DIVERSITY AND HABITAT PREFERENCE OF AQUATIC INSECTS ALONG THE LONGITUDINAL GRADIENT OF THE MACAÉ RIVER BASIN, RIO DE JANEIRO, BRAZIL

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ABSTRACT

Diversity and habitat preference of macroinvertebrates were studied in Macaé River basin, Rio de Janeiro State, Brazil, along its longitudinal gradient. We selected stream reaches corresponding to 1st, 2nd, 4th, 5th and 6th orders. A Surber sampler was used to collect four macroinvertebrates samples of each substrate (sand, litter in pool areas, stones, and litter in riffle areas) during the three sampling periods, defined based on the rain regime: April (end of the rainy season), July (dry season), and October (beginning of the rainy season). We identified 46,431 specimens corresponding to 117 taxa. Analysis of diversity numbers (both for family or genus level) indicated that all insect taxonomic orders had higher numbers on 2nd order stream reach, except for Ephemeroptera, on 4th order. However when considering morphspecies taxonomic level, the higher diversity number occurred on 4th order stream. The highest richness and diversity numbers were found at the dry season. Considering habitat preference, both litter in pool areas and litter in riffle areas had the highest faunal richness.

Key words: diversity, aquatic insects, longitudinal gradient, tropical river, Brazil.

RESUMO

Diversidade e preferência de insetos aquáticos por habitats no gradiente longitudinal na bacia do Rio Macaé, RJ, Brasil

A diversidade e a preferência de insetos aquáticos por habitats foram estudadas no gradiente longitudinal da bacia do Rio Macaé no Estado do Rio de Janeiro, Brasil. Foram selecionados trechos de rio correspondentes a 1ª, 2ª, 4ª, 5ª e 6ª ordens. Foram amostrados três períodos, abril, julho e outubro, representando o final da estação chuvosa, a estação seca e o começo da outra estação chuvosa, respectivamente. Um total de 46.431 espécimes de insetos aquáticos foram obtidos. Em cada mês, quatro amostras foram coletadas utilizando um amostrador do tipo Surber para cada substrato: areia, folhas depositadas em áreas de remanso, folhas em áreas de corredeiras e pedras. O padrão geral observado quanto às medidas de diversidade, considerando o número de gêneros ou famílias, indicou que todas as ordens de insetos aquáticos apresentaram seus maiores valores no trecho de 2ª ordem, exceto para Ephemeroptera, que foi registrado em 4ª ordem. No entanto, quando considerou-se uma menor resolução taxonômica (morfo-espécies), o pico de diversidade ocorreu em 4ª ordem. A maior riqueza e abundância ocorreram durante o período de seca. Quanto à preferência por habitat, os folhiços de fundo e de correnteza, em particular, foram os que apresentaram os maiores valores de riqueza.

Palavras-chave: diversidade, insetos aquáticos, gradiente longitudinal, rio tropical, Brasil.

INTRODUCTION

A great deal of research has been done on the use of aquatic macroinvertebrates in water quality biomonitoring programs and in assessing environmental impacts in the USA as well as in many European countries (Metcalfe, 1989; Rosenberg & Resh, 1993).

Several cost-effective methods for water quality assessment have been developed, like the Rapid Assessment Protocols – RAP (Resh & Jackson, 1993). The adequate application of such methodologies require, for each situation, previous knowledge about many aspects of lotic macroinvertebrates, which are still lacking in Brazil. Thus, it is important to understand temporal and spatial patterns of macroinvertebrates along the longitudinal gradients of brazilian rivers, as well as their distribution and abundance among different habitat types. This kind of information allow the determination of the most representative habitats in each situation, the degree of taxonomic resolution to be employed, and the number of samples to be taken (Plafkin *et al*., 1989).

Rivers can be studied on a variety of spatial scales (see Frissell *et al*., 1986). When the focus is on the distribution among different habitats, a comparison can be made between eroding and depositing habitats, like riffles and pools areas. On a broader scale, changes in ecological patterns can be recorded along the river, as well as in different river basins. Most of these studies have shown that local patterns are almost never reproduced identically in other streams (Vinson & Hawkins, 1998). In this way, the processes structuring aquatic insect assemblages in the different substrate types, already described and better evidenced in rivers located in temperate areas (Rabeni & Minshall, 1977; Minshall & Minshall, 1977), should be tested and compared with those detected in tropical and subtropical rivers (Arunachalam *et al*., 1991; Dudgeon, 1982, 1994; Kikuchi, 1996). Therefore, specific methodologies can be developed and adapted to these areas.

Baptista *et al*. (1998a) observed that aquatic insect assemblages along the Macaé River basin present a faunal disrupture along its longitudinal gradient, separating upper (upstream 4th order reaches, around 700 m a.s.l.) from lower (5th and 6th orders) stream reaches.

The aim of this study was to record the temporal variation of diversity and habitat preference of aquatic insects along a river system in South-eastern Brazil.

MATERIAL AND METHODS

Study area

The study area comprises the Macaé River basin, in the State of Rio de Janeiro, Brazil. This is a medium size river (6th order in the estuary) with about 110 km, placed in the coastal slope of the “Serra do Mar” (22^{o}21', 22^{o}28’S and 42^{o}27', 42^{o}35’W).

Five stations were chosen along this river system from the upper rhytron section to the upper potamon, representing 1st, 2nd, 4th, 5th, and 6th orders stream reaches. The first two stations were located at the Flores River (a tributary of the Macaé River), with 1,100 and 1,000 m a.s.l., respectively. All the other stations were placed along the Macaé River. A detailed description of the area is available in Baptista (1998), and Baptista *et al*. (1998a).

Macroinvertebrates

A stratified random sampling design was employed for aquatic insect collections. Sampling was carried out in April, July and October 1995, corresponding to the end of the rainy season, the dry season, and the beginning of the rainy season, respectively. In each station four samples were taken from each of the following habitat types: sand (A); litter deposited in pool areas (LP), litter held in riffle areas (LR), and stones (S) (except on 6th order). Thus, a total of 76 samples were taken in each month and 228 in the whole study. All insects were collected using a Surber sampler (900 cm^2 area and 120 µm mesh size) and were preserved in the field in a 10% formaldehyde solution, buffered with 2% borax.

In the laboratory all specimens were sorted, identified, counted under stereoscopic microscopes, and preserved in 80% ethanol. As the identification of aquatic insects to species level in South-eastern Brazil is not possible in most cases, specimens were assigned to Operational Taxonomic Units (OTUs) that represented the lowest taxonomic level that could be reached by means of the keys provided by Merritt & Cummins (1988), Dominguez *et al*. (1992), Trivinho-Strixino & Strixino (1995), Froehlich (1984) and Benedetto (1974), and/or with the aid of taxonomists.

Such fact resulted in some OTUs identified in higher taxonomic levels having a higher abundance than others in lower levels, which might have been responsible for some bias in the data. Specimens of the Order Blattaria and the Family Staphylinidae (Coleoptera) were included in this study despite their semi-aquatic habits.

In each sampling station three diversity indices were estimated for each insect order separately due to the different levels of taxonomic resolution obtained: Margalef richness index, Shannon-Wiener diversity index, and Pielou evenness index, according to Ludwig & Reynolds (1988).

The aquatic insect distribution among the four habitat types was recorded both by means of their abundance as well as by their density (expressed as the percentage of total specimens). In addition, the total number of OTUs was obtained for each habitat.

RESULTS

Diversity measures along the longitudinal gradient

The highest richness and diversity numbers were obtained in 2nd or 4th stream orders for all insect orders. This pattern was observed at all sampling occasions (Fig. 1).

Considering the longitudinal gradient of the stream, only a few taxa occurred at all sites. For example, the insect order Plecoptera exhibited 15 taxa, but only *Anacroneuria* had a wide distribution. The whole order had the highest diversity and richness numbers in 2nd order stream reach.

The ephemeropterans showed a different pattern, as the highest richness numbers was obtained in 4th order reach, while its highest abundance was found in 5th order. Four genera occurred along the stream gradient: *Pseudocloeon*, *Leptohyphes*, *Cloeodes*, and *Farrodes*. Some genera were predominant in the upper reaches (*Ulmeritus*, *Miroculis*, *Massartela* and *Askola*), while *Lachlania boanovae* and *Hagenulopsis* were found only in 6th order stream reach.

From the eighteen trichopteran genera found, fifteen were exclusive of the upper reaches. The genera *Phylloicus*, *Smicridea* and *Polycentropus* had a wide distribution (from 1st to 6th stream orders), often associated with litter in pools substrate. The highest diversity numbers were found in 2nd order stream reach.

Odonata had the higher diversity in low order stream reaches, in particular, 2nd order.

Coleoptera and Diptera were identified only to family level, but chironomids were identified to subfamily or tribe level. For both Coleoptera and Diptera, high diversity numbers were found in medium stream reaches, specially in 4th order.

Habitat preference

Substrate distribution and abundance

The complete list of aquatic insects found in this study can be consulted in Baptista (1998) and Baptista *et al*. (1998a).

PLECOPTERA – We can consider that the whole order occurred preferentially in litter substrates, both deposited in pools (LP) and held in riffle areas (LR), and in upper stream reaches. The genus *Anacroneuria* was the dominant taxon in LR in the upper reach presenting a density of 79% (of a total of 439 individuals), 35% (of 375) and 40% (of 321 individuals), respectively, in the three sampling occasions. On the other hand, the genus *Kempnyia*, was most often found in LP. The most representative groups were found in 4th order streams and there was no temporal substitution in dominance (Fig. 2a).

EPHEMEROPTERA – This insect order exhibited a higher abundance in the lower reaches, preferentially in riffle areas. The species *Hylister plaumanni* was the dominant taxon in LR in April, representing 46.2% of the total (335 individuals). In July, during the dry season, ephemeropterans were most often found in LP in the upper reach, with the genus *Farrodes* contributing with 50% (664 individuals). In October, there was a high dominance in riffle areas, with 33% (1,753 individuals) being found in stony substrates in the lower reach (5th order stream). The genus *Pseudocloeon* was the dominant taxon in this substrate with 74.2% (571 individuals). Ephemeropterans, differently from the plecopterans, showed a temporal substitution for each substrate (Fig. 2a).

TRICHOPTERA – The highest abundance of Trichoptera was exhibited in LP, in the upper reach, in all sampling occasions. In April, 54% of the trichopterans were found in LP and the genus *Triplectides* was the dominant taxon, representing 71.4% of the 898 specimens collected.

In July, specimens found in LP represented 46% of the total in this month and the genera *Triplectides* and *Notalina* were the most abundant groups (with 27.8% and 23.8% of 1,071 individuals, respectively). In October, once more, LP was the most important substrate with 47.4% of the specimens collected.

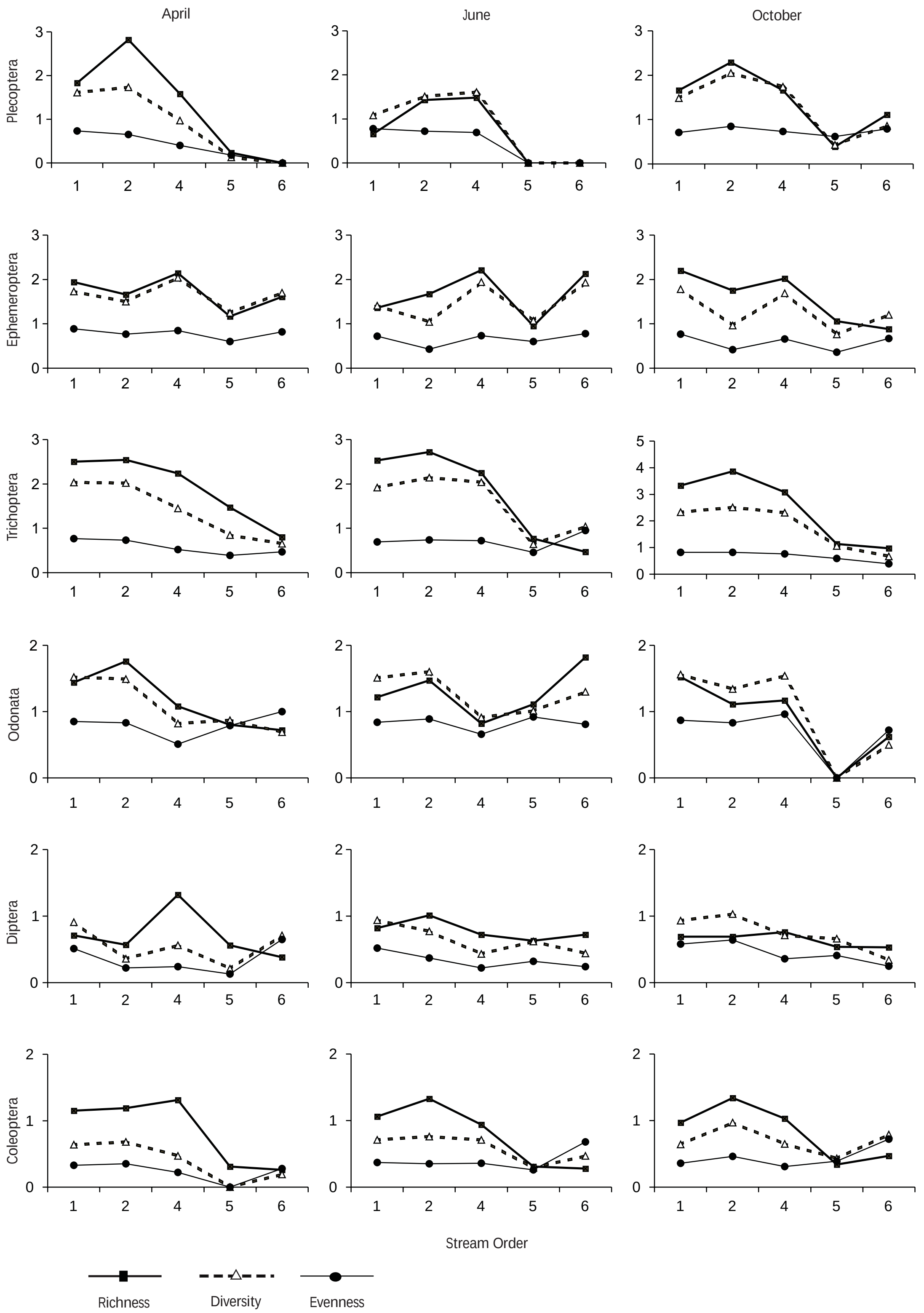

Fig. 1 — Richness (index of Margalef), evenness (Pielou) and diversity (index of Shannon) values for each insect order in the three sampling periods along the longitudinal gradient.

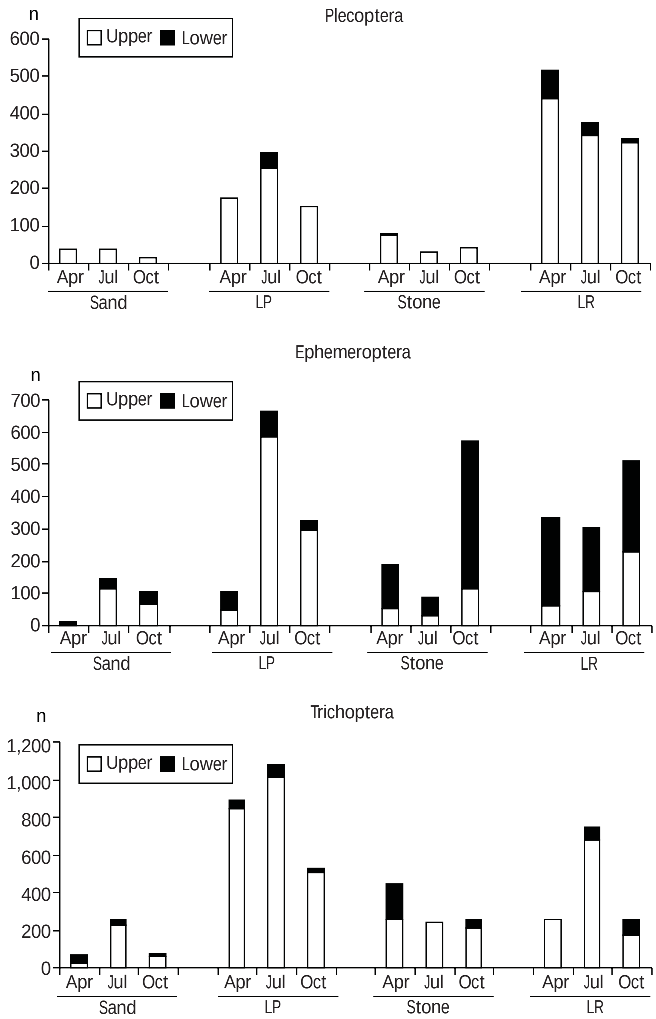

Fig. 2a — Abundance of Plecoptera, Ephemeroptera and Trichoptera found at each substrate (sand, litter in pool areas – LP, stone and litter in riffle areas – LR), comparing the upper and lower stream reaches, in the three sampling periods.

The genus *Phylloicus* was the dominant taxon, contributing with 34.3% of the total (Fig. 2a). The highest abundance of the whole order was found in 4th order stream.

ODONATA – There was a marked preference for areas of low water flow, notably LP, with 41% (April), 46.2% (July) and 51% (October), and for the upper reaches. It was observed a temporal substitution of the dominant taxon in each substrate. In April, the genus *Haeterina* represented 49% (43 individuals), in July, the dominant taxon of this substrate was *Argia*, with 44.7% (67) and in October, *Limnetron* had the highest abundance with 43.6% (55 specimens) (Fig. 2b).

COLEOPTERA – The family Elmidae was the dominant taxon in all substrates. However, it occurred preferentially in LR in the lower reaches, in April, and in the same substrate but in the upper reaches in July and October. In general, this particular family represented more than 50% of the total number of individuals for each substrate in the three sampling occasions (Fig. 2b).

HEMIPTERA – There was a preference for deposition areas (sand and LP). In April, 45.6% of the total individuals were found in sand substrate in the upper reaches. The genus *Neotrephes* (75% of 52 individuals) was the dominant taxon in this substrate. In July, the substrate LP had 43.5% of the hemipterans, and *Neotrephes* had 56% from 57 individuals collected. In October, *Neotrephes* was a dominante in LP was, contributing with 77.7% of the 27 specimens (Fig. 2b).

DIPTERA – Dipterans had a great variation in abundance among the substrates and sampling occasions. There was no clear habitat preference, with high abundance in sand, LP and LR. The Chironomini (Chironomidae, Chironominae) was the dominant taxon in the sand substrate in the upper reaches (with 60.1% of 1,824 individuals) in April. In July, the dipterans were more abundant in LP in the lower reaches and the dominant taxa were Chironomini, Simuliidae and Orthocladiinae, with 54.2%, 22% and 20% (of 5,316 individuals), respectively. In October, there was a high occurrence in upper reaches. In overall terms, the order Diptera had the highest abundance in 5th order stream reaches.

Substrate and stream order abundance and richness patterns

The variation among the three sampling periods is shown in Table 1. The higher abundance of macroinvertebrates in the upper reaches (1st to 4th orders streams) occurred in pool areas, in LP and sand. Together, the two substrates contribute with more than 70% of the individuals found in the end of rainy season (April) and in the dry season (July). In the beginning of the rainy season (October) there was a reduction in abundance in these substrates. In general, LR and LP had the highest taxonomic richness. The substrate LR had its highest richness numbers (54 taxa) in 4th order stream reach in October, and the lowest numbers (28 taxa) in 1st order in July. On the other hand, LP had the highest richness (50 taxa) in 2nd order stream in July, and the lowest (32 taxa) in 1st order in October. The sand substrate despite of high general abundance, had the lowest number of taxa at the upper reaches. Also, the pool area substrates (sand and LP) showed the highest richness numbers during the dry season and the lowest during the rainy season (Table 1). In 5th order, differently from the upper reaches, fast flow substrates (LR and stone) had higher abundance than depositional areas (LP and sand).

DISCUSSION

Diversity measures along the longitudinal gradient

Our results indicate that almost all insect orders had their highest richness and diversity numbers at the upper reaches, where Plecoptera, Trichoptera, Odonata, Coleoptera and Diptera occurred predominantly at 2nd order, while Ephemeroptera had a preference for 4th order stream reach.

This results were obtained when based on the taxonomic level of family or genus. However, if considering morph-species, the highest diversity number for the whole insect community occurred in 4th order (Fig. 3).

Stout & Vandermeer (1975) working in streams in Colombia and Costa Rica also found high diversity at medium to upper reaches. According to Vinson & Hawkins (1998), high diversity at this areas are related to higher habitat heterogeneity and complexity. Also, the River Continuum Concept (Vannote *et al*., 1980) suggest that the higher habitat heterogeneity at medium reaches will allow a higher diversity in streams.

We found some insect groups (e.g. Trichoptera and Coleoptera) presenting many shredder and scraper species at the upper stream reach, what suggest that these groups are very important in the transformation of the allochthonous particulate organic matter that will be transported and used by downstream communities. Thus, environmental disturbances in these areas affecting such groups may lead not only to a great local diversity loss but also to alterations in the downstream biota (Cummins & Klug, 1979).

Habitat preference

Substrate distribution and abundance

According to Ladle & Ladle (1992) the preference for one substrate or another is determined first by the oviposition behavior of the organism but this distribution may be modified later by passive drift or active migration.

High richness and diversity were found during the dry season, possibly due to a higher habitat stability and availability. The richest substrates (in general, litter substrates), during this season, are less affected by water flow, allowing a greater period for colonization and processing of benthic organic matter by macroinvertebrates. Also, the community established in stony substrates and sand substrates become more stable serving as refugia for younger organisms.

Although there was an occupation in all substrates, there was a clear preference for one or two specific substrates, LR and LP.

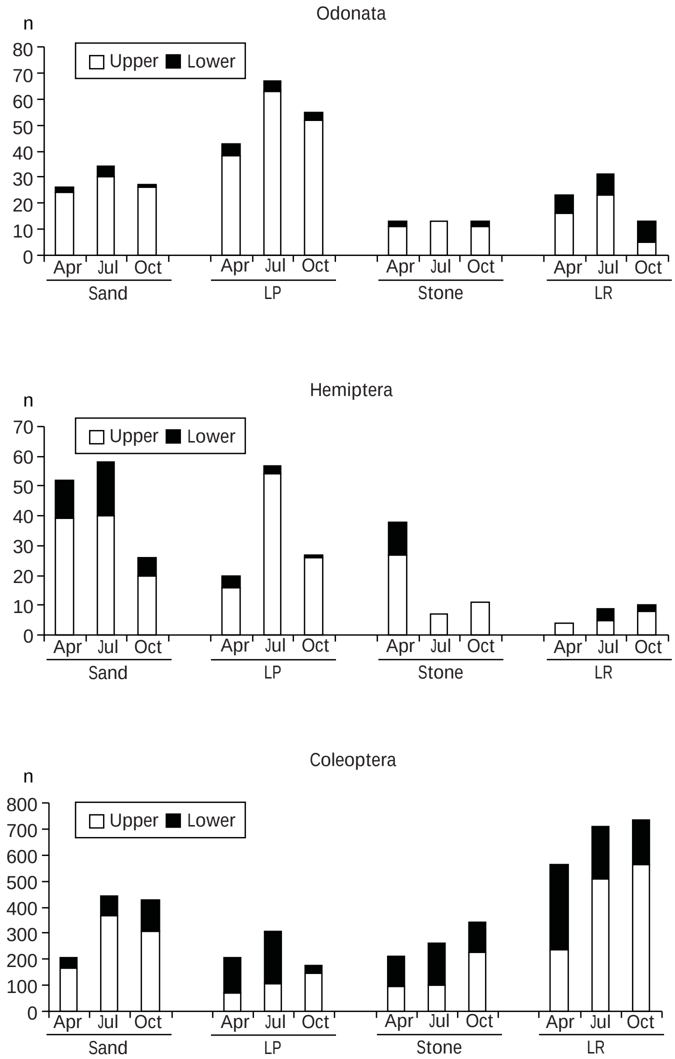

Fig. 2b — Abundance of Odonata, Hemiptera and Coleoptera found at each substrate (sand, litter in pool areas – LP, stone, and litter in riffle areas – LR), comparing the upper and lower stream reaches, in the three sampling periods.

Litter substrates are preferred by many taxa because they offer best shelter and feeding conditions due to the high habitat heterogeneity and a rich periphytic flora. On the other hand, in sand substrates the instability of the substrate and the low organic matter availability lead to a low diversity and richness numbers (Hawkins, 1984). Thus the habitat heterogeneity is a very important factor influencing macroinvertebrates distribution in streams (Vinson & Hawkins, 1998). Similar results were found in other South-eastern Brazil streams (Henry *et al*., 1994).

Pennak (1978) found that Plecoptera in North American streams, occur preferentially associated with stony substrate. Our study does not corroborate this pattern as the two most abundant genera found in Macaé basin (*Anacroneuria* and *Kempnyia*) occurred predominantly in litter substrates (LR and LP respectively).

The ephemeropterans were most often found in fast flowing substrates (LR and stone). According to Macan (1978), the behavior of stream species should be related to the velocity of flow, as fast waters should transport more nutrients in a determined period. This would allow many ephemeropteran filter-feeding species to occur. Besides, the preference for these substrates are also related to a high availability of dissolved oxygen concentrations.

Despite of the highest richness number of Ephemeroptera found at 4th order stream, its highest abundance was found at 5th order, probably due to the increase of two genera (*Leptohyphes* and *Pseudocloeon*). Yet, one can not affirm (as they are filter-feeders and collectors, respectively) if the observed pattern was a result of the natural gradient or due to high suspended nutrients originated from domestic effluents of the district of Lumiar.

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Although the trichopteran community exhibited its highest diversity numbers in riffle areas, like the pattern described by Merrit & Cummins (1988) for North American species, the higher abundance and dominant taxa (*Phylloicus*, *Notalina* and *Triplectides*) were found in LP substrate. Most species of these genera are shredders, using the coarse particulate matter for feeding and building cases for protection. Therefore, this high abundance in litter areas are influenced by the availability of coarse material, specially in pool areas in the upper stream reaches.

TABLE 1

Percentile of the total abundance (% n) and richness numbers for each substrate type and stream order at the three sampling periods.

Stream		April		July		October	
Order	Substrates	% n	Richness	% n	Richness	% n	Richness
1	Litter in riffle	13.81%	28	22.2%	26	13.2%	21
	Stone	9.82%	36	9.9%	26	17.6%	31
	Litter in pool	19.53%	32	42.6%	34	31.2%	34
	Sand	56.85%	23	25.3%	30	38.1%	28
	n	1,730		1,210		749	
2	Litter in riffle	14.59%	32	19.1%	42	17.4%	28
	Stone	11.68%	29	8.0%	27	19.1%	33
	Litter in pool	49.74%	37	54.0%	50	37.0%	40
	Sand	26.65%	21	18.9%	30	26.6%	26
	n	1,902		2,570		988	
4	Litter in riffle	28.2%	47	27.5%	46	59.8%	54
	Stone	9.8%	41	3.5%	35	11.2%	42
	Litter in pool	38.2%	35	53.0%	44	15.5%	40
	Sand	23.7%	18	16.1%	28	13.5%	34
	n	2,686		6,722		5,196	
5	Litter in riffle	50.0%	18	28.0%	18	46.3%	27
	Stone	23.3%	31	18.2%	16	26.4%	17
	Litter in pool	6.8%	20	37.1%	25	13.6%	15
	Sand	19.9%	22	16.7%	16	13.7%	15
	n	2,650		14,669		2,903	
6	Litter in riffle	32.78%	17	26.6%	29	60.9%	23
	Litter in pool	33.33%	16	20.3%	10	17.2%	18
	Sand	33.87%	7	53.1%	12	21.9%	16
	n	391		1,321		744	

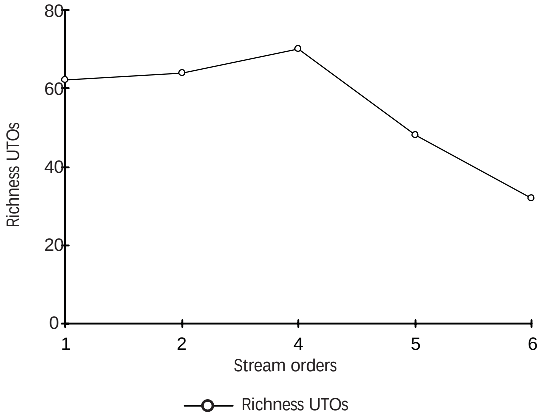

Fig. 3 — Richness numbers (morph-species) along the longitudinal gradient of the Macaé River basin.

The high occurrence of species of Odonata in the depositional areas of Macaé basin (sand and LP) are in accordance with the literature, as nymphs of these taxa are found in fine sediment and detritus (Merrit & Cummins, 1988).

Substrate and stream order abundance and richness patterns

In our study, the substrates sand and LP had its highest richness and abundance numbers at the dry season. The low insect abundance in depositional areas at the beginning of the rainy season (October) is probably a result of the impact of heavy rains that wash out these substrates. Oliveira (1996) and Kikuchi & Uieda (1998) registered similar results in the distribution and abundance of aquatic insect populations in other Brazilian streams.

A high abundance of macroinvertebrates was found at upper reaches at pool substrates (LP and sand), while riffle substrates had higher abundance at the lower stream reaches. The drop in the usage of substrates found in depositional areas is probably a reflect of sedimentation of these substrates by fine particulate matter, what made those substrates not available to many species (see Baptista, 1998; Baptista *et al*., 1998a).

As biomonitoring protocols are one of the goals for the next years in Brazil, we propose some considerations about rapid assessment protocols and its use in South American streams based on our study:

1) Biological diversity – the higher diversity number is found at upper and medium reaches (from 1^{st} to 4^{th} orders) and thus, water managers should take extra-care with these areas.
2) Stream order – there are natural differences in composition and structure between reaches of different orders as predicted by Vannote *et al*. (1980) and tested in South-eastern Brazil recently by Baptista *et al*. (1998b).
3) Habitat variation – the fauna had distinct composition on each substrate. Thus, diversity measures should consider habitat heterogeneity. Many rapid assessment approaches consider only riffle or run areas, but in Brazil the litter in pools proved to be the most diverse substrate. Thus, water managers should be aware of diversity losses in case of homogenizing stream beds.
4) Habitat availability – once there are temporal variation in substrate availability and quality, one should be careful in the interpretation of one-period experiments.
5) Temporal change in community dominant taxon. Although there was not great temporal changes in structure and function of the aquatic insect communities (Baptista *et al*., 1998b), there was some changes in the dominant groups for Ephemeroptera and Trichoptera. As EPT (Ephemeroptera + Plecoptera + Trichoptera) is a widely used index for measuring water quality by means of aquatic biota, it is important to note this change in dominant taxon, that naturally occur.

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