DIVERSITY AND COMMUNITY STRUCTURE OF AQUATIC INSECTS (EPHEMEROPTERA, PLECOPTERA AND TRICHOPTERA) IN A MOUNTAIN STREAM IN SOUTHEASTERN BRAZIL

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ABSTRACT: Diversity and community structure of aquatic insects (Ephemeroptera, Plecoptera and Trichoptera) in a mountain stream in southeastern Brazil. Diversity and community structure of the orders Ephemeroptera, Plecoptera and Trichoptera in streams of the Serra da Mantiqueira are presented. Multivariate analyses are used in an evaluation of the feeding habits of the immature insects and in an attempt to ascertain the ecological association among the taxa.

Key-words: Lotic, aquatic insects, community, feeding habits, multivariate analyses.

RESUMO: Estrutura da comunidade e diversidade de insetos aquáticos (Ephemeroptera, Plecoptera e Trichoptera) em um córrego de montanha no sudeste do Brasil. Visando diminuir a escassez de conhecimento sobre a fauna de insetos aquáticos de ambientes lóticos brasileiros, este trabalho apresenta a estrutura da comunidade e a diversidade das ordens Ephemeroptera, Plecoptera e Trichoptera, em córregos de montanha da Serra da Mantiqueira, São Paulo. Métodos de análise multivariada são utilizados numa avaliação dos diferentes hábitos alimentares das ninfas e larvas, numa tentativa de associação ecológica entre os diferentes táxons.

Palavras-chave: Lótico, insetos aquáticos, comunidade, hábitos alimentares, análise multivariada.

INTRODUCTION

The aquatic insects are dependent on water during at least part of their life cycles, playing a central role in freshwater ecosystems all around the world (Macan, 1962; Cummins, 1974; Wiggins & Mackay, 1978; Resh & Rosenberg, 1984, Roldan, 1990). However, the knowledge of the aquatic insects in Brazilian lotic freshwaters, is scanty (Vanzolini, 1964; Flint, 1981).

One of the most important factors explaining ecological association in animal communities is the feeding habit (Pianka, 1994). Cummins & Klug (1979) classified the aquatic insects into five trophic categories: collectors, in which the size of organic matter particles (usually plant debris) is smaller than 1mm (FPOM, fine particulate organic matter); shredders, in which the food particles (plant) are larger than 1mm (CPOM, coarse particule organic mater); scrapers, that ingest the periphyton; piercers, that feed on dissolved organic matter; and predators, that hunt other macroinvertebrates, especially aquatic insects larvae. In addition, to explore lotic habitat niches, morpho-physiological adaptations, such as depressed bodies, structures to retain food particles (nets, setae brushes) and sclerotized hooks (Schubart, 1946; Macan, 1962; Hynes, 1970 a and b) are necessary.

According to Hynes (1970a), one of the main difficulties in studying aquatic insect communities is the taxonomic identification of the immature stages. This leads to a dilemma: should we study aspects of ecology and natural history of these organisms in spite of the identification short-comings or should we wait for specific identification keys, uncertain in coming ? In this paper, we adopt the first alternative, since for the insect orders considered the authors are able to identify the immature stages at least to genus level. The objective of this paper was to study basic aspects of the ecology of the insect orders Ephemeroptera, Plecoptera and Trichoptera in a neotropical habitat. Aspects of their community structure, such as diversity and ecological association, and their relationships with feeding habits, will also be analysed using multivariate statistics.

MATERIAL AND METHODS

Study Area and Sampling

Field work was carried out in riffles of the micro-basin of Galharada Stream its tributaries, within the Campos do Jordão State Park, Brazil (22° 41'S and 45° 28'W). The riparian vegetation consisted mainly of ferns, underbrushes and *Araucaria angustifolia* mixed forest. The Galharada stream basin is situated in the Mantiqueira Mountains, at an altitude of 1550m.

Sampling was carried out at four stations (Figure 1): 1- tributary upstream of the Fisheries Institute of São Paulo State reservoir; 2- tributary near of the "Recanto das Mimosas" camping area; 3- Galharada Stream downstream from the track of "Cachoeira" in the Park; and 4- Galharada Stream, near the confluence with Sapucai-Mirim River. Stations 1 and 2, in the tributaries have a denser forest canopy cover than the stations in Galharada Stream. According with hydrological standard classification (Strahler, 1957) stations 3 and 4 are situated in a third order stream (Galharada) and stations 1 and 2, in first order streams (tributaries) (Figure 1).

The stations were sampled in May and November 1987 and March 1988. The removed stones were held downstream in a sieve 19cm in diameter and 1mm mesh. The insects were collected from both the stones and the sieve with entomological tweezers. Sampling was restricted to riffles and were done during 1 hour. The insects were preserved in 80% alcohol.

Insect Identification and Feeding Habits

In the laboratory, the specimens were sorted initially to family level, according to Merritt & Cummins (1979). Identification of stoneflies to genus level was based on Froehlich
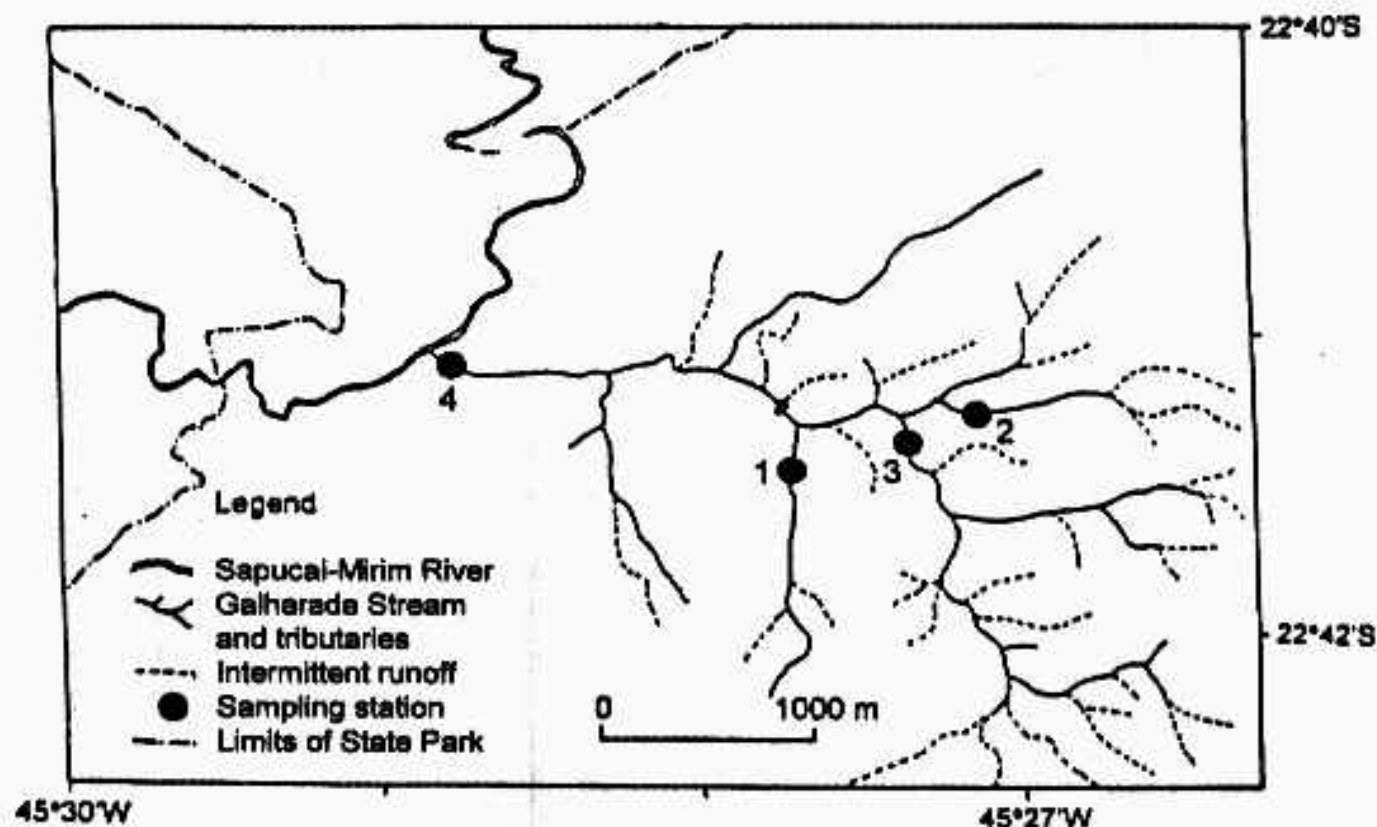
Figure 1. The Galharada Stream basin, Campos do Jordão State Park, São Paulo, Brazil (22°41'S and 45°28'W), showing the 4 sampling stations.

(1969, 1984, 1988, 1990, 1994), the mayflies on Dominguez et al (1992) and the caddisflies on Wiggins (1977), Guahyba (1988) and Holzenthal (1988).

To investigate the feeding habits of the immature stages of mayflies, stoneflies and caddisflies, the digestive tract of a few individuals (at least five in the case of caddisflies, in general fewer in the case of mayflies and gripopterygids) of each taxon was examined under the microscopic to identify food items. The perlids, considered predators, were not examined.

For the analysis, the food items were divided into four categories: sediments; algae; higher plant fragments, and animal fragments. When sediments or algae were found in the digestive tract the insect was classified as a collector or scraper, since more detailed evaluation of the food items was not carried out.

Statistical Analyses

Ecological diversity was estimated using the Shannon-Wiener index (H') (Magurran, 1991) and its evenness equivalent (E = H'/Hmax.).

The data matrix of insect abundance in sampling stations and months (observations) was analysed in both Q and R modes, using standard multivariate statistical analysis applied to community ecology (Gauch, 1982; Legendre & Legendre, 1983; Krebs, 1989; Norris & Georges, 1993). The analysis of similarity between observations, using both clustering (UPGMA) and ordination (NMDS) (see below) techniques, based on Morisita's similarity matrix, did not reveal time or space trends. Thus, all observations were used as replication to evaluate ecological association between pairs of genera, using Morisita's index.

Association between pairs of genera was initially analysed using unweighted pair group method arithmetic averages (UPGMA) clustering algorithm (Sneath & Sokal, 1973; Norris & Georges, 1993). The distortion involved in dimensional reduction was evaluated by the cophenetic correlation coefficient. Another approach to evaluate ecological association is to use an ordination technique. Is this paper, a nonlinear ordination, the non-metric multidimensional scaling (NMDS) (Kruskal, 1964) was used, for solutions in two and three dimensions. The position of genera in a 3D linear space of principal components was used as an initial configuration for NMDS. This ensures that NMDS will furnish better results than PCA. "Badness-of-fit"of ordination was computed by stress (S) and Pearson correlation between original Morisita's indices and distances in final configuration space.

A second data matrix, containing information about the feeding habits of each genus, was also analysed. Since this matrix contains only binary values (0 or 1) for each of the four categories described above, similarity between pairs of genera, in terms of feeding habits, was computed using Jaccard coefficient (Krebs, 1989). In this way, a single genus can have up to four values of 1,0 if all kinds of food items were found in its digestive tract.

The two similarity matrices between pairs of genera (Morisita's index based on abundance and Jaccard coefficient) were compared using the Mantel test (Manly, 1986). The Z statistics is computed as:

$$Z = E, Ej (Mij . Jij)$$

where Mij and Jij are the elements of the two matrices being compared (Morisita and Jaccard).

The observed Z value is then compared with numerous values, each one calculated after matrix randomization. In this way, it is possible to evaluate the statistical significance of association between matrices. In biological terms, this test permits to know to what extent ecological association among genera (Morisita's index) can be explained by their similarity patterns in feeding habits.

All analyses were performed on NTSYS-PC, version 1.5 (Rohlf, 1989).

RESULTS

General Results

The basic data matrix, with abundance of genera in sampling stations and months, and their general feeding category is shown in Table I. The Shannon-Wiener index (H') and Evenness (E) for each sampling is also given. A total of 35 genera were collected, but the maximum for an individual sampling was 27 (Station 2, November 1987), and the minimum was 16 (Station 2, May 1987). Considering the total number of individuals sampled, the maximum (312) was found in Station 3, November 1987. The minimum number of individuals (139) was found in Station 3, March 1988. Diversity indices ranged from 3.09 (Station 2, May 1987) to 4.04 (Station 2, November 1987); evenness from 0.771 (Station 1, May 1987) to 0.872 (Station 4, November 1987). These values indicate a relatively high diversity and an equidistribution of abundances.

Species belonging to four genera, *Gripopteryx*, *Anacroneuria*, *Kempnyia* and *Smicridea* were collected in all stations and months. On the other hand, species of the genera *Campylocia*, *Macronema* and *Chimarra*, common in other stations, were never registered in Station 4. The

Table I. Data matrix of the abundance Ephemeroptera, Plecoptera and Trichoptera in Córrego Galharada basin. At the botton are given the number od genera (G), the total number of individuals (N), Shannon-Wiener diversity index (H') and evenness (E = H'/H$_{max}$). FC - general feeding categories, C - collector and/or scraper, S - shredder, P - predator.

MONTH		May 1987				November 1987				March 1988				
STATION	(FC)	1	2	3	4	1	2	3	4	1	2	3	4	N
Ephemeroptera														
Baetis	(C)	0	0	3	14	4	3	12	12	2	0	0	13	63
Baetodes	(C)	0	1	13	30	0	9	7	26	0	2	18	36	142
Camelobaetidius	(C)	0	0	0	0	0	0	0	0	0	0	0	1	1
Hagenulopsis	(C)	5	1	0	0	28	36	20	1	7	3	1	0	102
Farrodes	(C)	0	0	0	0	8	14	28	0	0	0	0	0	50
Massartella	(C)	2	3	0	2	2	0	1	0	3	0	2	4	19
Hermanella	(C)	40	0	3	0	56	6	8	0	1	0	0	0	114
Aff. Hermanella	(C)	0	0	0	7	3	2	0	30	26	9	3	6	86
Thraulodes	(C)	6	14	17	0	13	36	29	4	11	16	14	0	160
Askola	(C)	0	0	0	0	1	3	3	0	0	0	0	0	7
Leptohyphodes	(C)	3	0	2	0	0	2	1	0	0	2	1	0	11
Leptohyphes	(C)	1	0	0	2	0	0	3	12	2	0	0	4	24
Genus I	(S)	0	0	0	0	0	3	0	0	1	2	0	0	6
Campylocia	(S)	26	17	0	0	10	4	1	0	27	20	1	0	106
Plecoptera														
Gripopteryx	(C)	1	2	6	32	1	4	7	1	1	3	5	4	67
Paragripopteryx	(C)	0	0	0	1	6	10	4	5	0	0	0	0	26
Anacroneuria	(P)	16	14	36	17	25	21	34	25	18	36	29	22	293
Kempnyia	(P)	14	2	4	9	8	4	13	7	9	6	8	17	101
Trichoptera														
Phylloicus	(S)	0	0	0	0	0	0	1	0	1	0	0	1	3
Mortoniella	(C)	0	1	38	16	5	13	2	16	0	0	7	9	107
Helicopsyche	(C)	0	0	0	4	10	0	3	1	1	3	2	9	33
Leptonema	(P/C)	2	0	6	7	1	3	0	5	3	2	1	3	33
Macronema	(C)	16	4	15	0	1	0	0	0	27	13	14	0	90
Smicridea	(P/C)	9	13	16	9	11	8	11	4	10	10	5	10	116
Amphoropsyche	(C)	1	0	0	0	0	0	0	0	0	0	0	0	1
Grumichella	(C)	1	0	29	10	17	5	36	27	1	0	6	3	135
Nectopsyche	(S)	1	11	5	1	1	5	23	5	1	0	2	1	56
Triplectides	(C)	1	0	7	1	0	2	7	0	0	0	4	2	24
Marilia	(P/C)	0	1	1	0	0	3	0	0	1	12	0	1	19
Chimarra	(C)	2	10	78	0	12	39	45	0	2	16	7	0	211
Polycentropus	(C)	0	1	0	0	0	0	0	0	1	0	0	0	2
Aff. Cyrnellus	(C)	0	0	1	0	0	2	3	0	0	1	0	0	7
Xiphocentron	(C)	0	0	0	0	1	1	0	0	0	0	0	0	2
Atopsyche	(P/C)	2	0	4	7	2	5	7	12	2	3	7	0	51
Grumicha	(P/C)	1	49	0	0	1	16	3	0	1	53	2	5	131
G		20	16	19	17	24	27	26	17	24	19	21	19	35
N		150	144	284	169	227	259	312	193	159	212	139	151	2399
H		3.33	3.09	3.40	3.52	3.71	4.04	3.99	3.56	3.59	3.48	3.77	3.56	
E		.771	.773	.802	.862	.811	.851	.851	.872	.784	.820	.859	.839	

most abundant species belonged to *Anacroneuria*, with 293 individuals (12.21% of the total number of individuals). *Camelobaetidius* sp and *Amphoropsyche* sp (1 specimen), *Polycentropus* sp and *Xiphocentron* sp (2 specimens each), and *Phylloicus* sp (3 specimens) were represented by few individuals, not typical riffle dwellers.

Multivariate Analyses

The Q-mode analyses (analysing similarity between sampling stations and months) did not show space-time patterns, i.e., there are no clusters of sampling stations or months. Thus, this paper will focus on association between genera (R-mode analysis) using time and space as replications in association coefficients.

The dendogram of UPGMA based on Morisita's index is shown in Figure 2. The cophenetic correlation was 0.831, indicating some distortions in relation to the original similarities. Species of some pairs of genera, such as *Anacroneuria* and *Smicridea*, *Baetodes* and *Mortoniella*, *Grumichella* and *Atopsyche*, *Thraulodes* and *Chimarra*, *Farrodes* and *Askola* are highly associated. There is a large cluster of genera comprising from *Anacroneuria* to *Helicopsyche* (Figure 2), with other genera or groups being related to this large cluster.
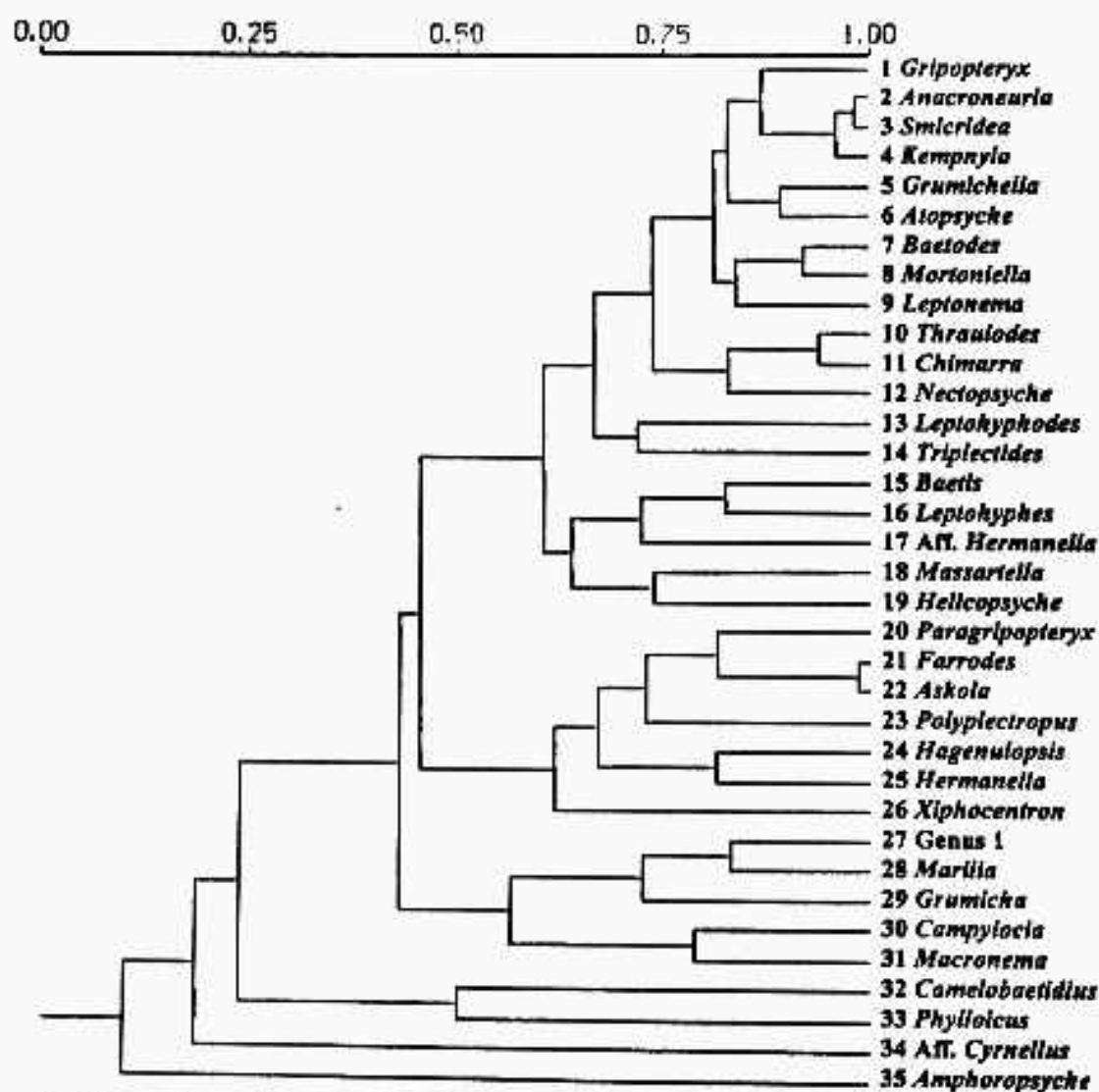

Figure 2. Clustering of Morisita-Horn association among genera of aquatic insects in the Galharada Stream basin, Campos do Jordão State Park, São Paulo, Brazil, using UPGMA (cophenetic correlation = 0.831).

A better representation of ecological association can be obtained using NMDS. Stress for 2D solution was not satisfactory (S = 0.378), and thus a 3D final solution was adopted, with S = 0.287. Although this value of stress is not also very good, matrix correlation between distances in final configuration space and original Morisita's association was 0.799, indicating a better representation than UPGMA clustering.

The projection of genera on the 3D space of NMDS indicates the same general patterns of UPGMA (Figure 3).

The comparison of ecological association and feeding habits between species of pairs of genera, using the Mantel test, indicates that at least part of the ecological associations can be explained by feeding habits. The Z value was significant at P = 0.0034 after 5.000 random permutations. The standardized Z value, equal to matrix correlation R, was 0.210. This indicates that species of more closely associated genera, in terms of relative abundance, tend to have distinct feeding habits (the R value is negative).
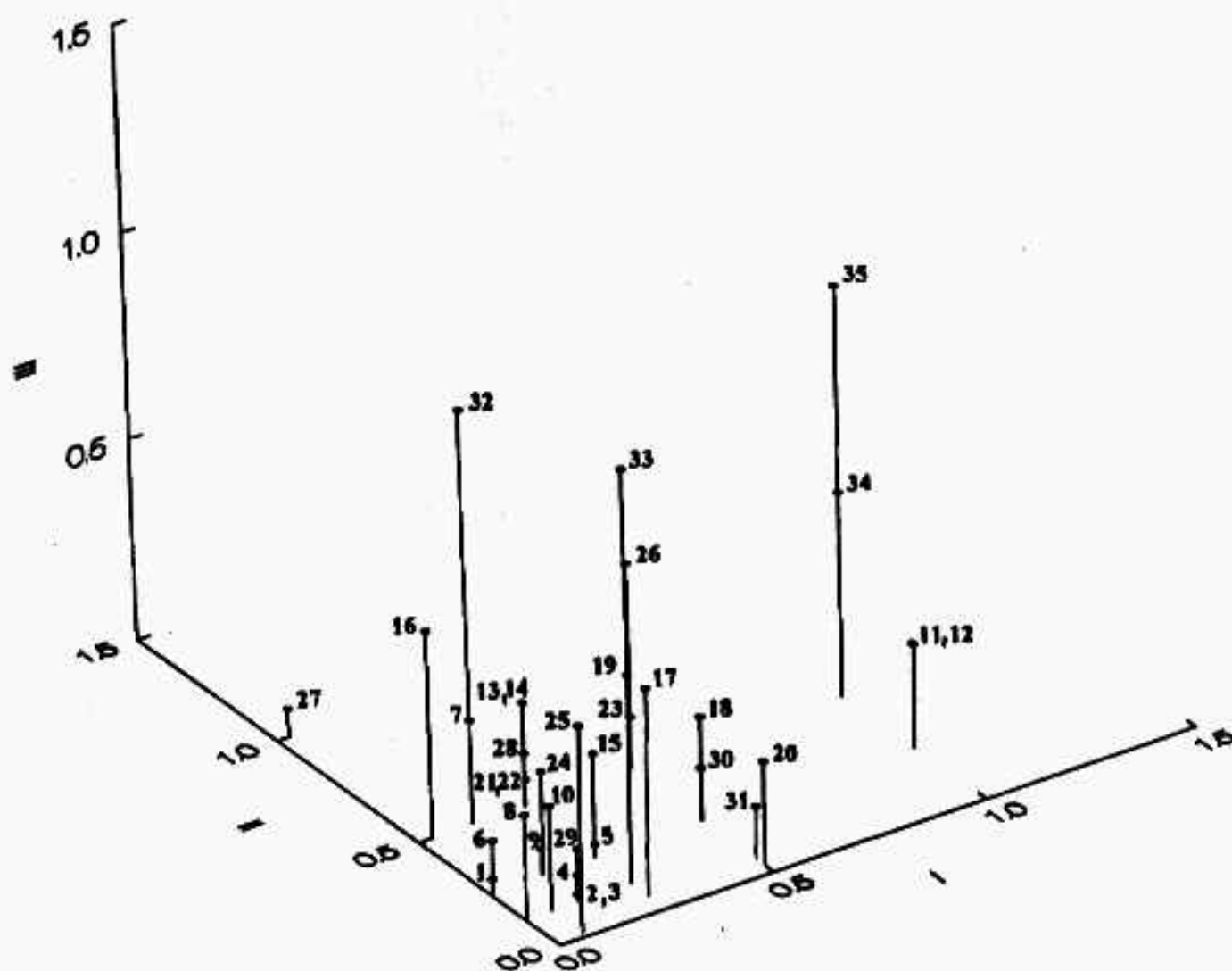

Figure 3. Tridimensional projection of genera scores obtained with NMDS (Stress = 0.287), for aquatic insects in the Galharada Stream basin, Campos do Jordão State Park, São Paulo, Brazil.

DISCUSSION AND CONCLUSIONS

The high diversity of stoneflies and caddisflies found in this study could be expected when one considers the ancestral environment of the two insect orders cool lotic (Wiggins, 1977), which are the conditions found in the environment studied. Is is not possible, at present, to evaluate the diversification at genus level in relation to the entire Brazilian fauna. However, it is important to note that species of all families (twelve) registered in Brazil (Oliveira, 1990), are represented at least by one genus. Information is not available for species of the family Hydroptilidae, since taxonomic identification at genus level was not possible to carry out.

Spatial or temporal patterns ot ecological similarity among sampling stations or months were not detected, probably due to the small scales on both dimensions (see Figure 1). This is interesting because all stations and months can be used as replications to study ecological associations among genera. However, species of some genera, such as *Campylocia*, *Chimarra* and *Macronema*, are never collected in Station 4. This could be due to the fact that this station is located downstream of a trout breeding facility and a plant nursery, which produce some enrichment, as well as a sawmill of the Campos do Jordão State Park, which at times releases a load of sawdust into the stream. Since species of two caddisflies genera possess very small mesh nets, this environmental condition is probably a limiting factor to their occurrence, in the same way that have been registered for other net-spinning caddisflies (Miller, 1984). On the other hand, although *Leptonema* and *Smicridea* belong to the same family as *Macronema*, their mesh nets are larger, which explain the presence of these genera in Station 4.

Associations among species at genus level are usually hard to interpret, since all ecological interactions between populations (especially competition and predation) can be found simultaneously for distinct pairs in the analysis (Legendre & Legendre, 1983). Historical factors related to adaptations to the environment are also present. In our analysis, there is no clear pattern related to taxonomic groups or body size differences among genera. Some high association values, such as between *Anacroneuria* and *Smicridea*, may reflect a predation of the first on the second. Of course, a large amount of theoretical, field and experimental studies should be performed to explain the patterns of association described in this paper. However, in general terms, it is possible to say that feeding habits explain at least a small part of the ecological associations, since the Mantel test was significant. The negative signal indicates that associated genera have distinct feeding habits, which can indicate predatory activities such as mentioned above for *Anacroneuria* and *Smicridea*. It is important to note, however, that the explanation power is extremely low ($R = 0.051$), indicating that only a very small part of the ecological associations showed by multivariate analyses (around 5%) is explained by feeding habits. This may be attributed, at least in part, to the low discrimination power of the Jaccard coefficient in comparing genera. Since only four feeding categories were established, few Jaccard values are possible by combination and differences among genera are not defined in a detailed way. Future studies should increase the definition of the food items and test the association between matrices in a more refined way. This does not invalidate our approach, since our coding system is congruent with the one proposed by Cummins & Klug (1979). For example, the species of genera *Campylocia* and *Phylloicus* as "shredder" since it shows value of 1,0 for our first three categories. Also, species of the genera *Paragripopteryx*, and *Helicopsyche* are "scrapers" and show values of 1,0 for our first two categories.

Another problem with the association analyses presented here is that some genera collected in this study are not typical members of the riffle fauna, increasing random asso-

ciation effects and, consequently, reducing the possibility of explanation of associations by ecological factors, such as feeding habits. However, when the rare genera are removed from the analysis (*Camelobaetidius, Askola*, Genus 1, *Phylloicus, Amphoropsyche, Polycentropus*, Aff. *Cyrnellus* and *Xiphocentron*), the matrix correlation decreases to -0.182 (P > 0.05), what does not support this hypotesis and indicates that correlation between ecological associations and feeding habits have elevated contributions from rare genera, probably because they increase ecological variability and make easier to detect these correlations. A general problem in benthic studies, however, is the large statistical error in sampling (Resh, 1979), what many produce widely scattered data, with the consequent loss of resolving power of the analyses.

We conclude that mayflies, stoneflies and caddisflies have high diversity, in terms of ecological and taxonomic distribution, in the environment studied. Also, that feeding habits have a role in defining community structure although further studies should be performed to evaluate in a more quantitative and precise way this influence.

Acknowledgements

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