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Oribatid mites (*Acari, Oribatida*) - bioindicators of forest soils pollution with heavy metals and fluorine

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Abstract. The present study analyzes the effects of pollution with heavy metals and fluorine on the oribatid mite communities populating the forest soils, on the basis of the researches carried on in three oak-type forests, situated at different distances from the Phosphoric Fertilizers Plant of Valea Călugărească (the Prahova county, Romania). In the forest strongly affected by pollution, the heavy metals concentrations were 2-9 times higher than the maximum allowable limits (MAL). In the perimeter with medium level of pollution, the content of Pb, Cr and Ni were over the MAL, while Co and Cd concentrations are closed to these limits. Two years after closing of this industrial unit, a decrease of soil loading with heavy metals was to be found, mostly in the surface sub-horizon. In the control perimeter, the oribatids constitute a complex community with a large specific diversity. The characteristic species for this zone (South-Eastern of Romania) are frequent and/or abundant, having a high ecological significance. In the affected forests, the oribatid mites' densities are 6-476 times lower than in the control perimeter. Their communities are constituted of a small number of tolerant species (euryplastic, unspecific fauna), being characterized by a low specific diversity and a marked structural instability. The analysis of the oribatid species distribution in the control and polluted ecosystems has evidenced that certain elements can be considered bioindicators for this type of pollution. Our researches carried out two years after the production stopping, have not evidenced a favourable evolution of the oribatid mites communities. It is probably that the recovery of the decomposers' trophic chains requires a longer time.

Keywords: forest soils, pollution, heavy metals, oribatid mites, bioindicators

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Introduction

The industrial pollution represents a complex phenomenon, with a more obvious impact on certain components of ecosystem, which affects the ecosystem on the whole. The soil pollution is produced in two main ways: direct dust deposition and, in addition, the pollutants which fall down together with the vegetal necromass; moreover, must be considered the cumulative processes of many pollutants during the time. In the case of forest soils - if considering the complexity of the forest as ecosystem - the assessment of the deterioration degree, and of the probable evolution of the phenomenon, also, is more difficult.

The previous researches carried out in some zones affected by industrial pollution (e. g.

Săvineşti, Copşa Mică, Baia Mare, Năvodari, Slatina, Taşca-Bicaz) have shown that the edaphic mesofauna reacts to the changes induced in soil by pollution; the diminution of the total effectives and some changes in the numerical ratios between the systematic and trophic groups were to be found (Călugăr et al. 1983, Vasiliu & Mihăilescu 1989, Vasiliu et al. 1995, Vasiliu & Ivan 1995 a,b). Within this functional complex, some groups show a special reactivity, having, therefore, a bioindicator value. The oribatids - detritophagous mites, actively involved in the bioconversion of the vegetal necromass into soil - count among these groups (Andre et al. 1984, Wallwork 1970).

Most of the previous researches were carried out in lawns and cultivated soils, affected by pollution; the forest soils were comparatively less investigated. This study comprises the results obtained during two years of researches carried on in some forest ecosystems from Valea Călugărească area.

Materials and methods

The field researches have been carried out in three oak forests, situated at different distances from the Phosphoric Fertilizers Plant of Valea Călugărească (the Prahova county): Păuleşti (control stand), Darvari and Valea Călugărească (polluted habitats).

Three series of samples were collected in 1997, and other series in 1999, two years after the facility was closed. The samples of 100 cm^2 each, have been taken over in every forest stand, from the organic horizon of the soil, at two different levels: superficial, litter and fermentation layer (olf), and a deep, humiferous layer (ah). The extraction of fauna from the soil samples was made by the selective Tullgren-Berlese`s method. Parallel series of samples were analyzed with the aim to determine the heavy metals content, at the Pedology and Agrochemistry Institute of Bucharest.

The analysis of the oribatid communities structure was based on the analytical ecological indices (average abundance of each species - $\overline{a}$, frequency - *C*, relative density - *D.r.*) and synthetic indices (the index of ecological significance-*W* (Dziuba), specific diversity (Shannon -Wiener - *H(s)max, H(s), H.r.)*. The global characterization of the oribatid coenoses used, also, the following parameters:

- global average abundance ($\overline{A}$), expressed as individuals/m^2;
- standard deviation and Pearson coefficient of variation (%);
- number of species (*S*), and the average number of species/sample (*S'*), expressing the richness in species and their distribution;
- the percent of individuals identified - out of their whole number - in the litter and fermentation sub-horizon (olf), which reflects the vertical distribution of the effectives;
- the adults/preadults ratio (expressed as an absolute value) providing information on the demographic structure of the communities under study;
- the representation (*R*%) (Müller et al. 1978) - the percent of individuals belonging to a certain species, recorded in each site, related to the total number of individuals identified in a series of ecosystems.

Results

In the forest plantation strongly affected by pollution at Valea Călugărească, the heavy metals concentrations were 2-9 times higher than the maximum allowable limits (MAL). In the perimeter with medium degree of pollution (Darvari forest, at 4-5 km distance from the emission source), the content of Pb, Cr and Ni were over the MAL, while Co and Cd concentrations are closed to these limits (Kloke 1980, Lăcătuşu 1995). Two years after closing of this industrial unit, a decrease of soil loading with heavy metals, mostly in the surface sub-horizon, was found (Table 1).

The coenological analysis carried out on the basis of the structural parameters shows that the oribatids evidence a special reactivity in relation with the bio-edaphic conditions modified by pollution (Table 2). Thus, in the control perimeter, the oribatid mites form a complex community - due to the number of species and individuals - with a high specific diversity. In the polluted forest stands, their effectives are 6-476 times lower, comparatively with the control zone; the oribatid communities are composed of a small number of tolerant species, being characterized by a low specific diversity and, consequently, a marked structural instability.

A detailed analysis on the oribatid communities, both quantitative and qualitative, was performed in the three forest stands during the year 1997. In the control forest at Păuleşti, the global average density of the oribatids put in evidence dynamics with an autumnal maximum (in October), when the effectives are almost twice higher than in the summer season (Table 3). The vertical distribution indicates the mainly populating of the litter and fermentation sub-horizon, in all the time sequences; in the autumn months an equalization tendency of the effectives in both the considered layers has been observed. The number of species - both the total number and the average number of species/sample - does not evidence ample fluctuations from a season to another, although the autumnal maximum of the density is accompanied by an increased number of taxa. The analysis of the specific diversity indices points out a high structural heterogeneity, which remains at this level in all the considered times. The relative diversity values, also very closed, indicate a stability state, a dynamic equilibrium of the oribatid community.

Within the structure of the oribatid community, a group of species with a high ecological significance should be noticed; these species, which cumulate 56-72% of the effectives, have as a rule, high frequencies and relative density variable from a season to another (Table 3, 4). The stability of this group of species during the time is remarkable, most of them having high values of W in all the considered times. All these facts show that the oribatid`s community

Table 1 Concentrations of the main pollutants and soil reaction in polluted forest stands from Valea Călugărească area

Station/ year	Sub-horizon	Cu	Zn	Pb	Co	Ni	Mn	Cr	Cd	F	pH
Darvari	olf	74±17	191±20	144±14	42±27	87±12	660±24	168±9	2.7±15		7.35±4.6
1997	ah	79±16	178±11	133±21	57±11	82±6	846±4	846±4	3±0.07	7.04±22	7.2±1.48
Darvari	olf	39±14	146±42	60±14					1.8±12		
1999	ah	59±4	156±6	73±16					2.6±8		
Valea	olf	495±16	1,065±15	788±25	85±30	79±23	361±18	180±17	7.7±12		6.05±3.8
Călugărească 1997	ah	502±10	1,031±19	995±37	132±17	95±4	300±24	209±4	8.7±13	7.3±44	4.75±5.1

Legend: - average concentration (ppm) ± Pearson coefficient of variation (%); the blank cells indicate that the corresponding estimations have not been made

Table 2 Structural global parameters of the oribatid mites communities in the investigated forest stands

Forest stands		Sub-horizon	$\bar{A}$		Adults/ preadults	*S*	*S'*	Specific diversity		
			adults	preadults				*H(s)max.*	*H(s)*	*H.r.*
Păuleşti (control)	June 1997	olf	11,100	6,380		35		5.1293	3.8654	75.36
		ah	1,000	560		24		4.5849	4.3487	94.85
		global	**12,100±65**	**6,940±92.4**	**1.74**	**40**	**19.8**	**5.3219**	**4.0408**	**75.92**
	June 1999	olf	8,160	3,520		34		5.0874	4.2142	82.83
		ah	1,280	180		24		4.5849	4.1135	89.72
		global	**9,440±34.67**	**3,700±43.16**	**2.55**	**41**	**21.8**	**5.3575**	**4.3932**	**82**
Darvari	June 1997	olf	500	500		6		2.5849	1.7931	69.37
		ah	860	80		9		3.1699	2.7299	86.12
		global	**1,360±56.6**	**580±123.9**	**2.34**	**11**	**6.6**	**3.4594**	**2.7183**	**78.58**
	June 1999	**holorganic layer**	**1,420±35.7**	**140±148.1**	**10.14**	**12**	**6.2**	**3.5849**	**2.7688**	**77.23**
Valea Călugărească	June 1997	**holorganic layer**	**40**	**-**	**-**	**2**	**0.4**	**-**	**-**	**-**

Legend: $\bar{A}$ - global average abundance, individuals/m^2± Pearson coefficient of variation (%); *S* - number of species*; S'*- average number of species/sample; *H(s)max* - maximal specific diversity; *H(s)* - real diversity; *H.r.*- relative diversity (%); olf - litter and fermentation subhorizon; ah- humiferous layer.

Table 3 Dynamics of the structural global parameters of the oribatid mites communities in the control and polluted forest stands (1997)

Forest stands		Â		Adults/ preadults	% ind. in olf	S	S'	Specific diversity		
		global	adults					*H(s)max.*	*H(s)*	*H.r.*
Păuleşti (control)	June	19,040	12,100	1.74	91.8	40	19.8	5.3219	4.0408	75.92
	October	33,680	25,940	3.35	77.2	42	24.4	5.3923	4.0476	75.56
	November	23,040	13,820	1.49	71.9	36	19.8	5.1699	4.0873	79.06
Darvari	June	1,940	1,360	2.34	51.5	11	6.6	3.4594	2.7183	78.58
	October	2,460	2,260	11.3	75.6	9	4	3.1699	2.2957	72.42
	November	2,760	2,260	4.52	72.5	14	5.2	3.8073	3.0166	79.23
Valea Călugărească	June	40	40	-	-	2	0.4	-	-	-
	October	720	680	17	55.5	7	2.6	2.8073	2.0084	71.54
	November	3,920	1,540	0.65	21.9	9	4	3.1699	2.9339	92.55

Legend: see Table 2

Table 4 Dynamics of the edifying and influential species group of oribatid mites in Păuleşti forest (the control stand, 1997)

Species	June		October		November	
	â	*W*	*â*	*W*	*â*	*W*
Phthiracarus (A.) bryobius (Jacot, 1930)	**8.2**	**IV**	**60.8**	**V**	**22.2**	**V**
Oribatella (O.) hungarica Balogh, 1943	**7**	**IV**	**20.2**	**IV**	**15.4**	**V**
Atropacarus platakisi (Mahunka, 1979)	**11.8**	**IV**	10.8	III	**9.6**	**IV**
Metabelba (M.) rohdendorfi Bulanova-Zachvatkina, 1965	**10.8**	**IV**	5.4	III	**13.2**	**IV**
Zetorchestes micronychus (Berlese, 1883)	**8.4**	**IV**	11.2	III	**13.6**	**IV**
Hypochthoniella minutissima (Berlese, 1904)	8.4	III	**14**	**IV**	**12.6**	**IV**
Suctobelbella (S.) subcornigera (Forsslund, 1941)	1.6	II	**35**	**V**	3.6	III
Phthiracarus (P.) serrulatus Parry, 1979	2	III	**15.6**	**IV**	4.8	III
Multioppa (M.) rangifera Ivan et Vasiliu, 1999	**13**	**V**	5.2	III	3.2	III
Oribatula (Z.) heterochaeta (Feider, Vasiliu et Calugar, 1970)	**20.2**	**IV**	–	–	–	–
Tectocepheus velatus (Michael, 1880)	**7.4**	**IV**	4.8	III	2	II
Suctobelbella (S.) acutidens (Forsslund, 1941)	0.2	I	10.4	III	6	III
Damaeolus ornatissimus Csiszár, 1962	7	III	4.6	II	3.2	III
Achipteria (A.) coleoptrata (Linné, 1758)	0.8	II	4.6	III	5.8	III
Suctobelbella (S.) forsslundi (Strenzke, 1950)	0.2	I	7	III	1.4	II
Lauroppia similifallax Subias et Minguez, 1986	1.2	II	6.4	III	4.8	III
Oppiella (O.) nova (Oudemans, 1902)	1.2	II	8	III	1.6	II
Hypochthonius luteus Oudemans, 1917	0.4	II	3.4	II	2.4	III
Suctobelbella (S.) subtrigona (Oudemans, 1900)	1.2	II	5.2	III	0.2	I
Acrotritia ardua (Koch, 1841)	–	–	3.6	III	1.4	II
Oppiella (P.) rara Ivan et Vasiliu, 1997	0.4	II	6.4	III	–	–
Poecilochthonius spiciger (Berlese, 1910)	0.4	I	1.8	II	3.2	III

Legend: $\overline{a}$ - average abundance, individuals/100 cm^2; *W* – ecological significance, classes: V, IV – edifying species, III – influential species, II, I – accompanying species

from the control stand Păuleşti is stable and functional, actively and efficiently involved in the bioconversion of the vegetal necromass into soil.

In the organic horizon of the Darvari forest, affected by industrial noxes, the average density of the oribatid mites evidences similar dynamics as in the control perimeter, with a minimum in summer and with a maximum in autumn (Table 3). However, the values of this parameter are different, 8-14 times lower than in the control forest stand. The vertical distribution of the effectives is different too, especially in the summer, when almost 2/3 of the effectives occurred in the deep sub-horizon. The number of identified species represents 21-38% of those recorded at Păuleşti. This parameter has not a balanced evolution with the global abundance; thus, in October, the effectives increase with about 66% related to June, but the number of species is reduced. The specific diversity is obviously lower related to the control stand, and seasonal fluctuations are more ample. The edifying group comprises especially euryplastic species and it changes the composition during the time - only *Protoribates capucinus* and *Acrotritia ardua* have high values of *W* in two of the considered sequences. The edifying species hold 52-83% of the effectives (Table 3, 5). All these data characterize a community in which the less exigent, non specific elements are dominant, a community with a reduced stability, but adapted to the bio-edaphic conditions modified by pollution.

The forest plantation at Valea Călugărească, situated in the vicinity of the pollution source, is the more affected ecosystem. The oribatid mites have an extremely low abundance (6-476 times lower than in the control stand), the maximum value found here being comparable with those at Darvari (Table 3). Substantial differences related to the control perimeter were found also concerning the number of species, which is 4-20 times lower. The edifying species - especially euryplastic elements - represent 88-95% of the effectives, being therefore an uneven repartition of the effectives on species (Table 5). The reduced number of species and their low abundances, the ample seasonal variations of all the structural parameters of the coenosis, including the adults/preadults ratio, the low specific diversity - are the reasons to consider this community as a extremely labile one, with reduced self-regulation possibilities.

Our researches carried out two years after the production's stopping, have not evidenced a favourable evolution of the oribatid mites' communities (Table 2). Thus, in the control station at Păuleşti, the oribatid community is complexly structured, with a remarkable sta-

Table 5 Dynamics of the edifying and influential species group of oribatid mites in the polluted forests (1997)

Species	Darvari						Valea Călugărească					
	June		October		November		June		October		November	
	â	*W*	*â*	*W*	*â*	*W*	*â*	*W*	*â*	*W*	*â*	*W*
Protoribates capucinus Berlese, 1908	**4.2**	**V**	0.2	II	**6.2**	**V**	-	-	-	-	**1.8**	**IV**
Acrotritia ardua (Koch, 1841)	0.6	III	**4**	**V**	**5.6**	**V**	-	-	**1.4**	**V**	**2**	**V**
Oribatula (Z.) heterochaeta (Feider, Vasiliu et Calugar, 1970)	-	-	**8.4**	**V**	-	-	-	-	**3.4**	**V**	**5.2**	**V**
Phthiracarus (A.) bryobius (Jacot, 1930)	-	-	**5.8**	**V**	-	-	-	-	-	-	-	-
Tectocepheus velatus (Michael, 1880)	**2.2**	**V**	-	-	0.4	II	-	-	**1.2**	**IV**	**1.6**	**IV**
Oribatula (O.) tibialis (Nicolet, 1855)	**3**	**V**	-	-	0.2	II	-	-	-	-	-	-
Neotrichoppia (C.) sp.	**1.8**	**V**	-	-	0.2	II	-	-	-	-	0.2	II
Sellnickochthonius immaculatus (Forsslund, 1942)	-	-	-	-	-	-	-	-	-	-	**4**	**V**
Multioppa (M.) rangifera Ivan et Vasiliu, 1999	0.6	III	-	-	2.2	III	-	-	0.2	II	-	-
Phthiracarus (P.) serrulatus Parry, 1979	-	-	1.8	III	1	III	-	-	-	-	-	-
Scheloribates (S.) laevigatus (Koch, 1836)	-	-	0.2	II	1.6	III	-	-	-	-	-	-
Epilohmannia imreorum Bayoumi et Mahunka, 1976	0.2	II	-	-	1.6	III	-	-	-	-	-	-
Ramusella (I.) insculpta (Paoli, 1908)	-	-	1.8	III	-	-	-	-	-	-	-	-
Hermanniella picea (Koch, 1839)	-	-	-	-	1.6	III	-	-	-	-	0.2	II
Multioppia (M.) orghidani Vasiliu et Ivan i.l.	0.4	III	-	-	-	-	-	-	-	-	-	-

Legend: see Table 4

bility of the specific composition. While the global density shows some fluctuations from a time sequence to another, the qualitative parameters vary between closed limits

In the affected forest ecosystem at Darvari, the global abundance, the number of species and specific diversity are drastically reduced related to the control stand, in spite of the polluting source's closing. The oribatid community is differently structured, the euryplastic, unspecific elements being dominant. From a time sequence to another, the edifying species group changes its composition, proving the slight stability of the coenosis (Table 2, 5).

The analysis of the oribatid species' distribution in the control and polluted ecosystems has evidenced three groups of species (Table 6). The first one includes some exigent species, which are present exclusively in the control forest stand. The second group comprises some tolerant species, recorded in all the investigated forests, but their representation and abundance is lower in the polluted stands. The third one includes any species which have a higher representation in the affected ecosystems; some of them should be noticed as bioindicators.

Discussion

The previous researches pointed out that in the mesophilous *Quercus* forests - because of the variety of the microhabitats and of the trophic resources - the oribatid mites constitute complex communities, with a high number of species, and a high specific diversity. In the control forest stand (Păuleşti), the oribatid community illustrates these features. Within the coenosis' structure, the characteristic species for this zone (South and South-Eastern part of Romania) are frequent and/or abundant, having a high ecological significance; among them, *Atropacarus platakisi, Multioppia rangifera, Phthiracarus serrulatus* should be mentioned, beside of some other species frequently recorded in the oak-type forests (Table 4, 6) (Vasiliu et al. 1993, Ivan & Vasiliu 2000, Ivan 2004).

In the polluted forest ecosystems, the decrease of the global abundance and of the species number are accompanied by qualitative changes in the communities structure. Some species with a large ecological plasticity - such as: *Protoribates capucinus, Ramusella* (I.) *insculpta, Neotrichoppia* (C.) sp., *Tectocepheus velatus, Acrotritia ardua* - become the

Table 6 Representation of the edifying* species of oribatid mites in the control and polluted forest stations

Species	Păuleşti (control perimeter)				Darvari				Valea Călugărească	
	1997		1999		1997		1999		1997	
	â	*R*	*â*	*R*	*â*	*R*	*â*	*R*	*â*	*R*
Oribatella (O.) hungarica	14.2	100	8	100	-	-	-	-	-	-
Atropacarus platakisi	10.7	100	3.4	100	-	-	-	-	-	-
Metabelba (M.) rohdendorfi	9.8	100	12.4	100	-	-	-	-	-	-
Zetorchestes micronychus	11.06	100	6.6	100	-	-	-	-	-	-
Hypochthoniella minutissima	11.66	100	7.4	100	-	-	-	-	-	-
Phthiracarus (A.) bryobius	30.4	94.03	3.8	100	1.93	5.97	-	-	-	-
Suctobelbella (S.) subcornigera	13.4	99.5	4.8	100	-	-	-	-	0.066	0.49
Suctobelbella (F.) forsslundi	2.87	97.75	7.2	100	-	-	-	-	0.066	2.24
Phthiracarus serrulatus	7.46	88.9	1.4	63.63	0.93	11.08	0.8	36.36	-	-
Multioppia (M.) rangifera	7.13	87.7	8.4	70	0.93	11.44	3.6	30	0.066	0.81
Oribatula (Z.) heterochaeta	6.73	54.3	-	-	2.8	22.6	-	-	2.86	23.08
Tectocepheus velatus	4.73	72.5	5	80.64	0.86	13.19	1.2	19.35	0.93	14.26
Oribatula (O.) tibialis	-	-	0.2	100	1.06	100	-	-	-	-
Acrotritia ardua	1.66	26.8	1	62.5	3.4	54.9	0.6	37.5	1.13	18.25
Protoribates capucinus	0.13	3.05	-	-	3.53	82.8	1	100	0.6	14.08
Neotrichoppia (C.) sp.	0.33	31.25	0.4	40	0.66	62.5	0.6	60	0.066	6.25
Ramusella (I.) insculpta	0.33	35.48	0.4	7.4	0.6	64.51	5	92.6	-	-
Sellnickochthonius immaculatus	-	-	-	-	-	-	-	-	1.33	100

Legend: *â* - average abundance, individuals/100cm^2 (1997 - arithmetic mean for three series of samples); *R* - representation (%); *-W>5 (classes V and IV).

edifying elements. These species, and especially the first three ones, may be considered as bioindicators for this type of pollution, being recorded previously in other polluted areas, with relatively high frequency and abundance (Vasiliu & Mihăilescu 1989, Vasiliu & Ivan 1995, Vasiliu et al. 1995).

A comparison of the present results with those gathered in 1989-1990 referring to the agricultural soils (Vasiliu et al. 1995) shows that at Valea Călugărească and in surrounding zone the pollution is serious and persistent, maintained by the immense dumps of pyrite cinders and phosphoric gyps; the fastening and/or coating of these dumps are the imperative measures, in order to limit the pollution`s effects.

Conclusions

Within the edaphic mesofauna, the oribatid mites show a special reactivity to the soil pollution. In the affected forests, a significant decrease of the densities, of the species number, and of the specific diversity are occuring. Because of their distribution, some oribatid species may be considered as bioindicators for the pollution with heavy metals.

Two years after the closing of the pollution source, no favourable evolution of the oribatid mites communities was found, in spite of the reduction of soil heavy metals content. It is probably that the recovery of the decomposers trophic chains requires a longer time.

This study shows that, in the assessment of the deterioration degree of some ecosystems, the data concerning certain groups of edaphic microarthropods are very valuable, beside of the chemical or physico-chemical parameters.

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