | - | - | - | X | X | - |
| | *Enochrus* | X | X | - | - | - | - |
| | *Oocyclus* | - | - | - | X | - | - |
| | Hydrophilinae tipo 1 | X | X | - | - | - | - |
| Lutrochidae | *Lutruchus* | X | X | X | X | X | X |
| Noteridae | *Suphisellus* | - | - | - | X | - | - |
| Psephenidae | | X | X | X | - | X | X |
| Ptilidae | | X | X | - | X | - | X |
| Ptylodactilidae | | - | X | - | X | X | - |
| Scirtidae | | X | X | X | X | - | X |
| Staphilinidae | | X | X | X | X | X | X |
| TRICHOPTERA | | | | | | | |
| Anomalopsychidae | *Contulma* | X | X | X | X | X | X |
| Calamoceratidae | *Phylloicus* sp.1 | X | X | X | X | X | X |
| | *Phylloicus* sp.2 | X | X | X | X | X | X |
| | *Phylloicus* sp.3 | X | X | X | X | X | X |
| | *Phylloicus* sp.4 | - | X | X | - | - | - |
| Ecnomidae | *Austrotinodes* | - | - | - | - | X | - |
| Glossosomatidae | | X | X | X | X | X | - |
| Helicopsychidae | *Helicopsyche* sp.1 | X | X | X | X | X | X |
| | *Helicopsyche* sp.2 | X | X | X | X | X | - |
| | *Helicopsyche* sp.3 | X | X | X | X | X | X |
| | *Helicopsyche* sp.4 | - | X | X | X | X | X |
| | *Helicopsyche* sp.5 | - | - | - | X | X | - |
| Hydrobiosidae | *Atopsyche* | X | X | X | X | X | X |
| Hydropsychidae | *Blepharopus* | X | X | X | X | X | - |
| | *Leptonema* sp.1 | - | X | X | X | X | X |
| | *Leptonema* sp.2 | X | X | - | - | - | X |
| | *Leptonema* sp.3 | - | - | - | - | X | - |
| | *Macronema* | - | - | - | - | X | X |
| | *Smicridea* sp.1 | X | X | X | X | X | X |
| | *Smicridea* sp.2 | X | X | X | X | X | X |
| | *Smicridea* sp.3 | X | X | X | X | X | X |
| | *Smicridea* sp.4 | X | X | X | - | - | - |

**Table 2.** Continued...

| Taxa | | Above 1500 (m) Zone 1 | 1200-1300 (m) Zone 2 | 900-1000 (m) Zone 3 | 400-700 (m) Zone 4 | 200-300 (m) Zone 5 | 0-100 (m) Zone 6 |
|---|---|---|---|---|---|---|---|
| Hydroptilidae | *Alisotrichia* | - | X | X | X | X | X |
| | *Leucotrichia* | - | - | X | X | X | - |
| | Leucotrichini | X | X | X | X | X | X |
| | *Metrichia* sp.1 | X | X | X | X | X | X |
| | *Metrichia* sp.2 | X | X | X | X | X | X |
| | *Metrichia* sp.3 | - | - | X | X | X | X |
| | *Metrichia* sp.4 | - | - | X | X | X | X |
| | *Metrichia* sp.5 | - | - | - | - | X | - |
| | *Neotrichia* sp.1 | X | X | X | X | X | X |
| | *Neotrichia* sp.2 | X | X | X | - | - | - |
| Hydroptilidae | *Neotrichia* sp.3 | X | X | X | X | X | X |
| | *Ochrotrichia* (?) | - | X | - | - | - | - |
| | *Rhyacopsyche* sp.1 | X | X | X | X | X | X |
| | *Rhyacopsyche* sp.2 | - | - | - | - | X | X |
| Leptoceridae | *Atanatolica* | - | - | - | X | X | - |
| | *Grumichella* | X | X | X | X | X | X |
| | *Nectopsyche* sp.1 | X | X | X | X | X | X |
| | *Nectopsyche* sp.2 | - | X | X | X | X | X |
| | *Nectopsyche* sp.3 | X | X | X | - | - | - |
| | *Nectopsyche* sp.4 | - | X | X | - | - | - |
| | *Nectopsyche* sp.5 | - | - | X | - | - | - |
| | *Nectopsyche* sp.6 | - | - | - | - | X | - |
| | *Notalina* | X | X | X | X | - | - |
| | *Oecetis* sp.1 | X | X | X | - | X | X |
| | *Oecetis* sp.2 | X | X | X | - | - | - |
| | *Triplectides* | X | X | X | X | X | X |
| | *Leptoceridae* sp.1 | X | - | X | - | - | - |
| Odontoceridae | *Anastomoneura guahybae* Huamantinco & Nessimian, 2004 | X | X | - | - | - | - |
| | *Barypenthus* | X | X | X | X | X | - |
| | *Marilia* sp.1 | X | X | X | - | X | X |
| | *Marilia* sp.2 | - | X | X | X | X | - |
| | *Marilia* sp.3 | - | X | - | - | - | - |
| | *Marilia* sp.4 | - | X | X | - | X | - |
| | *Marilia* sp.5 | - | X | - | - | - | - |
| Philopotamidae | *Chimarra* | - | X | X | X | X | X |
| | *Wormaldia* | - | X | X | - | X | X |
| Polycentropodidae | *Cyrnellus* | - | - | X | X | X | X |
| | *Polycentropus* | X | X | X | - | X | X |
| | *Polyplectropus* | X | X | X | X | X | - |
| | Polycentropodidae sp.1 | X | - | - | - | - | - |
| Sericostomatidae | *Grumicha* sp.1 | X | X | X | X | X | X |
| | *Grumicha* sp.2 | - | - | - | X | X | X |
| | Sericostomatidae sp.1 | X | - | - | - | - | - |
| Xiphocentronidae | *Xiphocentron* | X | X | X | X | - | X |
| LEPIDOPTERA | | | | | | | |
| Pyralidae | | X | X | X | X | X | X |
| DIPTERA | | | | | | | |
| Brachycera | | X | X | X | X | X | X |
| Blephariceridae | | - | - | - | - | - | X |
| Ceratopogonidae | Ceratopogonidae sp.1 | X | X | X | X | X | X |
| | Ceratopogonidae sp.2 | X | X | - | X | X | X |
| | Ceratopogonidae sp.3 | X | X | X | X | X | - |

**Table 2.** Continued...

| Taxa | | Above 1500 (m) | 1200-1300 (m) | 900-1000 (m) | 400-700 (m) | 200-300 (m) | 0-100 (m) |
|---|---|---|---|---|---|---|---|
| | | Zone 1 | Zone 2 | Zone 3 | Zone 4 | Zone 5 | Zone 6 |
| | Ceratopogonidae sp. 4 | X | X | X | X | X | X |
| Chironomidae | | X | X | X | X | X | X |
| Culicidae | | X | - | - | - | - | - |
| Dixidae | | X | X | X | X | X | X |
| Dolichopodidae | | - | X | - | X | - | - |
| Empididae | | X | X | X | X | X | X |
| Ephydridae | | X | - | - | - | - | X |
| Psychodidae | *Maruina* | - | X | X | X | X | X |
| | cf. *Pericoma* | X | - | - | - | - | - |
| | Psychodidae sp.1 | X | X | X | X | X | X |
| Simuliidae | | X | X | X | X | X | X |
| Stratiomyidae | | X | - | X | - | - | - |
| Tabanidae | | X | - | - | X | X | - |
| Tipulidae | | X | X | X | X | X | X |

**Table 3.** Total abundance, Estimated richnness (ES), Fisher Alpha index and Abundance without Gerridae, Mesoveliidae, Veliidae and Chironomidae individuals to streams (local) and altitudinal zones (zonal) in Mabucaba River basin, Serra da Bocaina National Park, SP-RJ, Brazil. ES was standardized for 820 individuals by rarefaction.

| Streams | Total Abundance # | ES** Rarefaction | Fisher alpha** | Abundance** |
|---|---|---|---|---|
| S1 | 2679 | 63.00 | 15.90 | 820 |
| S2 | 3510 | 87.58 | 25.01 | 1853 |
| S3 | 6146 | 68.76 | 19.98 | 2677 |
| S4 | 4436 | 70.79 | 21.62 | 3172 |
| S5 | 5339 | 82.12 | 23.66 | 3298 |
| S6 | 6196 | 80.44 | 23.33 | 3202 |
| S7 | 4434 | 75.02 | 22.17 | 2286 |
| S8 | 5705 | 70.24 | 20.60 | 2892 |
| S9 | 5860 | 64.13 | 19.53 | 3792 |
| S10 | 2979 | 63.35 | 16.72 | 1559 |
| S11 | 1896 | 57.15 | 15.07 | 1357 |
| S12 | 2799 | 71.57 | 20.42 | 1576 |
| S13 | 5334 | 68.00 | 18.79 | 2930 |
| S14 | 3725 | 75.34 | 20.48 | 2096 |
| S15 | 4024 | 61.31 | 16.43 | 2551 |
| S16 | 6872 | 53.31 | 14.87 | 4508 |
| S17 | 6602 | 38.44 | 10.38 | 4075 |
| S18 | 4990 | 52.60 | 13.41 | 2662 |
| **Zone Altitudinal** | | | | |
| > 1500 m | 12336 | 133.52 | 25.63 | 5350 |
| 1200-1300 m | 15976 | 142.28 | 27.03 | 9672 |
| 900-1000 m | 16000 | 130.53 | 24.97 | 8970 |
| 700-400 m | 7674 | 123 | 23.37 | 4492 |
| 100-300 m | 13090 | 123.43 | 23.12 | 7577 |
| 0-100 m | 18450 | 90.99 | 16.92 | 11245 |

** Gerridae, Mesoveliidae, Veliidae and Chironomidae were excluded for the analysis; # Total abundance were measured using all families and inviduals collected in the stream.

**Table 4.** Taxa with significative values of Indication (p < 0.05, 1000 permutations) for each altitudinal zone studied Mambucaba River basin at the Serra da Bocaina National Park, SP-RJ, Brazil. ID Indicator value.

| Taxa | ID value | Mean | S. Dev | p* |
|---|---|---|---|---|
| **Zone 2: 1200-1300 m** | | | | |
| *Austrolimnius laevigatus* | 48.9 | 29.6 | 9.28 | 0.0180 |
| *Hagenulopsis diptera* | 56.7 | 39.3 | 8.12 | 0.0250 |
| *Heterelmis* sp.1 | 51.0 | 34.7 | 7.20 | 0.0220 |
| *Heterelmis* sp.4 | 44.2 | 30.4 | 6.62 | 0.3220 |
| *Kempnyia* | 54.5 | 33.6 | 8.64 | 0.0310 |
| *Marilia* sp.1 | 73.5 | 41.4 | 16.93 | 0.0470 |
| *Neoelmis* sp.2 | 61.4 | 32.7 | 12.08 | 0.0280 |
| *Paracloeodes* | 73.7 | 29.9 | 12.91 | 0.0120 |
| *Paragripopteryx* | 48.2 | 30.9 | 6.62 | 0.0210 |
| *Smicridea* sp.4 | 62.5 | 28.2 | 13.94 | 0.0470 |
| **Zone 3: 900-1000 m** | | | | |
| *Promoresia* sp.2 | 62.5 | 30.0 | 12.90 | 0.0360 |
| *Tupiperla* | 60.9 | 31.1 | 11.82 | 0.0110 |
| *Xenelmis* sp.2 | 76.9 | 46.6 | 13.77 | 0.0110 |
| **Zone 5: 100-300 m** | | | | |
| *Caenis* | 91.1 | 43.7 | 19.19 | 0.0350 |
| *Phylloicus* sp.2 | 51.1 | 33.2 | 8.65 | 0.0330 |
| **Zone 6: 0-100 m** | | | | |
| *Camelobaetidius* | 100.0 | 35.4 | 14.81 | 0.0060 |
| *Chimarra* | 53.6 | 33.0 | 10.31 | 0.0280 |
| *Grumicha* | 75.1 | 34.0 | 15.35 | 0.0280 |
| *Mirooculos froehlichi* | 78.7 | 55.6 | 10.86 | 0.0060 |
| *Metrichia* sp.4 | 77.9 | 38.1 | 16.23 | 0.0450 |

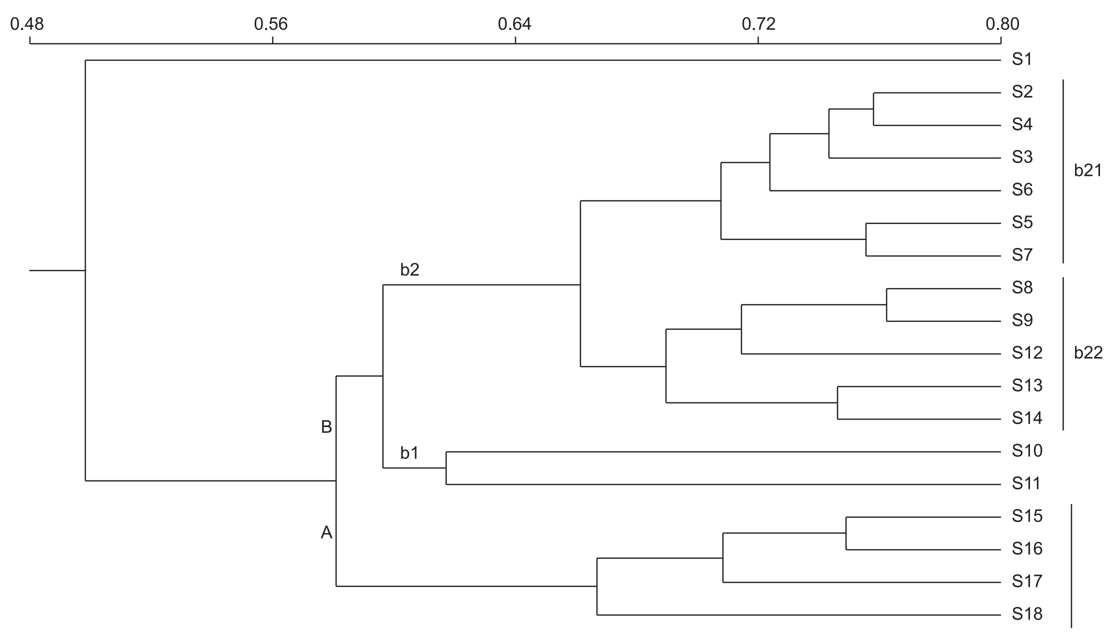


**Figure 2.** Cluster Analysis (UPGMA method) based on Sorensen's Index values to 18 streams in Mambucaba River basin, Serra da Bocaina National Park, SP-RJ (Cophenetic correlation coefficient = 0.852; A, B, b1, b2, b21 and b22 = are groups formed).

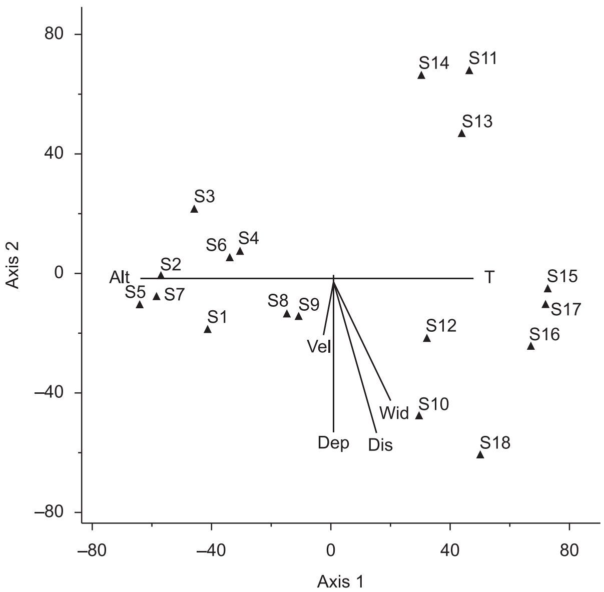


**Figure 3.** Canonical Correspondence Analysis (CCA) 1st and 2nd axes of the 18 sites studied and environmental parameters. Alt – Altitude, Vel. - Current velocity, Dep – Depth, Dis – Discharge, Wid – Width and T- Temperature.

values according to the increase in altitude. Jacobsen (2003) in a study of altitudinal changes in diversity of macroinvertebrates in Ecuadorian Andes found few variations of the environmental parameters among regions, with exception for altitude and temperature. According to Jacobsen et al. (1997), tropical rivers are more constant in relation to temperature regime than temperate rivers. However, dealing with zonal studies related to altitude or latitude, the temperature has been highlighted as the main abiotic factor that influences the structure and richness of benthic community both in temperate (e.g. Allan 1975, Ward 1986) and in tropical regions (e.g. Illies 1964, Palmer et al. 1994, Jacobsen et al. 1997, Ramirez et al. 2004).

Melo & Froehlich (2001) studying species richness in streams of different sizes in the Carmo River basin in São Paulo State, Brazil, found the highest values of taxonomic richness in the smallest streams and that differences of temperature in all sites was small. They observed that differences in temperature among rivers of different sizes, in altitudinal range of 200-800 m, are small in tropical regions and the temperature may not be a decisive element to determine local species richness. Tomanova et al. (2007) studying longitudinal and altitudinal changes of macroinvertebrates functional feeding groups in streams of Cochabamba, Bolivia, found altitude negatively related to water temperature and stream depth.

Studies carried out in areas with extensive altitudinal range, as in the Andes Mountains, show reduction in species richness as the altitude increases (e.g. Jacobsen et al. 1997, Jacobsen 2004). Jacobsen (2004) observed that the zonal family richness remained constant up to about 1800 m when, its start to decrease. In altitudes of 4000 m a.s.l. he found about one half of the total taxa at sea level. In Serra da Bocaina, we observed a reduction in taxonomic richness only in site 1, located at 1645 m, which presented a remarkable low richness value. Similar results were found by Huamantinco (2004) studying the Trichoptera fauna in mountain rivers in the State of Rio de Janeiro, with reduction of richness in the highest stream (Aiuruoca River, 1860 m).

We observed a slight increase in richness of families with the altitude, but many of these families were represented by a single taxon. Pringle & Ramirez (1998) reported overall higher diversity in highland compared to lowland streams. Jacobsen (2000) found the highest richness of Trichoptera morphospecies in streams at 1000-2000 m. Tate & Heiny (1995) found a positive relationship between richness and altitude in a catchment in Colorado (USA). They attributed this relationship to the higher human impact at lower altitudes. Lang & Raymond (1993) found a positive relationship between taxonomic richness and altitude in rivers in Switzerland due to a more significant human impact in lower altitudes, where taxa intolerant to pollution were predominant in headwaters. In the streams studied in PNSB, the increase in richness observed with the altitude may also be associated with a greater human influence in lower areas. In streams at 0-100 m, the high anthropic pressure in relation to land use and the state of riparian vegetation may have contributed to the lowest richness verified. Although some streams at high altitudes (sites S3 and S8), presented slight modifications in the riparian vegetation, the taxonomic richness was higher than in lowland streams.

## *2. Taxa composition in the altitudinal gradient*

Some taxa occurred exclusively in a single altitudinal zone. Others, even occurring throughout all gradient, presented higher abundance in certain altitude, such as *Hagenulopsis diptera* in altitudes of 1200-1300 m. *Hagenulopsis* is a characteristic genus of low rhithral regions (Da-Silva 2002). Baptista et al. (2001b) found *Hagenulopsis* occurring only on the 6th order reach at lower altitude areas of the Macaé River, RJ. However, this taxon occurred in almost all the rivers studied in PNSB and it was more abundant in the upper region of the altitudinal gradient.

Altitudinal zone 2, besides presenting the highest taxonomic richness, had the largest quantity of indicator taxa. In general, the indicator taxa to this altitudinal zone occurred in almost all the studied streams and presented higher abundance in the altitude 1200-1300 m such as *Austrolimnius laevigatus*, *Hagenulopsis diptera*, *Paragripopteryx* and *Kempnyia*.

In Zone 3 (900-1000 m), *Tupiperla* presented higher abundance. This genus together with other Gripopterygidae and *Kempnyia* are considered by Illies (1969) to be representatives of Oligostenothermal fauna, living in colder waters in rhithron areas. The elmids *Promoresia* sp.2 and *Xenelmis* sp.2 were indicators to this altitudinal zone too. Jacobsen et al. (1997) found representatives of Elmidae at all the studied altitudes (100 up to 4000 m), but the genera were not identified.

Amongst the taxa characteristics of the altitudes below 300 m (zone 5), *Miroculis froehlichi* is considered a very abundant Leptophlebiidae in Rio de Janeiro state and occurrs in both rhithral and potamal areas, in submerged litter or riffle litter (Da-Silva 2002a). Representatives of the caddisfly genus *Chimarra* are described as adapted to warmer temperatures; they are widely distributed and very abundant in tropical regions (Blahnik 1998, Huamantinco 2004).

Based on faunal composition, there was a marked separation of streams through the altitudinal gradient. Huamantinco (2004) also found the Trichoptera community divided into two groups of rivers: one group at higher altitude and higher genera richness, and other group of rivers at lower altitude and lower genera richness. In Serra da Bocaina, the streams below 200 m were characterized by taxa of potamal warm waters, such as *Camelobaetidius*, *Caenis*, *Miroculis froehlichi*, *Thraulodes itatiajanus*, *Chimarra*, *Macronema* and *Triplectides*. According to Illies (1964) some of these genera belong to families with wide range of distribution from the Andes, the Amazon lowland to the mountains of Eastern Brazil, adapted to warmer waters and are components of the potamal or polisternothermal fauna. Streams above 1000 m were characterized by higher faunal

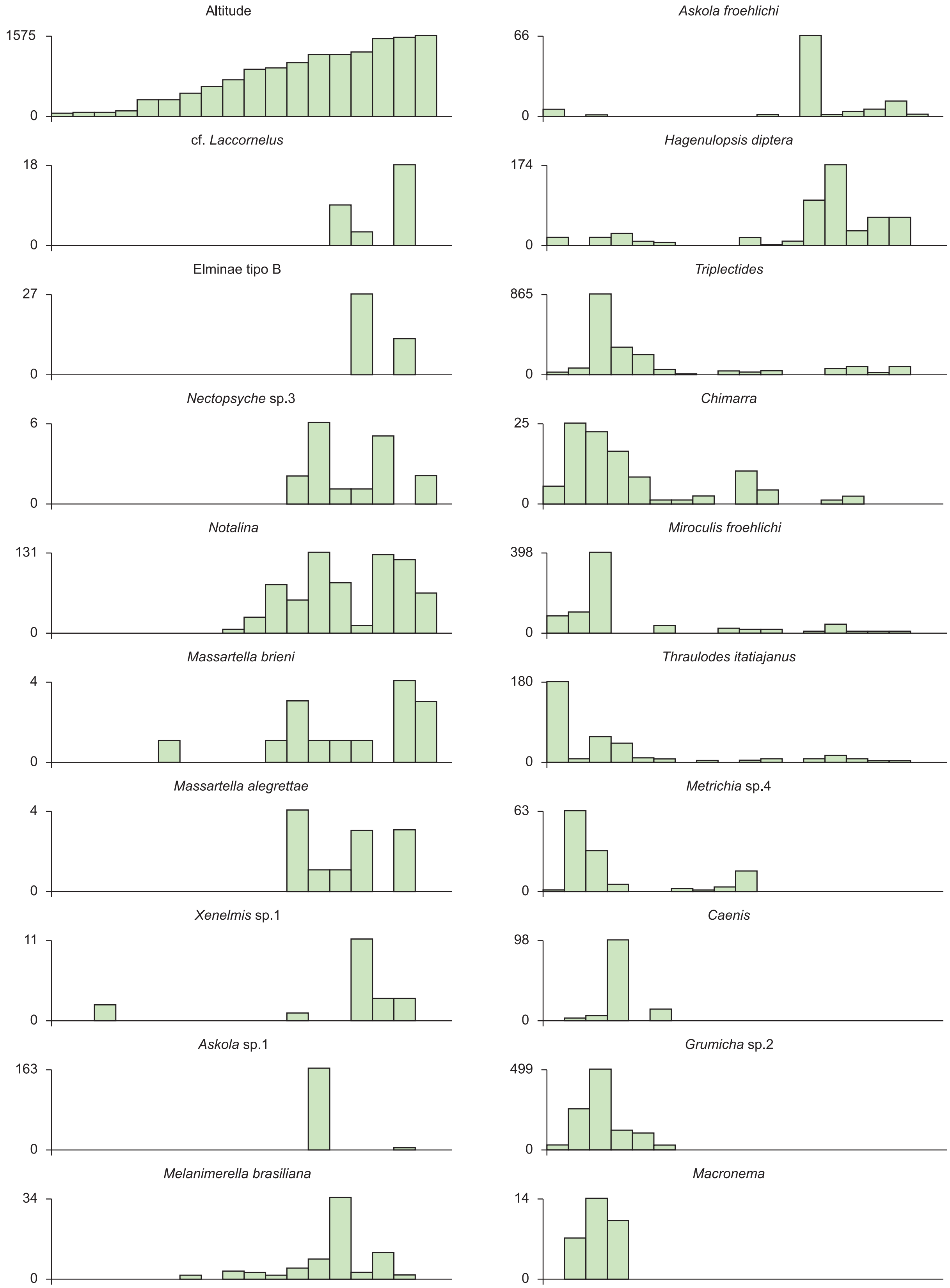


**Figure 4.** Distribution of the major indicative aquatic insect taxa for rhithral and potamal fauna in the altitudinal gradient of Mambucaba River basin, Serra da Bocaina National Park, SP-RJ.

richness, besides the presence of *Askola*, *Hagenulopsis diptera*, *Massartella* spp., *Melanemerella brasiliana*, *Anastomoneura guahybae* and *Notalina*. Many of these taxa are found normally in pristine rivers at altitudes higher than 800 m (e.g. Huamantinco 2004, Huamantinco & Nessimian 2004, Molineri & Domínguez 2003, Salles 2006).

The results presented here showed that despite the limited altitudinal range of Serra da Bocaina National Park, there is a distinct modification in the faunal community in relation to composition and abundance along this gradient, as pointed out by Illies (1964, 1969). Our results indicated that the altitudinal gradient is important not only to rivers of high mountains and high latitudes. Tropical rivers in lower altitud mountains may present important altitudinal distribution gradients of fauna. Palmer et al. (1994) found significant changes in composition and species richness in the Buffalo River (Africa) even in a small altitudinal range (600-1120 m). The absence of indicator species and the lower abundance in Zone 4 (between 500 and 800 m), when compared to the adjacent zones, suggest a transition zone of rhithral to potamal fauna, as pointed out by Illies (1964). This fauna seem to be completely distinct that of lower altitudes, as observed in cluster analysis, in which the streams below 200 m form a distinct group.

The present study is the first investigation of the aquatic insect community distribution in rivers at Atlantic Rain Forest in relation to altitude. The identification of characteristic zones in relation to the composition of the fauna is very important to guide programs of assessment and conservation of biodiversity in rivers of Southern Brazil.

## Acknowledgments

The authors thank The Nature Conservancy of Brazil and CNPq CT-HIDRO for financial support given to the first author, and CNPq for fellowship to the second author. ICMBIO-MMA and Serra da Bocaina National Park for collect permits. We are very grateful to the following specialists for help in identifications of aquatic insects: A.D. Santos, M.I.S. Passos and R.B. Braga (Coleoptera), E.R.Da-Silva and F.F. Salles (Ephemeroptera), F.F.F. Moreira, R.S. Longo and V.P. Alecrim (Hemiptera) and M.H. Olifiers (Plecoptera).

## References

ALLAN, J.D. 1975. The distributional ecology and diversity of benthic insects in Cemment Creek, Colorado. Ecology 56:1040-1053.

ANGRISANO, E.B. 1995. Insecta Trichoptera. In Ecosistemas de Aguas Continentales. Metodologia para su Estudio (E.C. Lopretto & G. Tell, eds.). vol. 3. Ediciones Sur, La Plata. p. 1199-1224.

BAPTISTA, D.F., DORVILLÉ, L.F.M., BUSS, D.F. & NESSIMIAN, J.L. 2001a. Spatial and temporal organization of aquatic insects assemblages in the longitudinal gradient of a tropical river. Rev. Bras. Biol. 61(2):295-304.

BAPTISTA, D.F., BUSS, D.F, DORVILLÉ, L.F.M & NESSIMIAN, J.L. 2001b. Diversity and habitat preference of aquatic insects along the longitudinal gradient of the Macaé river basin, Rio de Janeiro, Brazil. Rev. Bras. Biol. 61(2):249-258.

BELLE, J. 1992. Studies on ultimate instar larvae of Neotropical Gomphidae, with the description of *Tibiagomphus* gen. nov. (Anisoptera). Odonatologica 21(3):1-24.

BLAHNIK, R.J. 1998. A revision of the Neotropical species of the genus *Chimarra* subgenus chimarra (Trichoptera: Philopotamidae). Mem. Am. Entomol. Inst. 59:1-316.

BUSS, D.F., BAPTISTA, D.F., NESSIMIAN, J.L. & EGLER, M. 2004. Substrate specificity, environmental degradation and disturbance structuring macroinvertebrate assemblages in neotropical streams. Hydrobiologia 518:179-188.

CALLISTO, M., MORENO, P., GOULART, M., MEDEIROS, A.O., PETRUCIO, M., MORETTI, M., MAYRINK, N. & ROSA, C.A. 2001. The assessment of aquatic biodiversity along an altitudinal gradient at the Serra do Cipó (southeastern Brazil). Verh. Int. Verein. Limnol. 28:1814-1817.

CARVALHO, A.L. & CALIL, E.R. 2000. Chaves de identificação para as famílias de Odonata (Insecta) ocorrentes no Brasil, adultos e larvas. Papéis Avulsos de Zool. 41(15):223-241.

CARVALHO, A.L. 1989. Description of the larvae of *Neuraeschna costalis* (Burmeister), with notes on its biology, and a key to the genera of Brazilian Aeshnidae larvae (Anisoptera). Odonatologica 18(4):325-332.

CARVALHO, A.L., WERNECK-DE-CARVALHO, P. & CALIL, E.R. 2002. Description of the larvae of two species of *Dasythemis* Karsch, with a key to the genera of Libellulidae occurring in the states of Rio de Janeiro and São Paulo, Brazil (Anisoptera). Odonatologica 31(1):23-33.

CRISCI-BISPO, V.L.C., BISPO, C.P. & FROEHLICH, C.G. 2007. Ephemeroptera, Plecoptera and Trichoptera assemblages in two Atlantic Rainforest streams, Southeastern Brazil. Rev. Bras. Zool. 24(2):312-318.

DA-SILVA, E.R. 2002. Leptophlebiidae (Insecta: Ephemeroptera) ocorrentes no Estado do Rio de Janeiro: taxonomia e caracterização biológica. Dissertação de Mestrado, Museu Nacional-PPGZOO, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brasil, 134p.

DA-SILVA, E.R., SALLES, F.F., NESSIMIAN, J.L. & COELHO, L.B.N. 2003. A identificação das famílias de Ephemeroptera (Insecta) ocorrentes no Estado do Rio de Janeiro: chave pictórica para as ninfas. Bol. Mus. Nac., N.S., Zool. 508:1-6.

DIAS, L.G., SALLES, F.F., FRANCISCHETTI, C.N. & FERREIRA, P.S.F. 2006. Key to the genera of Ephemerelloidea (Insecta: Ephemeroptera) from Brazil. Biota Neotrop. 6(1): http://www.biotaneotropica.org.br/v6n1/pt/abstract?identification-key+bn00806012006.

DOMINGUEZ, E. & BALLESTEROS-VALDEZ, J.M. 1992. Altitudinal replacement of Ephemeroptera in a subtropical river. Hydrobiologia 246:83-88.

DUFRÊNE, M. & LEGENDRE, P. 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecol. Monogr. 67(3):345-366.

EGLER, M. 2002. Utilizando a comunidade de macroinvertebrados bentônicos avaliação da degradação de ecossistemas de rios em áreas agrícolas. Dissertação de Mestrado, Escola Nacional de Saúde Pública, FIOCRUZ, Rio de Janeiro, RJ, Brasil, 147p.

ELLIOT, J.M. 1977. Some methods for statistical analysis of samples of benthic invertebrates. 2th ed. Freshwater Biological Association, London, 160p. Scientific Publication 25.

GOTELLI, N.J. & COLWELL, R.K. 2001. Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. Ecology Letters 4:379-391.

GUIMARÃES, A.E., GENTILE, C., LOPES, C.M., SANT'ANNA, A. & JOVITA, A.M. 2000. Ecologia de mosquitos (Diptera: Culicidae) em áreas do Parque Nacional da Serra da Bocaina, Brasil. I– Distribuição por hábitat. Rev. Saúde Pública 34(3):243-250.

HAMMER, Ø., HARPER, D.A.T. & RYAN, P.D. 2001. PAST: Paleontological Satatistic software package for education and data analysis. Paleontol. Eletr. 4(1):9.

HUAMANTINCO, A.A, & NESSIMIAN, J.L. 2004. New Neotropical genus and species of Odontocerinae (Trichoptera: Odontoceridae) from southeastern Brazil. Aquat. Insects 26(3/4):281-288.

HUAMANTINCO, A.A. 2004. Estudo das comunidades de Trichoptera (Insecta) em riachos de quatro áreas de Mata Atlântica do Estado do Rio de Janeiro. Ph.D. Thesis, Museu Nacional-PPGZOO, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brasil, 91p.

ILLIES, J. 1964. The invertebrate fauna of Huallaga, a Peruvian tributary of the Amazon River, from the sources down to Tingo Maria. Verh. Int. Verein. Limnol. 15:1077-1083.

ILLIES, J. 1969. Biogeography and ecology of Neotropical freshwater insects, especially those from running waters. In Biogeography and Ecology in South America. (E.J. Fittkau, ed.) Dr. W Junk, The Hague. 2:685-707.

JACOBSEN, D. 2000. Gill size of trichopteran larvae and oxygen supply in streams along a 4000-m gradient of altitude. J.N. Am. Benthol. Soc. 19(2):329-343.

JACOBSEN, D. 2003. Altitudinal changes in diversity of macroinvertebrates from small streams in Ecuadorian Andes. Arch. Hydrobiologie 158(2):145-167.

JACOBSEN, D. 2004. Contrasting patterns in local and zonal family richness of stream invertebrates along an Andean altitudinal gradient. Freshwater Biol. 49:1293-1305.

JACOBSEN, D., SCHULTZ, R. & ENCALADA, A. 1997. Structure and diversity of stream invertebrate assemblages: the influence of temperature with altitude and latitude. Freshwater Biol. 38:247-261.

LANG, C. & RAYMOND, O. 1993. Empirical relation between diversity of invertebrates communities and altitudinal rivers: application to biomonitoring. Aquatic Sci. 55(3):188-196.

LUDWIG, J.A. & REYNOLDS, J.F. 1988. Statistical Ecology: a primer on methods and computing. John Wiley & Sons, USA, 337p.

McCUNE, B. & MEFFORD, M.J. 1999. Multivariate analysis of Ecological Data. Version 4.14. MJM Software, Gleneden Beach, Oregon, U.S.A.

MELO, A.S. & FROEHLICH, C.G. 2001. Macroinvertebrates in Neotropical streams: richness patterns along a catchment and assemblage structure between 2 seasons. J. N. Am. Benthol. Soc. 20(1):1-16.

MERRITT, R.W. & CUMMINS, K.W. 1996. An introduction to the Aquatic Insects of North America. 3th ed. Kendall/Hunt Publishing Company, 862p.

MISERENDINO, M.L. 2001. Macroinvertebrate assemblages in Andean Patagonian rivers and streams: environmental relationships. Hydrobiologia 444:147-158.

MOLINERI, C. & DOMÍNGUEZ, E. 2003. Nymph and egg of *Melanemerella brasiliana* (Ephemeroptera: Ephemerelloidea: Melanemerellidae), with comments on its systematic position and the higher classification of Ephemerelloidea. J. N. Am. Benthol. Soc. 22(2):263-275.

MONAGHAN, K.A., PECK, M.R., BREWIN, P.A., MASIERO, M., ZARATE, E., TURCOTTE, P. & ORMEROD, S.J. 2000. Macroinvertebrate distribution in Ecuadorian hill streams: the effects of altitude and land use. Arch. Hydrobiol. 149(3):421-440.

MOULTON, T.P. & MAGALHÃES, S.A.P. 2003. Responses of leaf processing to impacts in streams in Atlantic Rain Forest, Rio de Janeiro, Brazil – a test of the Biodiversity-ecosystem Functioning relationship? Braz. J. Biol. 63(1):87-95.

NIESER, N. & MELO, A.L. 1997. Os Heterópteros Aquáticos de Minas Gerais. Guia Introdutório com Chave de Identificação para as Espécies de Nepomorpha e Gerromorpha. Editora UFMG, Belo Horizonte, Minas Gerais, Brasil, 180p.

OLIFIERS, M.H., DORVILLÉ, L.F.M., NESSIMIAN, J.L. & HAMADA, N. 2004. A key to Brazilian genera of Plecoptera (Insecta) based on nymphs. Zootaxa 651:1-15.

OLIVEIRA, L.M.T. & SANTOS, P.R.A. 2001. Mapa imagem do Parque Nacional da Serra da Bocaina. In Anais X SBSR. Foz do Iguaçu, p. 1691-1697.

PALMER, C., PALMER, A., O'KEEFFE, J. & PALMER, R. 1994. Macroinvertebrate community structure and altitudinal changes in the upper reach of a warm temperate southern African river. Freshwater Biol. 32:337-347.

PASSOS, M.I.S., NESSIMIAN, J.L. & FERREIRA JR, N. 2007. Chaves para a identificação dos gêneros de Elmidae (Coleoptera) ocorrentes no Estado do Rio de Janeiro, Brasil. Rev. Bras. Entomol. 51(1):42-53.

PES, A.M.O., HAMADA, N. & NESSIMIAN, J.L. 2005. Chaves de identificação de larvas para famílias e gêneros de Trichoptera (Insecta) da Amazônia Central, Brasil. Rev. Bras. Entomol. 49(2):181-204.

PRINGLE, C.M. & RAMÍREZ, A. 1998. Use of both benthic and drift sampling techniques to assess tropical stream invertebrate communities along na altitudinal gradient, Costa Rica. Freshwat. Biol. 39:359-373.

RAMIREZ, J.J., ROLDÁN, P.G. & YEPES, G.A. 2004. Altitudinal variation of the numerical structure and biodiversity of the taxocenosis of Ephemeroptera in the South, North, and Central Regions of the Department of Antioquia, Colombia. Acta. Limnol. Bras. 16(4):329-339.

ROHLF, F.J. 1992. NTSYS-pc Numerical taxonomy and Multivariate Analysis System. University of New York, Setauret, New York, 244p.

ROQUE, F.O., TRIVINHO-STRIXINO, S., STRIXINO, G., AGOSTINHO, R.C. & FOGO, J.C. 2003. Benthic macroinvertebrate in streams of the Jaraguá State Park (Southeast of Brazil) considering multiple spatial scales. J. Ins. Conserv. 7:63-72.

SALLES, F.F. 2006. A ordem Ephemeroptera no Brasil (Insecta): taxonomia e diversidade. Ph.D. Thesis, Universidade Federal de Viçosa, Viçosa, MG, Brasil, 300p.

SALLES, F.F., DA-SILVA, E.R., SERRÃO, J.E. & FRANCISCHETTI, C.N. 2004. Baetidae (Ephemerotera) na Região Sudeste do Brasil: novos registros e chave para os gêneros no estágio ninfal. Neotrop. Ent. 33(5):725-735.

SILVEIRA, M.P., BUSS, D.F., NESSIMIAN, J.L. & BAPTISTA, D.F. 2006. Spatial and temporal distribution of benthic macroinvertebrates in a southeastern Brazilian river. Braz. J. Biol. 66(2B):623-632.

SITES, R.W., WILLIG, M.R. & LINIT, M.J. 2003. Macroecology of aquatic insects: a quantitative analysis of taxonomic richnees and composition in the Andes Mountains of Northern Ecuador. Biotropica 35(2): 226-239.

SOKAL, R.R. & ROHLF, F.J. 1995. Biometry. W.H. Freeman & Company, New York, 887p.

STATSOFT, INC. 2001. SATATISTICA (data analysis software system). Version 6. www.statsoft.com.

TATE, C.M. & HEINY, J.S. 1995. The ordination of the benthic invertebrates communities in the South Platte River Basin in relation to environmental factors. Freshwater Biol. 33:439-454.

TOMANOVA, S., TEDESCO, P.A., CAMPERO, M., VAN DAMME, P.A., MOYA, N. & OBERDORFF, T. 2007. Longitudinal and altitudinal changes of macroinvertebrate functional feeding groups in NETROPICAL streams: a test of the River Continuum Concept. Fundamental and Aplied Limnology, Arch. Hydrobiol. 170(3):233-241.

WARD, J.V. 1986. Altitudinal zonation in a Rocky mountain stream. Arch. Hydrobiol. Suppl. 74:133-195.

WATERWATCH AUSTRALIA STEERING COMMITTEE. 2002. Module 4–Physical and Chemical parameters. In Waterwatch Australia National Technical Manual. Environmental Australia, Canberra. http://www.waterwatch.org.au/libray/ (último acesso em: 07/2003).

WIGGINS, G.B. 1996. Larvae of the North America caddisfly genera (Trichoptera). 2nd ed. University of Toronto Press, Toronto, 457p.

*Received 12/02/2010*
*Revised 05/07/2010*
*Accepted 26/07/2010*