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ORIBATID MITE COLONIZATION OF SAND AND MANGANESE TAILING SITES

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ABSTRACT — We studied the colonization patterns of oribatid mites on post-industrial sand and manganese tailing sites, reclaimed areas, natural meadows and forests in the Chiatura region. A total of 89 species were recorded. In forests, the total number of species was high and the oribatid community was made up mainly of forest-specific species. *Scheloribates laevigatus* (Koch, 1835) predominated in dumps and reclaimed sites, whereas its abundance was lower in meadows and minor in forests. *Tectocepheus velatus sarekensis* Trägårdh, 1910 and *Scheloribates latipes* (Koch, 1844) were numerous in dumps and meadows, but their abundance was low in forests. *Punctoribates punctum* (Koch, 1839), however, was found in high densities only at dump sites. Detrended correspondence analyses and hierarchical cluster analyses show that oribatid mites of dump habitats grouped together with those of reclaimed and meadow sites, indicating high faunal similarity and low richness, whereas the forest inhabiting oribatid community was much more diverse. The results of our studies indicate that colonization of dumps is mainly by species of wide ecological preferences.

KEYWORDS — Chiatura; opencast mining; pioneer species; succession; colonization; dump

INTRODUCTION

The mining of manganese in the Chiatura region (Western Georgia) began in the second half of the XIXth century, with work carried out under ground. These activities caused damage to the soil surface but did not result in soil destruction, and such areas could still be used for agriculture. Since 1960, manganese has been extracted using opencast mining, which disrupted land use for agriculture. Opencast mining is ecologically unacceptable due to the increase in damaged soil area that cannot be used for agriculture without the appropriate reclamation (Andrés and Mateos, 2006). In addition, the abandoned quarries fill with water forming ponds where parasitic blood-sucking insects breed with consequent hazards to human health. From 1960-80, land reclamation was carried out in the Chiatura region, with Reclaimed land amounting to 556 ha (77 % of the previously damaged area) and complete recovery achieved on 478 ha (Sheklashvili *et al.*, 1997). This latter area was re-used for agricultural purposes.

Oribatid mites, in the acarine suborder Oribatida, are associated with organic matter in most terrestrial ecosystems. They are found throughout the soil profile, in surface litter, on grasses, herbs and low-growing shrubs, barks, twigs and leaves of trees and in aquatic, semi-aquatic and coastal habi-

TABLE 1: Sampling site description with GPS data and the number of species of oribatid mites found per site

Site ID	Site description	Coordinates (Latitude - longitude)	Species Number
D1	1 year old dump on sand quarry. Village Darkveti. No vegetation is developed	42.32662° - 43.32298°	14
D2	3 year old dump on manganese quarry. Village Mgvimevi. *Tussilago farfara* L. and *Cirsium* sp.	42.31728° - 43.29816°	14
D3	5 years old on manganese quarry. Village Mgvimevi. Scarce vegetation with predomination of *Cirsium* sp.	42.31712° - 43.29926°	11
D4	18 year old dump on manganese quarry. Village Darkveti. Low grasses	42.33966° - 43.33482°	10
D5	20 year old dump on sand quarry. Village Darkveti. Low grasses.	42.32506° - 43.32103°	18
D6	30 year old dump on sand quarry. Village Darkveti. Meadow grasses	42.32441° - 43.31977°	26
DR	Reclaimed dump on manganese quarry. Village Darkveti. Meadow grasses	42.33966° - 43.33479°	21
CM1	Cotrol. Meadow. Village Darkveti.	42.32624° - 43.32168°	17
CM2	Control. Meadow. Village Mgvimevi.	42.31641° - 43.29577°	14
CF1	Control. Oak Forest. *Quercus imeretina* Stev., *Carpinus caucasica* Grossh., *Rhododendron flavum* Don, *Crataegus* sp., *Smilax excelsa* L., *Mespilus germanica* L. Village Darkveti.	42.32747° - 43.32262°	17
CF2	Control. Oak Forest. *Q. imeretina, Rh. flavum, S. excelsa, M. germanica, Pteridium tauricum* (Presl.), *Erythronium caucasicum* G., *Viola* sp., *Primula* sp. Village Darkveti	42.32415° - 43.31926°	65
CF3	Control. Mixed Forest. *Castanea sativa* Mill., *C. caucasica*, individual *Fagus orientalis* Lipsky, *Q. imeretina, Rh. flavum, S. excelsa,Ilex colchica* Pojark., *E. caucasicum, Phyllitis sedopendrium* (L.) Newm., *Viburnum opulus* L., *Dryopteris filix mas* (L.) Schott. Village Mgvimevi	42.31597° - 43.29528°	25

tats (Behan-Pelletier and Eamer, 2007; Maraun *et al.*, 2007; Norton and Behan-Pelletier, 2009; Schneider *et al.*, 2004). Oribatida are numerically one of the most dominant arthropod groups in organic horizons of most soils, where their densities can reach several hundred thousand individuals per square meter (Norton and Behan-Pelletier, 2009). Their diversity is high, they occur in high numbers, they are easily sampled, they can be sampled in all seasons, adult identification is relatively easy and they represent a trophically heterogenous group. Their dispersal ability is low and only the adults disperse (Norton, 1994). As a result, oribatid mites cannot easily escape from stressful conditions, thus populations of oribatid mites decline rapidly when their habitat is damaged. Oribatid mites can be considered as "early warning" indicators of stressful soil conditions. Analyses of the structure of their communities help to reveal the degree of soil stability and trend of humus formation (Dunger *et al.*, 2001). They are considered useful indicators of specific soil parameters and quality (Bielska, 1996; Hutson, 1980; van Straalen, 1998).

Several authors have studied oribatid mite faunal responses to post-mining restoration treatments. Investigations were performed in coal mine dumps (Babenko, 1982; Hutson, 1980; Luxton, 1982; Skubala, 1997a, 1997b), ash dumps (Bielska and Paszewska, 1995), limestone (Andrés and Mateos, 2006), gravel (Eitminavichute and Umbrasiene, 1990; Matuseviciute, 2007) and minerals, zinc, iron, nickel, copper and galena-calamine dumps (Skubala, 1995, 1999; Skubala and Gulvik,

2005; St. John *et al.*, 2002). In Chiatura manganese tailing sites, the soil invertebrate assemblage was studied shortly after the first reclamation processes (Eliava *et al.*, 1976) and showed an increase in soil fauna on reclaimed sites. No further studies were performed on Chiatura quarries until the present study.

The re-colonization of oribatid mites was investigated on 1 to 5 and 15 to 30 year old post-industrial dumps, reclaimed territories, meadows and natural forests in the vicinity of Chiatura city. We investigated the patterns of colonization of disturbed sites by oribatid mites in the succession process of soil recovery to establish the pool of species capable of performing the role of colonizers. In particular, we asked (1) what are the differences in faunal composition or abundance between sites of differing history, and (2) how age differences of disturbed habitats affected Oribatida community composition.

Materials and methods

Site description

Sand and manganese quarries are situated 4 km north-east of Chiatura city. This area is quite populated and the natural meadows are intensively grazed by cattle. Six post-industrial dumps (D1-D6), one reclaimed and five control sites (two meadows and three forest sites, respectively) were sampled (table 1).

Sampling and treatment technique

The field work was carried out in January, March, June and October 2011 on sand and manganese tailing sites in the Chiatura region. Site CF1 was not accessible during winter, so samples were only taken during the other three seasons. At each 100 m^2 site, ten soil samples were taken randomly using a soil core borer of 10 cm diameter by 10 cm depth. Four replicates were obtained covering all four seasons of the year (one replicate per season). Oribatid mites were extracted over a one week period using a modified Berlese apparatus. Oribatids were collected every 24 hours during this period and stored in a solution containing 70 % alcohol, distilled water, glycerin and glacial acetic acid. Only adult individuals were identified to species level. Adult specimens were embedded in drops of lactic acid on temporary cavity slides. Identifications were made using the keys of Weigmann (2006) and Ghilarov and Krivolutsky (1975). The identified material is now stored in the personal collection of M. Murvanidze. A total list of species (see Appendix) for the studied area was made in accordance with Schatz *et al.* (2011).

Data analysis

To reveal the presence of differences in species richness (number of species) and densities (if any), we compared 1 to 5 and 15 to 30 year old dumps to the natural meadow and forest sites using One-way Analysis of Variance (ANOVA; Sokal and Rohlf, 1996). Species richness for each site was calculated as the sum of all species collected in all seasons. Abundance for each site was calculated as an average number of individuals sampled in all seasons. ANOVA was also used to compare the overall Diversity Index (Simpson, 1949) between dumps, natural meadows and forest sites. Simpson's Diversity Index (D) gives the probability that two individuals drawn randomly from the same site belong to the same species (Simpson, 1949).

To analyze patterns of community composition in the studied habitats we used cluster and Detrended Correspondence Analysis (DCA) (Hill and Gauch, 1980). DCA was used to visualize the latent environmental predictors along with sampled sites and species showing maximal correspondences. DCA was performed for a row dataset (include the seasonal data for each year) and seasonal samples averaged over the year.

To determine the similarity pattern in faunal composition, we used clustering techniques (based on the Sorensen Similarity Measure) for the whole data set and the data set containing only the abundance data of co-dominant species, which better characterizes the community. Calculating a number of co-dominants was based on slightly modified method of Kikvidze and Ohsawa (2002). This method is based on Simpson's Concentration and is calculated as follows: $A=1/D$, where A is the number of co-dominants and D is the Simpson's Diversity Index.

The method is very intuitive and an easy way to reveal co-dominant species in the community. However, the method frequently provides an unrealistically large number of co-dominant species, which regularly envelops 70-90 % of total abundance without consideration of abundance distribution within communities.

For example, a community composed of 10 species with an abundance distribution of 10,1,1,1,1,1,1,1,1,1 would result in three co-dominant species (*A=1/D=3*). Clearly, this calculation renders ambiguous results, which are difficult to interpret. To avoid this problem, we modified the algorithm and calculated the number of co-dominants (*A*) several times for each community in a way that each following calculation (A_{i+1}) is performed only for "co-dominant" species revealed by the previous calculation (*Ai*). This process is repeated until the rounded (to the nearest integer) number $A_{i+1}= A_i$ is obtained. In the example mentioned above, with A_i=3, the following calculation is made for just three species (A_{i+1}) that equals to one.

Software PAST v.2.14 (Hammer *et al.* 2001) were

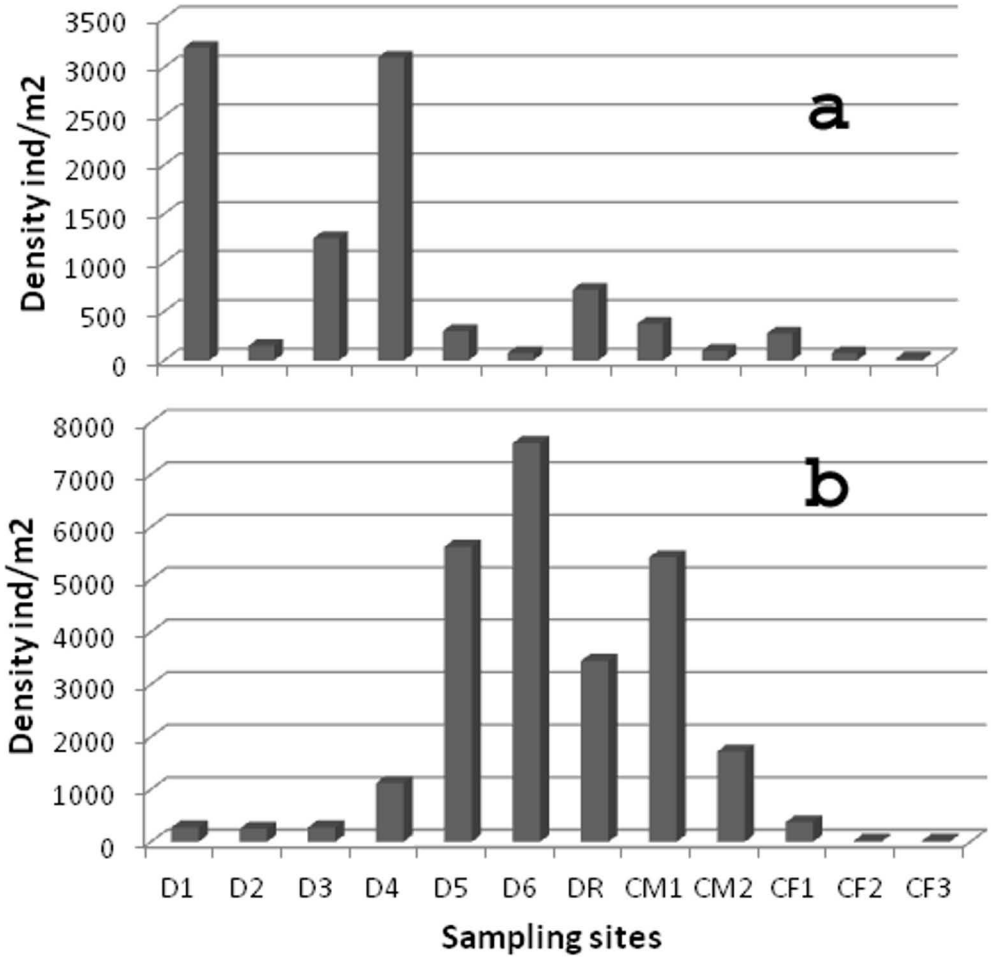


FIGURE 1: Average abundance of (a) *Punctoribates punctum* and (b) *Scheloribates laevigatus* at the sampling sites (see table 1 for description of the sampling sites).

TABLE 2: Co-dominant species for each sampling locality with their relative abundance (%) and average abundance of total fauna (ind/m^2)

Species	D1	D2	D3	D4	D5	D6	DR	CM1	CM2	CF1	CF2	CF2
Phthiracarus ferrugineus	0	0	0	0	0	0	0	0	0	0	0	13
Oppiella subpectinata	0	0	0	0	0	0	0	0	0	15	20	0
Ramusella clavipectinata	0	0	0	0	0	0	0	0	11	0	0	0
Parachipteria punctata	0	0	0	0	0	0	0	0	0	0	7	0
Oribatula tibialis	0	0	0	0	0	0	0	0	0	0	0	23
Scheloribates laevigatus	0	19	0	22	86	57	59	49	30	13	0	0
Sch. latipes	0	0	0	0	0	0	0	0	19	0	0	0
Chamobates voigtsi	0	21	0	0	0	0	0	0	0	9	0	0
Punctoribates punctum	70	11	52	61	0	0	0	0	0	10	0	0
Pergalumna nervosa	0	19	0	0	0	0	0	0	26	0	0	21
Total dominance	**70**	**70**	**52**	**83**	**86**	**57**	**59**	**49**	**86**	**47**	**27**	**57**
Abundance ind/m^2	4825	1375	2400	5125	6550	13325	5825	11100	5725	3900	20675	4000
Number of species	**14**	**14**	**11**	**10**	**18**	**26**	**21**	**17**	**14**	**17**	**65**	**25**

used in cluster building. DCA ordination was performed using CANOCO software (ter Braak and Šmilauer, 2002). ANOVA and dominance analysis were performed as a spreadsheet of MS Excel.

RESULTS

A total of 89 species of oribatid mites were identified in the study areas (see Appendix). Eight species were classified as dominant for all types of habitat, whereas 35 species (40 % of the total fauna) were found only in forests. The oribatid fauna of dumps totaling 5 species was numerically poorer than that of the control sites (a total of 41 species). *Pergalumna nervosa* (Berlese, 1914), *Scheloribates laevigatus* (Koch, 1835) and *Scheloribates latipes* (Koch, 1844) were abundant in meadows and successfully colonized adjacent dumps. *Scheloribates laevigatus* and *Punctoribates punctum* were the most successful colonizers of dump areas with high densities in dumps and lower densities in forest soils (Figure 1).

The abundance of oribatid mites varied from an average of 5600/m^2 in dumps up to 9500/m^2 in natural forests. Densities in dump areas were low with the exception of D6 - a 30 year old dump where meadow vegetation had already developed. Densities of Oribatida in meadows were similar to that in forested habitats. The highest density was recorded for CF2 - a natural oak forest (Table 2).

ANOVA followed by Tukey's Multiple Test showed significant differences only between forested and dump sites in species richness (F=10, df=2, 46, p<0.01) and in Simpson's Diversity Index (F=4.4,df=2,9, p=0.047). No significant differences in species richness or abundance were detected between the forest and meadow or between the dump and meadow sites.

Cluster analyses based on the whole dataset showed oribatid mites of all forest sites forming one cluster whereas no clear groupings occurred within other sites (Figure 2). DCA analysis revealed similar results for both datasets (seasonal and pooled data over the year) (Figures 3 and 4). For seasonal data, the first DCA axis (inertia 0.77) separates forests from other sites, whereas meadow and dump sites are not clearly separated (Figure 3). DCA on the pooled data gave more reliable results (Figure 4). Along the first ordination axis (inertia 0.66), forested sites are clearly separated from others with higher scores. Meadows and old (more than 5 years) dump sites (with lower scores at first DCA axis) are also separated from the younger dump sites, which are situated between the first two groups. Clustering of co-dominant species pool (Table 2) provides very similar results to the DCA (Figure 5) and clearly shows that older dumps are clustering with meadow sites and younger dump sites are closely related to that cluster. Forest sites are also clustering together and appear as a basic or source site for other sites.

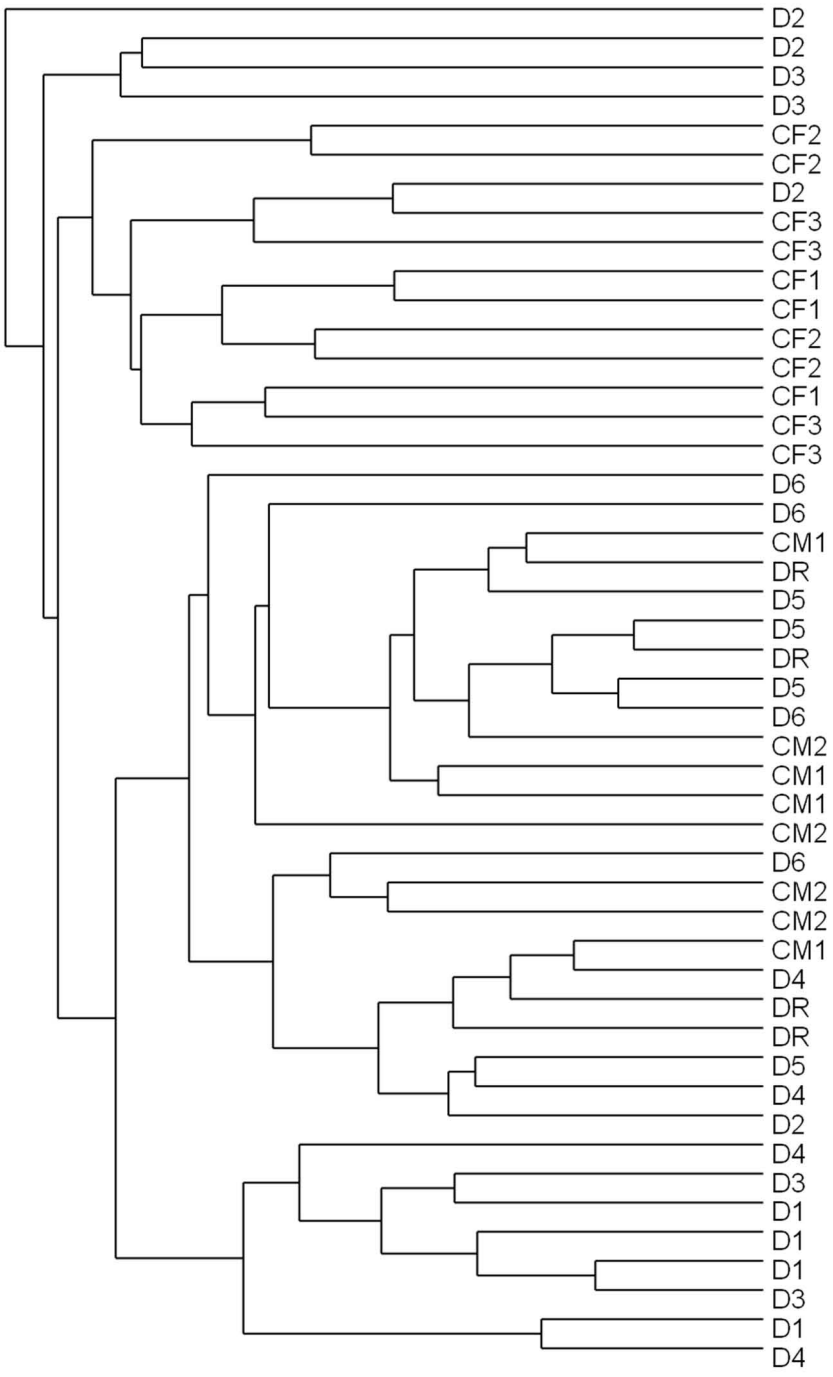


FIGURE 2: Cluster dendrogram depicting oribatid faunal similarities (based on Sorensen's distance) between sites for seasonal data (see table 1 for description of the sampling sites).

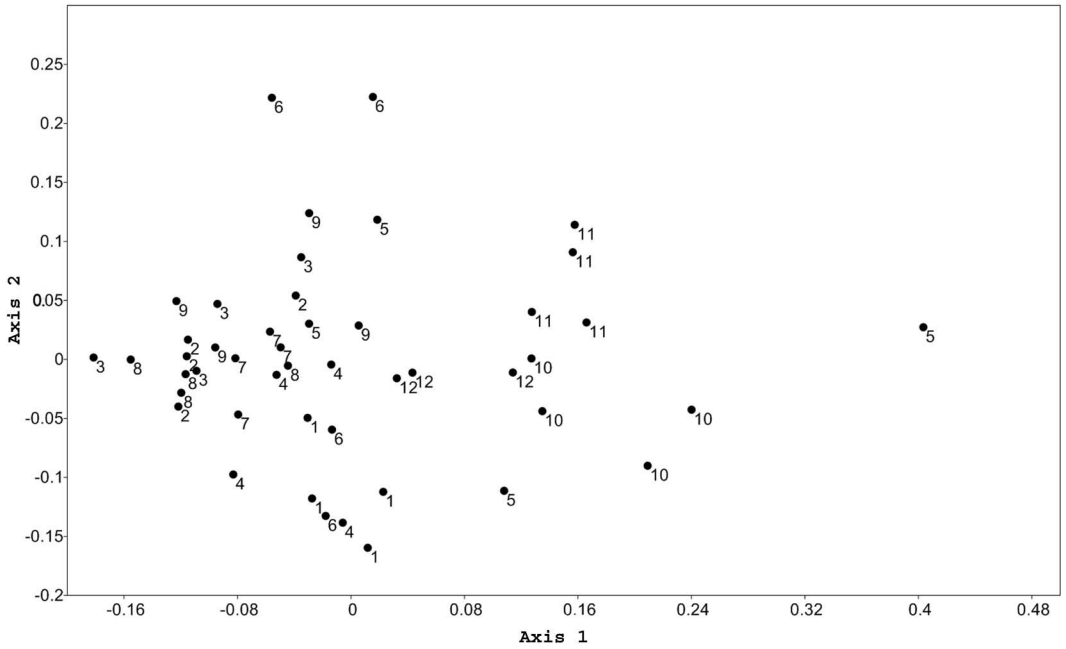


FIGURE 3: Detrended correspondence analysis (DCA) ordination diagram for seasonally sampled data. Ordination scores for first DCA axis plotted against scores for second DCA axis. The numbers indicate sampling localities as follows: 1-D1, 2-D2, 3-D3, 4-D4, 5-D5, 6-D6, 7-DR, 8-CM1, 9-CM2, 10-CF1, 11-CF2, 12-CF3 (see table 1 for description of the sampling sites).

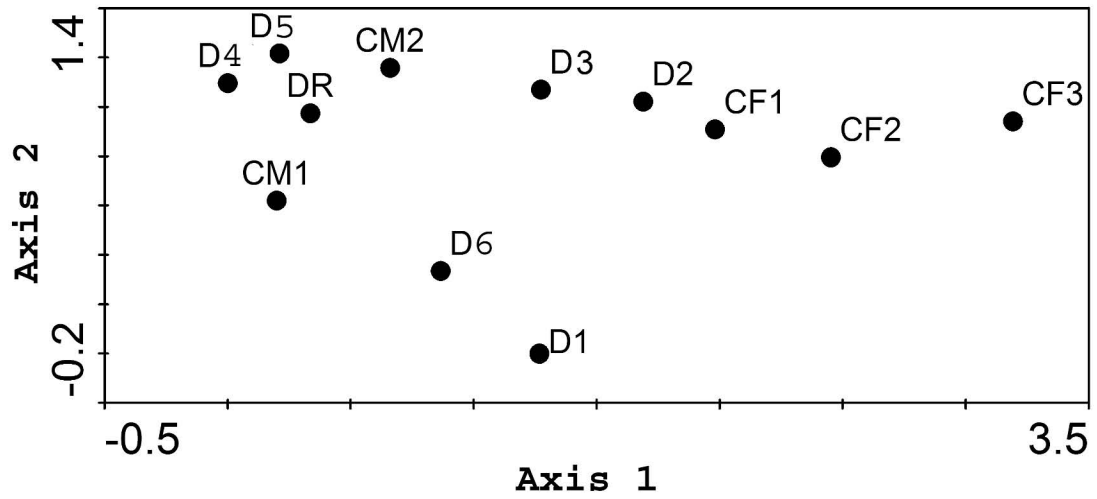


FIGURE 4: Detrended correspondence analysis (DCA) ordination diagram for abundance data averaged over the year. Ordination scores for first DCA axis plotted against scores for second DCA axis. (See table 1 for description of the sampling sites).

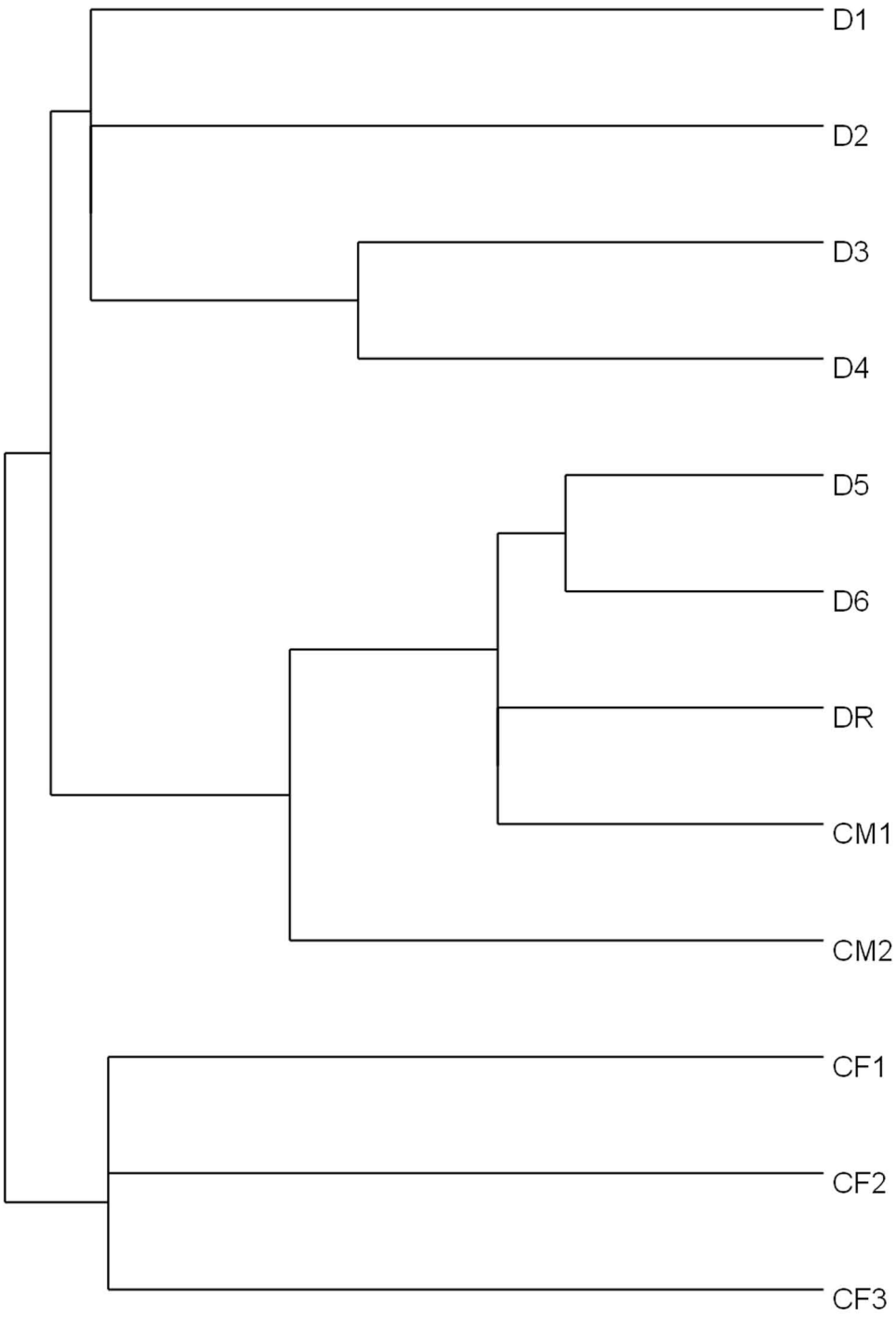


FIGURE 5: Cluster dendrogram depicting oribatid faunal similarities (based on Sorensen's distance) between sites for abundance data of co-dominant species in each sampling locality (see table 1 for description of the sampling sites).

DISCUSSION

Colonization of post-industrial dumps by soil invertebrates supports soil formation processes and can be regarded as a part of secondary succession (Andrés and Mateos, 2006; Scheu and Schulz, 1996). Although oribatid mites are known as having low mobility (Weigmann, 1982) and being slow colonizers (Dunger, 1989), their ability of passive dispersal is quite high (Karasawa *et al.*, 2005; Lebedeva, 2012; Lehmitz *et al.*, 2011, 2012). However, not all species of Oribatida are successful colonizers.

In our study, the faunal composition differed significantly between post-industrial and natural habitats. In dump soils, *Scheloribates laevigatus*, *S. latipes* and *Punctoribates puctum* dominated, whereas in natural forests, members of Oppiidae, *Galumnidae* and *Achipteriidae* were present in abundance. Nonetheless, our previous analyses showed that soil recovery processes take place on post-industrial dumps: the older the dump, the more diverse is the oribatid assemblage. The colonization route of oribatid mites proceeds from forests to dumps, via meadows, in spite of the fact that only a minor number of species are found in both forests and dump sites. DCA analyses provided for all sampling seasons and for the dominant species pool indicated that the oribatid fauna of newly created dump sites may be supplied by species from both meadow or older dumps and forested sites. The main colonizers of the new habitats were *P. punctum*, *S. laevigatus*, *S. latipes* and *Tectocepheus velatus sarekensis*. These species, especially *P. punctum* and *T. velatus sarekensis* (the latter species is not truly dominant but present in all dump sites as a moderately abundant species) can survive in extreme conditions (Malmström, 2008; Murvanidze *et al.*, 2008, 2011; Skubala, 1999) and reach high densities where species that are more sensitive to environmental disturbances are absent. In contrast, in forest soils *T. velatus sarekensis* and *P. punctum* were found in low abundance. Similar results were found on a dolomite dump in Poland where *T. velatus* and *S. laevigatus* dominated in a three year old dump and their abundance dropped in forested habitats (Skubala, 1999). *P. punctum*, *T. velatus* and *S. laevigatus* are considered cosmopolitan species and good colonizers during early stages of succession (Skubala, 1995; Skubala and Gulvik, 2005). They are often found in high densities in urban, rural and disturbed habitats (Maraun and Scheu, 2000; Maraun *et al.*, 2003; Murvanidze *et al.*, 2011; Scheu and Schulz, 1996; St. John *et al.*, 2002; Weigmann, 1995). We conclude that in forest ecosystems early succession species are outcompeted and that they find more favourable conditions in disturbed areas, where environmentally sensitive species cannot persist. The existence of several typical "forest" species in dumps, such as *Phthiracarus laevigatus* (Koch, 1841), *Microzetes caucasicus* (Krivolutsky, 1967), *Ceratoppia quadridentata* (Haller, 1882), *Parachipteria punctata* (Nicolet, 1855), *P. fanzagoi* Jacot, 1929 and *Pergalumna nervosa* (Berlese, 1914), suggests that the presence of manganese in soil has less (if any) influence on structuring the oribatid fauna. The main driving forces of shaping the community are either habitat disturbance and/or food supply. Under the latter conditions, species such as *P. punctum* and *S. laevigatus* seem to be more successful colonizers. They rapidly increase in abundance in the less competitive environment and maintain dominant positions until their habitats have recovered. The dominance of colonizers such as *P. punctum* and *S. laevigatus* in meadow habitats supports the disturbance hypothesis on the basis that all studied meadow sites are extensively grazed and hence disturbance occurs regularly.

The oribatid fauna of distantly located forests showed more similarities with each other than with neighboring meadows or dumps. Typical forest species were found in minor quantities even in meadow soils. Faunal dispersal from forested habitats was insignificant and meadow sites, along with the old aged dumps, can be regarded as a temporal source of new species for the younger dumps, whereas adjacent forests preserve permanent species pool as a refuge and represent colonization source with its visible effect only in large time scale. Returning to our questions raised at the end of the introduction, we conclude that (1) sites of differing history differ from each other by faunal composition and species dominance – different species predominate in different sites depending on

soil recovery processes and (2) that the age difference between the post-industrial dumps results in diverse and meadow-like oribatid fauna in older dumps, whereas the fauna of young dumps remains quite poor.

Reclamation measures carried out on the damaged territory create habitats similar to the natural meadows. However, natural succession processes can support even more diverse fauna than artificial reclamation (Skubala, 2006) and self-sustaining rehabilitation via natural processes is regarded as a good ecological restoration (Dunger *et al.*, 2001). Secondary succession is usually slow and incompatible with the societal requirements for rapid solutions (Ash *et al.*, 1994; Bradshaw, 1997) whereas artificial reclamation procedures fulfill societal needs for fast recovery of damaged surfaces and its reuse by the local population.

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APPENDIX

Numbers of oribatid mites found in sand and manganese tailing sites in Chiatura region (see table 1 for site description).

Species	D1	D2	D3	D4	D5	D6	DR	CM1	CM2	CF1	CF2	CF3
Hypochthoniella minutissima											11	
Epilohmannia cylindrica									1	4	3	
Rhysotritia ardua	5	2		2	2	14	1	14		4	23	2
Hoplophthiracarus illinoisensis										2	43	
Notophthiracarus (C) pavidus vicinus			1							2	1	3
Phthiracarus ferrugineus			5	1					2	8	14	21
Phth. laevigatus			1						1	1		1
Steganacarus spinosus										9		
St. (T) carinatus	1					1	1			2	6	3
Nanhermannia nana											1	
Nothrus biciliatus												
Trhypochthonius tectorum								5			1	
Hermanniella punctulata											4	
Arthrodamaeus femoratus											4	
Metabelba flagelliseta								1			1	
M. papillipes											1	
Microzetes caucasicus		1				1					12	
Amerus troisi											2	
Amerobelba decedens											3	
Ctenobelba pilosella											4	
Damaeolus ornatissimus											5	
Eremobelba geographica											3	
Eremaeus hepaticus										1	1	1
Zetorchestes falzonii											2	
Gustavia microcephala											3	
Ceratoppia bipilis	1										6	
C. quadridentata			4	2							2	
Adoristes ovatus												2
Dorycranosus splendens											2	
Liacarus brevilamellatus											3	
L. lencoranicus						1					11	2
L. xylariae										2		
Xenillus tegeocranus											2	
Carabodes rugosior											2	
Conchogneta traegardhi											24	9
Berniniella bicarinata											4	
B. silvatica											28	
Dissorhina ornata	6	1			1	1		1			47	2
Microppia minus					1	1					4	
Oppia nitens												1
Oppiella fallax	1									3	36	2
O. neerlandica											1	
O. nova		1									5	
O. similifallax	1		1			3				1	29	
O. subpectinata	2						2			17	164	10

Species	D1	D2	D3	D4	D5	D6	DR	CM1	CM2	CF1	CF2	CF3
Oxyoppioides decipiens											5	
Quadroppia quadricarinata											10	
Ramusella clavipectinata	5				2	8	2	31	25		26	5
R. insculpta		1		1		1		1	2		34	1
Suctobelba granulata	1										2	
Suctobelbella acutidens											1	
S. duplex											2	
S. forsslundi						1					2	
S. subtrigona		1										
Tectocepheus velatus velatus					1			3			1	
T. velatus sarekensis	8	2	8	10	6	27	31	19	3		1	3
Scutovertex sculptus					1		1					
Eupelops acromios											1	
E. torulosus							1				1	
Peloptulus phaenotus	1		1		1	4	1	8	9			
Parachipteria georgica											30	3
P. punctata			1				5	3		5	56	
P. fanzagoi		2			1	3	2	1			27	
Oribatella berlesei										1		
Haplozetes longisacculus	5											
Peloribates longipilosus				5	1	7		22			2	
Protoribates capucinus								10				
Oribatula tibialis	1	3				1			2	1	12	36
Zygoribatula cognata				4		1	3	25			1	
Z. exilis		1			1				2			2
Liebstadia pannonica				1			1					
Scheloribates laevigatus	11	10	11	45	225	304	138	217	69	15	1	1
Sch. latipes	1		1	9	1	78	6	48	43	7	29	
Ceratozetes gracilis	1					43	2	1		7	35	1
C. minutissimus		1	10			2						
Sphaerozetes piriformis												4
Chamobates cuspidatus		1							2			
Ch. kieviensis							1					
Ch. voigtsi		11					1	1		10	7	34
Euzetes globulus											1	
Minunthozetes pseudofusiger	1						1		4	3	5	9
Punctoribates punctum	128	6	50	124	12	3	29	15	4	11	3	1
Acrogalumna longipluma						1					12	
Galumna flagellata			1					1				1
Galumna tarsipennata						3		6				
Pergalumna nervosa	1	9	1	1	5	7	4	1	60		1	