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.

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ABSTRACT: 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. Aiming at the study of the altitudinal variation of the numerical structure and biodiversity of the taxocenosis of Ephemeroptera, samples were taken between June and December, 1998 in 35 streams located in three life zones in the Department of Antioquia. Seven families, 22 taxa and 19 genera were found, out of which Bernerius, Cloeodes, Mayobaetis, Atopophlebia, Farrodes, Haplohyphes, and Homothraulus are first records for Antioquia. Bernerius, Mayobaetis and Homothraulus genera are first cited for Colombian bentic fauna. The community found in the Premontane altitudinal zone was different to the rest. Similarity among zones was high; exchange among zones was moderate as shown by the reciprocal value of beta diversity with the two indexes used (DB_W = 62%, DB_R = 68%). The diversity of the Ephemeroptera community found in each zone was relatively high.
Key-words: Ephemeroptera, atitudinal gradient, numerical structure, biodiversity, Colombia.

RESUMO: Variação altitudinal da estrutura numérica da comunidade de Ephemeroptera nas regiões sul, norte e central do Departamento de Antioquia, Colômbia. Para estudar a variação altitudinal da estrutura numérica da taxocenosis de Ephemeroptera foram tomadas amostras entre os meses de Junho e Dezembro de 1998 em 35 sistemas lóticos localizados em três regiões do Departamento de Antioquia. Foram encontradas 22 táxons, sete familias e 19 gêneros. Bernerius, Cloeodes, Mayobaetis, Atopophlebia, Farrodes, Haplohyphes, e Homothraulus constituem-se em primerios registros para Antioquia; os gêneros Bernerius, Mayobaetis e Homothraulus são citados pela primeira vez para Colômbia. A comunidade encontrada na zona de vida premontana foi diferente das outras. A similaridade entre as zonas foi alta, e o intercambio de táxons entre elas foi moderado, segundo os resultados dos dois índices usados para calcular a Beta-diversidade (DB_W = 62%, DB_R = 68%). A diversidade de Ephemeroptera em cada zona foi relativamente alta.
Palavras-chave: Ephemeroptera, gradiente altitudinal, biodiversidade, Colômbia.

Introduction

Ephemeroptera are aquatic insects found in a wide range of habitats in lentic and lotic waters. The greatest diversity of species of this group is found in rocky substrates of second and third orders. Some of the life habits observed in the group are swimming (Baetidae, Leptophlebiidae), climbing (Heptageniidae), digging (Caenidae, Eutyplocidae) and drilling (Ephemeridae). From a functional point of view, Ephemeroptera belongs to the collecting group (filterers and detritivorus) and scrapers (Merritt & Cummins, 1979). Its members are probably the most primitive insects. The name of the order stands for the ephemeral life of the adult form, since generally the imaginal period lasts nearly one day, though there are extreme cases in which the imago lives for just a couple of hours (Morrone & Coscarón, 1998 in Domínguez, 1998).

Within the Ephemeroptera many genera and species are considered clean water indicators (Type I) with low tolerance to fluctuations in physical and chemical variables, and highly sensitive to the presence of organic residues (Roldán, 1980a; 1980b; 1988). In spite of being a group widely spread in South America, little is known about its biogeography due mainly to the few studies carried out on its taxonomy and distribution (Domínguez & Ballesteros, 1992).

As the organisms in any other group, Ephemeroptera populations are regulated by density dependent and independent factors. Among the independent factors are resource availability (generally trophic and habitat) and weather factors related to altitudinal and latitudinal variations (thermal, rainfall, and humidity patterns, as well as human impact, among others).

Illies (1969) divided lotic entomofauna in two ecological types: "oligostenothermals" or groups adapted to colder regions, and "polystenothermals" or groups adapted to warmer regions. Under this classification, initially adopted only for Plecoptera, Ephemeroptera belongs to the polystenothermal group (Domínguez & Ballesteros, 1992).

It is well known the weather complexity of any mountain system with its typical changes at short distances due mainly to the decisive effect of local climates as well as to the interaction of the different topoclimatic gradients, determined by factors such as topographical position, altitude, slope, exposure, passive effects, etc. If an isolated mountain configures a relatively complex tridimensional ecoclimate pattern, what can be expected from such an extensive orographic system as the Andes which, even if limited to the tropical zone, extends more than 30º latitude, from Macizo de Santa Marta in the Caribbean littoral of Colombia (11ºN) to 20ºS latitude in the center of Bolivia (Sarmiento, 1986).

The most evident and simplest altitudinal gradient in the Tropical Andes is the altithermal gradient with a decrease in its mean temperature of nearly 0.6º C per each 100 m of elevation. This altithermal range varies little regionally. The consequence of the altithermal range is that species are distributed within relatively precise altitudinal ranges. However, this ecological altitudinal variation, far from being continue as it is the thermal gradient, makes belts or life zones separated by structural and functional features, determined probably by a critical threshold in temperature. Rainfall and temperature combine to determine peculiar thermal climates in the high Andes (Sarmiento, 1986).

The aim of this research is to describe the altitudinal variation of the numerical structure of the Ephemeroptera community present in lotic ecosystems in the south, central and north regions of the Department of Antioquia. If the altitudinal and thermal gradients influence the structure of the Ephemeroptera community, we forsee that the biodiversity, evenness and richness decrease towards the low montane zone.

Material and methods

35 streams located in the south, central and north regions which include tropical, premontane and low montane life zones of the Department of Antioquia were selected for this study (Espinal, 1992) (Fig. 1).

1.Tropical Altitudinal Zone (0 – 1000 m): includes 9 sampling streams located in the north of Antioquia, including Caucasia at 50 m, Tarazá at 125 m, and Puerto Valdivia at 175 m.

2.Premontane altitudinal Zone (1000 – 2000 m): includes 14 sampling streams located in the central region of Antioquia in the municipalities of Porce at 1056 m, Valdivia at 1165 m, Barbosa at 1300 m, Envigado at 1550 m, Sabaneta at 1575 m, and Gómez Plata at 1865 m.

3.Low montane Altitudinal Zone (2000 – 3000 m): located in the south region of Antioquia that includes 12 sampling streams in Yarumal (2300 m), Alto de San Miguel (2350 m), Belmira and San Pedro (both to 2400 m), Alto de las Palmas (at 2450 m); and Santa Rosa de Osos (2562 m).

From June to December, 1998, four thorough samples were taken; two during the rainy season and two during the dry season. Sampling was done in shorelines with and without vegetation, and rocky, sandy and muddy bottoms. Screen nets and D-nets were

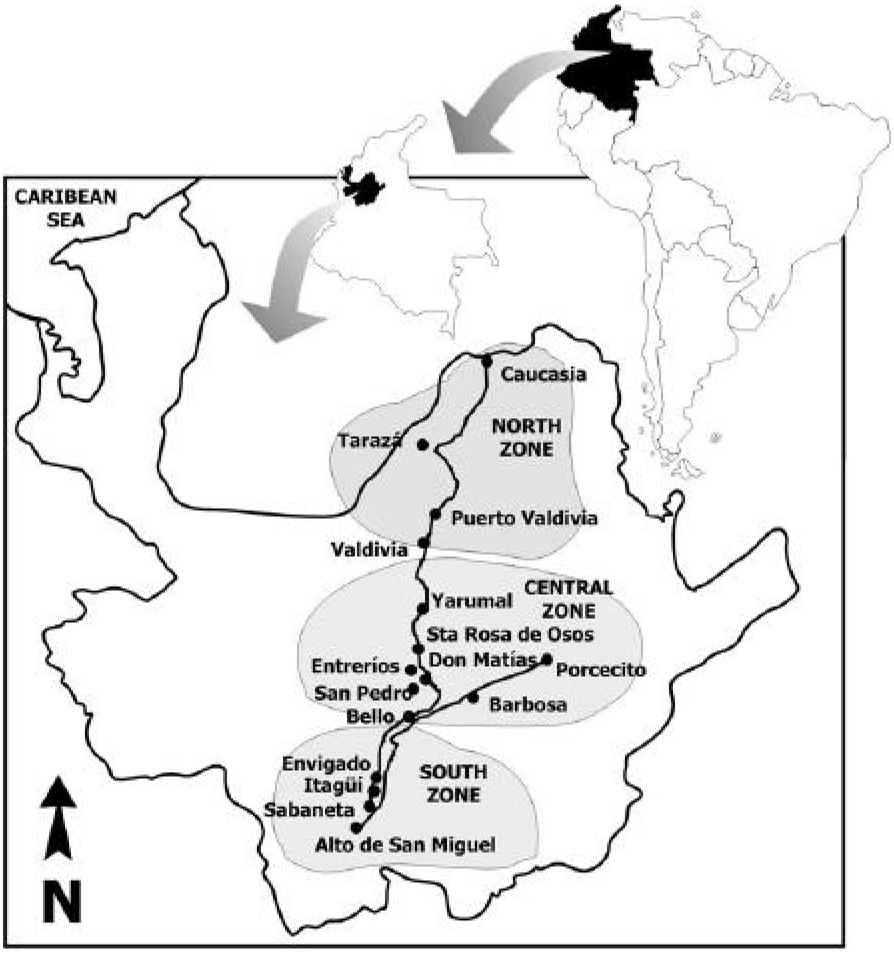

Figure 1: Geographic location of the municipalities in each zone studied in the Departament of Antioquia.

used for sampling, and organisms present in trunks, stones and fallen leaves were collected. When possible, sampling areas were similar for all ecosystems. Collecting was done in a two-hour period, but the number of people varied among sampling, so abundance values are reported as macroinvertebrates per collector in each sampling area.

With an Oximeter WTW, water temperature, dissolved oxygen and saturation percentage were measured in situ. Conductivity and pH were measured with a conductivimeter and pHmeter of the same brand.

In spite of having found 22 taxa, in fig. 2A and 2B only 21 are reported since the undetermined genera I and II were put together and considered as one.

Statistical Analysis. Diversity (H') (Shannon & Weaver, 1949), Evenness (E) (Pielou, 1975), Richness (R) and Dominance (d) (Berger & Parker, 1970) indexes were used to describe the numerical structures of the macroinvertebrate community found in each altitudinal zone. Additionally, species significance and rarefaction curves were constructed for each zone.

Rare species in the total community (Fig. 6A) were estimated with the formula:

$$S = (e^{H'} + D^{-1})$$

Where S stands for richness, $e^{H'}$ is the number of abundant species and D^{-1} is the reciprocal of Simpson (1949). Dominance index which corresponds to the number of the most abundant species. Diversity loss (¯H') in each zone was estimated using the numerical expression

$$H'_{máx} - H'_{obs} = Log_e S - H'_{obs}$$

Similarity among altitudinal zones was determined using two types of indexes. The first was Bray & Curtis (1957) of quantitative nature and the second was Jaccard index, of qualitative nature. Dissimilarity among taxa (Fig. 2B) was obtained using Mean Euclidean Distance index. The linking strategy for all cases was UPGMA. Cophenetic Correlation index was used for dendogram adjustment.

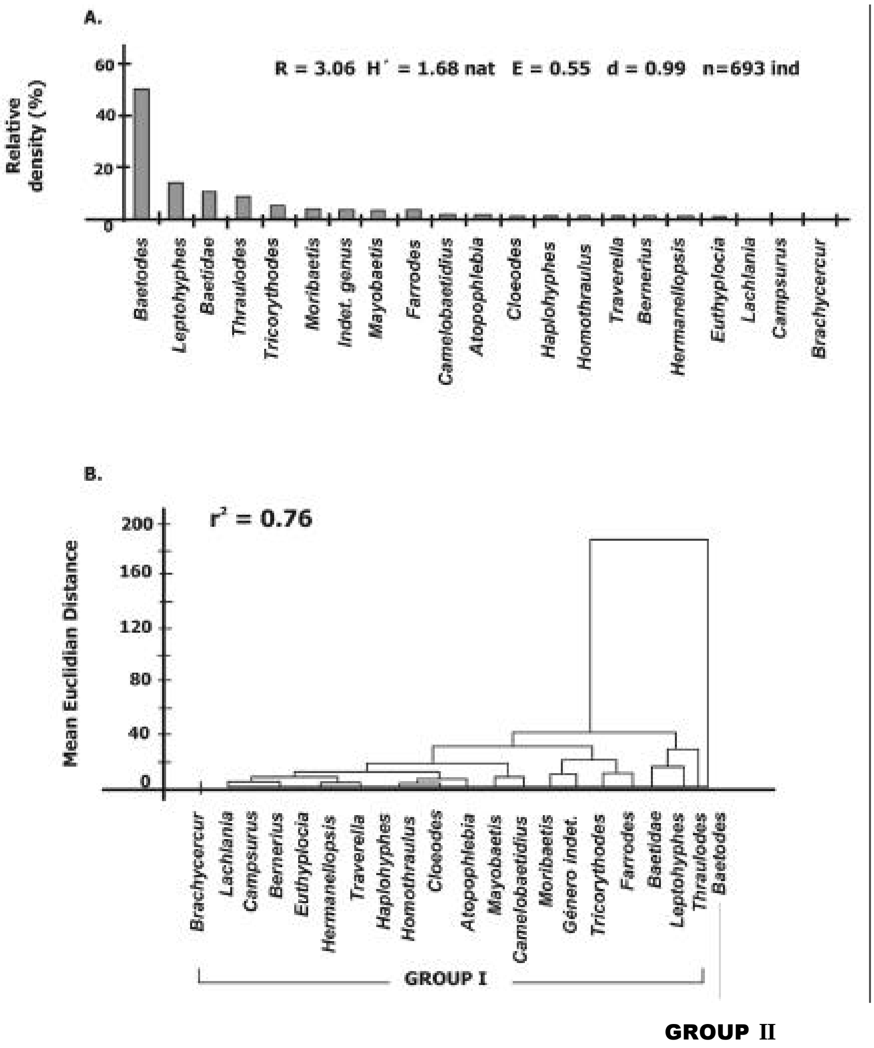

Figure 2: A) Rank-abundance curve of the total Ephemeroptera community. B) Cluster Analysis based in the Mean Euclidean Distance index for the Ephemeroptera community.

The turnover in taxa composition among altitudinal zones was established using the reciprocal of Beta Diversity index (DB) (expressed in percentage). DB was estimated in two ways:

1) by means of the exponential of the formula proposed by Routledge (1977):

$$DB_R = e^{BI}$$

$$B_I = \log_e T - ((1/T)Se_i \log_e e_i) - ((1/T)\ Sa_j \log_e a_j)$$

Where e_i is the number of zones where genus I is present, a_j stands for richness of the taxa in each altitudinal zone, and T is $Se_i = Sa_j$; and

2) by means of the expression proposed by Whittaker (1960):

$$DB_W = S_T/a$$

S_T stands for the number of taxa found (22 in this study), M the number of systems to be compared (3 in this study) and a was estimated using the following formula:

$$a = SS_j/M = S_T M/Se_i$$

DB measures how different or similar a range of habitats or samples is in terms of the variation of the taxa within the range. It estimates how the diversity, expressed in terms of richness, changes along a gradient. The smaller the number of shared species by the communities to be compared is, the greater the DB would be. Consequently, its reciprocal would be low, which corresponds to low taxa turnover and low similarity among samples or habitats.

To further explain the results obtained with the indexes used to calculate DB, Complementary value (C_T) was calculated, as understood by Colwell & Coddington (1996), stated as differentiation (distance or dissimilarity) in the taxa composition in a wide environmental spectrum.

The mathematical expression for C_T is:

$$C_T = SU_{jk}/M = S(S_j + S_k - 2V_{sk})/M$$

Letters S_j and S_k stand for richness in j and k places, respectively; V_{jk} is the number of taxa common to all j and k places; and U_{jk} stands for the number of unique species in each list. This index is used together with a formula to calculate the maximum value; its numerical expression is:

$$C_{Tmáx} = MS_T/4$$

Results

A total of 7 families and 19 genera were found. The genera Baetodes, Mayobaetis, Moribaetis, Leptohyphes, Tricorythodes, Mayobaetis, Moribaetis, and Thraulodes had a wide range of altitudinal distribution since all of them were present in all the studied zones. Genera Euthyplocia, Farrodes, Hermanellopsis, Homothraulus and Traverella were found only in the tropical zone, whereas Bernerius, Brachycercus, Lachlania and Campsurus were restricted to the low montane zone. The undetermined genus I was found only in the other two zones.

Out of the 21 taxa found and considering the field studies done by Hubbard & Peters (1981), Roldán (1985, 1988), Ramírez & Roldán (1989), Zúñiga de Cardozo & Rojas de Hernández (1995) and Muñoz & Ospina (1999), genera Bernerius, Mayobaetis and Homothraulus are new records for Colombian bentic fauna.

It can be observed in Fig. 3 that mean temperature decreases with altitude. Mean values for the other variables are within a normal range; though in the premontane zone, they increased slightly and had lower variations. The variables with greater dispersion were oxygen saturation and electrical conductivity.

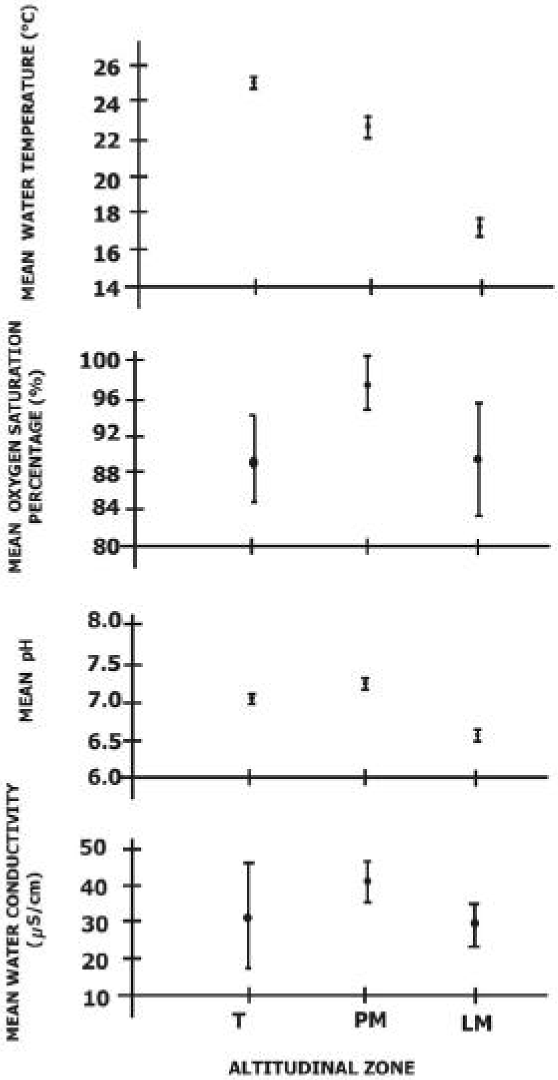

Figure 3: Mean and dispersion values for physical and chemical variables investigated in the three altitudinal zones. The value of standard deviation is showed in the superior part.

The relative diversity value (expressed as evenness) for each zone under our sampling conditions was relatively high. The premontane zone had the greatest loss of diversity ($\bar{H}'$ = 1.10 nat) as well as the lowest uncertainty (Fig. 4). It can be observed in Figs. 4 and 2 that Baetodes genus was dominant in all the altitudinal zones.

Dendogram in Fig. 5A, based on quantitative data, reveals that the premontane altitudinal zone was different to the others. It also shows a relatively low similarity among the three zones; although, the similarity value for the tropical zone was slightly different to the other two.

Rarefaction curve tends to level up quicker in the tropical zone than in the others (Fig. 6). DB_W was 1.61 and DB_R was 1.48. Their respective reciprocals were 62% and 68%. C_T was 10, with a $C_{Tmáx}$ value of 16.5.

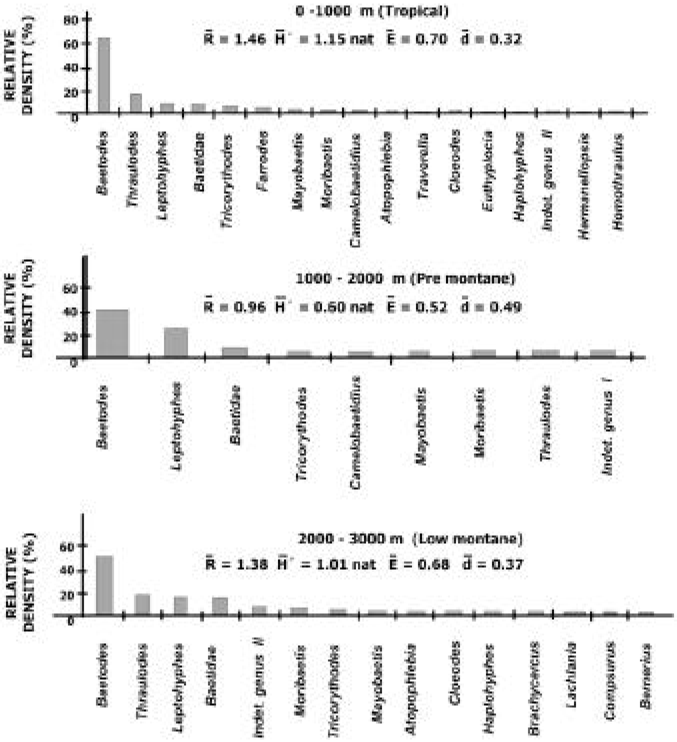

Figure 4: Rank-abundance curves for the Ephemeroptera community in each altitudinal zone.

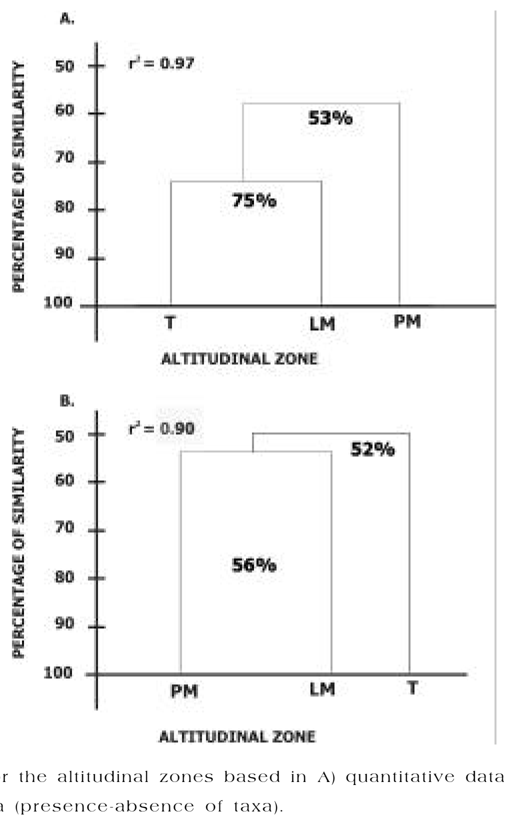

Figure 5: Cluster Analysis for the altitudinal zones based in A) quantitative data (numerical density) and B) qualitative data (presence-absence of taxa).

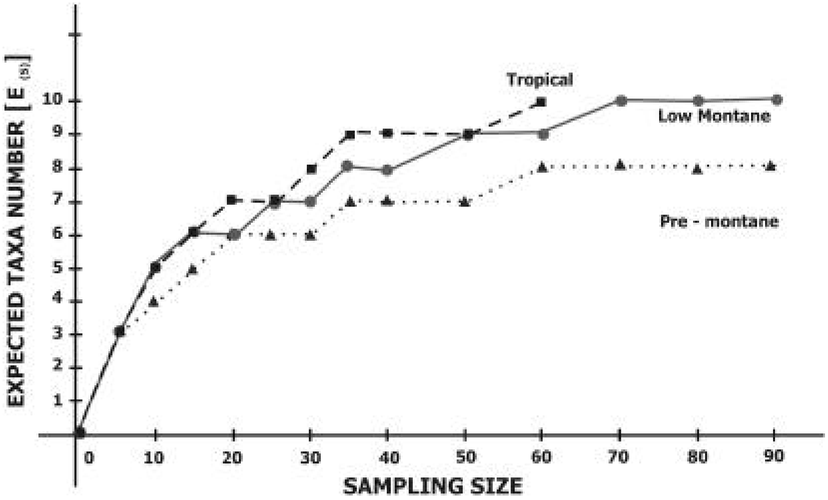

Figure 6: Rarefaction Curve for each altitudinal zone.

Discussion

Mean temperature values were as expected, that is, they decreased as altitude increased. Mean values for the other variables were standard which allows to conclude that the sampled ecosystems were in good chemical and physical conditions. A greater dispersion of oxygen saturation and electrical conductivity percentage implies relatively high differences in the data registered for these variables in the set of streams for each altitudinal zone.

Genera found in the three zones (Baetodes, Mayobaetis, Moribaetis, Leptohyphes, Tricorythodes, Mayobaetis, Moribaetis, and Thraulodes) can be considered organisms with a wide and tolerant ecological valence, especially, in a wide range of temperatures. The range for this study was 7.9 ^{o}C.

The premontane zone was different to the other two due to its lower mean values for richness, diversity, evenness, and greater dominance. As it was mentioned, the similarity observed for the three zones was relatively low, mainly due to the facts that 1) the percentage of common taxa among zones was not high and it was always below or near 50% (T – PM : 44.4%, T – LM: 52.4%, PM – LM: 41.1%), 2) taxa turnover among zones had moderate values as a consequence of the low number of shared species among them (only 31.8% of the total taxa, which total 41), and 3) the relatively low similarity observed in dendogram Fig. 5B; the lower similarity observed for the tropical zone is due to its higher diversity and richness values and to its rarefaction curve which levels up faster than the others.

The above results are a consequence of the low dispersion of Ephemeroptera among the analyzed zones. According to Hart & Fuller (1974), the adult form is shortlived, generally two or three days and its function is mainly breeding, which greatly diminishes its ability to disperse. Dispersion is further restricted because the adult forms are found only neighboring the immature forms (Pennak, 1978).

If we accept that the pressure of different kinds of stress factors increases loss of species, then we will have to accept that there was a stress factor that altered the Ephemeroptera community under study. Considering that most of the samples were taken during the rainy seasons in all ecosystems, it must be concluded that such a stress factor, independent from density, is natural in its origin and of climatic nature, which speeds up loss of species by drifting. Such a factor seems to be more prominent in the premontane zone.

The value for the Complementary Index (10) is not far from the maximum (16.5) which confirms the relatively high heterogeneity among zones, and the low turnover among members of the studied community. In spite of the fact that this research focused only on the Order Ephemeroptera, the percentage of dominant species was relatively low, whereas the percentage of rare species was high in the community as a whole and in any altitudinal zone. It is well recognized by ecologists that dominant species are responsible for the energy management of a significant quantity of the available resources, whereas rare species are responsible for the diversity of the community and the trophic webs. In this research, energy transfer from a trophic group in each altitudinal zone was channeled by only one genus: Baetodes, so this taxon is set apart from the others and is highly dissimil as can be seen in Fig. 2B.

Baetidae family is widely distributed, found in all continents and many islands. Within this family, the genus Baetodes is widely distributed, mainly in cold, well oxygenated fast running waters, over fallen leaves and stones and tolerates relatively high values of pollution. It belongs to the scraper group.

The mean diversity value found for each zone was relatively high since it is between 62 and 68% of the expected maximum theoretical value for this variable. Such percentage is represented by Evenness and it was 55% for the entire community. What we observe from the mean H' value is due mainly to the rare species which were half of the community of Ephemeroptera (58%). These organisms probably become part of the established community in each zone by drifting. It is worth noting that together with organisms from the Orders Diptera, Plecoptera and Trichoptera, Ephemeroptera stand out by being drifters (Allan, 1995).

Assertion with this statement is due to the fact that richness stands only for the resident species in the sampling area and not for those who arrive to the place by any means (Ludwig & Reynolds, 1988). This implies that in order to sample this community it is necessary to get rid of, by any means, the influence brought about by these arriving species, otherwise the results would be altered. One possible way to sample would be to do it only on the dominant substrate in each zone where the resident and 'permanent' community would be found (W. Riss, pers. com.).

Some authors (Roldán, 1980a; Escobar, 1989; Rojas de Hernández et al., 1992; Zúñiga de Cardozo & Rojas de Hernández, 1995) consider that the Order Ephemeroptera in Colombia is distributed from sea level to nearly 3500 m. They also consider that the maximum diversity is found between 1000 and 2000 m, that is, in the premontane zone. This was not the case in this study since mean diversity values for the tropical and montane zones, although low, were 1.92 and 1.68 times greater than for the premontane zone (Fig. 4), eventhough sampling in this zone included a greater number of streams (14).

Conclusions

From the statements above, it is possible to conclude:

1) That diversity depends more on the heterogeneity of the dominant conditions than to the number of sampled areas. Notice that the greatest absolute diversity was found in the tropical zone where only nine ecosystems were sampled. This agrees with what Pielou (1975) said: that when the sampling size is increased, richness and diversity do not necessarily increase at the same rhythm since new species are not added, but new individuals of the old species, since the "size" of a species is not measured by the number of individuals that it contains.

2) That the initial hypothesis must not be accepted and that the results are not due to the change in altitudinal and thermal gradients characteristic of each life zone, but to the influence of the weather conditions at sampling times, or in the worst cases, to possible sampling mistakes. However, if instead of comparing gross diversity values, we compare those of evenness, the proposed hypothesis must be accepted, since the low montane zone has a value farther away from the maximum probability value (maximum

diversity). It can then be said that it is in this value where more factors of a diverse type affect the diversity of the Ephemeroptera community. The greatest loss and lowest uncertainty expressed by its greater dominance value was observed in the low montane zone.

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References

Allan, J.D. 1995. Stream ecology: structure and function of running waters. Chapman and Hall, London. 387p.

Berger, W.H. & Parker, F.L. 1970. Diversity of planktonic Foraminifera in deep-sea sediments. Science, 168:1345-1347.

Bray, J.R. & Curtis, J.T. 1957. An ordination of the upland forest communities of southern Wis. Ecol. Monograph., 27:325-349.

Colwell, R.K. & Coddington, J.A. 1996. Estimating terrestrial biodiversity through extrapolation. In: Hawksworth, D.L. (ed.) Biodiversity: measurement and estimation. Chapman & Hall, London. p.101-118.

Domínguez, E. 1998. Ephemeroptera. In: Morrone, J.J. & Coscarón, S. (eds.) Biodiversidad de artrópodos argentinos: una perspectiva biotaxonómica. Ed. Sur. La Plata, Argentina. 599p.

Domínguez, E. & Ballesteros, J.M. 1992 Altitudinal replacement of Ephmeroptera in a subtropical river. Hidrobiología, 246:83-88.

Escobar, A.N. 1989. Estudio de las macrocomunidades bénticas en el río Manzanares y sus principales afluentes y su relación con la calidad del agua. Actual. Biol., 18:45-60.

Espinal, L.S. 1992. Geografía ecológica de Antioquia. zonas de vida. Universidad Nacional de Colombia, Seccional Medellín. Facultad de Ciencias. Editorial Lealon, Medellín. 106p.

Hart Jr., C.W. & Fuller, S.L.H. (eds.) 1974. Pollution ecology of freshwater invertebrates. Academic Press, New York. 205p.

Hubbard, M. & Peters, L. 1981. Distribución acuática de ninfas del orden Ephemeroptera. In: Hulbert, M, Rodríguez, S. & Santos, N.D. (eds.) Aquatic biota of tropical south america. Part I. Arthropoda. State University Press, San Diego. 310p.

Illies, J. 1969. Biogeography and Ecology of neotropical fresfwater insects, specially those from running waters. In: Fittkau, E.J.(ed.). Biogeography and ecology in South America. Dr. W. Junk. N.V., The Hague. v.2, p.685-708.

Ludwig, J.A. & Reynolds, J.F. 1988. Statistical ecology: a primer on methods and computing. Wiley, New York. 337p.

Magurran, A.E. 1988. Ecological diversity and its measurement. Princeton University Press, New Jersey. 179p.

Merrit, R.W. & Cummins, K.W. 1979. An introduction to the aquatic insects of North America. 2nd ed. Kendal Hunt Publishing Company, Dubuque. 540p.

Morrone, J.J. & Coscarón, S. (eds.) 1998. Biodiversidad de artrópodos argentinos: una perspectiva biotaxonómica. Ed. Sur. La Plata, Argentina. 599p.

Muñoz, D. & Ospina, R. 1999. Guía para la identificación genérica de los Ephemeroptera de la Sabana de Bogotá, Colombia. Ninfas y algunos géneros de adultos. Actual. Biol., 21: 47-60.

Pennak, R. 1978. Fresh-water invertebrates of the United States. 2nd ed. Wiley, New York. 628p.

Pielou, E.C. 1975. Ecological diversity. Wiley, New York. 803p.

Ramírez, J.J. & Roldán, G. 1989. Contribución al conocimiento limnológico y de los macroinvertebrados acuáticos de algunos ríos del Urabá antioqueño. Actual. Biol., 18:113-121.

Rojas de Hernández, A.M., Zuñiga de Cardoso, M.C., Burbano, M.H. & Serrato, C. 1992. Altitudinal distribution of Ephemeroptera in the Farallones de Cali National Park (Colombia). In: Memories of VII International Conference on Ephemeroptera. Maine.

Roldán, G. 1980a. Estudios limnológicos de cuatro Ecosistemas Neotropicales diferentes con especial referencia a su fauna de Efemerópteros. Actual. Biol., 9:103-117.

Roldán, G. 1980b. Los invertebrados acuáticos como indicadores ecológicos. Actual. Biol., 9:86-91.

Roldán, G. 1985. Contribución al conocimiento de las ninfas de los efemerópteros (Clase: Insecta, Orden: Ephemeroptera) en el Departamento de Antioquia, Colombia. Actual. Biol., 14:3-13.

Roldán, G. 1988. Guía para el estudio de los macroinvertebrados acuáticos del Departamento de Antioquia. Fondo FEN-Colombia. Editorial Presencia, Bogotá. 271p.

Routledge, R.D. 1977. On Whittaker's components of diversity. Ecology, 58:1120-1127.

Sarmiento, G. 1986. Ecological features of climate in high tropical mountains. In: Villeumieur, F. & Monasterio, M. (eds.) High altitude biogeography. University Press, Oxford. p.11-48.

Shannon, C.E. & Weaver, W. 1949. The mathematical theory of information. The University of Illinois Press, Urbana. 117p.

Simpson, E.H. 1949. Measurement of diversity. Nature, 163:688.

Whittaker, R. 1960. Vegetation of the Siskiyou Mountains, Oregon and California. Ecol. Monograph., 30:279-338.

Zúñiga del Cardoso, M. & Rojas de Hernández, A.M. 1995. Contribución al conocimiento del orden Ephemeroptera en Colombia y su utilización en estudios ambientales. In: Seminario de Invertebrados Acuáticos y su Utilización en Estudios Ambientales. Instituto de Ciencias Naturales, Universidad Nacional, Santafé de Bogotá.

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