

APPLICATION OF ORIBATID MITES AS INDICATORS

(REVIEW)

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Abstract. This review discusses the connection between quantitative changes of environmental factors and oribatid communities. With the overview of available studies, it can be clearly explored how various characteristics of Oribatid communities are modified due to changes in moisture, temperature, heavy metal concentration, organic matter content and level of disturbance. The most important question concerning the application of Oribatids as indicators is to clarify what kind of information content does natural Oribatid coenological patterns possess from the aspect of bioindication. Most of the variables listed above can be directly measured, since rapid methods are available to quantify parameters of the soil. Responses of Oribatids are worth to study in a more complex approach. Even now we have an expansive knowledge on how communities change due to modifications of different factors. These pieces of information necessitate the elaboration of such methods which render Oribatid communities suitable for the task to prognosticate what extent the given site can be considered near-natural or degraded, based on the Oribatid composition of a single sample taken from the given area. Answering this problem needs extensive and coordinated work.

Keywords: *community, bioindication, soil, ecology, coenology*

Introduction

Applicability of Oribatid mites as an indicator group has been emphasized by researchers for several decades. These organisms possess such kind of extraordinary characteristics by which (considered even separately or as a whole) they are able to indicate different changes in their environment. These characteristics have been summarized in several reviews, most thoroughly in the works of Lebrun and van Straalen (1995), Behan-Pelletier (1999) and Gulvik (2007).

Oribatid mites can be found in almost every kind of habitats worldwide: on land, water and most importantly in the layers of soil containing organic materials, but they also conquered several other kind of microhabitats (e. g. lichen, moss, treebark etc.). Apart from the diversity of habitats, their excessive adaptational ability is also shown by great abundance and species richness. In most habitats, they constitute the largest proportion of microarthropods. These characteristics mentioned above can be primarily used in the application of coenological methods.

Oribatid mites consume mainly living or dead parts of plants or fungi, however there are some predators and scavengers to be mentioned as exceptions (Behan-Pelletier, 1999). As a consequence, they consume various kinds of food, and as such, they participate in numerous ways in the structure of the food web (Lebrun and van Straalen, 1995). Thus they are in strong interaction with their microenvironment (e. g. Ca-storage, heavy metal accumulation (Norton and Behan-Pelletier, 1991, Behan-Pelletier

1999), play an important role in the forming of soil structure and decomposition processes (Behan-Pelletier, 1999). These features can be applied for indicating the effects of chemical or heavy metal pollutions, and disturbances in the succession of decomposition processes (Lebrun and van Straalen, 1995).

The reproduction biology and life cycle of Oribatid mites can be considered extraordinary among arthropods from several aspects. There are some species/populations with sexual and asexual reproduction, and the proportion of species with obligate thelytokous parthenogenesis is very high – around 10% (Lebrun and van Straalen, 1995). Iteroparity and multiannual life cycle are also quite prevalent among the species, especially in moderate and cold climate zones (Norton, 1994, Luxton, 1981, Behan-Pelletier, 1999). The slow development, low fecundity and long larval stage of Oribatid mites can help indicating long-term disturbances. Their low dispersion ability (Lebrun and van Straalen, 1995) is also quite important, since these mites can hardly flee from sites affected by some kind of stress. Oribatid mites are classified as a „K-selected” group; this can be lead back to their slow metabolism according to Norton (1994).

Based on the characteristics listed above, many researchers think that this group is quite promising since it can be used for various indication purposes. However, indication purposes can be quite different; two main types can be formed on the basis of available studies:

The first type examines the communal or individual characteristics of Oribatid mites as a function of a well-defined variable. Such variables are water content, temperature, heavy metal concentration and organic matter amount, these factors are included in this study. The second type compares Oribatid communities via habitats distinguished by complex factors and features. Studies of consequences of human activities or comparisons of different habitats belong to this type.

The following section discusses the connection between quantitative changes of environmental factors and oribatid communities, then the results of complex comparisons are summarized.

Change in a simple factor

Soil moisture (water content)

Soil moisture is one of the most decisive factors affecting the life of Oribatid communities. Two types of studies examining this factor exist. One of them monitors the change in seasonal precipitation as a field description via soil moisture, the second type applies irrigation experiments. Depending on the circumstances of the studies, different results has been obtained, though almost all of the studies support the theory that Oribatid mites generally like habitats with elevated humidity and they are susceptible to drought.

It can be observed in tropical areas, both in the primary (Trueba et al., 1999) and secondary (Badejo and Akinwale, 2006) rainforests that the density of Oribatid mites in soil samples has been much greater in the rainy season than that in the dry season. In the study of Noti et al., (2003) water content has been a key factor affecting the species richness of Oribatid mites, however its effect varied between seasons. Beside soil moisture, C-content, C/N ratio and N-content are also important factors. Higher soil moisture results in greater density (Noti et al., 2003, Lindo and Winchester, 2006, Melamud et al. 2007). Lindo and Winchester (2006) showed that spreading of species

on the soil and in the foliage of trees is limited primarily not by physical barriers but e. g. water content. It has to be mentioned however, that the study of Melamud et al. (2007) showed increasing species richness proceeding upwards on Mt Carmel (Israel), while the moisture gradient has grown downwards.

Tsiafouli et al. (2005) conducted short-term manipulation studies in Mediterranean sites. Various irrigation and drying methods have been applied and it was shown that drought decreased the species richness of Oribatid and Collembolan communities (differences in abundance were not significant), while irrigation increased diversity of both groups. This phenomenon could have been caused by the propagation of rare species after irrigation (Tsiafouli et al., 2005).

In another study however, irrigation lowered the abundance of mesofaunistic units (O’Lear and Blair, 1999), but this study has been conducted on prairie and has not focused on Oribatid mites. This study also pointed out that if a soil sample from a humid site was placed into the soil in an arid area, only the abundance of the Oribatid group decreased, which can be considered as a further proof of this group’s drought susceptibility.

Lindberg et al. (2002) conducted extensive studies in Swedish coniferous forests concerning drought effects. He also pointed out that long-term deprivation of precipitation decreases the abundance of Oribatid mites and the diversity of the community (Lindberg et al., 2002). Lindberg also examined what kind of long-lasting effects have been caused by draught to the community and how long the regeneration would take: he could not measure similar results even three years after the intervention comparing treated and untreated control sites. Besides, he pointed out that Oribatid mites are more sensitive and possess much moderate regeneration ability compared to Collembola or Mesostigmata (Lindberg and Bengtsson, 2006). Lindberg et al. (2002 and 2006) listed several supposed causes of high susceptibility: in some lifestages Oribatid mites are very sensitive to drought, larger species can not wander deeper into the soil, so they have an inferior dispersion ability. Additionally, biomass and diversity of fungi also decrease as an effect of draught and fungi present a food source for many Oribatid species. Moreover, oviposition of some species are connected to special fungi (Hågvar, 1998, Lindberg et al., 2002). Lindberg and Bengtsson (2005) described that there are differences among Oribatid groups in drought tolerance. Species with sexual reproduction and species with less prevalence have a better drought tolerance than generalists and parthenogenetics.

It has been found that additional water supplement had not affected Oribatid communities when desert species had been investigated (Cepeda-Pizarro et al., 1996). According to studies conducted in the Namib desert, C/N ratio and K-content had greater effect than water content. Taylor and Wolters (2005) observed difference between the drought tolerance of species living in the litter of coniferous and beech forests. Oribatids in coniferous forests were more susceptible to drought than species living in the litter of beech forests. Source limitation and deterioration of nutrient availability commence sooner in coniferous forest litter. According to Taylor and Wolters (2005), drought can be shown via the decrease in abundance values, but many of the studies mentioned above state that diversity also falls as a consequence of decreasing species richness.

In accordance with the aforementioned, we summarize the results of some observations regarding which part of the Oribatid group can be characterized with drought susceptibility, and what are the causes of this susceptibility. Only a few studies

mention species with proven drought tolerance or susceptibility. Papers describe *Zygoribatula exilis*, several *Entomobrya* spp. (Lindberg et al., 2002), *Chamobates borealis* and *Tectocephus velatus* as heavily affected by drought, while *Disshorina ornata* is characterized as drought tolerant (Taylor and Wolters, 2005). Species with sexual reproduction and narrow habitat preference are more tolerant to drought (Lindberg and Bengtsson, 2005) compared to species with greater size and living in the soil surface or forest litter (Lindberg et al., 2002) and those Oribatids which slowly colonized the offered litter in a litter colonization experiment (Taylor and Wolters 2005). The work of (Walter and Proctor, 1999, Taylor et al., 2002, Taylor and Wolters, 2005) states that adult individuals are able to tolerate a wide range of water content, but nymphs are quite susceptible to drought (Taylor and Wolters, 2005). According to the same study, water content does not directly affect Oribatids, drought exerts its effect via fungi and microbes which serve as food for the Oribatids. Thus, drought susceptibility exerts its effects via food limitation and Oribatids can indicate water deficiency in an indirect manner, affected by the decrease of the quantity of microbiota.

Temperature

Most of the studies examining the effects of temperature are manipulation experiments including both field and laboratory studies. The aim of these studies had been mostly to observe the effects of temperature change or fluctuation accompanying climate change on mite species and communities. These experiments dealt with polar habitats and coniferous forests.

A part of the experiments studied the frost tolerance of mites, and the effects of temperature fluctuation near the frost limit. Sulkava and Huhta (2003) started from the presumption that global warming shortens the period of snow cover, harmfully affecting animals in the soil by exposing them to greater fluctuation of temperature and aggravating the danger of frost. In field studies, snow cover in the coniferous forest was artificially removed, and consequently the species richness of microarthropoda decreased. In laboratories, the sample populations were exposed to hard frost and according to the results, a frost of -16°C decreased both the abundance and species richness of microarthropoda. However, no change could be measured in the populations in the summer following the treatment, which refers to a quick pace of regeneration.

In contrast with the abovementioned, weak frost or slight fluctuation around the freezing point had a positive effect on the communities. Sjørksen et al. (2005) experimented with microarthropod communities in tundra habitats and found that constant cooling around -2°C increased the number of Oribatids compared to control samples. This can be explained by the fact that low temperature decreased the number of predators and favourably modified the food sources (the biomass of fungi had grown). In the same study, Sjørksen showed abundance increase of the mites by a temperature fluctuation between -2°C and 2°C and explained this with the faster hatching of eggs as a consequence of frost induction. Sulkava and Huhta (2003) obtained similar results concerning both sub-zero temperature and fluctuation with samples from coniferous forests.

Another part of the experiments dealt with the effect of elevated temperature. Haimi et al. (2005) artificially increased temperature and CO_2 content in special boxes placed in Finnish coniferous forests to simulate the effects of warming. Elevated temperatures had been determined based on multiannual climatic scenarios. By increasing the temperature, no changes had been observed in the number of Oribatids as compared to

control samples. Elevated CO₂-levels caused small changes only in the flora and microbiota, but this had not been sufficient to change the structure of the mesofauna.

Other studies dealt with polar habitats. Warming had been induced by plastic tent cover. In the following experiments, a determined number of characteristic Oribatid species had been observed. Webb et al. (1998) conducted studies on tundra heath and semi-desert soils observing 6 species. It was found that primarily aridification accompanied by warming had negative effects on the species. Mainly those species had been affected which were typically abundant in other habitats, so they lived among suboptimal conditions in the examined sites. Webb also observed increasing abundance in case of one of the species, which can be explained by the fact that warming rendered the conditions optimal for this species. The explanation for the quick reactions given for the treatments is that polar species are not seasonal, their life-cycle is primarily influenced by temperature, thus such treatments also affect their propagation, not just their survival.

Coulson et al. (1996) had been observing consequences of tent warming on the Webb habitats for 3 years, by simulating excessive summer warming. The number of young Oribatid individuals had increased in semi-desert habitats, but no other significant change had been observed.

Hodkinson et al. (1996) applied both laboratory and field manipulations, including treatments with temperatures of 30°C and above. It was found that negative effect affecting Oribatids could be experienced only above 35°C, and time interval is an important factor in treatments around 30°C. The extent of tolerance also depends on the moisture of the soil, but it was found that warming had no strong deteriorating effect on Oribatids.

Extreme fluctuations in temperature had also been studied. Uvarov (2003) pointed out that daily temperature fluctuation of the soil affected the survival and reproduction ability of Oribatids. Fluctuations with 5 and 25 °C had strong negative effects, while fluctuations with 10 and 20°C enhanced reproduction. Intermediate values had been gained by measurements on constant 15°C.

To further study the effects of temperature, several indirect experiments had been conducted on tropical areas concerning the effects of light and shade (Badejo and Akinwale, 2006). It was concluded that the structure of the mesofauna was not affected whether the sample of the habitat was taken from a spot being in shade or exposed to direct sunlight.

Changes in temperature had not directly affected Oribatids, since in most experiments applying temperature changes the mites had not reacted significantly. Even if a significant change could have been observed, the possible reason for this could have been that researchers applied harsh fluctuations and extremities, which are unexpected to take place naturally. According to these results, if fluctuations in the temperature should cause significant changes in Oribatid communities, it must be suspected that this change had not been caused directly by temperature, but indirectly, via another factor which had been affected by temperature, e. g. the quantity of food, predators or a competitor group (i. e. springtails).

Heavy metal pollutions

In the studies, the effects of the following heavy metals had been primarily examined: Zn, Cu, Cd, Ni and Pb. These examinations took place mainly in the vicinity of metallurgy facilities using heavy metals, but several studies also examined the effects

of transport or the heavy metals released from sewage sludge used in agriculture. The first and most important question is to decide whether Oribatid mites are affected by excessive or elevated heavy metal concentrations or not. To answer this question, we must handle the different heavy metals separately. Zaitsev et al. (2001) and Skubala and Kafel (2004) found that Oribatid communities were just slightly affected by heavy metal pollution, but Migliorini et al. (2005) and Seniczak et al. (1995) pointed out that heavy metal pollution exerted serious effects on Oribatids. This difference can be explained quite simply: they measured different concentrations of heavy metals, and this also leads to a conclusion that the most „effective” heavy metal is lead. Table 1. shows the heavy metal concentrations measured by the different authors in the same units, with the lowest and highest concentrations indicated. Skubala and Kafel (2004) conducted their studies in the neighbourhood of a Zn metallurgy plant. Despite the enormous Zn concentrations, the results showed no significant decrease in density compared to the control, thus it had been concluded that Zn does not have a significant effect on this group. Similar results were obtained by Hågvar and Abrahamson (1990). Zaitsev found samples showing the greatest species richness on the most polluted sites. However these sites showed the greatest pollution in terms of zinc, copper, cadmium and lead, but the highest concentrations of Mg and Ca were also measured at these plots. According to the author, these metals had greater effects on the group than heavy metals.

It would be quite important to decide what kind of effects are exerted on Oribatid communities by heavy metal pollutions. The main question here is whether quantitative and/or qualitative effects can be expected. According to Zaitsev et al. (2001) and Seniczak et al. (1995) pollution primarily caused decrease in density, however Cortet et al. (1999), Stamou et al. (1995), Steiner (1995), Skubala and Kafel (2004) state that species richness and density were also affected. Migliorini et al. (2005) observed qualitative changes. Hågvar and Abrahamsen (1990) pointed out that although increasing lead concentration decreased species richness, there were only slight changes in total abundance because the density of several species had grown. Bargagli (1998) concluded that total abundance is far from ideal for indication purposes, since while some species vanish, others can thrive. Several studies pointed out that slight concentration of certain metals can increase the abundance of some species (Denneman and Van Straalen 1999, Hopkin et al 1985, Gackowski et al 1997, Skubala and Kafel, 2004). Consequently, Seniczak et al. (1995) classified observed species into three categories: some species were quite susceptible, others less susceptible, and some species were tolerant.

It must be mentioned that some Oribatid species are able to accumulate large quantities of metals, and great differences can be observed among species (Zaitsev and van Straalen 2001). This is because fungi can effectively take up heavy metal ions and accumulate them (Berthelsen et al., 1995; Khan et al., 2000; Valix et al., 2001, Skubala and Kafel, 2004), and as a consequence, fungivores are able to do so as well (Siepel 1995). A large part of Oribatid mites are fungivores. It could not be pointed out however that there's a correlation between the extent of accumulation and trophic level or body size (Bengtsson and Tranvik, 1989, Skubala and Kafel, 2004). These can be determined by other anatomical and physical factors (Skubala and Kafel 2004). According to the studies of Zaitsev and van Straalen (2001), microphytophagous mites are able to accumulate large amounts of zinc, but since the effect of Zn is negligible as mentioned above, it is of no significant importance in this case.

Based on the examined studies it can be stated that lead has the greatest negative effect on Oribatids, while other metal ions (including lead as well) can even have a positive effect in low concentrations on some species. Changes are primarily qualitative, but it can not be neglected which species' abundance increased and which species vanished. Steiner (1995) suggested that other factors of the habitat of the mites must also be taken into consideration while studying the effects of heavy metal pollution: for example water content, pH etc. Beside metal ion concentrations, mainly pH had been measured in a part of the studies, but no correlations had been pointed out.

Table 1. Range of heavy metal concentrations on sample sites from the studies of mentioned authors. Lead has been highlighted because cited authors gained uniform results for this metal: Oribatid mites has been negatively affected in all cases. Divergent results can also be explained as a consequence of different concentration ranges

articles	Migliorini et al. 2005	Zaitsev et. al 2001	Skubala and Kafel 2004	Seniczak et al. 1995
examined areas	clay pigeon shooting range, soil samples	metallurgical plant surrounding, soil and litter samples	forests near to smelters, soil samples	forests near to smelters, samples from the trunks of pines
Zn	115-170 µg/g	58-276 µg/g	151-10454 µg/g	46-117.8 ppm
Cu	40-65 µg/g	15.1-58.6 µg/g	46.9-10.7 µg/g	21.6-843.9 ppm
Cd	-	0.01-0.92 µg/g	0.8-81.9 µg/g	2.3-7.8 ppm
Pd	80.5-1898 µg/g	9.6-54.9 µg/g	-	64.6-702.6 ppm
Ni	47.4-76.9 µg/g	13.5-43.1 µg/g	-	0.3-6.7 ppm

Organic matter content

Effect of organic matter content has been studied by the authors in two ways.

- The original organic carbon content and percentage, total N content, C/N ratio or available P content were measured (Scheu and Schultz, 1996, Kovác et al., 2001, Black et al., 2003, Osler and Murphy, 2005, Bedano et al. 2006, Salmon et al. 2006, Mitchell et al., 2007).
- Organic manure (e.g. sewage sludge) (Krogh and Pedersen, 1997, Andres, 1999, Arroyo and Iturrondobeitia, 2006) or inorganic fertilizer (e.g. ammonium-nitrate) (Moore et al., 1984, Arroyo and Iturrondobeitia, 2006, Cole et al., 2008) was added to the soil, and its effect had been examined.

Sewage sludge addition decreased the diversity (Andres, 1999, Arroyo et al., 2006) and abundance (Arroyo et al., 2006) of Oribatid mites. Theoretically an increment could have been expected, since the addition of organic matter could have had positive effects on the physical and chemical properties of the soil (Korentajer, 1991, Arroyo et al., 2006), but sewage sludge may have posed a risk to soil processes and soil-based trophic networks (Bolger and Curry, 1984, Arroyo et al., 2006).

Addition and measurement of organic compounds of any other kind gave numerous contradictory results. According to some studies, the organic matter content had no effect on Oribatid communities (Osler and Murphy, 2005). Coleman (2008) pointed out that the food network of the soil is resistant to slight changes in the source quantity. This is supported by the results of many experiments, in which the organic matter content of the soil has been enhanced with the addition of C, N and P in vain, because

neither the abundance nor the diversity of the Oribatids changed significantly (e.g. Cepeda-Pizarro et al. 1996, Salmon et al., 2006, Cole, 2008).

Numerous studies found correlation however between the organic matter content and the structure of Oribatid communities. These works pointed out positive correlations primarily between the carbon content percentage of the soil and abundance (Kováč et al., 2001, Black et al., 2003, Bedano et al., 2006, Salmon et al., 2006) and species richness of Oribatid mites (Scheu and Schultz 1996). According to Enami et al., 1999, nitrogen content of the soil can also be determinative, in some cases even more decisive than carbon (Mitchell et al. 2007).

We compared total C% data of some studies in order to observe if there were differences of some level of magnitude in the studies giving two kinds of results. For the purpose of the analysis, we used the results of Bedano et al. (2006), and Kováč et al. (2001) from studies proving correlations, and results of Osler and Murphy, (2005) which refuted correlation. Results are shown in Table 2. The common feature of the studies is that each of them compared agricultural areas with natural habitats. We used only the average values of the original data sets. If the average value was not included in the original study, we calculated it in case of studies with data sets containing several months or plots.

Table 2. Average C% values of soil samples from individual studies. It can be observed that in cases where correlation between the organic matter content and Oribatid communities has not been found, the difference between the areas has been far less than in cases where correlation has been indicated

C%								
Correlation found					Correlation not found			
Bedano et al. (2006)				Kováč et al. (2001)		Osler and Murphy (2005)		
natural habitat	pasture	mixed	agricultural area	natural habitat	agricultural area	natural habitat	agricultural area1	agricultural area2
3.71	2.83	1.69	1.77	4.72	2.14	1.22	1.8	1.24

Further studies are needed concerning the indication of organic matter content of habitats by Oribatids. Determining total C% can be considered as a suitable method, but according to the abovementioned, it is not sufficient in some cases. Data recording by the application of fertilization is not sufficient, it would be useful to measure organic matter content also when taking animal samples. Studies are not comparable in some cases, thus it has to be emphasized that a standard method for data recording and measurements should be developed. It has to be determined that exactly which factor or component of the organic matter content of the soil has influence on the Oribatid mites.

Complex changes resulting from several factors

I. Agriculture and forestry

Agriculture

Almost all the authors examining the effects of agricultural activities on Oribatid mites pointed out that agricultural treatments affected Oribatid communities negatively: they decreased abundance and diversity (pl. Hulsman and Wolters, 1998). The reason

for this can be approached by the changes in soil properties and the characteristics of the Oribatid mites as well.

Agricultural treatments can be various: e.g. herbicide and pesticide use, ploughing, irrigation, harvesting, and burning or collection of plant residues after harvest. These modify the properties of the soil: among others via the deterioration of the upper soil levels, drought, habitat modification and deterioration of accessibility of nutrients (Hulsmann and Wolters, 1998; Neave and Fox, 1998; Fox et al., 1999, Bedano et al., 2006). Agricultural activities decreased the amount of organic matter (Bedano et al., 2006), however, according to Osler and Murphy, (2005) decrease in the organic matter content did not correlate with the decrease in species richness. Cole et al. (2008) stated that increasing the organic matter content of the soil had not affected the diversity of the Oribatids. Grazing and trampling caused soil compaction (Bedano et al., 2006). According to the work of Bedano et al. (2006), ploughing had not affected Oribatids, which can be explained with the beneficial effect of ploughing on soil structure.

Most problems arise because plant residues are removed from the field after harvest. Numerous studies pointed out that plant coverage provides favourable conditions for soil microarthropods, since the structure of the flora has a significant effect on soil fauna through the modification of the microclimate (Gill, 1969, Berg and Pawluk, 1984, Koehler and Born 1989, Minor et al., 2004) Presence of plant residues on natural habitats decreases temperature fluctuations and moisture loss of upper soil levels, and also provides food source for the mites (Edwards and Loftly, 1975; Fox et al., 1999; Coleman et al., 2002; Koukoura et al., 2003).

Some groups of the mesofauna, e.g. Prostigmata have better tolerance against unfavourable conditions (Bedano et al., 2006). Another reason for decreasing abundance is the way of life of Oribatids. Low metabolic rate, slow development and low fecundity are such characteristics that render them unable to respond quickly to short-term, hard stresses (Behan-Pelletier, 1999). Regeneration following population decrease is also quite slow (Zaitsev et al. 2002).

Some researchers think that given their susceptibility and way of life, Oribatid mites are suitable for the indication of degradations caused by agriculture as an indicator group. However, their reliable and effective application needs lots of further studies since our methods and knowledge are incomplete. Gulvik (2007) calls attention for a line of shortcomings, for example the lack of standardization of sampling and data processing methods.

This is most obvious and urgent in studies concerning land use. An expected requirement of an indicator group is that presence and quantity of species in the samples taken from a given area should indicate some kind of phenomenon. To reach this goal however, the studies and examinations should be carried out in a way that we would be able to give an exact description of phenomena, and link the two factors together based on the present Oribatid community. Information recording though, is quite inaccurate in land use studies. Life conditions of soil Oribatids are mainly determined by the properties of the soil and agricultural activities modify these circumstances. When a natural and a cultivated area are compared, mostly the organic matter content, pH and moisture of the soil are recorded beside flora (Bedano et al., 2006, Minor et al. 2004, Osler and Murphy, 2005). In most cases it turns out however, that there's no correlation among measured soil properties and observed characteristics of the community (Minor et al., 2004, Bedano et al., 2006), or just in case of organic matter content at best, but contradictions also can be found here (see „Organic matter content”). In many cases, not

even the agricultural treatment or tillage has been properly described, e.g. „low-input”, „high-input”, „conventional agricultural practices”; but these are considered as a basis for comparison (Bedano et al., 2006, Osler et al. 2008).

Another problem is how we can use Oribatid communities. There are some authors who took only abundance into consideration (e.g. Bedano et al. 2006). We have some information that some groups are susceptible or tolerant to agricultural activities (Gulvik, 2007). The species *Tectocepheus velatus*, and the groups of Nothroidea and Ptyctimia are tolerant (Gulvik, 2007). This is quite insufficient however to gain exact information in order to describe a site. The aim of studies conducted these days should be to remedy these problems, but suitable methods are required to achieve this goal. Gulvik (2007) calls for international standards in the phases of sampling, data processing and taxonomical processing. It should be clearly defined what agricultural activities cause which kind of changes in the soil, and which are those among these effects, that actually affect mite communities

Forestry

Behan-Pelletier (1999) emphasized that the most abundant and diverse group of soil mesofauna were the Oribatids even in forest habitats. Changes in this community can have an important indication role. According to Behan-Pelletier (1999) the density of groups with parthenogenetic reproduction increased following disturbance, which could cause changes in the structure of the community. Several studies tried to determine the changes in Oribatid communities caused by disturbances in forest habitats. Numerous types of disturbances have been examined in forests but these studies are hard to compare and as a consequence, obtained various results.

Lindo and Visser (2004) studied the effect of different extents of forest clearing. Partial forest clearing had milder effect than clear-felling, but the change could have been observed only at the level of abundance. In some cases diversity indices and uniformity had also grown due to disturbance, which could be explained with the abundance loss of dominant species. Change in abundance is related to organic matter content, litter input and microbial biomass - (Marra and Edmonds, 1998, Lindo and Visser, 2004), namely the reduction of available nutrients (Battigelli 2004, Lindo and Visser, 2004). Besides, the microclimate of the soil changes as well (Marra and Edmonds, 1998), the size of soil pores decreases, which means the soil compacts (Battigelli et al. 2004) due to forest clearing. Battigelli et al. (2004) studied the effect of soil compaction and organic matter decrease following forest clearing. It was found that these interventions modified species richness beside decreasing the density of species, and thus caused changes in the structure of the community. The difference between the results of the two studies could have been caused by the difference in the applied methods, since Lindo and Visser (2004) studied the mesofauna of the sites as late as 2.5 years following forest clearings.

While Battigelli et al (2004) observed significant decrease in density and number of species when organic matter (soil with roots) had been removed from the area, Berch et al (2007) did not point out significant difference comparing control and treated sites, where the upper layer of the soil had been removed. It has to be mentioned however, that the study of Berch et al (2007) took place 5 years following the treatment. Fire also removes the organic matter from the upper layers of the soil, but the work of Berch et al (2007) did not show changes in the Oribatid communities. Burning treatments gave

contradictory results in most cases, which could be attributed again to the differences in the treatments.

Maraun et al. (2003) studied the physical disturbance of the soil, when the soil had been sieved at regular intervals. The results of this study are hardly comparable to that of the former mentioned works, since this treatment is hardly reconcilable with the actually occurring disturbances like forest clearing, decrease in organic matter content or soil compaction. Maraun et al. (2003) however, in the wake of the results of Behan-Pelletier (1999) found that groups with parthenogenetic reproduction (*Tectocepheus* sp., Ooppiidae) were tolerant to disturbances. In the work of Lindo and Visser (2004), the proportion of species with parthenogenetic reproduction did not differ from that of the control sites. Changes expected in case of species with asexual reproduction could not be showed by Berch et al. (2007) as well.

Interventions taking place in forests can induce multiple changes in Oribatid communities, however the exact effects of these changes are not yet properly described. According to Lindo and Visser (2004) forest clearing can induce only quantitative, and not qualitative changes, thus the possibility of using Oribatids as indicators is quite limited. In case of other types of disturbances however, even the species structure has been changed (Berch et al., 2007, Battigelli et al., 2004, Maraun et al., 2003). Comparability of results needs methodological standardizations, just as Gulvik (2007) has recommended when studying the effects of agricultural activities.

If the observation of the effects of forest clearings is demanded, then sampling must be done in periods immediately both before and after the interventions (forest clearing, soil dumping, soil layer removal etc.), since circumstances in control areas are not necessarily identical to those present in the period before the disturbance. Apart from this, attention should also be paid for that the process of regeneration should not be studied by collection of samples just in a single period. Constant monitoring is needed beginning from the implementation of the treatment in order to exactly observe the changes.

II. Comparison of natural habitats

These examinations try to explore what properties of habitats play a role in pattern generation, among which spatial and temporal changes can be distinguished. Observations on seasonality have not yielded considerable results (Reynolds et al., 2003, Noti et al., 1996, Badejo et al., 2002, Moldenke and Thies, 1996). Habitats and sampling frequencies are quite different and hardly comparable. Currently we do not possess any satisfying results on seasonal dynamics. A number of studies (e.g. Reynolds et al., 2003) surveying temporal changes measured the total abundance of the community. Measuring the changes in the number of individuals of larger groups does not mean thorough examination. It is worth to survey the temporal structures of the entire community on such places where seasons are well discernible. One of the most important studies has been made by Irmeler (2006), who studied the seasonal changes of an Oribatid community living in the OL and OF layer of a beech forest. It was found that only the annual mean temperature had significant effect on the structure of the community. The study yielded more results when Irmeler surveyed the seasonal dynamics of individual species. Mainly the amount of precipitation affected the abundance of certain species, but some species had been affected more significantly by temperature (primarily by the mean temperature in January). The significance of

species-level examination was confirmed by the fact that certain species reacted differently on the surveyed parameters.

Spatial comparisons applied different scales; part of them compared soil and foliage of forests. These studies revealed that Oribatids of the soil showed greater α -diversity and species richness, but β -diversity proved to be greater in the foliage, which means difference among samples taken from individual trees has been greater than that of the samples collected from the soil (Lindo and Winchester, 2006, Fagan et al. 2006).

Comparison of elevations above sea level attracted great attention: primarily the abundance and species richness of Oribatids have been studied in zones of different altitudes. However, obtained data are not concordant: according to Migliorini and Bernini, (1999) and Fagan et al., (2006) the abundance of Oribatids decreased with altitude, but Jing et al., (2005) and Reynolds et al., (2003) observed an opposing tendency. Fagan et al., (2006) pointed out a decrease in species richness, Migliorini and Bernini, (1999) observed a growth in diversity as a function of increasing altitude. It has to be mentioned by these contradictory results that altitudes of sampling and habitats are hardly comparable, and even if they were, this would not guarantee consistent results. This has been pointed out by Andrew et al (2003) in an extended series of studies conducted on different altitudes in Australia and New Zealand.

Beside altitude, vegetation also changes greatly when progressing upwards on a hill. Studies mentioned above did not lay an emphasis on vegetation. The work of Balogh et al.(2008) however demonstrates altitude as a difference in the type of vegetation: rainforest, moss forest and paramo. Samples were taken from the mountains of Brazil, Costa-Rica and New-Guinea. This work showed that the structure of Oribatid mite communities was primarily determined by the type of vegetation and not by the distance of several thousand kilometres, which means that climate and ecological conditions have stronger effects than zoogeographical connections (Balogh et al., 2008).

Abundance, species richness and diversity - summary

Studies examining Oribatid communities almost always measure which Oribatid species and in what quantity are present in samples taken from the given area. Species composition, abundance, total abundance, species richness, diversity and the uniformity of the community can be calculated from these data. In most cases, changes in the communities are examined using these variables.

When given the same climate, abundance, species richness and diversity of the Oribatids are greater in natural areas (forest or habitats not strongly affected by human activity) than in areas affected by agriculture (e.g. plant production or animal husbandry) or forestry (e.g. clear-felling, burning etc.) (Bedano et al. 2006, Osler et al., 2006, Cole 2008, Olejniczak 2004, Arroyo and Iturrondobetia, 2006, Migliorini et al., 2003, Altesor et al., 2006). The observation of Bedano et al. (2006) can be mentioned as an exception: it was found that the abundance of pastures was higher than that of natural forests.

Decrease in abundance can be caused by hard frost (Sulkava and Huhta, 2003) and serious heavy metal pollution (Seniczak et al., 1995). According to Osler et al. (2006), mainly the number of individuals is lower in the initial state of succession. Decrease in abundance could be pointed out primarily as a result of water deficiency (O'Lear and Blair, 1999, Lindberg et al., 2002), but contradictory results had been also obtained (O'Lear and Blair, 1999, Melamud et al., 2007). Lindberg and Bengtsson, (2006)

showed that community regeneration following drought can not be satisfactorily measured by the sole application of total abundance. Decrease in the abundance of Oribatids can also be caused by ash treatment of sour, acidic soils (Liiri et al., 2002). In Japanese coniferous forests it has been shown that the abundance of Oribatids was greater in mixed litter (litter of several tree species) than in litters consisting of only one tree species (Kaneko and Salamanca, 1999). Kovác et al., (2001) explored positive correlation between the nutrient content of the soil and abundance, but it was contradicted by several other studies (e.g. Osler and Murphy, 2005).

Removal of winter snow cover lead to a decrease in species richness, since the mesofauna of the soil has been exposed to greater fluctuation of temperature (Sulkava and Huhta, 2003). Response of species to heavy metal pollution varied greatly, sometimes even moderate pollution resulted in the highest species richness (Skubala and Kafel 2004). Drought generally decreased species richness (Tsiafouli et al., 2005), but there were several examples for growth as well (Melamud et al., 2007). Ash treatment lowered abundance and also species richness (Liiri et al., 2002). In mixed litter, both species richness and abundance were higher (Kaneko and Salamanca, 1999). Fagan et al., (2006) found in Canadian coniferous forests that species richness of Oribatids in the soil had been greater when comparing Oribatid communities of the foliage and soil.

Table 3. Strongly abridged summary of information from studies on characteristics of Oribatid communities. (↑=increases or greater; ↓=decreases or lower)

abundance	species richness	diversity
artificial disturbance↓	artificial disturbance↓	artificial disturbance↓
hard frost↓	snow cover removal↓	irrigation↑
drought↓	drought↓	drought↓
early stage of succession ↓	ash↓	number of ecotones↑
diverse litter mix↑	diverse litter mix↑	diverse litter mix↑
ash treatment↓		soil > foliage
heavy metal pollution↓		
organic mater content↑		

Diversity data can be found primarily in agricultural and forestry studies. It has been pointed out that irrigation (enhancing the moisture content of the soil) increased the diversity of Oribatid communities, because it raised the individual numbers of rare species (Tsiafouli et al., 2005). Drought had a detrimental effect on diversity (Lindberg et al., 2002). Studies of Taylor and Wolters (2005) pointed out that Oribatid diversity had been greater in a more decomposed beech litter than in fresh litter. Seniczak et al., (2006) concluded that Oribatid diversity can be increased by increasing the number of

ponds of forest habitats, since this means more ecotones and leads to the presence of such kind of species which prefer humid habitats and are normally absent from forest habitats. Age of temperate deciduous forests did not affect diversity (Erdman et al., 2006). Growth in the diversity of tree species did not increase the diversity of Oribatids living in the soil of these forests (Kaneko and Salamanca, 2005). However, growing diversity of the litter not only increased abundance and species richness, but diversity as well (Coleman 2008). (*Table 3.*)

Conclusion and outlook

With the overview of available studies, it can be clearly explored how various characteristics of Oribatid communities are modified due to changes in moisture, temperature, heavy metal concentration, organic matter content and level of disturbance. The most important question concerning the application of Oribatids as indicators is to clarify what kind of information content do natural Oribatid coenological patterns possess from the aspect of bioindication. Most of the variables listed above can be directly measured, since rapid methods are available to quantify temperature, heavy metal content etc. of the soil. Responses of Oribatids are worth to study in a more complex approach. Even now we have an expansive (but far from satisfactory) knowledge on how communities change due to modifications of different factors. These pieces of information necessitate the elaboration of such methods which render Oribatid communities suitable for the task to prognosticate what extent the given site can be considered near-natural or degraded, based on the Oribatid composition of a single sample taken from the given area. Raising further questions will be possible only after obtaining the answer for this problem. However, answering this problem needs extensive and coordinated work: appropriate reference sites need to be appointed to clarify the concept of naturality, sampling and processing methods need to be standardized internationally – in conformity with the given environmental conditions – and the field of data processing methods also has to be developed. Definition and testing of Oribatid-based (or mesofauna-based in a broader sense) coenological indicators are also undoubtedly needed. The usefulness of Oribatid characteristics summarized in the introduction had been recognized long ago, now it is time to conduct research in a way that enables to explore and exploit the actual advantages Oribatid mites provide.

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REFERENCES

- [1] Altesor, A., Pineiro, G., Lezama, F., Jackson, R.B., Sarasola, M., Paruelo, J.M. (2006): Ecosystem changes associated with grazing in subhumid South American grasslands. – *Journal of Vegetation Science* 17:323-332.
- [2] Andres, P. (1999): Ecological risks of the use of sewage sludge as fertilizer in soil restoration effects on the soil microarthropod populations. – *Land Degradation & Development* 10 (1): 67-77.
- [3] Andrew, N.R., Rodgers, L., Dunlop, M. (2003): Variation in invertebrate-bryophyte community structure at different spatial scales along altitudinal gradients. – *Journal of Biogeography* 30 (5): 731-746.

- [4] Arroyo, J., Iturrondobeitia, J.C. (2006): Differences in the diversity of oribatid mite communities in forests and agrosystems lands. – *European Journal of Soil Biology* 42: 259-269.
- [5] Badejo, M.A., Espindola, J.A.A., Guerra, J.G.M., De Aquino, A.M., Correa, M.E.F. (2002): Soil oribatid mite communities under three species of legumes in an ultisol in Brazil. – *Experimental and Applied Acarology* 27(4): 283–296.
- [6] Badejo, M.A., Akinwale, P.O. (2006): Microenvironmental preferences of oribatid mite species on the floor of a tropical rainforest. – *Experimental and Applied Acarology* 40: 145-156.
- [7] Balogh, P., Gergócs, V., Farkas, E., Farkas, P., Kocsis, M., Hufnagel, L. (2008): Oribatid assemblies of tropical high mountains on some points of the „Gondwana-bridge” – a case study. – *Applied Ecology and Environmental Research* 6(3): 127-158.
- [8] Bargagli, R. (1998): *Trace Elements in Terrestrial Plants* – Springer and Landes Company, Berlin.
- [9] Battigelli, J.P., Spence, J.R., Langor, D.W., Berch, S.M. (2004): Short-term impact of forest soil compaction and organic matter removal on soil mesofauna density and oribatid mite diversity. – *Canadian Journal of Forest Research-Revue Canadienne de Recherche Forestiere* 34(5): 1136-1149.
- [10] Bedano, J.C., Cantu, M.P., Doucet, M.E. (2005): Abundance of soil mites (Arachnida : Acari) in a natural soil of central Argentina. – *Zoological Studies* 44(4): 505-512.
- [11] Behan-Pelletier, V.M. (1999): Oribatid mite biodiversity in agroecosystems: role for bioindication. – *Agriculture, Ecosystems and Environment* 74: 411-423.
- [12] Bengtsson, G., Tranvik, L. (1989): Critical metal concentrations for forest soil invertebrates. – *Water, Air and Soil Pollution* 47: 381-417.
- [13] Berch, S.M., Battigelli, J.P., Hope, G.D. (2007): Responses of soil mesofauna communities and oribatid mite species to site preparation treatments in high-elevation cutblocks in southern British Columbia. – *Pedobiologia* 51(1): 23-32.
- [14] Berg, N.W., Pawluk, S. (1984): Soil mesofauna studies under different vegetative regimes in north central Alberta. – *Can. J. Soil Sci.* 64: 209-223.
- [15] Berthelsen, B., Olsen, R., Steinnes, E. (1995): Ectomycorrhizal heavy metal accumulation as a contributing factor to heavy metal levels in organic surface soils. – *The Science of the Total Environment* 170: 141-149.
- [16] Black, H.I.J., Parekh, N.R., Chaplow, J.S., Monson, F., Watkins, J., Creamer, R., Potter, E.D., Poskitt, J.M., Rowland, P., Ainsworth, G., Hornung, M. (2003): Assessing soil biodiversity across Great Britain: national trends in the occurrence of heterotrophic bacteria and invertebrates in soil. – *Journal of Environmental Management* 67(3): 255-266.
- [17] Bolger, T., Curry, J.P. (1984): Influences of pig slurry on soil microarthropods in grasslands. *Rev. – Écol. Biol. Sol* 21: 269-281.
- [18] Cepeda-Pizarro, J.G., Gutierrez, J.R., Valderrama, L., Vasquez, H. (1996): Phenology of the edaphic microarthropods in a Chilean coastal desert site and their response to water and nutrient amendments to the soil. – *Pedobiologia* 40(4): 352-363.
- [19] Cole L., Buckland S.M., Bardgett R.G. (2008): Influence of disturbance and nitrogen addition on plant and soil animal diversity in grassland. – *Soil Biology & Biochemistry* 40(2): 505–514.
- [20] Coleman, D., Fu, S., Hendrix, P., Crossley Jr., D. (2002): Soil foodwebs in agroecosystems: impacts of herbivory and tillage management. – *Eur. J. Soil Biol.* 38(1): 21-28.
- [21] Coleman, D.C. (2008): From peds to paradoxes: Linkages between soil biota and their influences on ecological processes. – *Soil Biology & Biochemistry* 40(2): 271-289.
- [22] Cortet, J., Gomot-De Vauflery, A., Poinot-Balaguer, N., Gomot, L., Texier, C., Cluzeau, D. (1999): The use of invertebrate soil fauna in monitoring pollutant effects. – *Eur. J. Soil Biol.* 35(3): 115-134.

- [23] Coulson, S.J., Hodkinson, I.D., Webb, N.R., Block, W., Bale, J.S., Strathdee, A.T., Worland, M.R., Wooley, C. (1996): Effects of experimental temperature elevation on high-arctic soil microarthropod populations. – *Polar Biology* 16(2): 147-153.
- [24] Coulson, S.J., Leinaas, H.P., Ims, R.A., Sovik, G. (2000): Experimental manipulation of the winter surface ice layer: the effects on a High Arctic soil microarthropod community. – *Ecography* 23(3): 299-306.
- [25] Edwards, C.A., Lofty, J.R. (1975): The influence of cultivations on soil animal populations. – In: Vanek, J. (Ed.), *Progress in Soil Zoology* Academia Publishing House, Prague, pp. 399-406.
- [26] Enami, Y., Shiraishi, H., Nakamura, Y. (1999): Use of soil animals as bioindicators of various kinds of soil management in northern Japan. – *Jarq-Japan Agricultural Research Quarterly* 33(2): 85-89.
- [27] Erdmann, G., Floren, A., Linsenmair, K.E., Scheu, S., Maraun, M. (2006): Little effect of forest age on oribatid mites on the bark of trees. – *Pedobiologia* 50: 433-441.
- [28] Denneman, C.A.J., Van Straalen, N.M. (1991): The toxicity of lead and copper in reproduction tests using the oribatid mite *Platynothrus peltifer*. – *Pedobiologia* 35: 305-311.
- [29] Fagan, L.L., Didham, R.K., Winchester, N.N., Behan-Pelletier, V., Clayton, M., Lindquist, E., Ring, R.A. (2006): An experimental assessment of biodiversity and species turnover in terrestrial vs canopy leaf litter. – *Oecologia* 147: 335-347.
- [30] Fox, C.A., Fonseca, E.J.A., Miller, J.J., Tomlin, A.D. (1999): The influence of row position and selected soil attributes on Acarina and Collembola in no-till and conventional continuous corn on a clay loam soil. – *Appl. Soil Ecol.* 13(1): 1-8.
- [31] Franklin, E., Magnusson, W.E., Luizao, F.J. (2005): Relative effects of biotic and abiotic factors on the composition of soil invertebrate communities in an Amazonian savanna. – *Applied Soil Ecology* 29(3): 259-273.
- [32] Gackowski, G., Seniczak, S., Klimek, A., Zalewski, W. (1997): Soil mites (Acari) of young Scots pine forests in the region polluted by a copper smelting works at Głogów (in Polish) – *Zeszyty Naukowe ATR, Bydgoszcz, Ochrona Środowiska* 208: 27-35.
- [33] Gill, R.W. (1969): Soil microarthropod abundance following old-field litter manipulation. – *Ecology* 50: 805-816.
- [34] Gulvik, M.E. (2007): Mites (Acari) As Indicators of Soil Biodiversity and Land Use Monitoring: a Review. – *Pol. J. Ecol.* 55(3): 415-440.
- [35] Hågvar, S., Abrahamsen, G. (1990): Microarthropods and Enchytraeidae (Oligochaeta) in naturally lead-contaminated soils: a gradient study. – *Environmental Entomology* 19: 1263-1277.
- [36] Hågvar, S. (1998): Mites (Acari) developing inside decomposing spruce needles: biology and effect on decomposition rate. – *Pedobiologia* 42: 358-377.
- [37] Haimi, J., Laamanen, J., Penttinen, R., Raty, M., Koponen, S., Kellomäki, S., Niemela, P., (2005): Impacts of elevated CO₂ and temperature on the soil fauna of boreal forests – *Applied Soil Ecology* 30(2): 104-112.
- [38] Hodkinson, I.D., Coulson, S.J., Webb, N.R., Block, W. (1996): Can high Arctic soil microarthropods survive elevated summer temperatures? – *Functional Ecology* 10(3): 314-321.
- [39] Hopkin, S.P., Watson, K., Martin, M.H., Mould, M.L. (1985): The assimilation of heavy metals by *Lithobius variegatus* and *Glomeris marginata* (Chilopoda, Diplopoda) – *Bijdragen tot de Dierkunde* 55: 88-94.
- [40] Hulsman, A., Wolters, V., (1998): The effects of different tillage practices on soil mites, with particular reference to Oribatida. – *Appl. Soil Ecol.* 9: 327-332.
- [41] Irmeler, U. (2006): Climatic and litter fall effects on collembolan and oribatid mite species and communities in a beech wood based on a 7 years investigation. – *Eur. J. Soil Biol.* 42: 51-62.

- [42] Jing, S., Solhoy, T., Wang, H.F., Vollan, T.I., Xu, R.M. (2005): Differences in soil arthropod communities along a high altitude gradient at Shergyla Mountain, Tibet, China. – *Arctic Antarctic and Alpine Research* 37(2): 261-266.
- [43] Kaneko, N., Salamanca, E.F. (1999): Mixed leaf litter effects on decomposition rates and soil microarthropod communities in an oak-pine stand in Japan. – *Ecological Research* 14(2): 131-138.
- [44] Kaneko, N., Sugawara, Y., Miyamoto, T., Hasegawa, M., Hiura, T. (2005): Oribatid mite community structure and tree species diversity: A link? – *Pedobiologia* 49(6): 521-528.
- [45] Khan, A.G., Kuek, C., Chaudhry, T.M., Khoo, C.S., Hayes, W.J. (2000): Role of plants, mycorrhizae and phytochelators in heavy metal contaminated land remediation. – *Chemosphere* 41(1-2): 197-207.
- [46] Koehler, H., Born, H. (1989): The influence of vegetation structure on the development of soil mesofauna. – *Agriculture Ecosystems and Environment* 27(1-4): 253-269.
- [47] Korentajer, L. (1999): A review of the agricultural use of sewage sludge: benefits and potential hazards. – *Water Air Soil Pollut.* 17: 189-196.
- [48] Koukoura, Z., Mamolos, A.P., Kalburtji, K.L. (2003): Decomposition of dominant plant species litter in a semi-arid grassland. – *Appl. Soil Ecol.* 23(1): 13-23.
- [49] Kovác, L., L'uptácik, P., Miklisová, D., Mati, R. (2001): Soil Oribatida and Collembola communities across a land depression in an arable field. – *Eur. J. Soil Biol.* 37: 285-289.
- [50] Krogh, P.H., Pedersen, M.B. (1997): Ecological effects assessment of industrial sludge for microarthropods and decomposition in a spruce plantation. – *Ecotoxicol. Environ* 36(2): 162-168.
- [51] Lebrun, Ph., van Straalen, N.M. (1995): Oribatid mites: prospects for their use in ecotoxicology – *Experimental & Applied Acarology* 19: 361-379.
- [52] Liiri, M., Haimi, J., Setälä, H. (2002): Community composition of soil microarthropods of acid forest soils as affected by wood ash application. – *Pedobiologia* 46(2): 108-124.
- [53] Lindberg, N., Engtsson, J.B., Persson, T. (2002): Effects of experimental irrigation and drought on the composition and diversity of soil fauna in a coniferous stand. – *Journal of Applied Ecology* 39(6): 924-936.
- [54] Lindberg, N., Bengtsson, J. (2005): Population responses of oribatid mites and collembolans after drought. – *Applied Soil Ecology* 28(2): 163-174.
- [55] Lindberg, N., Bengtsson, J. (2006): Recovery of forest soil fauna diversity and composition after repeated summer droughts. – *Oikos* 114: 494-506.
- [56] Lindo, Z., Visser, S. (2004): Forest floor microarthropod abundance and oribatid mite (Acari: Oribatida) composition following partial and clear-cut harvesting in the mixedwood boreal forest. – *Canadian Journal of Forest Research-Revue Canadienne de Recherche Forestiere* 34(5): 998-1006.
- [57] Lindo, Z., Winchester, N.N. (2006): A comparison of microarthropod assemblages with emphasis on oribatid mites in canopy suspended soils and forest floors associated with ancient western red cedar trees. – *Pedobiologia* 50: 31-41.
- [58] Luxton, M. (1981): Studies on the Oribatid mites of a Danish Beech wood soil IV. Developmental biology. – *Pedobiologia* 21: 312-340.
- [59] Maraun, M., Salamon, J.A., Schneider, K., Schaefer, M., Scheu, S. (2003): Oribatid mite and collembolan diversity, density and community structure in a moder beech forest (*Fagus sylvatica*): effects of mechanical perturbations. – *Soil Biology & Biochemistry* 35(10): 1387-1394.
- [60] Marra, J.L., Edmonds, R.L. (1998): Effects of coarse woody debris and soil depth on the density and diversity of soil invertebrates on clearcut and forested sites on the Olympic Peninsula, Washington. – *Environ. Entomol.* 27(5): 1111-1124.
- [61] Melamud, V., Beharav, A., Pavlíček, T., Nevo, E. (2007): Biodiversity interslope divergence of oribatid mites at "Evolution Canyon", Mount Carmel, Israel. – *Acta Zoologica Academiae Scientiarum Hungaricae* 53(4): 381-396.

- [62] Migliorini, M., Bernini, F. (1999): Oribatid mite coenoses in the Nebrodi Mountains (Northern Sicily). – *Pedobiologia* 43(4): 372-383.
- [63] Migliorini, M., Fanciulli, P.P., Bernini, F., (2003): Comparative analysis of two edaphic zoocoenoses (Acari Oribatida, Hexapoda Collembola) in the area of Orio al Serio Airport (Bergamo, northern Italy). – *Pedobiologia* 47(1): 9-18.
- [64] Migliorini, M., Pigino, G., Caruso, T., Fanciulli, P.P., Leonzio, C., Bernini, F. (2005): Soil communities (Acari Oribatida, Hexapoda Collembola) in a clay pigeon shooting range. – *Pedobiologia* 49(1): 1-13.
- [65] Minor, M.A., Norton, R.A. (2004): Effects of soil amendments on assemblages of soil mites (Acari : Oribatida, Mesostigmata) in short-rotation willow plantings in central New York Canadian Journal of Forest Research-Revue (Canadienne de Recherche Forestiere) 34: 1417-1425.
- [66] Mitchell, R.J., Campbell, C.D., Chapman, S.J., Osler, G.H.R., Vanbergen, A.J., Ross, L.C., Cameron, C.M., Cole, L. (2007): The cascading effects of birch on heather moorland: a test for the top-down control of an ecosystem engineer. – *Journal of Ecology* 95(3): 540-554.
- [67] Moldenke, A.R., Thies, W.G. (1996): Application of chloropicrin to control laminated root rot: Research design and seasonal dynamics of control populations of soil arthropods. – *Environmental Entomology* 25(5): 925-932.
- [68] Moore, J.C., Snider, R.J., Robertson, L.S. (1984): Effects of different management practices on Collembola and Acarina in corn production systems. 1. The effects of no-tillage and Atrazine. – *Pedobiologia*, 26(2): 143-152.
- [69] Neave, P., Fox, C.A. (1998): Response of soil invertebrates to reduced tillage systems established on a clay loam soil. – *Appl. Soil Ecol.* 9(1-3): 423-428.
- [70] Norton, R.A., Behan-Pelletier, V.M. (1991): Calcium carbonate and calcium oxalate as cuticular hardening agents in oribatid mites (Acari: Oribatida). – *Canadian Journal Of Zoology* 69(6): 1504-1511.
- [71] Norton, R.A. (1994): Evolutionary aspects of oribatid mites life histories and consequences for the origin of the Astigmata. – In: M.A. Houck (Ed.), *Mites: Ecological and Evolutionary Analyses of Life-History Patterns*, Chapman & Hall, New York, pp. 99-135.
- [72] Noti, M.I., André, H.M., DufrSne. M. (1996): Soil oribatid mite communities (Acari: Oribatidaj from high Shaba (Zäire) in relation to vegetation. – *Applied Soil Ecology*, 5(1): 81-96.
- [73] Noti, M.I., Andre, H.M., Ducarme, X., Lebrun, P. (2003): Diversity of soil oribatid mites (Acari : Oribatida) from High Katanga (Democratic Republic of Congo): a multiscale and multifactor approach – *Biodiversity And Conservation* 12(4): 767-785.
- [74] O'Lear, H.A., Blair, J.M. (1999): Responses of soil microarthropods to changes in soil wateravailability in tallgrass prairie. – *Biology and Fertility of Soils* 29(2): 207-217.
- [75] Olejniczak, I. (2004): Communities of soil microarthropods with special reference to collembola in midfield shelterbelts. – *Polish Journal of Ecology* 52(2): 123-133.
- [76] Osler, G.H.R., Murphy, D.V. (2005): Oribatid mite species richness and soil organic matter fractions in agricultural and native vegetation soils in Western Australia. – *Applied Soil Ecology* 29(1): 93-98.
- [77] Osler, G.H.R., Cole, L., Keith, A.M. (2006): Changes in oribatid mite community structure associated with the succession from heather (*Calluna vulgaris*) moorland to birch (*Betula pubescens*) woodland. – *Pedobiologia* 50(4): 323-330.
- [78] Osler, G.H.R., Harrison, L., Kanashiro, D.K., Clapperton, M.J. (2008): Soil microarthropod assemblages under different arable crop rotations in Alberta, Canada. – *Applied Soil Ecology*, 38(1): 71-78.
- [79] Prinzing, A., Kretzler, S., Badejo, A., Beck, L. (2002) Traits of oribatid mite species thattolerate habitat disturbance due to pesticide application. – *Soil Biology & Biochemistry* 34(11): 1655-1661.

- [80] Reynolds, B.C., Crossley, D.A., Hunter, M.D. (2003): Response of soil invertebrates to forest canopy inputs along a productivity gradient. – *Pedobiologia* 47(2): 127- 139.
- [81] Salmon, S., Mantel, J., Frizzera, L., Zanella, A. (2006): Changes in humus forms and soil animal communities in two developmental phases of Norway spruce on an acidic substrate. – *Forest Ecology and Management* 237(1-3): 47-56.
- [82] Scheu, S., Schulz, E. (1996): Secondary succession, soil formation and development of a diverse community of oribatids and saprophagous soil macro-invertebrates. – *Biodiversity and Conservation* 5(2): 235-250.
- [83] Seniczak, S., Dabrowski, J., Dlugosz, J. (1995): Effect Of Copper Smelting Air Pollution On The Mites (Acari) Associated With Young Scots Pine Forests Polluted By A CopperSmelting Works At Giogow, Poland. I. Arboreal Mites. – *Water, Air, and Soil Pollution* 94(3-4): 71-84.
- [84] Seniczak, S., Bukowski, G., Seniczak, A., Bukowska, H. (2006): Soil Oribatida (Acari) of ecotones between Scots pine forest and lakes in the National Park „Bory Tucholskie”. – *Biological Lett* 43(2): 221-225.
- [85] Siepel, H. (1995): Are some mites more ecologically exposed to pollution with lead than others? – *Experimental and Applied Acarology* 19(7): 391-398.
- [86] Siepel, H. (1996): Biodiversity of soil microarthropods: The filtering of species. – *Biodiversity and Conservation* 5(2): 251-260.
- [87] Skubala, P., Kafel, A. (2004): Oribatid mite communities and metal bioaccumulation in oribatid species (Acari, Oribatida) along the heavy metal gradient in forest ecosystems. – *Environmental Pollution* 132(1): 51-60.
- [88] Stamou, G.P., Asikidis, M.D., Argyropoulou, M.D., Iatrou, G.D. (1995): Respiratory Responses of Oribatid Mites to Temperature Changes, *Journal of Insect Physiology* 41(3): 229-233(5).
- [89] Steiner, W.A. (1995): Influence of air pollution on moss-dwelling animals: 3. Terrestrial fauna, with emphasis on Oribatida and Collembola. – *Acarologia* 36(2): 149-176.
- [90] Straalen, N.M., Butovsky, R.O., Pokarzhevskii, A.D., Zaitsev, A.S., Verhoef, S.C. (2001): Metal concentrations in soil and invertebrates in the vicinity of a metallurgical factory near Tula (Russia). – *Pedobiologia* 45(5): 451-466.
- [91] Sulkava, P., Huhta, V. (2003): Effects of hard frost and freeze-thaw cycles on decomposer communities and N mineralisation in boreal forest soil. – *Applied Soil Ecology* 22(3): 225-239.
- [92] Taylor, A.R., Schröter, D., Pflug, A., Wolters, V. (2002): Response of different decomposer communities to the manipulation of moisture availability: potential effects of changing precipitation patterns. – *Global Change Biology* 10(8): 1314-1324.
- [93] Taylor, A.R., Wolters, V. (2005): Responses of oribatid mite communities to summer drought: The influence of litter type and quality. – *Soil Biology & Biochemistry* 37(11): 2117-2130.
- [94] Trueba, D.P., Gonzalez, M.M.V., Aragonés, C.R. (1999): Soil mesofaunal communities from a periodically flooded lowland forest in the Si'an Kaan, Biosfere Reserve, Quintana Roo, Mexico. – *Revista De Biología Tropical* 47(3): 489-492
- [95] Tsiafouli, M.A., Kallimanis, A.S., Katana, E., Stamou, G.P., Sgardelis, S.P. (2005): Responses of soil microarthropods to experimental short-term manipulations of soil moisture – *Applied Soil Ecology* 29(1):17 26
- [96] Uvarov, A.V. (2003): Effects of diurnal temperature fluctuations on population responses of forest floor mites. – *Pedobiologia* 47(4): 331-339.
- [97] Valix, M., Tang, J.Y., Malik, R. (2001): Heavy metal tolerance of fungi. – *Minerals Engineering* 14(5): 499-505.
- [98] Walter, D.E., Proctor, H.C. (1999): *Mites: Ecology, Evolution and Behaviour*. – CABI Publishing, Wallingford. 322pp.

- [99] Webb, N.R., Coulson, S.J., Hodkinson, I.D., Block, W., Bale J.S., Strathdee, A.T. (1998): The effects of experimental temperature elevation on populations of cryptostigmatic mites in high arctic soils. – *Pedobiologia*, 42(4): 298-308.
- [100] Zaitsev, A.S., van Straalen, N.M. (2001) Species diversity and metal accumulation in oribatid mites (Acari, Oribatida) of forests affected by a metallurgical plant. – *Pedobiologia* 45(5): 467-479.
- [101] Zaitsev, A.S., Chauvat, M., Pflug, A., Wolters, V. (2002): Oribatid mite diversity and community dynamics in a spruce chronosequence. – *Soil Biology & Biochemistry* 34(12): 1919-1927.