

Mayfly distribution along a longitudinal gradient in Serra do Cipó, southeastern Brazil.

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ABSTRACT: Mayfly distribution along a longitudinal gradient in Serra do Cipó, southeastern Brazil.

The main goals of this study were to evaluate the spatial distribution of mayfly nymphs and substrate associations along a longitudinal gradient in two lotic ecosystems of the same watershed at Serra do Cipó, southeastern Brazil. The main questions addressed here were: 1) Do mayfly nymphs present longitudinal zonation? 2) Do mayfly nymphs present specific associations with the type of substrate? 3) Which are the main consequences of mayfly distribution for the conservation strategies of headwaters in the Serra do Cipó? Samplings were realized in 1st up to 6th order reaches of the Indaiá stream and Peixe River, during the rainy and dry periods of 2000 and 2001, totaling 234 samples. Regarding the longitudinal distribution, most of the taxa showed a gradient (clinal), or zone patterns, being restricted (or presenting higher densities) to a specific river reach or river section. The highest densities of Baetidae nymphs were found in 4th up to 6th order reaches while the Leptophlebiidae and Euthyplociidae were found in higher densities in the upstream reaches. The Baetidae taxa were found associated preferentially with aquatic macrophytes, while the Leptophlebiidae and Euthyplociidae with pebbles, gravel and sand deposits. The results evidenced differences in the taxonomic composition and abundance of the mayfly fauna along the longitudinal gradient. The distribution patterns and substrate associations call attention to the importance of the preservation of the natural characteristics of the altitudinal headwaters in Brazilian watersheds.

Key-words: Ephemeroptera, habitat diversity, substrate association, conservation, river ecology.

RESUMO: Distribuição de Ephemeroptera ao longo de um gradiente longitudinal na Serra do Cipó, sudeste do Brasil. Os objetivos deste estudo foram avaliar a distribuição espacial de ninfas de Ephemeroptera e associações com substratos ao longo de um gradiente longitudinal em dois ecossistemas lóticos em uma mesma bacia hidrográfica na Serra do Cipó, sudeste do Brasil. As principais perguntas que nortearam este estudo foram: 1) As ninfas de Ephemeroptera apresentam zonação longitudinal?; 2) As ninfas apresentam associações específicas com os substratos?; 3) Quais seriam as implicações da distribuição dos Ephemeroptera para a conservação de nascentes na Serra do Cipó? Foram realizadas amostragens intensivas em trechos de 1^a. a 6^a. ordens ao longo do córrego Indaiá e rio Peixe, nos períodos de chuvas e seca de 2000-2001, totalizando 234 amostras. Quanto à distribuição longitudinal, a maioria dos taxa apresentou padrão de distribuição em gradientes (clinal) ou em zonas, sendo restritos (ou com altas densidades) em um determinado habitat ou trecho de rio. As maiores densidades de ninfas de Baetidae foram encontradas nos trechos médios (4^a a 6^a ordens), enquanto que Leptophlebiidae e Euthyplociidae foram encontradas em altas densidades nos trechos de cabeceira (1^a a 3^a ordens). Os Baetidae associaram-se preferencialmente com macrófitas aquáticas, enquanto que os Leptophlebiidae e Euthyplociidae com pedras, cascalho e depósitos de areias. Os resultados evidenciaram diferenças na composição taxonômica e abundância na fauna ao longo do gradiente longitudinal. Os padrões de distribuição e associações com substratos ressaltam a importância de preservação de nascentes de altitude no Brasil.

Palavras-chave: Ephemeroptera, diversidade de habitats, associação com substrato, conservação, ecologia de rios.

Introduction

The Ephemeroptera is a conspicuous and diverse group in the sediment and aquatic macrophytes in lotic ecosystems of Serra do Cipó, and often constitute the dominant group in the macroinvertebrate communities (Galdean et al., 1999; 2000; 2001). The distribution and abundance of mayfly nymphs, regarding the zoogeographical limitations and abiotic factors, are determined mainly by temperature, substrate type, current velocity and water quality (Brittain, 1982).

Ecological studies about mayflies are still scarce in the tropics, with few concerning distribution, diversity and assemblage structure (e.g., Ferreira & Froehlich, 1992; Froehlich & Oliveira, 1997; Oliveira & Froehlich, 1997; Bispo & Oliveira, 1998). Crucial information such as longitudinal distribution and substrate association in Neotropical freshwater ecosystems are still to be determined. Despite the efforts of some authors in describing such patterns, many studies are performed in temperate regions (e. g., Hawkins, 1984) and only a few studies based on Neotropical areas (e. g., Baptista et al., 2001a). According to Vannote et al. (1980) the structural and functional characteristics of invertebrate assemblages distributed along river gradients are determined by modifications in physical factors and fluvial geomorphologic processes along the river. These modifications include width, depth and flow volume increase, forcing the benthic organisms to adapt rapidly to the available energy sources, oscillating between heterotrophic (headwaters and mouth reaches) and autotrophic (medium reaches) metabolism (Callisto et al., 2001).

The study of mayfly spatial distribution and substrate association in tropical waters may reflect the overall quality of the ecosystems and also the main available trophic resources. However, there are still no studies about the longitudinal distribution and substrate association of these insects in the Minas Gerais State. The main goals of this study were to evaluate the spatial distribution of mayfly nymphs and their substrate associations along a longitudinal gradient in lotic ecosystems of the Serra do Cipó National Park. The main questions addressed here were: 1) Do mayfly nymphs present longitudinal zonation? 2) Do mayfly nymphs present specific associations with substrate type? 3) Which are the main consequences of mayfly distribution patterns for the conservation strategies of headwaters in the Serra do Cipó?

Study Area

Serra do Cipó is located south of the Espinhaço Cordillera (19°-20° S - 43°-44° W) in the center of Minas Gerais State. The lotic ecosystems of Serra do Cipó belong to two of the most important watersheds in Brazil, the Doce and São Francisco rivers. Within these two watersheds, some regions are in nearly "pristine" conditions (e.g., Indaiá and Capão da Mata streams, located within the Serra do Cipó National Park) while others (Cipó, Peixe and Preto do Itambé rivers) have been affected by human activities to varying degrees (Galdean et al., 2000). The Doce River watershed is in the southeastern part of Brazil, between the states of Minas Gerais and Espírito Santo, and with a drainage area of 83,400 km². The human population is about 2.8 million in 163 municipal districts (FEAM, 1990).

The vegetation is composed by tropical savannah (locally called "cerrado") in the lower altitudes (700-900 m), rock fields (locally called "campos rupestres") in the highest portions (above 1,000 m a.s.l.) and riparian forest in the humid valleys, along the river courses. The climate is classified as Cwb (Köppen, 1931), with rainy summers and dry winters, and an annual mean pluviosity of 1,500 mm (Galvão & Nimer, 1965). The longitudinal gradient was studied in the Indaiá stream (1st up to 4th orders) and Peixe River (5th and 6th orders), both belonging to the Doce River basin.

Indaiá Stream and Peixe River are characterized by acid to slightly neutral waters, with the pH varying between 4.2 and 7.3 and high dissolved oxygen concentrations (6.7 mg/L up to 9.1 mg/L). The values of electrical conductivity are usually low (< 15 mS/cm in the dry period and < 25 mS/cm in the rainy period) and the water column presents low turbidity (0 NTU to 34 NTU). The concentration of total dissolved solids is low and constant at 0.01 g/L. The temperature is highly variable, with higher values in the rainy period, in those reaches with open riparian vegetation (composed by rock fields or degraded by

pastures) and lower values in the well-developed riparian forest reaches (in the 3rd order reaches) (Callisto et al., 2001; 2004). A complete physical and chemical characterization of the studied ecosystems is provided by Callisto et al. (2001; 2002).

Methods

Substrate collection

The samples were collected during the rainy (February) and dry (June) periods of 2000 and 2001, along a longitudinal gradient in the Indaiá Stream (1st up to 4th order reaches) and Peixe River (5th and 6th order reaches). In each river reach we sampled the most representative substrates, varying from one to four substrates collected per river reach, totaling 120 samples in 2000 (60 samples in each sampling period) and 114 samples in 2001 (57 samples in each sampling period) (Tab.I).

The samples were collected in triplicates, using Surber samplers (0.250 mm mesh) with an area of 0.0625 m² (used in the substrates composed by gravel and sand, and in the substrate composed by the leaves and branches of marginal vegetation) and 0.01 m² (remaining substrates), and immediately fixed with 10% formaline.

In the laboratory, the samples were washed on 0.250 mm sieves, and the macroinvertebrates were sorted and identified under a stereomicroscope (40x) using the available literature (Dominguez et al., 1992; Dominguez & Pescador, 1994; Dominguez et al., 2001; Lugo-Ortiz & McCafferty, 1995; 1996a; 1996b; 1996c; Peters, 1971; Salles, 2002; Salles & Lugo-Ortiz, 2002). The organisms were preserved in 70% alcohol and deposited in the Reference Collection of Benthic Macroinvertebrates, Institute of Biological Sciences, Federal University of Minas Gerais, Brazil.

Table I: River stretches, riparian vegetation type, ecosystems, and sampled substrate during the rainy and dry periods of 2000-2001. *Collected only in the year 2000. **IS= Indaiá Stream; PS= Peixe River in Sobrado Farm locality; PC= Peixe River, confluence with Preto do Itambé River.

River stretch	Riparian vegetation	Ecosystem	Sampled Substrate
1 st order	Rupestrian fields	IS	Filamentous algae (F'a)*
1 st order	Rupestrian fields	IS	Deposit of fine detritus (D)
2 nd order	Rupestrian fields	IS	Algae biofilm (Ab)
2 nd order	Rupestrian fields	IS	Mosses banks (Mb)
2 nd order	Rupestrian fields	IS	Pebbles, gravel and sand deposits (PGs)
3 rd order	Riparian forest, closed canopy	IS	Mosses banks (Mb)
3 rd order	Riparian forest, closed canopy	IS	Pebbles, gravel and sand deposits (PGs)
3 rd order	Riparian forest, open canopy	IS	Algae biofilm (Ab)
3 rd order	Riparian forest, open canopy	IS	Mosses banks (Mb)
3 rd order	Riparian forest, open canopy	IS	Pebbles, gravel and sand deposits (PGs)
4 th order	Rupestrian fields	IS	Algae biofilm (Ab)
4 th order	Rupestrian fields	IS	Mosses banks (Mb)
4 th order	Rupestrian fields	IS	Pebbles, gravel and sand deposits (PGs)
4 th order	Rupestrian fields	IS	Eriocaulaceae banks (Eb)
5 th order	Secondary forest, pastures	PS	Algae biofilm (Ab)
5 th order	Secondary forest, pastures	PS	Mosses banks (Mb)
5 th order	Secondary forest, pastures	PS	Pebbles, gravel and sand deposits (PGs)
5 th order	Secondary forest, pastures	PS	Submerged angiosperms (Sa)
6 th order	Secondary forest, pastures	PC	Deposit of fine detritus (D)
6 th order	Secondary forest, pastures	PC	Leaves and branches of marginal vegetation (MV)

Results

Longitudinal distribution

Baetidae

This family presented wide distribution along the longitudinal gradient, being found in all river reaches (Fig. 1). The highest density values were found in the 4th up to 6th order reaches. Regarding the longitudinal distribution of baetid genera, the 5th and 6th order reaches were preferred by most of the Baetidae taxa (Tab. II).

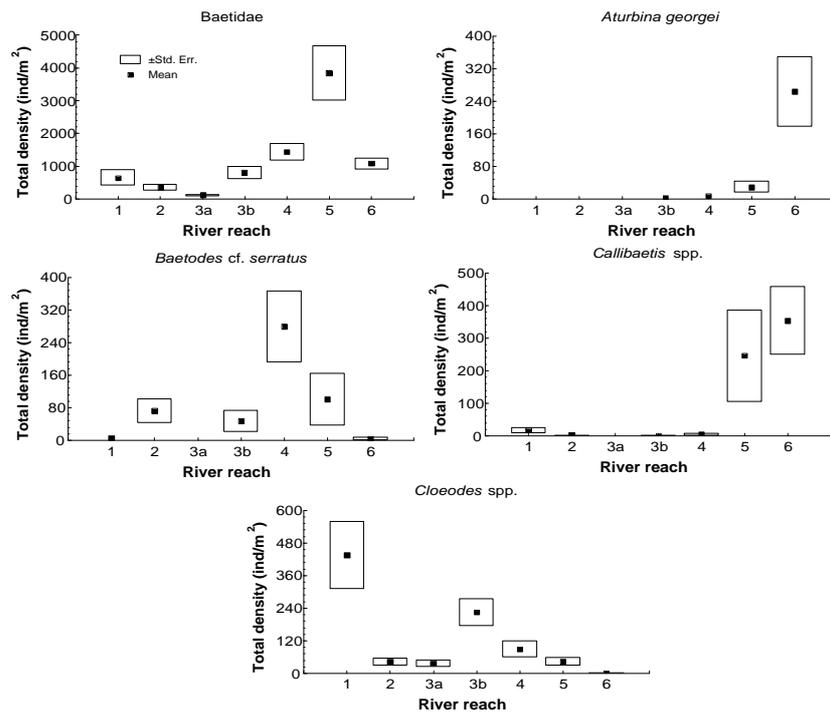


Figure 1: Total densities (ind/m², median and standard error) of Baetidae, *Aturbina georgei*, *Callibaetis* spp., *Baetodes cf. serratus* and *Cloeodes* spp. along the longitudinal gradient during the rainy and dry periods of 2000-2001 in the Indaiá Stream and Peixe River. *3a = riparian forest with a closed canopy; 3b = riparian forest with an open canopy.

Apobaetis fiuzai was found only in the 6th order reach. *Aturbina georgei* and *Callibaetis* spp. presented a gradient distribution pattern, from the 3rd order (open canopy) up to the 6th order reach (Fig. 1). *Camelobaetidius* spp. was found in low densities in the 2nd and 4th order reaches, being found in high numbers in the 5th order reach (323.6 ± 603.8 ind/m²). *Baetodes cf. serratus* was found in low densities in all river reaches, except by the 4th and 5th order reaches, which presented the highest densities (Fig. 1). *Waltzoyphius fasciatus* were found only in the 5th and 6th order reaches, with higher densities in the 5th order reach (187.5 ± 892.7 ind/m²).

Americabaetis spp., *Cloeodes* spp. and *Paracloeodes* spp. were the most abundant and widely distributed taxa. These taxa were found in all studied reaches, except *Paracloeodes* spp. in the 2nd order reach. This taxon present highest densities in the 5th order reach, also being found in high densities in the 3rd (open canopy) and 6th order reaches. *Americabaetis* spp. was the dominant taxon and presented a distribution pattern similar to the Baetidae specimens, with higher densities in the 4th and 5th order reaches. *Cloeodes* spp. presented high densities in the 1st order and a decreasing gradient from the 3rd down to the 6th order reach (Fig. 1).

Table II: Longitudinal distribution and substrate associations of mayfly nymphs along the longitudinal gradient during the rainy and dry periods of 2000 and 2001. *Significant values by Dunn's test at least in $p < 0.05$. **Non-significant relationships, however with large density values. The abbreviations are presented in the Table I.

Taxa	River stretch	Substrate Type
Baetidae		
Americabaetis spp.	All, 5 th *; 6 th * order stretches	All substrates (Eb** and Sm**)
Apobaetis fiuzai	6 th order stretch	Detritus deposits
Aturbina georgei	3 rd (open canopy) up to 6 th * order stretches	Ab, Pgs, Eb, Sm, Mv*
Baetodes cf. serratus	All, except by the 3 rd order stretch (closed canopy); 5 th * order stretch	D, Fa, Mb, Ab*, Pgs, Eb*, Sm, Mv
Callibaetis spp.	All, except by the 3 rd order stretch (closed canopy); 6 th * order stretch	D*, Fa, Mb, Ab, Pgs, Eb, Sm, Mv
Camelobaetidius spp.	2 nd , 4 th and 5 th * order stretches	Mb, Ab**, Pgs
Cloeodes spp.	All river stretches (1 st ** and 4 th ** order stretches)	All substrates (Fa** and D**)
Paracloeodes spp.	All river stretches, except by the 2 nd order stretch (3 rd **, open canopy, 5 th ** and 6 th ** order stretches)	All substrates, Sm*
Waltzoyphius fasciatus	5 th and 6 th order stretches	Sm* and Mv
Leptophlebiidae		
Askola cf. froehlich	1 st up to the 5 th order stretches (3 rd ** order stretches)	D, Fa, Mb, Ab, Pgs*, Sm
Farrodes spp.	2 nd up to the 6 th order stretch (3 rd order stretch**, closed canopy)	D, Mb**, Ab, Pgs, Eb**, Sm, Mv
Hagenulopsis sp.	4 th and 5 th * order stretches	Ab and Pgs*
Hagenulopsis ? sp.	5 th order stretch	Pgs
Hermanella spp.	4 th and 5 th order stretches	Mb, Ab, Pgs, Eb*
Leentvaaria sp.	3 rd (open canopy), 5 th ** and 6 th order stretches	Ab and Pgs**
Massartella spp.	1 st up to the 4 th order stretches	Fa, Mb**, Pgs
Miroculis sp.	All river stretches (3 rd order stretches)	Fa, Mb, Ab, Pgs*, Sm, Mv
Thraulodes spp.	2 nd up to the 6 th order stretches (5 th ** order stretch)	Ab, Pgs* and Mv
Leptohyphidae		
Leptohyphes spp.	2 nd up to the 6 th order stretches, 5 th ** order stretch	D, Mb**, Ab, Pgs, Eb, Sm**, Mv
Leptohyphodes sp.	2 nd up to the 6 th order stretch	Mb, Pgs**, Sm**, Mv
Tricorythopsis spp.	3 rd (open canopy) up to the 6 th order stretches; 5 th * order stretch	D, Mb**, Ab, Pgs**, Sm, Mv
Tricorythodes spp.	3 rd ** (closed canopy), 5 th and 6 th order stretches	Mb, Pgs, Mv**
Euthyplociidae		
Campylocia cf. bocainensis	2 nd * up to the 5 th order stretches	Pgs
Polymitarcyidae		
Asthenopus sp.	3 rd * and 6 th order stretch	Pgs and Mv**
Campsurus sp.	2 nd * up to the 3 rd (open canopy) stretch	Mb and Pgs*

Leptophlebiidae

Leptophlebiidae also showed wide distribution along the longitudinal gradient, being found in all river reaches (Fig. 2). A gradient in the distribution pattern of this family was observed between the 1st and 6th order reaches, close to a normal distribution curve. The highest density values were found in the 3rd order reaches (closed and open canopy) up to 6th order reaches (Tab. II).

Regarding the longitudinal distribution of leptophlebiid genera, two groups could be observed: an upstream and a downstream groups (Table II). The upstream group was composed by Askola cf. Froehlich, Miroculis sp., Massartella spp., and Farrodes spp. The Askola cf. Froehlich and Miroculis sp. presented a gradient from the 1st up to the 3rd order and down, to the 5th and 6th order reaches (Fig. 2). Massartella spp. also showed a gradient distribution pattern, although presenting high densities in the 3rd order reach

(closed canopy), probably due to its specific association with a particular soft moss, found abundantly in low current areas in this reach (Fig. 2). *Farrodes* spp. was found in almost all river reaches, except in the 1st order reach. This taxon also shows high densities in the 3rd order reach (closed canopy) ($401.0 \pm 1,058.3$ ind/m²).

The downstream group was characterized by scrapers and filtering-collectors (Pérez, 1988; Domínguez et al., 1992; Merritt & Cummins, 1996) and composed by *Hagenulopsis* sp., *Leentvaaria* sp., *Hermanella* spp., *Thraulodes* spp. and *Hagenulopsis* sp.. *Thraulodes* spp. was distributed along the entire studied longitudinal gradient, and *Hagenulopsis* sp. was found only in the gravel deposits in the 5th order reach. The remaining taxa were found in two or three reaches, with higher densities in the 4th and 5th orders (Tab. II).

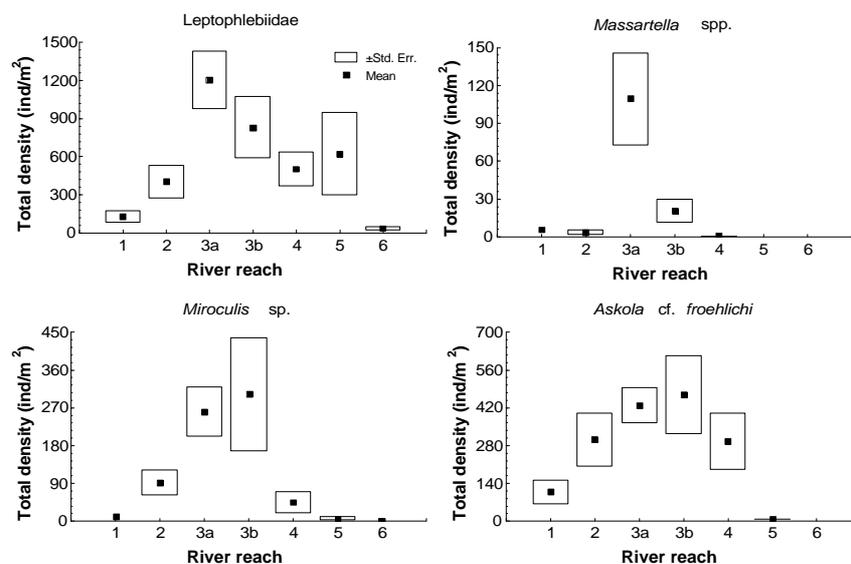


Figure 2: Total densities (ind/m², median and standard error) of *Leptophlebiidae*, *Miroculis* sp., *Askola* cf. *froehlichii*, *Massartella* spp. nymphs along the longitudinal gradient during the rainy and dry periods of 2000-2001 in the Indaiá Stream and Peixe River. *3a = riparian forest with a closed canopy; 3b = riparian forest with an open canopy.

Leptohiphidae

Leptohiphidae was found in almost all studied river reaches, except by the 1st order reach (Fig. 3). Low densities were found along the gradient, with an increase in the 5th order reach, mainly due to the high densities of *Leptohiphes* spp. and *Tricorythopsis* spp. (Fig. 3). *Tricorythodes* spp. was found with low densities, while *Leptohiphes* spp. was the most largely distributed genera, only absent in the 1st order reach. The highest densities were found in 3rd and 5th order reaches (Fig. 3). *Tricorythopsis* was present in low densities in the 3rd (open canopy) up to the 6th order reach, except by the 5th order reach which presented high densities ($1,147.8 \pm 2,639.3$ ind/m²). On the other hand, *Leptohiphodes* showed a marked gradient with an increase in the 3rd up to the 4th order reaches and down to the 5th and 6th order reaches (Fig. 3).

Euthyplociidae

Campylocia cf. *bocainensis* was the only species found. It could be observed a decreasing gradient in the densities of this species, from the 2nd down to the 5th order reaches (Fig. 4). In all reaches this taxon presented a restricted and specialized distribution, being found only in gravel deposits, close to the river margins.

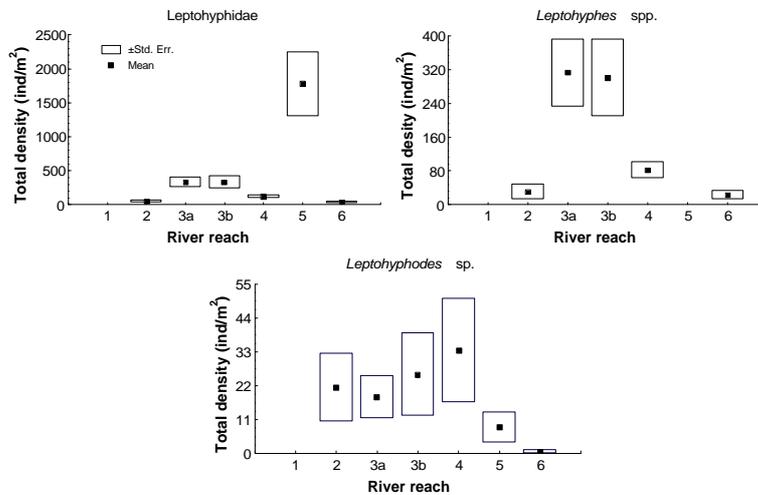


Figure 3: Total densities (ind/m², median and standard error) of Leptoxyphidae, Leptoxyphes spp., Leptoxyphodes sp., along the longitudinal gradient during the rainy and dry periods of 2000-2001 in the Indaiá Stream and Peixe River. *3a = riparian forest with a closed canopy; 3b = riparian forest with an open canopy.

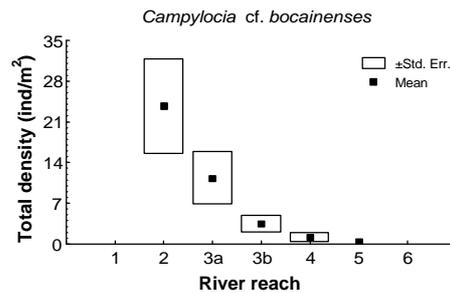


Figure 4: Total densities (ind/m², median and standard error) of *Campylocia cf. bocainenses* (Euthyplociidae) along the longitudinal gradient during the rainy and dry periods of 2000-2001 in the Indaiá Stream and Peixe River. *3a = riparian forest with a closed canopy; 3b = riparian forest with an open canopy.

Polymitarcyidae

This family was represented by only two species, *Campsurus* sp. and *Asthenopus* sp. *Campsurus* presented a decreasing gradient distribution pattern from the 2nd up to the 4th order reaches (Fig. 5). *Asthenopus* sp. was found in the 3rd (closed canopy) and 6th order reaches. The higher densities of this family was observed in the 2nd and 3rd order reaches.

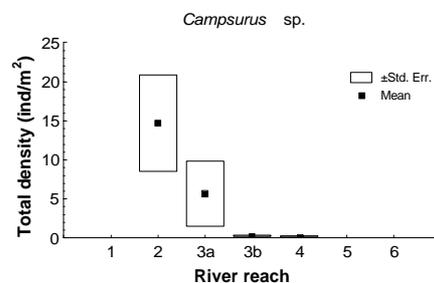


Figure 5: Total densities (ind/m², median and standard error) of *Campsurus* sp. (Polymitarcyidae) along the longitudinal gradient during the rainy and dry periods of 2000-2001 in the Indaiá Stream and Peixe River. *3a = riparian forest with a closed canopy; 3b = riparian forest with an open canopy.

Substrate Associations

Regarding the substrate associations, mayfly nymphs showed a distinct composition, with most of the identified taxa being found in a few substrate types (Tab. II). The substrate composed by pebbles, gravel and sand showed the highest taxonomic richness, with 23 taxa found, while the Eriocaulaceae banks and filamentous algae tufts showed the lowest taxonomic richness, with only 8 taxa (Fig. 6).

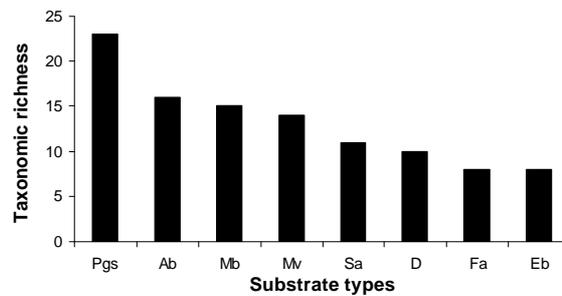


Figure 6: Taxonomic richness of the sampled substrates along the longitudinal gradient during the rainy and dry periods of 2000-2001 in the Indaiá Stream and Peixe River. The abbreviations are presented in the Table I.

Baetidae

The baetids were found in all sampled substrates, with highest densities in the aquatic macrophytes ($7,983.3 \pm 9,628.1$ ind/m²). Most of identified taxa were found in high densities associated with vegetal substrates, such as the aquatic macrophytes (Peixe River, 5th order reach), marginal vegetation (Peixe River, 6th order reach), and angiosperm and moss banks (Indaiá stream, 2nd up to 4th order reaches) (Tab. II).

Cloeodes spp., *Paracloeodes* spp. and *Americabaetis* spp. were found in all sampled substrates. *Cloeodes* spp. was the most generalist taxa, despite of its high density values in the algae substrate. *Paracloeodes* spp. showed a preference for the aquatic macrophytes (Peixe River, in Sobrado Farm locality), while *Americabaetis* spp., besides the mentioned substrate, also showed high density values on mosses and angiosperm banks (Tab. II). *Waltzoyphius fasciatus* was found only in the marginal vegetation and in the aquatic macrophytes, showing a marked preference for these substrates.

Apobaetis fiuzai was found only in the detritus deposits. This substrate, together with aquatic macrophytes, were also preferred by *Callibaetis* spp. This taxon is typical of low current areas, thus justifying the substrate association observed. *Aturbina georgei* was found in higher numbers in vegetal substrates, presenting a preference by the marginal vegetation. *Camelobaetidius* spp. was found in moss banks, biofilm and gravel deposits, presenting no preference for any of these substrates, while *Baetodes cf. serratus* was found preferentially in biofilm substrates, besides being found in high numbers on mosses and angiosperms banks (Tab. II). The high density values found in vegetal substrates indicate that this group belongs to the phytophilous fauna.

Leptophlebiidae

This family was found in all sampled substrates, with the highest density in the gravel and sand deposits, followed by the mosses and the angiosperms banks. The most generalist taxa were *Farrodes* spp., *Miroculis* sp. and *Askola cf. Froehlich* present in at least 6 types of substrates (Tab. II). However, *Miroculis* sp. and *Askola cf. Froehlich* presented the highest densities associated with gravel and sand deposits. Others, such as *Hagenulopsis* sp., *Leentvaaria* sp., *Thraulodes* spp. and *Hagenulopsis* (found only in this substrate type), also presented highest densities on gravel deposits (Tab. II). These taxa were found in only one up to three substrate types.

Massartella presented high densities associated with mosses, also being found in gravel deposits and algae, while Hermanella spp. presented higher densities in the angiosperm banks (Tab. II). The high density values found in rocky substrates indicate that most of the members of this group belongs to the psephophilous fauna.

Leptohyphidae

Leptohyphidae specimens were found in almost all sampled substrates, except on the filamentous algae. The higher densities were found in pebbles, gravel and sand deposits, followed by the submerged macrophytes and mosses banks. Leptohyphes spp. was found in almost all substrates, except by the algae substrate, on the 1st order reach. The highest densities of this taxon were found in aquatic macrophytes and moss banks, followed by pebbles, gravel and sand deposits (Tab. II). Tricorythopsis spp. was also found in almost all substrates, except by the algae and angiosperms banks. Tricorythodes spp. was found in moss banks, gravel deposits and marginal vegetation, with no specific association. Leptohyphodes sp. was found in mosses, aquatic macrophytes, gravel deposits and marginal vegetation. The highest densities were found in the gravel deposits, followed by the aquatic macrophytes (Tab. II).

Euthyplociidae and Polymitarciidae

Euthyplociidae nymphs belong essentially to the psephophilous fauna, once that the identified species, Campylocia cf. bocainensis was found only in gravel deposits (Table II). The Polymitarciidae also presented high density values in the gravel and sand deposits, mainly due to Campsurus sp. presence. However, this family could also be found in moss banks (3rd order reach, closed canopy) and marginal vegetation, due to Asthenopus sp. presence (Tab. II).

Discussion

Longitudinal zonation of mayfly nymphs

Downstream changes in assemblage structure and diversity along the river course has been a recent subject in running water studies in the Neotropics, with very few papers dealing with this subject (e. g., Baptista et al., 1998a, 1998b, 2001a, 2001b; Callisto et al., 2001). The two main proposals developed in the recent years were the River Zonation Concept (RZC) and The River Continuum Concept (RCC). The first states that the invertebrate communities distribution in running waters are divided into discrete unities or zones from the spring sources down to the sea (Ward, 1992). The RCC (Vannote et al., 1980) points out that the downstream changes in the invertebrate communities distribution are clinal, as a continuum gradient. We found both of these patterns in our results.

Several taxa, from different families such as Aturbina georgei (Baetidae), Askola cf. Froehlich (Leptophlebiidae), and Campylocia cf. bocainensis (Euthyplociidae) presented a clinal distribution, while others such as Waltzoyphius fasciatus (Baetidae) and Hagenulopsis (Leptophlebiidae) were restricted to a specific river reach. However, we cannot rule out the possibility of a presence of a set of conditions which, independently of a longitudinal trend, could explain the high abundance of particular species in a river sector.

According to Ward (1992), in the absence of adverse chemical conditions, temperature, flow and substrate appear to be the primary factors structuring the biological communities of streams. In the longitudinal gradient in Indaiá stream, the temperature and substrate type probably were the major factors determining the distribution of mayfly nymphs along the river reaches. According to Zamora-Muñoz et al. (1993) the temperature is one of the major factors determining the distribution of Baetidae, most of the species being positively related to this variable, with higher densities found in warmer waters. In our study we found higher densities and diversity of baetid nymphs in the downstream reaches and the first order reach, which presented the highest values for temperature. On the other hand, these reaches also presented higher biomass and diversity of aquatic

vegetation, which were the substrates that presented larger numbers of specimens and taxonomic richness of baetids.

Such diversity in mayfly distribution may be seen in the Leptophlebiidae family. The nymphs of this family presented a clear zonation, with an upstream and a downstream groups. Within the upstream group, most of the nymphs presented a clinal distribution pattern, while in the downstream group, the most common distribution pattern observed was the zonal distribution. An important factor that probably influenced the distribution of this family was the substrate type. The 3rd order reaches presented the highest diversity and density values of leptophlebiid nymphs. These river reaches also presented the highest substrate heterogeneity, composed mainly by pebbles, gravel and sand deposits, which were the preferred substrate types. This fact associated with the low temperature values, probably are the main factors explaining the distribution of this family.

It is important to note that the mayfly nymphs showed a wide and diverse distribution along the longitudinal gradient in Indaiá stream and Peixe River. The river zonation presented, in some cases, no specific patterns, such as the distribution presented by *Apobaetis fiuzai* (Baetidae) and *Hagenulopsis* (Leptophlebiidae), found in only one river reach. Thus, it must be taken in account when proposing and defining protection measures for conservation purposes, likewise the clinal or gradient distribution. The specific distribution of several taxa (e. g., *Campylocia* cf. *bocainensis*) in upstream reaches calls attention to the necessity to protect headwaters as a determinant factor and only effective source of freshwater biodiversity conservation. It should also be stated the need to preserve the riparian forest due to the maintenance of low temperatures water values, besides its importance as a source of allochthonous organic matter and energy input in headwater streams.

Substrate associations of mayfly nymphs

The substrate type is essential for benthic macroinvertebrates, since the egg stage up to adult emergence (Ward, 1992). Some substrate types are more appropriated to oviposition, due to protection against water flow and predators. While others are more suitable to emergence, since the structure of some substrates, as aquatic macrophytes with outside water projection, allows a secure place to the molting. The substrates also provide direct (e.g., detritus deposits) or indirect (as stones that support algae biofilm, or as trapping surfaces for organic particles) food resources, refuge against predators and supporting surfaces to filtering activities (Allan, 1995; Ward et al., 1995). Thus, as expected, most of invertebrate taxa possess some preference by one or a few types of substrates (Ward, 1992). The obtained results corroborate this information, with most of the identified taxa showing a marked preference for one to few substrate types. Baptista et al. (2001b) studying the diversity and habitat preference of mayflies along a longitudinal gradient in the Macaé River (Rio de Janeiro State) found similar results, with most of mayfly nymphs presenting a clear preference for one or two substrates (litter deposited in pool areas and litter held in riffle areas).

Some of the identified taxa presented their preference related to one of those mentioned factors. For instance, *Baetodes* cf. *serratus* is a scraper baetid, thus, presented its higher densities in surfaces covered by periphytic algae (algae biofilm), or *Hermanella* spp., which presented the highest densities in the Eriocaulaceae banks (4th order reach, Indaiá stream) which served as a secure surface to their filter-feeding activities. Several taxa such as *Paracloeodes* spp. and *Waltzoyphius fasciatus*, preferred the submerged macrophytes substrate. Aquatic macrophytes frequently constitute substrate for macroinvertebrates, offering protection against predators, serving as direct (vegetal tissue) and indirect (substrate for periphyton growth) food resource (Ward, 1992; Allan, 1995).

The substrate preference although, should be view not only under an ecological perspective, but also under an evolutionary point of view. The natural selection process took over million of years to select individuals of those species that are more capable to colonize one or other substrate type. For instance, most of the Leptophlebiidae nymphs possess a flattened body, which allows them to colonize gaps between rock fragments, and even smaller granulometric sediment, such as gravel and sand deposits. That could be frequently observed in Indaiá stream, in which the gravel and sand deposits are

intensely colonized by *Askola* cf. *Froehlich* and *Miroculus* sp. So, it is not surprising that most of these family specimens were associated with this type of substrate.

The Baetidae taxa possess a fusiform body, with bristles between their terminal filament and cerci, which allow them to swim between macrophyte branches and to colonize gaps in these branches, as it could be observed in *Americabaetis*. Some taxa, like *Callibaetis* spp. and *Apobaetis fiuzai* that were preferentially found in detritus deposits, show some special adaptations such as long and slender legs, with sharp claws which might possibly help maintain their bodies and consequently their respiratory surfaces out of the detritus. Although these evolutionary bases for such specialization are not clear, such specificity is a consequence of numerous processes, such as: 1) differential foraging ability between habitats, 2) differential competition ability among habitats, and 3) differential susceptibility to mortality among habitats (e.g., predation) (Hawkins, 1984).

Most of the taxa presented specific associations with different types of substrates, and in some cases, even being found in only one type of substrate, such as *Apobaetis fiuzai* (Baetidae), *Campylocia* cf. *bocainensis*, and others. So, we must point out that modifications in habitat and microhabitat conditions such as reduction of substrate diversity will lead invariably to three major consequences: i) change in community structure, due to a decrease on the optimal conditions to specialist taxa favoring generalists, such as *Cloeodes* spp.; ii) loss of species, as result of the reduction of overall stream diversity in consequence to the inability of specialist taxa to compete; iii) modifications in the ecosystems processes, such as organic matter flux (e.g., affecting filter-feeders), and food chains, due to the important linkage that mayflies constitute between the primary producers and consumers.

Mayfly diversity patterns and conservation strategies of Serra do Cipó headwaters

The obtained results evidenced a change in the constitution and abundance of the mayfly fauna along the longitudinal gradient. The specific distribution patterns and substrate associations, call attention to the importance of the preservation of the natural characteristics of upstream and downstream reaches in a watershed. The mayfly distribution patterns and diversity assessment (taxonomic richness) may provide fundamental information on the environmental changes of the Serra do Cipó lotic ecosystems. We suggest that such study may be extended for other Neotropical streams, since the mayflies are also a fundamental component of these ecosystems, both in biomass and diversity.

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References

Allan, J.D. 1995. Stream ecology: structure and function of running waters. Chapman and Hall, New York. 388p.

- Baptista, F.D., Dorvillé, L.F.M., Buss, D.F., Nessimian, J.L. & Soares, L.H.J. 1998a. Distribuição de comunidades de insetos aquáticos no gradiente longitudinal de uma bacia fluvial no sudeste brasileiro. In: Nessimian, J.L. & Carvalho, A.L. (eds.) Ecologia de insetos aquáticos. PPGE-UFRJ, Rio de Janeiro. p.191-207. (Series oecologia brasiliensis, v.5).
- Baptista, F.D., Buss, D.F., Dorvillé, L.F.M. & Nessimian, J.L. 1998b. O conceito de continuidade de rios é válido para rios de mata atlântica no sudeste do Brasil? In Nessimian, J.L. & Carvalho, A.L. (eds.) Ecologia de insetos aquáticos. PPGE-UFRJ, Rio de Janeiro. p.209-222. (Series oecologia brasiliensis, v.5).
- Baptista, D.F., Buss, D.F., Dorvillé, L.F.M. & Nessimian, J.L. 2001a. Spatial and temporal organization of aquatic insect assemblage in the longitudinal gradient of a tropical river. *Braz. J. Biol.*, 61:295-304.
- 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. *Braz. J. Biol.*, 61:249-258.
- Bispo, P.C. & Oliveira, L.G. 1998. Distribuição espacial de insetos aquáticos (Ephemeroptera, Plecoptera e Trichoptera) em córregos de Cerrado do Parque Ecológico de Goiânia, Estado de Goiás. In: Nessimian, J.L. & Carvalho, A.L. (eds.) Ecologia de insetos aquáticos. PPGE-UFRJ, Rio de Janeiro. p.19-33. (Series oecologia brasiliensis, v.5).
- Brittain, J.E. 1982. Biology of mayflies. *Ann. Rev. Entomol.*, 27:119-47.
- 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.
- Callisto, M., Ferreira, W.R., Moreno, P., Goulart M. & Petrucio, M. 2002. Aplicação de um protocolo de avaliação rápida da diversidade de habitats em atividades de ensino e pesquisa (MG-RJ). *Acta Limnol. Bras.*, 14:91-98.
- Callisto, M., Goulart, M., Medeiros, A.O., Moreno, P. & Rosa, C.A. 2004. Diversity assessment of benthic macroinvertebrates, yeasts and microbiological indicators along a longitudinal gradient in Serra do Cipó, Brazil. *Braz. J. Biol.* (in press).
- Dominguez, E. & Pescador, M.L. 1994. Los Ephemeroptera en Argentina. *Fauna de Agua Dulce Rep. Argent.*, 33:1-142.
- Dominguez, E., Hubbard, M.D. & Peters, W.L. 1992. Clave para ninfas y adultos de las familias y géneros de Ephemeroptera (Insecta) sudamericanos. *Biol. Acuát.*, 16:1-39.
- Dominguez, E., Hubbard, M.D., Pescador, M.L. & Molineri, C. 2001. Ephemeroptera. In: Fernández, H.R. & Domínguez, E. (eds.) Guía para la determinación de los artrópodos bentónicos sudamericanos. Ed. Universidad Nacional de Tucumán, Argentina. p.17-54.
- FEAM. 1990. Projeto Rio Doce. Fundação Estadual do Meio Ambiente (FEAM), Belo Horizonte. 35p.
- Ferreira, M.S.N. & Froehlich, C.G. 1992. Estudo da fauna de Ephemeroptera (Insecta) do Córrego do Pedregulho (Pedregulho, SP, Brasil) com aspectos da biologia de *Thraulodes schlingerii* Traver & Edmunds, 1967. *Rev. Bras. Entomol.*, 36:541-548.
- Froehlich, C.G. & Oliveira, L.G. 1997. Ephemeroptera and Plecoptera nymphs from riffles in low-order streams in southeastern Brazil. In: Landolt, P. & Sartori, M. (eds.) Ephemeroptera & Plecoptera: Biology-Ecology-Systematics. MTL, Fribourg. p.180-185.
- Galdean, N., Barbosa, F.A.R., Callisto, M., Rocha, L.A.R. & Marques, M.G.S.M. 1999. A proposed typology for the rivers of Serra do Cipó (Minas Gerais, Brazil) based on the diversity of benthic macroinvertebrates and the existing habitats. *Trav. Muz. Hist. Nat. Grigore Antipa*, 41:445-453.
- Galdean, N., Callisto, M. & Barbosa, F.A.R. 2000. Lotic Ecosystems of Serra do Cipó, southeast Brazil: water quality and a tentative classification based on the benthic macroinvertebrate community. *J. Aquat. Ecos. Health Man.*, 3:545-552.
- Galdean, N., Callisto, M. & Barbosa, F.A.R. 2001. Biodiversity assessment of benthic macroinvertebrates in altitudinal lotic ecosystems of Serra do Cipó (MG, Brazil). *Braz. J. Biol.*, 61:239-248.
- Galvão, M.V. & Nimer, E. 1965. Clima. In: Instituto Brasileiro de Geografia e Estatística-IBGE. Geografia do Brasil: grande região leste. IBGE, Rio de Janeiro. v.5, p.91-139.

- Hawkins, C.P. 1984. Substrate associations and longitudinal distributions in species of Ephemererellidae (Ephemeroptera: Insecta) from western Oregon. *Fresh. Invert. Biol.*, 3:181-188.
- Köppen, W. 1931. *Climatologia*. Fondo de Cultura Economica, Buenos Aires. 388p.
- Lugo-Ortiz, C.R. & McCafferty, W.P. 1995. Three distinctive new genera of Baetidae (Ephemeroptera) from South America. *Ann. Limnol.*, 31:233-243.
- Lugo-Ortiz, C.R. & McCafferty, W.P. 1996a. Taxonomy of the Neotropical genus *Americabaetis*: new status (Insecta: Ephemeroptera: Baetidae) from South America. *Stud. Neotrop. Fauna Environ.*, 31:156-169.
- Lugo-Ortiz, C.R. & McCafferty, W.P. 1996b. *Aturbina georgei* gen. et sp. n.: a small minnow mayfly (Ephemeroptera: Baetidae) without turbinate eyes. *Aquat. Insects*, 18:175-183.
- Lugo-Ortiz, C.R. & McCafferty, W.P. 1996c. The genus *Paracloeodes* (Insecta: Ephemeroptera: Baetidae) and its presence in South America. *Ann. Limnol.*, 32:161-169.
- Merritt, R.W. & Cummins, K.W. 1988. *An introduction to the aquatic insects of North America*. 3rd ed. Kendall, Hunt. 862p.
- Oliveira, L.G. & Froehlich, C.G. 1997. Diversity and community structure of aquatic insects (Ephemeroptera, Plecoptera and Trichoptera) in a mountain stream in southeastern Brazil. *Acta Limnol. Bras.*, 9:139-148.
- Pérez, G.P. 1988. *Guía para el estudio de los macrovertebrados acuáticos del departamento de Antioquia*. Editorial Presencia, Bogotá. 217p.
- Peters, W.L. 1971. A revision of the Leptophlebiidae of the West Indies (Ephemeroptera). *Smith. Contr. Zool.*, 62:1-48.
- Salles, F.F. 2002. *Contribuição ao estudo da taxonomia da família Baetidae (Insecta: Ephemeroptera) na região sudeste do Brasil*. Viçosa, UFV, 129p (Dissertação).
- Salles, F.F. & Lugo-Ortiz, C.R. 2002. A distinctive new species of *Apobaetis* (Ephemeroptera: Baetidae) from Mato Grosso and Minas Gerais, Brazil. *Zootaxa*, 35:1-6.
- Vannote, L.R., Minshall, G.W., Cummins, K.W., Sedell, J.R. & Cushing, C.E. 1980. The River Continuum Concept. *Can. J. Fish. Aquat. Sci.*, 37:130-137.
- Ward, J.V. 1992. *Aquatic insect ecology: biology and habitat*. John Wiley & Sons, New York. 438p.
- Ward, D., Holmes, N. & José, P. 1995. *The new rivers & wildlife handbook*. RSPB, NRA and The Wildlife Trusts, Bedfordshire. 426p.
- Zamora-Munoz, C.A., Sanchez-Ortega, A. & Alba-Tercedor, J. 1993. Physico-chemical factors that determine the distribution of mayflies and stoneflies in a high-mountain stream in Southern Europe (Sierra Nevada, Southern Spain). *Aquat. Insects*, 1:11-20.

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