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<https://doi.org/10.59531/ots.2024.2.1.59-95>

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## ECOLOGICAL INDICATION POTENTIAL OF ORIBATID MITES [ÖKOLÓGIAI INDIKÁCIÓ LEHETŐSÉGEI PÁNCÉLOSATKÁK ALAPJÁN]

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**Abstract.** Ecological indication potential of oribatid mites has been emphasized by researchers for several decades. These small arthropods possess biological characteristics through which they are able to indicate different changes in their environment. Oribatid mites can be found in almost every kind of habitat worldwide: terrestrial and aquatic habitats, and a lot of types of microhabitats (e.g. soil, lichen, moss, tree bark, foliage). Apart from the diversity of habitats, their huge adaptation ability is also shown by great abundance and species richness. In most habitats, they constitute the largest proportion of microarthropods. This study deals with works whose results point to the characteristics of oribatid mites that would allow their wider use in the ecological indication than at present.

**Keywords:** biodiversity, soil zoology, community structure, fauna, ecological role

### Introduction

Oribatids are an order of mites (Acari), one of the largest groups of soil microfauna regarding species number. Around 12 000 species are known, but many more are still to be described (Schatz and Behan-Pelletier, 2008). Their size generally ranges from 0.2 to 1.4 mm (Hoy, 2008). Juveniles do not have a thick cuticle yet and are light-coloured. Mature specimens are more pigmented, with various shades of yellow, orange and brown. Their body is mostly round or oval, but cylindrical and triangular species also occur. In dorsal view, two body plates can be distinguished, the frontal prodorsum and the notogaster. They have numerous hair-like formations on their body surface, which act as mechanical receptors or serve to repel predators; their number and arrangement are taxon-specific and therefore important in their identification (Alberti, 1998). Ventrally, genital and anal plates can be observed, but in some families, there is only one common plate. Oribatids are able to retract their legs and gnathosoma into the cavity of the idiosoma and encapsulate by deflecting the prodorsum (ptychoidy). In this case, only the hard cuticle is exposed to predators outwards, providing effective protection for the mite (Schmelzle et al, 2015). Mites are unique among chelicerates regarding their reproductive potential, diversity of

**Opuscula Theologica et Scientifica 2024(2)1: 59-95.**

A Wesley János Lelkészképző Főiskola Tudományos Közleményei

[Scientific Journal of John Wesley Theological College]

<https://opuscula.wjlf.hu/> • ISSN 2939-8398 (Online)

Mics: Ecological indication – [Mics: Ökológiai indikáció]

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reproductive strategies, genetic system and ontogeny (Norton et al, 1993; Walter and Proctor, 1999). Oribatids are diploid organisms (usually  $2n=18$ ). fertilization can be sexual (with the spermatophore being transferred from male to female) (Heethoff et al, 2006), or asexual type by parthenogenesis (Maraun et al, 2019). Larvae have six legs, however, protonymphs, deutonymphs, tritonymphs and adult specimens already have eight legs and 1-3 claws on the tarsus joint. Oribatid species reproducing by parthenogenesis are common. Parthenogenesis may have evolved several times during evolution with several other soil-dwelling groups. There is no definitive explanation as to why. Possible reasons could be reduced biotic interactions, stable habitat, and cellular mechanism such as holokinetic chromosomes with reverse meiosis. The cellular mechanism may be a prerequisite for the large number of asexual species (Maraun et al, 2004).

Oribatids are characterized by slow locomotion, slow metabolism, slow development and low reproductive rate with six larval stages. They are long-lived and reproduce several times during their lifetime (iteroparous). Their development rate depends on temperature, but is generally slower than that of other mites. Smaller species develop faster but have a shorter life span than larger species. Smaller species may have several generations per year. Larger-bodied species have one generation per year, but in cold climates, they may take several years to complete their life cycle (Hoy, 2008). They feed on living or dead plant parts, moss, lichen, and fungal filaments. Fungi produce exoenzymes to break down nutrients. Oribatids can utilize these exoenzymes during feeding (external rumen) (Swift et al, 1979). There are both scavenger and predator species, but parasitism is not present. Feeding of specimens at different stages may also differ from each other (Schneider et al, 2004).

The larvae of some species are strictly endophagous in tissues of higher plants, while mature specimens live freely in the leaf-litter on completely different food sources (Migge et al, 1998). Two different modes of consumption can be observed in species that consume fungi. In the first case, the animal pierces the fungal filaments or spores and actually drinks their content. In the second case, the animal consumes the cell wall completely. In the gut of these species, chitinase-producing bacteria can be isolated (Smrž, 2013). A wide variety of enzymes have been described from their organisms, such as glucanase, cellulase, chitinase, trehalase, amylase, xylanase, laminarinase, and lichenase activity has also been found in different species. The activity is, of course, dependent on the food recently consumed, and the utilization of exoenzymes must also be taken into account (Luxton, 1972; Luxton, 1979; Siepel and de Ruiter-Dijkman, 1993; Urbasék and Stary, 1994; Zinkler, 1971). In invertebrates, it is common that fatty acids are directly incorporated into the body from the diet and not synthesized de novo. Therefore, it is possible to infer the diet of oribatids and their role in the food chain from fatty acids. Saturated fatty acids longer than 20 carbon atoms and C16:1Δ9, C18:1Δ9, C18:3Δ9,12,15 molecules are the most suitable for this purpose. The ratios vary in different food sources and may therefore indicate the trophic level of a particular Oribatida species (Brückner et al, 2017).

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Kaneko (1988) classified the species into microphytophagous, macrophytophagous, panphytophagous and scavenger groups according to the size and shape of the chelicerae. Scavengers feed mainly on fragments of plants already broken up by other species. The feeding habits of the species can be inferred from the characteristics of the chelicerae. Anther classification is based on the presence or absence of certain enzymes (cellulase, chitinase and trehalase), from which the food utilisation can be inferred. Thus, a distinction can be made between grazers and browsers. The former can consume and digest both the cell contents and the cell wall. The latter consumes only the cell contents (Siepel and de Ruiter-Dijkman, 1993.) The presence of enzymatic activity is essential, without this the utilisation of the food cannot take place. However, there are also examples where the animal uses the enzyme only to access the food. It breaks down the cell wall with it, but does not utilize the products produced during the enzymatic breakdown of the cell wall, only the nutrients found inside the cell (Siepel, 1990).

Fossil remains of oribatids are also known from 410-million-year-old rocks dating back to the Devonian period. Even then, they were present in the developing terrestrial ecosystems (Norton et al, 1988). The molecular clock estimates that they have been present on Earth since the Precambrian (571±37 million years) (Schaefer et al, 2010). The early species were not as well sclerotised as modern species, but the formations on the body surface (setae) were similar and served to keep predators away (Subías and Arillo, 2002). Measured on an evolutionary timescale, the thick, sclerotised cuticle and various defence mechanisms that characterise them evolved in a short time (Norton, 2007). It is likely that these defence mechanisms are responsible for their radiance and distribution on Earth (Pachl et al, 2012). Traces of animal burrowing and coprolites are often observed on fossil plant remains (Rößler, 2000). Feng et al. (2015) observed oribatid burrows in a well-preserved fossil of a gymnosperm species from the Permian (Manebach Formation, Germany). The burrows are rectangular in cross-section with smooth walls, and ovoid or spherical coprolites are common in them. The burrows can be mainly observed in tracheids in the highly lignified cell wall. The animal probably consumed the cell walls primarily, rather than the parenchyma cells, which contain less lignin. Based on the position and arrangement of the burrows and coprolites, it is likely that the burrows were made in the already fallen, non-living wood lying horizontally. Oribatids may have already played a major role in the decomposition of organic matter at that time. Knowing the feeding habits is very important in order to map the relationships of the living beings that made up ancient ecosystems.

Oribatid mites play a major role in improving soil quality and maintaining good soil quality. In order to restore degraded soils, the activity of decomposing organisms in the soil needs to be increased to optimal levels. There are several projects to improve degraded soils and ensure their sustainable use in the future, such as the SWIFT programme (Studies of Human Impact on Forest and Floodplains in the Tropics). The programme aims to create an

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economically and ecologically viable system by planting fruit trees and species for timber production (Junk and Furch, 1993). Any agricultural practice that maintains soil health and balanced nutrient levels is very important for the food supply of mankind. Conservation or restoration of natural soil fauna is essential to protect good quality farmland (Haq, 2016). Haq (2019) developed an oriculture using *Vigna unguiculata* plants, investigating the soil amendment ability of oribatid mites. The improvement in soil fertility resulted in faster plant growth, with an average increase in pod length of 2 cm. Oribatid activity had a positive effect on soil quality, resulting in increased yields.

### Terrestrial and aquatic habitats

Few groups have been able to make the transition to a fully marine lifestyle, such as the family Halacaridae (Trombidiformes: Arachnida), whose members can even be found in the bathyal and abyssal zones (Bartsch, 2004). These are really marine organisms, however, there are also many species in the littoral zone, which have not fully converted to aquatic life yet, living intermittently in the water due to tidal movements. The superfamily Ameronothroidea represents the oribatid mites of the coastal environment, they are typical members of the littoral fauna with 17 genera and 84 species (Subías, 2004). Ameronothroidea species colonise a wide range of microhabitats in the littoral zone, even if this means only short spatial distance. In the case of long distances, a latitudinal distribution is also observed. In the case of species at lower latitudes, the attachment to the littoral environment is more pronounced. At higher latitudes, this is less pronounced, with affinity for terrestrial environments also observed (Marshall and Convey 2004; Schulte et al, 1975). They also colonise brackish and freshwater (Schulte et al, 1975). In tropical areas, stenotopic species are more common, with mangrove forests being one of their most important habitats (Karasawa and Hijii, 2004). Intertidal species are resistant to fresh and salt water and can tolerate flooding for weeks or even months (Pfungstl, 2013b; Schuster, 1979). They are poikilosmotic, i.e, they have osmotic pressure in the haemolymph similar to that of the surrounding water, and can regulate that by adapting to the environment (Karasawa and Hijii, 2004). They use the coaxial glands for osmoregulation and are able to reduce ion reuptake (Alberti and Storch, 1977; Woodring, 1973). Also, oribatids in the littoral zone have a surprisingly high dispersal capacity, individuals of a given species can be found at very large distances from each other on the coast (Pfungstl et al, 2019). Species adapted to this environment feed primarily on algae, with a wide range of species in their diet; *Pleurococcus*, *Chlorococcus*, *Lyngbia*, *Rhizoclonium*, *Enteromorpha*, *Prasiola* and *Porphyra* species were described as food sources (Peckham, 1967; Schulte, 1976a; Pugh, 1995; Pfungstl, 2013a). They also consume lichens, but primarily the phycobiont, i.e, the algal component of the lichen is their food (Bücking et al, 1998). In the case of some species, blue-green algae are the main food source, i.e, they are consumers of prokaryotes (Schuster, 1979; Søvik, 2004; Krisper and Schuster, 2008). However, the consumption of eukaryotic algae is more typical. It is often

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observed that the diet of the animal changes with its development. In *Ameronothrus* species, adults and tritonymphs consume macroalgae, while larvae, protonymphs and deutonymphs consume microalgae, often resulting in spatial segregation (Schulte, 1976a; Bücking et al, 1998). Habitat type is also a determinant of food choice. *Ameronothrus* species living in the rocky intertidal zone consume mainly epiphytic algae, species living in the supralittoral zone prefer lichens, while species in salt marshes consume fungi (Schulte, 1976a). In species of this genus, both feeding and faecal excretion are synchronised with the tidal rhythm. They feed at low tide and rest at high tide. Specimens living in the eulittoral zone are submerged for longer periods of time; they often begin feeding before low tide, as they have less time for this activity than individuals living higher up (Schulte, 1976b).

In wetland habitats, mites need to adapt to changing water levels, oxygen-depleted saturated or drying soils, often saline water and changes in salt concentration. Therefore, relatively few species live in such areas, most of them being cosmopolitan and broadly tolerant. The community structure is simple, with an uneven distribution and low diversity, indicating instability and disorder of the biocoenosis (Seniczak, 2011). Marshes and swamps are one such habitat. In tidal marshes, the number of floating vegetation can reach 304,800 individuals per square metre (Eitminavičiūtė, 1966) while in minerotrophic marshes it is 18 times lower (Seniczak et al, 2016). In these areas, aquatic and hygrophilous species such as *Limnozetes* dominate, while in degraded areas, species with high tolerance appear (Sidorchuk, 2008). The pH and nutrient content of the water determine the composition and abundance of the Oribatida community. The difference between ombrogenic and minerotrophic wetlands can be significant (Seniczak et al, 2019). Peat moss provides habitat and food for mites, but in minerotrophic marshes, sedges and cattails are the dominant vegetation, which provide less favourable conditions and therefore lower abundance (Markkula et al, 2019). Thus, the vegetation is another factor that has a major impact on Oribatida. Of course, abundance and species composition also vary seasonally. In winter, cold-tolerant species that require less water become dominant as ice drastically changes the character of the area, but Oribatid species do not disappear, and some species are even able to reproduce in winter (Seniczak et al, 2016). Water scarcity also occurs due to increasing summer droughts caused by climate change, which favours the proliferation of species with high tolerance (Markkula et al, 2019). Marshes, swamps and other wetlands influence micro- and mesoclimates, acting as islands without the extreme temperature fluctuations of areas further away (Hodgkins et al, 2018). Riparian zones are very species-rich, with species being very sensitive to any disturbance, pollution in the catchment or impacts associated with changes in water levels (Weilhoefer and Pan, 2007). Riparian zones link many terrestrial and aquatic ecological processes, influencing the physical, chemical and biological characteristics of rivers (Talley et al, 2006). There is a continuous flux of material and energy between the terrestrial and aquatic components of the ecosystem (Wallace et al, 2015). These areas are also suitable for studying the impact of human activities, such as water and air

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pollution. Indicator species can be very well used for this purpose. Vacht et al. (2018) used Oribatida mites and diatom algae simultaneously to study the impact of mine effluents. Both mite abundance and algae species composition differed according to the pollutant concentration. But the two taxa responded slightly differently to the toxic heavy metals released, suggesting that the two groups complement each other, and the different responses may provide new information for site restoration professionals. Using the two groups together will allow more accurate bioindication. To protect ecosystems, a metric is needed to designate a buffer zone that protects both aquatic and terrestrial resources from disturbance (Hickley and Doran, 2004). Oribatid mites may be suitable for this purpose, as there can be significant variation in Oribatid mite abundance along a transect away from the river. This in turn indicates changes in microclimate and soil water saturation (Clinton et al, 2010). Invasive plant species such as acacia (*Robinia pseudoacacia*) and palmetto (*Ailanthus altissima*) are also becoming more common in wetlands. Due to their specific characteristics, floodplain ecosystems are highly susceptible to invasive plants (Pinto et al, 1997). The emergence of invasive plants is a serious ecological threat, which also entails changes in the composition of the soil fauna. The presence of native species often allows a more species-rich soil fauna to persist. After the invasive plant has been introduced, the soil fauna becomes poorer, which is an adaptation to the changed conditions, as the new vegetation also affects biogeochemical cycles (Gutiérrez-López et al, 2014).

### Feeding habits

The degradation of organic matter depends on the quality of the material being degraded, the climate and the composition of the degrading community (Anderson and Swift, 1983). The mass of organic matter to be decomposed provides habitat for the decomposing organisms, however, the species composition varies with climate, which affects the rate of decomposition (Howard and Howard, 1980). Oribatids can be grouped according to their food source. The plant consuming species can be macrophytophages, i.e, they consume higher plants; microphytophages, i.e, they consume algae of microscopic size (microflora) primarily; and panphytophages, which consume both (Olszanowski and Niedbała, 2000). Observation of feeding habits is important to understand the role of organisms in the ecosystem and in the decomposition of organic matter. Due to the large number of species, a wide variety of life strategies and feeding habits can occur in an ecosystem (Hättenschwiler et al, 2005). Our current knowledge is based on the observation of the diet, diet preference tests, gut content tests, digestive enzyme tests, faecal analysis, or a combination of these (Badejo and Akinwale, 2007; Meier et al, 2008; Wickings and Grandy, 2011; Velez et al, 2018). More recently, molecular methods such as PCR-based techniques have been used in order to identify dietary species. The PCR reaction is very sensitive, and even very small amounts of hereditary material can be detected using it. However, the problem is that it is not easy to distinguish the origin of amplified DNA. In other words, it

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is difficult to distinguish whether the DNA and the fungus originates from the intestine or the body surface of the animal (Remén et al, 2010). In addition to molecular techniques, the isotopic composition of the food is also worth investigating. The ratio of stable isotopes shows the long-term trophic relationships in the community. Animal tissues are usually richer in  $^{15}\text{N}$  isotopes than their food source by an average of 3.4  $\delta$  units (DeNiro and Epstein, 1981; Post, 2002). Schneider et al. (2004) found in a study of 36 species that  $\delta^{15}\text{N}$  shows a gradient of 12  $\delta$  units, reflecting the trophic level and niche occupied by different species. Even the  $\delta^{15}\text{N}$  signal of species belonging to the same genus can be very different. The trophic level and niche occupied by a species appears to be independent of the habitat in which it lives. Differentiation within a taxonomic group contributes significantly to the establishment and maintenance of diversity. In many cases, niche differentiation can explain the emergence of diversity (Erdmann et al, 2007), however, there are cases where the results are contradictory. Some studies suggest that there may be a high diversity of their food sources (Scheu and Falca, 2000). Others have found a preference for so-called dark-pigmented fungi, often with a different preference among different Oribatida species ('Dematiaceae') (Maraun et al, 2003; Hubert et al, 2004). Farid (2019) investigated the development of Oribatida species *Nothrus silvestris* by feeding it with the preferred *Rhizoctonia solani* and *Alternaria alternata*, and with less preferred species (*Aspergillus fumigatus*, *Penicillium italicum*). When fed with the less preferred species, development slowed down and fecundity decreased, i.e. fewer eggs were laid. The diet of the species *Hyadesia fusca* covers a very wide range of food sources, including diatoms, lichens, detritus, blue, red and green algae, but not all food sources are equivalent regarding their quality. This species is seemingly generalist, however, different food sources affect length of life, mortality, egg numbers and reproductive success. Consumption of the algae *Blidingia* (Ulvaceae) resulted in the lowest mortality and was more frequently selected in preference tests. The prevalence of these algae in the intertidal zone correlates with mite occurrence (Bücking, 1998). In the case of decomposing organisms, such as oribatids, preference also depends on the stage of decomposition at which the residue to be consumed is. The tannin, polyphenol and lignin content of freshly fallen leaves makes them more difficult for decomposers to consume. Some species show a preference for certain plant remains at a certain stage of decomposition. Pande and Berthet (1973) investigated the preference of xylophagous *Microtritia minima*, *Rhysotritia duplicata* and *Phthiracarus* species in pine forests. *Phthiracarus* sp. was the first to consume dead plant remains. The other two species consumed organic matter only in the later stages of humification. A generalist species, *Archezogetes longisetosus*, was reared on four different food sources (Chlorella powder, lupin flour, wheatgrass powder and yeast) and then, adults were offered the others. They showed preference for the lupin flour with the highest fatty acid content. The fatty acid content is probably an olfactory stimulus for the animal. Thus, it was not possible to develop an imprinted preference for the diet on which they were reared, not even by rearing a group

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through four generations before offering them the other three food sources (Brückner et al, 2018). For an opportunistic species, this would not even be advantageous, as the available food source can often vary and is patchy in arrangement, and availability is also influenced by the presence and density of competitors (Hassall et al, 1986; Hodge, 2006).

Density significantly affects fecundity. Khalil et al. (2011) investigated egg number as a function of density. In *Scheloribates laevigatus*, there was a positive correlation between density and number of eggs per individual. The correlation was negative in the case of *Xylobates lophotrichus*. No correlation was found for *Zygoribatula undulata*. Analysis of the intestinal content of *Scheloribates laevigatus* showed that this species has the widest niche and *Xylobates lophotrichus* is the most specialised in terms of food source. The relationship between number of eggs and density of individuals is influenced by feeding habits. In the case of the specialist species, the relationship between density of individuals and fecundity is negative. As for the broad niche, the relationship is rather positive. Thus, feeding habits have a strong influence on population dynamics.

### General ecology

Oribatids are present everywhere, regardless of soil type, nutrient content and climatic conditions (Ivan, 2017). In general, species richness increases with increasing moisture, humidity and soil humus content (Murvanidze et al, 2011). Their ecological status and the diverse feeding guilds allow them to be important members of soil fauna in all climate zones (Behan-Pelletier, 2003). They are dominant members of the upper soil layer, with up to several hundred thousand individuals per square metre (Norton, 1990). The number of species and individuals is therefore influenced by climate, soil type, pH and vegetation, i.e. the plant species which constitutes the leaf-litter to be decomposed (de Moraes et al, 2011). Hågvar (2020) found the following values in the top 6 cm of soil of a taiga forest in Norway after 8 replicates: Prostigmata 490 000, Oribatida 220 000, Astigmata 10 000. So, on average, 720 000 mites were present per square metre. In extreme cases this number could be as high as 1 200 000 according to an earlier measurement by the author (Hågvar and Amundsen, 1981). In a similar habitat in nearby Finland, the number of oribatids per square metre varied between 186 000 and 351 000, and in Sweden it reached 425 000 (Persson et al. 1980; Huhta et al, 1986). The number of individuals per square metre can be tens of thousands even in tundra. Melekhina et al. (2021) found 63,553 individuals per square metre in dwarf birch tundra (65° 16' 47" N, 60° 04' 50" E; 567.6 m a.s.l.). Even in the case of very low average annual temperatures (4 °C) and long snow cover (240-250 days), oribatid mites are very important components of the fauna. Coulson et al. (1996) observed the effects of temperature manipulation on Oribatida and Collembola populations in the Spitsbergen. They observed the response of fauna living in desert areas free of vegetation as well as in areas covered with tundra vegetation to elevated temperatures. After three summers in the desert area, the number of springtail species decreased significantly, but not the number of oribatids. In



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the desert area, soil is not protected by vegetation and therefore dries out more quickly. Springtails were more vulnerable to desiccation, so their number decreased. Oribatids are less susceptible to desiccation and due to their slow development, one year is not enough to complete their life cycle. Therefore, their response to desiccation and higher temperatures is not as pronounced as in the case of the springtails. Cassagne et al. (2008) obtained similar results in a study on pine forest soils (La Plagne en Chartreuse, Savoy, France, 1100-1200 m). A long-term increase of 3.8 °C on average changed both the flora and the soil fauna composition. In Egypt, El-Sharabasy (2013) (30° 58' N and 32°23' E 13 m) found more species and higher densities in winter. Oribatid abundance decreased in summer due to high temperatures and low water content. In Egypt, rainfall is low but soil moisture is higher in winter. Density negatively correlated with temperature. In summer, high temperatures also made it difficult for oribatids to reproduce. High temperatures also hinder mating and increase sperm mortality, resulting in population decline (Badejo, 1990). According to Sharma and Paewez (2018), in Aligarh, India, the density and diversity of oribatids is the lowest in winter due to low soil temperature. Here, low winter temperatures reduce the number of individuals and species. In Greece, at Mount Holomon (40°26'N and 23°34'E 470 m), Tsiadouli et al. (2005) increased soil moisture in rainfall manipulation experiments, alleviating drought. Both mite and springtail numbers increased with higher soil moisture compared to controls. This was partly due to immigration, both horizontally and vertically. On the other hand, individuals in dormancy also became active due to higher-than-average moisture and lower soil temperature.

pH is also an influencing factor, which depends on bedrock among others (Jakšová et al, 2019). Soil pH depends on the decomposition processes of organic matter, including the mass of fallen needle leaves (Ashman and Puri, 2002). Soil acidity is determinant for the Oribatida community. They tolerate low pH, the effect is rather direct. Other soil fauna groups may disappear from acidic soils or colonisation of such soils may be slower (Erdmann et al, 2012). Acidity is an important determinant of the composition of soil fauna, however, the response of mites to changes in pH is not as pronounced as that of earthworms, for example (van Straalen, 1998). The response of individual species also depends on changes in other environmental factors and is context-dependent (Liiri et al, 2002). As edaphic communities, peat bogs are also common in cold climates. A common feature of peat bogs and zonal pine forests is the low soil pH. The number of Oribatida species is also similar and several common species have been observed (Wisdom et al, 2011). In peat bogs, peat moss (*Sphagnum* sp.) stems are the optimal microhabitat at low pH (4-5) and the most stable community is found here. In addition to acidity, oxygen deficiency is also a factor that must be tolerated by the species (Belanger, 1976; Behan-Pelletier and Bissett, 1994). Oxygen, water and organic matter content as well as temperature vary downwards in the soil. Therefore, the Oribatida community also shows a vertical arrangement in the soil. The top layer, which contains the most organic matter, has the highest abundance and the most

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species (Jakšová et al, 2019). The organic matter content of the soil is determined by the vegetation that covers it, as the decomposing plant parts are the source of the organic matter content. The oribatid community is organised along the successional gradient, with an increase in the number of individuals and species richness as the plant biomass per unit area increases (Noti et al, 1996). Noti et al. (2003) assessed the species richness of the Oribatida community in primary forest, miombo vegetation and savannah in Luiswishi, Democratic Republic of Congo. A total of 149 species were found, of which 47 species occurred in all three vegetation types. 29 species occurred only in the savannah, 24 only in the forest and 7 species only in the miombo vegetation. Within the vegetation types, the fewest species were found on vegetation-free soils and the most on termite mounds. This is probably explained by the accumulation of debris here, different C/N ratios and soil structure. So, there are microhabitats which are exceptions, but in general, as plant biomass increases, species richness increases. Also in Finland, decaying wood and anthills have been found to be the most species-rich microhabitats within the forest (Penttinen et al, 2008). In these cases, organic matter accumulated by other animal species also affects abundance.

Average annual rainfall determines both soil moisture and air humidity. In Mongolia, the number of species decreased with increasing aridity (from 381 mm to 201 mm) in steppe, i.e. treeless communities (Bayartogtokh, 2005). In months with more rainfall, the density of oribatids also increases. Density varies seasonally, following changes in rainfall (Badejo and Akinwole, 2006). The water holding capacity of the soil is also important for the soil fauna. If the water holding capacity of the soil is poor, precipitation will run off quickly and will not be available for a longer period of time for flora and fauna. The community in such areas is adapted to dry conditions and fluctuating moisture content and temperature. Thus, even a potential extreme drought has only a minor impact on the community (Flórián et al, 2019). Lindberg (2003) conducted similar experiments at two different locations in Sweden (Skogaby, 56° 33' N, 13° 13' E and Flakaliden, 64° 07' N, 19° 27' E), manipulating precipitation, but in contrast to the experiments by Flórián (2019), in a spruce forest (*Picea abies*). In Skogaby, irrigation caused an increase in both density and number of species in other groups of soil fauna (Collembola, Mesostigmata, Enchytraeidae) besides Oribatida. In Flakaliden, however, irrigation did not cause a positive change in community composition. Artificially induced drought caused a significant decrease, but drought tolerant species became dominant. The difference in the community response can be explained by the fact that the intensity of the treatment is different when considered in the context of natural rainfall conditions. Groundwater levels also fluctuate with the seasons and groundwater table height is influenced by the distance from water bodies. Water levels of lakes and rivers correlate with groundwater levels. Vertically, the distance from the groundwater table is also important in shaping the community. In saturated soils, lack of oxygen is not favourable for soil fauna. At high groundwater tables, hygrophilous species will dominate, and at low groundwater tables, species preferring drier, warmer conditions will predominate (Irmeler,

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2004). Soil moisture content is also determined by topography, valleys accumulate precipitation and the moisture content is higher there, however, in some cases the soil can also become saturated, which tends to reduce the density (Minor and Ermilov, 2015). Changes in community composition are not only related to soil, but also to vegetation. Lindo and Winchester (2008) found the proportion of species living on trees to be 20 percent in temperate rainforests in Washington State. Thus, Oribatida communities have established in the canopy of *Thuja plicata* that are significantly different from ground-dwelling communities and are not just a random subset of ground-dwelling species. The large surface area of the tree canopy also provides habitat for mites. Within the canopy of a given tree, a variety of microhabitats with different characteristics can occur. Heterogeneous environments, in turn, allow for greater diversity. Thus, there may be greater diversity within the crown of a given tree than between similar microhabitats of two trees (Behan-Pelletier and Walter, 2000). In rainforests, epiphytes also provide habitat for oribatids living in the canopy. Therefore, species living here have to be added to the species number of a given area in order to obtain an accurate picture of the species richness of the area (Franklin and Albuquerque, 2006). High up in the tree canopy, temperature and humidity change more rapidly than in the soil, to which the species living there must also adapt. Diurnal inactivity in groups is a behavioural response to this environment. Animals are active at night when temperatures are lower and humidity is higher. Also, the outgrowths and formations on the body surface of the animals are smaller and more rounded compared to the species living on the ground. This counteracts the effects of the wind, they are also morphologically adapted to their habitat (Behan-Pelletier and Walter, 2000).

All four factors are influenced by topography. As altitude increases, diversity in mountains generally decreases, but vegetation and soil structure can also change with altitude (Fischer and Schatz, 2013). There are often exceptions to this. For example, Khabir et al. (2014) studied the species richness of oribatids in the mountains of Iran. At altitudes between 1750-2000 m (Ghooshchi: N 37° 01', E 45° 56'), they found more species (44) than at altitudes between 1300-1450 m (14) (Ordooshahi: N 37° 27', E 45°15'), and the total number of species found was 71. The average temperature in the higher sampling area is lower (5-7.5 °C) than in the lower area (10-12.5 °C), but the precipitation is more in the higher area (500-600 mm) than in the lower area (300-400 mm). The soil moisture content is also higher, which is more favourable for the Oribatida community. In contrast, Fischer and Schatz (2013) found fewer species at the highest sampling site in the Alps (Liebener Rippe: N 46°49.250', E 11°03.339', 2900 m a.s.l). This is not only due to the lower average temperature, but also to the rocky, stony lithosol and the sparse Androsacetum vegetation on the surface. At lower altitudes (Hohe Mut: N 46°50.081', E 11°02.801', 2600 m and Schönwieskopf: N 46°50.852', E 11°00.967', 2300 m), pasture with podzol soil and Nardetum, Caricetum vegetation, or pine forest (*Pinus cembra*, *Pinus mugo*, *Larix decidua*) (Zirbenwald: N 46° 51.542', E 11°00.990', 2050) with ferruginous podzol soil provide a more favourable

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environment for the soil fauna. In cooler and wetter areas, the density and species number are higher than in warm and dry regions. Soil water content is also higher in wet areas and the wet environment increases the biomass and diversity not only of oribatids but also of the entire mesofauna (Rahgozar et al, 2019).

The composition of the vegetation, i.e, the plant species that live in the given area, is also an influencing factor. Bluhm et al. (2019) investigated the effect of *Fagus sylvatica*, *Acer pseudoplatanus*, *Fraxinus excelsior* and *Tilia cordata* species on the species composition of the Oribatida community in a temperate deciduous forest (51°26'27"N, 10°01'03"E, 340 m). The leaves of the four species and the nutrient content of the fallen leaves differ, but no significant differences were found in the Oribatida community, so for some reason they do not benefit from the higher nutrient content. This may be because the decaying leaf-litter also abolishes the habitat where the mites live. This has an opposite effect on diversity. Another explanation is that the different nutrient content and structural differences are compensated for by the bacteria and fungi colonising the leaf. Abiotic factors seem to have a greater influence on the community, such as pH, thickness of the leaf-litter and the soil, moisture content and porosity. A third reason could be that the Oribatida species living there are not specialists regarding feeding, so the species on which they feed is less important than the physical characteristics of their habitat. There were no significant differences between populations of different tree species, however, within the population of a given tree species, there were already significant differences in microhabitats. There are several hypotheses to interpret this. One reason could be that the leaf-litter connects sporadically occurring microhabitats, where specialist species tend to occur. Another possible explanation is that the leaf-litter is itself a habitat with its own specific characteristics, which allows diversity to be maintained. The third hypothesis is that the leaf-litter is a source of biodiversity, from which different species may migrate to other microhabitats located in patches. All three may be involved in shaping the observed distribution, however, their relative importance may vary by taxon and habitat (Wehner et al, 2016). Fewer mites occur in tropical forest soils than in temperate forest soils (Petersen and Luxton, 1982). One explanation may be that there are more sexually reproducing species there (Maraun et al, 2007). Their reproductive rate is lower than that of the temperate species (Franklin et al, 1997), and the leaf-litter layer and the O layer are not as pronounced as in temperate forests either (Wang et al, 2019). Tropical pine forests do not quite fit into this trend. Compared to forests dominated by angiosperms, they have higher density and species richness due to the layer of accumulating, partially decomposed pine needles. According to a study by Minor and Ermilov (2017), in Bi Doup-Nui Ba National Park in southern Vietnam, the area dominated by *Pinus dalatensis* and *Pinus kesiya* species showed significantly higher Oribatida species number and density compared to the area dominated by angiosperm species. In these areas, the physical properties of the resulting leaf-litter are important in shaping the observed species richness and composition. In other cases, plant

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species and their root systems may also be determinants of species composition. Wissuwa et al. (2013) investigated the density and species composition in a field covered by *Medicago sativa*, *Taraxacum officinale* and *Bromus sterilis* in Central Europe. Soil under *B. sterilis* showed higher density, probably due to the high amount of fine rootlets and their microbiome. Here, the root architecture of certain plants was dominant.

The large-scale geographical distribution of oribatid mites is facilitated by the ability of birds to spread them in their plumage. They do not feed on the feathers or skin of birds, but feed on fungi living on the feathers. All forms of larvae have been found on the feathers, and they can complete their entire life cycle in the feathers, where they also reproduce (Krivolutsky and Lebedeva, 2004a). These authors found 146 Oribatida species on the feathers or in the nests of 150 bird species of the order Passeriformes. The most common species were *Hypochthonius rufulus*, *Tectocephus velatus*, *Scheloribates laevigatus*, *Palaearcus hystericinus* and *Trhypochthonius tectorum*, and they migrate from the ground or from the nest into the feathers of the bird. Fewer oribatids were found on the bodies of birds of prey (Falconiformes and Strigiformes) (46 Oribatida species on 19 bird species), which may be explained by the higher body temperatures, which may be too high for oribatid mites (Prinzinger et al, 1991). Among waterfowl, the highest number of oribatid mites was found on the body of cormorants (*Phalacrocorax carbo*) and great egrets (*Ardea alba*), with 12 and 18 species as well as 65 and 42 specimens, respectively. The most common species were *Palaearcus hystericinus*, *Liochthonius* sp, *Brachychthonius* sp, *Hypochthonius rufulus*, *Nothrus silvestris*, and *Malaconothrus egregious*. However, oribatids were not present on the specimens of parasitic jaeger (*Stercorarius parasiticus*), red-knobbed coot (*Fulica cristata*) and wild duck (*Anas platyrhynchos*) examined, but Prostigmata, Gamasidae and Collembola species were present there. Charadriiformes and Gruiformes species can travel very long distances as migratory birds, thus, oribatid mites can also travel very long distances. On the 16 bird species, 38 Oribatida species were found, but several of them was represented by only one specimen. Among the Galliformes, 40 Oribatida species were found on the feathers of the hazel grouse (*Tetrastes bonasia*), the black grouse (*Lyrurus tetrrix*) and the western capercaillie (*Tetrao urogallus*), so in these cases, oribatid mites are quite common members of the epifauna. In contrast, no oribatids were found in the epifauna on the feathers of the grey partridge (*Perdix perdix*) (Krivolutsky and Lebedeva, 2004b). The physiological characteristics and behaviour of the bird species, i.e, how often and how they clean their feathers, is an important factor in the formation of the epifauna.

These data provide important information not only on the distribution of oribatids, but also on the birds themselves. As different indicators, they show the geographic distribution of the population and the migratory route. Travelling on birds, oribatid mites may occur beyond their known distribution range. For example, travelling on the feathers of swans (*Cygnus olor*), *Hermannia reticulata* has reached as far as Krasnodar, Russia. Or

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*Sphaerochthonius splendidus*, a Mediterranean species, has reached Belarus with the help of corncrakes (*Crex crex*) (Krivolutsky and Lebedeva, 2004a).

### Ecological indication

Once agriculture or any kind of disturbance has ceased, succession begins. The number of individuals and the number of species of oribatids in the soil changes, which does not necessarily mean an increase. At the beginning of the succession, generalist species are abundant and constitute a large proportion of the community, but as the succession progresses, their density decreases (Zaitsev et al, 2006). The limited presence of resources, competition and predation are then influencing factors (Caruso et al, 2012). After some time, the number of species, the species composition of the community will return to near-natural levels. The extent to which an area has been degraded can be indicated by the presence or absence of species known as indicator species. The taxon chosen should be diverse and abundant, representing several functional guilds and several levels of mobility. Mobility allows them to move away from the site of disturbance when environmental conditions change adversely. Less mobile species indicate microhabitat change, while species with higher mobility indicate fragmentation and general, overall change. Furthermore, the indicator taxon should be selected so that the results obtained from its study are comparable to those from other geographical regions, i.e, the effect of geographical distance on the community composition should be relatively small (Gerlach et al, 2013). Indicators of ecological integrity can be found at the species, population, landscape and ecosystem level (Niemi and McDonald, 2004). The methodology of identifying indicator species is reviewed by McGeoch and Chown (1998). The food consumed by oribatids may vary with age, so they may feed at several trophic levels. Their mobility is quite low, and they can only travel short distances by active locomotion. Intraspecific and interspecific competition, resource sharing, predation, dispersal limitation, diversity of vegetation and ecological niches, phoresis, habitat type as well as trophic resource complexity all influence the variability of indicator species (Gulvik, 2007; Gergócs and Hufnagel, 2009). As the Oribatida order is highly species-rich, this taxon is an ideal indicator of the extent of human disturbance. The abundance and diversity of oribatids can be an indicator of soil condition and the harmful impact of human activity (Gulvik, 2007). Biological indicators can be grouped into three categories. The first one is the so-called environmental indication, where certain species respond in a predictable way to environmental disturbances and changes. In the case of ecological indication, a given species is proven to be sensitive to a pollutant or habitat fragmentation. And finally, in the case of the biodiversity indication, the species richness of a particular taxon is used as an indicator of the species richness of the whole community (Gerhardt, 2012). Oribatids can be used to assess the damage caused by human activities. The soil fauna is highly sensitive to human disturbance, which should be taken into account in soil management. At the same time, it can indicate the extent of damage caused by human

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activity (Behan-Pelletier, 1999). The indicator taxon should reflect changes in environmental conditions, especially those related to disturbance. Most species are highly sensitive to human activity. Their numbers are rapidly declining in such areas. The distribution of species correlates with changes in environmental factors. There are dominant species with a wide range of tolerance which occur almost everywhere, but there are also species with a narrow range of tolerance which have specific habitat requirements. These occur in a smaller number of individuals, but their occurrence indicates the characteristics of their environment. They are more suitable for assessing the condition of the environment and the soil. Disturbance increases the number of thelytokous species having a wider range of tolerance in the community (Ruf and Beck, 2005). In order to determine the ecological status of an ecosystem, it is important to know the natural variation of biotic and abiotic factors over time in order to distinguish them from changes caused by anthropogenic influences (Sandlund and Aagaard, 2004). Oribatid mites are fairly easy to handle in the laboratory and are large enough that the accumulation and impact of contaminants can be easily studied (Van-Camp et al, 2004). The size of Oribatida species is also an important parameter for determining whether they are suitable as indicators. Epedaphic and hemiedaphic species are generally larger than euedaphic species. Due to their small size, euedaphic species move more easily among soil particles. This also makes them more resistant to damaging environmental effects. Therefore, the proportion of euedaphic species within the Oribatida community increases in contaminated areas compared to pristine areas (Andrievskii et al, 2015). They play an important role in nutrient cycling, soil formation and the maintenance of the soil structure (Wickings and Grandy, 2011). They are also important indicators of soil health as well as the degradation by human activities (Behan-Pelletier, 1999). They may therefore also be suitable for use as model organisms in ecotoxicological tests. This, however, requires knowledge of the genome and transcriptome in order to understand the response of an organism to xenobiotics at the molecular level, which leads to tolerance or sensitivity to a particular pollutant (Fajana et al, 2019). The response to a xenobiotic is thus reflected in the abundance and diversity of oribatid mites, indicating the state of the soil and the damaging effects of human activity (Gulvik, 2007).

The highest individual and species richness occurs in forests, and the first human activity to affect their community is forestry. The activity of oribatid mites in forest soils has a major impact on primary production indirectly, increasing microflora activity (Wolters, 1991) and accelerating the decomposition of plant debris by breaking it into smaller particles. Also, by constantly consuming bacteria and fungi, they induce them to grow continuously as it is necessary to compensate for their consumption. Under conditions where mycelium can grow rapidly, the Oribatida population also increases. For this reason, their use as indicators is also justified (Crotty and Adl, 2019). Forest humus and its fauna can be beneficial for horticultural plants. When such humus (edaphon) is inoculated into the soil around them, they grow faster. The beneficial effect can be mutual, so that certain plant species help to

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increase the number of individuals in the Oribatida population. Klimek and Rolbiecki (2014) inoculated the soil of forest-grown seedlings of birch (*Betula pendula*), linden (*Tilia cordata*) and Scots pine (*Pinus sylvestris*) with edaphon. Two years later, the number of oribatids was significantly higher in the edaphon-inoculated soil, but also significantly higher in the case of the linden and birch than in the soil of the Scots pine, despite the fact that the edaphon was from an old pine forest. The root systems of deciduous trees seem to provide more favourable conditions for the reproduction of oribatid mites. A number of microhabitats occur within the forest, which play a role in maintaining species richness. Fungi of the order Polyporales play an important role in the decomposition of wood in forests, and there are also species that attack living tissue and are pathogenic to the tree. They can also cause economic damage to forestry. At the same time, the fungal fruiting bodies provide a microhabitat for oribatid mites. Over time, both the wood and the fruiting bodies themselves decompose, but in different stages of decomposition, they host different communities. This actually maintains the species richness of the oribatids. Such fungi are less abundant in areas under forest management, which implies that they are more species-poor compared to forests without human intervention (Gdula et al, 2021).

However, both the number of individuals and the number of species are lower in disturbed areas than in places where natural vegetation is still present and there is no human disturbance. Intermediate values are observed in agricultural areas, and the values are the lowest in soils covered by industrial pollution or mechanically damaged. In agricultural areas, regular chemical use reduces their number (Moitra, 2013). Agricultural production now covers a large part of the Earth and is one of the activities with the largest impact, so it is important to know how much this activity affects soil fauna. The Oribatida community can indicate not only the presence of different toxic substances, but also the extent to which the soil or a particular area is still in a near-natural state or has been disturbed by human activity. Human activity also changes the relative proportions of oribatid mites and other groups. Disturbance is common in areas under intensive agricultural production, which means that the area is in the early stage of secondary succession. When disturbance ceases, there will be a gradual increase in the proportion of K-strategist oribatids relative to, for example, r-strategist Collembola species. The proportion of Oribatid species will be greater in stable, undisturbed environments (Gulvik et al, 2008). Seniczak et al. (2018) collected mites from soil samples from vineyards in Mediterranean climate in Spain (El Poble Nou de Benitatxell). Natural vegetation, which was not under cultivation, was used as a control. Here, the average was 5900 individuals per square metre. In the plantation, 2250 and 2820 individuals were found in the areas under organic and conventional cultivation, respectively. The difference between the two different types of cultivation is not significant. However, the community composition was significantly different between the control and the plantation. There was also no significant difference in the community composition between the two types of cultivation. This means



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that the chemicals used had little effect on Oribatida species in the conventionally cultivated area. Mechanical tillage had a greater effect, which significantly influenced the density at both sites. This may be the reason for the higher seasonal fluctuation compared to the control. The organic matter content and the absolute nitrogen concentration of the soil as well as the C/N ratio are determinants of oribatid abundance and diversity. However, too high values are no longer favourable for oribatids and abundance and species number start to decline. This can occur when agricultural land is fertilised. Graczyk et al. (2008) investigated how increased values due to fertilization affect abundance and diversity. 40 m<sup>3</sup> per hectare of cattle manure significantly increased abundance, but 60 and 80 m<sup>3</sup> per hectare of cattle manure significantly decreased it. Manure can contain a number of microorganisms that are harmful to domestic animals and humans, and is therefore treated with bactericidal and fungicidal chemicals. These may also contribute to the observed reduction, but the author does not mention which chemicals these are exactly. The abundance of Parachipteria bella was the highest in the area treated with 40 m<sup>3</sup> per hectare of manure, but Liebstadia humerata was insensitive to the amount of manure. The hedgerows separating the different agricultural areas act as refugia that can maintain the species richness, even if these mean a relatively small area. A stable microenvironment is established in this area, which does not occur within the agricultural area due to frequent disturbance. The disturbed area is dominated by a few species with a wide range of tolerance but poorer competitive ability. A few other species occur alongside them, with much smaller number of individuals. The beta diversity is also high, suggesting that the community composition is not stable and that the species composition may be random due to fluctuations in abiotic factors (Luptáčík et al, 2011).

Soil nitrogen and sulphur accumulation has increased due to industrial or agricultural activity (Bobbink et al, 2010). The consequence is soil acidification, which also has an impact on soil biota (Nijssen et al, 2017). Soil pH is a very important abiotic factor, determining the composition of the soil community (Hågvar and Abrahamsen, 1980) A negative trend has been observed between pH variation and community species richness (Guo and Siepel, 2020). Soil acidification triggers the mobilisation of toxic aluminium and heavy metals, and the reduction of the availability of the important nutrients, such as potassium, calcium and magnesium, which prevents some species from normally absorbing water at low pH (Francis, 1982; Brümmer, 1986; Pannatier et al, 2004). Absorption capacity is pH-dependent, decreasing at low pH, which can lead to dehydration and mortality of animals (Jaeger and Eisenbeis, 1984) Prolonged low pH leads to depletion of the soil buffer capacity and the reduction in species richness of the soil fauna. For some species, abundance correlates with the pH of the soil or the leaf-litter. pH can be altered by acid rain or dust from falling industrial dirt. Jung et al. (2002) investigated the abundance of Oribatida species in relation to pH in a deciduous forest in South Korea. The abundance of *Lasiobelba remota* reached its maximum around pH 5. *Ceratozetes* sp. increased in abundance with increasing pH, and

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*Tectocephalus velatus* showed a negative correlation with pH, i.e. higher abundance at lower pH. Thus, the decline or increase of the abundance of some species may indicate a change in pH, which requires intervention.

The physico-chemical properties, microbiome and flora of an abandoned industrial site can differ significantly from the surrounding unaffected areas and therefore be considered ecologically as an island, which may also have a different Oribatida fauna (Majer, 1989). The presence of toxic substances impoverishes the flora and fauna. Species with a wide range of tolerance occur that tolerate the presence of toxic substances in the environment. The process of succession is also slower than in unaffected areas. The community composition also changes more slowly over the years, with the same few dominant species occurring, but they can be highly abundant. *Ceratozetes mediocris*, *Peloptulus phaenotus* and *Protoribates variabilis* are common species in contaminated areas as well (Skubała, 2004). Even in soils with high concentrations of heavy metals, the biomass of bacteria, fungi and Actinomycetes can be quite high, so they tolerate high concentrations of these elements quite well. They are therefore a food source for mites as well (Lenart and Wolny-Koładka, 2013; Feketeová et al, 2016). Pioneer species with a wide range of tolerance are predominantly found in the Oribatida community in soils with high concentrations of heavy metals. The number of species and the abundance also depend on the time that has elapsed since the contamination or the cessation of industrial or mining activities. Succession then restarts, so the amount of plant biomass increases. The presence of several plants also increases the number of Oribatida species, even when the concentration of heavy metals is high in the soil (Manu et al, 2019). Iglesias et al. (2019) studied the effects of heavy metals on abundance and community structure in irrigated agricultural fields in Mexico (19°40' – 20°29' N; 99°57' – 99°27' W Mezquital Valley, Hidalgo). The study area is irrigated with wastewater, which has high concentrations of heavy metals that accumulate in the soil over time. The control area is not irrigated with such water. The difference in abundance observed in the two areas can be explained by the tolerance or sensitivity of the species to heavy metals. The species *Oppiella nova*, *Rhysotritia ardua*, *Schelorbates* sp. and *Tectocephus velatus* were the most abundant in the contaminated soil. The numbers of individuals were lower in the control area. *Epilohmannia pallida*, *Ramusella* sp. and *Zygoribatula connexa* species were more abundant in the less contaminated area. Due to industrial and mining activities, the heavy metal content of the soil is elevated (As, Ba, Cd, Co, Cr, Cu, Ni, Zn), pH is extreme, moisture content is low and C/N ratio varies widely. These conditions are not favourable for soil organisms and therefore the number of species and the number of individuals decrease. One species with a wide range of tolerance that can tolerate high concentrations of heavy metals is *Tectocephus velatus sarekensis*, which occurs even in such unfavourable soils (Technosol) (Feketeová et al, 2021). It is an opportunistic, r-strategist species that reproduces by parthenogenesis and is able to colonize such areas (Błoszyk et al, 2004).

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Another consequence of human activity is the emergence of alien plant species in the ecosystem. The soil fauna also reacts to the appearance of new species. An important question is whether introduced invasive plant species are able to change the composition of soil fauna, and thus biogeochemical cycles. In Poland (50°03'58 "N, 18°34'09 "E and 50°03'55 "N, 18°34'24 "E), Kohyt and Skubała (2013) investigated in Poland whether the Oribatida fauna in a population of northern red oak (*Quercus rubra*) introduced from North America and in a population of European pedunculate oak (*Quercus robur*) differs significantly. The number of individuals was significantly higher in the leaf-litter, which can be explained by the fact that the northern red oak produces more leaf-litter, so that a thicker layer allows the survival of a fauna with a higher number of individuals. Under the leaf-litter, in the soil, the number of individuals was lower in the population of the northern red oak, but the difference was not significant. No major differences were found in species composition, either. *Schelorbitates pallidulus* was found in the northern red oak stand and *Chamobates voigtsi* in the pedunculate oak stand. Both are fungivores, i.e, they consume fungal filaments and belong to the same guild. The small difference can be explained by the fact that 35-40 years is not a very long period for such trees, so that large differences have not developed yet. The situation is different for the invasive giant knotweed (*Reynoutria sachalinensis*). More species were found in the area partially covered by this plant (37%) than in the area completely covered by this plant (100%) and where it was completely absent. An explanation could be that the vegetation architecture of the area changed when the new plant appeared, but when it already covered the whole area and no other plants were present, it reduced the number of oribatids and with it the number and abundance of Collembola, Acaridida species. The reason of this may be the structure with simpler architecture and the less fungal filaments due to the fungicidal secondary metabolites (stilbene, catechin) produced by the plant. Here, the fauna already seemed to impoverish, but predator species were more numerous, probably because they hunt more efficiently in simpler environments (Skubała and Mierny, 2009).

Human-induced climate change is also a threat to the ecosystem. Climate change may alter the amount and distribution of precipitation. In turn, the amount of precipitation also determines the quality of the soil and the leaf-litter as habitats for soil fauna. Prolonged drought significantly reduces the reproductive potential, as the lack of water and heat also reduce the survival chances of eggs and larvae. In such environments, where rainfall is low and its distribution is unpredictable, r-strategist species dominate among Oribatida species as well (Wallwork and MacQuitty, 1986). In arid areas, in addition to the lack of water, soil structure and the rarity of favourable microhabitats usually do not allow high species richness to develop. The porous structure of the cryptobiotic crust in arid areas allows for richer soil fauna because this microhabitat provides a more stable environment where temperatures do not fluctuate as much. The damage of this layer due to human activities also implies a reduction in species richness (Villarreal-Rosas et al, 2014). On the soil of the

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mangrove forests, few but specialist species live in terms of vertical distribution. Tidal movement, water level elevation over longer periods and changes in water depth are important factors influencing community establishment, in particular, diversity and vertical distribution. Therefore, the Oribatida community can be used as a biological indicator to study the impact of sea level rise on the ecosystem (Vu et al, 2019).

Changes in the relative proportions of oribatid mites to other taxa, such as Actinedida, Mesostigmata or Astigmata, may also be an indicator. N'Dri et al. (2016) studied the soil fauna in Tai National Park and teak (*Tectona grandis*) plantations in West Africa. The Oribatida-Actinedida ratio was 52:28 in the pristine rainforest and 3:95 in the plantation, i.e., Actinedida increased in number. This may indicate human disturbance, i.e., the plantation is a less stable habitat. The Oribatida/Astigmata ratio is an indicator of stability and fertility. A ratio greater than one indicates fertile soil and stable conditions. A ratio less than one indicates disturbance, less fertile soil and stress. This is more favourable for Astigmata mites. The Oribatida/Prostigmata ratio can also indicate the organic matter and water content of the soil. Infertile soils, drought and intensive agricultural activity increase the number of Prostigmata mites (Socarrás and Izquierdo, 2014).

Oribatids can also be perfectly used in nature conservation. Seniczak et al. (2021) found 95 species in a deciduous forest in Norway in oceanic climate (Kjeøya Peninsula), which represents a very high species richness even within Europe. The terrain in this area is very rocky, which is not favourable for agricultural and forestry activities. So even a few hectares relatively undisturbed by human activity can support many species and are therefore important for nature conservation. Here, oribatids indicate a near-natural state, which can help in the designation of protected areas.

Finally, oribatid mites can also be used to reconstruct past environmental conditions using fossils. They are also suitable for isolating glacial and warmer interglacial periods, provided specimens are found. *Neoribates aurantiactus* and *Carabodes labyrinthicus* prefer lichens and drier environments, while *Limnozetes ciliatus* and *Platynothrus peltifer* are associated with *Carex* sp. The presence of the former species in the samples is typical of the colder periods and the presence of permafrost, the latter species are more typical of the warmer periods (Markkula et al, 2018). Of course, this requires knowledge of the plants and habitats with which these species are currently associated. Thus, it is possible to infer from their presence the climate of the not too distant past, within the period when these Oribatida species already existed.

### Closing remarks

Slow climate change does not cause a radical change in the community structure in the forest ecosystem because vegetation mitigates the stress caused by climate change. If there is direct human intervention, where vegetation is removed and the soil is cultivated, the soil fauna is subjected to much greater stress and the community structure changes more rapidly

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(Eitminavičiūtė et al, 2008). This is why it is important to maintain vegetation as it mitigates the effects of climate change.

It is worth using several taxa for the study because different taxa are differently related to the environmental factor under study. One taxonomic group is often not sufficient to describe all relevant factors. Thus, the correlation of the community composition is too low for a single group to be representative of the overall biodiversity. It is therefore advisable to study the consequences of anthropogenic impacts by involving several groups (Lehmitz et al, 2020). Although with some limitations, the use of biological indicators to monitor the quality of the natural environment has some advantages over physico-chemical assessments. First, biological study measures the cumulative effect on organisms rather than a transient state of the environment. Secondly, indicator organisms can indicate small amounts of pollutants that are not detectable by instrumentation yet, or the slightest human interference. Indicator organisms can respond both to individual and complex factors. Finally, a bioindicator can indicate the status of ecosystem components without the need to remove or damage them. It is therefore very important to choose the species used as indicators correctly.

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**Összefoglaló.** A talajlakó páncélosatkák alkalmazásában rejlő ökológiai indikációs lehetőségeket évtizedek óta hangsúlyozzák a terület kutatói. Ezek az apró élőlények olyan sajátosságokkal rendelkeznek, melyek alkalmassá teszik őket arra, hogy környezetük változásaira érzékenyen reagáljanak, így a bioindikáció révén információt hordoznak számunkra. Páncélosatkák majdnem minden élőhelytípusban előfordulnak, szárazföldön és vizekben egyaránt, sokféle mikrohabitatban (talaj, zúzmó, moha, fakéreg, epifitonok, lombozat). A széleskörű és változatos habitatokban való elterjedésén kívül alkalmazkodóképességük nagy észlelhető egyedsűrűségükben és fajdiverzitásukban is megmutatkozik. Korábban számos publikáció jelent már meg különböző szituációkban és módokon történő bioindikációjukkal kapcsolatban. A jelen dolgozat célkitűzése, hogy azokat az általános tulajdonságaikat gyűjtse össze, amelyek arra mutatnak, hogy a bennük rejlő bioindikációs potenciál lényegesen nagyobb és széleskörűbb, mint amit az eddig megjelent publikációk tükröznek.