Diversity of springtails (Hexapoda) according to a altitudinal gradient

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Abstract – The objective of this work was to elevate gradient effect on diversity of Collembola, in a temperate forest on the northeast slope of Iztaccíhuatl Volcano, Mexico. Four expeditions were organized from November 2003 to August 2004, at four altitudes (2,753, 3,015, 3,250 and 3,687 m a.s.l.). In each site, air temperature, CO_2 concentration, humidity, and terrain inclination were measured. The influence of abiotic factors on faunal composition was evaluated, at the four collecting sites, with canonical correspondence analyses (CCA). A total of 24,028 specimens were obtained, representing 12 families, 44 genera and 76 species. *Mesaphorura phlorae*, *Proisotoma* ca. *tenella* and *Parisotoma* ca. *notabilis* were the most abundant species. The highest diversity and evenness were recorded at 3,250 m (H' = 2.85; J' = 0.73). Canonical analyses axes 1 and 2 of the CCA explained 67.4% of the variance in species composition, with CO_2 and altitude best explaining axis 1, while slope and humidity were better correlated to axis 2. The results showed that CO_2 is an important factor to explain Collembola species assemblage, together with slope and humidity.

Index terms: Collembola, canonical correspondence analysis, CO_2, mesofauna communities, spatial variation.

Diversidade de colêmbolos (Hexapoda) de acordo com o gradiente de altitude

Resumo – O objetivo deste trabalho foi avaliar o efeito do gradiente de elevação na diversidade de Collembola, em uma floresta temperada no Vulcão Iztaccíhuatl, México. Quatro expedições foram organizadas de novembro 2003 a agosto 2004, em quatro altitudes (2.753, 3.015, 3.250 e 3.687 m). Em cada local foram medidas a temperatura, a concentração de CO_2 e a umidade do ar, além da inclinação do terreno. A influência de fatores abióticos na composição da fauna foi avaliada nos quatro locais de coleta, por meio da análise de correspondência canônica. Coletaram-se 24.028 espécimes, distribuídos em 12 famílias, 44 gêneros e 76 espécies. *Mesaphorura phlorae*, *Proisotoma* ca. *tenella* e *Parisotoma* ca. *notabilis* foram as espécies mais abundantes. A diversidade e a equitabilidade mais elevadas foram registradas a 3.250 m (H' = 2.85; J' = 0.73). A análise canônica mostrou que os eixos de correspondências 1 e 2, juntos, explicam 67.4% da variação na composição específica, em que o CO_2 e a altitude explicam melhor o eixo 1, ao passo que a inclinação e a umidade estão mais bem relacionadas ao eixo 2. Os resultados mostraram que o CO_2 é um fator importante para explicar o agrupamento das espécies de Collembola, juntamente com a inclinação e a umidade.

Termos para indexação: Collembola, análise de correspondência canônica, CO_2, comunidades da mesofauna, variação espacial.

Introduction

Altitude is a very important parameter to understand the distribution of plants and animals. The patterns of diversity and distribution of vascular plants, birds, mammals and ants are influenced by altitude. These groups show a clear decrease in species diversity and abundance as one moves up along the altitudinal gradient (Heaney, 2001; O'Donnell & Kumar, 2006). Opposite to this, the edaphic microarthropods show an increase in diversity with elevation, up to a threshold beyond which there is an important decrease (Sadaka & Ponge, 2003; Jing et al., 2005; Cutz-Pool et al., 2008).

Some important studies on altitudinal behavior of microarthropods were done by Sadaka & Ponge (2003) and Jing et al. (2005) in Morocco and Tibet, respectively. In these studies, the authors took into account elevation and humidity. In Mexico, Palacios-Vargas (1985) studied the springtails of the Popocatépetl Volcano, along an elevational gradient, and their preference for certain biotopes such as soil, litter and moss.

In this contribution, we studied the Collembola communities in an elevational gradient, on the northeast slope of the Iztaccíhuatl Volcano, in order to understand how those communities are distributed in a temperate ecosystem.

Materials and Methods

Iztaccíhuatl Volcano (19º10'98"N, 98º38'30"W) is located 64 km Southeast of Mexico City. Four collecting expeditions (November, 2003; and March, June and August, 2004) were performed at four different elevations: I, 2,753; II, 3,015; III, 3,250; and IV, 3,687 m. Elevation I, close to the National Park entrance, has the lowest slope and is frequently disturbed, due to the influx of many visitors and weekend campers (Table 1).

At each altitude, a square of 20x1 m was selected, where 10 points were randomly chosen, and 20 samples were taken (10 of litter, 10 of soil). The surface of each sample was 225 cm^2, and the total number of samples taken was 320. Samples were placed in plastic boxes (15x15x15 cm) until ready for processing. These samples were transported to Laboratorio de Ecología y Sistemática de Microartrópodos, at the Facultad de Ciencias, Universidad Nacional Autónoma de México (UNAM), and were processed using Berlese funnels during six days. After the fauna were extracted, the soil was analyzed for pH and organic carbon content, (Van Reeuwijk, 2002). In addition, samples of 100 g of soil were taken, in order to quantify soil moisture at each sample date. The soil analyses were performed at the Laboratorio de Edafología "Nicolás Aguilera", at UNAM.

Air temperature, CO_2 concentration, and humidity were recorded for each sample point using a thermo-hydrometer (IAQ-Calc 8760y8762).

Collembola were sorted and quantified under a dissecting microscope; slides were prepared in Hoyer's solution after clarifying them in KOH, and samples were identified with specialized keys (Palacios-Vargas, 1982; Mari Mutt & Palacios-Vargas, 1987; Jordana et al., 1997; Christiansen and Bellinger, 1998; D'Haese, 1998; Sánchez, 1999; Janssens, 2007).

Evaluation of species diversity, at each elevation, was done with Shannon index and compared with modified t test (Magurran, 1988), using the correction of Bonferroni (α = 0.004) for multiple comparisons. Dominance was estimated by Simpson's index (Zar, 1984; Magurran, 1988; Howell, 2002), and equitability by Pielou index.

The influence of elevation, date, environmental temperature, biotope (soil or litter), CO_2, slope degree, pH (real and potential), carbon, and humidity on the Collembola community was evaluated by canonical correspondence analyses (CCA), performed with the software CANOCO Ver. 4 (ter Braak & Smilauer, 1998).

Results and Discussion

Total density recorded in this study was 59,461 (average 13,346±64) individuals m^{-2}. Density at each elevation was, 2,049±4, at elevation I; 4,227±13, at II; 2,369±3, at III; and 4,701±9 individuals m^{-2} at IV.

A total of 86 species in 46 genera, belonging to 12 families of Collembola, were recorded (Table 2). The species *Ceratophysella* ca. *brevis* showed the highest density, followed by *Desoria* ca. *flora,* and *Isotoma* ca. *notabilis*. Species richness is shown in Table 2.

At elevation I, 45 species were found, 5 of which were present only at this altitude; *Mesaphorura macrochaeta* showed the highest density at this elevation (Table 2). At elevation II, 58 species were found, 8 of which were unique to this locality (all the from the Odontellidae

Table 1. General characteristics of the four sampling altitudes on the northeast slope of Iztaccíhuatl Volcano, Mexico.

Characteristic	Sampling altitude			
	2,753 m	3,015 m	3,250 m	3,687 m
Vegetation	*Quercus* forest	*Quercus* forest	*Abies-Pinus* forest	*Pinus* forest
Slope (degree)	29	36	33	35
Coordinates	19º12'40"N 98º44'02"W	19º12'30"N 98º43'41"W	19º12'16"N 98º42'54"W	19º12'06"N 98º41'25"W
Temperature (ºC range)	22–45	21–39	21–40	15–36
Humidity (mm^3)	0.8–1.4	0.9–1.6	0.7–1.6	0.7–1.6
CO_2 (ppm)	258–281	221–250	208–232	185–210
pH	4.0–4.4	4.0–4.4	3.8–4.1	3.6–4.0

family); and *Ceratophysella* ca. *brevis* had the highest density. Samples from elevation III contained 57 species, 5 of which were recorded only in this area, and *Isotoma* ca. *notabilis* was the most abundant. At elevation IV, 49 species were found, 9 of them, mainly from the Isotomidae family, are exclusive of this area; and *Desoria* ca. *flora* had the second highest abundance among all samples.

Table 2. Taxonomic list and total density (individuals m^{-2}±SE) of Collembola from four altitudes, at the northeast slope of Iztaccíhuatl, México.

Species	Altitudes			
	2,753 m	3,015 m	3,250 m	3,607 m
Hypogastruridae				
Hypogastrura ca. *hispanica*+	0	0	3±1	0
Hypogastrura ca. *sensilis* +	0	0	2±2	1±1
Ceratophysella ca. *brevis* +	3±2	2305±1000	9±6	9±8
Ceratophysella ca. *denticulata*	0	51±41	5±2	0
Ceratophysella ca. *succinea* +	0	133±86	0	0
Schoettella ca. *glasgowi*	0	0	0	67±26
Willemia ca. *bedosae*	0	2±1	16±7	15±6
Stenogastrura sp.	3±2	14±13	2±1	0
Odontellidae				
Odontella ca. *denticulata*	0	199±186	0	0
Superodontella ca. *conglobata*	0	23±16	0	0
Superodontella ca. *nana*	0	4±3	0	0
Stachiomella sp.	0	1±1	0	0
Neanuridae				
Friesea hoffmannorum	11±6	70±45	99±20	542±95
Neanura muscorum	16±6	2±1	1±1	0
Americanura ca. *prima*	0	6±2	4±2	0
Americanura ca. *izabalana*	0	4±2	14±6	1±1
Pseudachorutes ca. *romeroi*	6±3	34±14	39±12	19±12
Pseudachorutes ca. *simplex*	1±1	1±1	30±9	19±13
Micranurida pygmaea	0	3±2	0	0
Onychiuridae				
Protaphorura macrodentata	3±1	0	0	0
Protaphorura meridiata	1±1	0	0	0
Mesaphorura florae	10±4	0	24±12	2±2
Mesaphorura krausbaueri	0	1±1	0	0
Mesaphorura macrochaeta	664±141	148±24	229±46	11±10
Mesaphorura yosiii	13±7	11±5	52±33	125±62
Metaphorura affinis	189±47	1±1	0	0
Fissuraphorura sp.	0	1±1	0	0
Isotomidae				
Folsomides chichinautzini	18±17	0	0	0
Proisotoma ca. *alticola*	12±8	0	8±5	330±132
Proisotoma frisoni	0	0	5±5	0
Proisotoma minuta	0	0	0	14±8
Proisotoma ca. *sepulcralis*[1]	97±83	26±11	85±34	1±1
Proisotoma ca. *sepulcralis*[2]	0	5±3	1±1	0
Proisotoma sp. 1	0	3±2	6±5	1±1
Proisotoma sp. 2	0	0	4±4	1±1
Proisotoma sp. 3	0	4±3	1±1	0
Proisotoma sp. 4	0	0	0	4±3
Ballistura ca. *obtusicauda*	2±2	0	0	0
Folsomina onychiurina	7±6	18±9	40±19	0
Clavisotoma ca. *plicicauda*	6±5	44±22	10±8	0
Hemisotoma thermophila	1±1	0	13±8	174±81
Isotomurus ca. *palustroides*	0	0	0	21±13
Isotomorus ca. *tricolor*	1±1	1±1	4±4	167±60
Isotomiella minor	31±13	13±5	2±2	0
Isotoma ca. *subviridis*	287±60	39±15	41±16	115±46
Parisotoma ca. *notabilis*	207±52	549±92	549±99	5±3
Parisotoma ca. *tariva*	41±18	62±21	153±43	38±21
Desoria ca. *flora*	0	0	0	2203±593
Granisotoma comuna	0	0	0	1±1

Continue...

Tabela 2. Continuation...

Species	Altitudes			
	2,753 m	3,015 m	3,250 m	3,687 m
Entomobryidae				
Orchesella ca. *folsomi*	1±1	2±1	3±2	0
Americabrya arida	22±8	16±4	54±16	38±15
Entomobrya ca *triangularis*	21±6	34±7	70±19	33±9
Entomobrya sp. 1	0	3±2	3±3	0
Entomobrya sp. 2	6±4	4±1	18±7	3±1
Entomobrya sp. 3	0	7±3	153±45	0
Willowsia mexicana	13±5	22±7	4±2	1±1
Willowsia ca. *nigromaculata*	1±1	0	0	6±5
Seira purpurea	0	1±1	0	1±1
Lepidocyrtus finus	0	26±8	22±6	70±21
Pseudosinella ca. *dubia*	0	5±3	2±1	1±1
Pseudosinella ca. *hirsuta*	0	0	1±1	0
Pseudosinella ca. *orba*	0	0	8±6	0
Pseudosinella ca. *sexoculata*	0	8±4	37±11	0
Pseudosinella ca. *testa*	0	0	0	3±2
Tomoceridae				
Plutomurus ca. *californicus*	4±2	0	0	0
Sminthurididae				
Sminthurides ca. *lepus*	0	1±1	3±2	3±3
Sminthurides ca. *occultus*	11±6	32±12	20±6	220±74
Sminthurides sp. 1	6±4	16±8	82±30	253±92
Sphaeridia pumilis	109±74	18±8	47±18	59±23
Katiannidae				
Polykatiana ca. *intermedia*	0	1±1	2±1	2±1
Sminthurinus ca. *elegans*	36±14	0	0	4±4
Sminthurinus ca. *quadrimaculatus*	1±1	1±1	14±10	3±3
Sminthurinus sp. 1	0	0	0	1±1
Dicyrtomidae				
Dicyrtoma ca. *mithra*	0	1±1	0	0
Ptenothrix ca. *atra*	3±2	0	1±1	0
Ptenothix ca. *califormica*	0	3±2	2±2	5±3
Ptenothix ca. *renateae*	7±3	1±1	1±1	1±1
Ptenothix ca. *texensis*	0	0	1±1	0
Sminthuridae				
Sminthurus ca. *eisenii*	99±33	44±14	21±10	107±31
Sminthurus ca. *incisus*	2±1	9±4	0	0
Sminthurus ca. *fitchi*	0	0	0	1±1
Sminthurus ca. *sagittus*	2±1	0	0	2±1
Neelidae				
Neelus murinus	1±1	17±5	2±1	0
Neelides minutus	2±2	27±15	9±3	0
Megalothorax incertus	1±1	16±10	14±10	0
Megalothorax minimus	75±14	144±28	327±60	1±1
Total	2049±4	4227±13	2369±3	4701±9
Species richnes (S)	45	58	57	49
Shannon diversity index (H’)	2.43	1.99	2.88	2.11
Pielou's index (J’)	0.638742	0.4885866	0.7132977	0.544717
Simpson's dominancy index (λ)	0.153465	0.321053	0.0985814	0.247268

Highest diversity and equitability were found at the elevation III, followed by I, IV and II (Table 2). The t analyses showed significant differences between elevation II and III ($t_{80} = 4.11$; $p<0.005$) and elevation III with IV ($t_{80} = 3.88$; $p>0.005$). The diversity and dominance had a similar pattern throughout the year, and no differences were found at elevations I, III and IV. Dominant species encountered were: *Ceratophysella* ca. *brevis* and *Desoria* ca. *flora*, at the elevations II and IV, respectively. Higher diversity at III is probably due to the lower slope, the absence of more abundant species, and relatively constant humidity throughout the year. The months of March and June were less diverse, mainly at II, probably because of the relative abundance of the dominant species, *C.* ca. *brevis*. Elevation II had the lowest diversity and the highest dominance, particularly in June (Figure 1). This elevation also had the lowest equitability, probably due to the great abundance of *C.* ca. *brevis*.

CCA analyses showed that the canonic axes 1 and 2 explained 59.4% of the variance. CO_2 best explained axis 1 ($r = 0.70$), together with elevation ($r = 0.69$), while slope was better related with axis 2 (r = -0.77) (Figure 2). The Monte-Carlo test showed significant differences: *Americanura* ca. *prima*, *Clavisotoma* ca. *plicicauda*, *Seira purpurea*, *Sminthurus* ca. *incisus*, *Neelus murinus* and *Megalothorax incertus* were better correlated with axis 1; and *Pseudachorutes* ca. *romeroi*, *Proisotoma* sp. 1, *Proisotoma* sp. 4, *Orchesella* ca. *folsomi*, *Pseudosinella* ca. *testa*, *Sminthurus* ca. *eisenii* and *Megalothorax minimus* with axis 2.

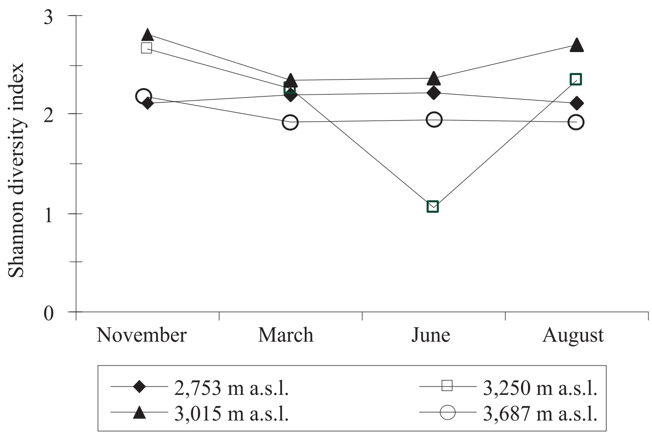

Figure 1. Annual variation of the diversity of Collembola from Iztaccíhuatl Volcano, Mexico, at four elevations.

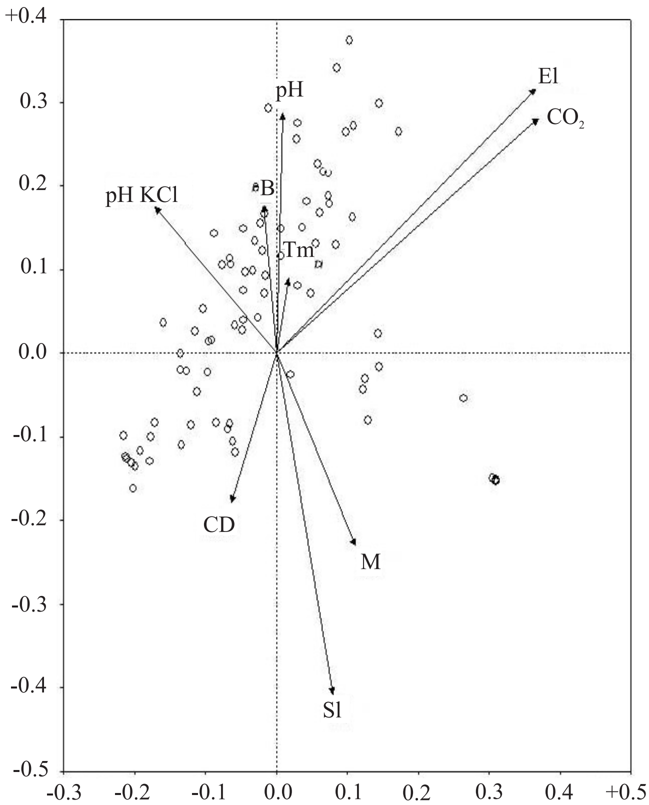

Figure 2. Canonical correspondence analysis of Collembola species collected along an altitudinal gradient, at Iztaccíhuatl Volcano, México. Sl, slope; M, humidity; CD, collection date; Tm, temperature; B, biotope (soil or litter); El, altitude.

The results showed new distributional records for five species (*Proisotoma frisoni, Proisotoma minuta, Folsomides chichinautzini, Folsomina onychiurina,* and *Lepidocyrtus finus*). Odontellidae, Onychiuridae, Sminthuridae and Neelidae were recorded for the first time in the area. Genera and species diversity were higher in our work than the one reported by Cutz-Pool et al. (2008), and number of species was also higher than in the neighboring Popocatépetl Volcano (Palacios-Vargas, 1985). These families are euedaphic and represent important new discoveries for the Collembola communities in the area.

Different and exclusive species were found at each elevation: five at I, nine at II, five at III, and eight at IV. *Desoria* ca. *flora* seems to be a good indicator of altitude, as is was abundantly found throughout the year at the highest elevation.

Bondarenko-Borisova & Gandul (2001) pointed out that Odontellidae is found in spruce forests, with little perturbation. This appeared to be the case in our study as well; this family was not found at elevation I, probably because it was the most disturbed.

Compared with the earlier study of Cutz-Pool et al. (2008), we observed higher species diversity in the same area of the Iztaccíhuatl Volcano. In fact, about half of the species encountered were new to science and must be still described.

The abundance and diversity of Collembola assemblage is due to the interaction of different variables, which vary along temporal and altitudinal gradients. In our study, altitude and humidity played an important role in the establishment of different assemblages; the highest density of Collembola was recorded at the highest elevation (IV). Furthermore, slope and CO_2 were also important factors. The importance of CO_2 for species assemblages of springtails is a factor, which had not been mentioned in previous studies.

Conclusions

1. CO_2 and altitude are factors of extreme importance for the establishment of the Collembola species.

2. The degree of slope is linked to humidity, where the species assemblage varied considerably in spite of CO_2, but not the altitude.

3. *Desoria* ca. *flora* only at 3,687 m elevation indicates that this species is specially adapted to the unique characteristics of this site (low air humidity and temperature).

4. Some Collembola species are able to adapt to the continuous disturbance of their habitat at 2,753 m elevation.

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