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Wydawnictwo
Uniwersytetu Śląskiego
Katowice 2004

Colonization and development of oribatid mite communities (Acari: Oribatida) on post-industrial dumps

Honour species
Pay attention to small organisms
WALTER & PROCTOR (1999)

PRACE
NAUKOWE
UNIWERSYTETU
ŚLĄSKIEGO
W KATOWICACH

NR 2219

Colonization and development of oribatid mite communities (Acari: Oribatida) on post-industrial dumps

Piotr Skubała

Wydawnictwo Uniwersytetu Śląskiego Katowice 2004

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We know more about the movement of celestial bodies than about the soil underfoot.

Leonardo Da Vinci, circa 1500's

Preface – soil as the basis for civilization

For centuries soil and the life in it were of little interest to humankind. Two centuries ago, in 1788, Gilbert White called our attention to life in the soil. He discussed seven functions of earthworms: "by boring, perforating, and loosening the soil, and rendering it pervious to rains and the fibres of plants, by drawing straws and stalks of leaves and twigs into it; and, most of all, by throwing up such infinite numbers of lumps of earth called worm-casts [...]" (Allen, 1900). The value of earthworms in the soil system is better known from Charles Darwin's classic book *The formation of vegetable mould through the action of worms with observations on their habits*. However, soil biology began to develop after the Second World War. There was no comprehensive publication on the soil fauna until 1950 when two books with the same title "Bodenbiologie" written by Kuhnelt and Franz, summarised the knowledge of soil fauna up to that time (Veeresh & Rajagopal, 1988). The situation has not changed much since. There are only a few academic books on soil biology, and these are not new ones; and soil science is rarely taught at universities, at least in Poland. The true enigma is that although decomposition is the equal of photosynthesis in ecosystem importance, and half or more of terrestrial biodiversity may be tied to the soil-litter system, the study of soil biology has been neglected (Walter & Proctor, 1999).

The soil is a living organism of fabulous complexity. Soil systems contain some of the most species-rich communities in nature. Most authors describe soil communities as being amongst the most species-rich components of terrestrial ecosystems (Anderson, 1975a, 1978; Ghilarov, 1977; Stanton, 1979). Well-developed temperate woodland soils may contain up to a thousand species of soil fauna

(ANDERSON, 1975a). The calculation made by FITTAKAU & KLINGE (1973) is even more impressive; they estimated that 80% of the total animal biomass in the Amazonian rainforest is soil fauna. USHER et al. (1979) used impressive words to describe soil communities as "the poor man's tropical rainforest". It is noteworthy that only a proportion of all the soil animal species has been described and very little is known about their role, community structure and dynamics.

Research concerning soil is not purely an academic subject. The soil is the very basis of earth's productivity. It is fundamental to agriculture and forestry, water purification and biogeochemical cycling, and is the grounding for civilization (BEHAN-PELLETIER & NEWTON, 1999). This is particularly true where human activity tends to induce irreversible disturbances (LEBRUN, 1979). At a time when demographic pressure is too high, and when the needs of human population are intense and immense, it is wise to realize that the soil is central to human survival. Meanwhile, soil biology has fallen somewhat behind advances in the understanding of other types of communities (GILLER, 1996). Soils are still the least understood habitats on Earth, while also being among the most biologically diverse (BEHAN-PELLETIER & NEWTON, 1999).

From both theoretical and applied perspectives, this state of affairs is surprising from three points of view (GILLER, 1996).

1. Firstly, in terms of the importance of soils to global biodiversity.

2. Secondly, in terms of the ecosystem processes, in particular those that occur in the soil. The soil performs a fundamental role as the location where 60% to 90% of terrestrial primary production is decomposed. Soil fauna appears to be the major regulatory agent of soil processes affecting the physical and chemical fertility of soils. Moreover, a full understanding of above-ground ecosystem processes is not possible without consideration of processes occurring in the soil (MAY, 1997; OSLER & BEATTIE, 2001).

3. Thirdly, soil fauna can offer a suite of bioindicators for classification of soils and detection of disturbances and pollution.

The place of mites, which are the subject of this study, within the soil, is important. Their quantitative and qualitative roles in energy flow are not fundamental; however, their interactions with other members of soil biota are of great ecological meaning. The contribution of Acarology to the understanding of our "black box", which may be a good description of the soil system, could be immense.

Acknowledgements

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I dedicate this book to those scientists whom I have met in Poland and abroad and who have supported me in my scientific career by interesting discussions and helpful comments. Special thanks to Prof. Paweł Migula (University of Silesia) and Prof. Henryk Skolimowski (Ann Arbor University in Michigan, U.S.A., Department of Ecological Philosophy at Technical University in Łódź) who have always shown personal interest in my scientific and private life and have supported me in the fields of ecology and environmental philosophy.

> Mites (Acari) are representatives of the taxonomic dilemma facing researchers who study soil ecosystem processes.
>
> BEHAN-PELLETIER & NEWTON (1999)

Chapter 1. **Introduction**

1.1. Oribatid mites – life hidden in the soil

Oribatida or moss mites are small, chelicerate arthropods, important representatives of mites (Acari). Mites are ubiquitous and, with the exception of the open oceans, they exist in every sort of terrestrial, aquatic, arboreal and parasitic habitat (WALTER & PROCTOR, 1999). They are found at every elevation and every latitude, from the Arctic to the Antarctic. Mites have a diversity of function in the ecosystem, as shown by the range of feeding guilds to which they belong (MOORE et al., 1988). They include predators, parasites, fungal feeders, root feeders, bacterial feeders, omnivores, and scavengers (KRANTZ, 1978). Ignoring mites, however, is a mistake. They are not passive inhabitants of ecosystems; rather they are strong interactors, important indicators of disturbance in ecosystems and major components of biological diversity (WALTER & PROCTOR, 1999). More than any other habitat, the soil litter stratum is the province of mites. Two-thirds of the mite fauna occur in this habitat (WALTER et al., 1996). Any true understanding of the soil system must include knowledge of the mite fauna.

Oribatid mites have successfully invaded all compartments of the biosphere (BERNINI, 1986). They constitute the main component of acarine populations in the soil. They are not confined to the soil, however, and may occur in considerable numbers in the above-ground parts of vegetation, among aquatic plants, in stored food, in the marine littoral zone, and in house dust. Temperate forests with well-developed surface organic layers and a predominance of fungal over bacterial decomposition are home to the highest diversities of oribatids. Oribatid mites can comprise about 50% of the total microarthropod fauna (González & Seastedt, 2000). Densities of 50 000–250 000 or more mites per square metre in the upper 10 cm of soil are commonly reported (Petersen, 1982). Rajski (1961) recorded in the Primaeval Białowieża Forest a count of 1 million oribatid mites per square metre. But even the driest, hottest or coldest of soils are dominated by Acari, and its most conspicuous representatives – oribatid mites (Walter & Proctor, 1999). Numerous peculiar, ephemeral and small habitats, such as dung, bird nests, lichen thallus, mosses, fungal mycelia, mushrooms, the inside of conifer needles, food products, etc., are colonized by oribatids (Lebrun & Van Straalen, 1995). Even more peculiar microhabitats can provide a home for oribatids, e.g. lumbricid galleries (Lebrun & Wauthy, 1981), aerial roots of orchids (Denmark & Woodring, 1965), cavities of curculionid beetle elytras (Gressit et al., 1966), or ant nests (Aoki et al., 1994). Even the man-made environment has been invaded by some endemic species belonging to the domestic genus *Cosmochthonius* or species of *Trimalaconothrus* living in environments such as swimming pools (Tagami et al., 1992). Olszanowski (1996) found oribatids in an aquarium. Oribatids are also frequently a dominating group among microarthropods on post-industrial wastelands (Davis, 1963; Skubała, 1995). No information is available concerning the ground-water subsystem, although oribatids could live in underground streams and lakes, as suggested by their presence in cold springs (Lebrun & Van Straalen, 1995). In conclusion we can say that all niches containing organic matter content are colonized by oribatids, usually in high numbers.

Oribatid mites constitute the order richest in species in the subclass Acari. Together with the Actinedida (Prostigmata), Acaridida (Astigmata) and Endeostigmata they constitute a group of mites of common origin called the Acariformes (Zachvatkin, 1947) or Actinotrichida (Hammen, 1972). Their evolutionary history is apparently a long one. They have the richest fossil record of any mite group, dating back to the Devonian, or 420–430 million years ago (Coleman & Crossley, 1996). The origin and phylogeny of the mites and oribatids is not clear yet. And the systematics of the Oribatida is therefore not finally accepted by the society of acarologists. The Oribatida are grouped in two supercohorts: Oribatida Inferiores or “lower oribatid mites” and Oribatida Superiores or “higher oribatid mites” (Grandjean, 1954, 1969). Lower oribatid mites include five cohorts – the Palaeosomata, Enarthronota, Parhyposomata, Mixonomata and Desmonomata (Grandjean, 1954, 1969). Oribatida Inferiores may be broadly characterized as species with contiguous genital and anal shields occupying the entire length of the genitoanal field, and with leg tibiae and genua of uniform length and shape

(Krantz, 1978). The great majority of described Oribatida belongs to Oribatida Superiores. The supercohort may be broadly characterized as aptychoid species with rounded, generally well separated genital and anal fields on a distinct ventral shield, and with leg tibiae distinctly longer and of a different shape than the adjacent genua. It comprises two cohorts – the Brachypylina and the Poronota. Cohortal separation is based on presence or absence of dorsal pores and pteromorphae (Krantz, 1978).

Oribatids are a highly morphologically diverse group of mites. The species diversity and the variability within species greatly differ in separate morpho-ecological types. Krivolutsky (1965, 1968, and 1995) divided oribatids into 6 groups, including 16 morpho-ecological types. These groups are: inhabitants of the soil surface; small dwellers in narrow soil pores; deep-soil weakly sclerotized oribatids; inhabitants of the substrate, able to widen the pores; non-specialized forms; and inhabitants of wet habitats and aquatic systems.

Oribatid mites in general have conservative life histories. Norton (1994) claimed that a low metabolic rate is the "driving force" of the oribatid life cycle. A low metabolism results in slow development, low reproductive output, limited body size and energy storage, and a long adult life. Iteroparity is common in oribatids and "*K*-selected" species prevailed because of the energy costs of maintenance requirements and dispersal (Fig. 1). All these characteristics may result in

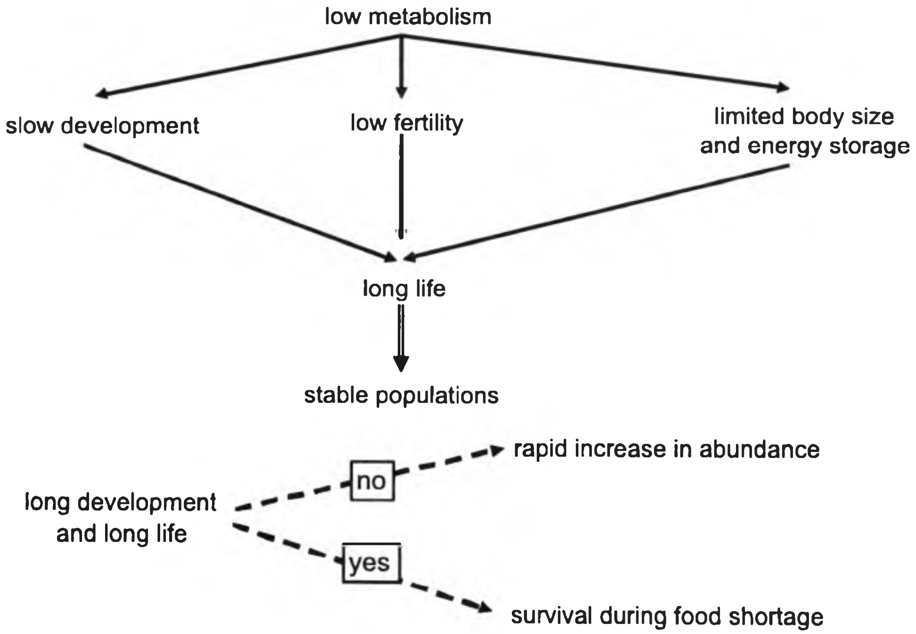


Fig. 1. Oribatid mite life strategy

rather stable populations as demonstrated by many authors (LEBRUN, 1964; MITCHELL, 1977; SCHATZ, 1985). The development time of oribatids is generally long and is worthy of registration in the *Guinness Book of Records*. The record in this context is held by the boreal inhabitant *Ceratozetes kananaskis*. Its mean development time is 770 days, while the adult lifespan approaches 4 years (MITCHELL, 1977). Long development and long life results in a low capacity for population increase. Oribatids are able to survive for a long period during food shortage. These constrained "*K* attributes" are plesiotypic for oribatids and have often played a role in preadaptation of species invading extreme habitats (BÜCKING et al., 1998). Most of these characteristics are unusual and illustrate why Oribatida are an exception within the acarological world (LEBRUN & VAN STRAALEN, 1995).

Thelytokous parthenogenesis is again peculiar to oribatids. Many hundreds of species of oribatids are parthenogenetic, and never produce functional male offspring (WALTER & PROCTOR, 1999). Approximately 10% of the species studied exhibit this clonal mode of gene-pool transmission and maintenance. Perhaps 1% of known insect species and 0.1% of known members of the animal kingdom are obligated parthenogens. In this respect, oribatid mites present a striking anomaly (LEBRUN & VAN STRAALEN, 1995; NORTON & PALMER, 1991).

Surprisingly, knowledge of feeding biology of oribatid mites is poor and the available information is in part contradictory. Unlike the vast majority of other Arachnida, which adopted a carnivorous mode of life, oribatids are, for the most part, vegetarian. Gut content analyses indicate that most oribatid mites ingest a wide range of food materials including spores of various fungal species, living and dead plant material, moss, lichens, conifer pollen and carrion (BEHAN-PELLETIER & HILL, 1983). Dietary features include poor nutritive value of ingested food, relatively low ingestion rates, and consequent minimal assimilation rates (BERTHET, 1964a; LUXTON, 1972, 1979; WALLWORK, 1983), which constrain their life-history parameters (NORTON, 1994).

Mites link together many components of soil food webs and a study of their behaviour can shed light on our understanding of ecosystem functioning (WALTER & PROCTOR, 1999). Unfortunately, rather little information is available on their relationships with other soil biota in comparison with other soil arthropods (WALLWORK, 1983). Let's consider the present knowledge on the role of oribatid mites in the soil system.

> The dormant microbes require the "kiss" of arthropod "Prince Charmings" to awaken.
>
> WALTER & PROCTOR (1999)

1.2. Oribatids perform an important "ecological service"

The sheer numbers of oribatids, at least in most soil systems, suggest that they play key, but still virtually unexplored, roles in their environment (soil). It is generally accepted today that oribatid mites are responsible for the indispensable process of antiphotosynthesis, achieving this by small, multiple and complementary stages that are a direct result of the species diversity of this group (WALLWORK, 1976). Mites play an essential part in the biological fertility of the soil and they affect soil energetics. Their activity contributes greatly to organic decomposition, the synthesis of humus, the restitution of biogenic elements, and the stimulation of fungal and bacterial metabolism (CROSSLEY, 1977a; LEBRUN, 1979; NORTON, 1986; RUSEK, 1975). It is noteworthy that oribatids are the most important group of arachnids from the standpoint of direct and indirect effects in the development and maintenance of soil structure in organic horizons (MOORE et al., 1988; NORTON, 1986). Many species sequester calcium and other minerals in their thickened cuticle (NORTON & BEHAN-PELLETIER, 1991). Thus, their bodies may form important "sinks" for nutrients, especially in nutrient-limited environments (CROSSLEY, 1977b).

Four major principles can be taken into account concerning the particular functions of oribatid mites.

- The result of mechanical breakdown and fragmentation is to increase the active surface of litter, enhancing its colonization by microorganisms, especially saprophytic fungi. The oribatid activity facilitates and accelerates the leaching of hydrosoluble elements and hydration of the organic matter (BEHAN-PELLETIER & HILL, 1983; CURRY, 1969; WITKAMP, 1971).
- The digestive transit ensures physical and chemical change as well as biological breakdown. This is accompanied by a mixing of mineral and organic elements and microorganisms (LEBRUN, 1979).
- The production of faecal pellets creates a highly fertile environment. It facilities growth of roots and the germination of seeds (HAARLÖV, 1960; LEBRUN, 1979; PANDE & BERTHET, 1973). The consumption of dead roots by saprophagous oribatids is also of great importance because it considerably increases soil porosity and the development of humus (LEBRUN, 1979).

- The grazing of mites stimulates microfloral activity. This function may be of major importance. They aid the dispersal of bacteria and fungi, both externally on their body surface and by ingesting spores that survive passage through their alimentary tract (Behan-Pelletier & Walter, 2000). Microbes have limited abilities to move from one resource patch to another. Once the energy in a particular patch has been expended, microbal biomass shuts down and remains dormant until new resources become available. Lavelle (1997) described this phenomenon as the "Sleeping Beauty Paradox". Walter & Proctor (1999) claimed that "dormant microbes require the »kiss« of arthropod »Prince Charmings« to awaken". Thus, microbial propagules are mixed with fresh resources in the faecal pellets and are transported to new sites.

Some data support the view that oribatids are essential for efficient decomposition and nutrient cycling. Nearly 56% of the net production of fungi is consumed by mycophagous mite species (McBrayer et al., 1974). Butcher et al. (1971) estimated that adult oribatid mites directly metabolise only 1.8% of the energy in forest litter, even though in one year they ingest an amount of material equal to about 50% of annual leaf fall. Ghilarov (1963) proved that organic decomposition is five times faster when microorganisms and mites work together than by microorganisms alone. Even though these general characteristics of oribatid mites are known, the role of most mite species in ecosystem functioning is unclear, as is the case with other groups of soil organisms (Behan-Pelletier & Newton, 1999).

In view of this, and since they normally exceed most other arthropods in abundance and diversity (see next part of this chapter), oribatid mites should be regarded as "key industry" animals in decomposer food chains (Wallwork, 1983).

> We must take it for granted that a large part of the mite fauna of the world will remain unsampled, unnamed, and unclassified (not to mention unwept, unhonoured, and unsung) for decades to come.
>
> MAY (1978)

1.3. Contribution of oribatids to global biodiversity

Exploring the diversity of life will be one of the essential topics in 21st century ecology. The importance of biodiversity arises from the fact that the world depends on self-sustaining biological systems that include many kinds of organisms. Knowledge of biodiversity is required to understand the natural and artificial changes it may undergo. Furthermore, such knowledge permits the wise use and management of ecosystems, both as elements of natural heritage and as reservoirs of actual and potential resources. Biological diversity has been used to refer to almost any measure (taxonomic, numerical, genetic, etc.) of the variety of organisms that live in a particular place. Three dominant themes can be distinguished in this field, namely:

- accounting for the diversity,
- determining how this diversity is maintained,
- enumerating principal functions provided by the diversity of life.

Monitoring the vitality of soil biota is one of the accepted issues to be found in the Global Diversity Assessment (HEYWOOD & GARDNER, 1995). The rationale for including arthropods in biodiversity studies has been established (DIDHAM et al., 1996; EHRLICH, 1988; WILSON, 1988; VERHOEF & BRUSSARD, 1990; WINCHESTER, 1997). The contribution of mites to global biodiversity is far from being appreciated. Mite and oribatid biodiversity may be one of the richest reservoirs of species in the world. WALTER & PROCTOR (1999) presented the hypothesis about likely mite megadiversity. There are approximately 45 000 named species of Acari (Table 1). Recent estimates of global acarine diversity range from between half to over 1 million species (WALTER & PROCTOR, 1999). So the number of species of mites described so far is estimated to represent between 4% and 8% of total mite diversity. As regards oribatid mites, 11,000 species in more than 1100 genera have been described; their total species richness could be 3 to 10 times higher. In temperate regions, the acarofaunas are certainly diverse, but not exceptionally so. If the Acari are a hyperdiverse group, then the majority of them wait to be explored in the acarologically unexplored tropics (WALTER & PROCTOR, 1999).

Table 1

Current and expected diversity in mites (Acari)

	Families	Genera	Species	Species estimates	
				minimum	maximum
Opilioacariformes	1	9	17	85	170
Parasitiformes					
Holothyrida	3	9	32	160	320
Ixodida	3	12	880	1 000	1 200
Mesostigmata	73	567	11632	97 520	200 500
Total	**79**	**588**	**12 544**	**98 680**	**202 020**
Acariformes					
Endeostigmata	11	25	120	1 200	2 400
Sarcoptiformes					
Oribatida	150	1 100	11 000	33 000	110 000
Astigmata	70	627	4 500	90 000	180 000
Trombidiformes	120	1 323	17 050	317 250	637 500
Total	**351**	**3 075**	**32 670**	**441 450**	**929 900**
Total Acari	**431**	**3 672**	**45 231**	**540 215**	**1 132 090**
Percentage of species described to date				**8,4**	**4,0**

Source: WALTER & PROCTOR (1999).

The future of oribatids with respect to biodiversity does not look very optimistic. Numbers of described taxa increase annually, but the Oribatida although fascinating and diverse, is not widely studied by taxonomists. Only eight scientists work with oribatids in Poland. Data on mites and on oribatid diversity in tropical ecosystems is especially rare (Walter & Proctor, 1999). The reasons for this neglect are the minute size of individuals (0.1 to 3 mm in length), difficulty of identification, their cryptic habits, and their relative lack of economic importance.

Continuing biodiversity losses and the ever-worsening quality of the environment are well-documented facts. Scientists differ in estimation of this process. According to conservative calculations more than 13 species become extinct each day. According to pessimistic estimations, it is possible that 410 species disappear every day (Goodland, 1991). Legal environmental constraints to stop losses of biodiversity are still largely unsatisfactory. The scientific community does insufficient work on this problem. Lebrun & Van Straalen (1995) underlined the obstinacy of scientists who wish to understand completely all the mechanisms involved before sounding the alarm bells. Walter & Proctor (1999) write about the present world fascinated by molecular mania, but where little attention is given to diminishing diversity and the destruction of nature. As regards animal biodiversity, a vertebrocentric view is rarely questioned, whereas invertebrates make up 95% of animal biodiversity. Do we also have a significant decrease in oribatid mite species in the world? Will species seen only under microscope disappear and will we not even record this lost? There are no answers to these questions. We do not have any calculations or suspicions. It is also one of the reasons why acarology is a fascinating discipline.

1.4. Oribatids in biomonitoring studies

The use of bioindicators to derive biological information on certain environmental variables has a long tradition, especially in botany. The potential indicator value of soil invertebrates has often been emphasized by authors (Van Straalen & Verhoef, 1997). As for the arthropod fauna, field studies have revealed correlations between groups of species and certain soil factors (Hågvar & Abrahamsen, 1984; Ponge, 1993), but no system for bioindication has been proposed (Van Straalen & Verhoef, 1997). Living in almost all biosphere microhabitats, oribatid mites are certainly an appropriate group for surveying all the environmental compartments to detect any structural or functional damage. This is particularly true for the soil where oribatids display high densities and diversities and so are well suited for biomonitoring studies (Lebrun & Van Straalen, 1995; Walter & Proctor, 1999).

Oribatid species and their communities offer several advantages for assessing the quality of terrestrial ecosystems (Behan-Pelletier, 1999; Lebrun & Van Straalen, 1995). Their high densities and diversities have been noted previously. They are easily sampled and they can be sampled at all seasons. It is noteworthy that oribatids are in close contact with defined microenvironmental conditions. When sudden changes occur, oribatids are unable to escape: they are sedentary or slow moving, lack marked dispersal mechanisms, and are therefore subjected directly to conditions of stress. In addition, oribatids are directly exposed to toxicants, by contact, by direct ingestion of soil particles and soil water, and through food-chain transfer (Fig. 2). In general, oribatids fulfil most criteria listed by Cranston (1990) in assessing the suitability of taxa for biomonitoring. However, there are also negative aspects of the use of oribatids in bioindication studies, e.g. their small size, difficulties in identification, the abundance of individuals often encountered, some difficulties in standardising sampling and extraction, and time taken in sorting (Hunt, 1994).

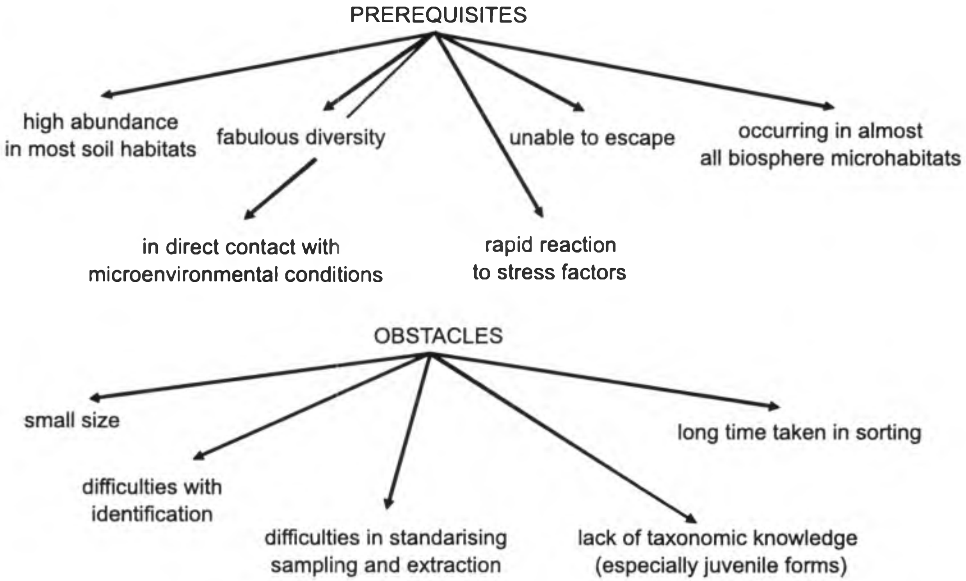


Fig. 2. Oribatids in biomonitoring studies

Mites are becoming increasingly used as bioindicators in soil. Oribatids may demonstrate the impact of various human activities:

- air pollution (André & Lebrun, 1984; Berina et al., 1989; Seniczak et al., 1997, 1998; Steiner, 1995),
- acid rain (Hågvar & Amundsen, 1981; Henegham & Bolger, 1996),
- cultivation (Dekkers et al., 1994; Ehrnsberger & Butz-Strazny, 1993; Franchini & Rocket, 1996),
- burning (Antony, 2001; Noble et al., 1989),
- use of fertilizers (Gatilova, 1970; Koskeniemi & Huhta, 1986; Żyromska-Rudzka, 1976),
- use of herbicides and insecticides (Bhattacharya & Joy, 1980; Edwards & Lofty, 1969; Hoy, 1990; Koehler, 1987; Mueller et al., 1990),
- radioactive pollution (Krivolutsky, 1979; Krivolutsky & Pokarzhevski, 1991),
- forest harvesting (Antony, 2001; Huhta, 1976),
- reclamation of post-industrial dumps (Cross & Wilman, 1982; Dunger et al., 2001),
- soil contamination (Denneman & Van Straalen, 1991; Ludwig et al., 1991; Salminen & Sulkam, 1997; Siepel, 1995a; Van Straalen et al., 1989),
- sewage water irrigation (Dindal, 1977),
- trampling (Borcard & Matthey, 1995; Schatz, 1983a).

Linden et al. (1994) list the different properties of soil animals, which can be potentially used as indicators of soil quality.

- **Use of single organism characteristics**. There have been numerous studies on the ecological and reproductive response of oribatid species in the past decade (Behan-Pelletier, 1999). Siepel (1996) has shown how effective this approach can be in predicting species loss. Nevertheless, this method will become more precise, useful and widely adopted as knowledge of taxonomy and ecology of species improves. No datasets exist to illustrate our knowledge on habitat and niche profiles of oribatid species (Behan-Pelletier, 1999).
- **Use of community level characteristics**. This approach is more advanced. However, knowledge of the taxonomy and ecology of species is still needed in order to use this method. Total mite density, species richness, dominance or constancy of certain species, as well as various biodiversity indexes can be used to determine the degree of disturbance. From this dataset, appropriate indicators can be selected once the stress has been defined (Linden et al., 1994).
- **Use of biological process level**. This method is still at a preliminary stage. Rusek (1986) presents an interesting example of this approach. He studied the structure of oribatid faeces and its contribution to soil structure.

Several authors have discussed the advantages of using oribatids in bioassay work and as ecological indicators, and the possibility of using the above mentioned approaches, e.g. Beck, 1994a; Behan-Pelletier, 1999; Hunt, 1994; Iturrondobietia et al., 1997; Krivolutsky, 1970; Lebrun & Van Straalen, 1995; Niedbała, 1983; Van Straalen, 1988.

Post-industrial dumps are an "experimental range" to study many ecological and even evolutionary processes.
TOKARSKA-GUZIK & ROSTANSKI (2001)

Chapter 2. **Save our dumps (SOD) as an entity**

2.1. Post-industrial dumps as a "unique" experiment for ecologists

Post-industrial wastelands are constantly increasing in area; some of them may be dangerous to human health (Fig. 3). These facts provide the major stimulus for the reclamation and restoration of large devastated areas. The reclamation of dumps, especially of toxic dumps, is a challenge and is a severe problem of today. For this purpose, a knowledge and understanding of soil development – mainly induced by soil organisms – is an important prerequisite for any form of soil management on dumps (WANNER et al., 1998). From the viewpoint of reclamation, a practice very poorly developed at this time, a knowledge of soil fauna development is required as an indicator for artificial cultivation techniques (DUNGER et al., 2001).

The restoration of disturbed ecosystems has recently received increasing attention from ecologists and land-use managers. This is due, in a large part, to more stringent government regulations, which mandate extensive reclamation procedures followed by biological monitoring efforts (PARMENTER & MACMAHON, 1987). It seems obvious that dumps should at first be managed biologically. In this way the negative influence of dumps on the natural environment may be limited, and the beauty of the landscape can be improved. Nevertheless, vegetation cover on dumps may develop naturally. Hitherto, reclamation measures taken on dumps have appeared unsatisfactory in many cases despite the high expenditure of money and effort. Spontaneous succession of plants is more desirable

Fig. 3. A general view of the zinc metallurgic dump at Katowice Wełnowiec

Fig. 4. The youngest part of the coal-mine dump at Zabrze Biskupice

Fig. 5. The initial plant assemblage with *Corynephorus canescens* at site 1 on the coal-mine dump at Zabrze Makoszowy

Fig. 6. The plant assemblage with *Calamagrostis epigejos* at site 2 on the coal-mine dump at Zabrze Makoszowy

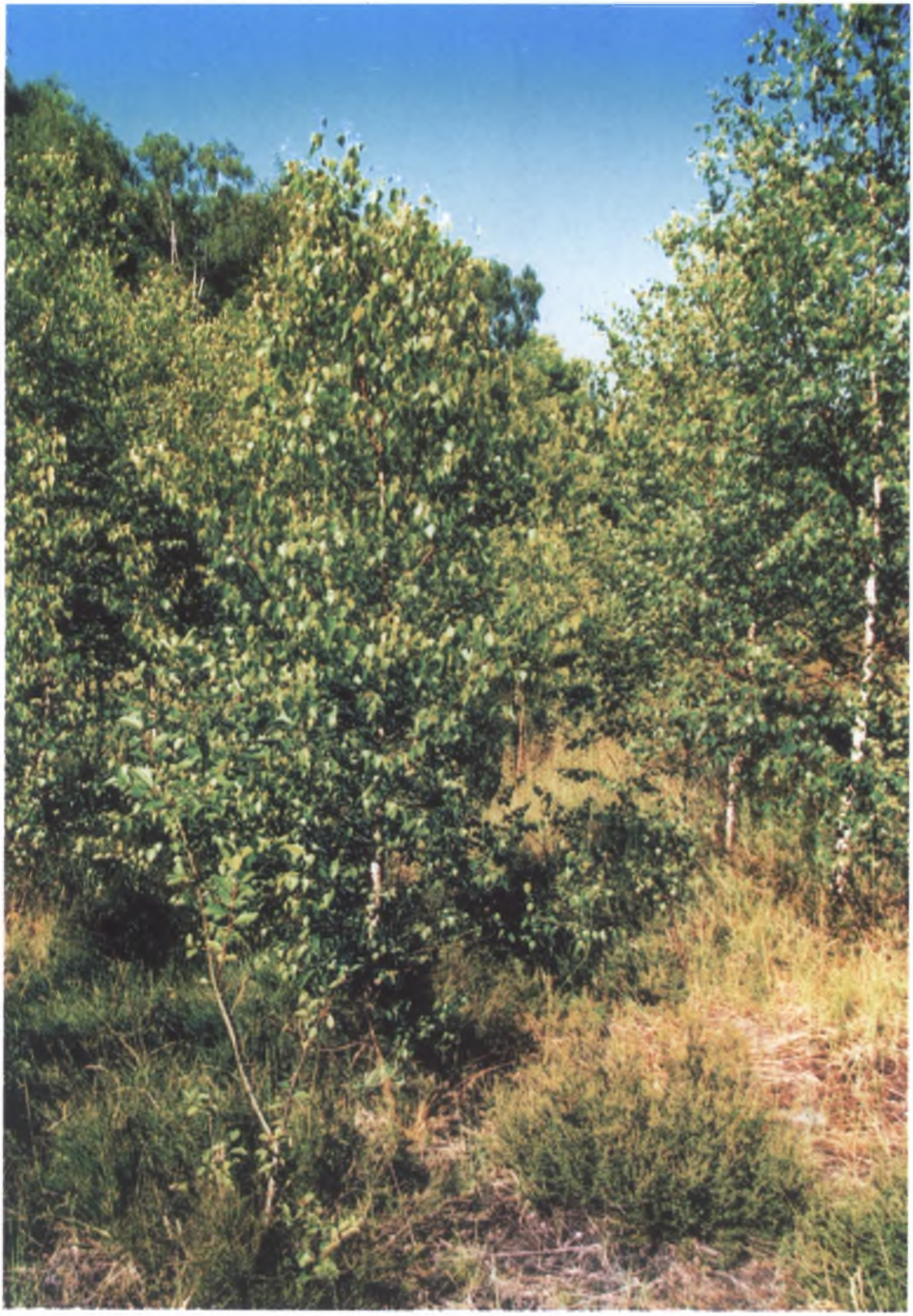


Fig. 7. The plant assemblage with *Betula pendula* – *Calluna vulgaris* at site 3 on the coal-mine dump at Zabrze Makoszowy

(Weidemann et al., 1982), but unfortunately the spontaneous process of colonization and succession is a long-term process.

Much of the research on land restoration has been devoted to the reestablishment of vegetation and vertebrates. Soil fauna has been treated marginally in many restoration practices and studies, whereas we can obtain useful results for derelict land management, acquiring knowledge of all processes during succession on wastelands. Studies on recolonization of arthropods on wastelands are few (Hawkins & Cross, 1982; Majer, 1985; Majer et al., 1982; Neumann, 1971; Nichols & Burrows, 1985; Usher, 1979), whereas arthropods can drastically influence revegetation efforts via herbivory, seed predation, litter decomposition, pollination, and soil aeration (Majer, 1989a). More empirical studies of these processes on different kinds of dumps are urgently needed to better understand the factors affecting soil fauna development in a post-industrial landscape (Frouz et al., 2001).

The growing area of dumps is a real disaster for humankind, although from the viewpoint of soil ecology dumps are not “waste land”. They offer a tremendous experimental field in which to study the colonization by animals and the development of their communities in this hostile environment. A new habitat for many new inhabitants is created as a result of spoilheap construction. A dump is a “land” lacking plants and animals, initially with a complete absence of soil. Then for a long period the “soil” that is present lacks stratification, has insufficient organic matter, few nutrients and an inadequate water content. Additionally, what makes post-industrial dumps an excellent polygon on which to test ecological hypotheses is the simplified and variable relationships between living components. Furthermore, they are usually not under threat by prospectors.

The variability of spoil heaps and the range of environmental conditions established on post-industrial dumps result in a heterogeneous environment for soil biota (Dunger, 1991; Schneider et al., 1995; Topp et al., 1992). Furthermore, different reclamation technologies used on dumps also create varied conditions. So ecologists get an experiment with many differentiated environmental variables.

2.2. A chance to test successional theories

The origin and progress of successional theory are based on our knowledge about primary and secondary succession of plant communities, which is well documented (Pullinen, 1986). Our knowledge of succession of soil organisms, particularly soil arthropods, associated with basic biological parameter changes is significantly poorer (Beckmann & Schriefer, 1989; Huhta et al., 1979; Pižl, 1992; Scheu & Schulz, 1996; Starý, 1999; Streit et al., 1985; Strüve-Kusenberg, 1982; Tajovský, 1990). Only a small part of research on succession deals with degraded post-industrial biotopes (e.g. Christian, 1993; Dunger, 1968; Hutson, 1980a; Hutson & Luff, 1978; Parr, 1978; Vogel & Dunger, 1991). The first worldwide review of the succession of soil animals on reclaimed areas was edited by Majer (1989a).

Several different pathways of succession are described in the literature (Majer, 1989b).

1. The facilitation pathway
2. The initial floristic composition pathway
3. The tolerance pathway
4. The inhibition pathway
5. The chronic disturbance pathway

These pathways are not mutually exclusive and elements of more than one type may be recognized within a particular succession. The evidence for these pathways has been derived from the study of plant communities (Connell & Slatyer, 1977). Possibly they are not all applicable to heteromorphic succession because of, for instance, the mobility of animals (Majer, 1989b).

The **facilitation model** assumes that colonization by later successional species depends upon the early species preparing favourable environmental conditions (Clements, 1916; Odum, 1969). The **inhibition model** assumes that irrespective of which species colonizes first, the primary colonist will adversely affect the colonization of other species by using up resources (Begon et al., 1986). The **tolerance model** (Connell & Slatyer, 1977) states that later invaders simply tolerate the conditions at the site and eventually outcompete the pioneers. Competition and mutualistic relationships are assumed to be of minor importance in this model. Egler (1954) (**initial floristic composition pathway**) claimed that representatives of all seral stages may be present very soon after disturbance, and that variations in life-history characteristics among the groups of species determine the succession. The **chronic disturbance** model (Horn, 1976) pertains to areas suffering chronic disturbance in small patches. It proposes that any species is likely to invade an opening and that locally a dominant species may be replaced by any number of other species.

Testing the successional theory is one of the most important trends in the study of ecosystems at present, and research on dumps can contribute a lot to this approach (Starý, 1999). Dumps seem to be an excellent tool for the study of biological communities in relation to environmental gradients. We may wish to know as much as possible about colonization by flora and fauna in order to direct or accelerate development of modified ecosystems (Davis, 1986). Oribatid mites are especially useful in successional research; they are sensitive to small differences in environmental factors (only a small percentage of oribatids are ubiquitous) and their species pool is large (Verschoor & Krebs, 1995).

2.3. Oribatids on dumps

If the succession of vegetation on post-industrial wastelands is to be described then some understanding of the fauna associated with plants and of decomposition in the soil seems imperative. The development of terrestrial populations in areas where such populations did not previously exist or had been eliminated has been studied by a number of workers. However, oribatid mite communities, which possibly also play a fundamental role on waste tips, have been neglected by ecologists. Dunger (1968) undertook work on the development of soil fauna on post-industrial dumps. For the findings of Dunger and his co-workers see Beck (1994b). His research on dumps in East Germany still continues. Unfortunately, oribatids have been looked at in detail only in some of Dunger's studies. Moreover, his investigations deal with one type of post-industrial dump, the open-cast mining areas. Baseline data concerning the development of mite communities on dumps are still lacking. Few studies deal with oribatids in detail (Table 2 and 3). Qualitative data on oribatids could be only found in half of the papers, e.g. Babenko, 1980; Beckmann, 1988; Bielska, 1982a, b, 1995; Bielska & Paszewska, 1995; Frouz et al., 2001; Hubert, 2001; Luxton, 1982; Stebaeva & Andrievskii, 1997; Żbikowska-Zdun, 1988. I have personally studied a broad selection of different dumps and have published results in various papers (Table 3). These articles cover 10 different types of dumps, e.g. coal-mine dumps, iron metallurgic dumps, zinc dumps, dolomitic dumps, mine sedimentation tank, dumps of chemical plants, galena-calamine wastelands and others. Precise quantitative and qualitative data on oribatids were analysed in all of these studies.

With regard to the acronym in the heading of this chapter – SOD – which means Save Our Dumps, it seems to be proven enough. Some other scientists have put forward such proposals in the past. It was not only the important value of the vegetation that inspired them (Tokarska-Guzik & Rostański, 2001; Wierzbicka & Rostański, 2002). Historical conditioning and widely understood touristic and

Table 2

Chronological list of publications of Oribatida on post-industrial dumps

Type of a dump	Country	Quantitative analysis	Qualitative analysis	References
Open-cast quarrying for ironstone	England	yes	no	Davis, 1963
Brown-coal spoil heaps	Germany	yes	yes (partly)	Dunger, 1968, 1978, 1989 et al. (see Beck, 1994)
Reclaimed pit heap	England	yes	no	Hutson, 1972
Lead mine spoil heaps	England	yes	no	Williamson & Evans, 1973
Brown-coal spoil heaps	Germany	yes	no	Bode, 1975
Brown-coal mining sites	Germany	yes	no	Hermosilla, 1976
Coal shale pit-heaps	England	yes	no	Hutson & Luff, 1978
Dumps of open rock mines	Russia	yes	yes	Babenko, 1980
Refuse tips	Germany	yes	no	Brockmann et al., 1980
Reclaimed coal pit heap	England	yes	no	Hutson, 1980a, b
Mine dumps	Poland	yes	yes	Bielska, 1982 a, b
Refuse tips	Germany	yes	no	Brockmann & Koehler, 1982
Rubble dumps	Germany	yes	no	Koehler, 1983
Coal-shale tips	England	yes	yes	Luxton, 1982
Refuse tips	Germany	yes	(partly) no	Weidemann et al., 1982
Rubble dump	Germany	yes	yes	Beckmann, 1988
Reclaimed mine dump	Poland	yes	yes	Żbikowska-Zdun, 1988
Mine and ash dumps	Poland	yes	yes	Bielska, 1995
Reclaimed ash dumps	Poland	yes	yes	Bielska & Paszewska, 1995
Brown coal dumps	Siberia	yes	yes	Stebaeva & Andrievskii, 1997
Reclaimed open-cast coal mining areas	Germany	yes	no	Wanner et al., 1998
Open-cast coal mine dumps	Germany	yes	yes	Dunger et al., 2001
Open-cast coal mining areas	Germany, Czech Republic	yes	yes (partly)	Frouz et al., 2001
Abandoned pyrite processing sedimentation ponds	Czech Republic	yes	yes	Hubert, 2001

Table 3

Author's publications of Oribatida on post-industrial dumps in Poland

Type of a dump	Locality	Quantitative analysis	Qualitative analysis	References
Iron metallurgic dumps	Bytom, Chorzów	yes	yes	SKUBAŁA, 1995
Abandoned galena-calamine wastelands	Galman	yes	yes	MADEJ & SKUBAŁA, 1996
Galena-calamine wastelands	Bukowno	yes	yes	SKUBAŁA, 1996
Five different types of post-industrial dumps	Jaworzno, Oświęcim, Katowice, Bytom, Bukowno	yes	yes	SKUBAŁA, 1997a, 1998
Mine dumps	Brzeszcze	yes	yes	SKUBAŁA, 1997b
Abandoned galena-calamine wastelands	Tarnowskie Góry	yes	yes	SKUBAŁA & MADEJ, 1997
Abandoned galena-calamine wastelands	Korzeniec	yes	yes	MADEJ & SKUBAŁA, 1998
Dumps of the zinc and lead industry	Żabie Doły	yes	yes	SKUBAŁA et al., 1998
Galena-calamine wastelands	Bukowno, Galman, Katowice	yes	yes	SKUBAŁA & NIEMI, 1998
Zinc metallurgic dump	Katowice	yes	yes	SKUBAŁA & CIOSK, 1999
Dolomitic dump	Tarnowskie Góry	yes	yes	SKUBAŁA, 1999
Mine dump	Katowice Murcki	yes	yes	SKUBAŁA, 2002a
Ten different types of post-industrial dumps	18 sites	yes	yes	SKUBAŁA, 2002b
Mine sedimentation tank	Katowice Murcki	yes	yes	SKUBAŁA, 2002c
Galena-calamine wastelands	4 localities	yes	yes	SKUBAŁA, 2003

educational purposes also support such ideas. LAMPARSKA-WIELAND (1997) suggested establishing legal protection to ensure nature preservation on one of the dumps in Upper Silesia. Are post-industrial dumps also important from acarological point of view? I have tried to support this idea in this study.

> Soil community ecology has fallen somewhat behind advances in understanding of other types of communities.
>
> Giller (1996)

Chapter 3. **Objectives of the study**

The general aim of the research is to contribute to our understanding of succession process, in particular colonization of "land" created by human activity, using the example of soil oribatid mites (Acari: Oribatida). For this purpose post-industrial dumps seem to be an important platform. The focal questions of the studies are as follows:

- How does the structure of oribatid mite communities change in the course of technogenic primary succession on dumps? Are the conclusions provided by space-for-time and direct long-term observations similar?
- How important is the species pool of potential colonists, present in habitats in close proximity to dumps, for oribatid community development?
- Can the structure of the oribatid mite community (e.g. abundance, species richness, relative dominance and frequencies) be predicted by a simple set of environmental descriptors?
- How does a group of oribatid species, typical of a particular dump, get selected?
- Which oribatid species play a role as colonizers and persisters on dumps?
- What are the specific characteristics of soils on dumps as habitats for the soil fauna, and which of the peculiarities of the deposited substrates are important for oribatid mites?
- To what extent does the development of mite communities depend on the vegetation cover?
- Do traditional reclamation measures, carried out on dumps, considerably accelerate the development of mite soil fauna?
- Which of the succession models best describes the development of oribatid mite communities on post-industrial dumps?
- Do post-industrial dumps contribute to the regional biodiversity of mites?

Chapter 4. **Environmental setting**

4.1. Dumps and their surroundings – history, origin, deposits and other considerations

4.1.1. General remarks

Waste tips, created as a result of the activity of industrial plants, are inescapable elements of the landscape of industrial regions. They are found in concentration in the Upper Silesian Region, the most industrial and urbanized region in Poland and, indeed, Europe. Over 50% of the territory of the Katowice province is covered by large areas of mining damage, waste-tips and quarries. The exploitation of natural resources in this region began in the Middle Ages. Over 44% of wastes in Poland are disposed in this region. The proportion of waste tips created by mining is highest in this region and is estimated at 72% (Jarzębski, 1997).

Seven post-industrial dumps have been thoroughly investigated from 1998 to 2002. They represent different types of dumps, having originated from the mining, iron metallurgy and zinc-processing industries (Appendix 1 – CD-ROM). Different types of coal-mine dumps were selected, e.g. “above-ground” and “surface” dumps and a coal-mine sedimentation tank. With regard to coal tips at Zabrze Biskupice, Zabrze Makoszowy, Katowice Murcki and Brzeszcze, they have been formed from generally similar waste material. Slightly different waste deposits have been found in a sedimentation tank at Katowice Murcki, although the difference is mainly related to the size of particles. Two other dumps (at Chorzów and Katowice Wełnowiec) were composed of totally different waste material. The height above sea level was similar for all sites and ranged from 222 (sedimentation tank at Katowice Murcki) to 298 metres a.s.l. (iron dump at Chorzów). The slope of the plots was generally close to 0^0. The slope was higher only at the first two sites on the coal-mine dump at Katowice Murcki (Table 4).

The estimations regarding the age of particular sites or the possible time period for the development of an oribatid mite community are approximate. They have been based on two calculations:

- the time when deposits stopped being added to a dump,
- the development of vegetation.

Both assessments are not very precise. Information on the history of a particular dump is very general. Usually, there is no specific information in the historic documentation of a dump. In some cases it was suspected that some extra wastes were deposited on a dump without permission and beyond the knowledge of the authorities. The second source of evaluation is also uncertain. The development of plant assemblages on post-industrial dumps is correlated with so many unpredictable factors that botanists or plant ecologists have many problems in tracing the exact time of development of a particular assemblage on post-industrial wastelands (Adam Rostański, personal comments). Only in one case is the information on development time of the soil community very precise; that of a reclaimed coal-mine dump at Brzeszcze.

Three sites were chosen on each dump, differing in age of deposits, plant composition and development of vegetation. It is probable that the development time of a mite community was between 10 and 15 years at the youngest sites (sites coded by number 1) (Table 4). The sites of medium age (site code 2) were characterized by a longer development time of an additional 5 years. The age of the oldest sites (site code 3) is estimated at about 20 to 25 years. The age of all sites on the zinc dump at Katowice Wełnowiec is considerably higher. This is possibly due to very high accumulation of heavy metals. The problem will be discussed later.

On most dumps there was no reclamation management, so the primary succession of soil communities proceeded more or less naturally. Some reclamation measures have been undertaken on the dumps at Katowice Wełnowiec, Zabrze Biskupice, Zabrze Makoszowy (Appendix 1 – CD-ROM), but they have been done only on small parts of a dump. Soil samples for this project were collected from other parts of the dumps. Therefore, I was able to look at oribatid communities that developed during the natural process of primary succession. Only in the case of “surface” coal-mine dumps at Brzeszcze were reclamation practices done on the whole area.

Table 4

List of the study sites, their characteristics and codes

Site code	City	Type of a dump	Site (dump, nearby biotope)	Possible development time of mite community (years)	Exposure	Slope
C	Chorzów	iron metallurgic dump				
C 1			site 1	< 15	N–W	5^0
C 2			site 2	15–20	N–W	10^0
C 3			site 3	20–25	–	0^0
C M			meadow	–	–	0^0
W	Katowice Wełnowiec	zinc metallurgic dump				
W 1			site 1	> 15	N–E	3^0
W 2			site 2	20–29	–	0^0
W 3			site 3	39–49	W	5^0
W M			meadow	–	–	0^0
B	Zabrze Biskupice	mine dump				
B 1			site 1	< 10	–	0^0
B 2			site 2	10–15	–	0^0
B 3			site 3	20–25	–	0^0
B M			meadow	–	W	3^0
M	Zabrze Makoszowy	mine dump				
M 1			site 1	4–5	N	0^0
M 2			site 2	5–8	N	10^0
M 3			site 3	~ 10	N	10^0
M F			forest	–	–	0^0
MD	Katowice Murcki	mine dump				
MD 1			site 1	< 15	N	30^0
MD 2			site 2	15–20	N	40^0
MD 3			site 3	20–25	N	3^0
MD F			forest	–	N	3^0
MT	Katowice Murcki	mine sedimentation tank				
MT 1			site 1	< 14	–	0^0
MT 2			site 2	16–18	S–E	2^0
MT 3			site 3	18–20	N–W	3^0
MT F			forest	–	S–E	10^0
BR	Brzeszcze	reclaimed mine dump				
BR 1			site 1	11	–	0^0
BR 2			site 2	16	–	0^0
BR 3			site 3	19	–	0^0
BR M			meadow	–	–	0^0

Additional research plots were chosen in biotopes adjacent to a dump. Some of the dumps are surrounded by biotopes of anthropogenic origin, e.g. the iron dump at Chorzów, the zinc dump at Katowice Wełnowiec or the coal-mine dumps at Brzeszcze. Others are surrounded or partly adjacent to semi-natural habitats. Four of seven locations studied are adjacent to meadows, e.g. dumps at Chorzów, Katowice Wełnowiec, Zabrze Biskupice and Brzeszcze. In the case of dumps at Katowice Murcki (mine dump and sedimentation tank) and Zabrze Makoszowy, they were mainly surrounded by forest. Details on plant assemblages are explained in the chapter 4.3.

4.1.2. Details of the post-industrial dumps

(see Appendix 1)

The **iron metallurgic dump at Chorzów** belonged to the "Kościuszko" steelworks. The dump is small (1.8 ha) with a very uneven surface. The dump was comprised of blast-furnace ash (42% Fe, 29% FeO, 0.28% Na, 0.75% K, 0.24% Zn, 0.036% Pb), pulp (28% CaO, 11% MgO, 1.15% Zn, 0.133% Pb), recrement, blast-furnace slag, pieces of brick, lime and refuse from the plant. The exploitation of the dump ceased in 1981. Sites 1 and 2 were selected at the top of the dump, whereas site 3 was located at the lower part of the dump. All sites were fairly flat.

The second location was on the dump of the zinc metallurgic plant "Silesia" **at Katowice Wełnowiec**. This **zinc metallurgic dump** is one of the oldest post-industrial features in Upper Silesia. It was established in 1856 (Tokarska-Guzik et al., 1991). The piling of wastes was stopped in 1984. It is 25 metres high and its area is about 25 hectares. The dump originated from slag, ash, and wastes from discillatory and ore-roasting furnaces and fired-clay bricks. All plots were chosen on the top of the dump on an almost even surface. Some reclamation practices have been undertaken on the oldest part of the dump, but this part of the dump was not sampled.

The **coal-mine dump at Zabrze Biskupice** belongs to the "Zabrze-Bielszowice" coal-mine (Fig. 4). It is an above-ground semispherically-table dump. Coal shales, carboniferous sandstones, ash and furnace slag have been deposited over several decades. Formation of the dump began in the late 1920s and piling ceased in the early 1990s. All samples were taken on the top of the dump.

Similarly to the previous dump, some reclamation measures had been undertaken, nevertheless plots were chosen from other parts of the dump.

The second **coal-mine dump** was investigated at **Zabrze Makoszowy**. The “Wymysłów” dump belongs to the “Makoszowy” coal-mine. It was constructed over 15 years and dumping stopped in 1996. It is a huge flat dump of large area (28 ha). In comparison with previous dumps, the height of 8 metres is moderate. Barren rock, coal shales and mudstones have been deposited at the site. Grassing was undertaken on the dump, but the results of this measure can be seen only on some parts of the dump. Site 1 was chosen at the top of the dump, whereas two other sites were located on the moderate slope.

Pedozoological investigations were also undertaken on the **coal-mine dump at Katowice Murcki**. The “Maria” dump belongs to the “Murcki” coal-mine. It was established as a huge hill up to 50 metres high and its area is about 14 ha. The dump was formed from mining wastes of various sizes, e.g. clay lumps, carboniferous sandstone, coal-mud, coal crumbs and midlines. After 20 years the dump ceased to be used in 1985. Two sites were located on the slope, and the third was chosen on an almost flat area. The dump is characterized by numerous deep ditches where rainwater flows.

The **coal-mine sedimentation tank** is located in the suburbs of **Katowice** (**Murcki** district). The mine tank was formed from coal shales and mudstones. Mine waters with these ingredients were pumped from underground galleries and discharged to the tank. It covers an area of several hectares. Use of the tank ceased in 1986. Any reclamation measures were undertaken on this area. Muddy ground in some periods of the year (rainy days) and hard substratum in others (dry or frosty days) characterize the dump.

Finally, plots were chosen on three “surface” **coal-mine dumps**, which are adjacent to each other. The dumps belong to the “Brzeszcze” coal-mine and are situated along the main road from Oświęcim to **Brzeszcze**. These “surface” dumps are mainly comprised of barren rock, which is extracted as a result of preliminary mining procedures. This kind of waste rock constitutes about 46% of the material on the dumps. The rest is mainly the barren rock separated in a sorting plant, together with sludge produced by rinsing machines and flotation devices. Three sampling sites were chosen on the dumps; they differ in terms of the time period of land reclamation and in their plant composition. Sites 1, 2 and 3 were located on the dumps, which were reclaimed in 1990, 1985 and 1982, respectively. Reclamation practices have been carried out at all sites. The surface of the dumps was not covered by soil. Trees and shrubs have been planted into holes, with fertile soil added. 90% of plants used for reclamation were trees (at a stocking of 3600 per ha) and 10% were shrubs (at 400 per ha). Furthermore, the dumps have been fertilized with urea and superphosphate. Some nursing and maintenance measures have been made on the mine dumps, including the mowing of grass and weeds around trees and shrubs, soil loosening, and the planting of new trees in places where the original plants did not grow well.

For a general view of the dumps studied, see Appendix 7 (CD-ROM).

> The soil and its associated habitats are immensely complex, from the ecological point of view.
>
> Wallwork (1976)

4.2. Soil on post-industrial dumps and in adjacent biotopes

Details concerning the particle-size analysis of the soil, the soil structure, and physical and chemical properties of the soil at the study sites on dumps and in the adjacent biotopes are presented in Appendices 2, 3 and 4 (a–g) (CD-ROM).

Mechanical (particle-size) analysis and soil structure on the **iron metallurgic dump at Chorzów** differ in many respects from most other study sites on the dumps. A high proportion of stones and gravel (∅ > 1.0 mm) was observed on the dump. Furthermore, the proportion of sand particles (∅ = 1.0–0.1 mm) was high, whereas a very small proportion of silt particles (∅ < 0.02 mm) was noted. The texture was classified as loamy sand or sandy silt. Consistence of the soil was described as loose at most sites and in most soil layers. A non-aggregate soil structure was identified at site 1 and in lower layers at other sites. A slight (site 2) or medium stable (site 3) aggregate granular structure was observed in the upper layers of the soil. Despite the lower proportion of particles bigger than 1.0 mm in diameter, the particle-size analysis of the soil on the adjacent meadow was generally similar to that observed on the dump. The aggregate granular structure was only observed in the upper layer of the soil.

Pore volume, which expresses the amount of soil spaces, was quite high at all study sites on the iron metallurgic dump at

Chorzów. It increased from site 1 (level A – 0.60 $m^3 \cdot m^{-3}$) to site 3 (level A – 0.73 $m^3 \cdot m^{-3}$). Pore volume was a little lower (0.56 $m^3 \cdot m^{-3}$) in the soil of the neighbouring meadow. The soil mellowness was high, especially in the upper sections of the soil. Bulk density varied from 0.60 to 0.84 $Mg \cdot m^{-3}$ at sites 3 and 1, respectively. The soil was lightly compact or normally porous in lower layers. Field capacity, which is an indicator of the waterholding capacity of soil, was progressively higher from the youngest to the oldest site. Mean annual soil temperature was a little higher at younger sites (at about 12^0C), which can be explained by the location of the sites. Sites 1 and 2 were situated on top of the dump (higher insolation), whereas site 3 was on the lower part of the dump. Mean moisture was generally very low, varying from 0.064 $m^3 \cdot m^{-3}$ (site 1A) to 0.129 $m^3 \cdot m^{-3}$ (site 3A). Similarly, moisture was low on the meadow (about 0.09 $m^3 \cdot m^{-3}$).

As regards some chemical properties of the soil, they varied between sites and sections of the soil. The soil was slightly or moderately alkaline and pH was a little lower at older sites. Organic carbon and total nitrogen increased from site 1 to site 3. The amount of these elements was less in the lower layers of the soil. The amount of available potassium (K_2O), phosphorus (P_2O_5) and magnesium (MgO) varied between sites. Potassium and magnesium content were generally very high at all sites, whereas phosphorus content was low (site 3, meadow) or moderate (site 1 and 2). The presence of these elements was significantly less in lower sections of the soil at all plots. Levels of four cations (Na^+, K^+, Ca^{2+} and Mg^{2+}), which are important parts of the soil sorption complex, were usually higher at the oldest sites (the only exception was Mg^{2+} content). The level of these elements was higher in the soil of the meadow than on the dump. Generally, soil sorption capacity was very strong at all sites. Heavy metal contamination was high in most locations. Cadmium and zinc contents were high, whereas lead pollution was moderate and nickel pollution was slight. In general, heavy metal contamination was highest at the youngest site.

The proportion of the biggest particles (Ø > 1.0 mm) was comparatively lower on the **zinc dump at Katowice Wełnowiec** than on the previous dump. The proportion of fine sand particles (Ø = 0.1–0.02 mm) was the highest, despite the lower layer of the soil at sites 1 and 3. The substrate can be classified as silt (most sites) or fine silty loam (site 1B) and loamy light sand (site 3B). The substrate on the dump was slightly compact or loose and the soil structure was a medium stable granular aggregate. A non-aggregate structure was noted only at site 3 and in the lower layer at site 1. The highest proportion (> 70%) of sand particles (Ø = 1.0–0.1 mm) and the small amount of stones and gravel (Ø > 1.0 mm) are characteristic of the mechanical composition of the soil on the meadow. The medium stable aggregate granular structure was identified for both layers on the meadow. The soil was described as loamy coarse or light sand.

Pore volume was generally high at the study sites on the zinc dump. It was lowest (46%) in the soil of the adjacent meadow. The soil was mellow on the dump (bulk density < 1.1 $Mg \cdot m^{-3}$) and normally porous on the meadow (bulk density = 1.25 $Mg \cdot m^{-3}$). Field capacity was higher on younger sites than on the older one (site 3). It was lowest on the meadow. Mean annual temperature varied from 9.7^0C (site 2B) to 10.7^0C (meadow A). Mean moisture was higher than on the previous dump and attained the highest value at site 2 (18.8% – level A, 19.9% – level B).

The soil was slightly acid (sites 1 and 2) or neutral (site 3 and meadow). The carbon and nitrogen contents were the highest at site 2 and the lowest on the meadow. Content of available potassium was high at older sites and on the meadow and the lowest at site 1. Phosphorus content (P_2O_5) was average at site 3 and on the meadow and low at the other plots. Magnesium content was high only at site 3 (level A) and low or moderate at other plots. Soil sorption capacity was weak at site 1 and 3, whereas it was strong at site 2 and on the meadow. The amount of heavy metals was extremely high in the soil of the zinc dump. Only nickel contamination was slight. As regards pollution of heavy metals on the meadow, it was slight.

Significant differences have been observed in the grain-size analysis, texture and soil structure between site 2 and other sites on the **coal-mine dump at Zabrze Biskupice**. The proportion of stones and gravel (Ø > 1.0 mm) and sand particles (Ø = 1.0–0.1 mm) was higher at sites 1 and 3 compared with site 2. Loamy sand (sites 1A and 3A, B) and fine loam (sites 1B, 2A, B) have been identified on the dump. The soil was very compact at site 2, whereas it was loose or slightly compact at the other sites. Furthermore, the stable subangular aggregate structure was identified at site 2. The non-aggregate structure (sites 1A, B and site 3B) and the granular aggregate structure have been identified at other sites. The particle-size composition of the meadow was different from that on the dump. The proportion of sand particles was the highest (level A – 51%). The soil was compact and of a stable aggregate tubercular structure.

In contrast to most other dumps, pore volume was low on the coal-mine dump at Zabrze Biskupice. It was very low at site 1 and of similar value ($>0.40\ m^3 \cdot m^{-3}$) at other sites. According to bulk density, the soil was classified as compact (sites 1, 2 and meadow) or loose (site 3). Field capacity was also lower than on the previous dumps. It was the highest on the meadow (29.2 $m^3 \cdot m^{-3}$) and slightly lower at site 2 (27.0 $m^3 \cdot m^{-3}$). Site 2 had the highest mean annual temperature (level A – 18.2^{0}C) and the highest moisture (level A – 0.114 $m^3 \cdot m^{-3}$). As regards the meadow, the temperature was lower and moisture much higher than on the dump.

The soil was slightly acid (sites 1 and 2) or moderately acid (site 3, meadow). Site 2 was characterized by the lowest content of organic carbon, total nitrogen and C-to-N ratio. These parameters attained moderate values on the meadow. Available potassium and magnesium content were high at all sites on the dump. Phosphorus content varied between sites being the highest at site 2. The content of these elements was the lowest on the meadow and usually smaller in lower sections of the soil. Sorption capacity was very strong at all sites being the highest on the meadow. The heavy metals contamination was generally low. Nickel (sites 1 and 3), lead (sites 1, 2 and meadow) and zinc (all sites) pollution were slight. Only cadmium pollution was moderate at site 3 and on the meadow.

The grain-size composition of the soil on the **coal-mine dump at Zabrze Makoszowy** was generally similar at all study sites with the highest proportion of sand particles (∅ = 1.0–0.1 mm) (69–82%). The only important difference was the higher proportion of stones and gravel (∅ > 1.0 mm) at site 1 than on the others. The soil was described as loamy sand. It was loose and the non-aggregate structure at all sites and in all layers was noted. The soil in the neighbouring forest was characterized by a higher proportion of sand particles and lack of gravel and stones. It was slightly compact and of slight aggregate granular structure. Similarly to the soil on the dump, loamy fine sand occurred in the forest.

Pore volume increases with the age of the site and became high at site 3 (> 0.60 $m^3 \cdot m^{-3}$) on the mine dump at Zabrze Makoszowy. It was also high in the adjacent forest (over 0.73 $m^3 \cdot m^{-3}$). Similarly field capacity increased from site 1 to site 3. Waterholding capacity was a little higher in lower sections of the soil. In terms of bulk density, the soil was classified as compact (site 1), slightly compact (site 2) or mellow at site 3 and in the forest. As regards the soil temperature, it was much higher at site 1 (level A – 14.6^{0}C) than at site 3 (level A – 11.6^{0}C). Mean annual soil temperature was below 9^{0}C in the forest. Very low mean soil moisture was recorded at site 1 (level A – 5.3%). Higher and similar values of moisture were recorded at other sites (over 14.5% in upper layers).

The soil was strongly or moderately acid at all sites on the dump and in the forest. As regards organic carbon and total nitrogen content, these parameters were the lowest at site 2 and the highest at site 3. C-to-N ratio was low compared with the previous dumps. The content of available potassium, phosphorus and magnesium was high or moderate at site 1 and low at the others. Soil sorption capacity was high at site 1 and moderate at others. The content of Mg^{2+} was high at all sites. The content of heavy metals was natural on the dump and in the forest. Only the zinc content in the forest was a little higher than expected.

The highest proportion of silt particles (∅ < 0.02 mm) characterized the soil on the **coal-mine dump at Katowice Murcki**. Their proportion ranged from 62% (site 3A) to 74% (site 1B). The proportion of stones and gravel (∅ > 1.0 mm) was high at younger sites (1 and 2). Coarse loam (sites 2 and 3) and clay (site 1) have been described for the substrate on the dump. As regards soil structure and consistency, no differences between sites or layers were observed. The soil was described as slightly compact and of a stable subangular aggregate structure. The particle-size analysis of the soil in the forest gave totally different results than on the dump, with the highest proportion of sand particles (∅ = 1.0–0.1 mm) and a small amount of bigger ones. The soil structure and consistency in level A (medium stable granular aggregate, slightly compact) were different than in level B (non-aggregate, loose). Loamy light and coarse sand have been described in the forest.

Pore volume of the soil was generally low and ranged from 39% to 45% on the mine dump at Katowice Murcki. It was noticeably higher in the adjacent forest (about 70%). The soil was slightly compact (sites 1 and 2) or mellow (site 3 and forest). As regards field capacity, there was little difference between sites. Field capacity was a little higher at site 3 (level A – 36.0 $m^3 \cdot m^{-3}$) than at other sites. As regards soil temperature, similarly only a small difference was noted between sites. With regard to mean moisture, it was low at site 1 (level A – 0.157 $m^3 \cdot m^{-3}$) and considerable higher at site 3 (level A – 0.157 $m^3 \cdot m^{-3}$).

The soil was strongly acid at all investigated study plots. Carbon and nitrogen content were low, especially at sites 1 and 2. Slight difference was noted between site 3 and the forest in terms of these two elements. The content of available potassium and magnesium was very high at all plots on the dump, whereas phosphorus content was low. Forest soil was abundant in available potassium and phosphorus. Magnesium content was vestigial only a trace. Soil sorption capacity was slight at all plots on the dump. It was strong in the soil of the forest. Heavy metals content was natural on the dump. Cadmium, lead and zinc content were slight in the forest.

The deposits were totally different in **the coal-mine sedimentation tank at Katowice Murcki** than those on the other investigated dumps. Characteristics of the soil were also quite different than from that of other mine dumps. No significant differences were observed between soil on plots or in layers. The proportion of particles of different sizes was similar with a slightly higher amount of sand particles (∅ = 1.0–0.1 mm). Stones or gravel were not observed in the sedimentation tank. Fine silty loam (sites 1, 2) or medium loam (site 3) were identified in the tank. The soil structure was described as slight sharp-edged regular-polyhedral aggregate and was a very minute one. The soil was compact (site 2, 3) or slightly compact (site 1). The characteristics of the soil in the adjacent forest were generally similar to the one described for the forest at the previous locality. The only differences were lack of stones and gravel (∅ > 1.0 mm) and the presence of the medium stable granular aggregate structure in both layers of the soil.

Slight variation in pore volume of the soil was observed in the sedimentation tank. It was high only at site 1 and in the forest. According to soil bulk density, the soil is classified as mellow at all sites. Field capacity was the highest at site 2 and a little lower at other sites. Mean annual soil temperature varied from 10.3^0C (site 1A) to 10.6^0C (site 3A). It was lower in the forest (level A – 9.4^0C). The highest moisture was noted at site 2 (level A – $0.172\ m^3 \cdot m^{-3}$) and the lowest at site 1 (level A – $0.139\ m^3 \cdot m^{-3}$). Lower sections of the soil have been characterized by lower moisture.

The soil was strongly or moderately acid on the dump and in the forest. The differences in the carbon and nitrogen content were not high. The highest amount of these elements was noted at site 2 on the dump. Usually lower sections were characterized by a smaller amount of carbon and nitrogen. Available potassium content was low at sites 1 and 2 and moderate at site 3 and in the forest. Phosphorus content was low in all plots. With regard to available magnesium content, it was low at site 2, moderate in the forest and high at sites 1 and 3. The amount of these elements was lower in level B. The situation was opposite only at site 3. Soil sorption capacity was medium at site 2, whereas it was high at other sites. Especially, the amount of exchangeable magnesium was high at all sites. Heavy metal content was natural on the dump. Lead and zinc content were raised and cadmium content was high in the adjacent forest.

The **reclaimed coal-mine dumps at Brzeszcze** were characterized by a very high proportion of stones and gravel (∅ > 1.0 mm) (from 50% to 90%). The proportion of other particles was similar and did not vary much between sites or layers. The soil was classified as fine, medium or coarse loam. The soil structure was stable subanugular (sites 1 and 3) or tubercular (site 2). It was slightly compact at all sites. The characteristics of the soil on the adjacent meadow were similar in both sections of the soil. The proportion of different particles was very similar with a small amount of stones and gravel (20%). The soil was slightly compact and of a stable tubercular aggregate structure.

The highest pore volume (level A – 0.51 $m^3 \cdot m^{-3}$) characterized site 2. This parameter was slightly lower at sites 1 and 3. It was highest on the adjacent meadow (0.64 $m^3 \cdot m^{-3}$). Soil bulk density was the highest at site 3 (slightly compact soil) and a little lower at site 1 and 3 (normally porous soil). The soil was mellow on the meadow (bulk density = 0.93 $Mg \cdot m^{-3}$). With regard to field capacity, the differences between sites were small. Higher field capacity was observed on the meadow (level A – 36.5 $m^3 \cdot m^{-3}$). As regards mean soil temperature, only a small difference was noted between sites. Mean moisture was the highest at site 1 and the lowest at site 3. Lower sections of the soil have been characterized by lower moisture. As regards the meadow, the temperature was similar and moisture higher than on the dumps.

The soil was strongly (site 1), moderately (site 3 and meadow) or slightly acid (site 2). Organic carbon and total nitrogen content were the highest at site 1 being 231.2 $g \cdot kg^{-1}$ (level A) and 8.2 $g \cdot kg^{-1}$ (level A), respectively. It was lower at other sites. Content of available potassium was high (sites 1 and 3) or moderate (site 2 and meadow). Similarly, magnesium content was high at sites 1 and 3 and low (meadow) or moderate (site 2) at other sites. Available phosphorus was scarce at site 1 and more abundant at others. Soil sorption capacity was very high at all sites. Notably calcium (Ca^{2+}) content was high and ranged from 316.2 mmol(+) $\cdot kg^{-1}$ (meadow A) to 634.7 mmol(+) $\cdot kg^{-1}$ (site 2A). Cadmium and nickel content were very low. As regards lead and zinc contamination, slight pollution was observed at site 2 and on the meadow.

> Ironically the poor quality of the substrates forming industrial waste tips – often render them peculiarly suitable for the spontaneous development of unusual vegetation and the survival of uncommon species.
>
> Trueman et al. (2001)

4.3. Vegetation on post-industrial dumps and adjacent biotopes

Sites representing three phytosociological "stages" have been chosen on most dumps (Fig. 5, 6 and 7). They differ in the development of vegetation and in plant composition. The general characteristics of vegetation of selected sites are as follows. Site 1 was chosen on the youngest part of a dump. An initial assemblage of plants covered this site. A layer of litter had not yet developed. Site 2 was covered by better-developed vegetation with a more or less dense assemblage of herbaceous plant species and a thin layer of litter. Site 3 was chosen on the oldest part of a dump. Shrubs or trees were a permanent element of plant assemblage at this site and a litter layer was well developed. The check-list of plant species on all study plots is presented in Appendix 5 (CD-ROM). Phytosociological relevés were done to document the plant communities' occurrence (Braun–Blanquet, 1964). All details concerning plant assemblages on dumps and in other biotopes are contained in Tables 5 and 6. The full photographic documentation of the study sites on dumps and in the nearby biotopes can be seen in Appendix 7 (CD-ROM).

The initial assemblage with *Agrostis capillaris* covers site 1 on the **iron metallurgic dump at Chorzów**. Seventeen plant species were identified at the plot, however the cover in the herb layer was low (20%). *Ceratodon purpureus* (Hedw.) Brid. occurred in the moss layer. A shrub layer (B) with four tree species occurred at site 2. Single self-sown birches (*Betula pendula* Roth), black poplar (*Populus nigra* L.) and self-sown sallow (*Salix caprea* L.) have been observed at the site. Fifteen species were identified in the herb layer and the cover in this layer was 30%. The development of the moss layer (D) was the same as at the previous site. The assemblage with *Calamagrostis epigejos – Robinia pseudoacacia* was identified at site 3. Fewer species occurred at the site, however the cover in the shrub (B) and herb layer (C) was much higher (60% and 100%, respectively). Mosses did not occur in the D layer. It is noteworthy that the vegetation on the whole dump appeared as a result of natural

Table 5

List of the study plots and plant assemblages on post-industrial dumps and in the nearby biotopes

C – iron metallurgic dump “Ogródki” at Chorzów		
C 1	site 1	assemblage with *Agrostis capillaris*
C 2	site 2	assemblage with *Betula pendula*
C 3	site 3	assemblage *Calamagrostis epigeios – Robinia pseudoacacia*
C M	meadow	assemblage with *Calamagrostis epigeios*
W – zinc metallurgic dump at Katowice Wełnowiec		
W 1	site 1	assemblage *Festuca ovina – Silene vulgaris*
W 2	site 2	assemblage with *Festuca ovina*
W 3	site 3	assemblage with *Populus tremula*
W M	meadow	assemblage *Arrhenatheretum medioeuropaeum*
B – mine dump “Biskupice” at Zabrze Biskupice		
B 1	site 1	assemblage with *Conyza canadensis*
B 2	site 2	assemblage with *Festuca rubra*
B 3	site 3	assemblage *Larix decidua – Populus maximowiczi*
B M	meadow	assemblage *Arrhenatheretum medioeuropaeum*
M – mine dump “Wymysłów” at Zabrze Makoszowy		
M 1	site 1	assemblage with *Corynephorus canescens*
M 2	site 2	assemblage with *Calamagrostis epigeios*
M 3	site 3	assemblage *Betula pendula – Calluna vulgaris*
M F	forest	assemblage *Betula pendula – Quercus robur*
MD – mine dump “Maria” at Katowice Murcki		
MD 1	site 1	assemblage with *Tussilago farfara*
MD 2	site 2	assemblage with *Calamagrostis epigeios*
MD 3	site 3	assemblage with *Betula pendula*
MD F	forest	mixed forest of *Querco roboris – Pinetum*
MT – mine sedimentation tank at Katowice Murcki		
MT 1	site 1	assemblage with *Spergularia rubra*
MT 2	site 2	assemblage with *Dactylis glomerata*
MT 3	site 3	assemblage *Salix caprea – Betula pendula*
MT F	forest	beech forest of *Luzulo nemorosae – Fagetum*
BR – reclaimed mine dump at Brzeszcze		
BR 1	site 1	assemblage with *Populus tremula*
BR 2	site 2	assemblage with *Betula pendula, Quercus robur* and *Tilia cordata*
BR 3	site 3	assemblage *Betula pendula – Quercus rubra*
BR M	meadow	assemblage with *Dactylis glomerata*

succession and is of anthropogenic origin. Industrial premises and a small area of meadows surround the dump. Soil samples were collected from the assemblage with *Calamagrostis epigejos*. Only 14 species have been found at the study plot, however the cover in the herb layer was high (100%).

The vegetation was very poorly developed at the youngest site on the **zinc dump at Katowice Wełnowiec**. The initial assemblage of *Festuca ovina – Silene vulgaris* was recognized at the site. Six plant species occurred in the herb layer and few mosses (*Bryum capillare* HEDW.) covered the area. The assemblage with *Festuca ovina* L. covered site 2. Vegetation was particularly dense, with more herbaceous plant species (10) than on the previous one. Trees and shrubs did not occur at the site. The dominant species in the herb layer (apart from *Festuca ovina*) were as follows: *Silene vulgaris* (MOENCH) GARCKE, *Cardaminopsis halleri* (L.) HAYEK and *Agrostis stolonifera* L. Site 3 was chosen on the oldest part of the dump. The vegetation cover was best developed at this site. This area has been developed in the course of about 40 years from a bare-ground site to a plot with grass, and a tall herbage community, with aspen (*Populus tremula* L.), some birch (*Betula pendula* ROTH) and sallow (*Salix caprea* L.) in the tree layer. The dominant plant species identified in the herbage layer were *Agrostis capillaris* L. and *Calamagrostis epigejos* (L.) ROTH. Wastelands and meadows surround the dump. Soil samples were collected from the assemblage with *Arrhenatheretum medioeuropaeum*. *Phleum pratense* L. and *Agrostis capillaris* dominated in the herb layer. In total, 21 plant species were found on the study plot and the cover in the C layer was the highest (100%).

Twenty plant species have been identified in the initial assemblage with *Conyza canadensis* on the **coal-mine dump at Zabrze Biskupice**. *Conyza canadensis* (L.) CRONQUIST, *Chamaenerion palustre* SCOP., *Potentilla norvegica* L. and *Inula conyza* DC. dominated in the herb layer. The cover was very low (20%) in this layer. The assemblage with *Festuca rubra* was well developed at site 2. The cover in the C layer was very high (100%) and the moss layer was also developed. Twenty-seven species were noted in the herb layer with *Festuca rubra* L., *Agrostis capillaris* L., *Trifolium repens* L., *Lolium perenne* L. and *Achillea millefolium* L. being the most numerous. Fewer species were found on the oldest plot, although, well-developed tree (cover – 80%) and shrub layers (cover – 20%) characterized the plot. The assemblage *Larix decidua – Populus maximowiczi* was described at the site. *Tilia cordata* MILL. and *Betula pendula* ROTH also occurred in the tree layer. A large area of meadow adjoins the dump. Soil samples were collected from the assemblage with *Arrhenatheretum medioeuropaeum*. The C layer was well-developed (100% of cover) with the following species: *Deschampsia caespitosa* (L.) P. BEAUV., *Lotus uliginosus* SCHKUHR., *Centaurea jacea* L., *Plantago lanceolata* L., *Ranunculus acris* L. and *Ranunculus repens* L. Two mosses occurred in the moss layer: *Atrichum undulatum* (HEDW.) P. BEAUV. and *Brachythecium rutabulum* (HEDW.) B., S & G.

Table 6

Characteristics of plant assemblages on the investigated post-industrial dumps and in the nearby biotopes

Site	Number of species	*H′*	*J*	Cover in the following layers [%]				Litter depth [cm]	Complexity of the habitat*
				A	B	C	D		
Iron dump at Chorzów (C)									
Site 1	17	1.029	0.363	–	–	20	30	–	4
Site 2	20	1.548	0.501	–	50	30	30	< 1	7
Site 3	19	1.767	0.590	–	60	100	–	> 1	9
Meadow	14	1.193	0.452	–	–	100	–	> 1	6
Zinc dump at Wełnowiec (W)									
Site 1	7	0.096	0.049	–	–	50	m	–	3
Site 2	10	0.658	0.286	–	–	80	10	< 1	6
Site 3	19	1.471	0.491	–	50	90	m	< 1	6
Meadow	21	1.240	0.407	–	–	100	–	> 1	6
Mine dump at Biskupice (B)									
Site 1	20	0.805	0.269	–	–	20	–	–	2
Site 2	27	1.943	0.590	–	–	100	30	> 1	8
Site 3	23	1.652	0.513	80	20	30	–	< 1	9
Meadow	23	1.423	0.454	–	–	100	20	> 1	8
Mine dump at Makoszowy (M)									
Site 1	5	0.934	0.580	–	–	20	–	–	2
Site 2	7	0.874	0.449	–	–	80	20	> 1	8
Site 3	18	1.847	0.627	–	50	80	10	> 1	9
Forest	23	1.609	0.506	50	50	70	–	> 1	9
Mine dump at Murcki (MD)									
Site 1	6	0.288	0.161	–	–	40	–	–	2
Site 2	14	1.088	0.412	–	–	60	10	< 1	5
Site 3	21	1.820	0.589	–	50	40	40	> 1	8
Forest	32	1.992	0.565	90	50	60	m	> 1	12
Mine settlement tank at Murcki (MT)									
Site 1	10	0.786	0.341	–	–	10	5	–	2
Site 2	31	2.339	0.688	–	–	95	30	< 1	7
Site 3	45	2.794	0.722	–	60	80	20	> 1	11
Forest	26	2.395	0.685	80	25	90	10	> 1	13
Reclaimed mine dumps at Brzeszcze (BR)									
Site 1	12	1.568	0.553	60	5	60	10	< 1	9
Site 2	23	2.051	0.622	50	50	30	10	< 1	9
Site 3	25	2.324	0.698	50	30	20	20	< 1	9
Meadow	24	1.767	0.556	–	–	100	–	> 1	6

m – minimal.

A – tree layer, B – shrub layer, C – herb layer, D – moss layer.

* Explained in the chapter 5.2.4.

The initial assemblage with *Corynephorus canescens* was very purely developed on the **coal-mine dump at Zabrze Makoszowy**. Only five species were recorded on the plot and the cover of the herb layer was low (20%). Two more species were noted at the second site, however the cover of the C layer was considerable higher (80%) and a moss layer was present. In the assemblage with *Calamagrostis epigejos*, *Festuca ovina* L. also dominated. The assemblage *Betula pendula – Calluna vulgaris* was identified at the oldest site. The well-developed shrub layer characterized site 3. The cover in other layers was similar to the previous site. Additionally, other species dominated at the site: *Calluna vulgaris* (L.) HULL, *Aster novi-belgii* L. and *Deschampsia flexuosa* (L.) TRIN. The forest identified as assemblage *Betula pendula – Quercus robur* adjoins the dump. Twenty-three species were found in the sampled plot. Birch (*Betula pendula* ROTH) (layer A), oak (*Quercus robur* L.) (layer B), *Poa trivialis* L., *Holcus mollis* L., *Veronica chamaedrys* L., *Lupinus polyphyllus* LINDL. and *Deschampsia flexuosa* (L.) TRIN. (layer C) predominated.

The initial assemblage with *Tussilago farfara* was identified at the youngest site on the **coal-mine dump at Katowice Murcki**. Only six plant species were recorded in the herb layer, in which *Tussilago farfara* L. predominated. Organic matter did not appear to be present in the surface layer. Better-developed vegetation with 14 herbaceous plant species (*Calamagrostis epigejos* (L.) ROTH and *T. farfara* dominated) and *Ceratodon purpureus* BRID in the D layer covered site 2. A thin layer of humus and a more advanced succession of ruderal vegetation (assemblage with *Betula pendula*) was noted at site 3. Four tree species occurred in the shrub layer with *Betula pendula* ROTH and *Pinus sylvestris* L. most numerous. The cover of the herb and moss layer was quite high (40%). The dump is surrounded by forest (part of it is a beech forest reserve). A fourth study plot was chosen in adjacent mixed forest of the *Querco roboris-Pinetum* type. *Betula pendula* and *Quercus robur* L. in the tree layer and *Padus serotina* (EHRH.) BORKH. in the shrub layer comprised the highest cover. Thirty-two plant species were identified at the study plot.

Large area of the **coal-mine sedimentation tank at Katowice Murcki** is covered by very poorly developed vegetation. The first site was chosen from such a part of the tank and the initial assemblage with *Spergularia rubra* was identified on the sampling plot. The cover in the herb layer was very low (10%). Better-developed vegetation with 31 herbaceous plant species and mosses covered site 2. The vegetation is classified as the meadow assemblage with *Dactylis glomerata*. *Vicia tetrasperma* (L.) SCHREB., *Daucus carota* L., and *Festuca ovina* L. also dominated at the site. The herb layer is dense (95%) and more mosses occur at the site (30% cover). Three moss species occurred at the plot with *Brachythecium rutabulum* (Hedw.) B., S & G. predominating. The vegetation at the third site was classified as the brushwood assemblage *Salix caprea – Betula pendula*. Forty-five species were identified at the study plot. Nineteen more species occurred at site 3 than in the adjacent forest. A well-developed shrub layer (60% cover) characterized the site. The beech forest of the *Luzulo nemorosae–Fagetum* association (part of it is a beech forest reserve) surrounds the tank. Eight tree species, e.g. *Quercus rubra* L., *Fagus sylvatica* L. and *Quercus robur* L. which predominated in the tree and shrub layers, were identified at this study plot. The cover in these layers was 80% and 25%, respectively.

As regards the **coal-mine dumps at Brzeszcze**, all study sites were covered by plant assemblages with a well-developed tree level (artificially established). The lowest number of species (12), and low cover in the shrub layer characterized site 1 (reclaimed 11 years ago), although the cover of the tree and herb layer was the highest of the dumps. *Populus tremula* L., *Betula pendula* Roth, and *Quercus rubra* L. were the most abundant species in tree (A) and shrub (B) layers. The area where site 2 was situated was reclaimed 5 years earlier than the previous one. Many more plant species occurred at this site (23). The site was dominated by four tree species: *Betula pendula* Roth and *Quercus robur* L. in layers A and B, with *Tilia cordata* Mill. and *Sambucus racemosa* L. only in layer B. The cover of the tree (50%) and herb (30%) layers were a little lower than at the previous site, and much higher in the shrub layer (50%). The vegetation at site 3 (reclaimed 19 years ago) was well developed. The highest number of plant species was observed at this dump (25). The cover in the tree and shrub layers was 50% and 30%, respectively. The cover in the herb layer was the lowest (20%) of three plots studied. Eight species occurred in layers A and B with *Betula pendula* and *Quercus rubra* dominant amongst the trees.

Chapter 5. Material and methods

5.1. Collection, extraction, separation and identification of mites

A comprehensive review of the main methods of obtaining absolute and relative population estimates of the soil fauna and particularly of mites is given by Górny and Grüm 1993. Soil samples of 18 cm^2 surface and 7.5 cm depth were taken with a steel tube corer. Twenty samples were taken from a homogenous site (explanation see chapter 4.3) on a sampling date. These samples were used to extract soil mesofauna. Furthermore, five samples were collected at each site to measure moisture. Collecting of samples was done according to “quadrat” method (Górny & Grüm, 1993). Soil samples were taken from a representative quadrat (10 x 10 metres) in each plant assemblage on each dump and nearby biotopes. Samples were collected between 9 and 11 in the morning in each case, never during or immediately after rain. The fauna was sampled seasonally from 1998 to 2002. Samples from three dumps were also taken in 1986–1987 (Chorzów), 1991–1992 (Wełnowiec) and 1994–1995 (Brzeszcze). Results of analyses from these dumps were published by Skubała (1995, 1996) and Skubała & Ciosk (1998), but the data have also been used in this work in a sequential analysis of succession (Table 7). Samples were cut horizontally into two pieces: 0–3.5 cm and 3.5–7.5 cm. Soil cores were transported to the laboratory in polyethylene bags, sealed to prevent as much moisture loss as possible. In total 7288 soil samples were taken. Most of them (5620) were used in quantitative and qualitative analysis of oribatid fauna. Others were collected to measure moisture (1444) and to make soil analyses (224) (Table 7).

Table 7

Study plots' sampling data

Locality	Sampling time	Sampling frequency	Number of soil samples used in zoological analyses	Number of additional samples	
				moisture	soil analyses
Chorzów dump	1998–2000	seasonally	480	120	$15^{c} + 9^{p}$
Chorzów meadow	1998–2000	seasonally	220	40	$5^{c} + 3^{p}$
Chorzów dump*	1986–1987	monthly	120	72	–
Wełnowiec dump	1998–2000	seasonally	480	120	$15^{c} + 9^{p}$
Wełnowiec meadow	1998–2000	seasonally	220	40	$5^{c} + 3^{p}$
Wełnowiec dump*	1991–1992	monthly	360	108	–
Biskupice dump	2000–2002	seasonally	480	120	$15^{c} + 9^{p}$
Biskupice meadow	2000–2002	seasonally	160	40	$5^{c} + 3^{p}$
Makoszowy dump	2000–2002	seasonally	480	120	$15^{c} + 9^{p}$
Makoszowy forest	2000–2002	seasonally	160	40	$5^{c} + 3^{p}$
Murcki dump	1998–2000	seasonally	480	120	$15^{c} + 9^{p}$
Murcki forest	1998–2000	seasonally	220	40	$5^{c} + 3^{p}$
Murcki tank	2000–2002	seasonally	480	120	$15^{c} + 9^{p}$
Murcki forest	2000–2002	seasonally	160	40	$5^{c} + 3^{p}$
Brzeszcze dump	2001–2002	seasonally	480	120	$15^{c} + 9^{p}$
Brzeszcze meadow	2001–2002	seasonally	160	40	$5^{c} + 3^{p}$
Brzeszcze dump*	1994–1995	monthly or fortnightly	480	144	–
Total number of samples			**5 620**	**1 444**	**140^{c} + 84^{p}**

^{c} – samples used in chemical analyses, the volume – 250 cm^3.
^{p} – samples used in physical analyses, the volume – 100 cm^3.
Samples A and B are counted separately.
* Sites investigated in the past (Skubała, 1995, 1996; Skubała & Ciosk, 1998) used in the sequential approach of succession studies

Microarthropods were immediately extracted with litter profile inverted for 5–7 days (until thoroughly dry) on a modified Tullgren-style high-gradient extractor with 25 W incandescent lights. Fauna extracted were those capable of passing through a 1.5 x 1.5 mm screen mesh, and they were directly collected into a preservative (75% ethyl alcohol with 1–3% glycerine to keep the specimens moist if the alcohol evaporates). Samples were initially sorted and counted with a wide-field binocular microscope at x70 magnification. The extracted microarthopods have been sorted into Oribatida, Gamasida, Actinedida and Acaridida, Collembola and "others". The applied kind of dynamic methods of extraction relies on the active participation of the animals by their movement out of the soil containing them in response to a repellent stimulus, e.g. heat, moisture (lack of) (Górny & Grüm, 1993). Adult oribatid mites are satisfactorily extracted in most commonly used apparati. Nevertheless, the extraction of soft-bodied immatures, usually slower moving and less resistant to desiccation than adults, is usually much less efficient (Dindal, 1990).

For identification the oribatid mites were macerated in lactic acid, then mounted on slides in glycerine (Górny & Grüm, 1993) and examined under a microscope for adult and instar identification. Juvenile forms were identified only partly. Precise identification of juveniles was made for homoeomorphic oribatids. Heteromorphic immatures of brachypyline oribatid mites, which bear little resemblance to conspecific adults, were identified only for some, mainly dominant species. There is still no monograph on oribatid mites for identification of the immatures of all species (Behan-Pelletier, 1999). Immatures of mites have been described for only 5–10% of species (Behan-Pelletier & Newton, 1999). In this work the classification system according to Grandjean (1969), modified by Marshall et al. (1987) was used. Additionally, in the case of the superfamilies Oppioidea and Phthiracaroidea the system according to Subias & Balogh (1989) and Niedbała (1992) was used.

Some selected oribatids (dominants, species new for the Polish fauna) have been studied with the help of a scanning electron microscope. Fixed mites were put into solution of ether in chloroform to clean the surface of their bodies. Then they were put into antistatics (Brody & Wharton, 1971). After the treatment with antistatics the body was coated with a thin layer of colloidal gold. Such preparations covered with gold were photographed.

A large amount of material containing almost 100 thousand oribatid specimens belonging to 179 oribatid species was studied.

> Let nature guide mathematics, not *vice versa*.
>
> Walter & Proctor (1999)

5.2. Statistical analyses

5.2.1. Basic indices

The oribatid communities were characterized by the following indices:

- Abundance (the mean abundance was calculated from 80 or 110 samples and standardized (individuals/m^2)

- Species richness (number of species per plot)
- Dominance (D) (% of the number of all adult individuals of all species)

  The following classes of dominance were assumed:
  superdominants, over 30.0% of all individuals,
  eudominants, 10.1–30.0%,
  dominants, 5.1–10.0%,
  subdominants, 2.1–5.0%,
  recedents, 1.1–2.0%,
  subrecedents, less than 1.0%.
- Constancy of occurrence (C) (% of the number of samples containing species i-th of the total number of samples).
- Species-abundance relations were described by following methods:

Shannon index of diversity (H'), equitability (J) following Pielou (1969) and the species-abundance curve, a plot of log N against the rank of the catch of each species (Ludwig & Reynolds, 1988).

$$H' = -\sum_{i=1}^{S} (n_i / N)(\ln n_i / N)$$

$$J = H' / \ln S$$

where n_i is the number of individuals in the i-th taxon, N is the number of individuals in the entire sample and S is the total number of taxa in the sample.

To calculate the diversity index of a plant assemblage a transformation of the Braun–Blanquet cover-abundance scale according to Tuxen–Ellenberg, 1937 (Maarel, 1979) was used.

- Aggregation

The presence of oribatids in aggregates is demonstrated by correlation formula $s^2/x > 1$ (Usher, 1975), which can be assessed by the hypothesis $s^2 = x$. The t test for (n-1) degrees of freedom after Greig–Smith (1964) permits acceptance of the existence of a prounced “aggregation”.

$$t = [(s^2/x) - 1] \ / \ \sqrt{2} \ / \ (n - 1)$$

where: s^2 – variance, x – average number of individuals and n – number of samples.

A variety of diversity indices exist (Legendre & Legendre, 1983). The Shannon index (H') is an index particularly popular among researchers. There is controversy regarding the use of it for species diversity measurement (Peet, 1974), but its use in the present study is justified for the following reasons. Firstly, it is widely used in ecological studies, secondly, it is largely independent of sample size and thirdly, it is insensitive to the presence of rare species (ANDERSON, 1978a).

Most of the indices were calculated only for adult stages.

5.2.2. Similarities and differences

Comparisons of oribatid communities among sites were made using Euclidean distance (KREBS, 1999). The data were log (n+1) transformed. The index of similarity used with raw data can give false results of classification (LORO, 1998). The index was used to create resemblance matrices of pairwise comparisons among all sites. The resemblance matrices were then analysed in a hierarchical cluster analysis (Program STATISTICA), employing Ward's method (KOVACH, 1998).

To examine the relative similarity across the various sites, a correspondence analysis (CA) (HILL, 1980) was also conducted. The analysis was made on log-transformed (log x + 1) abundance data.

To determine the similarity of species composition between oribatid and plant communities the *chi*-square test was used (ZAR, 1999). The data were arranged in a 2 x 4 contingency table for testing the independence of a set of data (number of species, number of dominants, number of exclusive species). The tau c Kendall's index was calculated to express similarity of the data arrangement for two measured variables on an ordinal scale.

The differences in the abundance of oribatids between sites, between collection date (seasons) and site by date interactions were tested by two-dimensional analysis of variance (ANOVA). Normality was tested with the Kolmogorov–Smirnov test. Data were tested for homogeneity of variance by using the Levene's test of equality of error variances, and skewness. Log transformation was employed when the data did not meet the assumptions of normality (JONGMAN et al., 1987). When a statistically significant difference ($p < 0.05$) was noted differing pairs were identified with the SNK (Student–Newman–Keuls) test.

5.2.3. Associations and correlations

Correlations between edaphic parameters and between them and the abundance of oribatids were calculated with the product-moment correlation test of Pearson. Prior to the analysis data which did not meet the assumptions of normality were log-transformed to improve normality.

The diversity of oribatid mite communities and plant assemblages, transformed as shown to stabilize their variances, were used in a linear regression model. The data were summed from all investigated sites and they were run on a regression program.

The *chi*-square test was used to search for affinity of numerous species with a particular site. The null hypothesis that all frequencies of species are the same was tested. If the null hypothesis $H = p_I = p_{II} = \ldots p_k$ was rejected, then Tukey-type multiple comparison testing was used (ZAR, 1999).

5.2.4. Multivariate analysis

The composition of the oribatid communities and the environmental factors were analysed with a multivariate data analysis technique. A correlation between the occurrence of species and the measured set of environmental variables was analysed with Canonical Correspondence Analysis (CCA) (TER BRAAK, 1988) using the program MVSP version 3.21. The aim of these analyses was to describe and compare patterns in the mean numbers of oribatid species per site in relation to soil quality parameters and other environmental factors.

Multivariate methods, such as correspondence analysis, have been employed in many cases to interpret the observed pattern of soil community distribution (DEKKERS et al., 1994; GITTINGS & GILLER, 1998; HOWARD & ROBINSON, 1995; KOVÁČ et al., 1999; VERSCHOOR & KREBS, 1995). The strengths and weakness of multivariate methods have been extensively reviewed and evaluated by GAUCH (1982) and PIELOU (1984). Most of the times, and for complicated situations such as those occurring in the soil, evidence provided by the above methods of community ordination is the only way to account for the results. They have been suggested as a possible remedy to the problem of extreme variation in soil communities (SANTAS, 1986). CCA is a multivariate direct gradient analysis which ordinates species and samples by axes which are linear combinations of known environmental variables (Ter Braak, 1988). The results of the CCA ordinations can be interpreted as joint plots displaying species and sample arrangements and environmental variation in the ordination space. Quantitative environmental variables are shown as arrows indicating their direction of variation. Length of an arrow indicates their relative importance in explaining species variation. The approximate ranking of species along an environmental vector is given by the order of endpoints of perpendicular lines dropped from species points onto the vector.

CCA was used on logarithmically transformed data. To avoid an excessive amount of noise in the data matrix, which could obscure some data features, all species present in fewer than five samples were removed from the analysis.

Twenty environmental descriptors have been taken into account, and are listed below:

1) pH in KCl (pH),
2) organic content (C_{org}),
3) total nitrogen (N_t),
4) C-to-N ratio (C/N),
5) pore volume (pv),
6) field capacity (fc),
7) K available (K_{av}),
8) P available (P_{av}),
9) Mg available (Mg_{av}),
10) Na^+ exchangeable (Na),
11)K^+ exchangeable (K),
12) Ca^{2+} exchangeable (Ca),
13) Mg^{2+} exchangeable (Mg),
14) cadmium (Cd),
15) nickel (Ni),
16) lead (Pb),
17) zinc (Zn),
18) mean annual temperature (t),
19) mean annual moisture (m),
20) complexity of the habitat.

Complexity of the habitat is calculated as summed presence of the following layers in plant assemblages: A, B, C, D and litter.

Cover in the particular layer was calculated as follows:

0 – absent,
1 – cover less than 20%,
2 – 20 to 50%,
3 – 50 to 70%,
4 – more than 70%.

As regards the thickness of litter they were numbered:

0 – absent,
1 – less than 1 cm,
2 – 1 cm and more.

This gives a scale ranging from 0 to 18.

5.2.5. Analysis of dispersal

The index of dispersal direction was used for quantitative (presence–absence) data (Legendre & Legendre, 1983). Comparison of two adjacent regions is based upon a combination of three values: the number of species present in both regions (*a*), the number of species found in region 1 but not in 2, and the number of species found in region 2 but not in 1.

$$DD_2 = [2a/(2a + b + c)]\,[(b - c)/(a + b + c)]$$

To test the null hypothesis that there is no asymmetry between two sites, the log-linear form of the McNemar test was used, which is preferable when the values of *b* and c can be small (Borcard et al., 1995).

$$x^2 = 2\,[b \ln b + c \ln c - (b + c) \ln (b + c)/2]$$

To address the question of species turnover along the transect, *ß*-diversity index after Wilson and Shmida (1984) was computed.

$$\text{ß} = [g(H) + l(H)]/2\alpha$$

where *g*(*H*) and l(*H*) are the numbers of species that are respectively gained and lost along the transect, and α is the average species richness of the whole system.

Accurate measurement of *ß*-diversity is important in at least three ways (Wilson & Shmida, 1984):

– it indicates the degree to which habitats have been partitioned by species,

– values of *ß*-diversity can be used to compare the habitat diversity of different study systems,

– *ß*-diversity and α-diversity together measure the overall diversity or biotic heterogeneity of an area.

5.3. Soil analysis

Analyses were made of the physical and chemical properties of the soils, which were thought to be of importance in the pedogenesis of the sites and of possible significance to the mite fauna. All environmental factors have been determined from soil cores, which have been taken in close vicinity to the cores used for mesofauna extraction.

Soil composition was determined according to the aerometric method of Bouyocos–Casagrande modified by Prószyński (Lityński et al., 1976). Soil colour was based on Standard Soil Colour Charts, whereas soil structure was described following *Systematyka gleb Polski* (1989).

The methods and appropriate authors used in chemical and physical analyses of the soil are listed in Table 8. Five samples were collected from each horizon for chemical analyses (volume – 250 cm^3) and three for physical one (volume – 100 cm^3) (Table 7). The determination of soil characteristics was done in pooled material collected from each of the investigated horizons.

Table 8

List of methods used, with some remarks on physical and chemical analyses of the soil

Properties of the soil	Method	References
pH (H_2O), pH (KCl)	potentiometric method	Lityński et al., 1976
Organic content	Tiurin's method, as modified by K. Oleksynowa	Lityński et al., 1976
Total nitrogen content	Standard Kjeldahl method	Lityński et al., 1976
Solid particle density	pycnometric method	Klute, 1986
Bulk density	determined in soil cores (natural system was preserved) put into cylinders (diameter 53 mm, volume 100 cm^3) and dried at 105^0 C	Klute, 1986
Field capacity	determined in Richards chambers on porous plates	Klute, 1986 Richards, 1941
K and P available	Egner–Riehm's method	Lityński et al., 1976
Mg available	Schachtschabel's method	Lityński et al., 1976
K^+, Na^+, Ca^{2+}, Mg^{2+} exchangeable	determined in chemical hood of 1 n ammonium acetate	Lityński et al., 1976
Content of Cd, Ni, Pb and Zn	AAS method, PU 9100x model of apparatus	Ostrowska et al., 1991
Moisture	gravimetrical method, soil samples were dried at 105^{0}C	Brady, 1990

Pore volume was determined according to the following formula:

$$p = [D - d/D]\ 100\%$$

where D is solid particle density and d is bulk density.

Temperature readings have been taken at the times of sampling in the air immediately above the dump/meadow/forest floor, at a depth of 3.5 cm and 7.5 cm.

Chapter 6. **Sampling strategy**

A thorough investigation of succession of oribatid communities on seven post-industrial dumps of different types was carried out using deductive and sequential methods. The deductive approach was applied to all dumps. As regards three of the study dumps, I had an unusual opportunity to use the sequential approach for the study of primary succession of oribatid mites.

Generally, there are two approaches to the study of succession (Koehler, 1999; Starý, 1999).

– space-for-time studies (the deductive approach) are a short-term investigation based on the comparison of biotic and abiotic parameters of a higher number of selected localities with different age, and probably the same origin,

– direct long-term observations (the sequential approach) are a long-term study of permanent localities under uninterrupted succession development.

Both of these methods have certain theoretical as well as practical limits. Concerning the first approach we are not absolutely sure that differences found between successive stages are the result of successive development. Long-term studies are rare because of a lack of appropriate sites and project funds. Furthermore, it would not be possible to recognize the main determining factors. These approaches in the study of primary succession are not alternatives, but are complementary techniques. A combination of both approaches is therefore necessary for the study of general successive trends (Clements, 1963).

Soil samples were collected in all four seasons, on the dumps and in the neighbouring biotopes, during the two years. It is a well-known phenomenon that oribatids in Europe display two maxima of abundance – in spring and summer (Niedbała, 1980; Wallwork, 1970). Many authors cite that oribatids are most abundant during spring and autumn or at least in autumn in the European climate (Block, 1966; Haarlöv, 1960; Hammer, 1972; Harding, 1969; Lebrun, 1964, 1965; Mitchell, 1977; Schenker, 1986; Thomas, 1979). Many workers therefore decided to collect samples only in these seasons (e.g. Beckmann, 1988; Bielska, 1982a, b, 1995; Bielska & Paszewska, 1995; Brockmann et al., 1980; Frouz et al., 2001; Rajski, 1961). Usually they excluded sampling in the winter.

It might be surprising that at most sites on the dumps and other investigated biotopes, the richest oribatid fauna was collected during the winter period (Table 9). This was the case on the dumps at Makoszowy, Biskupice, Murcki (sedimentation tank) and neighbouring biotopes (meadows or forests) at Makoszowy, Murcki (tank), and Chorzów. Generally the highest proportion of species was collected on the dumps in winter (28.5%) during the first year of sampling and in autumn and spring during the second year (27.3% in both seasons). As regards adjacent biotopes, the highest proportion of species was collected during winter periods (28.8% – I year, 27.5% – II year) (Fig. 8). The list of species collected in soil samples during the winter is very long (Table 10). These species were found at the youngest as well as on the older sites and in the adjacent biotopes. Similarly the highest abundance of oribatids was noted in the winter period in many cases (Table 11). Such a situation was observed on the iron dump at Chorzów (site 3), the zinc dump at Wełnowiec

Table 9

Total number of oribatid species from the study plots on dumps and in the adjacent biotopes, according to season

Locality	Seasons							
	spring	summer	autumn	winter	spring	summer	autumn	winter
Chorzów – dump	36	**48**	43	39	42	21	36	29
Chorzów – meadow	21	11	17	**25**	15	12	23	**25**
Wełnowiec – dump	24	27	**43**	40	29	19	28	33
Wełnowiec – meadow	9	**13**	8	10	6	6	**13**	10
Biskupice – dump	57	14	49	**76**	61	41	57	52
Biskupice – meadow	**29**	10	25	22	25	23	20	21
Makoszowy – dump	24	21	19	**26**	**26**	23	**26**	22
Makoszowy – forest	19	25	23	27	25	24	25	**34**
Murcki – dump	19	**37**	33	14	21	27	20	11
Murcki – forest	36	47	**62**	52	52	56	55	52
Murcki – tank	30	19	22	**39**	25	27	28	19
Murcki – forest	42	34	34	**53**	38	39	37	45
Brzeszcze – dump	55	56	62	60	63	60	**72**	59
Brzeszcze – meadow	30	24	23	30	19	**37**	22	30

Bold type indicates the highest number of species on a particular site.

(site 1) and mine dumps at Biskupice (site 1 and 2), Makoszowy (site 3), Brzeszcze (site 1). Moreover, the highest number of oribatids was collected during winter in the adjacent biotopes, e.g. at Chorzów, Makoszowy, Murcki (close to sedimentation tank). It might be striking that even on the youngest plots, where usually there was almost no organic matter and only a few plants covered the area, a comparatively high number of mites could be observed in cold months.

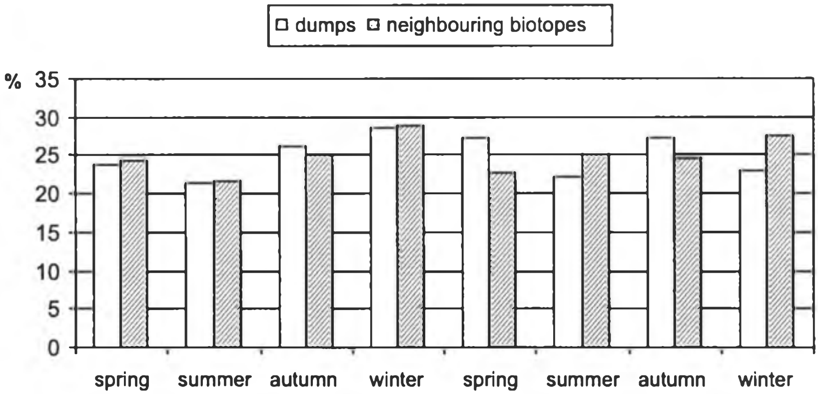


Fig. 8. Proportion of oribatid species collected at various seasons from study plots on the dumps and in the adjacent biotopes

Taking into consideration the above remarks it must be reasonable to collect mites during all seasons, especially in the winter time. Even if the surface is covered with a thick layer of snow or ice, or especially when we meet with such a situation.

Species accumulation curves were constructed following the bootstrapping method of Colwell and Coddington (1995). In the species accumulation curves the number of samples is accumulated on the x-axis and total species richness is accumulated on the y-axis. It is a well-known phenomenon that the number of new species captured with an increasing number of samples asymptotically tends to zero. It means that additional samples added no more information about species richness. In the present study the species accumulation curves reach an asymptote (i.e. flattens out) in many cases (Fig. 9 a–g). However, it happens quickly, after collecting 50–60 samples, only at the youngest sites. In some cases the curve shows no sign of levelling off, meaning that the total number of oribatid species is higher than the maximum collected. Even during the last (eighth) sampling some new species (usually 1–3) could be collected, e.g. at Chorzów – site 2 and 3 and on the meadow, Makoszowy – in the forest or at Biskupice – site 2. It seems that

Table 10

Oribatid species collected in soil samples only during winter period

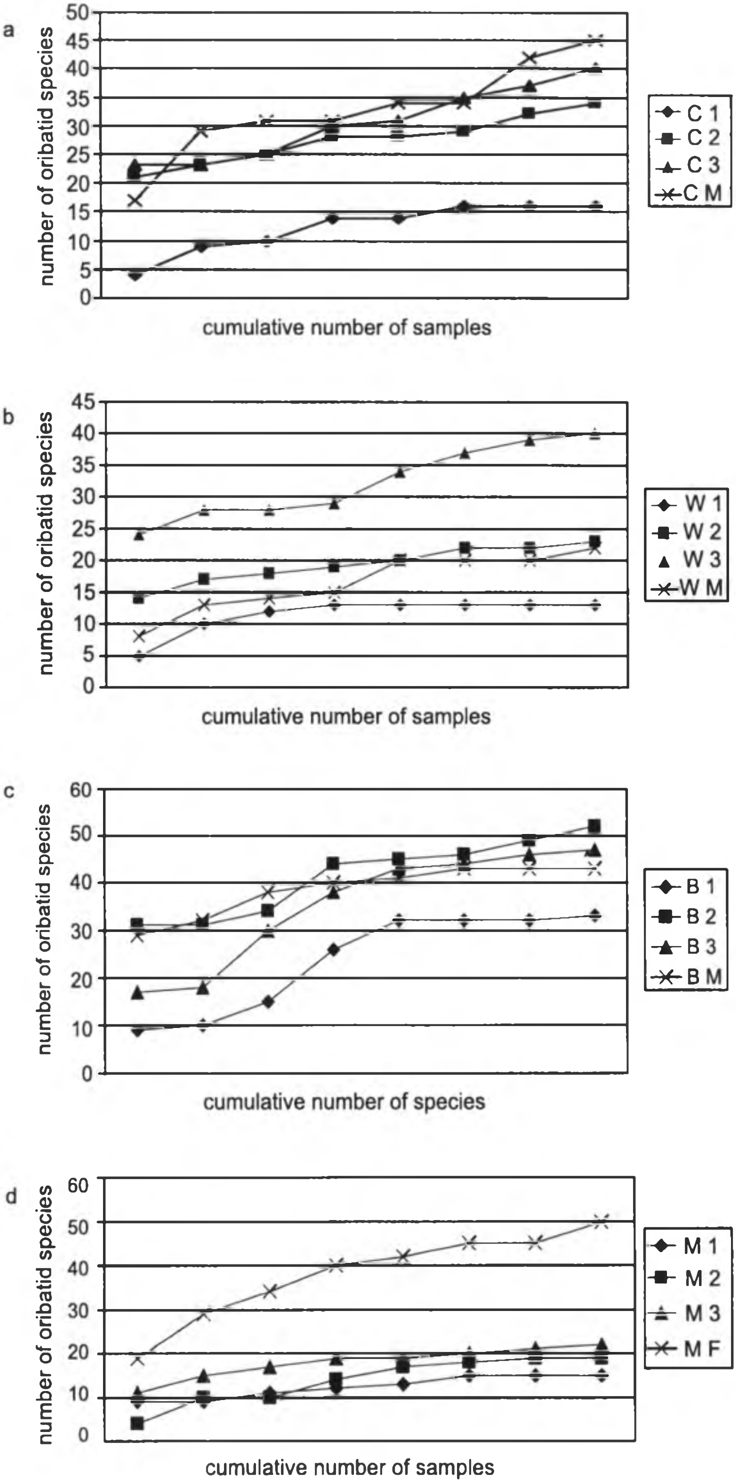
Locality	Site	Species
Chorzów	Site 2	*Brachychochthonius cricoides, Conchogneta delacarlica*
	Meadow	*Banksinoma lanceolata canadensis*
Wełnowiec	Site 3	*Suctobelbella cornigera, Scutovertex sculptus*
Biskupice	Site 1	*Belba paracorynopus, Ceratozetes gracilis, Damaeobelba minutissima, Galumna obvia, Heminothrus peltifer, Nothrus silvestris, Oribatula tibialis, Scheloribates latipes, Suctobelbila tuberculata*
	Site 2	*Liebstadia similis, Liochthonius propinquus*
	Site 3	*Chamobates voigtsi, Liochthonius tuxeni, Nothrus anauniensis, Spatiodamaeus boreus, Suctobelbella similis, Suctobelbila tuberculata*
	Meadow	*Quadroppia quadricarinata virginalis*
Makoszowy	Site 1	*Berniniella sigma*
	Site 2	*Ceratozetes bulanovae*
	Site 3	*Suctobelbella nasalis*
	Forest	*Discoppia cylindrica, Liochthonius globuliferus, Liochthonius piluliferus, Liochthonius strenzkei, Quadroppia quadricarinata maritalis, Paradamaeus clavipes*
Murcki (dump)	Site 2	*Ramusella insculptum*
	Site 3	*Platyliodes scaliger*
	Forest	*Cepheus grandis, Eupthiracarus reticulatus*
Murcki (tank)	Site 1	*Atropacarus striculus, Ceratozetes gracilis, Eniochthonius minutissimus, Lauroppia falcata, Quadroppia paolii*
	Site 2	*Chamobates voigtsi, Quadroppia paolii*
	Site 3	*Banksinoma lanceolata canadensis, Ceratozetes gracilis, Chamobates voigtsi, Eupelops plicatus, Lauroppia falcata, Suctobelbella nasalis*
	Forest	*Carabodes marginatus, Hypodamaeus interlamellaris, Liochthonius propinquus, Liochthonius simplex, Suctobelba trigona, Suctobelbella messneri, Suctobelbella similis, Suctobelbella subtrigona*
Brzeszcze	Site 1	*Liochthonius sellnicki*
	Site 2	*Medioppia obsoleta, Nothrus silvestris*
	Site 3	*Metabelba papillipes, Nanhermannia nanus, Poeciliochthonius italicus, Trichoribates trimaculatus*
	Meadow	*Quadroppia paolii*

Table 11

Abundance (per square metre) of oribatid mites on the study sites, according to season

Sites	Seasons							
Chorzów								
	sum	aut	win	spr	sum	aut	win	spr
Site 1	1 167	**5 222**	4 111	1 444	611	2 500	167	778
Site 2	30 111	**47 556**	19 333	12 778	6 166	16 055	6 389	7 334
Site 3	27 667	30 944	**34 167**	11 444	6 333	29 444	17 778	18 722
Meadow	3 611	17 074	**24 076**	13 222	5 704	15 148	23 776	6 944
Wełnowiec								
	aut	win	spr	sum	aut	win	spr	sum
Site 1	444	**16 667**	18 333	222	167	8 666	3 666	56
Site 2	**23 445**	6 833	3 444	3 778	3 556	6 889	5 389	5 611
Site 3	**62 333**	29 833	7 722	6 889	22 722	6 722	15 722	9 889
Meadow	7 444	9 222	4 611	4 722	**20 333**	9 222	3 722	19 000
Biskupice								
	spr	sum	aut	win	spr	sum	aut	win
Site 1	5 000	1 500	5 500	14 611	12 556	1 000	18 000	**43 389**
Site 2	22 000	1 722	9 889	**69 111**	25 278	18 833	73 833	45 056
Site 3	12 722	667	**19 833**	17 833	18 556	4 333	19 611	5 944
Meadow	11 556	5 889	**20 167**	16 222	13 833	14 667	8 778	8 167
Makoszowy								
	spr	sum	aut	win	spr	sum	aut	win
Site 1	5 556	6 111	8 222	5 444	7 056	11 222	**23 500**	10 611
Site 2	2 677	1 611	778	2 556	10 167	4 389	**11 889**	9 889
Site 3	7 778	4 444	8 167	**23 833**	10 778	6 222	9 056	6 722
Forest	14 111	24 500	33 500	**54 667**	32 444	29 222	21 556	35 889
Murcki (dump)								
	sum	aut	win	spr	sum	aut	win	spr
Site 1	**6 222**	4 389	722	556	778	56	0	111
Site 2	**15 222**	11 166	1 000	2 111	1 222	1 778	611	1 945
Site 3	21 222	**40 945**	8 666	14 389	33 556	19 556	2 833	10 000
Forest	55 037	45 852	71 185	41 722	68 889	**72 148**	70 445	51 407
Murcki (tank)								
	spr	sum	aut	win	spr	sum	aut	win
Site 1	**1 389**	56	333	556	667	778	889	0
Site 2	2 111	4 833	2 167	**6 278**	5 222	2 611	1 000	111
Site 3	13 000	18 000	17 167	22 222	28 000	16 500	24 611	**49 278**
Forest	46 111	18 667	50 944	**68 611**	63 389	37 556	42 500	58 944
Brzeszcze								
	win	spr	sum	aut	win	spr	sum	aut
Site 1	**20 389**	6 722	11 889	7 500	6 333	8 111	10 611	15 611
Site 2	12 667	17 278	11 167	**36 556**	20 556	17 444	24 611	18 056
Site 3	33 778	**85 444**	47 722	23 278	58 111	68 389	14 889	69 778
Meadow	14 667	13 444	17 833	10 778	14 167	12 722	10 278	**31 833**

Bold type indicates the highest abundance on a particular site.


a
number of oribatid species
50
45
40
35
30
25
20
15
10
5
0
cumulative number of samples
C 1
C 2
C 3
C M
b
number of oribatid species
45
40
35
30
25
20
15
10
5
0
cumulative number of samples
W 1
W 2
W 3
W M
c
number of oribatid species
60
50
40
30
20
10
0
cumulative number of species
B 1
B 2
B 3
B M
d
number of oribatid species
60
50
40
30
20
10
0
cumulative number of samples
M 1
M 2
M 3
M F

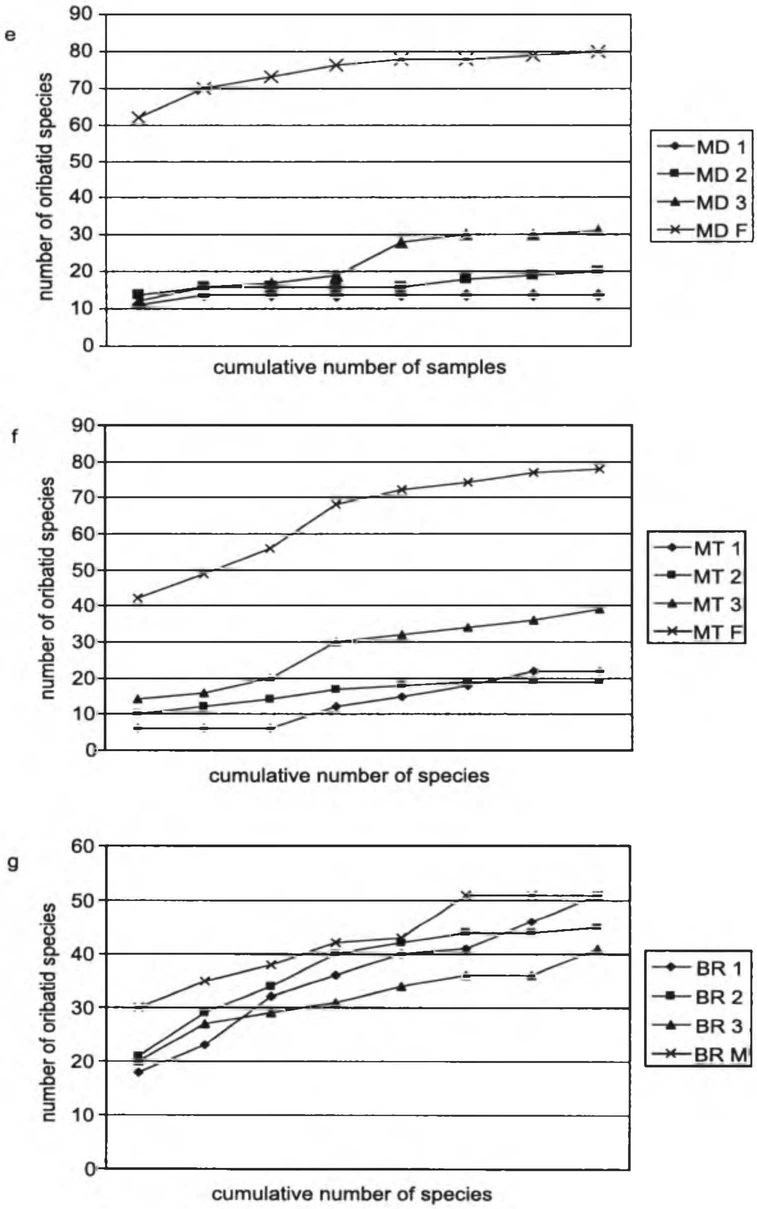


Fig. 9. Cumulative "species-sample" curves representing the number of oribatid species captured by successively cumulating samples

a – Chorzów (C), **b** – Wełnowiec (W), **c** – Biskupice (B), **d** – Makoszowy (M), **e** – Murcki (dump) (MD), **f** – Murcki (tank) (MT), **g** – Brzeszcze (BR)

the question put forward by Borcard et al. (1995), whether the total number of mite species captured can be obtained or not, is always actual. Trojan (2000) stresses that a researcher never can be certain that the full set of species was recognized for the study area. Each faunistical/ecological study is burdened with error, having a magnitude that is difficult to estimate. There may be more or fewer species inhabiting the area than has been recorded during the investigations. Together with resident species inhabiting the ecosystem, there are immigrant, emigrant and visiting species occurring in it. The fauna is part of a living dynamic system (Trojan, 2000).

Chapter 7. Oribatid mites on post-industrial dumps – characteristics of communities

The most complex oribatid communities occur in forests. Our understanding of their structure and function is still far from complete (Wallwork, 1983). Will the task be simplified by narrowing the study to the oribatid communities on post-industrial dumps? Such degraded land usually displays low spatial complexity, an absence of biological diversity, a harsh microclimate and, in biological terms, an extremely unpredictable future (Majer, 1989b). These conditions place such degraded areas within the *r*-selecting zone of the habitat templet. As time proceeds and the vegetation develops, plants buffer the microclimate and the area moves towards a *K*-selecting zone (Majer, 1989b).

Since a post-industrial dump differs in its physical and botanical structure from that of the surrounding vegetation, it may function as an ecological "island" (Majer, 1989b). Significant areas of post-industrial wastelands, as we know them, differ from other man-made habitats in being the by-products of man's activities rather than deliberate creations (Davis, 1986). Taking into consideration the immense loss of biological diversity, which is mainly associated with the loss of wildlife, there is a strong need to study this aspect of the environment. There is also a need to study artificial biotopes, those created by man. One of the reasons is because they form a significant part of our present landscape (Niedbała, 1972). Moreover, post-industrial dumps represent a rare opportunity to observe, from the very beginning, how a new ecosystem is built from its constituent elements.

In this work, we observe, using the example of the most important part of the soil mesofauna, the colonization and development of oribatid mite fauna in an unfriendly environment. Over 133 300 specimens of mesofauna, representatives of Acari and Collembola, were extracted from 5260 soil samples collected at seven localities (Table 12). During the study period over 73 000 oribatid mites were collected, of which 52 942 adults were identified to 172 morphospecies. Additionally, the data on oribatids from three dumps (Chorzów, Wełnowiec and Brzeszcze) were used in the study of primary succession using the sequential approach. These results have been published in the following papers: Skubała (1995, 1997b) and Skubała & Ciosk (1999). The material included 25 416 oribatid mites. Eight other oribatid species were found on these dumps in the past.

Table 12

General data on the material collected at seven localities

Locality	Oribatida				Number of individuals			
	number of adults	number of juveniles	total number	number of species	Gamasida	other Acari	Acari in total	Collembola
Chorzów (C)	6 042	2 900	8 942	68	1 890	4 611	15 443	3 246
Wełnowiec (W)	4 240	1 439	5 679	51	1 299	4 563	11 541	1 936
Biskupice (B)	6 842	3 347	10 189	87	1 354	3 197	14 740	2 147
Makoszowy (M)	5 942	2 060	8 002	76	3 051	5 130	16 183	3 785
Murcki (MD)	11 548	3 910	15 458	99	2 247	4 738	22 443	5 219
Murcki (MT)	8 243	2 633	10 876	94	1 893	2 203	14 972	2 476
Brzeszcze (BR)	10 085	3 822	13 907	90	1 494	1 825	17 226	1 977
In total	**52 942**	**20 111**	**73 053**	**171**	**13 228**	**26 267**	**112 548**	**20 786**
data used in the sequential approach of the successional studies								
Chorzów (Skubała, 1995 – sites 1 and 2)	810	708	1 518	38	710	1 763	3 991	.
Wełnowiec (Skubała & Ciosk, 1999)	2 543	1 199	3 742	32	.	.	.	.
Brzeszcze (Skubała, 1996)	16 434	3 722	20 156	66	.	.	.	.

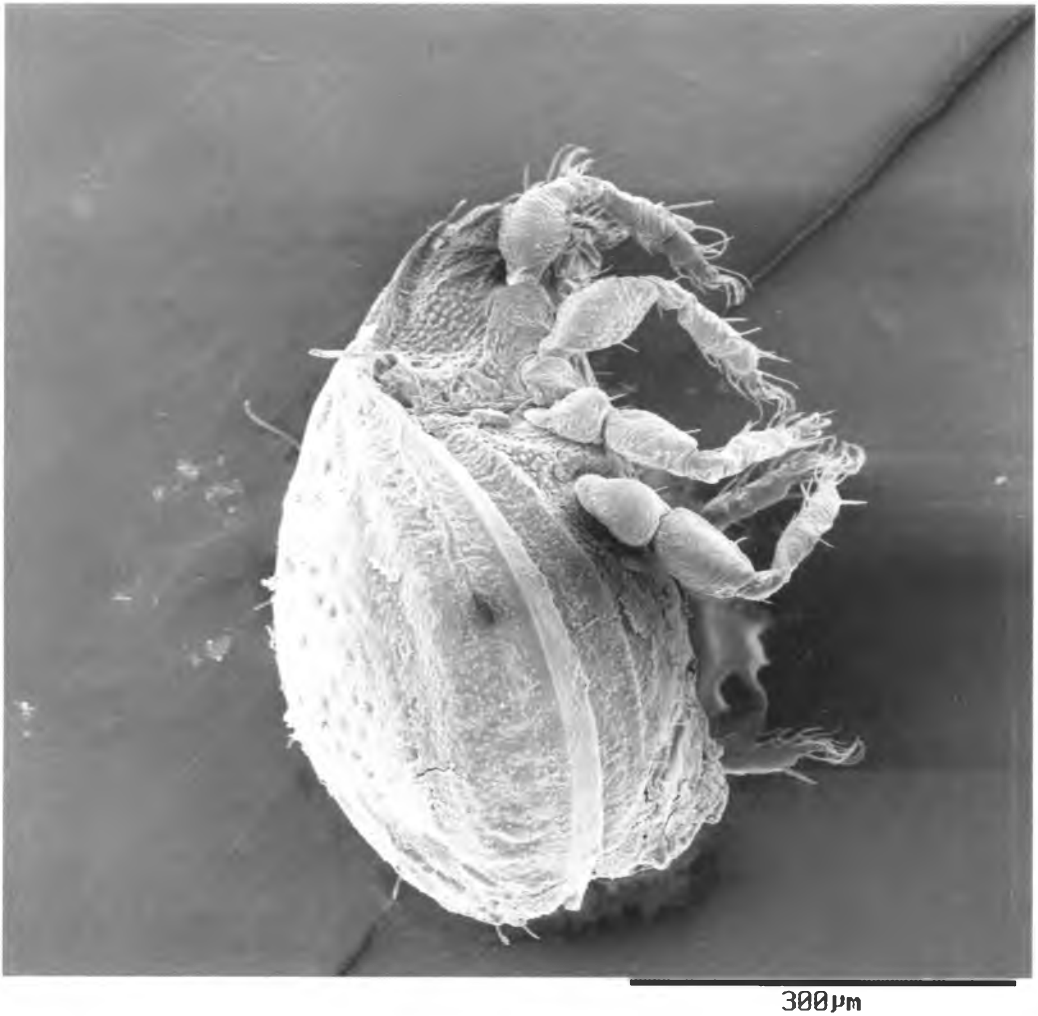


Fig. 10. *Scutovertex sculptus* MICHAEL, 1879 – a big and heavily sclerotized oribatid mite from the establishment phase (site 1) of the iron dump at Chorzów and the mine dump at Biskupice

Fig. 16. *Ceratozetes mediocris* Berlese, 1908 – “early” successional species on the contaminated zinc dump at Katowice Wełnowiec

Fig. 34. *Liochthonius propinquus* Niedbała, 1972 – a representative of the Brachychthonidae family, abundantly present in early successional stages on the dumps

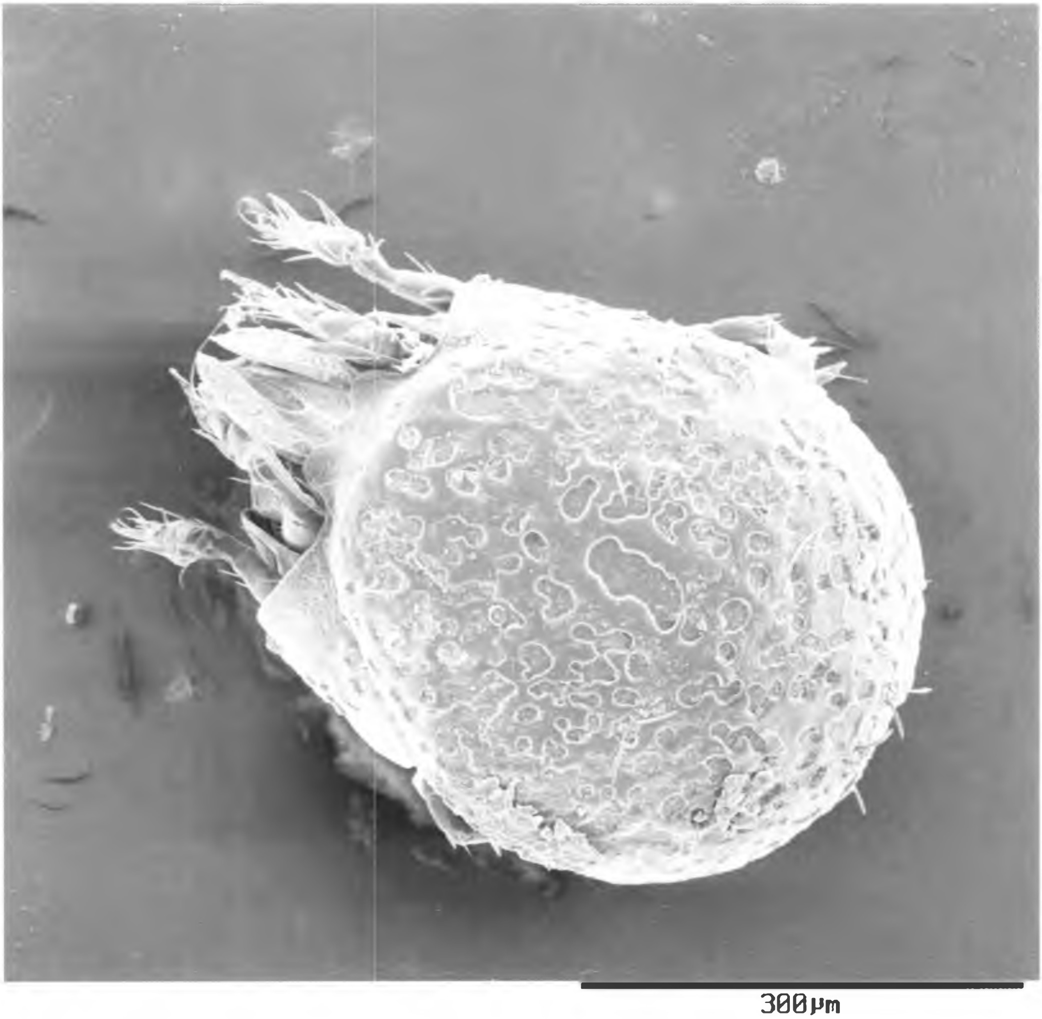


Fig. 35. *Eupelops tardus* (C.L. Koch, 1836) – “late” successional species on the iron metallurgic dump at Chorzów

7.1. Pioneer oribatid communities in extreme habitats

The colonization of new substrates is clearly akin to succession being essentially the first stage of a successional process (Usher et al., 1982). Six sites at different types of dumps were selected to study the earliest successional stage. The coal-mine dumps at Brzeszcze were excluded from this analysis because of reclamation measures carried out on them. Initial plant assemblages similar in their stage of vegetation development covered all these plots, although the time since dumping had ceased varied between sites. It ranged from 4–5 years (Makoszowy) to over 15 years (Wełnowiec) (see Table 4). The abundance of oribatids was generally low and did not exceed 2100 individuals per square metre at most sites (Table 13). However, the mite population was surprisingly high at the mine dump at

Table 13

Characteristics of pioneer oribatid mite communities on the post-industrial dumps studied

	Chorzów (C)	Wełnowiec (W)	Biskupice (B)	Makoszowy (M)	Murcki (MD)	Murcki (MT)
Abundance of adults	1 035 ± 244	1 403 ± 383	2 972 ± 705	4 271± 461	583 ± 117	479±117
Abundance of juveniles	966 ± 222	667 ± 156	9 723 ±2 161	5 444±839	1 021 ± 339	69 ± 28
Total abundance	2 001 ± 400	2 090 ± 472	12 695±2 533	9715±1 144	1 604 ±422	548±128
Proportion of oribatids in total number of mites (%)	31.9	22.0	77.0	38.7	32.0	43.7
Number of families	8	8	18	8	7	14
Number of species	16	13	33	15	14	22
Species diversity (*H'*)	1.742	1.711	1.899	1.208	2.048	2.366
Equitability (J)	0.628	0.667	0.543	0.446	0.776	0.765
Proportion of oribatids in lower section (B) of the soil (%)	8.7	6.0	14.8	7.7	10.0	32.9

Abundance is the mean value ± S.E. number of specimens m^{-2}.

Biskupice (over 12 000 per square metre) and slightly fewer than 10 000 per square metre on the mine dump at Makoszowy. The proportion of juvenile forms varied between sites. It was very low in the sedimentation tank (12.7%) and high on the mine dump at Biskupice (76.6%).

As regards the proportion of oribatids among the general population of mites, the mine dump at Biskupice also had the highest percentage (77.0%). The proportion of oribatids was noticably lower in other mite communities. The number of oribatid species, which occurred in the colonizer populations, was very similar at most sites (from 13 to 22). Again, the mine dump at Biskupice displayed the highest species richness (33 species). The analysis of the species diversity (H') and equitability (J) leads to different conclusions. It was generally low; the highest species diversity as well as very high equitability was observed with the oribatid mite community in the sedimentation tank. The proportion of oribatids collected in the lower section of the soil (3.5–7.5 cm) was lowest on the zinc dump (6.0%) and highest in the sedimentation tank (32.9%) (Table 13).

Sixty-one oribatid species were found on six dumps, after several years of colonization (see Appendix 6 – CD-ROM). Is the high biodiversity of oribatid fauna in the colonizer populations only the result of species occasionally visiting the sites and disappearing soon? It seems not, because 14 species were found as dominants on six dumps studied (Table 14). Only *Oppiella nova* and

Table 14

Dominant species in the pioneer communities of oribatid mites on the dumps

Species	Chorzów (C)	Wełnowiec (W)	Biskupice (B)	Makoszowy (M)	Murcki (MD)	Murcki (MT)
Adoristes poppei	–	–	**7.0**	0.2	–	–
Autogneta longilamellata	–	–	–	–	–	**8.7**
Brachychochthonius cricoides	0.7	–	0.2	**9.3**	**5.9**	–
Brachychochthonius immaculatus	–	1.5	0.2	1.1	**14.3**	–
Ceratozetes mediocris	–	**11.9**	0.9	–	–	–
Liochthonius piluliferus	–	–	–	–	**13.1**	–
Liochthonius propinquus	**9.4**	1.5	–	–	3.6	–
Liochthonius simplex	–	–	–	**5.8**	–	2.8
Oppiella nova	**15.4**	**8.9**	3.8	**6.0**	**36.9**	**40.6**
Peloptulus phaenotus	–	**23.8**	–	–	–	–
Ramusella (I.) insculptum	–	–	–	–	7.1	–
Scutovertex sculptus	**51.0**	–	**35.4**	–	–	–
Suctobelbella sarekensis	2.0	1.5	0.5	0.2	–	**7.3**
Tectocepheus velatus	**7.4**	**42.1**	**35.6**	**69.2**	**7.1**	2.8

Bold typed values indicate dominant species on a particular dump.

Tectocepheus velatus, the most well-known and ubiquitous of oribatids, occurred as dominants (or superdominants) at most sites. Their proportion in the communities differed considerably between dumps. The other dominant species were different at particular dumps. Even dumps of a similar type were characterized by a totally different set of dominants. For instance *Adoristes poppei*, *Scutovertex sculptus* (Fig. 10) dominated on the mine dump at Biskupice, whereas *Brachychochthonius cricoides*, *Liochthonius simplex* and *Oppiella nova* were dominants on the mine dump at Makoszowy. The colonizing species are discussed in detail in the chapter “Colonizers and persisters on dumps”.

Let’s consider the results of the canonical correspondence analysis (CCA). This ordination method (Ter Braak, 1988) was used to disentangle the relative importance of environmental factors as regulating forces during the development of pioneer oribatid communities on the dumps. The analysis was made separately for the level A (0–3.5 cm) and level B (3.5–7.5 cm depth) (Fig. 11 and 12). The eigenvalue (the dispersion of the sites/species distribution along the ordination axis) was significant for axis 1 (0.520 – level A and 0.472 – level B) and axis 2 (0.752 – level A and 0.532 – level B) in both analyses. The ordination axes are considered as significant when their eigenvalue is higher than 0.3 (Dekkers et al., 1994). High eigenvalues reflect the great dissimilarity of the oribatid mite communities at the pioneer stage of primary succession on different dumps. The first and the second axis of ordination explained over 48 per cent of the total variance of the pioneer communities in upper levels. Sites are well separated on the ordination plot, and they are influenced by different environmental variables.

The pioneer populations on the zinc dump at Wełnowiec are mainly affected by zinc, lead and cadmium content. That is not surprising, because the amount of heavy metals in the soil on that dump is extremely high. Other pioneer communities are most closely correlated with other variables, e.g. organic carbon content at Biskupice, potassium content at Murcki (tank) or moisture at Murcki (dump). With regard to oribatid fauna inhabiting the lower section of soil, axis 1 and 2 explained 53% of the total variance. Four pioneer communities are ordinated in the negative part of axis 1 and in the lowest position of axis 2. They were influenced by a similar set of environmental variables, e.g. pH, organic carbon, potassium and available phosphorus content. The pioneer oribatid community on the mine dump at Murcki is ordinated at the right end of axis 1. It is affected by the content of available magnesium and by the field capacity. Oribatids of the pioneer community in the sedimentation

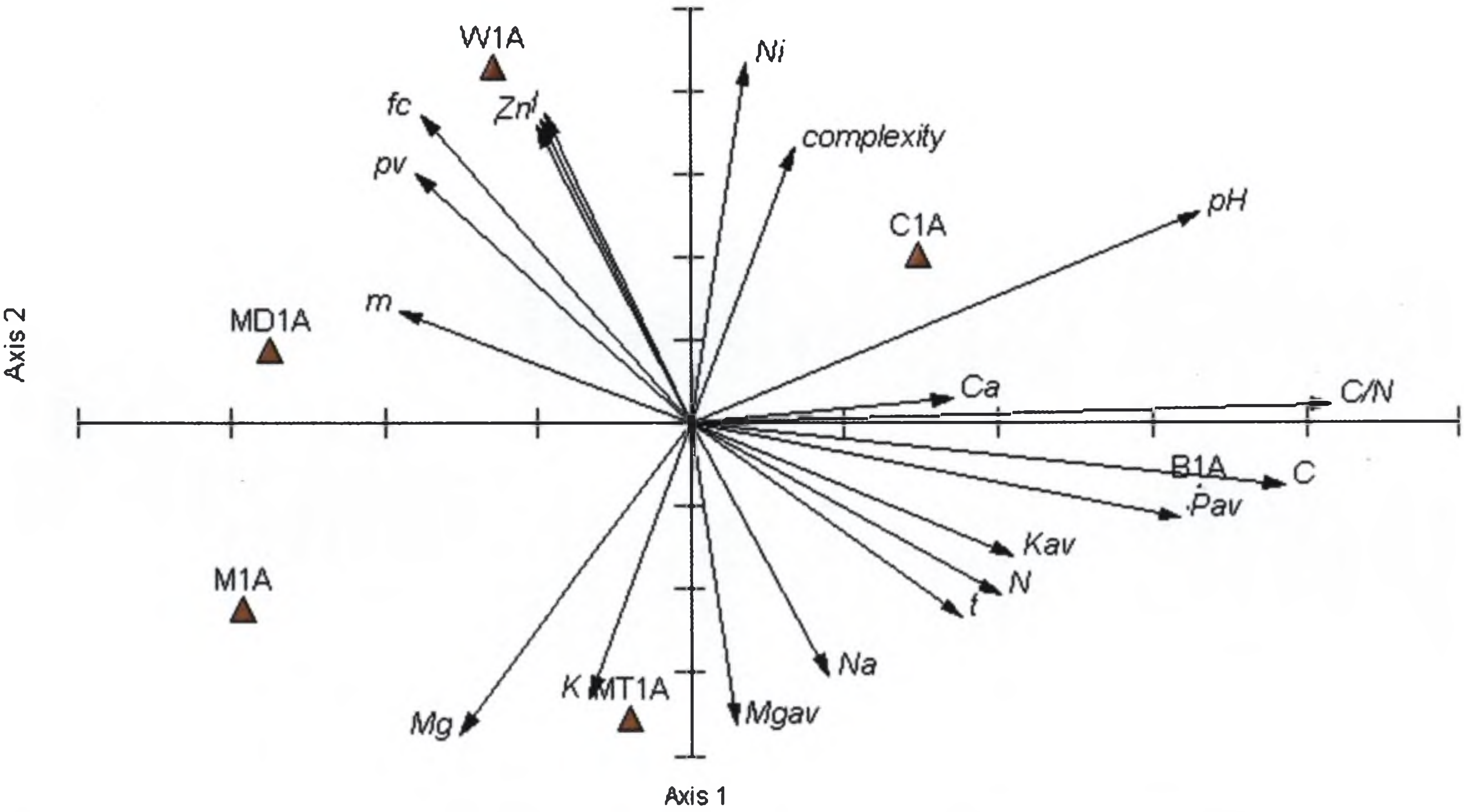


Fig. 11. CCA ordination biplot of sites for the pioneer oribatid communities on dumps (level A); first and second axis
codes of the sites: Table 4
codes of the environmental variables: Appendix 4

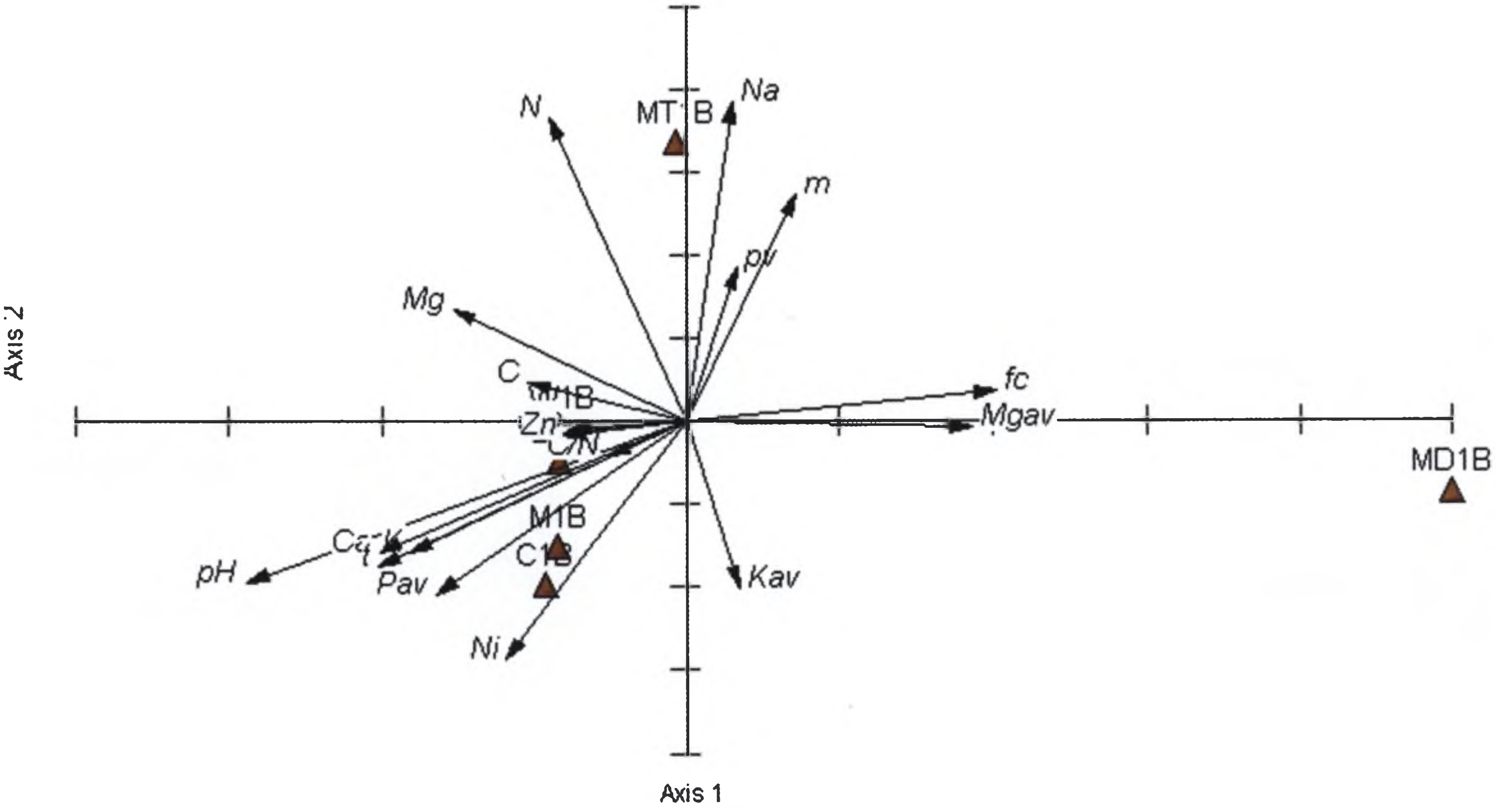


Fig. 12. CCA ordination biplot of sites for the pioneer oribatid communities on dumps (level B); first and second axis
codes of the sites: Table 4
codes of the environmental variables: Appendix 4

Table 15

Basic data on oribatid mite fauna on selected post-industrial dumps

Type of dump	Age (in years)	Abundance (indiv./m^2)	Number of species	Species diversity (H')	Dominant species	References
1	2	3	4	5	6	7
Leveled ironstone quarry	.	1 771	9 and 12	.	*Punctoribates punctum*	Davis, 1963
Reclaimed ironstone workings	.	5 533.5	5 and 8		*P. punctum*, *Oppia clavipectinata* and *Tectocepheus velatus*	
Reclaimed brown-coal spoil heaps	1	11 894	.	.	.	Dunger, 1968
	3	50 033	.	.	.	
	7	7 902				
	10	6 198	.	.	.	
Reclaimed pit heap	.	very low	.	.	.	Hutson, 1972
Lead mine spoil heaps	.	very low	.	.	.	Williamson & Evans, 1973
Reclaimed brown-coal mining sites	1 month	0				Hermosilla, 1976
	1	0				
	3	very low				
	5, 8, 10 and 12 (mean)	very low				
Coal shale pit-heaps	1–2	< 580	.	.	.	Hutson & Luff, 1978
Dumps of open rock mines (forest restoration)	4	3 520	9		*Oppiella nova* (64%)	Babenko, 1980
	8	1 000	9			
	11	31 000	12		*Oppiella nova* (66%), *Microppia minus* (30%)	
	7	15 840	10		*Tectocepheus velatus* and *Scheloribates laevigatus* (to 57%)	
	12	22 560	12			
	25	21 800	13		*Punctoribates punctum*	
Refuse tips		very low	.	.	.	Brockmann et al., 1980

Reclaimed coal pit heaps	0	0				Hutson, 1980 a
	3 months	302			mainly Belbidae and Oribatellidae	
	18 months	176				
	18 months	107				
Reclaimed mine dumps	7	2 214	9	1.792	*Tectocepheus velatus* (40.4%), *Scutovertex minutus* (14.9%)	Bielska, 1982 b
	10	26 267	14	1.975	*Ceratozetella sellnicki* (37.2%)	
	23	29 528	21	2.267	*Eupelops torulosus* (24.3%), *Punctoribates zachvatkini* (21.8%)	
	40	29 199	16	1.730	*Quadroppia quadricarinata* (32.5%), *Oppiella nova* (11.8%)	
Refuse tips	.	very low	.	.	.	Brockmann & Koehler, 1982
Rubble dumps	.	very low	.	.	.	Koehler, 1983
Coal-shale tips						
– Welch Whittle	3–4	5 800–50 900	9–15		*Mixochthonius laticeps* (48.2– 82.9%)	Luxton, 1982
– Pennington Flash	3–4	1 100–62 000	7–18		*Oppiella nova* (8.4–87.2%)	
Rubble dump						Beckmann, 1988
– non-reclaimed	0–4	to 48 000	13	to 0.75	*Oppiella nova*, *Tectocepheus sarekensis*	
– reclaimed	0–4	to 59 600	17	to 0.98	*Tectocepheus sarekensis*, *Oppiella nova*	
Reclaimed mine dump	8–12	8 928	63	2.645	*Punctoribates punctum* (23.6%), *Tectocepheus velatus* (15.3%), *Eupelops occultus* (11.6%), *Scheloribates laevigatus* (10.2%)	Żbikowska-Zdun, 1988

Table 15 cont.

1	2	3	4	5	6	7
Non-recultivated mine dumps	7	795	2	0.636	*Oppiella nova* (33%)	Bielska, 1995
	10	3 963	3	0.551	*Tectocepheus velatus* (75.0%)	
	15	5 535	11	2.012	*Oppiella nova* (21%), *Tectocepheus velatus* (18%)	
	20	13 396	9	1.975	*Ceratoppia bipilis* (21%), *Tegoribates latirostris* (16%), *Quadroppia quadricarinata* (16%)	
	30	45 539	15	1.710	*Oppia globosa* (27.6%), *Tectocepheus velatus* (15.8%), *Oppiella nova* (15.1%)	
Reclaimed ash dumps	3	13 896	40	2.801	*Tectocepheus velatus* (12.3%), *Scheloribates laevigatus* (12.1%)	Bielska & Paszewska, 1995
	3	486	9	2.084	*Tectocepheus velatus* (20%), *Nanhermannia nanus* (20%)	
	11	3 681	18	1.507	*Tectocepheus velatus* (64.1%)	
	11	243	4	1.089	*Tectocepheus velatus* (60%)	
	11	265	5	1.362	*Tectocepheus velatus* (40%), *Ceratozetes mediocris* (33.3%)	
	11	2 091	12	1.181	*Quadroppia quadricarinata* (68.9%)	
Brown coal dumps	1 month	73–182	2–5	0.69–1.4	*Tectocepheus velatus* (50%), *Protoribates hexagonus* (50%), *Trichoribates trimaculatus* (50%)	Stebaeva & Andrievskii, 1997
	7	901–4 427	2–5	0.07–0.7	*Tectocepheus velatus* (98.8%), *Microppia minus* (50%)	
	25	9 724–28 873	11–15	1.44–1.82	*Tectocepheus velatus* (45.4%), *Punctoribates sphaericus* (22.8%)	
Open-cast coal mine dumps (afforested in 1952)	~50	26 500 (1985) 24 400 (1997–98)	63			Dunger et al., 2001

	~50	95 400 (1985) 18 300 (1997–98)	65			
Reclaimed open-cast coal mining areas	~30 ~60				*Tectocepheus sarekensis*, *Oppiella nova*	Frouz et al., 2001
Abandoned pyrite processing sedimentation ponds		0–4015	0–17		*Tectocepheus velatus* (to 72.4%), *Galumna lanceata* (to 15.8%)	Hubert, 2001
– non-reclaimed – reclaimed		2 257–15 302	8–17		*Tectocepheus velatus* (to 68.8%), *Ceratozetes mediocris* (to 41.0%)	

Table 16

General characteristics of oribatid mite communities on selected dumps
(in author's publications)

Type of dump	Age (in years)	Abundance (indiv./m^2)	Number of species	Species diversity (H')	Dominant species	References
1	2	3	4	5	6	7
Iron metallurgic dumps (Bytom)						Skubała, 1995
– non-reclaimed	5	15 167	35	2.789	*Tectocepheus velatus* (18.6%), *Punctoribates punctum* (14.7%), *Scheloribates laevigatus* (10.6%)	
– reclaimed	30	15 779	32	2.213	*Tectocepheus velatus* (45.1%)	
– reclaimed	40	25 611	42	2.651	*Tectocepheus velatus* (23.6%), *Liebstadia similis* (19.0%)	
Abandoned old galena-calamine wastelands	> 100 (pine)	51 792	84	3.203	*Oppiella nova* (19.5%), *Lauroppia falcata* (15.0%), *Quadroppia paolii* (6.1%)	Madej & Skubała, 1996
	> 100 (beech)	29 378	73	3.353	*Lauroppia falcata* (13.5%), *Oppiella nova* (10.8%)	
Galena-calamine wastelands	5–30	4 806–20 528	26–42	2.188–3.043	*Zygoribatula exilis*, *Scutovertex sculptus*, *Oribatula tibialis*, *Eupelops tardus*, *Achipteria nitens*, *Oppiella nova*, *Achipteria coleoptrata*	Skubała, 1996
Dump of a coal burning power plant	30	9 833	46	1.993	*Oppiella nova* (46.7%), *Medioppia obsoleta* (17.4%)	Skubała, 1997a
Dump of a chemical plant	30	9 446	45	2.069	*Tectocepheus velatus* (34%), *Berniniella rafalskii* (19%)	Skubała, 1998

Abandoned galena-calamine wastelands	> 150	23 578	68	3.304	*Oppiella nova* (13.3%), *Quadroppia quadricarinata virginalis* (8.6%), *Dissorhina ornata* (6.8%)	Skubała & Madej, 1997
Abandoned galena-calamine wastelands						Madej & Skubała, 1998
– afforested	> 50	9 318	38	2.38	*Achipteria coleoptrata* (23%), *Dissorhina ornata* (20.5%), *Chamobates voigtsi* (12.9%)	
– unforested	> 50	5 674	28	1.76	*Tectocepheus velatus* (43.5%), *Protoribates variabilis* (28.2%)	
Dumps of the zinc and lead industry						Skubała et al., 1998
– reedy area	~6	13 384	18	1.60	*Oppiella nova* (37.3%), *Liochthonius lapponicus* (26.8%), *Liochthonius propinquus* (15.2%)	
– afforested	> 20	6 911	17	0.94	*Tectocepheus velatus* (80.6%)	
– unforested	> 20	633	10	1.51	*Oppiella nova* (53%)	
Dolomitic dump						Skubała, 1999
– bottom	> 30	14 241	34	2.154	*Tectocepheus velatus* (32.5%), *Protoribates capucinus* (24.5%), *Achipteria coleoptrata* (14.4%)	
– top	> 30	8 296	17	1.278	*Tectocepheus velatus* (71%)	

tank are located in the upper section of axis 2 and are mainly affected by the sodium content.

There were striking differences between the six pioneer oribatid communities that were investigated, which may suggest that chance rules during the formation of pioneer communities. What are the reasons for the significantly higher abundance, species richness, large proportion of oribatids in mite assemblages, and the highest proportion of juveniles in the oribatid community on the mine dump at Biskupice? It could not be the time duration, because the development of oribatid communities on the dumps at Murcki or Chorzów had extended for a greater length of time than on the dump at Biskupice. Furthermore, vegetation development did not differ considerably between the pioneer sites. The dump is adjacent to meadow, whereas forests are particularly abundant in mites. Three other dumps were surrounded by forest (Makoszowy, Murcki – dump and sedimentation tank). The only possible factor affecting the development of oribatid fauna in the pioneer community at Biskupice seems to be the amount of organic carbon, as shown by CCA analysis.

According to biocoenotic principles (THIENEMANN, 1939), there are only a few species at "extreme" habitats, albeit sometimes in great numbers. Is the pile of toxic or non-toxic waste 5–10 years after the cessation of deposition an "extreme" habitat for oribatids? Looking at the abundance of several thousand specimens per square metre and the occurrence of over 30 oribatid species in the plot, we should consider whether such a habitat is really an "extreme" one from the point of view of oribatids. Oribatid mites appear to be successful colonizers of spoil heaps.

We can conclude that successional oribatid communities are not initially similar. They can differ noticeably with regard to abundance, species richness, diversity, proportion of juveniles, or set of dominant species. The environmental factors that influence the differentiation between pioneer oribatid communities are also variable.

General data on oribatid communities on different kinds of post-industrial dumps, which have been studied in the past by a limited group of authors, are presented in Tables 15 and 16. Unfortunately, to compare our data with those in the Tables is not always possible. Most of the studies were strictly associated with the reclamation of dumps. And reclamation measures (delivery of soil, introduction of vegetation, liming, etc.) considerably influence the development of oribatid fauna. Some of the newly reclaimed dumps displayed high abundance and species richness of oribatids, e.g. brown-coal spoil heaps in Dunger's study – over 50 000 m^2 (DUNGER, 1968) or coal-shale tips in England – up to 60 000 m^2 and 18 species

(Luxton, 1982). Other pioneer populations of oribatids on newly reclaimed dumps are low, e.g. coal pit heaps in England – up to 300 m^2 (Hutson, 1980a) or an ash dump in Poland – fewer than 500 m^2 and 9 species (Bielska & Paszewska, 1995). As regards new non-reclaimed dumps, the abundance and species richness of mites varied between dumps, as they did between the sites of this current study. Between 2 and 5 oribatid species with the abundance from 901 to 4427 m^2 were noted on brown coal dumps in Russia (Stebaeva & Andrievskii, 1997). Bielska (1995) noted only 2 species (Oppiidae and Suctobelbidae, not determined to species!) and an abundance of 795 m^2 on mine dumps (7 years of age). Skubała (1995) found 35 oribatid species with an abundance of over 15 000 m^2 on a 5-year-old iron metallurgic dump in Bytom.

7.2. Formation of oribatid mite communities – rate of development

A number of physical and chemical changes occur in the soil as a dump matures. Moreover, botanical changes are the most visible and are well documented in the literature (Majer, 1989b). Changes in the soil and vegetation on the dumps studied are summarized in Appendices 2–4 (CD-ROM) and Tables 5 and 6. These include some of the following:

- a reduction in the proportion of bare ground,
- a more buffered microclimate,
- an increase in plant cover in certain strata,
- an increase in plant height,
- an initial increase in plant species richness,
- an increase in the structural complexity of the vegetation,
- an increased litter layer,
- an increase in soil porosity,
- an increase in the organic content,
- an increased capacity for water holding.

How does the development of oribatid fauna proceed on the dumps? Do oribatid mite communities follow clear and predictable changes in relation to vegetation development and habitat improvement? Do particular characteristics for Oribatida (e.g. abundance, species richness, and diversity) gradually increase with the increasing age of dumps? In this chapter we will consider some general features of oribatid communities.

7.2.1. Abundance

At first we start with a comparison of the mean abundance of the oribatid mite communities that were studied on the dumps. Table 17 gives the calculated *F*-values after the analysis of two-way ANOVA and the confidence level for two sources of variation – site and season. Prior to analysis of variance, data were log-transformed to improve normality. The SNK (Student-Newman-Keuls) test was used to compare site means ($\alpha = 0.05$) within each locality. The two-way ANOVA revealed significant differences in oribatid abundance among all sites and between most of the seasons. Significant differences within the interaction of these two variables ($p < 0.05$) at most locations were not observed. A site-by-date interaction ($p < 0.05$) was observed on the dump at Wełnowiec, Brzeszcze and for three other dumps (Biskupice, Makoszowy and Murcki – dump) when the neighbouring biotopes were also included in the analysis.

A smooth developmental trend was seen at five localities (Chorzów, Wełnowiec, Murcki – dump and tank, Brzeszcze) when we compared the mean abundance during successional stages. The mean oribatid abundance differs significantly ($p < 0.05$, the SNK test) between pairs of sites within each location. The fastest development occurred between the intermediate (site 2) and sub-climax (site 3) stages. Only on the dump at Chorzów were the differences in abundance between the sites not so remarkable, although they were still statistically significant ($p < 0.05$, the SNK test). Three of the dumps were studied using sequential methods (see the chapter “Direct long-term studies of succession”). We will see if this clear trend is to be confirmed.

Two other coal-mine dumps at Biskupice and Makoszowy did not follow this pattern. Strikingly high abundance of oribatids was found at site 2 at Biskupice (33 215 m^{-2}). The number of mites in the pioneer community (12 695 m^{-2}) was also high, slightly higher than in the forest assemblage at site 3. Statistically significant differences (the SNK test, $p<0.05$) were noted only between the following pairs of sites: 1–2 and 2–3. The opposite situation was found on the dump at Makoszowy. Abundance at site 2 (5493 m^{-2}) was noticably lower than on other sites. Surprisingly the abundance at site 1 was highest (9715 m^{-2}), even slightly higher than at site 3 (situated very close to the forest and with some tree species in the B layer). There was no statistical difference between abundance at these sites (the SNK test, $p = 0.28$). We will look at the reasons for these different levels of abundance on these dumps in the following chapters. We concluded that the general rule of a faster change in abundance dur-

Table 17

The mean abundance of oribatid mites (figures are mean ± S.E. number of specimens m^{-2}) on the study sites and results of variance tests (two-way ANOVA). Mean abundances (indiv./m^{2}) are compared by the Student-Newman-Keuls (SNK) method to test for differences between sites. Tests are carried out on the log (x+1) transformed data

		Site 1	Site 2	Site 3	Two-way ANOVA		Neighbouring biotope	Two-way ANOVA	
					F-ratio	*p*		*F*-ratio	*p*
Chorzów	sites	2 001±400 ^{a}	18 215±3 761 ^{b}	22 062±2 089 ^{c}	**104.04**	0.000	14 414±1 839 ^{b}	**70.33**	0.000
	seasons				**5.89**	0.001		**11.21**	0.000
	sites x seasons				0.49	0.81		1.64	0.10
Wełnowiec	sites	2 090±472 ^{a}	7 368±1 250 ^{b}	20 194±2 811 ^{c}	**87.06**	0.000	7 116±783 ^{b}	**58.16**	0.000
	seasons				**10.09**	0.000		**10.99**	0.000
	sites x seasons				**7.84**	0.000		**6.58**	0.000
Biskupice	sites	12 695±2 533 ^{a}	33 215±3 455 ^{b}	12 437±1 661 ^{a}	**39.98**	0.000	12 410±1 050 ^{a}	**30.28**	0.000
	seasons				**45.33**	0.000		**41.65**	0.000
	sites x seasons				1.83	0.09		**4.69**	0.000
Makoszowy	sites	9 715±1 144 ^{b}	5 493±833 ^{a}	9 625±1 117 ^{b}	**11.88**	0.000	30 736±2 855 ^{c}	**54.70**	0.000
	seasons				2.59	0.053		**3.59**	0.014
	sites x seasons				2.09	0.054		**2.36**	0.013
Murcki dump	sites	1 604±422 ^{a}	4 382±817 ^{b}	18 896±1 983 ^{c}	**111.47**	0.000	59 974±4 067 ^{d}	**257.00**	0.000
	seasons				**26.63**	0.000		**20.51**	0.000
	sites x seasons				1.35	0.24		**3.32**	0.001
Murcki tank	sites	548±128 ^{a}	3 042±661 ^{b}	23 597±3 878 ^{c}	**182.01**	0.000	48 340±3 778 ^{d}	**311.17**	0.000
	seasons				0.86	0.46		2.34	0.073
	sites x seasons				0.61	0.72		1.49	0.151
Brzeszcze	sites	10 896±1 056 ^{a}	19 792±1 889 ^{b}	50 174±5 200 ^{c}	**60.32**	0.000	15 715±1 772 ^{b}	**44.17**	0.000
	seasons				1.52	0.208		1.10	0.348
	sites x seasons				**3.23**	0.004		**2.33**	0.015

Bold typed values denote significant differences between abundances at the 0.05 and lower probability level. The results of the SNK test are given by letters. Means sharing a common letter (a, b or c) do not differ significantly from other means at the 5% level.

ing early successional stages rather than in later ones (Frouz et al., 2001) is not an established phenomenon.

Regarding the abundance noted in neighbouring biotopes, it was considerably higher when a particular dump was adjacent to a forest (Makoszowy, Murcki – dump and Murcki – tank). On the other hand when a dump was surrounded by meadows (Chorzów, Wełnowiec, Biskupice), the abundance of oribatids at site 2 (covered by similar plant assemblages) was higher than in adjacent biotopes.

Some authors observed a clear progression in the abundance of oribatids with increasing age of the dumps, e.g. Bielska, 1982b, 1995 and Stebaeva & Andrievskii, 1997 (Table 15 and 16), although fluctuations in oribatid abundance were also frequently observed (Babenko, 1980; Dunger, 1968). It should be mentioned that there is a lack of space-for-time or of direct long-term observations in which oribatids have been studied on dumps.

7.2.2. Species richness

A marked progression in the number of mite species, from sites with an initial plant assemblage (site 1) to sites with pre-forest assemblage (site 3), was observed on most dumps (Table 18). However, site 2 on the mine dump at Biskupice was characterized by the highest number of species (52). Furthermore, the sedimentation tank at Murcki revealed a slightly lower number of species at site 2 than on the youngest site. A totally different situation was found on the reclaimed mine dump at Brzeszcze. The number of oribatids gradually decreased with the age of the dump. At site 3, which was reclaimed 8 years earlier than site 1, the number of oribatid species was lower by ten. It might have been the effect of reclamation measures, which initially deliver (with the soil) many oribatid species. Nevertheless, some of them are unable to live in the specific conditions on the dumps and disappear. Later we will consider if this trend can be confirmed by the sequential method.

From the above data it cannot be concluded that species numbers increased more slowly at older sites, than in the younger ones. Such a phenomenon has been observed in many soil animal groups (Frouz et al., 2001). Competition between resident species and new invaders, as well as a reduction in invader influx, can explain this. It may also be caused by the fact that soil invertebrates naturalized in old forest/meadow are often very poor migrants, even in those groups that normally migrate quickly (MOLDENKE & LATIN, 1991; NEUMANN, 1971). Probably, competition does not play an important role among oribatids (WAUTHY et al., 1989). Furthermore, there may be some ways in which oribatids can achieve successful migration, at least over short distances (see chapter *Ways of migration, pool of colonizers*).

Species richness in adjacent biotopes was usually higher than on any particular site on the dumps. A remarkable difference was noted when the dump was adjacent to a forest (Makoszowy and Murcki). The conclusion is obvious because forest soil is a favourite habitat for oribatids and the abundance of oribatids in meadows is considerably lower (WALLWORK, 1983).

From the literature, it is difficult to make a general conclusion about changes in species richness during succession on dumps. In a few studies a progressive increase in the number of species was not always observed (BABENKO, 1980; BIELSKA, 1982b, 1995) (Table 15 and 16). Unfortunately, it is difficult to make specific conclusions on species richness from Bielska's studies (BIELSKA, 1982a, b, 1995; BIELSKA & PASZEWSKA, 1995) because the author did not determine the species of Belbidae and Suctobelbidae. The latter is usually rich in species on dumps (SKUBAŁA, 1995, 1999; SKUBAŁA et al., 1998).

7.2.3. Species diversity

In general two different trends in changing species diversity were observed. A marked increase in species diversity was noted on some dumps, e.g. at Makoszowy, Chorzów, Wełnowiec and Biskupice (Table 18). It was mainly related with the species number, which was higher on older sites. The relative diversity (depending on evenness of the animals over the species) was in some cases lower on older sites, although a slight decrease in species diversity was observed at site 2 on the dumps at Chorzów and Wełnowiec. On the other hand, a slight decrease in diversity was found at site 3 compared with site 2 on the dump at Biskupice. On the remaining dumps (Murcki – dump and tank, Brzeszcze), species diversity decreased gradually with the age of plots. This was mainly caused by the constantly decreasing equitability (the number of species was higher on the older sites on the dumps at Murcki). These relationships were generally the same in the upper and lower layers of the substratum.

Table 18

Species richness, species diversity (*H'*) and equitability (*J*) of the oribatid communities on the study dumps

Level	Site 1			Site 2			Site 3			Meadow/Forest		
	A	B	A+B	A	B	A+B	A	B	A+B	A	B	A+B
number of species												
Chorzów (C)	16	4	16	30	19	34	40	17	40	42	22	45
Wełnowiec (W)	13	7	13	18	8	22	39	12	40	20	9	22
Biskupice (B)	29	10	33	51	15	52	42	14	47	43	17	43
Makoszowy (M)	14	5	15	16	6	19	20	11	22	47	18	50
Murcki (MD)	10	7	14	15	12	20	24	16	31	78	40	80
Murcki (MT)	15	12	22	15	11	20	36	18	39	74	25	78
Brzeszcze (BR)	50	15	51	45	22	45	41	19	41	50	26	52
species diversity (*H'*)												
Chorzów (C)	1.755	1.180	1.742	1.782	1.097	1.640	2.523	2.109	2.557	2.087	2.326	2.216
Wełnowiec (W)	1.640	1.750	1.711	1.591	1.973	1.624	1.980	1.692	1.991	1.494	1.778	1.542
Biskupice (B)	1.817	1.401	1.899	2.519	2.234	2.522	2.339	2.002	2.360	2.807	2.292	2.835
Makoszowy (M)	1.204	0.904	1.208	1.214	1.227	1.246	1.447	1.446	1.549	2.435	1.413	2.407
Murcki (MD)	1.837	1.834	2.048	1.791	1.391	1.796	1.561	1.245	1.554	3.116	2.769	3.122
Murcki (MT)	2.185	1.963	2.366	1.776	1.396	1.824	1.577	0.545	1.490	2.810	2.553	2.817
Brzeszcze (BR)	2.385	1.903	2.371	2.303	1.894	2.286	1.628	1.439	1.623	3.188	2.933	3.205
equitability (*J*)												
Chorzów (C)	0.633	0.851	0.628	0.524	0.373	0.465	0.684	0.744	0.693	0.558	0.752	0.582
Wełnowiec (W)	0.639	0.899	0.667	0.550	0.949	0.526	0.541	0.681	0.540	0.499	0.809	0.499
Biskupice (B)	0.540	0.609	0.543	0.641	0.825	0.638	0.626	0.759	0.613	0.746	0.809	0.754
Makoszowy (M)	0.456	0.562	0.446	0.438	0.685	0.423	0.483	0.603	0.501	0.632	0.489	0.615
Murcki (MD)	0.798	0.943	0.776	0.661	0.560	0.599	0.491	0.449	0.453	0.715	0.751	0.712
Murcki (MT)	0.807	0.790	0.765	0.656	0.582	0.609	0.440	0.189	0.407	0.653	0.793	0.647
Brzeszcze (BR)	0.610	0.703	0.603	0.605	0.613	0.601	0.438	0.489	0.437	0.815	0.900	0.811

Species diversity recorded in adjacent biotopes was generally considerable higher than on dumps. Both components of diversity (species richness and equitability) contribute to this higher occurrence. However, the species diversity in mite communities on the meadows at Chorzów and Wełnowiec was a little lower than on the oldest sites on the reference dumps. The dumps at these localities are surrounded by highly anthropogenically modified biotopes and the nearby meadows do not represent a stable plant assemblage.

Values of species diversity on dumps (cited by authors or calculated from the current data by the author) are generally low in comparison with undisturbed ecosystems (Beckmann, 1988; Bielska, 1982b, 1995; Bielska & Paszewska, 1995; Skubała et al., 1998; Stebaeva & Andrievskii, 1997) (Tables 15 and 16). In some cases younger stages of oribatid succession are characterized by higher species diversity, e.g. on brown coal dumps in Russia (Stebaeva & Andrievskii, 1997) or reclaimed mine dumps in Silesia (Bielska, 1982b).

7.2.4. Structural changes

In the course of the succession studied on the different dumps, structural changes of oribatid communities were found, especially in the structure of dominant and recedent species. These changes are documented in Table 19. Regarding the dominance structure, the presence of one superdominant species (>30%) was characteristic for all sites on the dumps. The only difference was the presence of two such species at site 1 at Biskupice and the lack of a superdominant at site 3 at Chorzów. On the other hand, there were no superdominants in most adjacent habitats. Only one superdominant species was recorded on the meadows at Chorzów and Wełnowiec and in the forest at Makoszowy. Furthermore, the absolute increase in the number of dominant species (super-, eu-, dominants plus subdominants) with a simultaneous decrease in their relative proportions was the general tendency in changes observed in the dominance structure of oribatid communities in relation to the age of the dumps. This trend was not confirmed with regard to dominant species on both the dumps at Murcki, where the number of species was lowest at site 2. Moreover, no significant changes in the number of dominant species and a decrease in the number of recedent species were observed on the reclaimed dumps at Brzeszcze.

Table 19

Dominance structure (number of species in classes of dominance) of the oribatid communities on the dumps

Locality	Site 1						Site 2						Site 3						Meadow/Forest					
	S	E	D	SD	R	SR	S	E	D	SD	R	SR	S	E	D	SD	R	SR	S	E	D	SD	R	SR
Chorzów (C)	1	1	2	1	6	5	1	1	1	4	2	25	–	3	4	3	2	28	1	1	–	8	3	32
Wełnowiec (W)	1	2	1	1	4	4	1	2	1	1	2	15	1	1	2	3	4	29	1	2	–	2	3	14
Biskupice (B)	2	–	1	3	3	24	1	2	1	5	5	38	1	2	2	4	5	33	–	2	4	8	3	26
Makoszowy (M)	1	–	3	1	3	7	1	1	1	2	1	13	1	1	2	3	1	14	1	2	1	5	3	38
Murcki (MD)	1	2	3	3	5	–	1	3	–	3	3	10	1	1	1	6	1	21	–	2	3	7	5	63
Murcki (MT)	1	–	2	8	11	–	1	3	1	1	2	12	1	1	1	5	–	31	–	2	3	7	3	63
Brzeszcze (BR)	1	1	2	4	4	39	1	1	2	3	5	33	1	1	–	6	–	33	–	1	5	8	8	30

Explanations: S – superdominants, E – eudominants, D – dominants, SD – subdominants, R – recedents, SR – subrecedents.

It might be concluded that only when the oribatid community attained the age of 25–30 years (site 3), did the dominance structure begin to approach that typical of undisturbed ecosystems. However, the number of dominants was still lower than in the adjacent habitats and at least one superdominant species was present in the community. According to Thienemann's biocoenotic principles, there are only a few species at "extreme" habitats and they can comprise high abundance (Meyer & Thaler, 1995). After between 5 and more than 15 years of development (site 1) none of the oribatid communities follow this rule.

7.2.5. Species abundance relationship

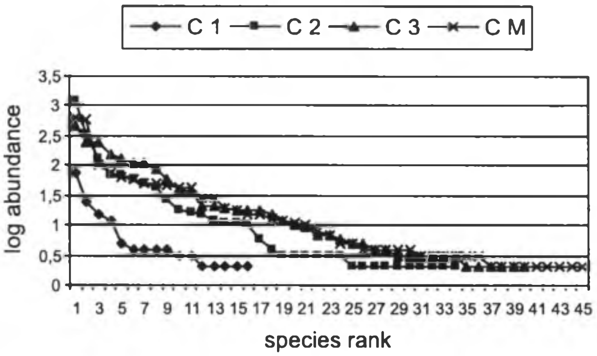
The structure of the oribatid mite communities was also examined using the species-abundance relationship (Magurran, 1988). Individual rank/abundance curves for the total number of mites collected at the study sites are presented in Fig. 13 (a–g). The observed species abundance relationships on the youngest sites are of similar form on almost all the dumps studied. The only difference is the situation observed on the reclaimed dump at Brzeszcze. The curves for the six dumps show a tendency toward a logarithmic distribution. A steep decline of the curves demonstrates their early successional status. Logarithmic series distributions indicate a strong degree of dominance (GILLER, 1996). They are characteristic of disturbed environments and are observed during early succession (STENSETH, 1979). A direct test of the prediction that instability leads to a logarithmic distribution is presented by DIAMOND'S (1972, 1975) study or LASSEN's (1975) study on gastropods.

The species abundance curves on the older sites are less steep. The fauna is richer in species and less dominated by a single species. It is a well-known phenomenon that as the ecosystem becomes mature, the *S*-shaped curves of immature communities become convex (GILLER, 1996). Differences between sites 2 and 3 are not very striking. The slope of the curve for sites 3 are always less steep than for sites 2. Only at site 2 at Biskupice is the dominance curve much flatter than for the two other sites on the dump as well as for the meadow. The species abundance relationship showed a tendency towards a log-normal distribution for at least some of the older sites, e.g. at Chorzów, Biskupice or Brzeszcze. Log-normal distributions are indicative of a few abundant and relatively few rare species and a majority of intermediates (GILLER, 1984). It has been suggested that log-normal distributions are considered to be characteristic of greater environmental stability and are observed in a climax community (STENSETH, 1979).

Regarding the fauna of the adjacent biotopes (at Biskupice, Makoszowy, Murcki – dump and tank and Brzeszcze), the even distribution is reflected in log-series distribution. This pattern indicates the presence of stable oribatid communities in the soil of these biotopes. The rank-abundance species distribution for the meadow at Chorzów was similar to that noted at site 3, whereas the curve of the community for the meadow at Wełnowiec was similar to the curve at site 2 and much steep than at site 3. These curves are not similar to ones for natural biotopes and indicate disturbed environments.

Deviations from the log-normal distribution of soil animals have often been observed and are related to the effects of pollution or other disturbances (e.g. GRAY & MIRZA, 1979; MAGURRAN, 1988; NAGASAWA & NUORTEVA, 1974). Similar deviations with regard to oribatid mites have been noted by SKUBAŁA, 1997b, 1999; VANEK, 1968; ZAITSEV & KRIVOLUTSKY, 1999. It should be realized, however, that if a certain level of pollution or disturbance prevails for a longer period, a return (or relaxation, cf. DIAMOND, 1975) to a log-normal distribution is, according to the Red Queen Hypothesis, to be expected (STENSETH, 1979).

a


C 1
C 2
C 3
C M
log abundance
3,5
3
2,5
2
1,5
1
0,5
0
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species rank

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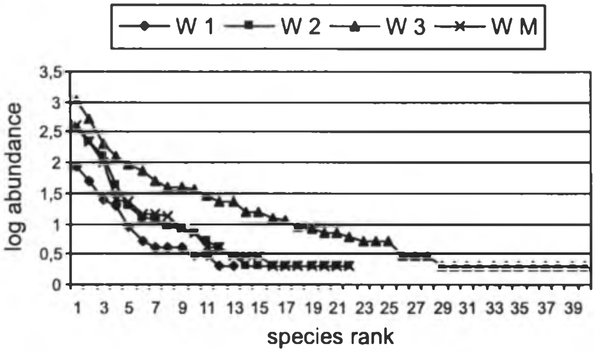
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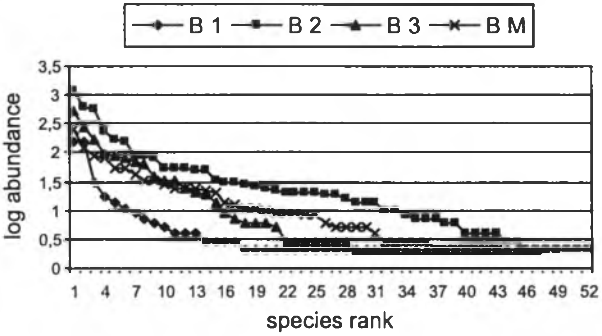
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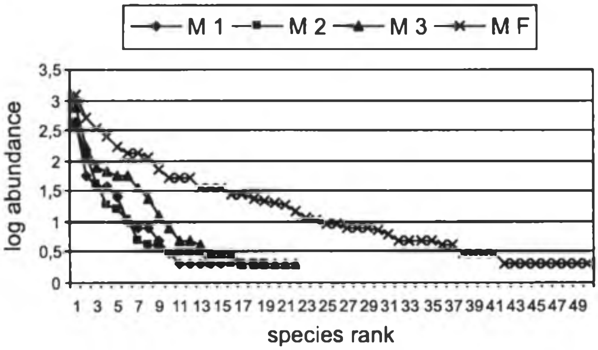
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species rank

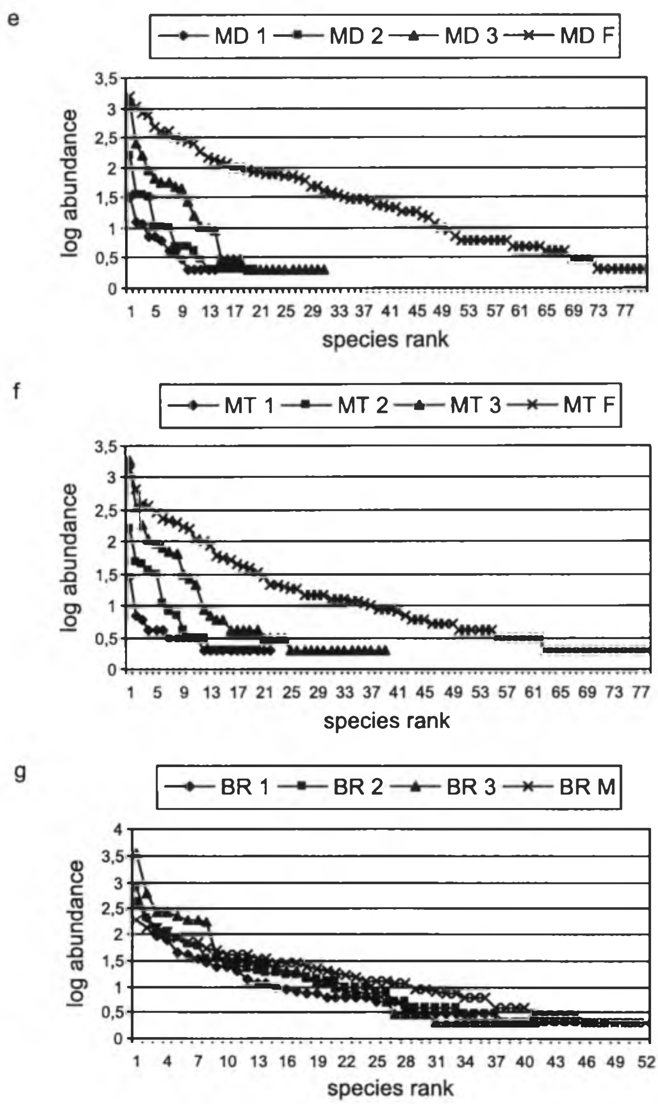


Fig. 13. Species abundance curves for Oribatida on the dumps and in the nearby biotopes

a – Chorzów (C), **b** – Wełnowiec (W), **c** – Biskupice (B), **d** – Makoszowy (M), **e** – Murcki (dump) (MD), **f** – Murcki (tank) (MT), **g** – Brzeszcze (BR)

7.2.6. Spatial distribution

The general trend of increasing aggregation with increasing age of the dumps, and the increased abundance of oribatids, may be recognized in this study (Table 20). Only on the dump at Biskupice was a markedly higher value in the “t” test noted at the site covered with the initial plant assemblage, compared with the other sites. The aggregation in adjacent biotopes was lower than on the older sites on the dumps at many localities, e.g. Wełnowiec, Biskupice, Murcki – tank and Brzeszcze. It may be concluded that post-industrial dumps are apparently heterogeneous environments. Even in

Table 20

Aggregation of oribatid mites on the study sites

Site	Arithmetical mean x	Variance s^2	s^2/x	Greig–Smith-assay $t = (s^2/x - 1) / \sqrt{(2/n - 1)}$
Chorzów 1	3.60	41.61	11.56	66.37*
2	32.79	3 666.65	111.82	696.54*
3	39.71	1 130.43	28.47	172.66*
Chorzów meadow	26.02	1 206.00	46.35	334.93*
Wełnowiec 1	3.76	58.51	15.56	91.51*
2	13.26	403.64	30.44	185.04*
3	36.22	2 049.36	56.58	349.34*
Wełnowiec meadow	12.80	219.90	17.18	119.50*
Biskupice 1	22.85	1 667.14	72.96	452.29*
2	59.79	3 098.98	51.83	319.48*
3	22.39	716.01	31.98	194.72*
Biskupice meadow	22.34	286.28	12.81	74.23*
Makoszowy 1	17.46	340.15	19.48	116.15*
2	9.89	179.37	18.14	107.73*
3	17.32	324.98	18.76	111.63*
Makoszowy forest	55.32	2 113.51	38.20	233.81*
Murcki dump 1	2.89	46.40	16.05	94.59*
2	7.89	173.09	21.94	131.61*
3	34.01	1 019.99	30.0	182.27*
Murcki dump forest	108.04	5 903.03	54.64	396.16*
Murcki tank 1	0.99	4.44	4.48	21.87*
2	5.47	56.94	10.41	59.14*
3	42.57	3 899.56	91.60	569.45*
Murcki tank forest	87.02	3 701.25	42.53	261.03*
Brzeszcze 1	19.62	289.35	14.75	86.42*
2	35.62	928.06	26.05	157.45*
3	90.31	7 014.42	77.67	481.89*
Brzeszcze meadow	28.29	815.14	28.81	174.79*

*Significant at the 0.001 probability level.

apparently homogenous habitats – those sites covered with poor initial plant assemblages – significant aggregation occurs. The aggregation tendencies are related to the gradients of food supply, and to various properties of the soil (MITCHELL, 1978).

7.2.7. Vertical distribution

Most of oribatid mites are included to hemiedaphic forms (GÓRNY, 1975). Usually over 80% of them live in upper horizons, between 0 and 5 cm, at least in temperate climates (KRIVOLUTSKY, 1995; LEBRUN, 1971; NIEDBAŁA, 1967; RAJSKI, 1961; WALLWORK, 1970). However, this may result from the fact that the mean depth of synecological studies has been only 8 cm. Some studies have indicated that soil microarthropod density and biodiversity have been significantly underestimated (DUCARME et al., 2000). The distribution of oribatids should be more concentrated in the upper layer on post-industrial dumps than in other habitats; for instance DAVIS (1963) recorded over 90% of oribatids in the top 7.6 cm on iron-stone quarries.

Regarding the vertical distribution of oribatids in the soil on the dumps studied, usually less than 15% were found in the lower layer (3.5–7.5 cm) (Fig. 14). A significantly higher proportion of oribatids below 3.5 cm was collected only at two sites. These were site 2 on

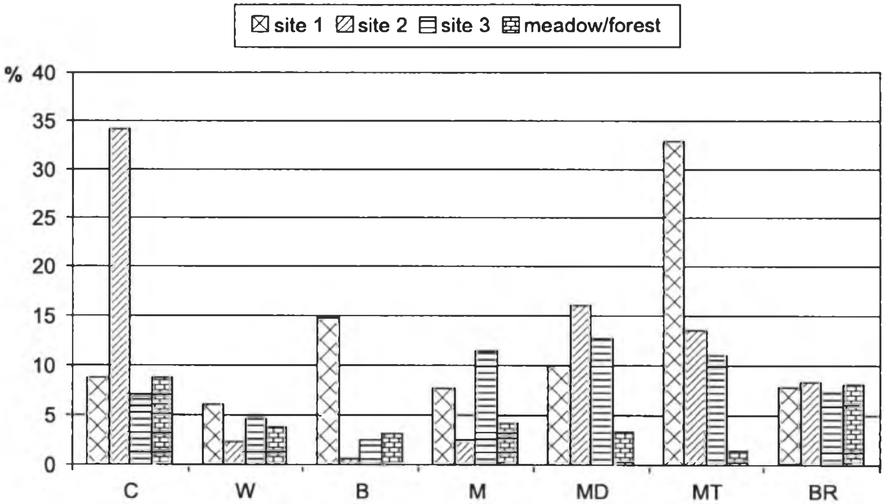


Fig. 14. Proportion of oribatids in the lower section of the soil (3.5–7.5 cm) on the study dumps and in the nearby biotopes
codes of the sites: Table 4

the iron dump at Chorzów and site 1 in the sedimentation tank, where 34.2% and 32.9% of the total number of oribatids occurred in the lower layer. The relationships between the physical and chemical properties of the upper and lower sections of the soil were not remarkably different at these sites, compared with the others (Appendix 4 – CD-ROM). So some of these particular features were not the reason for the higher occurrence below 3.5 cm. The mechanical composition of the substrate (coal-dust) at site 1 in the sedimentation tank was almost identical in both layers (Appendix 2 – CD-ROM). This characteristic might be the main reason for the more homogenous distribution of oribatids in the soil profile of the sedimentation tank.

In general the percentage of oribatids in the lower section of the soil in the adjacent forests and to a lesser extent in meadows was lower than on the dumps (Fig. 14). The higher concentration of litter and organic matter in the upper layer in these undisturbed (or less disturbed) biotopes, especially in forests, may influence the spatial distribution of oribatids. Some chemical parameters of the soil (e.g. carbon or nitrogen content, the amount of available potassium, magnesium and the amount of exchangeable cations of sodium, potassium, calcium and magnesium) attained noticeably higher values in the 0–3.5 cm layer than below this level (Appendix 4 – CD-ROM). Such a situation was well distinguished in the sedimentation tank, at the dump and in the nearby forest at Murcki.

To answer the question "how many species from the total number of oribatid species are missed by taking samples only from the 0–7.5 cm level?", soil samples from deeper soil layers (7.5–15 cm) were taken at site 3 on the dump at Biskupice, Makoszowy and Murcki (sedimentation tank). The proportion of oribatids that occupied this layer of the soil fluctuated from 4.1% (Biskupice) to 14.2% (Makoszowy) (Fig. 15). So even in technogenic biotopes, e.g. post-industrial dumps, we may lose 5–15% or more of oribatid fauna while sampling in the traditional way.

Many species of different morphological structure occur in the lower horizons of the soil on the dumps. There were two most abundant oribatid species on dumps, e.g. *Oppiella nova* and *Tectocepheus velatus,* as well as *Microppia minus* (Table 21). Furthermore, other species characteristic of a particular dump occurred abundantly down in the soil. They were mainly representatives of the family Oppiidae and were of the following genera: *Ceratozetes*, *Microtritia*, *Protoribates* or *Punctoribates*, although only four species may be regarded as characteristic of lower horizons of the soil on dumps, namely *Microppia minus* (C 2), *Oppiella nova* (B I), *Microtritia minima* (M 3) and *Protoribates capucinus* (C 3). Their abundance was

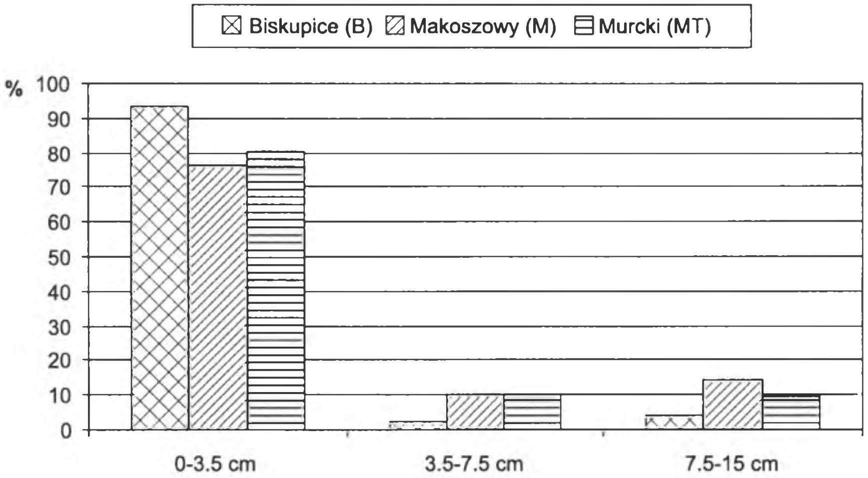


Fig. 15. Proportion of oribatid mites in the three layers of the soil at site 3 on the mine dumps at Biskupice, Makoszowy and Murcki

significantly higher in the lower section of the soil, at least at some sites (in brackets). The length of these species varied from 0.21 μm (*Microtritia minima*) to 0.35–0.40 μm (*Protoribates capucinus*). All these species are characterized by narrow body shape, e.g. *Microppia minus*, *Microtritia minima*.

Bearing in mind that pore space dimensions decrease progressively down the profile, and that oribatids utilize these spaces for living quarters, there is a selection for small body size with increasing depth (Holt, 1981). Small body size and the absence of a thick cuticular waterproofing layer (Madge, 1964) in these mites result in the danger of excessive transpiration losses. This may prevent small soil dwellers from venturing into upper horizons (Wallwork, 1983). Evidence for vertical separation of oppiids, e.g. *Oppiella nova*, *Quadroppia quadricarinata*, *Microppia minus* (Evans et al., 1961) and *Microtritia minima* (Pande & Berthet, 1975) is well documented. Pande and Berthet (1975) claimed that an important limiting factor in ability to penetrate the soil is body width. Niedbała (1976) studied the vertical distribution of the smallest oribatid species – the family Brachychochthonidae – and discovered that they did not penetrate into the lower soil layers. Indeed, these species seldom occurred in the lower layer on the investigated dumps, where brachychthoniids were numerous, at least not in the “pioneer” stage.

Table 21

Numerous oribatid species (*D* > 10%) in the lower section of the soil (3.5–7.5 cm) on the study sites

Species	Chorzów (C)				Wełnowiec (W)				Biskupice (B)				Makoszowy (M)				Murcki (MD)				Murcki (MT)				Brzeszcze (BR)			
	1	2	3	M	1	2	3	M	1	2	3	M	1	2	3	F	1	2	3	F	1	2	3	F	1	2	3	M
Ceratozetes gracilis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	10.0	–	–	2.4	–	–	–	**11.7**	–	–	–	1.9
Ceratozetes mediocris	–	0.1	–	–	**12.5**	–	**14.8**	6.4	–	3.2	–	–	–	–	–	–	–	–	2.5	–	–	–	0.5	–	1.1	–	6.8	6.7
Conchogneta delacarlica	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**22.5**	–	–	–	–	–	–	–	–
Cultroribula lata	–	–	–	–	–	–	**21.3**	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lauroppia fallax	–	–	**13.1**	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.3	–	–	–	–	–
Liebstadia similis	–	–	**10.6**	**20.2**	–	–	–	6.4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**11.5**
Medioppia obsoleta	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1.8	**18.4**	0.4	–	–	–	–	5.6	0.6	5.2	–
Microppia minus	–	**32.2**	3.1	–	–	–	–	9.8	–	–	**15.5**	**17.6**	–	7.1	**18.9**	**32.9**	–	–	–	**10.5**	–	**12.7**	1.1	**14.3**	4.5	3.3	–	2.9
Microtritia minima	–	–	–	–	–	–	**43.5**	–	–	–	–	–	1.8	–	**25.8**	–	–	–	–	0.7	–	–	–	1.3	–	–	–	–
Oppiella nova	**18.8**	**59.1**	6.2	**10.8**	**31.2**	10.0	**43.5**	**12.9**	**24.4**	**35.5**	**37.8**	**35.3**	**19.6**	**64.3**	**44.0**	**50.3**	**20.0**	**66.8**	**63.3**	**18.1**	**45.8**	**63.6**	**90.8**	**29.9**	**48.3**	**52.0**	**66.5**	**11.5**
Pillogalumna tenuiclava	–	–	–	**22.1**	–	–	–	–	2.2	3.2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Protoribates capucinus	–	–	**37.5**	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Protoribates variabilis	–	–	–	–	–	–	–	6.4	–	–	–	–	–	–	–	0.6	–	–	–	–	–	–	–	–	–	0.6	–	**11.5**
Punctoribates punctum	–	0.1	1.9	0.6	–	–	–	–	2.2	–	**17.8**	2.9	–	–	–	0.6	–	–	–	6.9	4.2	3.6	0.3	–	**11.2**	6.6	3.2	1.9
Ramusella (R.) assimilis	–	–	–	–	**12.5**	–	4.1	–	2.2	–	**17.8**	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.6	–	–
Ramusella (I.) insculptum	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**30.0**	–	6.7	–	–	–	0.3	1.3	–	–	–	1.9
Rhysotritia ardua	–	–	3.8	**11.7**	–	–	–	–	–	3.2	2.2	–	–	–	–	–	–	–	–	–	–	–	–	1.3	–	–	–	–
Scutovertex sculptus	**50.0**	0.3	0.6	1.4	–	10.0	–	3.2	2.2	3.2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Tectocepheus minor	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	5.1	–	1.8	0.8	1.3	–	**13.8**	–	–
Tectocepheus velatus	**25.0**	0.9	**11.3**	**11.7**	**25.0**	**30.0**	5.8	**45.3**	**55.5**	**16.1**	4.4	2.9	**69.6**	–	0.6	0.6	–	5.6	5.5	–	4.2	3.6	0.5	2.6	3.4	3.9	5.6	1.9

Bold typed values indicate dominant species on a particular dump.

7.3. Oribatid systematic cohorts on dumps

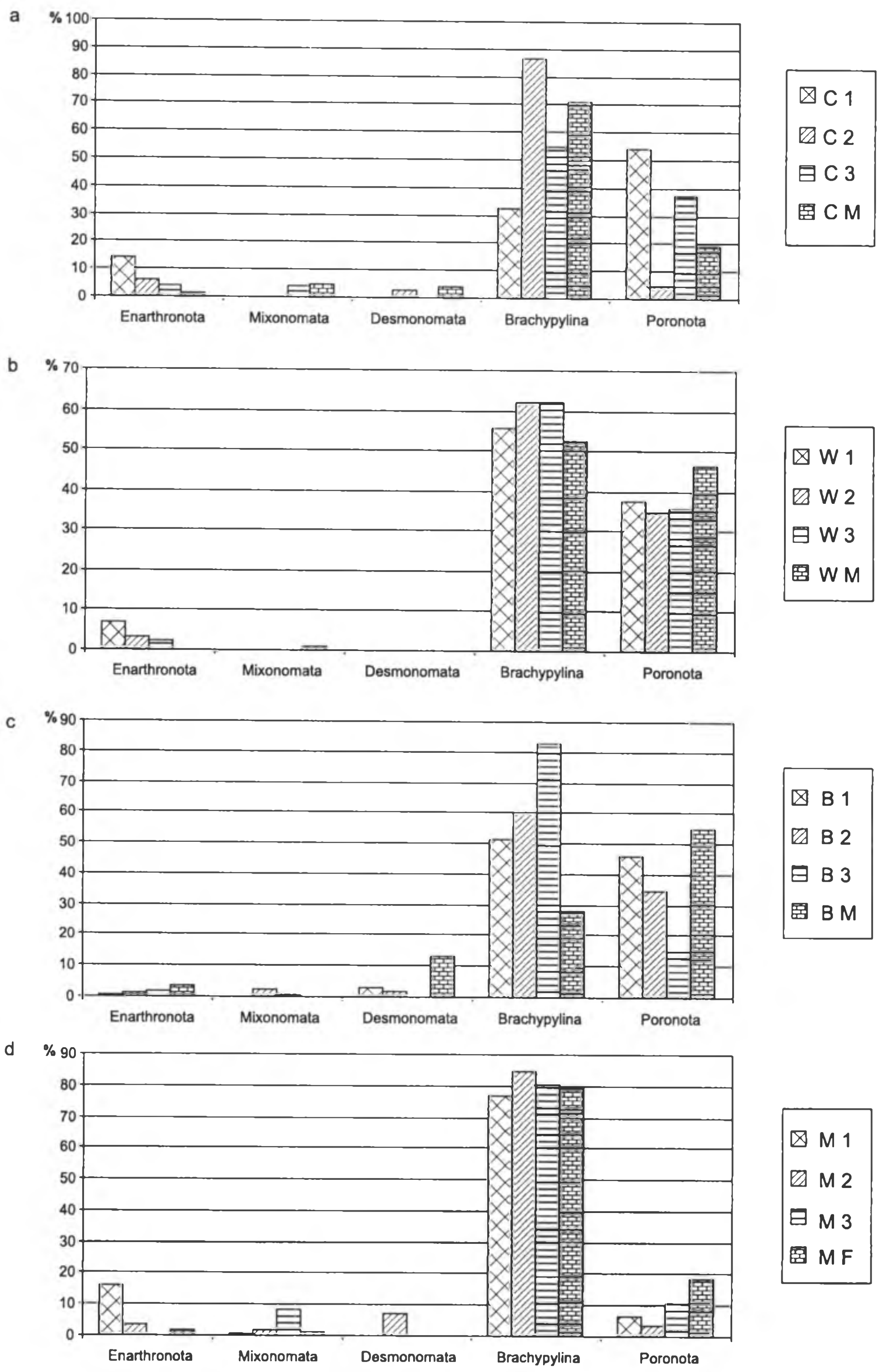
Some distinct trends in the proportion of phylogenetic categories were recognized on the dumps (Fig. 17 a–g). The Brachypylina cohort was the most numerous group on the dumps. Its proportion ranged from 32.1% (Chorzów – site 1) to 86.2% (Chorzów – site 2). The second most abundant group was Poronota, however, its proportion was smaller than that of the previous cohort at almost every site. Three other cohorts – Enarthronota, Mixonomata and Desmonomata – were represented by a significantly lower number of individuals. Paleosomata and Parhyposomata were not collected from the dumps. As regards the relationships in the nearby biotopes, usually Brachypylina were more numerous than Poronota. The proportion of the other cohorts in these biotypes was much smaller than on the dumps.

The high proportion of the Enarthronota representatives at the "pioneer" stage of succession (site 1), and their systematically decreasing proportion in the community as dumps age, was characteristic in the analysis. Maraun & Scheu (2000) stressed that Enarthronota appear to suffer most from disturbance. This is indicated by the strong reduction in their abundance from moder to mull humus and their low numbers in anthropogenically formed habitats. Enarthronota produce only a few eggs, which develop slowly (Forsslund, 1957). Furthermore, despite their small size they are assumed to be *K*-selected. Nevertheless, it is evident from the analysis that Enarthronota may play an important role on post-industrial dumps, especially on the youngest sites of technogenic ecosystems. Due to their small size and cryptic habitat, our knowledge of the ecological characteristics of Enarthronota is limited.

Brachypylina, the dominant cohort on the dumps and in most adjacent biotopes, is a very heterogeneous group that includes species with different ecological characteristics. The high proportion of Brachypylina is mainly due to the numerous occurrence of the following families: Oppiidae, Suctobelbidae and Tectocepheidae.

Poronota reach relative high densities in disturbed soils (Maraun & Scheu, 2000). Members of this cohort appear to tolerate mechanical disturbances, which is presumably due to high sclerotization. Many of the species, e.g. of the genus *Galumna*, *Achipteria*, *Euzetes*, are accustomed to living on the surface (Krivolutsky, 1968). Nevertheless, their significance is lower than that of Brachypylina on post-industrial dumps.

The Phthiracaridae, the main representatives of Mixonomata, are easy to recognise morphologically. They are able to close up and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% 100
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Enarthronota
Mixonomata
Desmonomata
Brachypylina
Poronota
C 1
C 2
C 3
C M
b
% 70
60
50
40
30
20
10
0
Enarthronota
Mixonomata
Desmonomata
Brachypylina
Poronota
W 1
W 2
W 3
W M
c
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Enarthronota
Mixonomata
Desmonomata
Brachypylina
Poronota
B 1
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B 3
B M
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% 90
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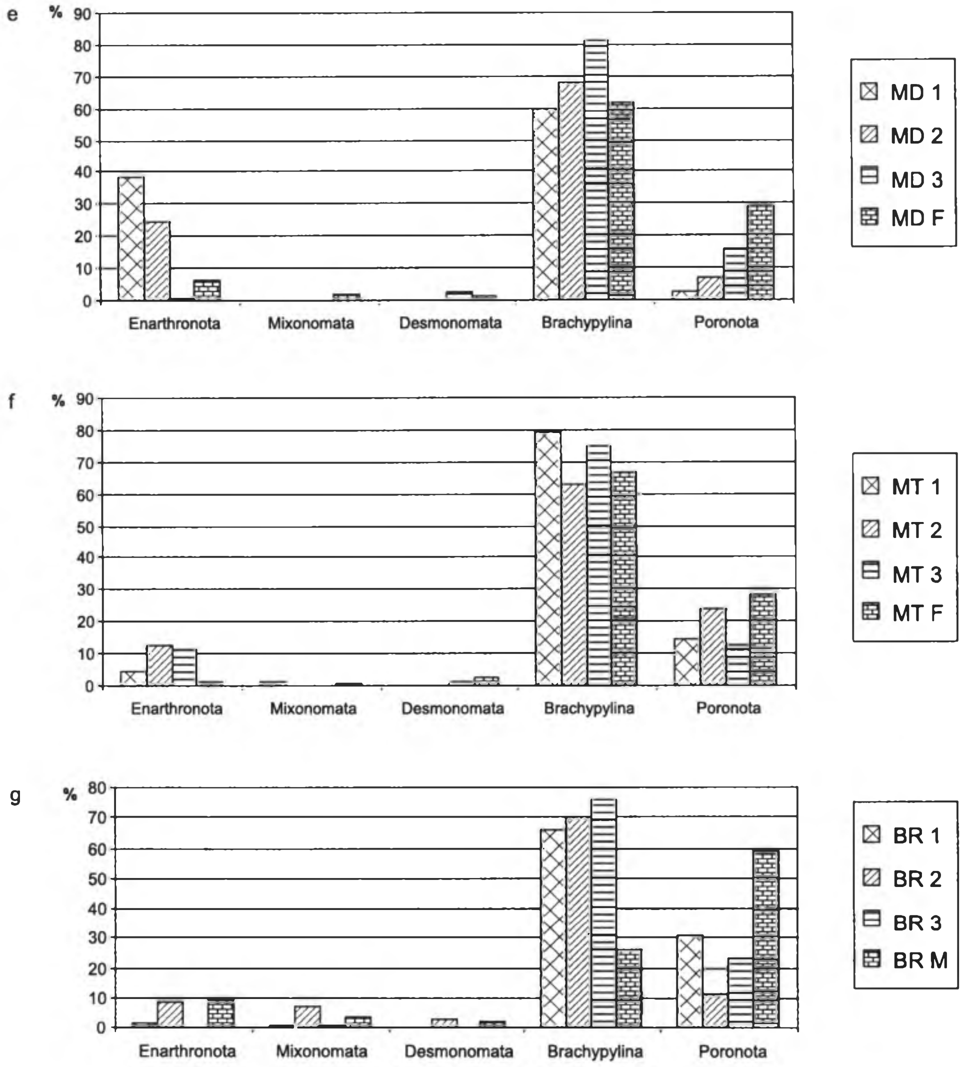


Fig. 17. Proportion of cohorts in oribatid communities on the post-industrial dumps and the nearby biotopes

a – Chorzów (C), **b** – Wełnowiec (W), **c** – Biskupice (B), **d** – Makoszowy (M), **e** – Murcki (dump) (MD), **f** – Murcki (tank) (MT), **g** – Brzeszcze (BR)

protect their body with sclerotized plates. Therefore, Phthiracaridae may exist in a habitat without threat from enemies (Norton, 1994). Egg development is slow (>120 days) in this group and adults may live for more than one year (Luxton, 1981b). All immature stages of this group are endophagous, burrowing in decaying plant material (Norton, 1994). The features described above are possible obstacles in the ability of the Phthiracaridae to colonize new habitats.

Desmonomata play a limited role on dumps. Most species reproduce by thelytoky (Norton, 1994) and lay from 5 to 40 eggs (Luxton, 1981b; Travé et al., 1996). They have a wide food spectrum, appear to be habitat generalists, and some are of cosmopolitan distribution (Maraun et al., 1998). Although, these features seem to be advantageous on dumps, Desmonomata are rare in this environment. Slow egg development may be disadvantageous for colonization.

All species within individual families in the cohorts Enarthronota, Mixonomata and Desmonomata reproduce asexually (Norton et al., 1993). Suggested advantages of parthenogenesis include the ease of colonization in new areas (Norton et al., 1988; Norton & Palmer, 1991). Parthenogenetic reproduction facilitates rapid population growth and is one of the main oribatid strategies for colonizing pioneer habitats (Smrž, 1992). Nevertheless, the representatives of these cohorts play a minor part in the colonization of technogenic systems, e.g. post-industrial dumps. Only the role of Enarthronota in pioneer communities is recognized. On the other hand, the most important species that are able to attain a high abundance in almost all of these unfriendly habitats (dumps) – *Oppiella nova* and *Tectocepheus velatus* – are thelytokous species (Norton & Palmer, 1991).

7.4. Oribatids on contaminated dumps

Some authors (Seniczak et al., 1996; Stamou & Argyropoulou, 1995; Strojan, 1978; Zaitsev, 1999) observed the impoverishment of oribatid populations on contaminated sites. One of the dumps studied – the zinc dump at Wełnowiec – was characterized by extremely high doses of cadmium, lead, zinc and nickel in the soil (Appendix 4 – CD-ROM). Taking into consideration that the age of the sites was between 1.5 and 5 times higher than the age of comparative sites on other dumps, the abundance of oribatids should be considered as low. Similarly the species richness (13 to 40 species) was low in comparison with other younger non-contaminated dumps (Table 17 and 18). The dominance structure of oribatid communities is only slightly transformed during the succession, and the species abundance curves for site 1 (>15 years) and site 2 (>20 years) are still steep (Table 19, Fig. 13 b). Although the overall abundances and species richness of oribatids were low, some oribatid species were recorded in higher numbers on the contaminated dump, compared with other dumps and with their reference sites. These species were: *Ceratozetes mediocris* (Fig. 16), *Peloptulus phaenotus* and *Protoribates variabilis*.

The possibility of development of the oribatid community in polluted areas seems to be slight. The reason for this lies in the nature of the pollution. Aerially deposited metals are concentrated in the upper organic horizons for long periods of time by ion exchange, surface adsorption and chelation-reaction mechanism (Mortensen, 1963). High concentrations of metal contaminants are likely to remain in the soil for many centuries (Strojan, 1978). Furthermore, certain abilities to store or excrete heavy metals can explain the poorer oribatid fauna on contaminated dumps with a certain species composition. Oribatids take up heavy metals with the food and store them in the midgut within the spherites (Ludwig et al., 1993). It seems likely that metals stored within the spherites can be extruded into the lumen of the midgut. This suggests that oribatids are able to eliminate at least a part of their body burden of heavy metals (Ludwig et al., 1991).

Oribatids are a group sensitive to heavy metal concentrations. Their capacity for accumulating heavy metals differs greatly between species and within species with regard to a specific metal (Lebrun & Van Straalen, 1995; Parmelee et al., 1993). For instance *Heminothrus peltifer* appears to be relatively sensitive to lead, but not especially sensitive to copper (Denneman & Van Straalen, 1991). However, the effect of heavy metals on reproduction seems to be the most relevant criterion for soil microarthropods. Higher doses of heavy metals have a negative effect on the reproduction of certain oribatid species (Van Straalen et al., 1989; Denneman & Van Straalen, 1991).

The contact of soil animals with heavy metals is mainly mediated by trophic chains. Various species of oribatids feed on fungi, which are known to be effective heavy metals accumulators (Berthelsen et al., 1995; Khan et al., 2000; Valix et al., 2001). Therefore, oribatids are directly exposed to heavy metal concentrations. Another factor influencing the ability of oribatids to live in contaminated area is their feeding habits. Herbofungivorous and fungivorous grazers have a higher exposure in contaminated environments than other mite species. In the severely heavy-metal-polluted site, members of these guilds are almost absent (Siepel, 1995b). Fungivorous grazers (e.g. *Scheloribates laevigatus, Oribatula tibialis, Punctoribates punctum*) appeared to accumulate lead faster than fungivorous browsers (e.g. *Hemileius initialis, Chamobates borealis*) (Siepel, 1995b; Siepel & Ruiter-Dijkman, 1993). Nevertheless, many oribatid populations are able to live in a toxic environment and to achieve moderate abundance, as was observed on the zinc metallurgic dump at Wełnowiec.

7.5. Developmental stages of oribatid communities

Anderson (1977) argued that soil animals do not form well-developed communities and therefore it is difficult to associate species configurations or assemblages with vegetation types or physiochemical features of the habitat, although he did show that oribatid species diversity is significantly correlated with microhabitat diversity (Anderson, 1978a). Plowman (1981) stresses that without sharply defined boundaries the definition of species communities becomes particularly difficult, and it must be asked whether such a search is valid.

This work reveals that related sets of oribatid species forming a community can be identified on dumps. A "pioneer" community can be identified on dumps covered with initial plant assemblages. It is characterized by low abundance (usually below 10 000 mites per m^2) and low species richness (usually between 10 and 15 species). Other community features also classify them as less stable. The second "meadow" stage is described on dumps with a well-developed herb layer. The zoocenotic characteristics of oribatid communities at sites 2 situate them at a higher level of a community formation. The third "forest-like" stage is recognized on dumps where the shrub and tree level has developed. This stage was described at dumps where deposition had ceased between 10 (Makoszowy) and 50 (Wełnowiec) years ago. The zoocenotic characteristics of oribatid communities of this stage still differ from those described in non-disturbed adjacent biotopes. It is worth mentioning that the sites are situated on a transect and the distance between them is 10–30 metres.

Similar stages of soil animal/microarthropod succession were described by some other authors on dumps. Dunger's analysis of the extensive data on 13 variants of coal dumps in Germany demonstrated the existence of at least four main stages of pedobiont development (Dunger, 1989). The first and second stages are called "pioneer", the third is "meadow" and the fourth is the "forest-like" stage. This valuable research was undertaken on dumps that had undergone rehabilitation. The first pioneer stage was characterized by hot dry conditions and the absence of organic matter. In the present succession studies on oribatid mites the first "pioneer" stage was not selected. Oribatids as slower colonizers of new dumps are practically absent at sites where the piling stopped only 1–2 years previously, which is why this stage was not selected in the present research. Stebaeva & Andrievskii (1997) distinguished three developmental stages (after Dunger) during studies on the spontaneously formation of technogenic ecosystems on brown coal dumps in Siberia. These were: a community on a "fresh dump" (1 month to 1 year) and a "medium-age dump" (7–8 years). The oldest dump (25–26 years) investigated in this research was at the "meadow" stage.

7.6. Similarities and differences

A qualitative comparison of the oribatid communities studied is shown in Figs. 18 and 19. A dendrogram of hierarchical classification and Correspondence Analysis (CA) were used to search for site groupings.

The dendrogram shows the clusters established among 28 sampled sites on the dumps and adjacent habitats according to their ecological affinities on the basis of species composition (Fig. 18). Sites are divided into two main clusters. Cluster A encloses two subgroups. Sub-cluster A1 consists of 6 sites. They are sites 2 and 3 from different localities as well as site 1 from the reclaimed dump at Brzeszcze and the meadow at Chorzów. Sub-cluster A2 contains

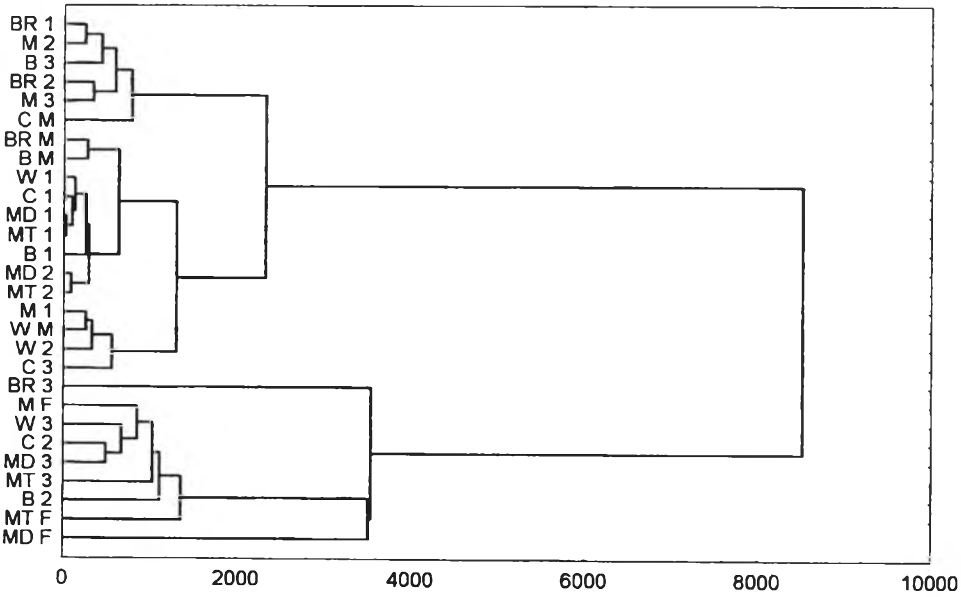


Fig. 18. Cluster analysis of community data from the study sites on dumps and in the nearby biotopes (Euclidean distance, Ward's method)
codes of the sites: Table 4

site 1 from all remaining localities and site 2 from three localities. The remaining sites 2 and 3 and the "forest" sites form a separate cluster B. The sites are not grouped according to localities. A clear separation was observed only between the species groupings in "pioneer" communities and the others.

Ordination for the first and second components of the correspondence analysis (CA) of oribatids on the dumps and in the nearby biotopes is shown in Fig. 19. The ordination axes are interpreted as gradients in one or more environmental factors. The eigenvalue of axis 1 (0.396) was significant and axis 2 also attained a high value (0.258). These axes explained only about 20% of the total data variability. In the interpretation of the CA analysis, the closer the data sets are to each other, the more similar is the community structure. The sites on the dumps are grouped into four sets. Oribatid communities of the forests (MT F and MD F) at Murcki are ordinated along axis 1 and are most separated from other sites. All communities from Brzeszcze, the meadow at Biskupice and the forest at Makoszowy formed the second cluster. The communities are ordinated in the lower section of axis 2. All oribatid communities from Chorzów (dump and meadow), Wełnowiec (dump and meadow) and Biskupice (dump) are ordinated along the negative part of axis 1. Oribatid communities from Murcki (MD – sites 1 and 2, MT – site 2) and Makoszowy (sites 2 and 3) formed the last group. They are ordinated in the upper section of axis 2 and the negative part of axis 1. The pioneer oribatid community of the mine dump at Makoszowy appears to be noticeably different from the other communities. This community is situated at the end of axis 2 and in the middle of axis 1.

The results of CA ordination are not in accordance with successional divergence. Rather, sites are grouped in accordance with the localities, although sites (1, 2 and 3) of different age are in most cases separated from each other. Both analyses of species abundance (cluster and correspondence analysis) do not show identical groupings of species configurations. It seems that the opinion of Wauthy (1981) regarding correspondence analysis as efficient in bringing out the zoosociological groupings in the case of hemiedaphic oribatid communities is well confirmed in this analysis. Both analyses confirm that successional oribatid communities do not necessarily follow the same course. Early ("pioneer") communities that are initially more or less similar (see cluster analysis) do not converge on similar pre-climax communities.

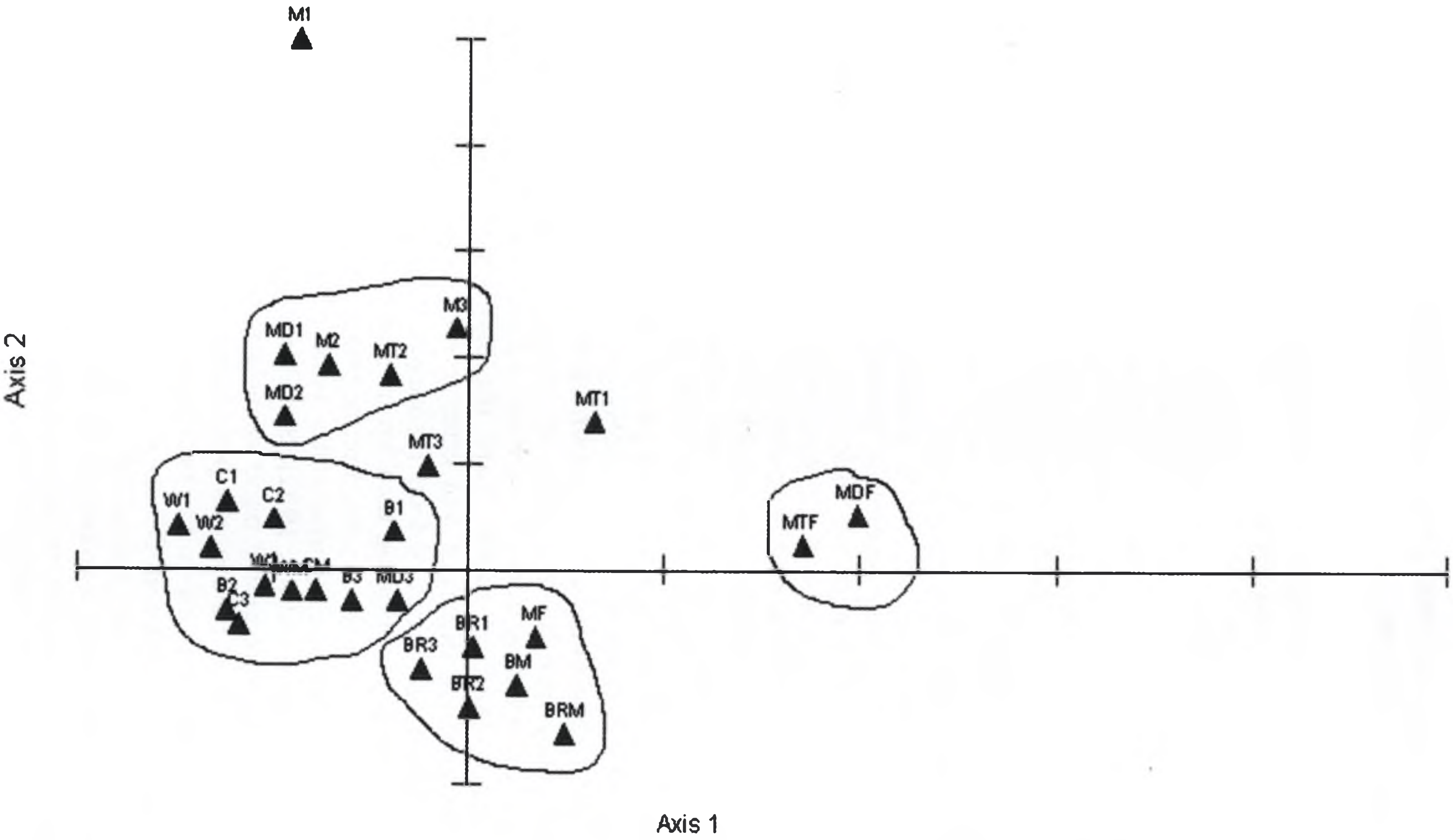


Fig. 19. A plot of the first two axes of correspondence analysis (CA) of the 28 sampling sites on the dumps and in the nearby biotopes
codes of the sites: Table 4

7.7. Driving factors and the formation of oribatid communities

The study of succession in soil arthropod communities, however much still in its preliminary stages, reveals that changes in vegetation must play a major role (Usher et al., 1982). According to feeding habits, vegetation can be regarded as the main factor affecting change in oribatid communities (Niedbała, 1972). As long as vegetation is absent on a certain substratum, oribatids are unable to colonize it (Beckmann, 1988; Smrž & Jungova, 1989). This is also true for mined areas (Dunger et al., 2001; Felinks et al., 1999; Skubała, 1997a; Wiegleb et al., 2000). Plant species are major determinants of local site conditions, mediating many soil variables, such as sunlight, moisture and soil nutrients, and therefore have the potential to influence the composition and structure of soil mite communities (Beare et al., 1995; Wardle & Lavelle, 1997; Wardle et al., 1998). Moreover, vegetation produces litter and is a source of organic matter in general, which is a food source for oribatids (Seastedt, 1984; Tousignant & Coderre, 1992). Thanks to plants, fluctuations of temperature and humidity are generally less extreme and provide a more suitable environment for oribatids than open areas.

Vegetation is especially important in the renaturalization of post-industrial dumps. Lebrun (1979) showed that planting adequate vegetation could shorten the time period involved in restoration of abandoned quarries. Seniczak (1994) proposed planting different deep-rooted species capable of retaining water, and also deciduous trees (as they give more shade) on dumps. Oribatid species are probably attracted by microflora, which changes during the succession (Heal & Dighton, 1986). Thus, the planting of more tree species that produce different leaf litter is recommended in order to provide broad spectrum of food resources (Miko, 1995). Nevertheless, it is worth mentioning that an increasing number of authors have found the effects of introducing plant species unsatisfactory and indicate that the spontaneous succession of plants is more desirable (Weidemann et al., 1982). Spontaneous succession leads to more stable and interesting plant associations and is good evidence of self-regulation of biocenoses (Rostański, 1991). The development of oribatid communities on the reclaimed mine dumps at Brzeszcze also confirms this opinion. Dunger et al. (2001) claimed that the presence of a very poor soil fauna on a 35-year-old pyrite-rich spoil at Damsdorf was partly caused by planting exotic oaks. A similar situation occurred on the reclaimed dumps at Brzeszcze where some exotic plants were introduced, e.g. *Quercus rubra*.

The outcome of the coupling between mites and the botanical environment is presented in Table 22 and Figs. 20 and 21. A close correlation between oribatid communities and plant assemblages was observed in the chi-square test (Table 22). The null hypothesis that there is a similarity of data arrangement (total number of species, number of exclusive and dominant species) was rejected only in a few cases. No correlation was detected between the total (χ^2 = 25.19, tau *c* Kendall's index = –0.205) and exclusive (χ^2 = 20.53, tau *c* Kendall's index = –0.404) number of oribatid and plant species in

Table 22

Species composition of the oribatid and plant communities on the post-industrial dumps and the adjacent biotopes (χ^2 analysis)

	Oribatida				Plants				χ^2	P	tau *c* Kendall's index
	1	2	3	M/F	1	2	3	M/F			
Chorzów											
Total number of species	16	34	40	45	17	20	19	14	7.57	0.055	–0.19
Number of exclusive species	0	10	8	14	7	5	4	5	**12.52**	0.005	0.37
Number of dominant species	4	3	7	2	2	3	2	1	1.25	0.741	–0.10
Wełnowiec											
Total number of species	13	22	40	22	7	10	19	21	3.65	0.301	0.12
Number of exclusive species	0	3	18	9	1	1	10	19	**7.84**	0.049	–0.28
Number of dominant species	4	4	4	3	1	2	3	2	0.75	0.862	0.16
Biskupice											
Total number of species	33	52	47	43	20	27	23	23	0.33	0.954	–0.021
Number of exclusive species	5	8	4	13	14	12	17	13	5.77	0.123	0.243
Number of dominant species	3	4	4	6	1	2	4	3	0.913	0.822	0.049
Makoszowy											
Total number of species	15	19	22	50	5	7	18	23	3.66	0.299	0.023
Number of exclusive species	3	2	7	36	2	3	8	18	2.89	0.400	–0.155
Number of dominant species	4	3	4	4	2	2	3	3	0.158	0.983	0.076
Murcki (dump)											
Total number of species	14	20	31	80	6	14	21	32	3.34	0.342	–0.086
Number of exclusive species	0	4	9	51	1	3	11	28	4.07	0.253	–0.094
Number of dominant species	6	4	3	5	1	3	4	5	3.13	0.372	0.278
Murcki (tank)											
Total number of species	22	20	39	78	10	30	45	26	**25.19**	0.000	–0.205
Number of exclusive species	3	3	6	40	1	6	6	3	**20.53**	0.000	–0.404
Number of dominant species	3	5	3	5	3	12	22	16	4.55	0.207	0.120
Brzeszcze											
Total number of species	51	45	41	52	12	23	25	24	5.01	0.171	0.089
Number of exclusive species	11	6	7	14	3	11	8	17	6.05	0.110	0.23
Number of dominant species	4	4	2	6	4	5	5	3	2.37	0.499	–0.10

the sedimentation tank. Lack of correlation was also noted on the iron (χ^2 = 12.52, tau c Kendall's index = 0.37) and zinc dump (χ^2 = 7.84, tau *c* Kendall's index = 0.049), but only with regard to the number of exclusive species. Very strong correlation among species diversity of Oribatida and the diversity of plants was recorded on the dumps, *r* = 0.955 (Fig. 20). A significant positive correlation between oribatid and plant diversity was also found in adjacent biotopes, *r* = 0.883 (Fig. 21).

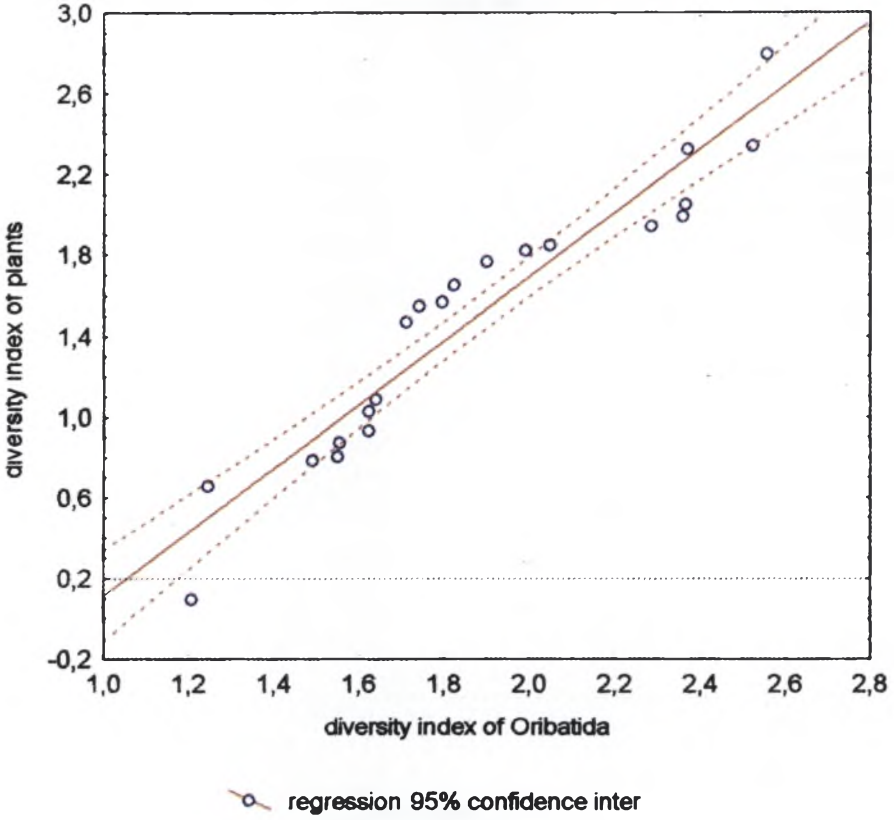


Fig. 20. Relationship between species diversity of Oribatida and plants on the dumps
($y = -1.472 + 1.5806\,x$; correlation coefficient $r = 0.95546$, $p = 0.000$)

There is evidence for slight relationships as well as for strong correlation between vegetation and soil animals (e.g. Curry, 1978; Healy, 1980; MacFadyen, 1952; Parr, 1978; Petersen & Krogh, 1987). A clear correlation between succession of oribatid mite fauna and succession in the vegetation was observed by some authors (e.g. Černova & Čugunova, 1967; Majer, 1989b; Maraun & Scheu, 2000; Webb, 1994). Anderson (1978a) showed a positive relationship between habitat complexity and community diversity of oribatid mites in forest soils. There is also considerable evidence for close relationships between plant and animal communities on reclaimed post-industrial sites. MAJER (1989b) analysed numerous positive statistical associations between arthropod, bird and mammal colonization and plant parameters. The only negative associations are those between soil arthropod diversity and declining plant diversity in maturing quarries in Britain (USHER, 1979).

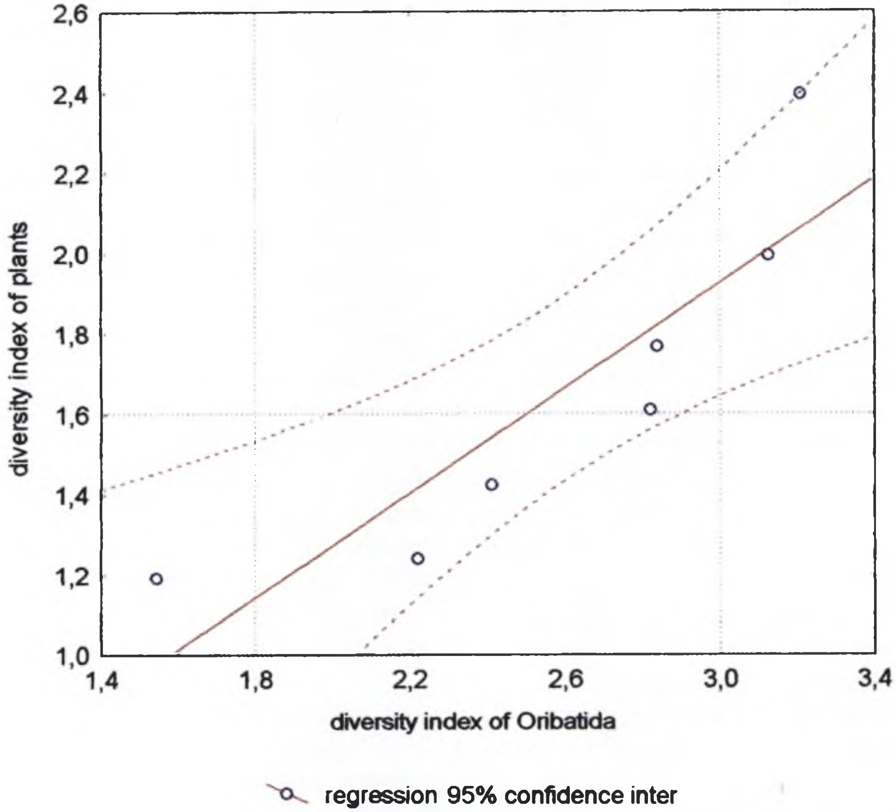


Fig. 21. Relationship between species diversity of Oribatida and plants in the adjacent biotopes
(y = –0,0304 + 0,65209 x; correlation coefficient r = 0,88293, $p < 0.05$)

A close correlation between vegetation and oribatid mites indicates that the structure of the mite communities can be predicted, knowing the structure of plant assemblages. This seems to be true only partly. Plants and particularly the presence of trees or shrubs affect soil oribatid mite communities. They influence abundance, number of species, species diversity and dominance structure. Even a slight difference in a plant assemblage can cause change in the characteristics of a community. However, the effect on species composition has not been recognized.

A great variety of different oribatid species colonize and live on different successional stages on dumps. None of the oribatid species were restricted to one plant type. Other factors are likely to be more important for influencing the species composition of an oribatid mite community. Other authors have made similar observations. CURRY & GANLEY (1977), MACFADYEN (1952) and OSLER & BEATTIE (2001) showed that soil habitats associated with different dominant plant species have little effect on mite species composition. MARAUN & SCHEU (2000) claimed that there is not a single oribatid mite species known that will selectively colonize only one type of litter, i.e. litter from a single plant species. Obviously the type of forest/litter is of minor importance for the abundance and community structure of oribatid mites (MIGGE et al., 1998). OSLER and BEATTIE (2001) remarked that effect of plants on the soil environment is not strong enough to cause a change in the mite species present under them.

The organisms living in the soil and their impact on plant populations have traditionally been ignored, whereas members of the soil community can have a dramatic impact on plant populations and communities (WATKINSON, 1998). Changes in saprophagous soil invertebrates may be more closely linked to changes in plant species. In general soil fauna helps plant growth. As regards the situation on post-industrial dumps, MAJER (1989b) emphasized that if we take care of soil fauna development we can minimize the need to use additional fertilizers in reclamation practices (the need to intensify reclamation measures).

Oribatids, being mycophagous, are in close relationships with plants (Fig. 22). Mycorrhizal fungi are "digestive mutualists" that colonize roots, infiltrate the rhizosphere soil and sequester and transport phosphorus, nitrogen and other nutrients into the roots of higher plants in return for carbohydrates (LAVELLE et al., 1994). So, these fungi are mutualist extensions of the root of plants (WALTER & PROCTOR, 1999). The interactions between oribatids and mycorrhizal fungi have been little studied, but are potentially of great importance for understanding plant health and ecosystem processes (WALTER & PROCTOR, 1999). If mycorrhizae are to become established on post-industrial dumps it is desirable that the dispersing animals, e.g. oribatids, first colonize the degraded area (MAJER, 1989b). Furthermore, by their feeding activity oribatid mites may also contribute to an increase in heterogeneity (PARR, 1978) and therefore, to an increase in species numbers.

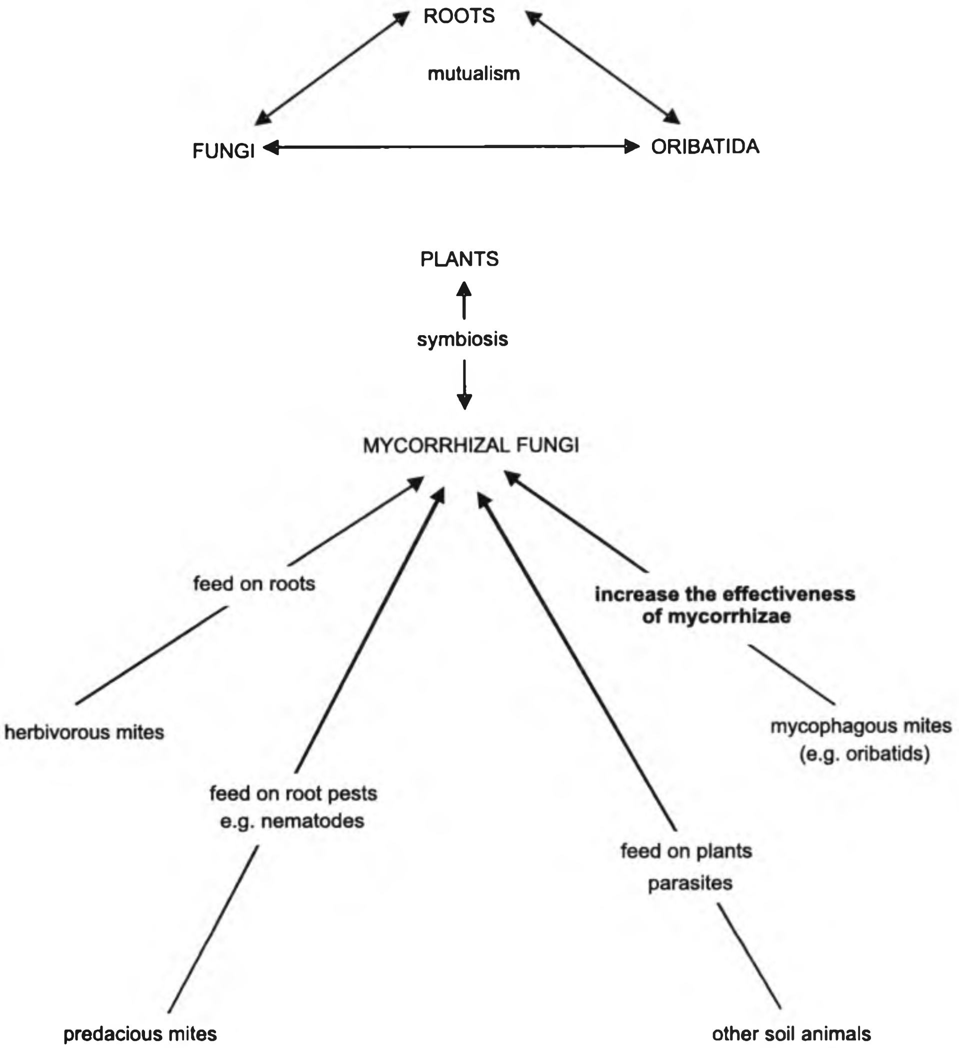


Fig. 22. Mycorrhizae and mites

Canonical correspondence analysis (CCA) (Ter Braak, 1988) was used to relate changes in oribatid species to environmental factors. The analysis was run for each of the localities separately. The results of CCA ordination for the iron dump at Chorzów are plotted on the plane of the first two axes in Fig. 23. The analysis was carried out with 33 species (species which occurred in five or more samples). The first two canonical axes explain 36.2% and 28.5% of the total variance in species and sites occurrence. The eigenvalue of axis 1 is 0.292 and of axis 2 is 0.230. The scatter of species may be divided into four distinct branches. Branch A is composed of species (e.g. *Microppia minus*, *Liochthonius propinquus*, *Scutovertex sculptus*)

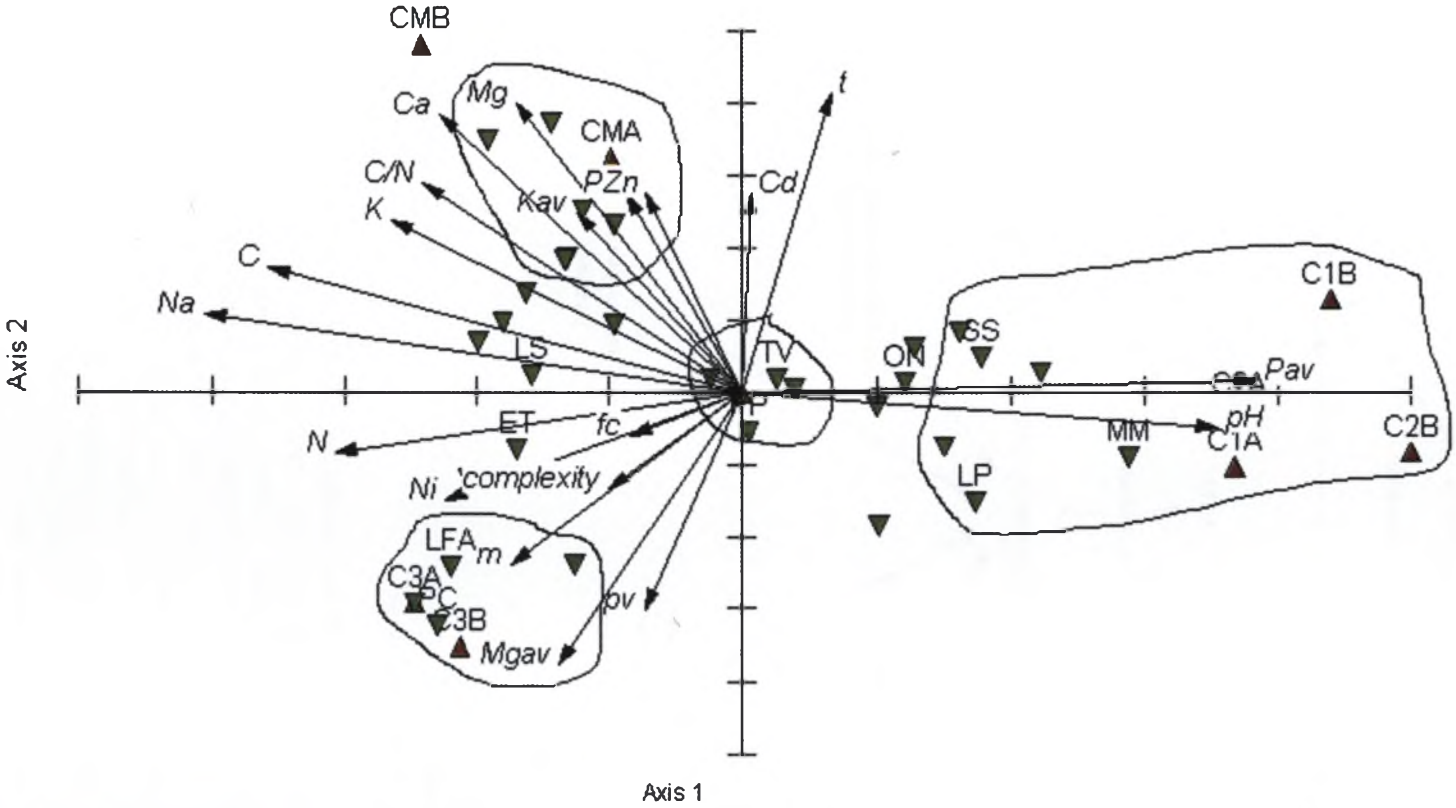


Fig. 23. Canonical correspondence analysis (CCA) biplots showing species and site arrangements at Chorzów in relation to environmental parameters
codes of the species: Appendix 6
codes of the sites: Table 4
codes of the environmental variables: Appendix 4

that occurred abundantly only at sites 1 and 2. The species were mainly affected by pH and available phosphorus. Both factors show high correlation with the first axis; 0.781 and 0.844, respectively. Branch B is composed of species connected with the oldest site on the dump. Among several species two dominants, *Lauroppia fallax* and *Protoribates capucinus*, were noted in this group. The species are ordinated in the negative part of both axes. They were affected by several environmental factors, of which available magnesium and moisture were the most important ones. Branch C consists of species typical of the meadow. Several factors, e.g. calcium, magnesium and potassium content and C/N ratio were the most important. Several species, e.g. *Tectocepheus velatus* and *Punctoribates punctum*, were crowded around the intersection point of the two axes. The species show no preference for any site.

Figure 24 shows the outcome of a canonical correspondence analysis on the contaminated zinc dump at Wełnowiec. Axis 1 explains 50.4% of the total variance and axes 1 and 2 together 71.2%. The eigenvalue of axis 1 was significant (0.416). The eigenvalue of axis 2 was smaller (0.171). Many species were ordinated close to the intersection point of the axes. They were species that do not show any preference (*Oppiella nova*, *Punctoribates punctum*, *Ceratozetes mediocris*). Two other groups of species were well separated. The species ordinated in the negative part of axis 1 and the positive part of axis 2 were strongly associated with available magnesium. They were species typical of site 3. Species noted frequently on the meadow, e.g. *Protoribates variabilis*, *Scutovertex sculptus*, were grouped close to the end of axis 1. They were ordinated along the arrow, which represents the magnesium content. Some species (associated with younger sites on the dumps) were grouped along the negative part of axis 1. Several factors influence the occurrence of these species, e.g. field capacity, pore volume and content of heavy metals.

Figure 25 shows the outcome of CCA analysis for the mine dump at Biskupice. The eigenvalue of axis 1 was significant (0.417), whereas the value of axis 2 was smaller (0.252). Both axes explained over 58% of the total variance. Species that constituted the pioneer stage of succession of the mite community were separated from others. Two dominant species (*Scutovertex sculptus* and *Adoristes poppei*) were located in the upper part of axis 2. No one environmental factor was a main influence over the distribution of pioneer species. The separation of species characteristic of the later successional stages was not distinct. On the left side of axis 2 along the perpendicular line species typical of sites 2 and 3 were distributed. Factors having the most influence on the occurrence of these spe-

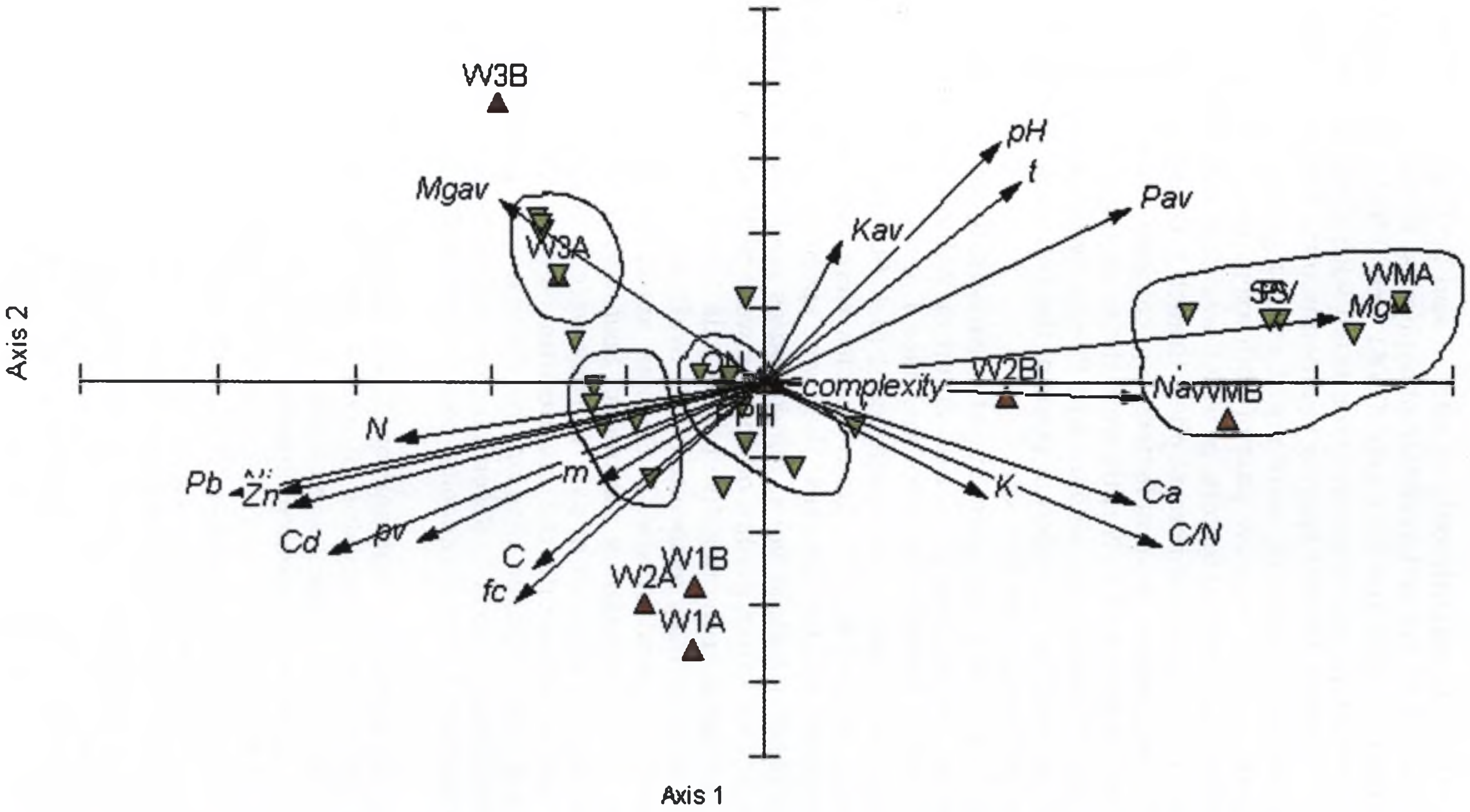


Fig. 24. Canonical correspondence analysis (CCA) biplots showing species and site arrangements at Wełnowiec in relation to environmental parameters
explanation of abbreviations: see Fig. 23

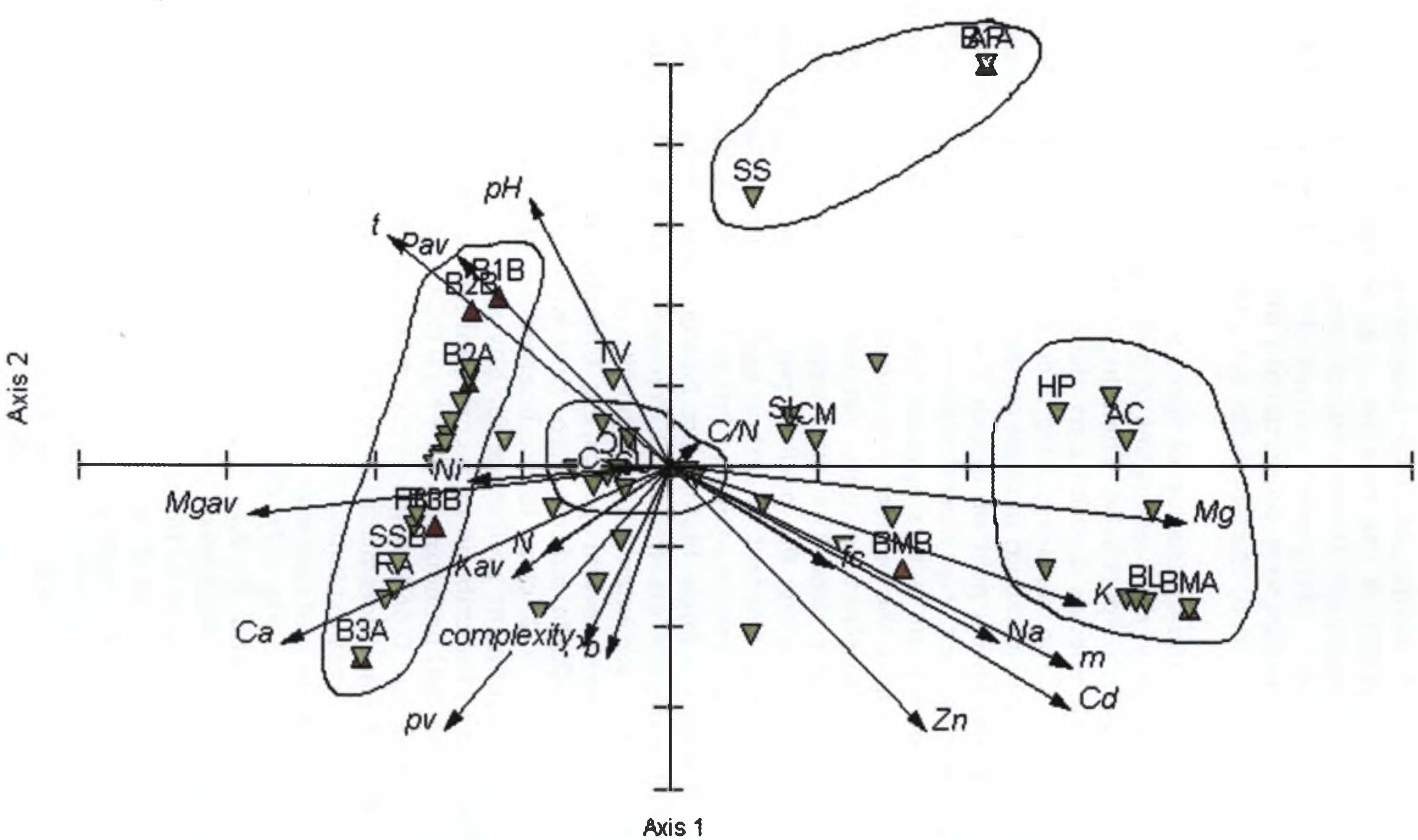


Fig. 25. Canonical correspondence analysis (CCA) biplots showing species and site arrangements at Biskupice in relation to environmental parameters
explanation of abbreviations: see Fig. 23

cies are content of calcium, available magnesium and temperature. Species characteristic of the meadow, e.g. *Achipteria coleptrata*, *Banksinoma lanceolata* and *Heminothrus peltifer*, are ordinated in the positive part of axis 1. Many species crowded the intersection of the two axes. These species were proportionally distributed at all study sites, e.g. *Oppiella nova*, *Suctobelbella subcornigera* or *Ceratozetes mediocris*.

With regard to the ordination of species and sites on the mine dump at Makoszowy, the eigenvalues of both axes were significant (0.640 and 0.330, respectively). Their high values denote a good separation of the species distributions along these axes. Both axes explain 67.7% of the variance. Axis 2 could be interpreted as a transition from forest habitat to those on the dump (Fig. 26). Species ordinated at the lowest position of axis 2 and the right part of axis 1 are pioneer species, e.g. *Liochthonius simplex* and *Brachychochthonius cricoides*. Four factors appeared to be of similar influence in the structuring of the pioneer community: sodium, magnesium, potassium and phosphorus content. Pioneer species were separated from species of older sites. The latter were ordinated in the upper part of axis 2 and along the positive part of axis 1 (e.g. *Trhypochthonius tectorum*). Content of carbon and nitrogen influence the occurrence of the species. On the left side of axis 1 all species associated with the forest biotope are located. Most of the species are located along the arrows, which represent zinc and lead content, and to a lesser extent the complexity of the vegetation. Furthermore, there were several species, e.g. *Oribatula tibialis*, *Microppia minus* or *Suctobelbella subcornigera*, that were ordinated in the positive part of axis 2, close to the intersection of the axes. They do not show significant preference for any site.

Differences in the oribatid mite communities on the mine dump at Murcki were well pronounced. The high CCA eigenvalues of axes 1 and 2 (0.643 and 0.363, respectively) reflect the great dissimilarity of oribatid mite communities at different stages of primary succession. The axes explained 72.1% of the total variance in data. The scatter of sites and species forms three distinct clusters in the ordination diagram (Fig. 27). Cluster 1 indicates species of the younger sites (1 and 2), e.g. *Brachychochthonius immaculatus*, *Brachychochthonius cricoides* or *Liochthonius piluliferus*. No environmental factor was shown to influence the occurrence of the species. The second cluster revealed by CCA comprises species of the oldest site on the dump, e.g. *Medioppia obsoleta*, *Ceratozetes mediocris* or *Ramusella insculptum*. They were influenced most by field capacity. This correlates most with the first axis (correlation coefficient = 0.813). The third faunal cluster involves species of the adjacent forest

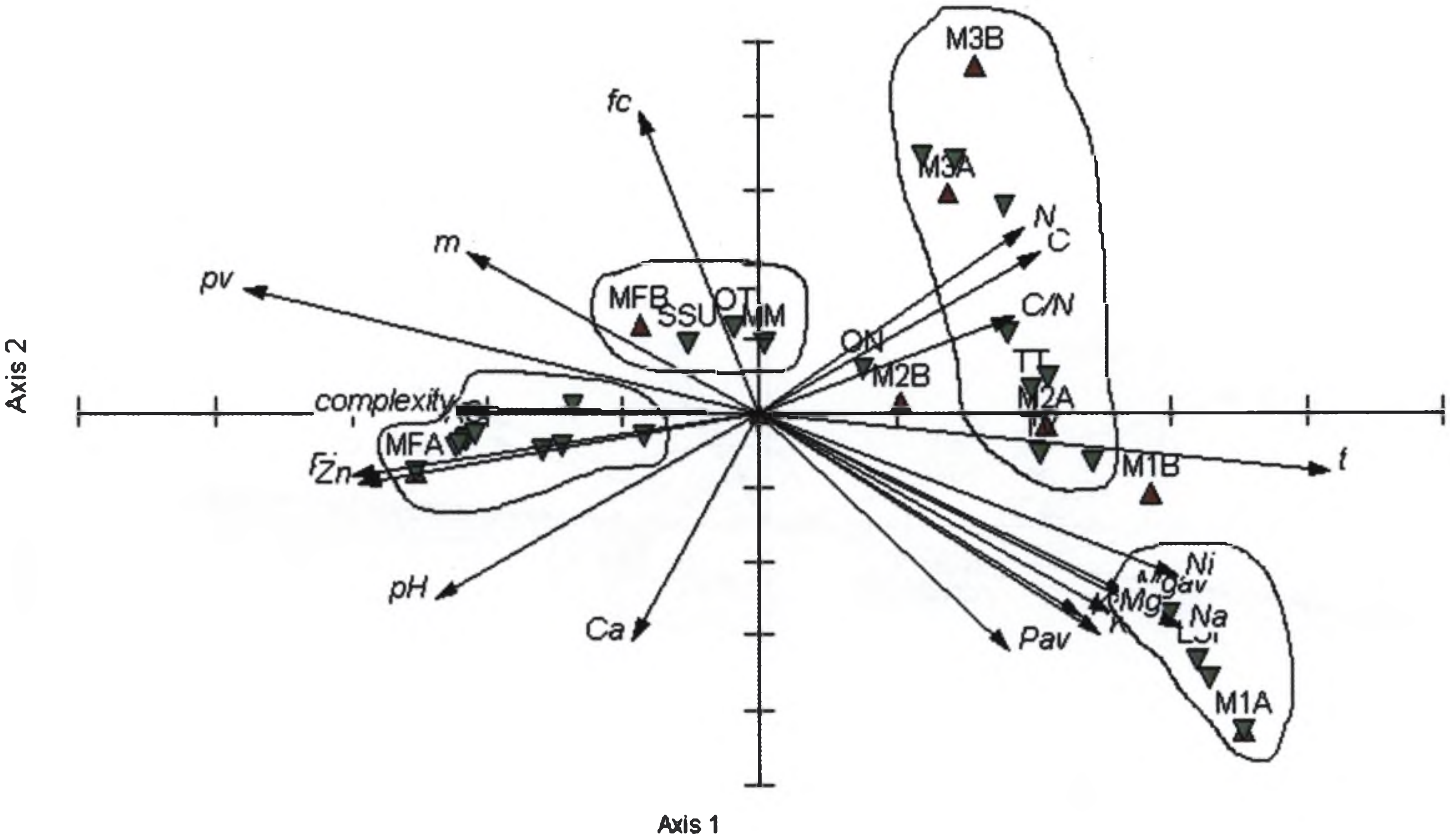


Fig. 26. Canonical correspondence analysis (CCA) biplots showing species and site arrangements at Makoszowy in relation to environmental parameters

explanation of abbreviations: see Fig. 23

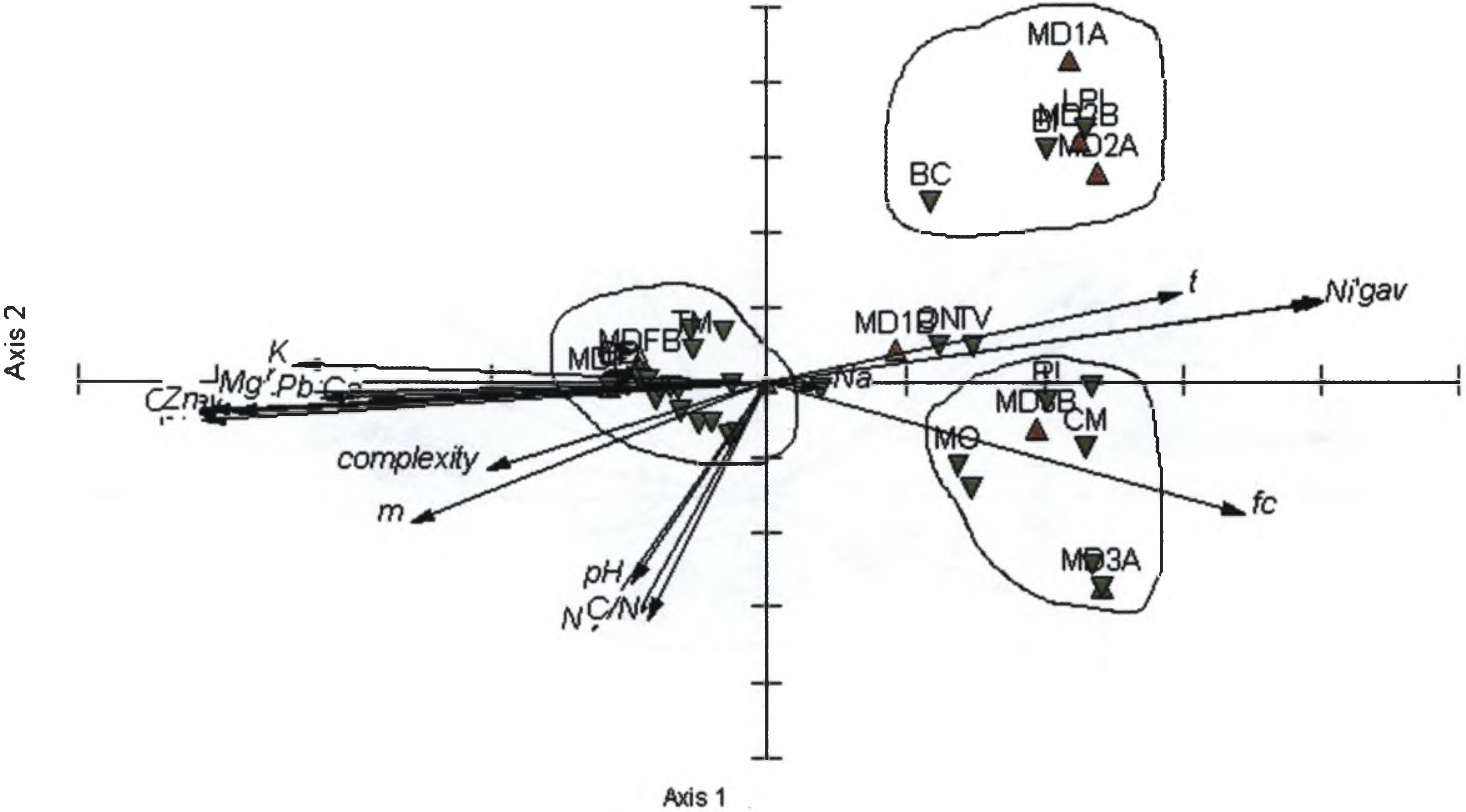


Fig. 27. Canonical correspondence analysis (CCA) biplots showing species and site arrangements at Murcki (dump) in relation to environmental parameters
explanation of abbreviations: see Fig. 23

(dominants *Conchogneta delacarlica*, *Lauroppia falcata*, *Punctoribates punctum* or *Tectocepheus minor*). They were located close to the centre of ordination. A set of environmental factors (e.g. potassium, calcium, magnesium and zinc content) has most influenced the distribution of these species.

As regards the diagram of the sedimentation tank at Murcki, the first two canonical axes explain 62.2% of the variance of species. The eigenvalue of axis 1 is 0.429, and of axis 2 is 0.173. Axis 2 separates species of the forest from oribatids of the dump (Fig. 28). In the negative part of axis 1, but close to the intersection point of both axes, species that dominated in the forest, namely *Ceratozetes gracilis*, *Chamobates voigtsi* and *Lauroppia falcata* were ordinated. Several environmental variables, e.g. pore volume, zinc, cadmium and lead content, were recognized as regulatory forces in the distribution of these species. The interest correlation values of these factors and axis 1 were very high (from 0.909 to 0.982). The separation of the species in the mine tank was not very distinct, although species plotted at the highest position of axis 2 were found to be more numerous on the younger sites. *Autogneta longilamellata* and *Trichoribatella baloghi* belong to this group. Sodium content and C/N ratio mainly affected these species. Species located in the lower position of axis 2 prefer the oldest site on the dump (e.g. *Tectocepheus minor* or *Liochthonius simplex*). The most important factor influencing the occurrence of species at site 3 was pH.

The outcome of CCA analysis on the reclaimed dump at Brzeszcze is presented in Fig. 29. The first two axes resulting from CCA give a meaningful interpretation of the species and sites distribution. Axis 1 and 2 accounted for 40.8% and 25.1% of the total variance, respectively. Eigenvalues of axis 1 and 2 were 0.319 and 0.196, respectively. There is no clear grouping for the species of the meadow, although those species that more frequently occurred in the meadow (e.g. *Liebstadia similis*, *Minunthozetes semirufus*, *Protoribates variabilis*) were ordinated in the positive part of axis 1. Three factors appeared to be of similar influence: field capacity, moisture and pore volume. These environmental variables may have influenced changes in the community of oribatid mites on the meadow. In the negative part of axis 1 and the higher position of axis 2 species associated mainly with site 2 were ordinated. Potassium, nickel, lead and to a lesser extent sodium content influence the occurrence of these species. Species typical of sites 1 and 3 were located in the lower position of axis 2. They were not separated well. Magnesium content accounts for the largest part of the variance in the occurrence of species typical of the youngest site. Content of available potassium and temperature mainly influence the occur-

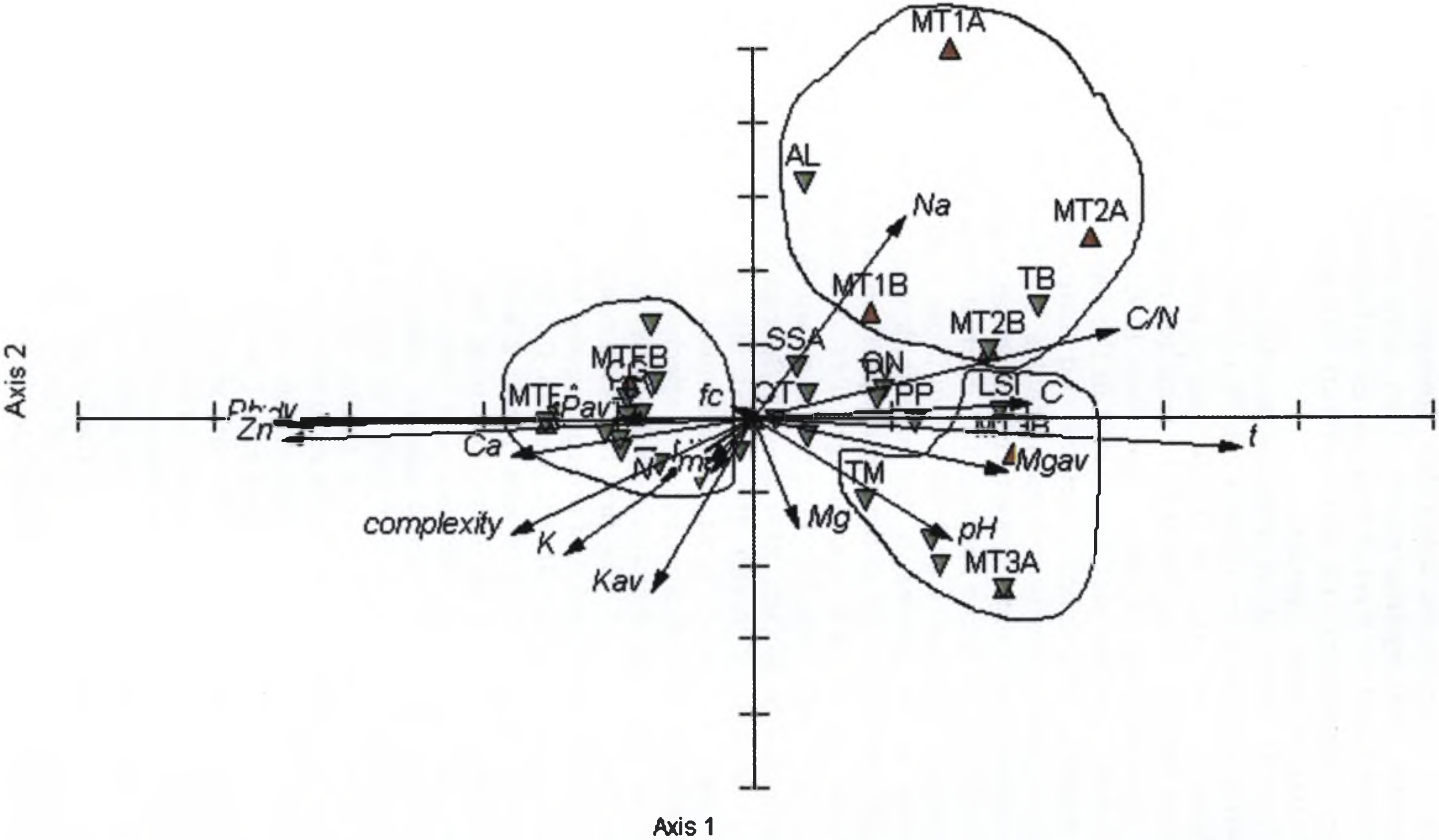


Fig. 28. Canonical correspondence analysis (CCA) biplots showing species and site arrangements at Murcki (tank) in relation to environmental parameters
explanation of abbreviations: see Fig. 23

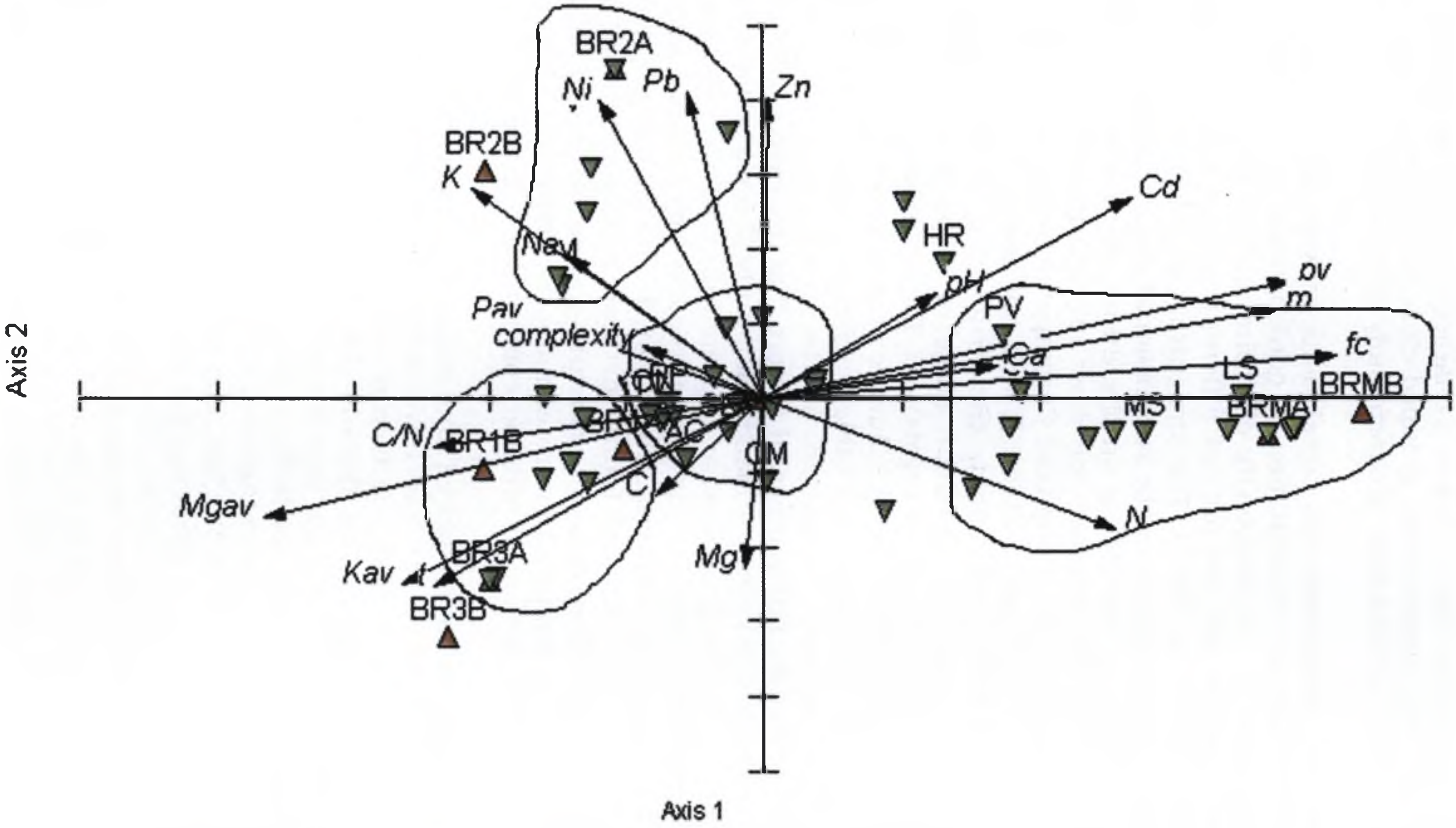


Fig. 29. Canonical correspondence analysis (CCA) biplots showing species and site arrangements at Brzeszcze in relation to environmental parameters
explanation of abbreviations: see Fig. 23

rence of oribatids at site 3. It was a characteristic of the reclaimed dump that many species were grouped close to the intersection of the axes. These species were proportionally distributed at all study sites.

It has been suggested that correlations between environmental factors and species communities or configuration are of limited value, because of the complexity of environmental factors acting upon the species and because of different species physiological tolerances (WALLWORK, 1976). The structuring forces that influence the oribatid communities on the successional stages on the dumps were very variable, depending on the dump. With regard to the pioneer oribatid communities the most important environmental factors, revealed by the Canonical Correspondence Analysis, were magnesium and sodium content. It was not possible identify an environmental factor influencing the structuring of the oribatid communities at the intermediate stage of primary succession (areas covered by herbaceous vegetation). Eleven different environmental variables appear to be of influence at sites covered by shrubs and/or trees on the dumps. Available magnesium content was most frequently recognized as important for the structuring of the community of oribatids. Environmental factors that are responsible for the development of a diverse oribatid community at a particular type of dump (e.g. metallurgic dumps or coal-mine dumps) were also very differentiated. With regard to the undisturbed nearby biotopes, more common environmental variables were noted. The following factors appear to influence oribatid fauna in these habitats: content of magnesium, potassium, calcium, moisture and complexity of habitat. Moisture and complexity were common environmental factors influencing the formation of oribatid communities in the adjacent forests.

Many of studies have explored mite abundance, species richness and community structure and have subsequently attempted to elucidate the biotic and abiotic factors responsible for the formation of mite communities in the soil. Often factors such as soil acidity, humidity, forest type, organic matter content or inorganic nutrients, are indicated as factors that correlate with oribatid abundance and community structure. It has also been determined that particular features of the soil, e.g. the presence of toxicants, soil pH etc., significantly influence the rate of ecosystem transition through a certain stage (DUNGER, 1968).

One of the prime factors responsible for changes in abundance and community structure of oribatid mites is assumed to be soil pH (e.g. KOSKENNIEMI & HUHTA, 1986; LEBRUN & VAN STRAALEN, 1995; VAN STRAALEN et al., 1988). Generally, increased soil acidity results in a higher dominance of oribatids and therefore a variety of oribatid mite species have been termed "acidophilic". However, MARAUN & SCHEU (2000) emphasized that changes in oribatid mite communities with soil pH are in fact driven by humus form. Obviously the reactions of the soil fauna are not directly caused by pH changes, but the interpretation of true causal relationships is not easy. HÅGVAR (1984) presented a detailed discussion about potential mechanisms, explaining the effects of acidity on microarthropods. These mechanisms may include direct influences of pH, but more probably they are mediated through indirect effects, especially changes in the composition of microflora that form the diet of most oribatids. Only a slight relationship between abundance of oribatids and pH (Pearson correlation coefficient = 0.23 for level A and 0.38 for level B) was observed in the present study. Most dumps that were studied were characterized by acid soil/substratum and only the soil on the iron dump is characterized by a pH higher than 7.0.

Some authors recognized organic matter as an important factor in the development of mite communities. GHILAROV (1975) showed proportional interrelationships between the density of microarthropods and the content of soil organic matter in a range of agricultural soils. RUSSELL et al. (1996) suggested that the increasing abundances along the phytosociological gradient are most probably related to an increase in soil-borne organic matter. HASEGAWA (2001), using CCA ordination, described the total amount of organic matter as the most important variable for the organization of an oribatid community in forest soils. However, many other studies that focus on the effect of organic matter or biomass of microorganisms on oribatid mite density and community structure indicate that bottom-up forces are of minor importance (BEHAN et al., 1978; HUHTA et al., 1967; KOSKENNIEMI & HUHTA, 1986; MARSHALL, 1974). The basis for the view that saprophages (e.g. oribatids) are controlled predominantly by resource supply (bottom-up hypothesis) is the limited ability of saprophages to modify the amount of litter entering the decomposer community (MARAUN & SCHEU, 2000). Carbon and nitrogen, which show an indirect effect of soil organic matter on oribatid communities on the dumps, were rarely recognized as driving forces in CCA analysis. However, on the other hand it is difficult to deny that food may play a major role (probably an indirect one) in the ability of species to survive and reproduce within a new habitat (WHELAN, 1978).

Soil humidity has been proposed as an important factor influencing the structure of oribatid mite communities (BORCARD, 1991; MITCHELL, 1979; RAJSKI, 1967, 1968; WAUTHY et al., 1989; WEST, 1984). BORCARD & VAUCHER-VON BALLMOSS (1997) found soil type and water content were the most significant local environmental determinants of the oribatid mite assemblage structure, although these variables explained only about one fourth of the total variance of the data. Seniczak et al. (1994) indicated that soil humidity seemed to have a very important effect in soils polluted by nitrogen compounds. Humid soil can absorb more pollutants, including poisons, into sorption complexes than dry soils. The correlation between humidity and oribatids may represent a causal relationship between them. According to Maraun & Scheu (2000), soil humidity is only of minor importance for abundance and community structure of oribatid mites. Indeed, soil moisture was only incidental factor in the structuring of oribatid communities in this research. Its effect was more evident in the adjacent biotopes than on the dumps.

Inorganic nutrients have a heterogeneous vertical and horizontal distribution and may thus indirectly affect the distribution of oribatids. Usher (1976) found that the distribution of Collembola was correlated with certain nutrients (N, P, K and Ca). He found that fixed nitrogen was an important factor in predicting the abundance of mites as well as springtails, since it had a large loading in principal component analysis (PCA) in which a variety of factors were analysed. Filimonova et al. (2000) emphasized that high concentrations of calcium and magnesium, among other factors (organic matter, water-holding capacity and pH), provide favourable conditions for the development of soil biota in general. Tousignant & Coderre (1972) recognized potassium and sodium content (among others) as influencing the composition and abundance of these organisms. It is worth mentioning that oribatids themselves may have an indirect effect on the distribution of nutrients through their overall impact on decomposition (Dickinson & Pugh, 1974; Edwards et al., 1970). With regard to the research carried out on post-industrial dumps, the content of inorganic nutrients was most frequently recognized as an important factor in the Canonical Correspondence Analysis.

Furthermore, predator-prey interaction and competition might be important. However, trophic interactions have not been well studied in oribatids (Anderson, 1978b). Generally, due to a thick cuticle and other traits for predator avoidance, including various mechanisms for protection of the legs, oribatid mites have been assumed to live in an enemy free space (Norton, 1994), although as reported by Travé et al. (1996), this only applies to adults; juvenile oribatid mites are little sclerotized. They are observed to be attacked by predators like gamasid mites (Maraun & Scheu, 2000). The interrelationships between oribatids and gamasids will be discussed in the chapter “Oribatid mites in assemblages of mesofauna”. Among the biotic factors, predation seems to be a major structuring influence, as suggested by LEBRUN et al. (1991). Other biotic interactions such as competition have never been clearly shown to act significantly, so that some authors have suggested that soil mite communities could often be in a state of non-equilibrium (WAUTHY et al., 1989).

MARAUN and SCHEU (2000) stressed another, and in their opinion the most important, structuring force in the soil habitat, especially for oribatids. Disturbance has been advocated as one of the primary factors driving animal (and plant) distribution (CONNELL & SLATYER, 1977; HUSTON, 1994; SOUTHWOOD, 1988). Surprisingly, disturbance as a structuring factor for soil animal communities (FRECKMAN & VIRGINIA, 1997) or oribatid mite communities (AOKI, 1979; SCHEU & SCHULZ, 1996), has had little attention until now. Disturbance in soil caused by soil organisms themselves is more important than in most other habitats, since soil organisms are very densely packed and are therefore likely to be affected by the activity of other soil invertebrates, particularly by larger species (MARAUN & SCHEU, 2000). Oribatid mites are generally sensitive to disturbances. However, sensitivity varies considerably among oribatid mite groups forming a gradient from high (Enarthronota) to low (*Punctoribates* and *Tectocepheus*) sensitivity. Effects of disturbance might be severe for oribatids because the reproduction rates of most oribatid mites are low.

More variables of different origins can influence the occurrence of oribatids. In the chapter *Oribatids on contaminated dumps* the influence of heavy metals on oribatids was discussed. Lead, zinc and cadmium were recognized as factors important in the structuring of oribatid communities on the contaminated zinc dump at Wełnowiec. The content of some heavy metals was also occasionally included among the important variables on other dumps. The degree of slope can influence oribatid abundance and community structure on dumps. It influences soil humidity and, in consequence, can lead to a certain degree of stress. This factor only influenced oribatids on the mine dump at Murcki where the two sites were not situated on an even surface (site 1–30^0, site 2–40^0).

It seems reasonable that the variety of factors, physical and biological, by which dumps and sites differ, produce a patchwork of environmental conditions and that different abundance of species and community structures result from the responses to these factors.

NIEDBAŁA (2000) discussed the problem of making precise studies of soil mites, and mentioned how difficult it is to determine the influence of microhabitat conditions because of the relatively expensive and hardly accessible equipment required. It is difficult to obtain repeatable results. In his opinion, it is impossible to repeat a study because of fast changes in the microhabitats. Moreover, it is very difficult to perform an accurate assessment of a microhabitat, in particular, in long cycles of studies, because of its small size. In the long term, the conditions are different because of the succession process (NIEDBAŁA, 2000). Niedbała's remarks are valuable because we should always recognize that even with use of sophisticated statistical analyses and expensive equipment, the real influence of environmental conditions on mites in the soil may be entirely different. On the other hand, we should remember that part of Niedbała's remarks on the limitations of ecological studies are simply unresolved. NIEDBAŁA (2000) suggested the necessity of using "micro-receptors" – small devices able to measure abiotic factors in a very small volume – to investigate the microcosmos of mite species properly. This sounds interesting, but when using this expensive apparatus, we would measure only abiotic factors, in particular small spaces used by certain species, or rather by certain individuals of certain species. Environmental conditions might be different (at least slightly) a few centimetres away. Oribatids show an aggregated pattern of dispersal and they live surrounded by food. Nevertheless, mites, despite being poor "walkers", may move from one microhabitat to another many times a week. According to BERTHET (1964b) oribatid species may move on average 5 cm a day, whereas, KRIVOLUTSKY (1977) estimated the movement of oribatids at from a few to 10 metres a day and night.

7.8. Direct long-term studies of succession

Three of the dumps studied had been sampled in the past and a sequential approach for the study of succession of oribatid mites was able to be used. The oribatid fauna on the iron dump at Chorzów was analysed again on two sites after 12 years. The fauna of the zinc dump and of the reclaimed mine dump were studied again at three sites after 7 years.

The abundance of oribatids had significantly increased from 4055 m^{-2} to 18 215 m^{-2} over 12 years at the younger site on the iron dump at Chorzów (Fig. 30). The number of species had doubled. The species diversity (H') also increased. The dominance structure was rebuilt (Table 23). Three species exceed 5% of the total (*Oppiella nova*, *Microppia minus* and *Tectocepheus velatus*) in 1998/2000. *T. velatus* had comprised over 73% of the community in the past, but only 6.3% in 1998/2000. Another species, *O. nova*, constituted the majority of that community (57%) twelve years later. The third numerous species, *M. minus,* had been absent in the past. Surprisingly, the number of common species between the two periods at the site was low (11). As regards the older site, the increase in abundance and number of species was not so high (Fig. 30). The abundance doubled but only another three species were found in 1998/2000. The number of common species (27) was twice as high than on the younger site. The changes in species composition and dominance structure were also high. Only three of the abundant species attained similar proportions in 1986/1987 and 1998/2000,

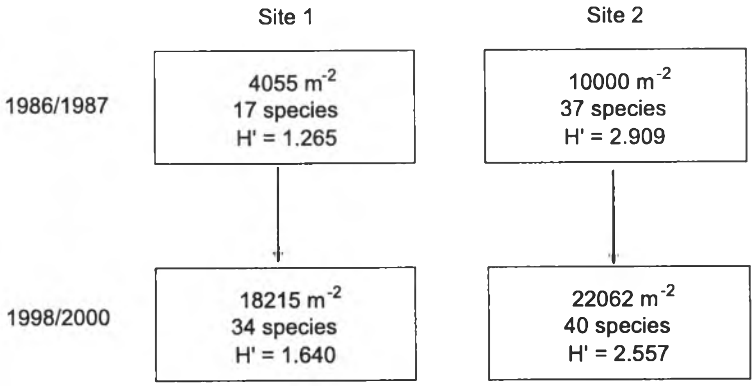


Fig. 30. General characteristics of the oribatid mite communities on the iron metallurgic dump at Chorzów in 1986/1987 and 12 years later

Table 23

Dominant species (%) in the oribatid mite communities on the iron metallurgic dump at Chorzów in 1986/1987 and 12 years later

Species	Site 2		Site 3	
	1986/1987 (S 1)	1998/2000	1986/1987 (S 2)	1998/2000
Ceratozetes mediocris	1.4	0.05	**5.4**	–
Eupelops tardus	2.3	–	**7.9**	**7.0**
Lauroppia fallax	0.5	–	3.0	**12.8**
Liebstadia similis	1.8	0.05	**10.2**	**13.2**
Microppia minus	–	**16.2**	–	0.3
Oppiella nova	4.1	**57.2**	3.0	**7.9**
Protoribates capucinus	1.4	–	0.5	**5.8**
Punctoribates punctum	2.3	1.9	**6.8**	**5.9**
Rhysotritia ardua	1.4	–	**5.6**	3.2
Scheloribates laevigatus	1.8	–	**7.5**	4.7
Tectocepheus velatus	**73.3**	**6.3**	**13.9**	**24.8**
Trichoribatella baloghi	0.9	0.05	**11.5**	0.1

Bold typed values indicate dominant species on a particular site.

e.g. *Eupelops tardus*, *Liebstadia similis* and *Punctoribates punctum* (Table 23). The dominance structure was even less stable in 1998/2000, and was marked by lower species diversity.

There was also the possibility to compare the proportion of oribatids and other mite groups in the community on the iron dump in 1986/1987 and 12 years later (Fig. 31). The proportion of oribatids increased on both sites and they constituted over 50% of the total mite number in 1998/2000. The proportion of gamasids and other mite groups (Actinedida and Acaridida) decreased. The pattern of these changes was particularly significant on the older site.

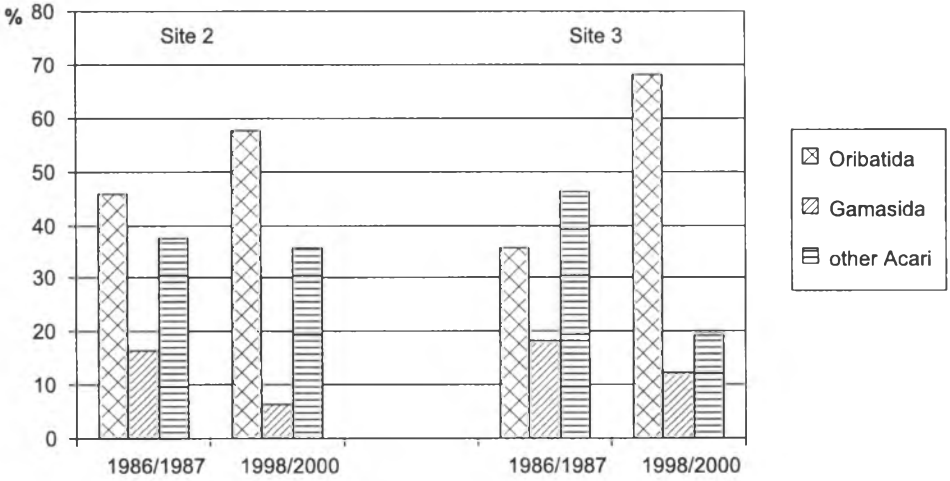


Fig. 31. The proportion of different groups of mites in the communities on the iron metallurgic dump at Chorzów

Three analysed parameters of the oribatid mite community (abundance, species richness and diversity) increased at the pioneer stage (site 1) on the zinc dump at Wełnowiec (Fig. 32), although the increase was only slight. With regard to the intermediate site, the abundance increased from 5907 m^{-2} (1991/1992) to 7368 m^{-2} (1998/2000), whereas the number of species and diversity slightly decreased. The abundance doubled at the oldest site and the number also significantly increased from 28 to 40 species. A slight increase in species diversity was noted at this site. Reconstruction of the dominance structure was noted at three sites studied (Table 24). The proportion of three species (*Ceratozetes mediocris*, *Oppiella nova* and *Tectocepheus velatus*) was similar at the sites in 1991/1992 and seven years later. Some new abundant species occurred in 1998/2000, e.g. *Peloptulus phaenotus* (site 1), *Pilogalumna allifera* and *Cultroribula lata* (site 3). *Suctobelbella subcornigera* was the only abundant species present at site 1 on the dump in 1991/1992,

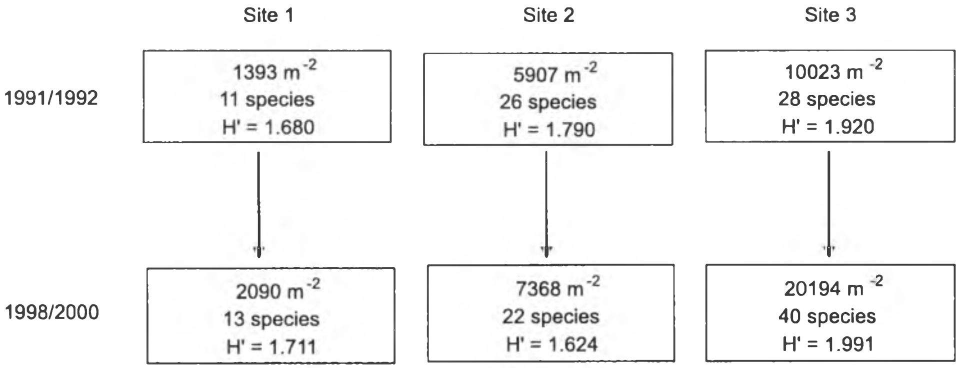


Fig. 32. General characteristics of the oribatid mite communities on the zinc dump at Wełnowiec in 1991/1992 and 7 years later

Table 24

Dominant species (%) in the oribatid mite communities on the zinc dump at Katowice Wełnowiec in 1991/1992 and 7 years later

Species	Site 1		Site 2		Site 3	
	1991/1992	1998/2000	1991/1992	1998/2000	1991/1992	1998/2000
Ceratozetes mediocris	4.4	**11.9**	**6.3**	**27.5**	**7.7**	**21.7**
Oppiella nova	**34.8**	**8.9**	**11.0**	**15.7**	**50.9**	**42.9**
Peloptulus phaenotus	–	**23.8**	0.5	**5.3**	1.9	**5.1**
Ramusella assimilis	–	2.0	3.2	0.7	**5.5**	2.2
Tectocepheus velatus	**36.3**	**42.1**	**56.5**	**41.8**	**11.2**	**8.5**
Trichoribatella baloghi	**5.4**	0.5	4.7	0.2	0.4	1.5

Bold typed values indicate dominant species on a particular site.

which had disappeared seven years later. The number of common oribatid species varied from 8 (site 1) to 20 species (site 3).

The abundance of oribatids was 2.5 times higher at the youngest site on the reclaimed dump at Brzeszcze after 7 years (Fig. 33). The increase of abundance was lower at the intermediate site and a decrease in numbers of oribatids was noted at the oldest site. The same trend was observed with regard to the number of species and species diversity. The dominance structure of the oribatid community became more stable after the stated period of time at site 1 (Table 25). Instead of two superdominants (*Oppiella nova* – 31.9% and *Tectocepheus velatus* – 45.8%), four dominant species of more even proportions were found at the site in 2001/2002. At the older sites, opposite changes occurred in the dominance structure. *O. nova* comprised a very high proportion (43.9%) of the total number of oribatids at site 2 in 2001/2002. This trend was even more distinct at the oldest site, where *O. nova* comprised over 60% of the total community. The number of common species and their proportion of the general number of species increased from site 1 to site 3.

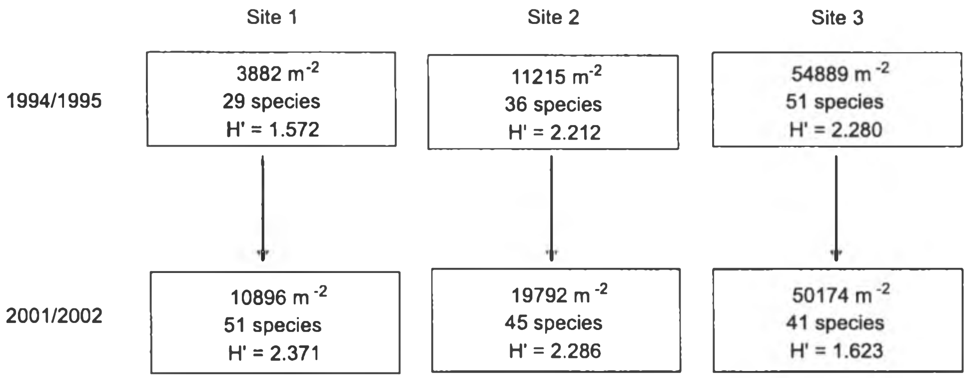


Fig. 33. General characteristics of the oribatid mite communities on the reclaimed mine dump at Brzeszcze in 1994/1995 and 7 years later

Table 25

Dominant species (%) in the oribatid mite communities on the reclaimed mine dump at Brzeszcze in 1994/1995 and 7 years later

Species	Site 1		Site 2		Site 3	
	1994/1995	2001/2002	1994/1995	2001/2002	1994/1995	2001/2002
Achipteria coleoptrata	–	0.2	0.5	0.6	4.2	**10.7**
Ceratozetes peritus	2.0	–	1.7	–	**28.0**	–
Hypochthonius rufulus	–	–	0.05	**7.2**	0.2	–
Medioppia obsoleta	0.8	2.4	0.2	0.5	**22.9**	3.2
Oppiella nova	**31.9**	**37.3**	3.1	**43.9**	**11.3**	**60.7**
Protoribates variabilis	0.8	0.4	**6.2**	0.95	0.03	-
Punctoribates punctum	1.1	**18.0**	2.7	**6.2**	**5.3**	3.3
Scheloribates laevigatus	0.7	0.7	**26.8**	0.25	0.8	0.02
Scheloribates latipes	3.0	**7.7**	–	0.1	0.6	0.03
Sphaerozetes orbicularis	–	–	**10.9**	–	0.04	–
Tectocepheus minor	**8.8**	0.9	2.1	**11.9**	0.7	0.5
Tectocepheus velatus	**45.8**	**6.8**	**29.3**	3.6	**10.9**	4.5

Bold typed values indicate dominant species on a particular site.

Some interesting conclusions may be derived from the observed patterns in direct long-term studies on the dumps. The oribatid fauna on younger sites of post-industrial dumps can double after 10 years. The increase in abundance is lower at older sites. The species turnover is higher in the earlier successional stages of the oribatid succession and decreases with the age of a dump. The development of oribatid fauna is slower on the contaminated dumps, possibly due to heavy metals content and its influence on vegetation. The positive aspects of a dump's reclamation are distinct only over the first ten years. Later the development of oribatids slows and after 20 years the abundance and species richness starts to decrease.

Chapter 8. Colonizers and persisters on dumps

A large number of species (172) were collected at 28 sites and 7 localities (Appendix 6 – CD-ROM). High differentiation was observed between the sites with regard to species composition. Of 140 species collected on 7 different dumps and from 21 plots, only 8 mite species were common to all locations: *Brachychochthonius immaculatus*, *Ceratozetes mediocris*, *Oppiella nova*, *Scheloribates laevigatus*, *Suctobelbella acutidens*, *Suctobelbella sarekensis*, *Suctobelbella subcornigera* and *Tectocepheus velatus*. Even if compared dumps are heaped with the same sort of waste, e.g. coal-mine dumps (Biskupice, Makoszowy and Murcki), the number of common species is small (14). When we compare a particular stage of succession on the dumps, the number of common species is very small. Of 78 species recorded on the youngest sites on the dumps only 2 species (*Oppiella nova* and *Tectocepheus velatus*) occurred at all sites. On the whole, few species were lost from the oribatid fauna during the succession. New species were added regularly, up to the stage of 25 years.

To determine whether a species is associated positively or negatively, with sites, observed frequencies (C) were compared in a contingency table using χ^2. Dominant species were taken into account in this analysis. The results are given in Tables 26 to 32. A great number of positive associations with one of a site was found. The analysis helped to select three groups of species characteristic of the successive phases on dumps. The successional changes in Oribatida reflect the responses of individual species to changes in the environment during succession (Bellido & Deleporte, 1994). There were "early" successional species, which occurred on the

Table 26

Dominant oribatid species – their abundance (A) (indiv./m^2), dominance (D) and frequency of occurrence indices (C) (%) and association of species with sites (χ^2 analysis) on the dump at Chorzów and in the adjacent biotope

Species	Site 1 (C 1)			Site 2 (C 2)			Site 3 (C 3)			Meadow (C M)			Association with sites					
	A	D	C	A	D	C	A	D	C	A	D	C	C1	C2	C3	CM	χ^2	p
Eupelops tardus	7	0.7	1.2	–	–	–	903	**7.0**	57.5	56	0.6	6.4	–	A	+	–	141.37	0.000
Lauroppia fallax	–	–	–	–	–	–	1 646	**12.8**	42.5	10	0.1	1.8	A	A	+	–	116.86	0.000
Liebstadia similis	7	0.7	1.2	7	0.05	1.2	1 701	**13.2**	75.0	500	5.0	20.9	–	–	+	–	156.18	0.000
Liochthonius propinquus	97	**9.4**	6.2	104	0.7	7.5	125	1.0	12.5	–	–	–	+	–	–	A	13.34	0.004
Microppia minus	–	–	–	2 333	**16.2**	46.2	42	0.3	7.5	5	0.05	0.9	A	+	–	–	109.54	0.000
Oppiella nova	160	**15.4**	6.2	8 250	**57.2**	76.2	1 021	**7.9**	25.0	2 975	**30.0**	53.6	–	+	–	+	93.79	0.000
Protoribates capucinus	–	–	–	–	–	–	743	**5.8**	26.2	–	–	–	A	A	+	A	75.39	0.000
Punctoribates punctum	7	0.7	1.2	278	1.9	21.2	757	**5.9**	40.0	91	0.9	7.3	–	–	+	–	53.49	0.000
Scutovertex sculptus	528	**51.0**	47.5	410	2.8	30.0	28	0.2	5.0	252	2.5	28.2	O	O	–	O	36.46	0.000
Tectocepheus velatus	76	**7.4**	8.7	917	**6.3**	50.0	3 187	**24.8**	87.5	3 256	**32.8**	78.2	–	–	+	+	128.73	0.000

+ positive association, – negative association, O no association, A absent.
Bold typed values indicate dominant species on a particular site.

Table 27

Dominant oribatid species – their abundance (A) (indiv./m^2), dominance (D) and frequency of occurrence indices (C) (%) and association of species with sites (χ^2 analysis) on the dump at Katowice Wełnowiec and in the adjacent biotope

Species	Site 1 (W 1)			Site 2 (W 2)			Site 3 (W 3)			Meadow (W M)			Association with sites					
	A	D	C	A	D	C	A	D	C	A	D	C	W1	W2	W3	WM	χ^2	p
Ceratozetes mediocris	167	**11.9**	11.2	1 563	**27.5**	58.7	3 569	**21.7**	80.0	121	2.8	10.9	–	+	+	–	133.46	0.000
Oppiella nova	125	**8.9**	15.0	896	**15.7**	13.8	7 056	**42.9**	58.7	66	1.6	10.0	–	–	+	–	74.66	0.000
Peloptulus phaenotus	333	**23.8**	25.0	299	**5.3**	16.2	847	**5.1**	61.2	61	1.4	5.4	–	–	+	–	81.43	0.000
Protoribates variabilis	–	–	–	–	–	–	7	0.04	1.2	505	**11.8**	30.0	A	A	–	+	75.36	0.000
Scutovertex sculptus	–	–	–	–	–	–	7	0.04	1.2	1 101	**25.6**	60.0	A	A	–	+	173.06	0.000
Tectocepheus velatus	590	**42.1**	32.5	2 382	**41.8**	85.0	1 396	**8.5**	60.0	2 111	**49.1**	65.4	–	+	–	+	47.69	0.000

+ positive association, – negative association, O no association, A absent.
Bold typed values indicate dominant species on a particular site.

Table 28

Dominant oribatid species – their abundance (A) (indiv./m^2), dominance (D) and frequency of occurrence indices (C) (%) and association of species with sites (χ^2 analysis) on the dump at Zabrze Biskupice and in the adjacent biotope

Species	Site 1 (B 1)			Site 2 (B 2)			Site 3 (B 3)			Meadow (B M)			Association with sites					
	A	D	C	A	D	C	A	D	C	A	D	C	B1	B2	B3	BM	χ^2	*p*
Achipteria coleoptrata	35	1.3	2.5	–	–	–	–	–	–	375	**5.3**	43.7	–	A	A	+	108.40	0.000
Adoristes poppei	208	**7.0**	1.2	–	–	–	–	–	–	–	–	–	–	A	A	A	6.04	0.11
Banksinoma lanceolata	–	–	–	–	–	–	–	–	–	382	**5.4**	32.5	A	A	A	+	84.89	0.000
Ceratozetes mediocris	28	0.9	3.7	542	2.1	36.2	7	0.05	1.2	854	**12.1**	53.7	–	–	–	+	86.69	0.000
Heminothrus peltifer	69	2.3	1.2	7	0.03	1.2	–	–	–	549	**7.8**	42.5	–	–	A	+	104.41	0.000
Oppiella nova	111	3.8	12.5	8 049	**30.4**	67.5	3 576	**32.6**	67.5	618	**8.8**	43.7	–	O	O	O	65.36	0.000
Pergalumna nervosa	–	–	–	382	1.4	28.7	604	**5.6**	46.2	–	–	–	A	–	+	A	81.89	0.000
Ramusella assimilis	7	0.2	1.2	–	–	–	1 181	**10.9**	21.2	–	–	–	–	A	+	A	49.21	0.000
Scheloribates laevigatus	42	1.5	5	3 951	**14.9**	75.0	7	0.05	1.2	1 694	**24.0**	71.2	–	+	–	+	166.65	0.000
Scutovertex sculptus	1 049	**35.4**	55.0	118	0.4	8.7	–	–	–	–	–	–	+	–	A	A	124.53	0.000
Suctobelbella subcornigera	21	0.7	3.7	1 569	**5.9**	53.7	542	4.9	35.0	222	3.1	25.0	–	+	+	–	50.19	0.000
Suctobelbella subtrigona	–	–	–	118	0.4	11.2	1 847	**16.9**	66.2	–	–	–	A	–	+	A	154.36	0.000
Tectocepheus velatus	1 056	**35.6**	37.5	4 208	**15.9**	90.0	639	**5.9**	50.0	35	0.5	5.0	O	O	O	–	119.46	0.000

+ positive association, – negative association, O no association, A absent.
Bold typed values indicate dominant species on a particular site.

Table 29

Dominant oribatid species – their abundance (A) (indiv./m^2), dominance (D) and frequency of occurrence indices (C) (%) and association of species with sites (χ^2 analysis) on the dump at Zabrze Makoszowy and in the adjacent biotope

Species	Site 1 (M 1)			Site 2 (M 2)			Site 3 (M 3)			Forest (M F)			Association with sites					
	A	D	C	A	D	C	A	D	C	A	D	C	M1	M2	M3	MF	χ^2	p
Achipteria coleoptrata	–	–	–	–	–	–	–	–	–	1 764	**7.4**	78.7	A	A	A	+	235.33	0.000
Brachychochthonius cricoides	396	**9.3**	23.7	14	0.3	2.5	–	–	–	–	–	–	+	–	A	A	51.93	0.000
Liochthonius simplex	250	**5.8**	13.7	14	0.3	2.5	–	–	–	–	–	–	+	–	A	A	26.54	0.000
Microppia minus	28	0.6	2.5	28	0.6	3.7	465	**5.4**	21.2	3 576	**15.0**	55.0	–	–	+	+	84.54	0.000
Oppiella nova	257	**6.0**	28.7	2 806	**64.0**	66.2	5 090	**58.4**	86.2	8 333	**34.9**	81.2	–	O	O	O	71.97	0.000
Oribatula tibialis	–	–	–	7	0.15	1.2	542	**6.2**	22.5	236	1.0	18.7	A	–	+	+	34.35	0.000
Suctobelbella subcornigera	–	–	–	21	0.5	3.7	236	2.7	20.0	2 458	**10.3**	67.5	A	–	–	+	132.90	0.000
Tectocepheus velatus	2 958	**69.2**	81.2	840	**19.2**	60.0	1 153	**13.2**	76.2	28	0.1	5.0	O	O	O	–	118.75	0.000
Trhypochthonius tectorum	–	–	–	278	**6.4**	7.5	7	0.08	1.2	–	–	–	A	+	–	A	14.46	0.002

+ positive association, – negative association, O no association, A absent.
Bold typed values indicate dominant species on a particular site.

Table 30

Dominant oribatid species – their abundance (A) (indiv./m^2), dominance (D) and frequency of occurrence indices (C) (%) and association of species with sites (χ^2 analysis) on the dump at Katowice Murcki and in the adjacent biotope

Species	Site 1 (MD 1)			Site 2 (MD 2)			Site 3 (MD 3)			Forest (MD F)			Association with sites					
	A	D	C	A	D	C	A	D	C	A	D	C	MD1	MD2	MD3	MDF	χ^2	p
Brachychochthonius cricoides	35	**5.9**	5.0	28	1.3	5.0	–	–	–	20	0.04	2.7	O	O	A	O	4.47	0.21
Brachychochthonius immaculatus	83	**14.3**	8.7	215	**10.2**	15.0	–	–	–	5	0.01	0.9	+	+	A	–	23.73	0.000
Ceratozetes mediocris	–	–	–	69	3.3	11.2	1 076	**7.2**	48.0	–	–	–	A	–	+	A	150.58	0.000
Conchogneta delacarlica	–	–	–	–	–	–	–	–	–	8 020	**17.7**	90.9	A	A	A	+	305.45	0.000
Lauroppia falcata	–	–	–	–	–	–	–	–	–	4 242	**9.3**	78.2	A	A	A	+	248.76	0.000
Liochthonius piluliferus	76	**13.1**	6.2	236	**11.2**	15.0	–	–	–	–	–	–	+	+	A	A	27.84	0.000
Medioppia obsoleta	–	–	–	–	–	–	1 764	**11.7**	55.0	76	0.2	9.1	A	A	+	–	128.58	0.000
Oppiella nova	215	**36.9**	16.2	1056	**49.8**	52.5	9 118	**60.7**	87.5	3 747	**8.3**	70.0	–	O	O	O	93.13	0.000
Punctoribates punctum	–	–	–	–	–	–	–	–	–	5 419	**11.9**	90.0	A	A	A	+	301.19	0.000
Ramusella (I.) insculptum	42	**7.1**	7.5	7	0.3	1.2	319	2.1	26.2	–	–	–	–	–	+	A	50.75	0.000
Tectocepheus minor	–	–	–	28	1.3	2.5	–	–	–	2 480	**5.5**	80.9	A	–	A	+	251.55	0.000
Tectocepheus velatus	42	**7.1**	5.0	236	**11.2**	18.7	604	4.0	33.7	318	0.7	30.0	–	O	O	O	23.99	0.000

+ positive association, – negative association, O no association, A absent.
Bold typed values indicate dominant species on a particular site.

Table 31

Dominant oribatid species – their abundance (A) (indiv./m^2), dominance (D) and frequency of occurrence indices (C) (%) and association of species with sites (χ^2 analysis) in the sedimentation tank at Katowice Murcki and in the adjacent biotope

Species	Site 1 (MT 1)			Site 2 (MT 2)			Site 3 (MT 3)			Forest (MT F)			Association with sites					
	A	D	C	A	D	C	A	D	C	A	D	C	MT1	MT2	MT3	MTF	χ^2	p
Autogneta longilamellata	42	**8.7**	2.5	–	–	–	–	–	–	14	0.04	2.5	O	A	A	O	4.05	0.26
Ceratozetes gracilis	7	1.4	1.2	–	–	–	7	0.03	1.2	2 799	**8.2**	76.2	–	A	–	+	215.88	0.000
Chamobates voigtsi	–	–	–	7	0.3	1.2	7	0.03	1.2	2 028	**5.9**	78.7	A	–	–	+	225.09	0.000
Lauroppia falcata	14	2.8	2.5	–	–	–	7	0.03	1.2	4 674	**13.7**	80.0	–	A	–	+	224.93	0.000
Liochthonius simplex	14	2.8	2.5	299	**12.1**	12.5	2 306	**11.5**	17.5	7	0.02	1.2	–	+	+	–	19.21	0.000
Oppiella nova	194	**40.5**	15.0	1 118	**45.3**	52.5	12 701	**63.1**	97.5	8 722	**25.5**	87.5	–	–	+	+	169.76	0.000
Oribatula tibialis	21	4.3	3.7	14	0.5	2.5	493	2.5	43.5	2 437	**7.2**	90.0	–	–	+	+	176.49	0.000
Punctoribates punctum	7	1.4	1.2	201	**8.1**	13.7	632	3.1	40.0	132	0.4	16.2	–	–	+	–	42.93	0.000
Suctobelbella sarekensis	35	**7.2**	3.7	21	0.8	3.7	35	0.18	5.0	583	1.7	45.0	–	–	–	+	81.34	0.000
Tectocepheus minor	–	–	–	7	0.3	1.2	1 292	**6.4**	50.0	97	0.3	15.0	A	–	+	–	94.32	0.000
Tectocepheus velatus	14	2.8	5.0	250	**10.1**	25.0	444	2.2	41.2	403	1.2	37.5	–	O	O	O	37.60	0.000
Trichoribatella baloghi	21	4.3	3.7	326	**13.2**	2.5	56	0.3	8.7	–	–	–	–	+	–	A	39.72	0.000

+ positive association, – negative association, O no association, A absent.
Bold typed values indicate dominant species on a particular site.

Table 32

Dominant oribatid species – their abundance (A) (indiv./m^2), dominance (D) and frequency of occurrence indices (C) (%) and association of species with sites (χ^2 analysis) on the reclaimed mine dump at Brzeszcze and in the adjacent biotope

Species	Site 1 (BR 1)			Site 2 (BR 2)			Site 3 (BR 3)			Meadow (BR M)			Association with sites					
	A	D	C	A	D	C	A	D	C	A	D	C	BR1	BR2	BR3	BRM	χ^2	p
Achipteria coleoptrata	14	0.2	2.5	172	0.6	11.2	4 271	**10.7**	95.0	326	3.4	35	–	–	+	–	181.28	0.000
Ceratozetes mediocris	42	0.5	3.7	28	0.25	3.7	1 875	4.7	73.5	486	**5.1**	33.7	–	–	+	+	128.88	0.000
Hypochthonius rufulus	–	–	–	889	**7.2**	62.5	–	–	–	882	**9.2**	58.7	A	+	A	+	139.46	0.000
Liebstadia similis	–	–	–	7	0.05	1.2	–	–	–	875	**9.1**	51.2	A	–	A	+	136.05	0.000
Minunthozetes semirufus	42	0.5	5.0	–	–	–	–	–	–	590	**6.1**	35.0	–	A	A	+	75.55	0.000
Oppiella nova	2 944	**37.3**	71.2	5 493	**43.9**	83.7	24 306	**60.7**	95.0	479	5.0	37.5	O	O	O	O	73.52	0.000
Protoribates variabilis	35	0.4	3.7	118	0.95	7.5	–	–	–	785	**8.2**	41.2	–	–	A	+	75.97	0.000
Punctoribates punctum	1 417	**18.0**	61.2	764	**6.2**	50	1 333	3.3	75.0	278	2.9	25	O	O	O	O	43.17	0.000
Scheloribates laevigatus	56	0.7	8.7	28	0.25	5.0	7	0.02	1.2	1 250	**13.0**	68.7	–	–	–	+	148.66	0.000
Scheloribates latipes	611	**7.7**	41.2	14	0.1	2.5	14	0.03	2.5	83	0.9	12.5	+	–	–	–	64.32	0.000
Tectocepheus minor	69	0.9	8.7	1 486	**11.9**	66.2	194	0.5	15.0	–	–	–	–	+	–	A	122.29	0.000
Tectocepheus velatus	535	**6.8**	52.5	444	3.6	45.0	1 812	4.5	70.0	97	1.0	10	O	O	O	–	61.73	0.000

+ positive association, – negative association, O no association, A absent.
Bold typed values indicate dominant species on a particular site.

youngest sites. Some of the species were no longer present on the older sites. These are called “sprinters”. Other species did not lose their status as the community developed and sometimes even improved it. These are called “long-distance runners”. The third group of oribatids, the so called “late” successional species, comprises species that are absent or very rare at the younger sites but are abundant at the oldest sites. Large groups of both “early” and “late” successional species were indicated by the analysis (Table 33). There were 12 and 11 oribatid species in these groups, respectively. Most of those species were much less abundant in the nearby undisturbed biotopes. Only two species showed different responses. *Ceratozetes mediocris* was an eudominant species at all sites on the zinc dump (“long distance runner”) and occurred on older sites on the mine dump at Murcki (“late” successional species). Similarly *Liochthonius simplex* was classified as a “sprinter” on the mine dump at Makoszowy and as a “late” successional species in the sedimentation tank.

Two species deserve special attention when describing colonization and succession on dumps – *Oppiella nova* and *Tectocepheus velatus*. Both species are characterized by a strong ability to colo-

Table 33

“Early” and “late” successional species on post-industrial dumps (*s* – “sprinter”, *l* – “long-distance runner”)

“Early” successional species	“Late” successional species
Adoristes poppei (B – *s*)	*Eupelops tardus* (C)
Autogneta longilamellata (MT – *s*)	*Lauroppia fallax* (C)
Brachychochthonius cricoides (M, MD – *s*)	*Liebstadia similis* (C)
Brachychochthonius immaculatus (MD – *s*)	*Medioppia obsoleta* (MD)
Liochthonius piluliferus (MD – *s*)	*Microppia minus* (M)
Liochthonius propinquus (C – *l*)	*Oribatula tibialis* (M)
Oppiella nova (C, W, M, MD, MT – *l*)	*Pergalumna nervosa* (B)
Peloptulus phaenotus (W – *l*)	*Protoribates capucinus* (C)
Ramusella (I.) insculptum (MD – *l*)	*Punctoribates punctum* (C, MT)
Scutovertex sculptus (C, B – *s*)	*Ramusella assimilis* (B)
Suctobelbella sarekensis (MT – *l*)	*Suctobelbella subtrigona* (B)
Tectocepheus velatus (C, W, B, M, MD – *l*)	*Tectocepheus minor* (MT)
Species characterized by different reactions on particular dumps	
Ceratozetes mediocris	
W – *l*	MD
Liochthonius simplex	
M – *s*	MT

Explanation of abbreviations – see Table 4 and 5.

nize. They occurred on all dumps and at each site. They were dominant and frequently superdominant species at almost all sites, although the abundance of the species, its dominance or frequency of occurrence fluctuated considerably among sites at a particular dump.

Oppiella (Oppiella) nova (OUDEMANS, 1902) is a relatively small oribatid with an average body size of 250 µm in length. The short developmental period of this species, repeated egg deposition and parthenogenetic reproduction probably favour the wide and varied habitat selection of *O. nova* (KANEKO, 1988a). The species is therefore expected to respond to various climatic conditions by altering the number of generations according to changes in the ambient temperature. This may partly explain the cosmopolitan distribution of the species (KANEKO, 1988a). The opinions concerning the feeding habits of *O. nova* are unanimous; the species belongs to the feeding guild of microphytophages (KANEKO, 1988b; LEBRUN, 1965; LUXTON, 1972).

Tectocepheus velatus (MICHAEL, 1880) is one of the most frequent and common species of oribatid mites throughout the world. It is without doubt an extremely ubiquitous species with very wide ecological tolerance, whose habitat includes preserved natural areas (AOKI, 1967; LUXTON, 1981a), or extremely disturbed biotopes such as agroecosystems (SCHEU & SCHULZ, 1996), urban environment (SKUBAŁA & DZIUBA, 1995) or post-industrial dumps (SKUBAŁA, 1995). Presumably, due to its parthenogenetic mode of reproduction (NORTON et al., 1993) the species recovers quickly from disturbance. It has 3-5 generations per year, a developmental cycle that lasts only a few weeks and a total lifespan of less than a year. If the amount of food is sufficient, development may proceed even faster. In addition, *T. velatus* is known to tolerate harsh environmental conditions, e.g. low pH (HÅGVAR & AMUNDSEN, 1981). According to SIEPEL & RUITER-DIJKMAN (1993) *T. velatus* belongs to the feeding guild of opportunistic herbo-fungivores. The species is able to digest cellulose in cell walls of living green plants and trehalose in fungi. LUXTON (1972) classified the species as a microphytophage. It is a peculiar species, because it probably depends on the environmental conditions as to what kind of food will be used by the species (SIEPEL & RUITER-DIJKMAN, 1993).

Both species are well known as frequent inhabitants of dumps of various kinds (see Tables 15 and 16). In contrast with most other oribatid mites *T. velatus* is known to colonize new habitats quickly (NORTON, 1994; SKUBAŁA, 1995). O. *nova* is also regarded as a species characteristic of pioneer habitats (RJABININ & PAN'KOV, 1987).

After considering *O. nova* and *T. velatus*, any similarities in the group of successional species on the dumps are finished. Most other oribatids are unable to sustain populations under such a broad range of conditions, although species living successfully, at least on some of the dumps, would likewise be equipped to withstand these conditions.

Four representatives of the family Brachychthoniidae were included as "early" successional species. Three of them were classified as "sprinters" (*Brachychochthonius cricoides* (WEIS-FOGH, 1948), *B. immaculatus* FORSSLUND, 1942 and *Liochthonius piluliferus* (FORSSLUND, 1942)) and one as a "long-distance runner" (*Liochthonius propinquus* NIEDBAŁA, 1972 – Fig. 34). Mites of this family have been observed as tolerant to air pollutants (SENICZAK et al., 1994) and as the most successful colonizers of young pine forest (NIEDBAŁA, 1976). *Mixochthonius laticeps* was found as the most numerous species on newly vegetated acid coal-shale tips (LUXTON, 1982). *Liochthonius lapponicus* and *L. propinquus* dominated on a young reedy area of zinc and lead dumps (SKUBAŁA et al., 1998). The preference of brachychthoniids for low pH was recognized by LUXTON (1982) and has been confirmed by other studies (SKUBAŁA, 1997b, 1999). The pH of the soil on dumps at Makoszowy and Murcki (MD) where brachychthoniids play an important role was acid. However, the soil was neutral on the dump at Chorzów, where *L. propinquus* was recognized as an "early" successional species. In other studies carried out on dumps the brachychthoniids were not identified as dominants (Tables 15 and 16). Brachychthoniidae only lay one or two eggs per brood (FORSSLUND, 1942, 1957) and develop slowly from the juvenile to the adult stage (TRAVE et al., 1996). As indicated by the present study, it did not prevent the species from being a successful colonizer.

Many species of the Suctobelbidae were found on the dumps studied (21 species in total). The range was from 6 species on the dumps at Makoszowy and Murcki (MD) to 10 species on the zinc dump at Wełnowiec, although only a few species occurred in high abundance. *Suctobelbella sarekensis* (FORSSLUND, 1941) was classified as an "early" successional oribatid, whereas *Suctobelbella subtrigona* (OUDEMANS, 1900) belonged to the "late" successional species. Presumably the Suctobelbidae are ecologically similar; similarities in respect of morphological characteristics among the species is high (small size, sucking "suctobelbid" mouthparts). Because of the rarity of males, thelytokous reproduction is suspected (NORTON & PALMER, 1991). That might be an important advantage in colonizing dumps. Only limited information on feeding biology and on life-history characteristics of suctobelbids is available. The high biodiversity of suctobelbids in artificial biotopes, e.g. post-industrial wastelands, has been confirmed by other studies (Skubała, 1995, 1996, 1999; Skubała et al., 1998), although these species rarely attain high abundance. Rjabinin & Pan'kov (1987) emphasized that the genus *Suctobelbella* is characteristic of pioneer habitats.

Together with *Oppiella nova*, five other species of the Oppiidae play an important role on the dumps. *Ramusella (I.) insculptum* (Paoli, 1908) was recognized as an "early" successional species on the mine dump at Murcki, and four other species (*Lauroppia fallax* (Paoli, 1908) – Chorzów, *Medioppia obsoleta* (Paoli, 1908) – Murcki (MD), *Microppia minus* (Paoli, 1908) – Makoszowy and *Ramusella* (*R.*) *assimilis* (Mihelčič, 1956) – Biskupice) were classified as "late" successional species. In contrast with most oribatids the relationship between habitat and density appears to be less pronounced in Oppiidae. The family is generally abundant in forest soils, although in strongly disturbed habitats like fields their density is usually low (Maraun & Scheu, 2000). However, Aoki (1979) classified Oppiidae as being an environmentally insensitive family. This is not confirmed by the present observations. *R. insculptum* and *M. obsoleta* were much more numerous on the dump than in the nearby forests. Only *M. minus* – the abundant species at site 3 at Makoszowy – occurred in higher numbers in the forest. Oppiidae are known to reproduce quickly. Thelytokous reproduction is widespread. Eggs develop quickly (< 40 days) and the adult lifespan is comparatively short (30–300 days, Luxton, 1981b). They appear to have wide ecological ranges, colonize a wide spectrum of ecosystems and presumably are more opportunistic feeders with a wider food spectrum (Stefaniak & Seniczak, 1981) than most other groups of oribatid mites (Rajski, 1967, 1968). On the other hand, the Oppiidae are a heterogeneous group and species may differ significantly in respect to ecological characteristics (Maraun & Scheu, 2000). A few oppioids were reported as dominant species from several dumps, e.g. *Microppia minus* (Babenko, 1980; Stebaeva & Andrievskii, 1997), *Ramusella assimilis* (Skubała, 1998), *Quadroppia quadricarinata* (Bielska, 1982b, 1995), *Medioppia subpectinata* (Bielska, 1995), *Medioppia obsoleta* (Skubała, 1998; Bielska, 1982b) and *Berniniella rafalskii* (Skubała, 1998). Hitherto, *Ramusella insculptum* (a "long distance runner" from the mine dump at Murcki) had not been recorded on dumps.

The occurrence of *Adoristes poppei* (Oudemans, 1906) on the "fresh" mine dump at Biskupice (a "sprinter") is surprising. Niedbała (1972) described the biotope of a pine forest as the optimal habitat of the species. Other authors do not mention its typical biotope. It is a mesohygrophilous oribatid (Niedbała, 1972). Strenzke (1952) recorded the species in situations of medium and high moisture, having similar abundance. With regard to food preferences, it is the only macrophytophage (SCHATZ, 1983b) among the successional species.

Autogneta longilamellata (MICHAEL, 1885) was found as an "early" successional species ("sprinter") in the mine sedimentation tank, whereas according to the literature it is a "forest" oribatid (RAJSKI, 1968; SCHATZ, 1983b). Little information could be found on the ecology of the species. Hitherto, *A. longilamellata* had not been found on post-industrial dumps.

Peloptulus phaenotus (C.L. KOCH, 1841) was found as an "early" successional species ("long-distance runner") on the highly contaminated dump at Wełnowiec. It is a heliophilous oribatid characteristic of open biotopes (RAJSKI, 1968; SCHATZ, 1983b). The species consumes plant material and microorganisms (non-specialist) (OLSZANOWSKI & NIEDBAŁA, 2000). *P. phaenotus* has rarely been recorded on post-industrial dumps in high numbers. It was classified as dominant only on a single ash dump in Silesia (BIELSKA & PASZEWSKA, 1995).

Scutovertex sculptus MICHAEL, 1879 is a typical pioneer species on the dumps at Chorzów and Biskupice (Fig. 10). Its abundance decreases on older sites. Little information exists on the ecology of the species. The species is found mostly in Southern and Central Europe (SCHATZ, 1983b). It has rarely been recorded as a dominant on dumps. It has been found in great numbers on the young unforested galena-calamine wastelands in Bukowno (SKUBAŁA, 1996), on ash dumps (BIELSKA & PASZEWSKA, 1995), and on a dolomitic dump (SKUBAŁA, 1999). Furthermore, the mite was also abundant in salt soils (SENICZAK et al., 1985) and on slopes of waste product deposits from the sodium industry (KLIMEK et al., 1991). It has features that may be useful in colonizing wastelands. LIONS (1966), WEIGMANN & STRATIL (1979) and ZALEWSKA (1989) found it in dry habitats. TRAVÉ (1963) noted it in habitats of low organic matter content, e.g. on stony areas lacking vegetation. Nevertheless, *S. sculptus* has comparatively rarely been observed as an abundant "pioneer" oribatid species.

Eupelops tardus (C.L. KOCH, 1836) is one of the "late" successional species on the iron dump at Chorzów (Fig. 35). It was absent or occurred only rarely in other studies carried out on dumps (see Tables 15 and 16). It occurred abundantly on the iron dump in Bytom (SKUBAŁA, 1995) and on the galena-calamine wastelands in Bukowno (SKUBAŁA, 1996). RAJSKI (1968) pointed out that *E. tardus* prefers open habitats. With regard to water requirements, it is probably xerophilous (SCHATZ, 1983b). This feature might be advantageous for colonizing dumps. It is another panphytophage among successional oribatids (SCHATZ, 1983b).

Liebstadia similis (Michael, 1888) is another species associated with older sites on the iron dump at Chorzów. The species is regarded as an oribatid typical of open biotopes (Niedbała, 1977; Rajski, 1968; Seniczak et al., 1996), although Borcard (1994) described the species as eurytopic. According to Schatz (1983b) *L. similis* is hygrophilous, although Rajski (1968) reported the species as mesohygrophilous. The species is heliophilous and well known as the host of anoplocephalids (Rajski, 1968; Schatz, 1983b). As regards feeding habits, *L. similis* is a panphytophage (Borcard, 1994). Siepel & Ruiter-Dijkman (1993) included it in the biggest guild among oribatids – herbifungivorous grazers. The species was previously recorded in high numbers on some dumps in Poland. *L. similis* was the dominant species (19% of the total number) on the reclaimed old dump at Bytom (Skubała, 1995). Furthermore, it was the dominant species on many sites on ash dumps (Bielska & Paszewska, 1995) and on the reclaimed mine dump at Katowice (Żbikowska-Zdun, 1988).

Oribatula tibialis (Nicolet, 1855) occurred frequently at the oldest site on the mine dump at Makoszowy. Its ecology is uncertain. Most authors believe that *O. tibialis* should be classified to the mesohygr group (Rajski, 1968; Schatz, 1983b; Strenzke, 1952). Its preference for organic matter is also uncertain (Strenzke, 1952; Rajski, 1968). Most authors have classified *O. tibialis* as panphytophagous (Borcard, 1994; Luxton, 1972), although Schatz (1983b) reported it as a microphotophage and panphytophage. It is the host of *Moniezia expansa* (Schatz, 1983b). The species belongs to the feeding guild of fungivorous grazers (Siepel & Ruiter-Dijkman, 1993). This means that *O. tibialis* has chitinase as well as trehalase activity. *O. tibialis* has been observed on post-industrial dumps in the past, but in low numbers (Bielska, 1989; Madej & Skubała, 1998; Skubała, 1999; Żbikowska-Zdun, 1988). It was found frequently on one of the sites on the “new” galena-calamine wastelands at Bukowno (Skubała, 1996). Weigmann & Kratz (1987) noted that the species disappeared at high levels of pollution.

Pergalumna nervosa (Berlese, 1914) was the most abundant oribatid at the oldest site on the mine dump at Biskupice, although it was absent from the nearby meadow. Some ecological characteristics of the species indicate its ability to colonize technogenic ecosystems. Strenzke (1952) observed it as most frequent at sites where the litter was slightly developed. Rajski (1968) described *P. nervosa* as eurytopic, although Schatz (1983b) classified it as a forest species and a tyrphobiont. Zalewska & Rajski (1990) regarded it as resistant to large changes in humidity and temperature. Its other ecological features are as follows: myrmecophilous, nidicolous and heliophilous (SCHATZ, 1983b; SMRŽ & STARÝ, 1995). *P. nervosa* is an another intermediate host of cestods (RAJSKI, 1959). Hitherto, the species was very rarely observed on dumps. SKUBAŁA (1995) recorded *P. nervosa* on the iron dump at Bytom, but with low abundance. It was the most important species on some sites on the "new" galena-calamine wastelands (SKUBAŁA, 1996).

Protoribates capucinus BERLESE, 1908 occurred abundantly only at site 3 on the iron dump at Chorzów. It is an euryecious mite (SCHATZ, 1983b). Other known ecological features of *P. capucinus* are as follow: panphytophagous and a species of broad moisture requirements (euryhygrophilous) (RAJSKI, 1968; SCHATZ, 1983b). The only known dump where the species recorded as abundant are the dolomitic dump at Tarnowskie Góry (SKUBAŁA, 1999) and older sites covered with dense vegetation on the "new" galena-calamine wastelands at Bukowno (SKUBAŁA, 1996). The species was recorded as absent in other studies on post-industrial dumps.

Punctoribates punctum (C.L. KOCH, 1839) prefers older sites with shrubs and trees rather than open habitats in the current research. Its proportion was higher in nearby forests than in the meadows. The abundance of *P. punctum* was higher on reclaimed sites on the dumps at Brzeszcze than in the adjacent meadow. This observation of the occurrence of the species is not in agreement with the opinion that *P. punctum* is a meadow and heliophilous oribatid (SCHATZ, 1983b; SENICZAK et al., 1996; ZALEWSKA & RAJSKI, 1990). The species feeds on fungi and is able to digest both cell walls and contents. It is included in the guild of fungivorous grazers (SIEPEL & RUITER-DIJKMAN, 1993). It is another intermediate host of anoplocephalids (SCHATZ, 1983b). *P. punctum* was reported as a dominant species on dumps of various ages (BABENKO, 1980; BIELSKA, 1982a, b; BIELSKA & PASZEWSKA, 1995; DAVIS, 1963; SKUBAŁA, 1995; ŻBIKOWSKA-ZDUN, 1988).

Ceratozetes mediocris BERLESE, 1908 was one of the most abundant species at all sites on the zinc dump (Fig. 16). It occurred only on older sites on the mine dump at Murcki. In the literature it is described as a sylvan species (MAHUNKA, 1983) or a species characteristic of open biotopes (RAJSKI, 1968). The present observations correspond with Rajski's opinion. *C. mediocris* was usually a dominant species on the meadows studied, whereas it occurred rarely in or was absent from the forests. Some features of *C. mediocris* indicate the ability of the species to colonize artificial biotopes. It is a heliophilous and termophilous species (SCHATZ, 1983b). DINDAL (1977) noted the considerable environmental insensitivity of *C. mediocris*. When exposed to DDT application, *C. mediocris* went from subdominant to dominant. The species was numerous on some of the mine dumps in Silesia (Bielska & Paszewska, 1995; Skubała, 1995). It was absent in most studies carried out on dumps in Poland and abroad (see Tables 15 and 16). Hubert (2001) found a considerably high number of *C. mediocris* in reclaimed sedimentation ponds.

*

Traditional niche theory predicts that greater biodiversity should result in more specialized niches (smaller niche width) and a greater degree of resource partitioning (reduced niche overlap) (Giller, 1994). Species from the same genus tend to occupy more similar diet niches than less closely related animals. Therefore, there must be sufficient diversity and abundance of resources to accommodate one member from each genus before a second member from any one dietary group can be accommodated (Majer, 1989b).

Let's study some examples of niche partitioning amongst species of the same genus and test the hypothesis that the common occurrence of closely related species is good evidence on improvement in the environment. Canonical correspondence analysis was used to search for the differentiation of ecological niches of *Tectocepheus velatus*/*Tectocepheus minor* and *Scheloribates laevigatus*/*Scheloribates latipes* (Figs. 36 and 37).

Axis 1 explains almost the whole variance (90.6%) in data for the occurrence of *Tectocepheus velatus* and *Tectocepheus minor*. The eigenvalue of the axis was significant (0.306). The species were ordinated on the opposite sides of axis 1 (Fig. 36). Different environmental variables influence the occurrence of the species. The complexity of the habitat has most influence on the occurrence of *T. minor*. The amounts of carbon, nitrogen, zinc and other factors influence the occurrence of *T. velatus*. *T. minor* never occurred in pioneer communities, whereas *T. velatus* was always present at that successional stage. Usually *T. minor* appears in higher numbers at older sites on dumps and in the forests. It was described as a “late” successional species in the mine sedimentation tank. *T. velatus* and *T. minor* are described as similar in environment requirements, although these are still not well documented. Both species are mesohygrophilous and classified as fragment feeders (Kaneko, 1988a; Schatz, 1983b). *T. velatus* is a ubiquitous species (Schatz, 1983b), whereas *T. minor* seems to prefer wooded areas (Rajski, 1968). *T. velatus* was practically always recorded on dumps, whereas *T. minor* was found only in low numbers on a few dumps (see Tables 15 and 16).

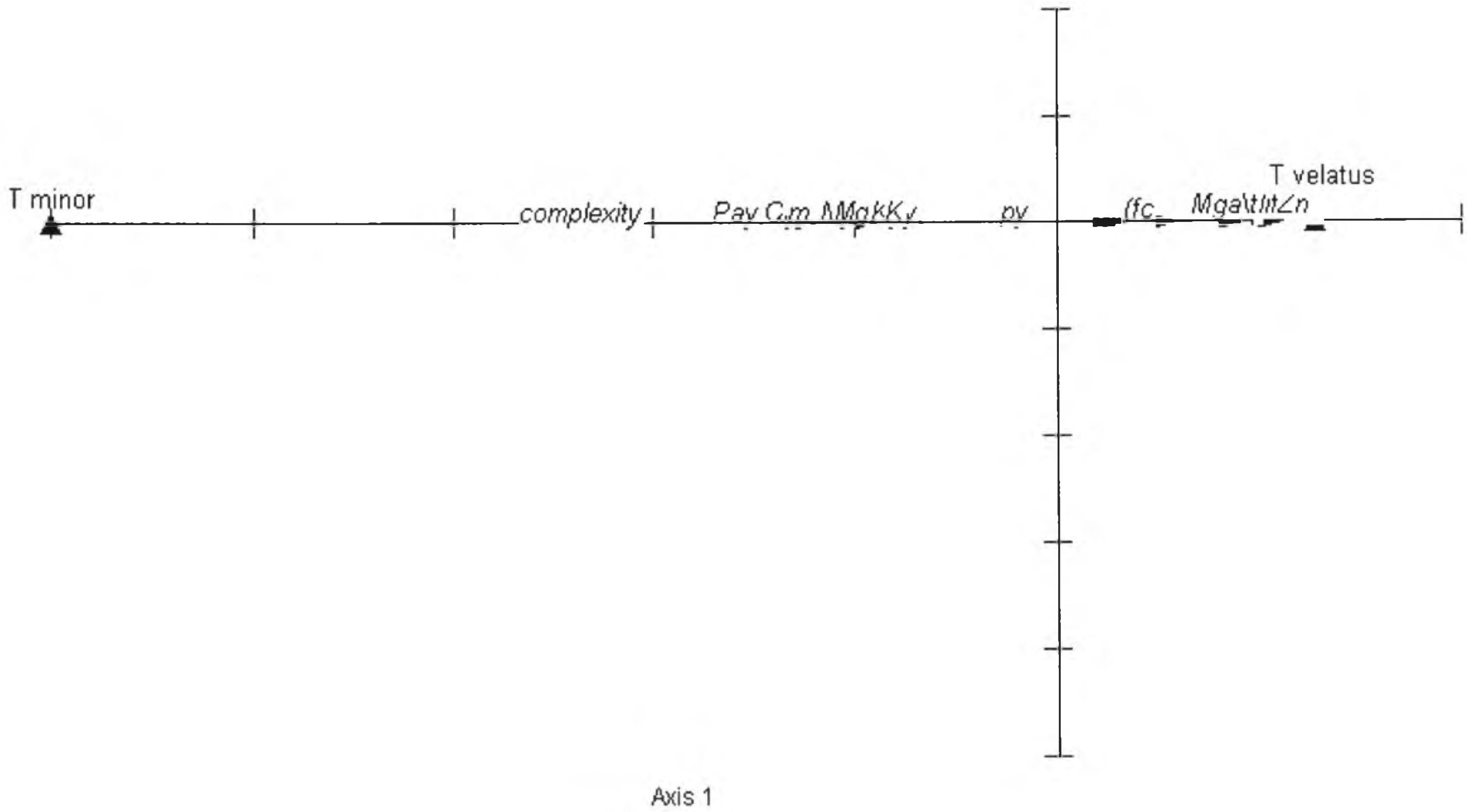


Fig. 36. Canonical correspondence analysis (CCA) ordination diagram for *Tectocepheus velatus* and *Tectocepheus minor* in relation to environmental variables
codes of the environmental variables: Appendix 4

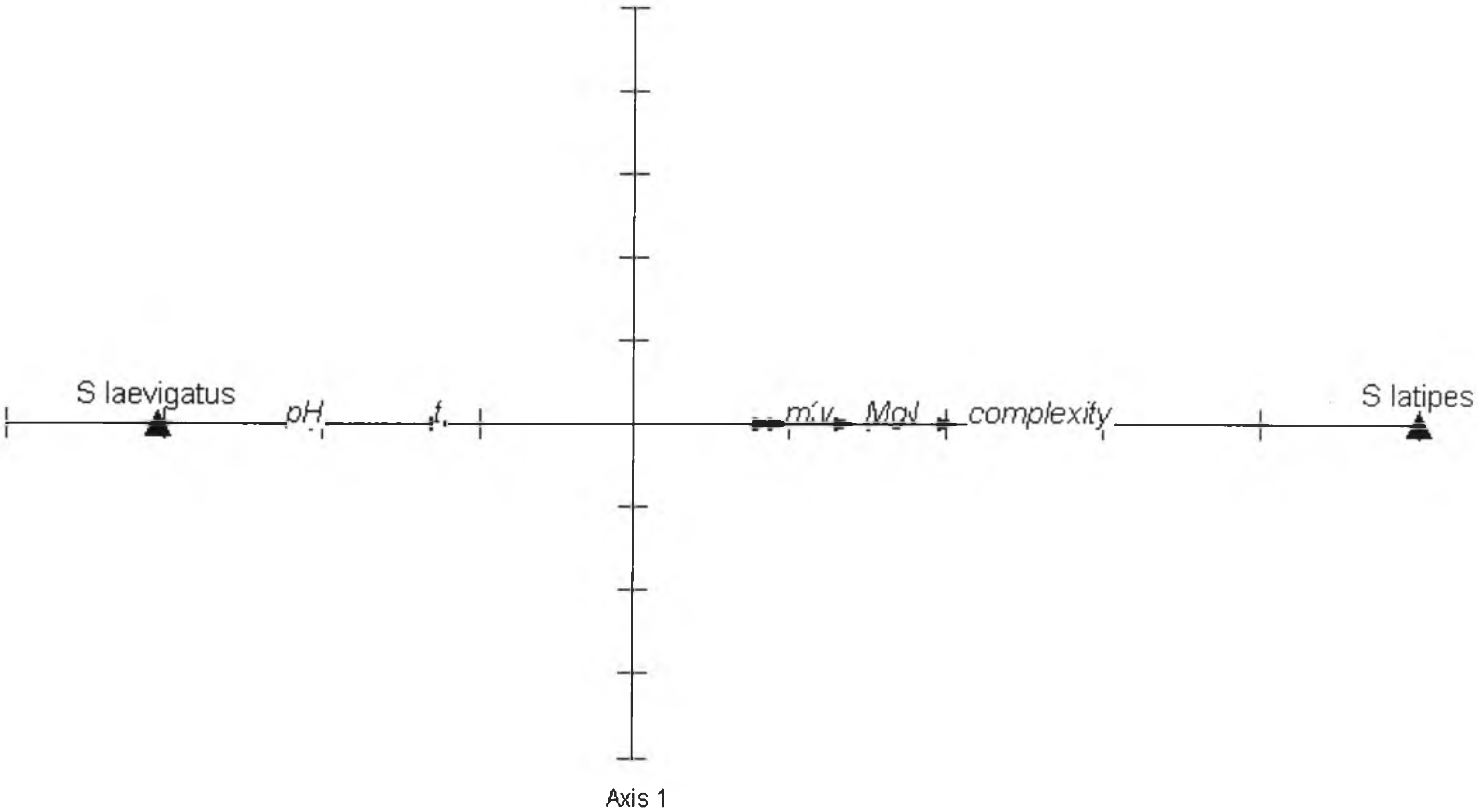


Fig. 37. Canonical correspondence analysis (CCA) ordination diagram for *Scheloribates laevigatus* and *Scheloribates latipes* in relation to environmental variables
codes of the environmental variables: Appendix 4

The results of CCA ordination for *Scheloribates laevigatus* and *Scheloribates latipes* were practically identical as in the case of the previous species. *S. latipes* was ordinated on the right end of axis 1 and *S. laevigatus* along the negative part of the axis (Fig. 37). Axis 1 explains 100% of the total variance in the data. The eigenvalue of the axis was 0.317. Different environmental variables influence the occurrence of the species. Complexity of the habitat has greatest impact on the occurrence of *S. latipes* and pH has most influence on the development of *S. laevigatus*. Both species are considered as eurytopic mites (Schatz, 1983b). They are abundant oribatids in meadow soils (Baur et al., 1996; Černova & Čugunova, 1967; Rajski, 1968; Woodring & Cook, 1962). The species are frequently reported as acting as intermediate hosts of anoplocephalids (Denegri, 1993; Rajski, 1959). Moreover, they are very similar in humidity requirements (mesohygrophilous) and are myrmecophilous and heliophilous oribatids (Schatz, 1983b). According to the literature both species belong to different feeding guilds. *S. latipes* is microphytophagous (Borcard, 1994; Schatz, 1983b), feeding on fungal hyphae and/or bacteria. *S. laevigatus* is a panphytophagous mite (Schatz, 1983b). Siepel & Ruiter-Dijkman (1993) using the presence or absence of three digestive enzymes, classified *S. laevigatus* as a fungivorous grazer (having chitinase and trehalase). Both species are known from dumps, but only *S. laevigatus* has been recorded as dominant, e.g. on the chemical dump at Oświęcim (Skubała, 1998), on mine dumps (Bielska, 1982a) or on open mountain field dumps in Russia (Babenko, 1980).

The differential use of the environment by closely related species, e.g. *Tectocepheus velatus*/*T. minor* and *Scheloribates laevigatus*/*S. latipes* is well proven by use of the CCA ordination method. Common appearance of species of the same genus is good evidence of the successional stage of oribatid communities.

*

Juvenile forms were identified to species or genus level only in a small proportion of the total number of species. Juvenile forms characterized by a thick cuticle, e.g. *Scutovertex sculptus*, *Eupelops spp.*, *Achipteria coleoptrata*, *Tectocepheus velatus*, *Nothrus spp.*, *Trhypochthonius tectorum*, usually occurred in high numbers in extracted material (Table 34). On the other hand, juveniles characterized by a delicate thin cuticle, e.g. representatives of Oppiidae or Suctobelbidae, occurred rarely. The proportion of adult and juvenile forms in Oppiidae at all study sites is very symptomatic (see Table 35). The disproportion between adult and juvenile forms is

Table 34

Abundance (indiv./m²) of juvenile and adult stages of selected "early" and "late" successional species

Species	Site 1		Site 2		Site 3		Meadow/Forest	
	adult	juvenile	adult	juvenile	adult	juvenile	adult	juvenile
Chorzów (C)								
Scutovertex sculptus[1]	528	924	410	194	28	7	252	76
Tectocepheus velatus[1]	76	69	917	174	3 188	833	3 257	1 086
Eupelops tardus[2]	7	–	–	–	903	382	56	15
Liebstadia similis[2]	7	–	7	–	1 701	556	500	157
Wełnowiec (W)								
Peloptulus phaenotus[1]	333	118	299	69	847	132	61	25
Tectocepheus velatus[1]	590	188	2 382	528	1 396	257	2 111	803
Ceratozetes mediocris[1]	167	63	1 563	333	3 569	625	121	40
Biskupice (B)								
Scutovertex sculptus[1]	1 049	1 924	118	28	–	–	–	–
Tectocepheus velatus[1]	1 056	7 757	4 208	1 917	639	486	35	76
Makoszowy (M)								
Tectocepheus velatus[1]	2 958	5 104	840	653	1 153	542	28	35
Oribatula tibialis[2]	–	–	7	–	542	42	236	69
Murcki dump (MD)								
Tectocepheus velatus[1]	42	104	236	118	604	111	318	76
Ceratozetes mediocris[2]	–	–	69	76	1 076	208	–	–
Murcki tank (MT)								
Tectocepheus minor[2]	–	–	7	–	1 292	521	97	125

[1] "Early" successional species.
[2] "Late" successional species.

very high. Some authors have indicated that the age structure of Oppiidae is not clear because of the low extraction efficiency of juveniles compared with that of adults (Kaneko, 1988a; Reeves, 1969). A low proportion of juveniles in *Oppiella nova* (~1% of the total number) was observed by Seniczak (1975). The author claimed that the extraction apparatus did not extract most of the juvenile of this species.

Another problem concerning demographic analyses of oribatid populations (e.g. overestimation of adults) is the large difference in extraction efficiency generally observed between adults and juveniles. Marshall (1972) estimated an average extraction efficiency of 88% for oribatid juveniles, compared with 98% for adults. Nevertheless, other authors noted a much higher difference in extraction efficiency between juveniles and adults. MacFadyen (1953) calculated average efficiencies of 29 and 79% for respectively juveniles and adults. Søvik & Leinaas (2002) in a recent study recorded extraction efficiencies

Table 35

Abundance (indiv./m^2) of the representatives of the Oppiidae (juveniles and adults) on the study sites

Locality	Site 1		Site 2		Site 3		Meadow/Forest	
	adult	juvenile	adult	juvenile	adult	juvenile	adult	juvenile
Chorzów (C)	174	14	10 653	69	2 764	49	3 247	25
Wełnowiec (W)	153	7	951	21	7 542	76	81	15
Biskupice (B)	174	7	8 611	97	5 278	56	986	14
Makoszowy (M)	299	7	2 840	35	5 563	83	12 410	111
Murcki dump (MD)	243	14	1 090	21	11 410	97	10 212	86
Murcki tank (MT)	257	14	1 208	21	12 938	63	18 278	118
Brzeszcze (BR)	3 521	76	5 785	118	27 431	104	1 125	42

of active mites of *Ameronothrus lineatus* ranging from 29–36% for juvenile instars to 75% in adults. Lower extraction efficiency of immature stages is probably a common phenomenon among oribatid mites. To some extent this may be due to the softer cuticle of larvae and nymphs, and the lower mobility of these life stages, although the occurrence of the quiescent stage in pre-moult juveniles is also important (Søvik & Leinaas, 2002). Mites in this stage will not be extracted, and according to Luxton (1981b), up to a third of their development is spent inactive.

Taking into consideration the above remarks, the characteristics of juvenile forms can be discussed only with regard to some of the successional genera, e.g. *Tectocepheus*, *Scutovertex*, *Eupelops*, and *Liebstadia* (Table 34), and on a limited scale. It was very characteristic that the proportion of juvenile stages of most species was highest in the "pioneer" communities, decreasing gradually thereafter. For instance the ratio of juveniles to adults of *Scutovertex sculptus* ranged from 1:0.6 (site 1) to 1:4 (site 3) on the iron dump at Chorzów. The proportion of juveniles and adults in *Tectocepheus velatus* on the mine dump at Makoszowy changes from 1.7:1 (site 1) to 1:2.1 (site 3).

Seniczak (1978) indicated that the age structure of *Tectocepheus velatus* is of important diagnostic value. It is a good indicator of the soil fertility. A high proportion of juvenile stages and their prevalence over adults indicates better conditions for the development of the species and therefore higher fertility of the soil (Seniczak, 1994). With regard to the present research on post-industrial dumps, it may be concluded that a proportion of juvenile stages of some species, e.g. *Tectocepheus*, *Scutovertex*, *Peloptulus*, *Liebstadia*, is a good indicator of the successional stage of oribatid communities. Their proportion is higher on younger sites and decreases on older ones.

It is worth mentioning that due to the disproportionate extraction of juvenile and adult stages and an uneven extraction efficiency of juvenile forms from different species, our knowledge of oribatid communities and their function is far from realistic. This and many others problems concerning the limitations and difficulties in ecological inquiries of soil mites are discussed in a very inspiring article by NIEDBAŁA (2000). Despite the problems mentioned above, the author stressed that although juveniles of oribatids constitute usually about 30% of the total number, they might participate in 70% of the total annual metabolism of oribatids. In the present study, the proportion of juveniles varied from 9.4% (Makoszowy – 3) to 76.6% (Biskupice – 1). So our precise knowledge of what is going on in oribatid communities on dumps is restricted, at least in some cases.

Oribatid larvae and nymphs are more voracious and metabolize plant substances faster than adults. Moreover, they are weakly sclerotized and more easily attacked by predators. Therefore, the juvenile stages are more important in the transmission of matter and energy to a higher trophic level (NIEDBAŁA, 2000). Until detailed keys of juveniles are prepared and improvements in extraction methods are established, our ecological studies on soil mites, which are primarily based on adults, can only yield approximate results.

*

For the successful colonization of new territory by a species, two conditions are required (SAFRIEL & RITTE, 1980):

a) that the colonizer is preadapted to the new physical environment,

b) that it can find an ecological niche in the existing biological community.

The great adaptive spectrum of mites in general and Oribatida in particular has enabled them to colonize the most extreme environments. Recent findings confirm that these animals, like most edaphic fauna, are highly sensitive to ecological factors (LEBRUN, 1981), often occupy precise ecological niches, and subsist in competitive relationships (ANDERSON, 1978a). Existing data on the reproductive strategy of oribatids seems to situate them close to *K*-strategists. On the other hand, many authors claim that the best colonizers are those that adopt *r*-strategies (BERNINI, 1990). Nevertheless, many successful oribatid species in the colonization of post-industrial dumps were selected in the present research, and they reached comparatively high abundance after 5–10 years. It may be concluded that mites, despite having some features that do not classify them among good colonizers (K-strategy of reproduction, sensitivity to ecological factors), are successful enough in the colonization of technogenic habitats. Furthermore, substrate/ soil on dumps appears to offer a broad selection of ecological niches that can be occupied by many oribatid species. It seems worthwhile to mention that there are some species that occur in high numbers in the surrounding biotopes, but seem unable to colonize dumps. A list of these species from several localities is presented in Table 36.

Table 36

List of numerous oribatid species found in the neighbouring biotopes but which had not colonized the dumps

Achipteria coleoptrata – M
Banksinoma lanceolata – B
Ceratozetes gracilis – MT
Chamobates voigtsi – MT
Conchogneta dalecarlica – MD
Lauroppia falcata – MD, MT
Protoribates variabilis – W
Punctoribates punctum – MD
Scutovertex sculptus – W
Tectocepheus minor – MD

Explanation of abbreviations – see Table 4 and 5.

An important question is “why do so many oribatid species occur on dumps?” Why are there so many species that are able to colonize “fresh” dumps? Wardle et al. (1997) suggested three hypotheses while discussing the general problem of species richness.

a) The **species redundancy hypothesis**, which predicts that there is considerable “redundancy” and that several species are capable of performing each soil system function.

b) The **ecosystem rivet hypothesis**, in which all species are potentially important to ecosystem functioning. All species have a distinct ecological role to play and if one species is lost the soil system loses some aspect of its function.

c) The **idiosyncratic hypothesis**, in which diversity changes ecosystem function, but not in predictable directions.

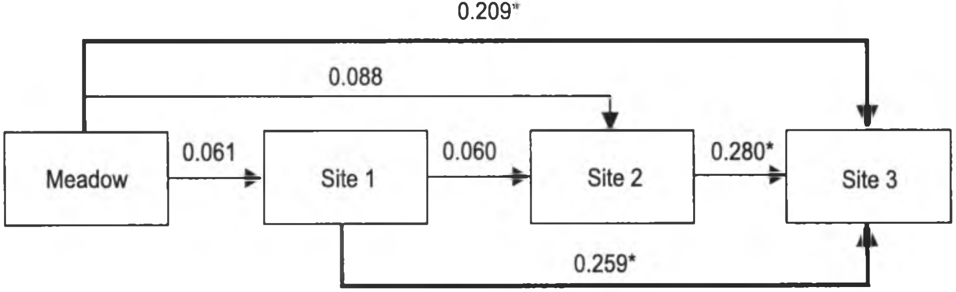
Doherty et al. (2000) add a fourth potential hypothesis: the **insurance policy hypothesis**, that diversity of species aids the stability of a system, particularly in the face of unusual, extreme events as well as human-induced perturbations. It should be noted that there is considerable overlap between the components of each hypothesis as they are currently formulated (Doherty et al., 2000).

Taking into account the occurrence of species in “pioneer” stages (the presence of a large set of species on a particular dump) and at older sites of technogenic ecosystems, the species redundancy hypothesis, suggesting redundancy in a species pool, is most probable, although as Walker (1992) admitted, little is known about the degree of functional redundancy in ecosystems in general.

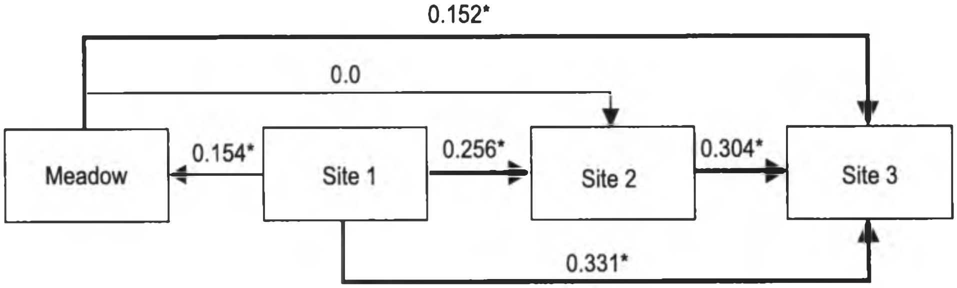
Chapter 9. Ways of migration, pool of colonizers

One of the main prerequisites for the successful colonization of post-industrial dumps by oribatid mites is effective migration. Migration is hard to observe, but it is possible to draw some conclusions about it from the situation on reclaimed and non-reclaimed dumps and in the nearby biotopes. What is the main pool of oribatid species colonizing dumps?

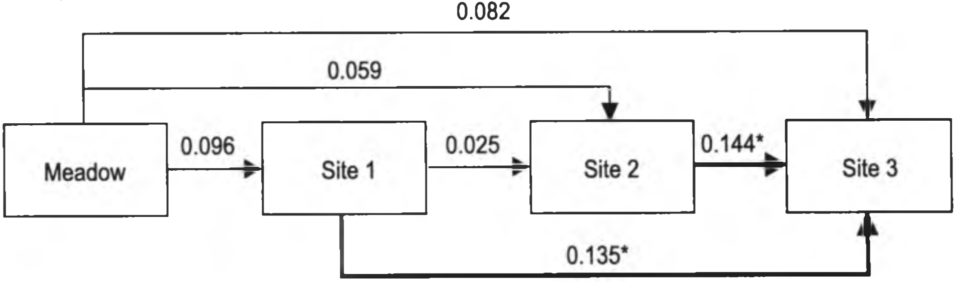
Figure 38 illustrates the results of the DD_2 dispersal index. The computed indices of dispersal direction allow an assessment of general trends, indicating the most probable direction of migration of a majority of species. The possible mite species flows are represented by arrows. The primary colonization of the dumps probably occurs in two steps. One step is the import of mites from a nearby forest or meadow to a dump. In the second step the species have to radiate outwards from an older site to newly created habitats on a dump. Analysis of dispersal direction indicated that the most probable direction of migration of species was from a nearby forest/meadow to particular sites on the dump. However, this trend was significant (McNemar test, $p < 0.05$) between all pairs of sites only on the dumps surrounded by forests (Makoszowy, Murcki – dump, Murcki – sedimentation tank). As regards the iron and zinc dump, this way of migration was not so obvious. The general trend of migration from the meadow to the mine dump at Biskupice was not significant (McNemar test, $p < 0.1$). In the case of site 2 at Biskupice, the opposite way of migration was suggested. This might be an additional sign that the natural succession of oribatids on this dump was disturbed by some human interaction. A flow of mite species from older to younger sites on the dumps was observed. The



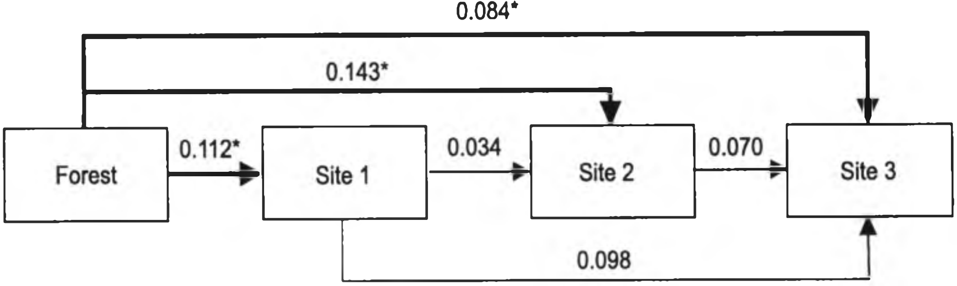
Chorzów



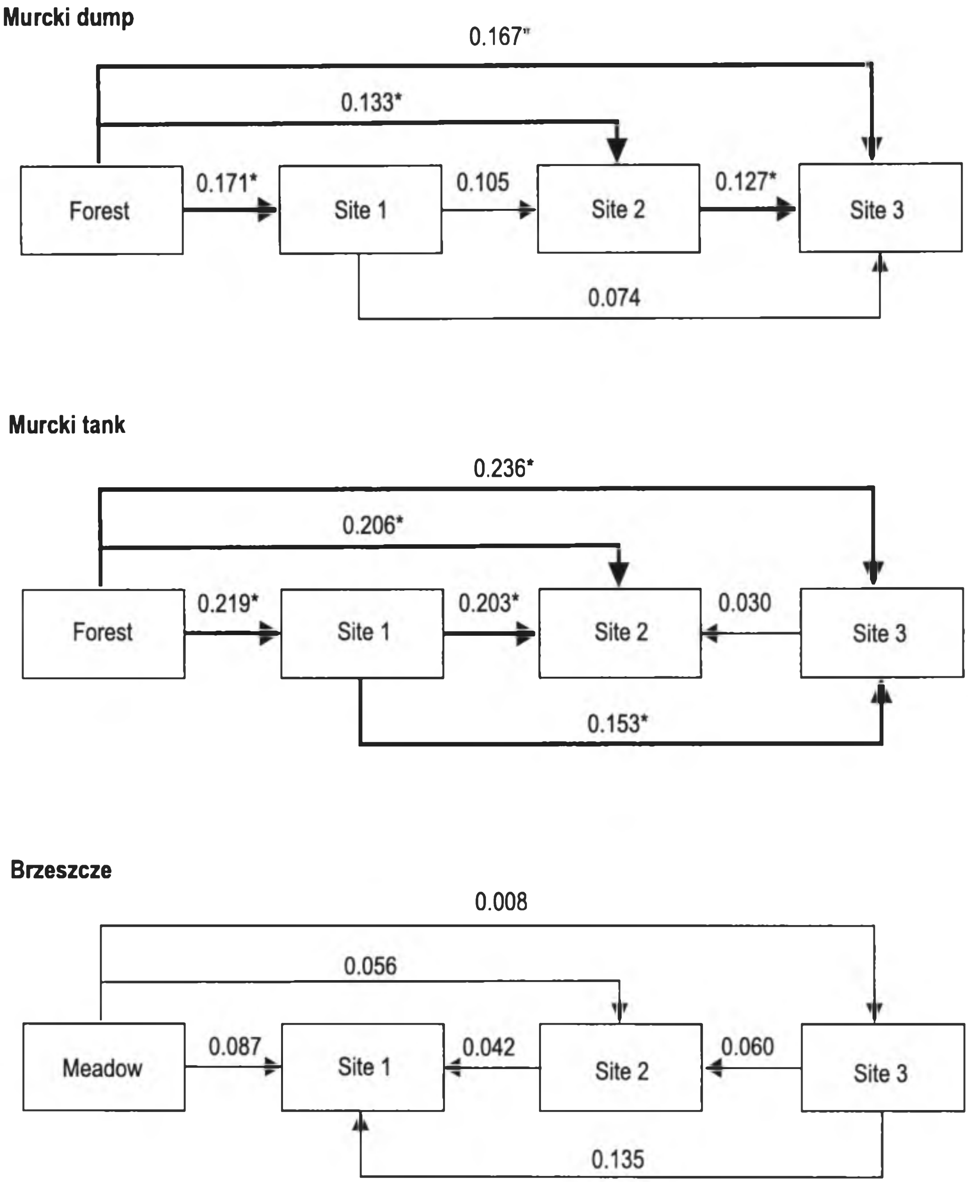
Wełnowiec



Biskupice



Makoszowy


Murcki dump

Murcki tank

Brzeszcze

Fig. 38. Analysis of dispersal direction and values of DD_2 index for four pairs of study sites at each locality

the asterisk denotes a statistically significant value at the 0.05 probability level (McNemar's test) results indicate a little stronger association of the faunas on the dumps at Chorzów, Wełnowiec and Biskupice, which are adjacent to meadows than on other dumps surrounded by forest. With regard to the reclaimed mine dumps at Brzeszcze, the flow of mite species from the meadow to a dump and from older to younger sites was practically not observed. The reclamation measures disturbed the succession process, and even after 19 years the natural ways of migration of oribatids are difficult to recognize.

Some general data and trends on possible oribatid migration are also presented in Fig. 39. It might be surprising that only 31% (zinc dump) to 66% (sedimentation tank) of species recorded on a particular dump were also noted in the nearby meadow or forest. So, usually half or more of the species come from other, more distant, biotopes. Many dominant oribatid species on dumps were absent in the adjacent biotopes. As regards the mine dump at Biskupice, five dominant species (*Adoristes poppei*, *Pergalumna nervosa*, *Ramusella assimilis*, *Scutovertex sculptus* and *Suctobelbella subtrigona*) were not found in the nearby meadow during the 2-year

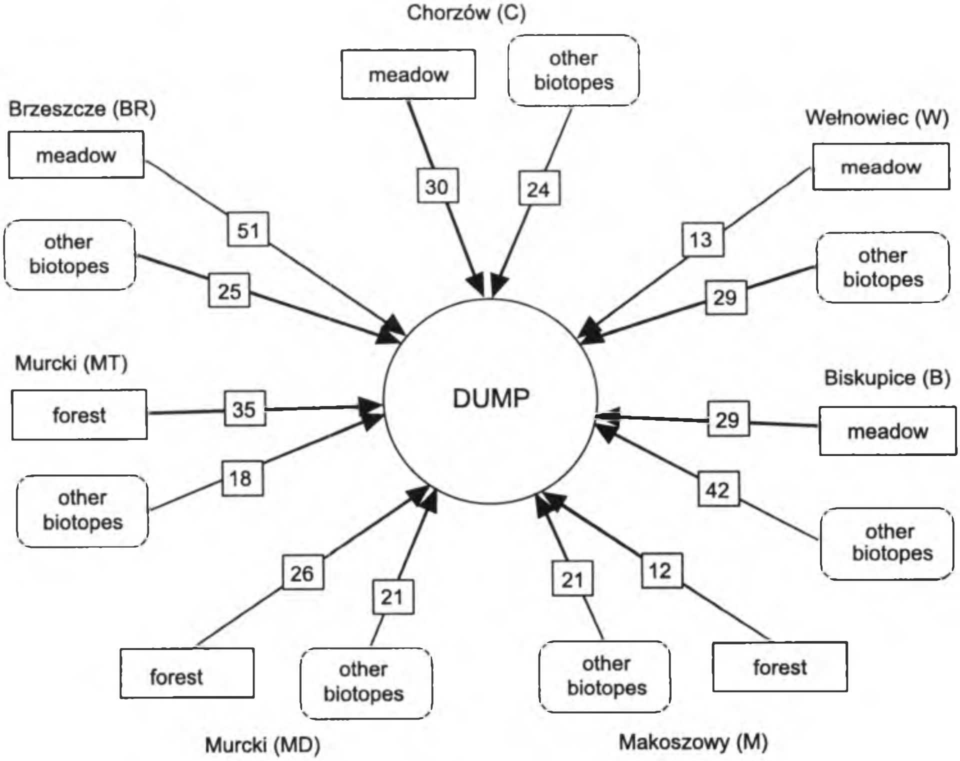


Fig. 39. Ways of migration of oribatids on the dumps (figures are the number of species)

sampling period. Only in the case of the zinc dump were all dominant species also recorded in the meadow.

To address the question of species turnover along the transect, ß-diversity indices were computed (Table 37). ß-diversity can be defined as the extent of species replacement or biotic change along environmental gradients (WHITTAKER, 1972). According to the ß-diversity index, the biological length of the gradient was the highest on dumps surrounded by forest (Makoszowy, Murcki – dump). However, ß-diversity was also low at generally young sites in the sedimentation tank surrounded by forest. The value of the index was also comparatively high on the oldest dump (15 to 50 years) – the zinc dump at Wełnowiec. It was characteristic that the measure of the amount of change (ß-diversity) was very low on the reclaimed mine dumps at Brzeszcze.

Table 37

Values of alfa and beta diversity measure for adjacent plots on the study sites (dumps and neighbouring biotopes)

Locality	Chorzów (C)	Wełnowiec (W)	Biskupice (B)	Makoszowy (M)	Murcki dump (MD)	Murcki tank (MT)	Brzeszcze (BR)
Alfa-diversity	33.75	24.25	43.75	26.5	36.25	39.75	47.25
Beta-diversity	1.11	1.42	1.12	1.64	1.43	1.11	0.81

LISS et al. (1986) stress the importance of the species pool of potential colonists present in natural habitats in the surroundings for arthropod assemblage development. Such a species pool was mentioned for Collembola (KOVAČ & MIKLISOVA, 1997) and Gamasida (KOVAČ et al., 1999). This phenomenon was not so significant in the present study. Usually over 50% and even 70% (Wełnowiec) of an oribatid community on a dump can be formed from species that have migrated from distant biotopes.

Possibly there are many ways of passive or active dispersion of oribatid mites over a longer distance, which play a role in a dump's colonization. Oribatid mites undoubtedly are dispersed by wind currents from one site to another (BEHAN-PELLETIER & WINCHESTER, 1998; LINDROTH et al., 1973; STARÝ & BLOCK, 1998). Some authors discounted wind as important source of dispersal (HAMMER, 1965; SEYD, 1962, 1979). BERNINI (1990) stated that a number of researchers collected extremely few mites and even fewer oribatids in the "aerial plankton". This is not surprising because with oribatids being prevalently edaphic it would be very difficult for the wind to lift them up and carry them. Another disadvantage for Oribatida of this type of transport is their low resistance to dehydration. The smaller species and many Oribatida lacking the cerotegument are very sensitive to dehydration and live at greater depth in the soil (BERNINI, 1990; SEYD, 1992). However, these disadvantages seem to be important only when considering wind-borne passive dispersion over long distances. Such a transportation scenario was analysed by BERNINI (1990), HAMMER (1965) and SEYD (1962, 1979). The importance of air transport during the pioneer period on post-industrial dumps was suggested for a large component of the microarthropod fauna by DUNGER (1989) and WANNER et al. (1998). EMMANUEL (quoted in WHELAN, 1978) found that oribatid nymphs were carried by air currents. Air current dispersal would influence the size of the species transported to a new habitat. Would it be the reason for the low proportion of big and heavy sclerotized oribatids found on "fresh" dumps? Such a possibility is worthwhile considering. WHELAN (1978) claimed that this might be directly responsible for the small species of Oribatida present in a 2-year ley.

No oribatid mites have developed an obligatory relationship with vertebrates or their nests, however, rodents, birds and domestic animals are known to pick up and disperse them passively (KRIVOLUTSKY & LEBEDEVA, 2002; MIKO & STANKO, 1991; NORTON, 1980). The principal group of animals that transport oribatids are birds (BERNINI, 1990). KRIVOLUTSKY & LEBEDEVA (2002) recorded very high numbers of individuals of oribatid species amongst bird feathers.

NORTON (1980) surveyed phoresy in oribatid mites and reported that some adults of the genera *Mesoplophora*, *Paraleius*, *Metaleius*, *Oppia*, *Euscheloribates* and *Tectocepheus* are phoretic on Coleoptera, especially passalids, as well as *Metaleius* on Diptera and *Mesoplophora* on Dictyoptera. Many of the phoretic oribatids are endophagous, feeding on wood at particular stages of decay. Their phoretic associations are primarily with wood-burrowing insect species. That is why phoresy is rather unlikely to be an important source of the oribatids found on dumps.

HOLZAPFEL & HARRELL (1968) claimed that man is the primary means of dispersal of many organisms. Few data are available to indicate passive transport by man, but existing observations, e.g. made by HAMMER (1969) indicate the enormous role of human activity. So human intervention should always be seriously considered when discussing the introduction of oribatids on dumps.

Another possibility for the colonization of dumps by oribatids is their active dispersal through random movement. According to OJALA & HUHTA (2001) populations of many mite species can cover a distance of 30 metres in 30 years. Large edaphic oribatid species indicate displacements of a few centimetres per day (BERTHET, 1964b). In fact, oribatids appear to migrate so slowly that land dispersal could not explain their occurrence on the dumps, at least not from more distant biotopes.

Many oribatid species of different morphological and ecological characteristics occurred on dumps. It seems that there are many possibilities for oribatids to invade dumps. All or at least some dispersal modes are successful enough. This leads to the conclusion that reclamation of dumps is a useless effort, at least on the grounds of the development of oribatid fauna.

According to Neumann (1971) soil fauna hardly migrate into a site (brown-coal mining areas) if it is too far away from one originally inhabited. This remark may be applicable to representatives of macrofauna, e.g. millipedes or woodlice (studied by Neumann), but not to mites. Neumann (1971) proposed introducing the animals with the soil into a new site. The imported soil will start a new population, which might later spread throughout the new site. It is worth mentioning that nowadays botanists or plant ecologists focus on the management of post-industrial wastelands by the use of natural processes, which can be accelerated by man on the basis of local gene resources (Tokarska-Guzik & Rostański, 2001). This leads to more stable and interesting plant associations and is good evidence of the self-regulation of biocenoses (Rostański, 1991). With regard to soil animals, Glück (1989) and Wolf (1985) observed no clear beneficial effects of the experimental application of (faunated) woodland topsoil and litter. In some cases the introduction of suitable species of earthworms succeeded in accelerating soil biological processes, especially in stabilizing aggregates and increasing soil microbial biomass (Scullion & Malik, 2000). Such effects have also been shown at dumps without inoculation by earthworms or other components of the soil fauna, and can even be demonstrated under the hampering influence of pyrite substrates (Dunger et al., 2001; Keplin et al., 1999). Dunger et al. (2001) also revealed equivalent development of soil biological processes at non-reclaimed mine sites, compared with reclaimed ones.

Chapter 10. **Oribatid mites in assemblages of mesofauna**

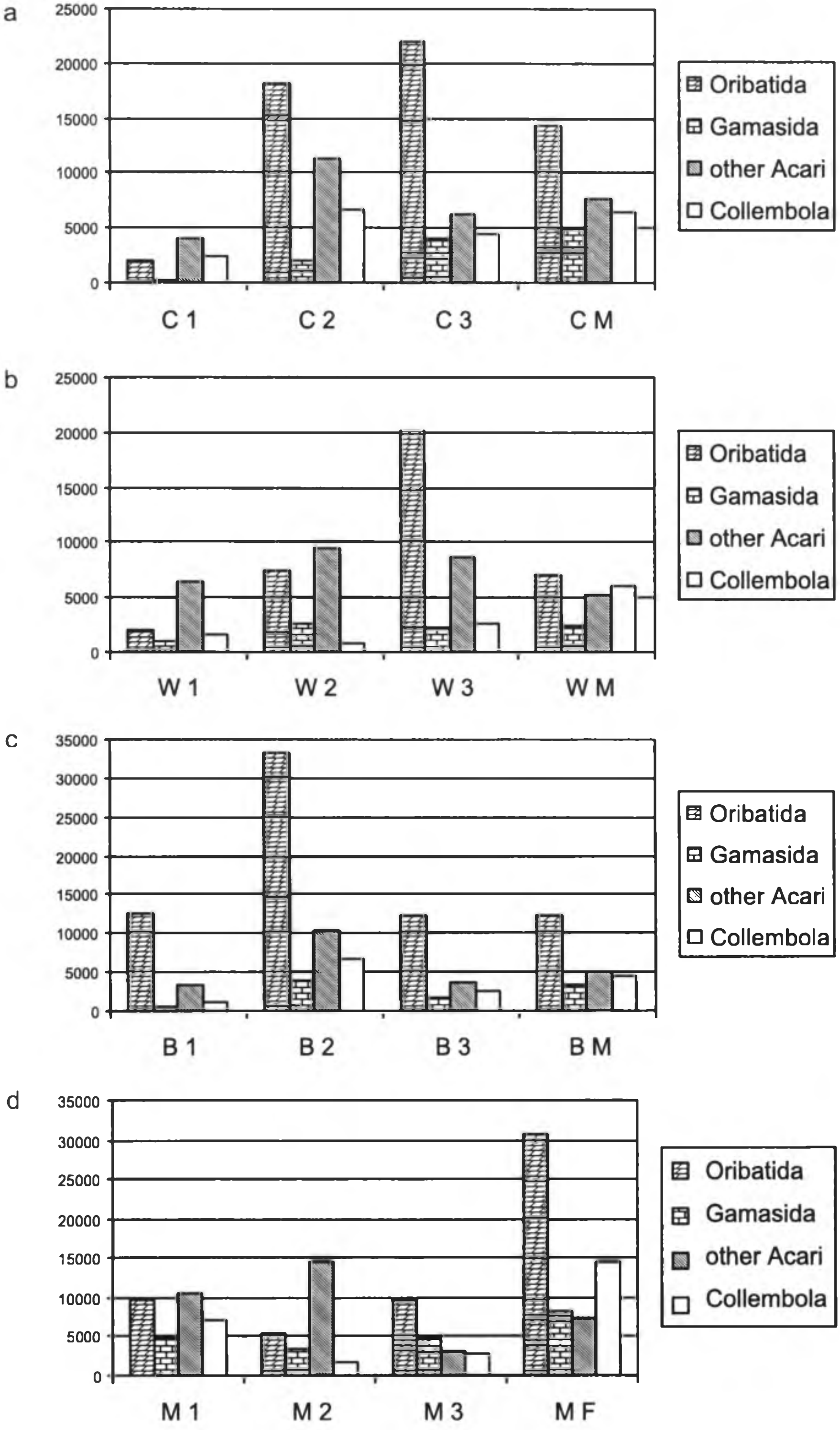
Oribatids are known to predominate over other groups of mites and mesofauna in most soils and especially in forest soils. On the other hand, slow colonization of different sites by oribatid mite species has been observed by various authors (e.g. Beckmann, 1988; Dunger, 1968; Karg, 1967). This was ascribed to the low mobility of these animals (Weigmann, 1982) and their low reproduction rate (Lebrun & van Straalen, 1995). Do oribatids also dominate on post-industrial dumps? When do they start to prevail over other representatives of microarthropods in these disturbed habitats? In this study oribatids are compared with Gamasida, Actinedida and Acaridida (other Acari), and Collembola (Fig. 40 a–g).

Oribatids do not predominate in most of the studied pioneer communities on non-reclaimed dumps (Chorzów, Wełnowiec, Makoszowy, Murcki – dump). Representatives of Actinedida and Acaridida prevailed over oribatids on these dumps. Collembola also attained higher abundances than oribatids on some of these dumps, e.g. at Chorzów and Murcki. Oribatids were the dominant group among mesofauna at the pioneer stage of succession on two non-reclaimed dumps, namely at Biskupice and Murcki (sedimentation tank). After fewer than 10 years of development of oribatid fauna on the mine dump at Biskupice, oribatids attained very high abundance (12 695 m^{-2}). The abundance of Gamasida (452 m^{-2}), Actinedida and Acaridida (3326 m^{-2}) and even Collembola (1077 m^{-2}) was much smaller. The abundance of other Acari was slightly lower (521 m^{-2}) than Oribatida in the sedimentation tank at Murcki, whereas the abundance of Oribatida and Collembola was the same. The proportion of Oribatida in the mite communities in the pioneer populations varied from 22% at Wełnowiec to 77% at Biskupice. It was characteristic that the abundance of gamasid mites was lowest from all the analysed groups, significantly lower than the abundance of oribatids in all pioneer assemblages.

As regards older sites on the dumps, oribatid mites usually significantly prevailed over other mites and springtails. However, Actinedida and Acaridida predominated at site 2 on the zinc dump and on the mine dumps at Murcki and Makoszowy. Collembola were less abundant than oribatids at sites 2 and 3 in all cases. The proportion of Oribatida at sites with pre-forest vegetation (site 3) fluctuated from 54.6% at Makoszowy to 70.8% at Biskupice. The situation on the reclaimed mine dump at Brzeszcze, where some trees were planted in holes with soil added, was totally different. Oribatid mites were the dominant group at all sites. Their abundance was nine times higher than the abundance of Gamasida and five times higher than the abundance of Actinedida and Acaridida at site 1. As regards the site reclaimed 19 years ago (site 3), oribatids were even twenty four times more numerous than Gamasida and thirteen times more than springtails.

Most authors agree that oribatids are slow colonizers and that other groups of mesofauna prevail over them during succession for many years. The examples that consider post-industrial dumps of various kinds are grouped in Tables 38 and 39. Davis (1963) found all the main groups of mites and springtails to be well-established in non-reclaimed, heavy clay spoil from ironstone workings in Northamptonshire (UK). The predatory Gamasida were particularly diverse and abundant (51.4% of the total mite number). On the reclaimed ironstone workings, the abundance of Oribatida (5 474 m^{-2}) was higher than Gamasida (4 760 m^{-2}). And the abundance of Collembola was a little lower than the abundance of Acari on both sites. Oribatid mites were relatively important during the first stages of soil formation on reclaimed brown-coal spoil heaps in Germany (Dunger, 1968). The abundance of oribatids at sites reclaimed for only 3 years exceeded 50 000 per square metre. The second numerous group of mites were Actinedida. The abundance of springtails was lower than mites at all sites. Hermosilla (1976), Hutson (1972, 1980a) and Hutson & Luff (1978) observed actinedid and acaridid mites as pioneer animals on reclaimed plots on mining areas. The abundance of springtails was also usually lower than the abundance of mites.

Colonization of rehabilitated dumps by oribatids accelerates once vegetative cover has developed (Hutson, 1980a). On the other hand, Luxton (1982) found that the mite fauna of coal shale in Lancashire, UK (3–4 years old) was dominated by two species of Oribatida. The proportion of oribatids varied from 52.7% to 82.9% in Welch Whittle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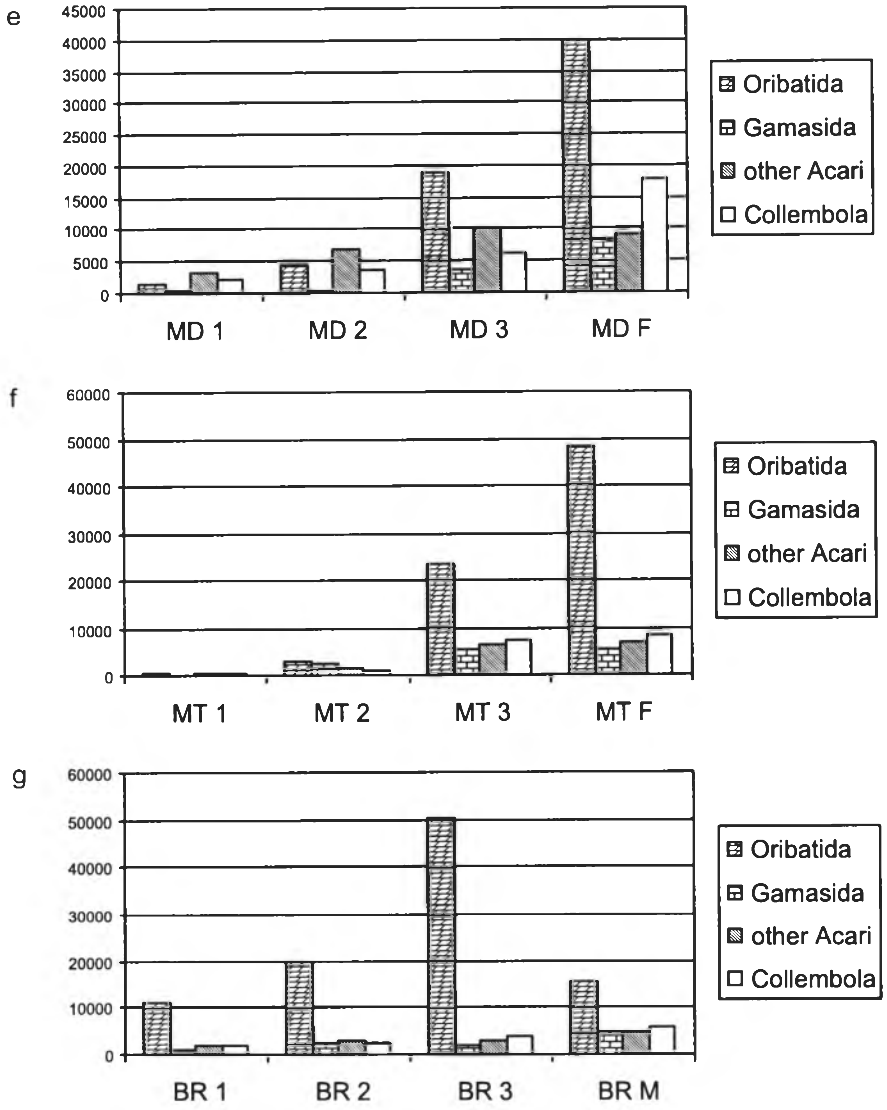

Fig. 40. The abundance (per square metre) of selected groups of mesofauna on the dumps and in the nearby biotopes

a – Chorzów (C), **b** – Wełnowiec (W), **c** – Biskupice (B), **d** – Makoszowy (M), **e** – Murcki (dump) (MD), **f** – Murcki (tank) (MT), **g** – Brzeszcze (BR)

Table 38

Oribatid mites and other groups of mesofauna on post-industrial dumps

Type of a dump	Age (in years)	Abundance (indiv./m^2) or proportion (%) in total Acari number						References
		Oribatida	Gamasida	Actinedida	Acaridida	Acari	Collembola	
				other Acari				
Leveled ironstone quarry		1 771	3 958	1 455	516	7 700	6 800	Davis, 1963
Reclaimed ironstone workings		5 474	4 760	833	833	11 900	7 100	
Reclaimed brown-coal spoil heaps	1	11 894	912	6 194		19 000	2 900	Dunger, 1968
	3	50 033	6 067	18 800		74 900	39 700	
	7	7 902	2 904	6 794		17 600	16 000	
	10	6 198	1 308	5 194		12 700	8 800	
Reclaimed pit heap, shale		very low				400	1 100	Hutson, 1972
Reclaimed pit heap, with topsoil		very low				600	1 600	
Lead mine spoil heaps		very low				28 400	22 500	Williamson & Evans, 1973
Reclaimed brown-coal mining sites	1 month	0	1.9%	23.1%	75.0%			Hermosilla, 1976
	1	0	16,5%	60.0%	23.5%			
	3	7.6%	7.6%	38.2%	46.6%			
	5, 8, 10 and 12 (mean)	6.6%	6.9%	41.1%	45.3%			
Coal shale pit-heaps	1–2	< 580 (less than 1%)	low	73–91%	20%	to 58 000	to 53 600	Hutson & Luff, 1978
Dumps of open rock mines (forest restoration)	4	3 520				8 760	5 460	Babenko, 1980
	8	1 000				3 080	8 560	
	11	31 000				34 360	20 920	
	7	15 840				33 320	12 360	

	12	22 560				31 120	9 100	
	25	21 800				24 720	10 000	
Refuse tips		very low	< 40%	>60%		4 400–72 800	7 600–70 000	Brockmann et al., 1980
Reclaimed coal pit heaps	0	0	442	40 369	14 489	55 300	2 900	Hutson, 1980a
	3 months	302	605	32 886	4 007	37 800	53 600	
	18 months	176	706	41 219	16 699	58 800	11 200	
	18 months	107	694	21 787	4 112	26 700	28 500	
Coal-shale tips	3–4							Luxton, 1982
– Welch Whittle		5 800–50 900	800–2 600	2 600–14 100	0–100	11 000–614 000		
– Pennington Flash		1 100–62 000	900–6 600	600–8 500	0–100	8 300–71 600		
Brown coal dumps	1 month	73–182					133–1 155	Stebaeva & Andrievskii, 1997
	7	901–4 427					15 634–50 653	
	25	9 724–28 873					15 128–55 040	
Abandoned pyrite processing sedimentation ponds								Hubert, 2001
– non-reclaimed		0–4 015	to 450	to 165	to 74	to 4 704		
– reclaimed		2 257–15 302	to 213	to 2 132	0	to 17 647		

Table 39

Oribatid mites and other groups of mesofauna on post-industrial dumps (in author's publications)

Type of a dump	Age (in years)	Abundance (indiv./m^2) or proportion (%) in total Acari number					References
		Oribatida	Gamasida	Actinedida Acaridida other Acari	Acari	Collembola	
Iron metallurgic dumps (Bytom)							Skubała, 1995
– non-reclaimed	5	15 167	3 636	10 751	29 566		
– reclaimed	30	15 779	3 269	15 814	34 342		
– reclaimed	40	25 611	3 375	25 796	54 783		
Abandoned old galena-calamine wastelands	> 100 (pine)	51 792	4 814				Madej & Skubała, 1996
	> 100 (beech)	29 378	5 022				
Abandoned galena-calamine wastelands	> 150	23 578	3 378				Skubała & Madej, 1997
Abandoned galena-calamine wastelands							Madej & Skubała, 1998
– afforested	> 50	9 318	2 777				
– unforested	> 50	5 674	4 711				
Dumps of the zinc and lead industry							Skubała et al., 1998
– reedy area	~6	13 384	1 707	35 767	50 858	2 874	
– afforested	> 20	6 911	4 939	15 600	27 450	13 389	
– unforested	> 20	633	2 744	11 883	15 260	10 050	
Dolomitic dump							Skubała, 1999
– bottom	> 30	14 241	10 555				
– top	> 30	8 296	6 593				

and from 13.3 to 88.1% in Pennington Flash. Colonization of brown coal dumps investigated by STEBAEVA & ANDRIEVSKII (1997) proceeded faster by springtails than by oribatid mites. Springtails prevailed over oribatids in the initial (1 month) and middle stages (7 years) of group formation. At the late succession stages (25 years), the rates of dump colonization by the two groups became identical due to the increasing rate of group formation in oribatids. On the other hand, HUBERT (2001) observed that the colonization of abandoned pyrite processing sedimentation ponds proceeded faster by oribatids than by other mites. Oribatids accounted for 85.3% and 86.7% in non-reclaimed and reclaimed ponds, respectively. The proportions of oribatids, actinedid and acaridid mites were similar at old (30 and 40 years) reclaimed iron dumps at Bytom (SKUBAŁA, 1995). On toxic dumps from the zinc and lead industry in Silesia the abundance of oribatids was considerable lower than the abundance of Actinedida and Acaridida (SKUBAŁA et al., 1998). Gamasid mites were usually the least numerous groups on these dumps.

With regard to other biotopes, the shift in taxonomic composition of the microarthropod communities along the succession gradient follows a pattern suggested by KETHLEY (1990), SANTOS et al. (1978), STEINBERGER et al. (1990) and WOOD (1971). They observed mite communities of nutrient poor areas that were dominated by Prostigmata. The Oribatida and Collembola dominated the zoocommunities in the more eutrophic soils. Similarly JANETSCHEK (1970) and LOOTS & RYKE (1967) found Prostigmata more abundant in soils with low rather than high organic matter content. Furthermore, BOLGER (1985) and TAKEDA (1988) claimed that oribatid mites are later colonizers than collembolan species in the decomposition phases. SENICZAK et al. (1998) observed that Gamasida colonized cultivated fields more quickly than Oribatida. The high proportion of Gamasida in mite communities indicates the field character of mite fauna (SENICZAK et al., 1991). A change in the taxonomic composition of microarthropod communities is also recognized with increasing air pollution. STROJAN (1978) noted that oribatid mites comprised 53% of all mites in the control site, whereas they attained only 40% at the site situated 6 km from the zinc smelter and 20% of all mites at about 1 km from the smelter.

The indication of slow colonization of new habitats by oribatid mites is not totally supported from results of research carried out on several different non-reclaimed and reclaimed dumps. Oribatids became a dominant group among the mesofauna after 15 years on areas covered with herbaceous vegetation of varied density. In certain circumstances they even predominated after less than 10 years at sites covered with initial plant assemblages (e.g. the mine dump at Biskupice).

Chapter 11. Succession theories applicable to oribatids on dumps

In contrast with plants, little is known of changes in animal species, particularly soil arthropods, during succession (see chapter 2.2). The problem of whether changes in the soil animal community can be explained by similar mechanisms of succession to those proposed for plants (and sessile marine organisms) is still not resolved (Scheu & Schulz, 1996).

The changes in abundance, number of species and species diversity along transects on the dumps and in the nearby biotopes were discussed in the chapter "Formation of oribatid communities – rate of development" (Tables 17 and 18). The first two variables showed considerable increase with the age of the dumps. An exception was the mine dump at Biskupice. The number of individuals and species were highest at site 2. As mentioned previously, this was possibly due to reclamation measures or simply to the dumping of imported soil carried out at this site. A fall and rise pattern was noted with regard to the abundance of oribatids on the mine dump at Makoszowy and for species richness in the sedimentation tank. The oribatid fauna in adjacent biotopes is richer where a forest surrounds the dump. If a meadow is adjacent to a dump the oribatid fauna is better developed on the dump, at least at the oldest sites. With regard to species diversity, the patterns of change are very variable during primary or secondary (Brzeszcze) succession. The fall pattern was noted on three mine dumps, wheras the fall and rise pattern was noted on both metallurgic dumps (Chorzów and Wełnowiec). The species diversity on the mine dump at Biskupice was highest at site 2. However, as mentioned before, it might be the result of human interference. A slight constant increase in species diversity was noted only on the mine dump at Makoszowy.

First, the fauna should be considered at the individual species level to see which of the succession pathways most accurately describes the colonization. Whichever pathway of succession is followed, animals must first initially colonize the area. The rate at which species colonization takes place depends both on the nature of the degraded area as well as on characteristics of the species themselves (MAJER, 1989b). Since a dump differs in its physical, chemical and botanical structure from that of a neighbouring habitat, it may function as an ecological "island". There is considerable evidence from the reclamation literature that the degree of isolation influences the number of species occurring in an area (MAJER, 1989b). This was not shown in the present research on the dumps. Oribatids are thought to be introduced easily on dumps during the pioneer period. This was mentioned previously in the chapter "Ways of migration, pool of colonizers" and also suggested by DUNGER (1989). Some species are more successful than others in invading dumps. This has been discussed in the literature on colonization by fauna on reclaimed land (MAJER, 1989b) and has also been well demonstrated in the present investigations. However, MAJER'S (1989b) second observation that early colonizers are the same species on all reclaimed sites was not confirmed. In addition to *Oppiella nova* and *Tectocepheus velatus*, many different species are able to colonize "fresh" dumps.

As regards soil fauna on post-industrial wastelands, there is not much evidence of the initial floristic composition pathway being followed. The species composition of the three successional stages on the dumps is different. Species of the pioneer populations have special characteristics. Different starting points for the chronic disturbance pathway have also not been observed on post-industrial dumps. Many abundant oribatid species were found in the neighbouring biotopes, which were unable to invade the dump area. The degraded area became colonized most probably by a suite of species consistent with the facilitation, tolerance or inhibition pathways (MAJER, 1989b). The facilitation model was conceived to describe the succession of plant communities. Numerous positive relationships between vegetation and mites (discussed in the chapter "Driving factors and the formation of oribatid communities") allow us to suspect plant facilitation of mite invasions. Furthermore, soil arthropods themselves may alter the environment so as to cause changes in the composition of communities. USHER et al. (1982) thought it unlikely that this could be a strong enough mechanism to be totally responsible for observed changes in the soil arthropod communities. On the other hand, Scheu & Schulz (1996) claimed that oribatid mites might contribute to an increase in heterogeneity and therefore to an increase in species numbers, by their feeding activity. This may work as a self-augmenting process that may continue as long as resources are not limiting, and before competition arises as a structuring element of the community (Scheu & Schulz, 1996). The changes in oribatid communities on several of the dumps studied (Chorzów, Wełnowiec, Murcki – dump and Brzeszcze) may fit the facilitation model.

Brenner et al. (1982) claimed that in addition to the major influence of plant community composition, inter- and intraspecific interactions between animals may also direct the nature of the succession. In other words the tolerance or inhibition pathways may also contribute to the process of animal succession in degraded land (Majer, 1989b). Could these theories be applicable to soil oribatids occurring on dumps? An increase in the number of oribatid mite species on the oldest site (with pre-forest vegetation) is in contrast with inhibition models of succession indicating that interspecific competition among oribatid mite species (as well as among oribatid mites and other species) is of little importance. Maximum abundance, the highest number of species and diversity of oribatids at the intermediate stage (site 2) on the mine dump at Biskupice, appear to be in agreement with the inhibition model of succession which assumes that some species are removed by intense competition at later stages when environmental conditions are more stable (Connell & Slatyer, 1977; Horn, 1974). However, this situation seems to have been caused by human intervention at site 2, rather than by the phenomenon described above. Surprisingly high abundance, species richness and some other zoocenotic characteristics of the oribatid community at site 2 at Biskupice lead us to suspect that some reclamation measures must have been carried out in this area.

Species diversity is assumed to be at a maximum in pre-climax stages (Connell, 1978; Horn, 1974). Intermediate stages of succession are likely to be mixtures of early and late successional species, and hence to have a higher diversity than either early or late stages. Such a situation was observed only on the mine dump at Biskupice. At other sites different patterns of species diversity were seen. It may be assumed that species diversity is an unreliable factor from which to draw conclusions about successional pathways of oribatid fauna.

Changes in the oribatid mite communities investigated on post-industrial dumps in this study could not be explained in a straightforward way by any of the succession theories (facilitation, inhibition or tolerance). However, the facilitation pathway seems the one best suited to most situations observed on the dumps.

Chapter 12. Biodiversity of oribatid fauna on dumps and in nearby biotopes

Biodiversity is not only the diversity at species level, but also at the higher taxa and community levels, and goes "from genes to ecosystems" (Convention on Biological Diversity; WILSON, 1992). In terms of ecological systems its meaning and measurement cannot be reduced only to an estimate of the richness of system components, as indicated by the number of species, but should also be extended to estimates of species abundance, spatial distribution and hierarchical position, among other characteristics (CANCELA DA FONSECA & SARKAR, 1996). In this chapter the diversity of species is discussed in its narrow meaning. Oribatid diversity is high compared with other groups of soil microarthropods such as Gamasida, Actinedida, Acaridida or Collembola (WALLWORK, 1983). Some botanists and plant ecologists emphasize the fact that ironically the poor quality of the substrates forming industrial waste tips often renders them peculiarly suitable for the spontaneous development of unusual vegetation and the survival of uncommon species (BOX, 1993; COHN et al., 2001; GREENWOOD & GEMMELL, 1978; JEFFERSON, 1984; TRUEMAN et al., 2001). Does this situation also occur on post-industrial dumps, with regard to oribatid mites? Does the oribatid fauna of artificially created biotopes, e.g. dumps, contain interesting, rare and/or valuable (from scientific point of view) species?

In the course of investigations carried out on seven post-industrial dumps and nearby biotopes, 172 oribatid species were collected (Appendix 6 – CD-ROM). Taking into account that some 500 oribatid species are recorded in *Catalogus faunae Poloniae* (OLSZANOWSKI et al., 1996) and several tens of species have been described subsequently, we can estimate that the oribatid mites at these seven localities constituted over 30% of the total known Polish oribatid fauna. As regards oribatids recorded in the Upper Silesian Region (excluding the mine dump at Brzeszcze), we can estimate that oribatids (162 species) at the six localities represent over 69% of the total number of known oribatid species in this region (234 species). The difference between these two figures is probably the result of disproportional studies on mites in the natural and artificial biotopes in Upper Silesia. Fifty-six reserves of different kinds are present in the region. Acarological researches have been conducted only in five natural reserves (Skubała & Bielska, 2000).

It is worth mentioning that in the course of the research on the dumps in the seven localities, 8 species and 1 subspecies new to the Polish fauna were noted. Furthermore, 37 oribatid species and 2 subspecies were new for the Upper Silesian Region. Some of the species new for the Polish fauna or for Upper Silesia were described earlier (see Table 40).

Table 40

List of the new species for the Polish fauna and the Upper Silesian Region

1. *Banksinoma lanceolata canadensis* Fujikawa, 1979 *** [Skubała, 2002c – Murcki tank]
2. *Belba paracorynopus* B.-Z., 1962 *** [Skubała, 2002c – Murcki tank]
3. *Berniniella rafalskii* (Opłotna et Rajski, 1983) [Skubała, 1995 – Chorzów]
4. *Berniniella sigma conjuncta* (Strenzke, 1951)
5. *Brachychochthonius cricoides* (Weis-Fogh, 1948) [Skubała, 1995 – Chorzów]
6. *Brachychthonius bimaculatus* Willmann, 1936
7. *Camisia biurus* (C.L. Koch, 1839)
8. *Cepheus grandis* Sitnikova, 1975 [Skubała, 2002c – Murcki tank]
9. *Ceratozetes mediocris* Berlese, 1908 [Skubała, 1995 – Chorzów] (Fig. 16)
10. *Ceratozetes bulanovae* Kuliew, 1962 *** (Fig. 41)
11. *Ceratozetes sp.* *** (Fig. 42)
12. *Cultroribula lata* Aoki, 1961 *** (Fig. 43)
13. *Damaeobelba minutissima* (Sellnick, 1920)
14. *Discoppia cylindrica* (Pérez-Inigo, 1964) [Skubała, 2002c – Murcki tank]
15. *Entomotritia piffli* Markel, 1964
16. *Epidamaeus tatricus* (Kulczyński, 1902)
17. *Euphthiracarus reticulatus* (Berlese, 1913) (Fig. 45)
18. *Galumna tarsipennata* Oudemans, 1913
19. *Graptoppia (Stenoppia) italica* Bernini, 1973 *** [Skubała, 2002a – Murcki dump]
20. *Heminothrus thori* (Berlese, 1904)
21. *Hypochthonius luteus* Oudemans, 1917 [Skubała, 1995 – Chorzów]
22. *Hypodamaeus interlamellaris* (Willmann, 1931) ***
23. *Hypodamaeus tenuitibialis* Bulanova-Zachvatkina, 1957 ***
24. *Lasiobelba sp.*
25. *Liochthonius piluliferus* (Forsslund, 1942) [Skubała, 2002a – Murcki dump]
26. *Malaconothrus punctulatus* van der Hammen, 1952

27. *Melanozetes meridianus* Sellnick, 1928
28. *Metabelba rohdendorfi* B.-Z., 1965
29. *Micreremus brevipes* (Michael, 1888)
30. *Moritzoppia unicarinata* (Paoli, 1908)
31. *Ophidiotrichus vindobonensis* Piffl, 1961 [Skubała, 2002c – Murcki tank]
32. *Phthiracarus ferrugineus* (C.L. Koch, 1841)
33. *Pilogalumna allifera* (Oudemans, 1919)
34. *Protoribates capucinus* Berlese, 1908 [Skubała, 1995 – Chorzów]
35. *Quadroppia paolii* Woas, 1986 [Skubała, 2002c – Murcki tank] (Fig. 46)
36. *Quadroppia quadricarinata maritalis* Lions, 1982 [Skubała, 1995 – Chorzów]
37. *Quadroppia quadricarinata virginalis* Lions, 1982 [Skubała, 1995 – Chorzów]
38. *Ramusella (Insculptoppia) insculptum* (Paoli, 1908)
39. *Ramusella (Rectoppia) fasciata* (Paoli, 1908) [Skubała, 2002a – Murcki dump]
40. *Rhysotritia ardua* (C.L. Koch, 1841) [Skubała, 1995 – Chorzów]
41. *Spatiodamaeus tecticola* (Michael, 1888) (Fig. 47)
42. *Suctobelbella cornigera* (Berlese, 1902) [Skubała, 1998 – Katowice]
43. *Suctobelbella duplex* (Strenzke, 1951) [Skubała, 2002a – Murcki dump]
44. *Suctobelbella messneri* Moritz, 1971 [Skubała, 1995 – Chorzów] (Fig. 48)
45. *Suctobelbella sarekensis* (Forsslund, 1941) [Skubała, 1995 – Chorzów]
46. *Suctobelbila tuberculata* Aoki, 1970 *** (Fig. 44)
47. *Synchthonius elegans* Forsslund, 1957
48. *Trhypochthonius tectorum* (Berlese, 1896) [Skubała, 1995 – Chorzów]

The species marked with asterisks (***) are recorded for the first time in Poland.

Remarks on selected oribatid species (subspecies) new for the Polish fauna and for Upper Silesia

Banksinoma lanceolata canadensis Fujikawa, 1979

This species was mainly found on the meadows (Chorzów, Biskupice and Brzeszcze). Single specimens were collected in the sedimentation tank (sites 1 and 3). This subspecies is named after its place of origin – Canada. It is closely related to *B. lanceolata islandica* and differs from this subspecies by its smooth prodorsum between costulae and its smooth notogastral setae (Fujikawa, 1979). Information on ecology and geographical distribution is available only for the main species. *B. lanceolata* is a common oribatid of holoholartic distribution. However, ecological characteristics of the species (eurytopic, panphytophagous, polimezohygrophilous) allow it to colonize different habitats (Rajski, 1968; Schatz, 1983b). *B. lanceolata* belongs to a group unable to colonize post-industrial dumps.

Belba paracorynopus Bulanova-Zachvatkina, 1962

Most specimens of *Belba paracorynopus* were collected from the forest at Murcki (MD F – 27 individuals, MT F – 9 individuals). It was also found on the meadow at Chorzów and on the dump at Biskupice, but its occurrence was incidental there (1–2 individuals). The species was described by Bulanova-Zachvatkina (1962) from the Far East in forests and hitherto, it had been found in that region. The occurrence of the species in the present investigation confirmed its preference for a forest habitat.

Ceratozetes bulanovae Kuliew, 1962 (Fig. 41)

This species occurred only at Makoszowy. It was quite numerous among pioneer populations (25 individuals, 4.1% of the total number). Additionally, one specimen was collected at site 2. The species is comparatively easy to recognized by its long and narrow cuspis without teeth. Hitherto, *Ceratozetes bulanovae* has only been found in Russia (Karppinen et al., 1986), the Caucasus and Crimea (Karppinen et al., 1987) and the Ukraine (Karppinen et al., 1992).

Ceratozetes sp. (Fig. 42)

Only single specimens of this species were found at site 2 on the zinc dump at Wełnowiec. One specimen was collected at the same site in 1991/1992. The systematic position of the oribatid is uncertain. The specimens are characterized by a medium fused lamella, which ends with one long seta. The lamellas cover half of the prodorsum. Taking into account the extremely high doses of heavy metals at the site, it is possible that the morphological characteristics of these specimens are an effect of mutation.

Cultroribula lata Aoki, 1961 (Fig. 43)

Cultroribula lata was found at four sites on the dumps. It was abundant only at site 3 on the zinc dump at Wełnowiec (74 specimens). It also occurred at site 2 at Wełnowiec (1 individual), Chorzów (site 3 – 1 individual) and Biskupice (site 2 – 6 individuals). The species is known from the East. It has been recorded from Japan, New Zealand (Aoki, 1970), Siberia and the Far East (Golosova et al., 1983) and the Altai Mountains (Karppinen et al., 1986). The farthest finding in the West was in the Ukraine (Karppinen et al., 1992). No information on the ecology of the species is

Fig. 41. *Ceratozetes bulanovae* Kuliew, 1962 – a new species for the Polish fauna from the coal-mine dump at Zabrze Makoszowy

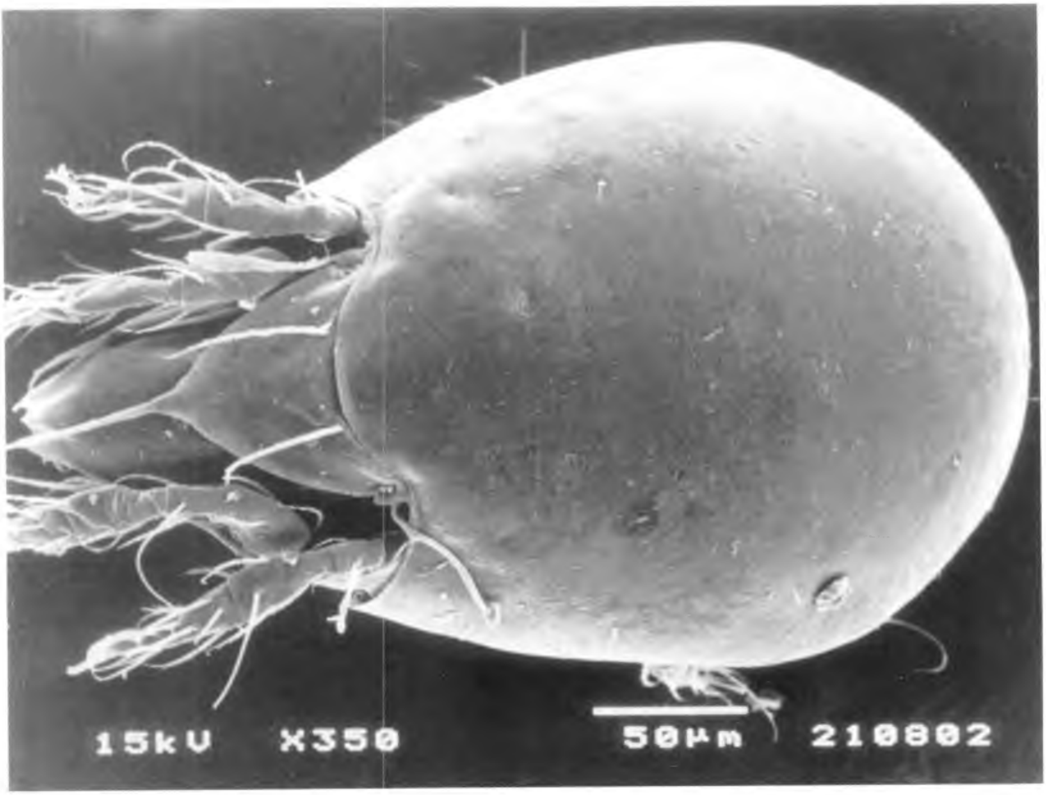

Fig. 42. *Ceratozetes* sp. – an undescribed species with fused lamellas, from the highly contaminated zinc dump at Katowice Wełnowiec

Fig. 43. *Cultroribula lata* Aoki, 1961 – a species known from the East, abundantly recorded on the contaminated dump at Katowice Wełnowiec

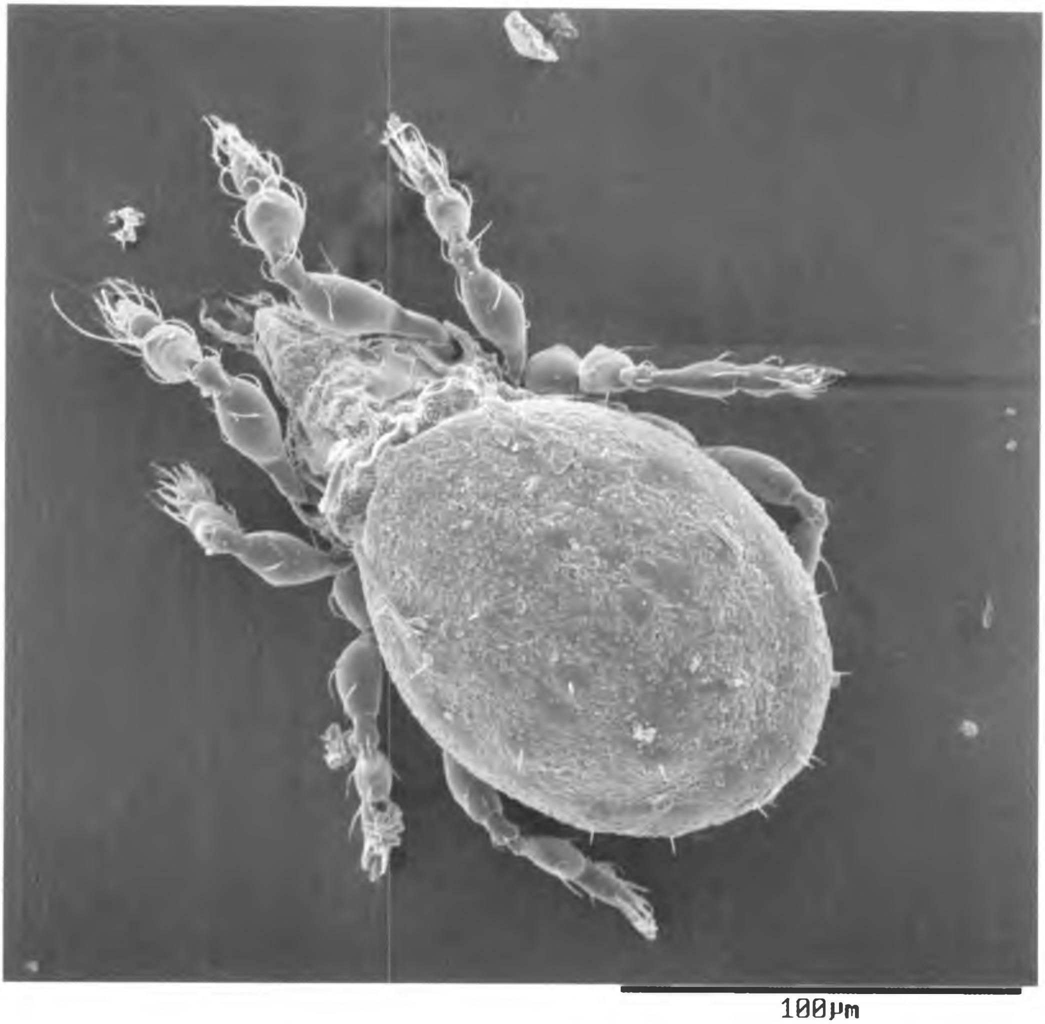

Fig. 44. *Suctobelbila tuberculata* Aoki, 1970 – a new species for the Polish fauna, the genus has not been recorded in Poland so far

Fig. 45. *Euphthiracarus reticulatus* (BERLESE, 1913) – a species from the mine dump at Zabrze Makoszowy and the forest at Katowice Murcki; the second reported finding in Poland

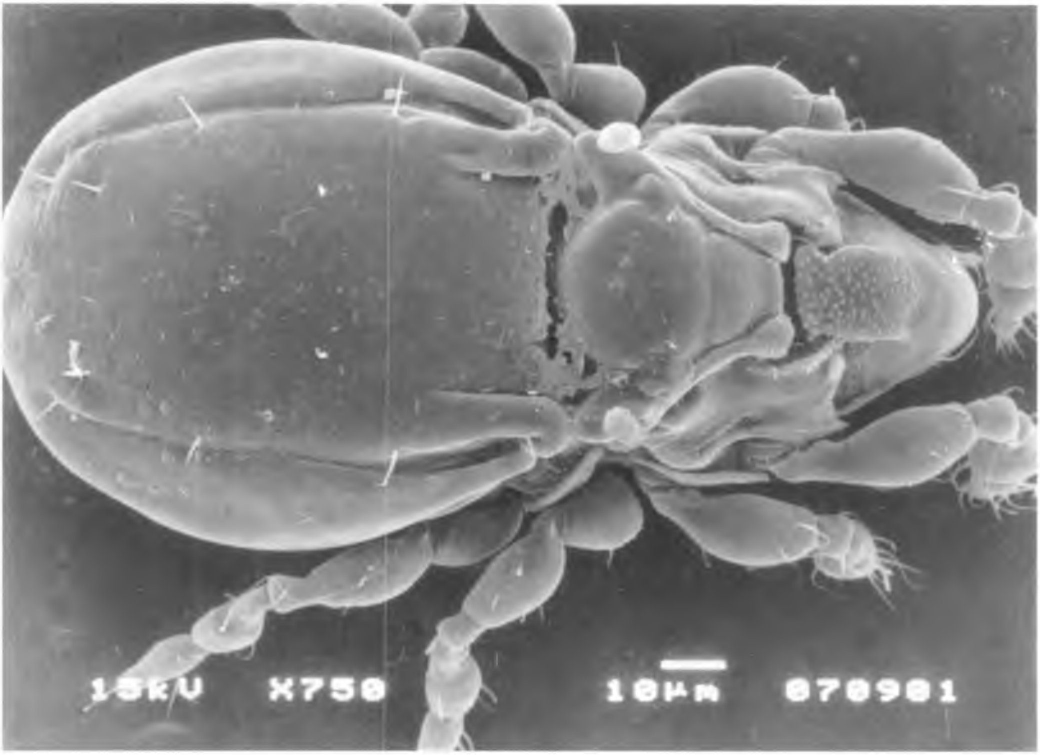

Fig. 46. *Quadroppia paolii* Woas, 1986 – an oribatid mite from the sedimentation tank; a new species for Upper Silesia

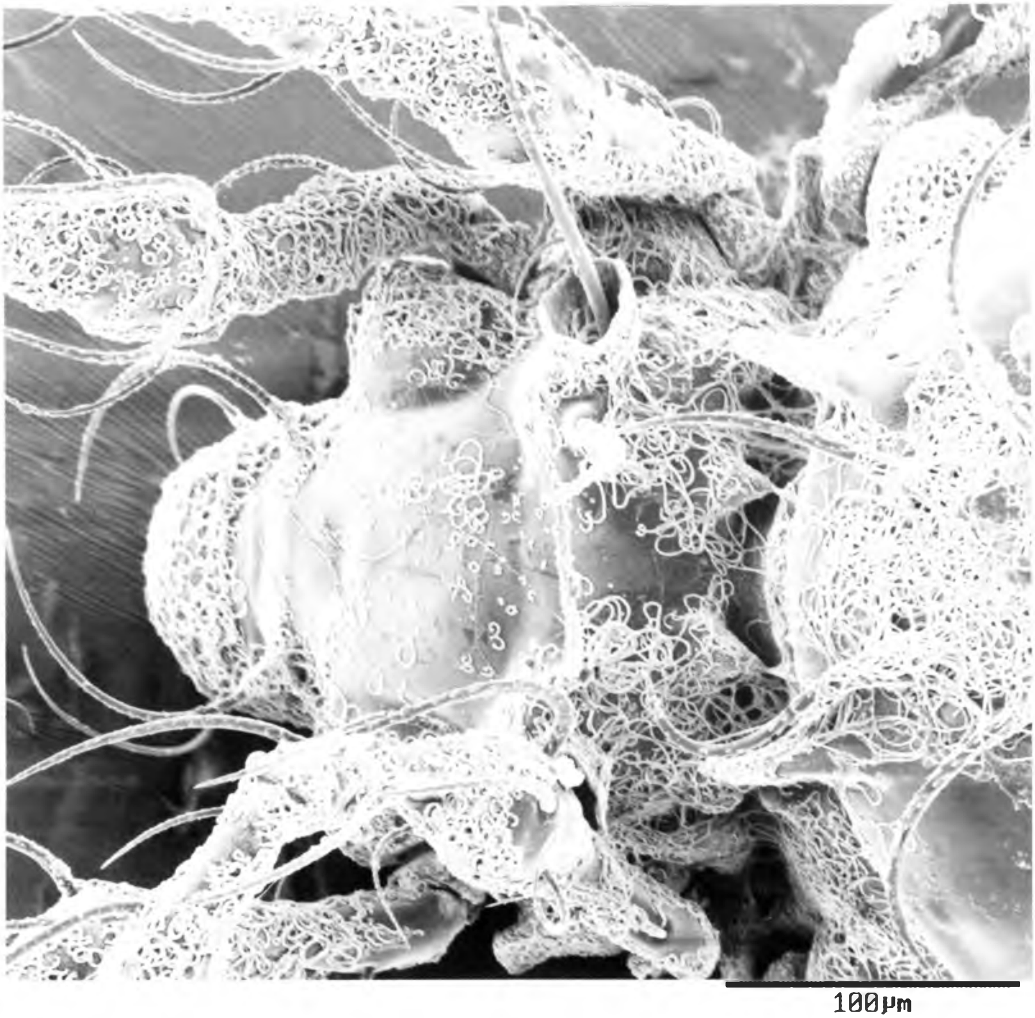

Fig. 47. *Spatiodamaeus tecticola* (Michael, 1888) covered with mycelium – an European oribatid species recorded only twice in Poland (1902, 1956)

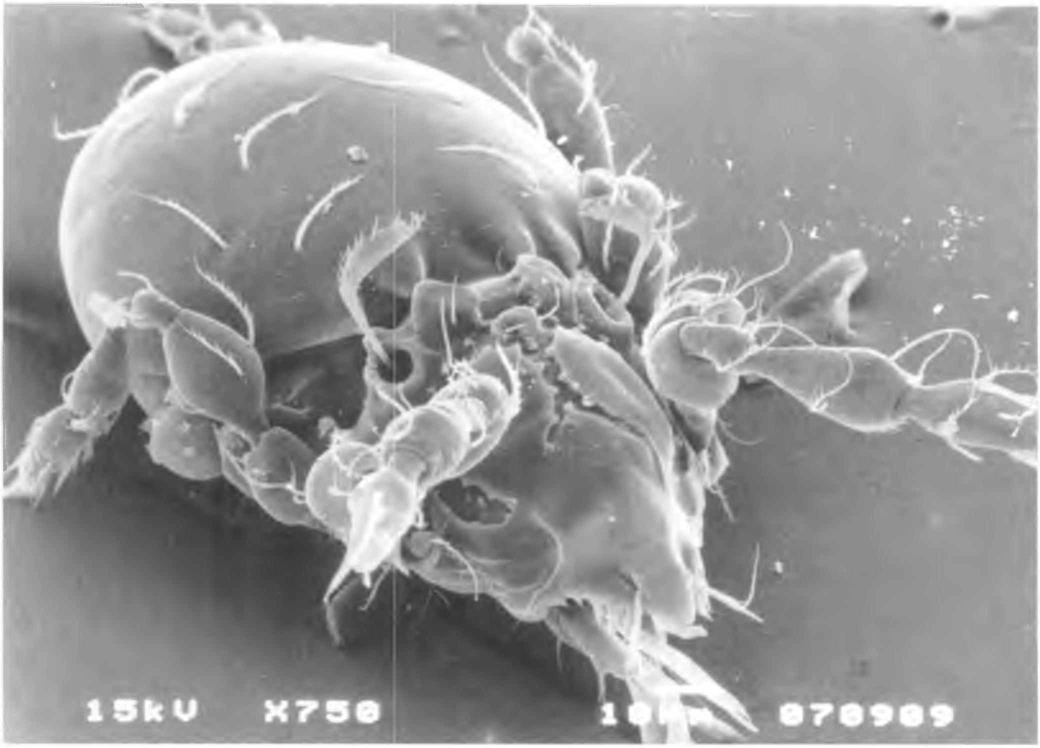

Fig. 48. *Suctobelbella messneri* Moritz, 1971 – a mid-European oribatid species

available. KANEKO (1988b) recognized *C. lata* as a microphytophage and a fragment feeder.

Graptoppia (Stenoppia) italica BERNINI, 1973

The species has been recorded at seven sites on the dumps (see Appendix 6) and on the meadow at Brzeszcze. Other individuals were found only at Biskupice (site 2 – 15 individuals) and at Chorzów (site 2 – 10 individuals). Hitherto, the species has been recorded from southern Europe (SUBIAS & BALOGH, 1989). There is lack of information on the ecology of the species.

Hypodamaeus interlamellaris (WILLMANN, 1931)

One individual of *H. interlamellaris* was found in the forest at Murcki. The species was known from Western Europe (GHILAROV & KRIVOLUTSKY, 1975); however, it has recently been collected in the Ukraine (KARPPINEN et al., 1992).

Hypodamaeus tenuitibialis BULANOVA-ZACHVATKINA, 1957

One individual of the species was found at site 1 on the reclaimed mine dump at Brzeszcze. The species has been recorded in Southern Sakhalin, Primorsky kray and Khabarovsk in the Far East (GOLOSOVA et al., 1983) and in Kirgisia (GHILAROV & KRIVOLUTSKY, 1975).

Suctobelbila tuberculata AOKI, 1970 (Fig. 44)

The species was collected on the mine dump at Biskupice. Fifty-two specimens were found at site 2 and only single individuals at the other sites. The genus has not been recorded in Poland and possibly not in Europe so far. Representatives of the genus are known from the USA and from all tropical regions (BALOGH, 1972; GHILAROV & KRIVOLUTSKY, 1975). The only species from the Palaearctic Region is *S. tuberculata* described from the Islands of Thushima (Japan) (AOKI, 1970).

Euphthiracarus reticulatus (BERLESE, 1913) (Fig. 45)

Twelve specimens were collected at site 3 on the mine dump at Makoszowy and two individuals from the forest at Murcki. The species was recently found for the first time in Poland. It was collected in the Bieszczady Mountains at 600–700 m a.s.l. (Melamud, 1999). It has been collected in Siberia (Golosova et al., 1983), the Caucasus and Crimea (Karppinen et al., 1987), and in the Ukraine (Karppinen et al., 1992). The preference for forest habitat (Schatz, 1983b) is confirmed from the present study.

Suctobelbella duplex (Strenzke, 1951)

Twenty-two individuals of *S. duplex* have been collected from the forest adjacent to the mine dump at Murcki. The species has been found previously only once in Poland in the Bieszczady National Park (Melamud, 1999). *S. duplex* has been recorded hitherto in the east of Poland, in Siberia (Golosova et al., 1983), the Caucasus (Karppinen et al., 1987), the European part of Russia (Karppinen & Krivolutsky, 1982), and in the Ukraine (Karppinen et al., 1992). The preference for forest habitat is confirmed from the present study.

Chapter 13. **Conclusions**

In a short transect on post-industrial dumps (from a site with initial vegetation to a site with pre-forest assemblage) oribatid mite populations and community organization exhibited sharp changes. Three successional stages of oribatid development on post-industrial dumps can be demonstrated. The boundaries between the oribatid communities of the "pioneer", "meadow" and "forest-like" stages are sharp. A considerable time period (>30 years) is needed for the composition of the mite fauna of post-industrial dumps to approach that of the pre-disturbance vegetation. There are some evidences for the possible existence of multiple stable equilibria in which the developing oribatid communities may equilibrate at more than one possible combination of species.

The most reliable features that allow the identification of successional stages of oribatid communities are:

- the dominance structure (observed using the proportion of different dominant species, species diversity, equitability or species abundance relationship),
- the proportion of juvenile forms characterized by a thick cuticle,
- the proportion of certain systematic cohorts, e.g. Enarthronota,
- the appearance of closely related species (analysed by CCA ordination with regard to *Tectocepheus velatus/Tectocepheus minor* and *Scheloribates laevigatus/Scheloribates latipes*.

Basic zoocenotic characteristics of the soil animal community, e.g. abundance and species richness, are considerably variable at a particular stage of oribatid succession on post-industrial dumps. The development of oribatid fauna and the species turnover are higher at the earlier successional stages, and slow down as the dumps age.

Pioneer oribatid mite communities are initially varied (especially in species composition) and they do not converge as similar pre-climax communities. The initial colonization of oribatids on post-industrial dumps seems to be random, and due to the variety of species that invade dumps. However, the process is possibly non-random and depends on the characteristics of the individual species. Considerable "redundancy" in the species pool of those species able to colonize post-industrial dumps in the establishment and in the following phases of succession on dumps was observed. The only species capable of reaching high abundance in pioneer populations on each dump were *Tectocepheus velatus* and *Oppiella nova*. Three categories of oribatid species colonizing dumps were recognized, based on a contingency table using chi-square analysis. "Early" successional species (pioneer oribatids) can be divided into two groups. The so-called "long-distance runners", which did not lose their status with increasing age of the dumps, e.g. *Oppiella nova, Tectocepheus velatus, Liochthonius propinquus* and *Peloptulus phaenotus*; and "sprinters", whose abundance noticeably decreased at older sites, e.g. *Brachychochthonius cricoides*, *Brachychochthonius immaculatus*, *Liochthonius piluliferus* and *Scutovertex sculptus*. The third group of oribatids, the so-called "late" successional species, comprises species that were absent or rare at the younger sites but were abundant at the oldest sites, e.g. *Eupelops tardus*, *Liebstadia similis, Oribatula tibialis*, *Punctoribates punctum*, *Tectocepheus minor*.

Despite the "*K* attributes" (low metabolic rate, slow development, low fertility, long adult life) that characterize oribatids, these mites can be regarded as successful colonizers of post-industrial dumps. They can attain an abundance of 12 000 per square metre after several years, and they usually become the dominant group of mesofauna after 10–15 years on sites with dense herbaceous vegetation. Representatives of Actinedida and Acaridida prevailed over oribatids only on the sites covered with initial vegetation. However, oribatids may predominate among mites at some of the youngest sites, e.g. on the mine dump at Biskupice.

The variety of factors, physical and biological, by which dumps and sites differ, produce a patchwork of environmental conditions. Different abundance of species and community structures result from the responses to these factors. Therefore, it may be difficult to predict specific features of a community on the basis of environmental characteristics. The structuring forces that influence the oribatid communities in their successional stages on the dumps were varied and depended on the dumps. Magnesium and sodium content were frequently recognized as the most important environmental factors influencing the pioneer oribatid communities. Many different environmental factors influence the structuring of the communities at the intermediate stage of primary succession. Of eleven environmental variables, available magnesium content was most frequently recognized as important for the structuring of the community at the oldest sites. Oribatid colonization studies indicate numerous positive correlations between oribatid abundance, richness and diversity with richness and diversity of plant cover. Therefore, the status of oribatid communities (despite species composition) can be comparatively easily predicted through knowledge of the structure of plant assemblages on the surface. However, an effect of vegetation on the species composition of oribatid communities was not recognized. The type of substratum (deposited wastes) does not generally influence the development of a specific community of mites. Due to heavy metal contents and their negative influence on vegetation, the rate of development of oribatid fauna is significantly slower on contaminated dumps. However, permanent oribatid mite communities develop at these sites and are characterized by an abundance of over 20 000 individuals per m^2 and by the presence of 40 oribatid species after 50 years (site 3).

The soil on the dumps is slightly more homogenous in vertical distribution and this results in a higher proportion of oribatids in the lower horizons on the dumps than in the adjacent biotopes. The influence of organic matter and body dimensions (especially body width) on the vertical distribution of oribatids on the dumps was recognized.

The influence of neighbouring biotopes (forest, meadow or ruderal vegetation) on the species richness of an oribatid community on a dump and on the rate of its development is weak. To a large extent, the initial oribatid colonization of post-industrial dumps was accomplished by species that were either rare in the undisturbed area, or had immigrated from other habitats a considerable distance away. Usually half or more of the species came from sites other than adjacent biotopes. It seems that all (or at least some) dispersal modes are successful enough to establish oribatid communities in a comparatively short time. This brings the necessity of reclamation measures into question.

The reclamation measures carried out on post-industrial dumps introduce an element of randomness in the succession of oribatid fauna, which does not help to accelerate the succession process over the long-term. The effects of reclamation measures on dumps seem to be effective only in the first period of oribatid fauna development. Twenty years after reclamation, decline in abundance, species richness decrease, and other negative trends in the community structure were observed.

None of the successional models (facilitation, inhibition or tolerance) explain the development of oribatid fauna on post-industrial dumps in a straightforward way. Nevertheless, the facilitation pathway seems to be the one best suited to most observed situations in these artificial habitats.

Deposited wastes forming post-industrial dumps appear to offer oribatid mites suitable enough conditions for the survival and development of many species. In the course of investigations 172 oribatid species (140 species on the dumps) were collected. Eight species and one subspecies were new to the Polish fauna. Thirty-seven species and two subspecies were new for the Upper Silesian Region.

References

ALLEN G. (ed.). 1900. The Natural History of Selborne by Gilbert White. Published by John Lane, The Bodley Head. London–New York.

ANDERSON J.M. 1975a. The organization of soil animal communities. In: LOHM U. & PERSSON T. (eds.). Soil Organisms as Components of Ecosystems. Ecol. Bull. **25**: 15-23.

ANDERSON J.M. 1975b. The enigma of soil animal species diversity. Proc. 5th Intern. Coll. Soil Zool., Prague: 51–58.

ANDERSON J.M. 1977. The organization of soil animal communities. In: LOHM U. & PERSSON T. (eds.). Soil Organisms as Components of Ecosystems. Ecol. Bull. **25**: 15–23.

ANDERSON J.M. 1978a. Inter- and intra-habitat relationships between woodland Cryptostigmata species diversity and the diversity of the soil and litter microhabitats. Oecologia **32**: 341–348.

ANDERSON J.M. 1978b. Competition of two unrelated species of soil Cryptostigmata (Acari) in experimental microcosms. J. Anim. Ecol. **47**: 787–803.

ANDRÉ H.M. & LEBRUN Ph. 1984. On the use of *Humerobates rostrolamellatus* (Acari) as an air pollution bioassay monitor. The incidence of SO_2 – NO_2 synergism and of winter temperature. Sci. Total Environ. **39**: 177–187.

ANTONY L.M.K. 2001. Soil Acari response to deforestation and fire in a Central Amazon Forest. In: HALLIDAY R.B., WALTER D.E., PROCTOR H.C., NORTON R.A. & COLLOFF M.J. (eds.). Acarology: Proceedings of the 10th International Congress. CSIRO Publishing. Melbourne: 277–282.

AOKI J. 1967. Microhabitats of oribatid mites on a forest floor. Bull. Nat. Sci. Mus., Tokyo **10**: 133–138.

AOKI J. 1970. The Oribatid mites of the Islands of Tsushima. Bull. Nat. Sci. Mus., Tokyo **13**: 395–442.

AOKI J. 1979. Difference in sensitivities of Oribatid families to environmental change by human impacts. Rev. Écol. Biol. Sol. **16**, 3: 415–422.

AOKI J.-I., TAKAKU G. & ITO F. 1994. Aribatidae, a new myrmecophilous oribatid mite family from Java. Int. J. Acarol. **20**: 3–10.

BABENKO A.B. 1980. Some regularities in formation of the complex of soil microarthropods on the dumps of open rock mines (in Russian). Zool. Zh. **69**, 1: 43–54.

BALOGH J. 1972. The Oribatid Genera of the World. Budapest, pp. 188.

Baur B., Joshi J., Schmid B., Hanggi A., Borcard D., Stary J., Pedroli-Christen A., Thommen G.H., Luka H., Rusterhol Z.H.P., Oggier P., Ledergerber S. & Erhardt A. 1996. Variation in species richness of plants and diverse groups of invertebrates in three calcareous grasslands of the Swiss Jura mountains. Rev. Suisse Zool. **103**: 801–833.

Beare M.H., Coleman D.C., Crossley D.A., Hendrix P.F. & Odum E.P. 1995. A hierarchical approach to evaluating the significance of soil biodiversity to biogeochemical cycling. In: Collins H.P., Robertson G.P. & Klug M.J. (eds.). The Significance and Regulation of Soil Biodiversity. Kluwer Academic Publishers. The Netherlands: 5–22.

Beck L. 1994a. Milben als Reaktionsindikatoren. In: Umlauff-Zimmermann R. (ed.). Methoden zu Wirkungserhebungen Landesanstalt für Umweltschutz Baden-Würtemberg. Karlsruhe: 42–43.

Beck L. 1994b. Bodenzoologie, Collembolen und einiges mehr – Anmerkungen zum wissenschaftlichen Werk WOLFRAM DUNGERs. Abh. Ber. Naturkundemus. Görlitz **68**, 1: 5–13.

Beckmann M. 1988. Die Entwicklung der Bodenmesofauna eines Ruderal--Ökosystems und ihre Beeinflüssung durch Rekultivierung. I: Oribatiden (Acari: Oribatei). Pedobiologia **31**, 5/6: 391–408.

Beckmann M. & Schriefer T. 1989. Besiedlung einer Kompostdreiecksmiete durch die Mesofauna. Verh. Ges. Ökol. **18**: 755–760.

Begon M., Harper J.L. & Townsend C.R. 1986. Ecology: Individuals, Populations, Communities. Blackwell Scientific Publications. Oxford.

Behan V.M., Hill S.B. & Kevan D.K. McE. 1978. Effects of nitrogen fertilizers, as urea, on Acarina and other arthropods in Quebec black spruce humus. Pedobiologia **18**: 249–263.

Behan-Pelletier V.M. 1999. Oribatid mite biodiversity in agroecosystems: role for bioindication. Agriculture, Ecosystems and Environment **74**: 411–423.

Behan-Pelletier V.M. & Hill S.B. 1983. Feeding habits of sixteen species of Oribatei (Acari) from an Acid Peat Bog, Glenamoy, Ireland. Rev. Écol. Biol. Sol. **20**: 221–267.

Behan-Pelletier V. & Winchester N. 1998. Arboreal oribatid mite diversity: Colonizing the canopy. Appl. Soil Ecol. **9**: 45–51.

Behan-Pelletier V. & Newton G. 1999. Linking soil biodiversity and ecosystem function – The taxonomic dilemma. BioScience **49**, 2: 149–153.

Behan-Pelletier V. & Walter D.E. 2000. Biodiversity of oribatid mites (Acari: Oribatida) in Tree Canopies and Litter. In: Coleman D.C. & Hendrix P.F. (eds.). CAB. International 2000. Invertebrates as Webmasters in Ecosystems: 187–202.

Bellido A. & Deleporte S. 1994. Oribatid mites/Diptera interactions in a deciduous forest leaf-litter: an application of multivariate analysis under linear constraints. Pedobiologia **38**: 429–447.

Berina D., Lapina J., Melecis V. & Spungis V. 1989. Investigation of the impact of highway transport emissions on soil microarthropods by the method of principal components (in Russian). In: The impact of highway transport emissions on natural environment. Riga. Zinante: 48–73.

Bernini F. 1986. Current ideas on the phylogeny and the adaptative radiation of the Acarida. Boll. Zool. **53**, 3: 279–314.

Bernini F. 1990. Oribatids and insular biogeography. Atti dei Convegni Lincei **85**: 23–43.

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.

Berthet P. 1964a. L'activité des oribatides (Acari: Oribatei), d'une Chênaie. Mémoires de l'Institut Royale de Sciences Naturales de Belgique **152**: 1–152.

Berthet P.L. 1964b. Field study of the mobility of Oribatei (Acari) using Radioactive Tagging. J. Anim. Ecol. **33**: 443–449.

Bhattacharya T. & Joy V.C. 1980. Effect of two herbicides on the soil inhabiting cryptostigmatid mites. In: Dindal D.L. (ed.). Soil Biology as Related to Land Use Practices. Proc. VIIth Int. Coll. Soil Zool., EPA, Washington, DC. XV: 109–117.

Bielska I. 1982a. Communities of moss mites (Acari, Oribatei) of degraded and recultivated areas in Silesia. I: Communities of moss mites of mine dumps. Pol. ecol. Stud. **8**, 3–4: 499–510.

Bielska I. 1982b. Communities of moss mites (Acari, Oribatei) of degraded and recultivated areas in Silesia. II: Communities of moss mites of recultivated areas. Pol. ecol. Stud. **8**, 3–4: 511–520.

Bielska I. 1989. Communities of moss mites (Acari, Oribatei) of grasslands under the impact of industrial pollution. III: Communities of moss mites of wastelands. Pol. ecol. Stud. **15**, 1–2: 101–110.

Bielska I. 1995. Mining dump and electrical power plant Oribatida. In: Kropczyńska D., Boczek J., Tomczyk A. (eds.). The Acari Physiological and Ecological Aspects of Acari-Host Relationships. Oficyna Dabor. Warszawa: 173–182.

Bielska I. & Paszewska H. 1995. Communities of moss mites (Acarida, Oribatida) on recultivated ash dumps from power plants. Pol. ecol. Stud. **21**, 3: 263–275.

Block W.C. 1966. Seasonal fluctuations and distribution of mite populations in moorland soil with a note on biomass. J. Anim. Ecol. **35**: 487–503.

Bode E. 1975. Pedozoologische Sukzessionsuntersuchungen auf Rekultivierungsflächen des Braunkohlentagebaues. Pedobiologia **15**: 284–289.

Bolger T. 1985. The rate of disappearance of *Salix* litter on cutway bog and the microarthropods associated with it. Pediobiologia **28**: 145–153.

Borcard D. 1991. Les Oribates des tourbières du Jura suisse (Acari, Oribatei). Faunistique II. Les relations Oribates – environnement à la lumière du test de Mantel. Rev. Écol. Biol. Sol. **28**: 323–339.

Borcard D. 1994. Les Oribates des tourbiéres du Jura suisse (Acari, Oribatei). Faunistique VI. Oppioidea (Thyrisomidae), Hydrozetoidea, Cymbaeremoidea, Oribatuloidea (part.). Bull. Soc. entomol. suisse **67**: 363–372.

Borcard D. & Matthey W. 1995. Effect of a controlled trampling of *Sphagnum* mosses on their Oribatid mite assemblages (Acari, Oribatei). Pedobiologia **39**: 219–230.

Borcard D., Geiger W. & Matthey W. 1995. Oribatid mite assemblages in a contact zone between a peat-bog and a meadow in the Swiss Jura (Acari, Oribatida): influence of landscape structures and historical processes. Pedobiologia **39**: 318–330.

Borcard D. & Vaucher-von Ballmoss C. 1997. Oribatid mites (Acari, Oribatida) of a primary peat bog-pasture transition in the Swiss Jura mountains. Écoscience **4**: 470–479.

Box J. 1993. Conservation or greening? The challenge of post-industrial landscapes. British Wildlife **4**, 5: 273–279.

Braun-Blanquet J. 1964. Pflanzensoziologie. Springer Verlag. Wien, pp. 865.

Brenner F.J., Kelly R.B. & Kelly J. 1982. Mammalian community characteristics on surface mine lands in Pennsylvania. Environ. Managem. **6**: 241–249.

Brady N.C. 1990. The Nature and Properties of Soils. Macmillan Publishing Company. New York, pp. 621.

Brockmann W., Koehler H. & Schriefer T. 1980. Recultivation of refuse tips: soil ecological studies. In: Dindal D.L. (ed.). Soil Biology as Related to Land Use Practices. Proc. VII Int. Soil Zool. Coll. EPA, Syracuse, N.Y., USA: 161–168.

Brockmann W. & Koehler H. 1982. Colonization of secondary raw soils on refuse tips by soil mesofauna. In: Bornkamm R. et al. (eds.). Urban Ecology. Blackwell Oxford: 337.

Brody A.R. & Wharton G.W. 1971. The use of glycerol KCl in scanning microscopy of Acari. Ann. Ent. Soc. Amer. **64**, 2: 528–530.

Bücking J., Ernst H. & Siemer F. 1998. Population dynamics of phytophagous mite inhabiting rocky shores – *K*-strategists in an extreme environment? In: Ebermann E. (ed.). Arthropod Biology: Contributions to Morphology, Ecology and Systematics. Biosystematics and Ecology Series **14**: 93–143.

Bulanova-Zachvatkina E.M. 1962. Bulavonogie pancirnye klešči semejstva Damaeidae BERLESE, 1896 (triba Belbini, triba n.). Zool. Zh., Moskva **1**, **2**: 203–216.

Butcher J.W., Snider R. & Snider R.J. 1971. Bioecology of edaphic Collembola and Acarina. Ann. Rev. Ent. **16**: 249–288.

Cabała S. & Sypień B. 1987. Development of vegetation on the coal mine spoil heaps of the Upper Silesian Industrial Region (in Polish). Archiwum ochrony środowiska **3–4**: 169–184.

Cancela da Fonseca & Sarkar S. 1996. On the evaluation of spatial diversity of soil microarthropod communities. Eur. J. Soil Biol. **32**, 3: 131–140.

Černova N.M. & Čugunova N.M. 1967. Analysis of the horizontal distribution of microarthropods in the relation to plant distribution in one phytocenological unit (in Russian). Pedobiologia **7**: 67–97.

Christian A. 1993. Untersuchungen zur Entwicklung der Raubmilben fauna (Gamasina) der Halden des Braunkohlentagebanes Berzdorf/OL. Abh. Ber. Naturkundemus, Görlitz **67**: 2–64.

Clements F.E. 1916. Plant Succession. Carnegie Institute. Washington Publication 242, pp. 512.

Clements F.E. 1963. Plant succession and indicators. A definitive edition of plant succession and plant indicators. Hafner. Publishing Comp. New York, pp. 453.

Cohn V.J., Rostański A., Tokarska-Guzik B., Trueman I.C. & Woźniak G. 2001. The flora and vegetation of an old solvay process tip in Jaworzno (Upper Silesia, Poland). Acta Soc. Bot. Pol. **70**, 1: 47–60.

Coleman D.C. & Crossley D.A. Jr. 1996. Fundamentals of soil ecology. Academic Press. San Diego, California, pp. 205.

Colwell R.K. & Coddington J.A. 1995. Estimating terrestrial biodiversity through extrapolation. In: Hawksworth D.L. (ed.). Biodiversity measurement and estimation. Chapman Hall. London: 101–118.

Connell J.H. 1978. Diversity in tropical rain forests and coral reefs. Science **199**: 1302–1310.

Connell J.H. & Slatyer R.O. 1977. Mechanisms of succession in natural communities and their role in community stability and organization. American Naturalist **111**: 1119–1144.

Convention on Biological Diversity
(http://www.biodiv.org/convention/articles.asp?lg=0&a=cbd-02)

Cranston P.S. 1990. Biomonitoring and invertebrate taxonomy. Environmental Monitoring and Assessment **14**: 265–273.

Cross A.E. & Wilman J.M. 1982. A preliminary study of the refaunation of alkaline shale coal surface mine spoil by arthropods. In: Graves D.H. (ed.). Proceedings: 1982 Symposium on Surface Mining Hydrology, Sedimentology and Reclamation. Univ. Kentucky. Lexington: 353–358.

Crossley D.A. 1977a. Oribatid mites and nutrient cycling. In: Dindal D.L. (ed.). Biology of Oribatid Mites. Suny-Cesf. Syracuse, NY: 71–85.

Crossley D.A. 1977b. The roles of terrestrial saprophagous arthropods in forest soils: current status of concepts. In: Mattson W.J. (ed.). The Role of Arthropods in Forest Ecosystems. Springer. Berlin–Heidelberg–New York: 226–232.

Curry J.P. 1969. The qualitative and quantitative composition of the fauna of an old grassland site at Celbridge, co. Kildare. Soil Biol. Biochem. **1**: 219–227.

Curry J.P. 1978. Relationships between microarthropod communities and soil and vegetational types. Sci. Proc. R., Dublin Soc. **A, 6**: 131–141.

Curry J.P. & Ganley J. 1977. The arthropods associated with the roots of some common grass and weed species of pasture. Ecol. Bull., Stockholm **25**: 330–339.

Davis B.N.K. 1963. A study of the micro-arthropod communities in mineral soils near Corby, Northants. J. Anim. Ecol. **32**: 49–71.

Davis B.N.K. 1986. Colonization of Newly Created Habitats by Plants and Animals. J. Environ. Managem. **22**: 361–371.

Dekkers Th.B.M., Werff P.A. van der & Amelsvoort P.A.M. van 1994. Soil Collembola and Acari related to farming systems and crop rotations in organic farming. Acta Zool. Fennica **195**: 28–31.

Denegri G.M. 1993. Review of oribatid mites as intermediate hosts of tapeworms of the Anoplocephalidae. Exp. & Appl. Acarol. **17**: 567–580.

Denmark H.A. & Woodring J.P. 1965. Feeding habits of *Hemileius* new species (Acari: Cryptostigmata; Oribatulidae) in Florida orchids. Florida Entomol. **48**: 9–16.

Denneman C.A.J. & Van Straalen N.M. 1991. The toxicity of lead and copper in reproduction tests using the oribatid mites *Platynothrus peltifer*. Pedobiologia **35**: 305–311.

Diamond J.M. 1972. Biogeographic kinetics: Estimation of relaxation times for avifaunas of Southwest Pacific Islands. Proc. Natl. Acad. Sci. US. **69**: 3199–3203.

Diamond J.M. 1975. Assembly of species communities. In: Cody M.L. & Diamond J.M. (eds.). Ecology and Evolution of Communities. The Belknap Press of Harvard Univ. Press. Cambridge: 342–444.

Dickinson C.H. & Pugh G.J.F. (eds.). 1974. Biology of plant litter decomposition. Academic Press. London.

Didham R.K., Ghazoul J., Stork N.E. & Davis A.J. 1996. Insects in fragmented forests: a functional approach. Trends Ecol. Evol. **11**: 255–260.

Dindal D.L. 1977. Influence of human activities on oribatid mite communities. In: Dindal D.L. (ed.). Biology of Oribatid Mites. St. Univ. N.Y. Coll. Environ. Sci. For., Syracuse, NY: 105–120.

Dindal D.L. 1990. Soil Biology Guide. Wiley. New York.

Doherty M., Kearns A., Barnett G., Sarre A., Hochuli D., Gibb H. & Dickman C. 2000. The Interaction Between Habitat Conditions, Ecosystem Processes and Terrestrial Biodiversity – a review. Australia: State of the Environment, Second Technical Paper Series (Biodiversity), Department of the Environment and Heritage, Canberra, pp. 114. (http://www.erin.gov.au/soe/techpaper/pubs/biodiversity.pdf)

Ducarme X. & Lebrun P. 2000. Vertical distribution of microarthropods in a temperate forest soil. Abstracts of XIII International Colloquium on Soil Zoology, České Budějovice, Czech Republic, August 14–18, 2000, p. 26.

Dunger W. 1968. Die Entwicklung der Bodenfauna auf rekultivierten Kippen und Halden des Braunkohletagebaus. Abh. Ber. Naturkundemus. Leipzig 43, **2**: 1–256.

Dunger W. 1978. Parameter der Bodenfauna in einer Catena von Rasen-Ökosystemen. Pedobiologia **18**: 378–380.

Dunger W. 1989. The return of soil fauna to coal mined areas in the German Democratic Republic. In: Majer J.D. (ed.). Animals in Primary Succession – The Role of Fauna in Reclaimed Lands **13**: 307–337.

Dunger W. 1991. Zur Primärsukzession humiphager Tiergruppen auf Bergbauflächen. Zool. Jahrb. Syst. **118**: 423–447.

Dunger W., Wanner M. with Hauser H., Hohberg K., Schulz H.-J., Schwalbe T., Seifert B., Vogel J., Voigtländer K., Zimdars B. & Zulka K.P. 2001. Development of soil fauna at mine sites during 46 years after afforestation. Pedobiologia **45**: 243–271.

Edwards C.A. & Lofty J.R. 1969. The influence of agricultural practices on soil micro-arthropod populations. In: Sheals J.G. (ed.). The Soil Ecosystem. Systematic Pub. 8.X+, 237–247.

Edwards D.E., Reichle D.E. & Crossley D.A. Jr. 1970. The role of soil invertebrates in turnover of organic matter and nutrients. In: Reichle D.E. (ed.). Analysis of temperate forest ecosystems. Springer-Verlag. New York: 147–171.

Egler F.E. 1954. Vegetation science concepts. I. Initial floristic composition – a factor in old-field vegetation development. Vegetatio **14**: 412–417.

Ehrlich P.R. 1988. The loss of diversity: causes and consequences. In: Wilson E.O. & Peter F.M. (eds.). Biodiversity. National Academy Press. Washington, DC: 21–27.

Ehrnsberger R. & Butz-Strazny F. 1993. Auswirkung von nuterschiedlicher Bodenbearbeiting (Grubber und Pflug) auf die Milbenfauna im Ackerboden. Inf. Natursch. Landschaftspfl. **6**: 188–208.

Evans G.O., Sheals J.G. & Macfarlane D. 1961. Terrestrial Acari of the British Isles. Br. Mus. Nat. Hist. London: pp. 219.

Felinks B., Hahn B. & Wiegleb G. 1999. Vegetationstypen der terrestrischen Bereiche in der Niederlausitzer Bergbaufolgelandschaft. Archiv. für Naturschutz und Landschaftsforschung **38**: 43–84.

Filimonova Zh.V., Pokarzhevskii A.D., Zaitsev A.S., Krivolutsky D.A. & Verhoef S.K. 2000. Ecological Mechanisms of Soil Biota Tolerance to Metal Contamination. Doklady Biologia Sciences **370**: 77–80.

Fittakau E.J. & Klinge H. 1973. On biomass and trophic structure of the central Amazonian rainforest ecosystem. Biotropica **5**: 2–4.

Forsslund K.H. 1942. Schwedische Oribatei (Acari). I. Ark. Zool. **34**: 1–11.

Forsslund K.H. 1957. Notizen über Oribatei (Acari). I. Ark. Zool. **10**: 583–593.

Franchini P. & Rockett C.L. 1996. Oribatid mites as "indicator" species for estimating the environmental impact of conventional and conservation tillage practices. Pedobiologia **40**, 3: 217–225.

Freckman D.W. & Virginia R.A. 1997. Low-diversity Antarctic soil nematode communities: distribution and response to disturbance. Ecology **78**: 363–369.

Frouz J., Keplin B., Pižl V., Tajovský K., Starý J., Lukešová A., Nováková A., Balik V., Háněl L., Materna J., Düker Ch., Chalupský J., Rusek J. & Heinkele T. 2001. Soil biota and upper soil layer development in two contrasting post-mining chronosequences. Ecol. Engineering **17**: 275–284.

Fujikawa T. 1979. Revision on the family Banksinomidae (Acari, Oribatei). Acarologia **20**, 3: 433–467.

Gatilova F.G. 1970. The effect of fertilizers on the fauna and numbers of oribatid mites in the soil under maize (in Russian). In: Oribatid mites (Oribatei) and their role in soil-forming processes. Akad. Nauk Litov. SSR. Vilnius: 195–199.

Gauch H.G. 1982. Multivariate analysis in community ecology. Cambridge University Press. Cambridge. England, pp. 298.

Ghilarov M.S. 1963. In: Doeksen M.J. & Drift J. van der (eds.). Soil organisms. North Holland Publ. Co. Amsterdam: 255–259.

GHILAROV M.S. 1975. General trends of changes in soil animal population of arable land. In: VANĚK J. (ed.). Progress in Soil Zoology. Academia. Praha: 31–39.

GHILAROV M.S. 1977. Why so many species and so many individuals can coexist in the soil. In: Soil Organisms as Components of Ecosystems. Ecol. Bull. **25**: 593–597.

GHILAROV M.S. & KRIVOLUTSKY D.A. (eds.). 1975. Identification of soil mites, Sarcoptiformes (in Russian). Izd. Nauka. Moscow.

GILLER P.S. 1984. Community Structure and the Niche. Chapman & Hall. London.

GILLER P.S. 1996. The diversity of soil communities, the "poor man's tropical rainforest". Biodivers. Conserv. **5**: 135–168.

GITTINGS T. & GILLER P.S. 1998. Resource quality and colonisation and succession of coprophagous dung beetles. Ecography **21**: 581–592.

GLÜCK E. 1989. Waldbodenverbringung: zoologische Aspekte. Natur und Landschaft **64**: 456–458.

GOLOSOVA L., KARPPINEN E. & KRIVOLUTSKY D.A. 1983. List of oribatid mites (Acarina, Oribatei) of northern palaearctic region. II: Siberia and the Far East. Acta Entomol. Fenn. **43**: 1–14.

GONZÁLEZ G. & SEASTEDT T.R. 2000. Comparison of the abundance and composition of litter fauna in tropical and subalpine forests. Pedobiologia **44**: 545–555.

GOODLAND R. 1991. The case that the world has reached limits. More precisely that current throughput growth in the global economy cannot be sustained. In: Environmentally sustainable economic development: Building on Brundtland. UNESCO. Paris: 15–28.

GÓRNY M. 1975. Zooecology of forest soil (in Polish). PWRiL. Warszawa, pp. 311.

GÓRNY M. & GRÜM L. 1993. Methods in Soil Zoology. PWN – Polish Scientific. Warszawa.

GRANDJEAN F. 1954. Essai de classification des Oribates (Acariens). Bull. Soc. Zool. France **78**, 5–6: 421–446.

GRANDJEAN F. 1969. Considérations sur le classement des Oribates. Leur division en 6 groupes majeurs. Acarologia, Abbeville **11**: 127–153.

GRAY J.S. & MIRZA F.B. 1979. A possible method for detection of pollution-induced disturbance on marine benthic communities. Mar. Poll. Bull. **10**: 142–146.

GREENWOOD E.F. & GEMMELL R.P. 1978. Derelict industrial land as a habitat for rare plants in S. Lancs. (v.c.59) and W. Lancs (v.c.60). Watsonia **12**: 33–40.

GREIG-SMITH P. 1964. Quantitative plant ecology. Butterworths. London, 2nd ed., XII, pp. 256.

GRESSIT J.L., SEDLACEK J. & SZENT-IVANY J.J.H. 1966. Flora and fauna on backs of large Papuan moss-forest weevil. Science **150**: 1833–1835.

HAARLÖV N. 1960. Microarthropods from Danish Soils. Ecology, Phenology. Oikos **3**: 1–176.

HÅGVAR S. 1984. Effects of liming and artificial acid rain on Collembola and Protura in coniferous forest. Pedobiologia **27**: 341–354.

HÅGVAR S. & AMUNDSEN T. 1981. Effects of liming and artificial acid rain on the mite (Acari) fauna in coniferous forest. Oikos **37**: 7–20.

HÅGVAR S. & ABRAHAMSEN G. 1984. Collembola in Norwegian forest soils. III. Relations to soil chemistry. Pedobiologia **27**: 331–339.

HAMMEN L.v.d. 1972. A revised classification of the mites (Arachnidea, Acarida) with diagnoses, a key, and notes on phylogeny. Zool. Meded. **47**: 273–292.

HAMMER M. 1965. Are low temperatures a species-preserving factor? Acta Universitatis Lundensis, Sec. II, **2**: 1–10.

HAMMER M. 1969. Oribatids Found at Plant Quarantine Station in the U.S.A. Vidensk. Meddr. Dansk Naturh. Foren. **132**: 63–78.

Hammer M. 1972. Microarthropods of oribati mites on a Danish woodland floor. Pedobiologia **12**: 412–423.

Harding D.J.L. 1969. Seasonal changes in the abundance of Cryptostigmata in the forest floor of an oak woodland. In: Proc. of 2-nd Intern. Congr. Acarol. Acad. Kiadó. Budapest: 23–30.

Hasegawa M. 2001. The relationship between the organic matter composition of a forest floor and the structure of a soil arthropod community. Eur. J. Soil Biol. **37**, 4: 281–284.

Hawkins B.A. & Cross E.A. 1982. Patterns of refaunation of reclaimed strip mine spoils by non-terricolous arthropods. Environ. Entomol. **11**: 762–775.

Heal O.W. & Dighton J. 1986. In: Mitchell M.J., Makas R. (eds.). Microflora and Faunal Interactions in Natural and Agro-ecosystems: 14–73.

Healy B. 1980. Distribution of terrestrial Enchytraeidae in Ireland. Pedobiologia **20**: 159–175.

Henegham L. & Bolger T. 1996. Effect of components of "acid rain" on the contribution of soil microarthropods to ecosystem function. J. Appl. Ecology **33**: 1329–1344.

Hermosilla W. 1976. Beobachtungen an der Bodenfauna von rekultivierten Böden im Braunkohlentagebaugebiet der Ville. Decheniana (Bonn) **129**: 73–75.

Heywood V.H. & Gardner K. (eds.). 1995. Global Diversity Assessment. UNEP & Cambridge University Press.

Hill M.D. 1980. Correspondence analysis: a neglected multivariate method. Appl. Statist. **23**: 340–354.

Holt J. 1981. The vertical distribution of cryptostigmatic mites, soil organic matter and macroporosity in three North Queensland rainforest soils. Pedobiologia **22**: 202–209.

Holzapfel E.P. & Harrell J.C. 1968. Transoceanic dispersal studies of insects. Pac. Insects **10**: 115–153.

Horn H.S. 1974. The ecology of secondary succession. Ann. Rev. Ecol. Syst. **5**: 25–37.

Horn H.S. 1976. Succession. In: May R.M. (ed.). Theoretical Ecology. Blackwell Scientific Publications. Oxford: 187–204.

Hoy J.B. 1990. Long-term effects of Lindane on the Oribatid community in a Pine plantation. Environ. Entomol. **19**, 4: 898–900.

Howard P.J.A. & Robinson C.H. 1995. The use of correspondence analysis in studies of successions of soil organisms. Pedobiologia **39**, 6: 518–527.

Hubert J. 2001. Oribatid mites (Acari: Oribatida) on reclaimed and unreclaimed wasteland near Chvaletice (Czech Republic). Acta Soc. Zool. Bohem. **65**: 5–16.

Huhta V. 1976. Effects of clear-cutting on numbers, biomass and community respiration of soil invertebrates. Ann. Zool. Fenn. **13**: 63–80.

Huhta V., Karppinen E., Nurminen M. & Valpas A. 1967. Effect of silvicultural practices upon arthropod, annelid and nematode populations in coniferous forest soil. Ann. Zool. Fenn. **4**: 87–143.

Huhta V., Ikonen E. & Vilkamaa P. 1979. Succession of invertebrate populations in artificial soil made of sewage sludge and crushed bark. Ann. Zool. Fenn. **16**: 223–270.

Hunt G.S. 1994. Oribatids – a mite biodiverse (Acarina). Memoirs of the Queensland Museum **36**, 1: 107–114.

Huston M.A. 1994. Biological diversity. The coexistence of species on changing landscapes. Cambridge Univ. Press.

Hutson B.R. 1972. The invertebrate fauna of a reclaimed pit heap. Landscape Reclamation. Guildford. IPC Press **2**: 64–79.

HUTSON B.R. 1980a. Colonization of industrial reclamation sites by Acari, Collembola and other invertebrates. J. Appl. Ecol. **17**: 255–275.

HUTSON B.R. 1980b. The influence on soil development of the invertebrate fauna colonizing industrial reclamation sites. J. Appl. Ecol. **17**: 277–286.

HUTSON B.R. & LUFF M.L. 1978. Invertebrate colonization and succession on industrial reclamation sites. Scientific Proceedings of the Royal Dublin Society (**A**) **6**: 165–174.

ITURRONDOBEITIA J.C., SALONA M.I., PEREDA J., CABALLERO A.I. & ANDRÉS M.C. 1997. Oribatid mites as an applied tool in studies on bioindication: a particular case. Abh. Ber. Naturkundemus, Görlitz **69**, 6: 85–96.

JANETSCHEK H. 1970. Environments and ecology of terrestrial arthropods in the high Antarctic. In: HOLDGATE M.W. (ed.). Antarctic Ecology. Academic Press. London: 871–885.

JARZĘBSKI L. (ed.) 1997. Raport o stanie środowiska w województwie katowickim w latach 1995-1996. Państwowa Inspekcja Ochrony Środowiska. Wojewódzki Inspektorat Ochrony Środowiska w Katowicach. Biblioteka Monitoringu Środowiska, pp. 371.

JEFFERSON R.G. 1984. Quarries and wildlife conservation in the Yorkshire Wolds. England. Biol. Conserv. **29**: 363–380.

JONGMANN R.H., Ter BRAAK C.J.F. & VAN TONGEREN O.F.R. 1987. Data analysis in community and landscape ecology. Pudoc Wageningen, pp. 299.

KANEKO N. 1988a. Life history of *Oppiella nova* (OUDEMANS) (Oribatei) in cool temperate forest soils in Japan. Acarologia **29**: 215–221.

KANEKO N. 1988b. Feeding habit and cheliceral size of oribatid mites in cool temperate forest in Japan. Rev. Écol. Biol. Sol. **25**: 353–363.

KARG W. 1967. Synökologische Untersuchungen von Bodenmilben aus forstwirtschaftlich und landwirtschaftlich genutzten Böden. Pedobiologia **7**: 198–214.

KARPPINEN E. & KRIVOLUTSKY D.A. 1982. List of oribatid mites (Acarina, Oribatei) of northern palaearctic region. I. Europe. Acta Entomol. Fenn. **41**: 1–18.

KARPPINEN E., KRIVOLUTSKY D.A. & POLTAVSKAJA M.P. 1986. List of oribatid mites (Acarina, Oribatei) of northern palaearctic region. III. Arid lands. Ann. Entomol. Fenn. **52**: 81–94.

KARPPINEN E., KRIVOLUTSKY D.A., TARBA Z.M., SHTANCHAEVA V.YA. & GORDEEVA E.W. 1987. List of oribatid mites (Acarina, Oribatei) of northern palaearctic region. IV. Caucasus and Crimea. Ann. Entomol. Fenn. **53**: 119–137.

KARPPINEN E., MELAMUD V.V., MIKO L. & KRIVOLUTSKY D.A. 1992. Further information on the oribatid fauna (Acarina, Oribatei) of the northern palaearctic region: Ukraina and Czechoslovakia. Entomol. Fenn. **3**: 41–56.

KEPLIN B., DAGEFÖRDE A., DÜKER C. 1999. Untersuchungen zum Abbau von organischer Substanz und zur Bodenbiozönose auf forstlich rekultivierten Kippstandorten. In: HÜTTL R.F., KLEM D. & WEBER E. (eds.). Rekultivierung von Bergbaufolgelandschaften. Walter de Gruyter. Berlin–New York: 73–87.

KETHLEY J. 1990. Acarina: Prostigmata (Actinedida). In: DINDAL D.L. (ed.). Soil Biology Guide. Wiley Publ. New York: 667–756.

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**: 197–207.

KLIMEK A., SENICZAK S., ŻELAZNA E. & DĄBROWSKA B. 1991. Acarofauna (Acari) on the slopes of waste products deposits at the Janikowskie Sodium Works (in Polish). Zesz. Nauk. ATR Bydgoszcz. Zootechnika **22**: 151–165.

KLUTE A. (ed.). 1986. Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods. Agronomy Monography. American Society of Agronomy. Madison. Wisconsin **9**: 799–823.

KOEHLER H. 1983. Studies on the development of soil mesofauna in a rubble dump cover. In: LEBRUN Ph. et al. (eds.). New Trends in Soil Biology. Proc. of the VIII Int. Colloquium of Soil Zoology: 561–567.

KOEHLER H. 1987. Die Sukzession der Acarina – Synusie eines Ruderalökosystems unter Aldicarb – Belastung. Verh. Ges. Ökol. **16**: 399–406.

KOEHLER H.H. 1999. Gamasina in a succession of thirteen years. In: BRUIN J., GEEST L.P.S. van der & SABELIS M.W. (eds.). Ecology and Evolution of the Acari. Kluwer Academic Publishers: 531–539.

KOSKENNIEMI A. & HUHTA V. 1986. Effects of fertilization and manipulation of pH on mite (Acari) populations of coniferous forest soil. Rev. Écol. Biol. Sol. **23**, 3: 271–286.

KOVÁČ L. & MIKLISOVÁ E. 1997. Collembolan communities (Hexapoda, Collembola) in arable soils of East Slovakia. Pedobiologia **41**: 62–68.

KOVÁČ L., SCHNITZEROVÁ E., MIKLISOVÁ D., MATI R. 1999. Gamasina communities (Acari, Parasitiformes) of arable soils with two different soil types. Pedobiologia **43**: 54–63.

KOVACH W.L. 1998. MVSP – A MultiVariate Statistical Package for Windows, ver. 3.0. Kovach Computing Services, Pentraeth, Wales, U.K.

KRANTZ G.W. 1978. A manual of acarology. 2nd ed. Oregon State University Book Stores Inc. Corvallis, pp. 509.

KREBS C.J. 1999. Ecological Methodology. Addison Wesley Longman, Inc., pp. 620.

KRIVOLUTSKY D.A. 1965. Morfo-ekologičeskije tipy pancirnych kleščej (Acariformes, Oribatei). Zool. Zh. **44**, 8: 1176–1189.

KRIVOLUTSKY D.A. 1968. Ekologičeskaja specialitacija i formoobrazovanije u pancirnych kleščej. Zool. Zh. **67**, 6: 820–827.

KRIVOLUTSKY D.A. 1970. Indicational significance of the oribatid mite complexes (in Russian). In: Oribatid mites (Oribatei) and their role in soil-forming processes. Akad. Nauk Litov. SSR. Vilnius: 21–31.

KRIVOLUTSKY D.A. 1977. Puti prisposobitel'noj evolucii pancirnych kleščej w počve. In: Adaptacja počvennych životnych k uslovijam sredy. Izd. Nauka. Moskva: 102–128.

KRIVOLUTSKY D.A. 1979. Oribatid mite complexes as bioindicators of radioactive pollution. Rec. Adv. Acarology **1**: 615–618.

KRIVOLUTSKY D.A. & LEBEDEVA N.V. 2002. The oribatid mites and other soil microarthropods in the bird feathers. In: TAJOVSKÝ K., BALIK V. & PIŽL V. (eds.). Studies on Soil Fauna in Central Europe. ISB AS CR, České Budějovice: 101–104.

KRIVOLUTSKY D.A. 1995 (ed.). Oribatid mites. Morphology, development, phylogeny, ecology, methods of study, model species *Nothrus palustris* C.L. KOCH, 1839 (in Russian). Izd. Nauka. Moscow.

KRIVOLUTSKY D.A. & POKARZHEVSKY A.D. 1991. Soil Fauna as Bioindicators of Biological After-Effects of the Chernobyl Atomic Power Station Accident. Bioindicators and Environmental Management: 135–141.

LAMPARSKA-WIELAND M. 1997. Dolomitic dump in Tarnowskie Góry Bobrowniki as a potential preservation object (in Polish). Geographia. Studia et Dissertationes **21**: 101–115.

LASSEN H.H.1975. The diversity of freshwater snails in view of the equilibrium theory of island biogeography. Oecologia **19**: 1–8.

LAVELLE P. 1997. Faunal Activities and Soil Processes: Adaptative Strategies that Determine Ecosystem Function. Advances in Ecological Research **27**, 93–132.

LAVELLE P., LATTAUD C., TRIGO D. & BAROIS I. 1994. Mutualism and biodiversity in soils. Plant and Soil **170**: 23–33.

Lebrun Ph. 1964. Quelques aspects de la phénologie des populations d'Oribatides (Acari, Oribatei) dans le sol forestier en Moyenne-Belgique. Bull. Acad. Belg. Cl. Sci. **50**: 370–392.

Lebrun Ph. 1965. Contribution á l'étude écologique des Oribates de la litiére dans une forêt de Moyenne–Belgique. Mém. Inst. Sci. nat. Belg. **153**: 1–96.

Lebrun Ph. 1971. Écologie et biologie de quelques peuplements d'arthropodes édaphiques. Mém. Inst. Sci. nat. Belg. **165**: 1–203.

Lebrun Ph. 1979. Soil mite community diversity. Rec. Adv. Acarology **1**: 603–613.

Lebrun Ph. 1981. «Problèmes d'acarologie» ou «De l'ècologie fondamentale à l'ècologie appliquèe.» Ann. Soc. R. Zool. Belg. **110**: 143–172.

Lebrun Ph. & Wauthy G. 1981. Quelques observations et reflections sur les peuplements d'oribates hypoges (Acariens). Ann. Soc. R. Zool. Belg. **111**: 131–142.

Lebrun P., van Impe G., de Saint Georges-Gridelet D., Wauthy G. & André H.M. 1991. The life strategies of mites. In: Schuster R. & Murphy P.W. (eds.). The Acari. Reproduction, Development and Life-history Strategies. Chapman & Hall. London: 1–22.

Lebrun P. & Van Straalen N.M. 1995. Oribatid mites: prospects of their use in ecotoxicology. Exp. & Appl. Acarol. **19**, 7: 361–380.

Legendre L. & Legendre P. 1983. Numerical ecology. Elsevier. Amsterdam, pp. 419.

Linden D.R., Hendrix P.F., Coleman D.C. & Van Vliet P.C.J. 1994. In: Doran J.W., Coleman D.C., Bezdicek D.F. & Stewart B.A. (eds.). Defining Soil Quality for a Sustainable Environment. SSSA Special Publication **35**: 91–106.

Lindroth C.H., Andersson H., Bodvarsson H. & Richter S.M. 1973. Surtsey, Iceland. The development of a new fauna, 1963–1970. Terrestrial invertebrates. Entomol. Scand. Suppl. **5**: 1–280.

Lions J.-C. 1966. Contribution á l'étude de la faune provençale des Oribates (Acariens). Bulletin du Muséum National d'Histoire Naturelle **38**, **4**: 43–447.

Liss W.J., Gut L.J., Westigard P.H. & Warren C.E. 1986. Perspectives on arthropod community structure, organization and development in agricultural crops. Ann. Rev. Entomol. **31**: 455–478.

Lityński T., Jurkowska H. & Gorlach E. 1976. Chemical-agricultural analysis (in Polish). PWN. Warszawa, pp. 330.

Loots G.C. & Ryke P.A. 1967. The ratio Oribatei: Trombidiformes with reference to organic matter content in soils. Pedobiologia **7**: 121–124.

Loro P.M. 1998. Choice of resemblance coefficients in plant communities researches (in Polish). In: Kaźmierczak E., Nienartowicz A., Piernik A. & Wilkoń-Michalska J. (eds.). Computer Methods in Investigation of the Structure and Functioning of the Vegetation Cover. Toruń: 119–130.

Ludwig J.A. & Reynolds J.F. 1988. Statistical Ecology. A primer on methods and computing. Wiley. New York, pp. 337.

Ludwig M., Kratzmann M. & Alberti G. 1991. Accumulation of heavy metals in two oribatid mites. In: Dusbábek F. & Bukva V. (eds.). Modern Acarology. SPB Academic Publishing. Prague, **1**: 431–437.

Ludwig M., Kratzmann M., Alberti G. 1993. The influence of some heavy metals on *Steganacarus magnus* (Acari, Oribatida). Angew. Zool. **30**: 455–467.

Luxton M. 1972. Studies on the oribatid mites of a Danish beech wood soil. I. Nutritional biology. Pedobiologia **12**: 434–463.

Luxton M. 1979. Food and energy processing by oribatid mites. Rev. Écol. Biol. Sol. **16**: 103–111.

Luxton M. 1981a. Studies on the oribatid mites of a Danish beech wood soil. III. Introduction to the field populations. Pedobiologia **21**: 301–311.

Luxton M. 1981b. Studies on the oribatid mites of a Danish beech wood soil. IV. Developmental biology. Pedobiologia **21**: 312–340.

Luxton M. 1982. The ecology of some soil mites from coal shale tips. J. Appl. Ecol. **19**: 427–442.

Maarel E. van der 1979. Transformation of cover-abundance values in phytosociology and its effects on community similarity. Vegetatio **39**, 2: 97–114.

MacFadyen A. 1952. The small arthropods of a *Molinia* fen at Cothill. J. Anim. Ecol. **21**: 87–117.

MacFadyen A. 1953. Notes on methods for the extraction of small soil arthropods. J. Anim. Ecol. **22**: 65–77.

Madej G. & Skubała P. 1996. Communities of mites (Acari) on old galena-calamine mining wastelands at Galman, Poland. Pedobiologia **40**: 311–327.

Madej G. & Skubała P. 1998. Gamasid and oribatid mites of anthropogenically transformed galena-calamine mining wastelands. Zesz. Nauk. ATR: Ochrona Środowiska. Bydgoszcz **2**: 229–234.

Madge D.S. 1964. The water relations of *Belba geniculosa* Oudms. and other species of oribatid mites. Acarologia **6**: 199–223.

Magurran A.E. 1988. Ecological Diversity and Its Measurement. Princeton University Press. Princeton–New Jersey, pp. 179.

Mahunka S. 1983. The Oribatids (Acari: Oribatei) of the Hortobágy National Park. Fauna Hortobágy National Park: 377–397.

Majer J.D. 1985. Recolonization by ants of rehabilitated mineral sand mines on North Stradbroke Island, Queensland, with particular reference to seed removal. Aust. J. Ecol. **10**: 31–48.

Majer J.D. 1989a. Animals in Primary Succession. The Role of Fauna in Reclaimed Lands. Cambridge University Press. New York, pp. 516.

Majer J.D. 1989b. Fauna studies and land reclamation technology – a review of the history and need for such studies. In: Majer J.D. (ed.). Animals in Primary Succession. The Role of Fauna in Reclaimed Lands. Cambridge University Press. New York: 5–33.

Majer J.D., Sartori M., Stone R. & Perriman W.S. 1982. Recolonization by ants and other invertebrates in rehabilitated mineral sand mines near Eneabba, Western Australia. Reclam. Reveg. Res. **1**: 63–81.

Maraun M., Migge S., Schaefer M. & Scheu S. 1998. Selection of microfungal food by six oribatid mite species (Oribatida, Acari) from two different beech forests. Pedobiologia **42**: 232–240.

Maraun M. & Scheu S. 2000. The structure of oribatid mite communities (Acari, Oribatida): patterns, mechanisms and implications for future research. Ecography **23**, 3: 374–383.

Marshall V.G. 1972. Comparison of two methods of estimating efficiency of funnel extractors for soil microarthropods. Soil Biol. Biochem. **4**: 417–426.

Marshall V.G. 1974. Seasonal and vertical distribution of soil fauna in a thinned and urea-fertilized Douglas fir forest. Can. J. Soil Sci. **54**: 491–500.

Marshall V.G., Reeves R.M. & Norton R.A. 1987. Catalogue of the Oribatida (Acari) of Continental United States and Canada. Mem. Ent. Soc. Can. **139**: 1–418.

May R.M. 1978. The dynamics and diversity of insect faunas. In: Mound L.A. & Waloff N. (eds.). Diversity of Insect Faunas. Blackwell Scientific Publications. Oxford: 188–204.

May R.M. 1997. Animal multitrophic interactions? In: Gange A.C. & Brown V.K. (eds.). Multitrophic Interactions in Terrestrial Ecosystems. Blackwell Science. Oxford: 305–306.

McBrayer J.F., Reichle D.E. & Witkamp M. 1974. Energy Flow and Nutrient Cycling in a Cryptozoan Food Web. EDFB-IBP-73-8 Oakridge National Laboratory Tennessee.

Melamud V. 1999. Oribatid mites (Acari) of *Dentario glandulosae-Fagetum* in the Western Bieszczady Mts. (Polish Eastern Carpathians) – preliminary report (in Polish). Roczniki Bieszczadzkie **8**: 249–256.

Meyer E. & Thaler K. 1995. Animal Diversity at High Altitudes in the Austrian Central Alps. Ecol. Stud. **113**: 97–108.

Migge S., Maraun M., Scheu S. & Schaefer M. 1998. The oribatid mite community (Acarina) of pure and mixed stands of beech (*Fagus sylvatica*) and spruce (*Picea abies*) of different age. Appl. Soil Ecol. **9**: 119–126.

Miko L. 1995. Succession of Oribatid communities in different type of litter on a field edge (litter-bag study). In: Kropczyńska D., Boczek J. & Tomczyk A. (eds.). The Acari Physiological and Ecological Aspects of Acari-Host Relationships. Oficyna Dabor. Warszawa: 235–248.

Miko L. & Stanko M. 1991. Small mammals as carriers of non-parasitic mites (Oribatida, Uropodina). In: Dusbábek F. & Bukva V. (eds.). Modern Acarology. SPB Academic Publishing Prague **1**: 395–402.

Mitchell M.J. 1977. Population dynamics of oribatids mites (Acari, Cryptostigmata) in an aspen woodland soil. Pedobiologia **17**: 305–319.

Mitchell M.J. 1978. Vertical and horizontal distribution of Oribatid mites (Acari: Cryptostigmata) in an aspen woodland soil. Ecology **59**, 3: 516–525.

Mitchell M.J. 1979. Effects of physical parameters and food resources on oribatid mites in forest soils. Rec. Adv. Acarology **1**: 585–592.

Moldenke A.P. & Latin D.J. 1990. Dispersal characteristics of old-growth arthropods: the potential for loss of diversity and biological function. Northwest Environ. J. **6**: 408–409.

Moore J.C., Walter D.E. & Hunt H.W. 1988. Arthropod regulation of micro- and mesobiota in below-ground detrital food webs. Ann. Rev. Ent. **33**: 419–439.

Mortensen J.L. 1963. Complexing of metals by soil organic matter. Soil Sci. Soc. Amer. Proc. **27**: 179–186.

Mueller B.R., Beare M.H. & Crossley Jr. D.A. 1990. Soil mites in detrital food webs of conventional and no-tillage agroecosystems. Pedobiologia **34**: 389–401.

Nagasawa S. & Nuorteva P. 1974. Failure of survey data to conform to mathematical population models as an indicator of environmental disturbance. Ann. Zool. Fenn. **11**: 244–250.

Newmann U. 1971. Die Sukzession der Bodenfauna (Carabidae [Coleoptera], Diplopoda und Isopoda) in den forstlich rekultivierten Gebieten des Rheinischen Braunkohlenreviers. Pedobiologia **11**: 193–226.

Nichols O.G. & Burrows R. 1985. Recolonization of revegetated bauxite mine sites by predatory invertebrates. For. Ecol. Managem. **10**: 49–64.

Niedbała W. 1967. Investigations of the quantitative occurrence of moss-mites (Acari, Oribatei) in the Park of Sołacz in Poznań depending on some agricultural activities (in Polish). Bad. Fizjogr. Pol. Zach. **28**: 29–44.

Niedbała W. 1972. Ecological succession of moss-mites communities (Acari, Oribatei) in afforested stations of "Uroczysko Marcelin" in Poznań (in Polish). Pr. Kom. Biol. PTPN **31**, 3: 1–94.

Niedbała W. 1976. Brachychthonidae of Poland (Acari, Oribatei). Ecological-faunistic study (in Polish). Monogr. Fauny Polski **6**: 1–144.

Niedbała W. 1977. Biocenotic studies on moss-mites (Acari, Oribatei) in Ślęża Massif. Bad. Fizj. Pol. Zach., Poznań **30C**: 47–73.

Niedbała W. 1980. Moss-mites – Mites of Terrestrial Ecosystems (in Polish). PWN. Warszawa.

Niedbała W. 1983. Moss-mites (Oribatida) as ecological indices (in Polish). Zesz. Probl. Post. Nauk Przyr. **252**: 137–146.

Niedbała W. 1992. Phthiracaroidea (Acari, Oribatida). Systematic Studies. PWN. Warszawa. Elsevier. Amsterdam–Oxford–New York–Tokyo, pp. 612.

Niedbała W. 2000. Dlaczego przestałem zajmować się ekologią roztoczy glebowych? Materiały XXVI Sympozjum Akarologicznego „Akarologia polska u progu nowego tysiąclecia". Kazimierz Dolny, 24-26 października 1999: 193–201.

Noble J.C., Kaliszewski M. & Whitford W.G. 1989. Soil Acari from burnt and unburnt mallee habitats in western New South Wales. In: Noble J.C., Joss P.J. & Jones G.K. (eds.). The Lallee Lands. A Conservation Perspective. CSIRO: 224–225.

Norton R.A. 1980. Observations on phoresy by Oribatid mites (Acari: Oribatei). Internat. J. Acarol. **6**, 2: 121–130.

Norton R.A. 1986. Aspects of the biology and systematics of soil arachnids, particularly saprophagous and mycophagous mites. Quaest. Entomol. **21**: 523–539.

Norton R.A. 1994. Evolutionary aspects of oribatid mite life histories and consequences for the origin of the Astigmata. In: Houck M.A. (ed.). Mites: Ecological and evolutionary analyses of life-history patterns. Chapman and Hall. New York: 99–135.

Norton R.A., Palmer S.C. & Wang H.-f. 1988. Parthenogenesis in Nothridae and related groups. In: Channabasavanna G.P., Viraktamath C.K. (eds.). Progress in Acarology. Proc. VIIth Intern. Congr. Acarology, Bangalore (August, 1986). Oxford & IBH Publ. Co. New Delhi **1**: 255–259.

Norton R.A. & Palmer S.C. 1991. The distribution, mechanisms and evolutionary significance of parthenogenesis in oribatid mites. In: Schuster R. & Murphy P.W. (eds.). The Acari: Reproduction, Development and Life-History Strategies. Chapman & Hall. London: 107–136.

Norton R.A. & Behan-Pelletier V.M. 1991. Calcium carbonate and calcium oxalate as cuticular hardening agents in oribatid mites (Acari: Oribatida). Can. J. Zool. **69**, 6: 1504–1511.

Norton R.A., Kethley J.B., Johnston D.E. & O'Connor B.M. 1993. Phylogenetic perspectives on genetic systems and reproductive modes of mites. In: Wrensch D. & Ebbert M. (eds.). Evolution and diversity of sex ratio in insects and mites. Chapman & Hall, USA: 8–99.

Odum E.P. 1969. The strategy of ecosystem development. Science **164**: 262–270.

Ojala R. & Huhta V. 2001. Dispersal of microarthropods in forest soil. Pedobiologia **45**: 443–450.

Olszanowski Z. 1996. Moss-mites (Acari: Oribatida) – little known parasites of fish (in Polish). Przegl. Zool. **40**, 1–2: 123–126.

Olszanowski Z., Rajski A. & Niedbała W. 1996. Catalogus faunae Poloniae. Acari. Oribatida (in Polish). PAN, Muzeum i Instytut Zoologii. SORUS. Poznań **34**, 9: 1–243.

Olszanowski Z. & Niedbała W. 2000. Moss-mites (Acari: Oribatida) from the Słońsk nature reserve: Geographic elements and the types of phagism. Biological Bulletin, Poznań **37**, 2: 299–302.

Osler G.H. & Beattie A.J. 2001. Contribution of oribatid and mesostigmatid soil mites in ecologically based estimates of global species richness. Austral Ecology **26**: 70–79.

Ostrowska A., Gawliński S. & Szczubiała Z. 1991. Metody analizy i oceny właściwości gleb i roślin. Katalog. Instytut Ochrony Środowiska. Warszawa, pp. 334.

Pande Y.D. & Berthet P. 1973. Studies on the food and feeding habits of soil Oribatei in a Black Pine Plantation. Oecologia **12**, 4: 413–426.

PANDE Y.D. & BERTHET P. 1975. Observations on the vertical distribution of soil Oribatei in a woodland soil. Trans. R. ent. Soc. **127**, 3: 259–275.

PARMELEE R.W., WENTSEL R.S., PHILLIPS C.T., SIMINI M. & CHECKAI R.T. 1993. Soil microcosm for testing the effects of chemical-pollutants on soil fauna communities and trophic structure. Environ. Toxic. Chem. **12**, 8: 1477–1486.

PARMENTER R.R. & MACMAHON J.A. 1987. Early Successional Patterns of Arthropod Recolonization on Reclaimed Strip Mines in Southwestern Wyoming: The Ground-dwelling Beetle·Fauna (Coleoptera). Environ. Entomol. **16**, 1: 168–177.

PARR T.W. 1978. An analysis of soil-arthropod succession. Sci. Proc. R. Dublin. **A, 6**: 185–196.

PEET R.K. 1974. The measurement of species diversity. Ann. Rev. Ecol. Syst. **5**: 285–307.

PETERSEN H. 1982. Structure and size of soil animal populations. Oikos **39**: 306–329.

PETERSEN H. & KROGH P.H. 1987. Effects of perturbing microarthropod communities of a permanent pasture and a rye field by an insecticide and a fungicide. In: STRIGANOVA B.R. (ed.). Soil Fauna and Soil Fertility. Proceedings of the 9th International Colloquium on Soil Zoology, Moscow 1985. Izd. Nauka. Moscow: 217–229.

PIELOU E.C. 1969. An Introduction to Mathematical Ecology. Wiley. New York.

PIELOU E.C. 1984. The Interpretation of Ecological Data. A Primer on Classification and Ordination. John Wiley & Sons. New York, pp. 263.

PIŻL V. 1992. Succession of earthworm populations in abandoned fields. Soil Biol. Biochem. **24**: 1623–1628.

PLOWMAN K.P. 1981. Inter-relation between environmental factors and Cryptostigmata and Mesostigmata (Acari) in the litter and soil of two Australian subtropical forests. J. Anim. Ecol. **50**: 533–542.

PONGE J.-F. 1993. Biocenoses of Collembola in Atlantic temperate grass-woodland ecosystems. Pedobiologia **37**: 223–244.

PULLINEN S. 1986. The vegetation succession on abandoned fields. Memoranda Soc. Fauna Flora Fennica **62**: 83–87.

RAJSKI A. 1959. Moss-mites (Acari: Oribatei) as intermediate hosts of *Anoplocephalata*. Review. Zesz. Nauk. UAM **2**: 163–192.

RAJSKI A. 1961. Faunistic-ecological investigations on moss-mites (Acari, Oribatei) in several plant associations (in Polish). Pr. Kom. Mat. Przyr. PTPN **25**: 1–161.

RAJSKI A. 1967. Autecological-zoogeographical analysis of moss mites (Acari, Oribatei) on the basis of fauna in the Poznań environs. Part I. Pol. Pismo Entomol. **37**: 69–166.

RAJSKI A. 1968. Autecological-zoogeographical analysis of moss mites (Acari, Oribatei) on the basis of fauna in the Poznań environs. Part II. Fragm. Faun. **14**, 12: 277–405.

REEVES R.M. 1969. Seasonal distribution of some forest soil oribatei. Proc. 2nd Int. Congr. Acarology, Sutton Bonington 1967: 23–30.

RICHARDS L.A. 1941. A pressure-membrane extraction apparatus for soil solution. Soil Science **51**, 5: 377–386.

RJABININ N.A. & PAN'KOV N. 1987. The role of parthenogenesis in biology of Oribatid mites (in Russian). Ecologia **4**: 62–64.

ROSTAŃSKI A. 1991. A spontaneous succession of plant cover on selected industrial heaps in the voivodeship of Katowice (in Polish). Kształtowanie środowiska geograficznego i ochrona przyrody na obszarach uprzemysłowionych i zurbanizowanych. Katowice–Sosnowiec **3**: 35–38.

ROSTAŃSKI A. 1997. Flora of the industrial dumps of Upper Silesia Region (in Polish). Archives of Environmental Protection **23**, 3-4: 159–165.

Rusek J. 1975. Die bodenbildende Funktion von Collembolen und Acarina. Pedobiologia **15**: 299–308.

Rusek J. 1986. Soil microstructures – contributions on specific soil organisms. Quaest. Ent. **21**: 497–514.

Russell D.J., Zeller U., Kratzmann M. & Alberti G. 1996. The mite fauna of continental sand dunes in the Upper Rhine Valley, Germany. In: Rodger M., Horn D.J., Needham G.R., Welbourn C. (eds.). Acarology IX: Proceedings. Vol. 1. Ohio Biological Survey Columbus, Ohio: 75–80.

Safriel U.N. & Ritte U. 1980. Criteria for the identification of potential colonizer. Biol. J. Linn. Soc. **13**: 287–297.

Salminen J. & Sulkava P. 1996. Distribution of soil animals in patchily contaminated soil. Soil Biol. Biochem. **28**, 10/11: 1349–1355.

Santas Ph. 1986. Soil communities along a gradient of urbanization. Rev. Écol. Biol. Sol **23**, 4: 367–380.

Santos P.F., Depree E. & Whitford W.G. 1978. Spatial distribution of litter and microarthropods in a Chihuahuan desert ecosystem. J. Arid Environ. **2**: 41–48.

Schatz H. 1983a. Der Einfluß des Tourismus auf Mesoarthropoden des Hochgebirges. Ber. nat.-med. Verein Innsbruck **70**: 93–97.

Schatz H. 1983b. Catalogus Fauna Austriae, Teil IXi U. – Ordn.: Oribatei, Hornmilben. Vienna: Österreichischen, Akademie der Wissenschaften, pp. 118.

Schatz H. 1985. The life cycle of an Alpine oribatid mite, *Oromurcia sudetica* Willmann. Acarologia **26**: 95–100.

Schenker R. 1986. Population dynamics of oribatid mites in a forest soil ecosystem. Pedobiologia **29**, 4: 239–246.

Scheu S. & Schulz E. 1996. Secondary succession, soil formation and development of a diverse community of oribatids and saprophagous soil macro-invertebrates. Biodivers. Conserv. **5**: 235–250.

Schneider R., Schneider H. & Schröder D. 1995. Beziehung zwischen bodenorganismen und gefügeentwicklung auf Löss-Neuland unter acker – und waldnutzung. Z. Pflanzenernähr. Bodenk. **158**: 197–204.

Scullion J. & Malik A. 2000. Earthworm activity affecting organic matter, aggregation and microbial activity in soils restored after opencast mining for coal. Soil Biology & Biochemistry **32**: 119–126.

Seastedt T.R. 1984. The role of microarthropods in decomposition and mineralization processes. Ann. Rev. Entomol. **29**: 25–46.

Seniczak S. 1975. Wpływ gatunkowej analizy stadiów młodocianych na wskaźniki ekologiczne mechowców (Acarina, Oribatei). Streszczenie referatów. I Sympozjum Zoologii Gleby, PTG **1**: 129–132.

Seniczak S. 1978. Juvenile stages of moss-mites (Acarina, Oribatei) as an essential component of agglomerations of these mites transforming the organic matter of soil (in Polish). Zeszyty Naukowe UMK, Toruń: 1–171.

Seniczak S. 1994. The differentation of soil mites in a Scots pine forest with the specific analysis of Oribatida (Acari) (in Polish). Zesz. Nauk. ATR. Zootechnika. Bydgoszcz **26**: 103–110.

Seniczak S., Klimek A. & Kaczmarek S. 1994. The mites (Acari) of an old Scots pine forest polluted by a nitrogen fertilizer factory at Włocławek (Poland). II: Litter/soil fauna. Zool. Beitr., N. F. **35**: 199–216.

Seniczak S., Górniak G. & Kaczmarek S. 1985. Mite fauna of selected salt soils in the region of influence of Janikowo Soda Factory (in Polish). Zesz. Nauk. ATR. Zootechnika. Bydgoszcz **10**: 101–112.

Seniczak S., Kaczmarek S. & Klimek A. 1991. The soil mites fauna (Acari) of some spinney in the region of Turew. I. (in Polish). Zesz. Nauk. ATR. Zootechnika. Bydgoszcz **19**: 143–153.

SENICZAK S., DĄBROWSKI J., KLIMEK A. & KACZMAREK S. 1996. The mites associated with young Scots pine forests polluted by a copper smelting works in Głogów, Poland. In: RODGER M., HORN D.J., NEEDHAM G.R., WELBOURN C. (eds.). 1996. Acarology IX: Proceedings. Vol. 1. Ohio Biological Survey Columbus, Ohio: 573–574.

SENICZAK S., KLIMEK A., GACKOWSKI G., KACZMAREK S. & ZALEWSKI W. 1997. Effect of copper smelting air pollution on the mites (Acari) associated with young *Scots pine* forests polluted by a copper smelting works at Głogów, Poland. II. Soil mites. Water, Air and Soil Pollution **97**, 287–302.

SENICZAK S., DĄBROWSKI J., KLIMEK A. & KACZMAREK S. 1998. Effects of air pollution produced by a nitrogen fertlizer factory on the mites (Acari) associated with young Scots pine forests in Poland. Appl. Soil Ecol. **9**: 453–458.

SEYD E.L. 1962. The moss mites of Kinder Scout, Derbyshire (Acari: Oribatei). J. Linn. Soc. (Zool.) **44**: 585–591.

SEYD E.L. 1979. The evolution and distribution of *Calyptozetes sarekensis* (Acari: Oribatei). Biol. J. Linn. Soc. **12**: 1–18.

SEYD E.L. 1992. Moss-mites (Acari: Oribatida) in a lichen sample from Mount Leinster, Co. Carlow, Eire, and their bearing on a land connection between Britain and Ireland during Quaternary and Post-glacial times. J. Biogeogr. **19**: 401–409.

SIEPEL H. 1995a. Applications of microarthropod life-history tactics in nature management and ecotoxicology. Biol. Fertil. Soils **19**: 75–83.

SIEPEL H. 1995b. Are some mites more ecologically exposed to pollution with lead than others? Exp. & Appl. Acarol. **19**, 7: 391–398.

SIEPEL H. 1996. Biodiversity of soil microarthropods: the filtering of species. Biodivers. Conserv. **5**: 251–260.

SIEPEL H. & DE RUITER-DIJKMAN E.M. 1993. Feeding guilds of oribatid mites based on their carbohydrase activities. Soil Biol. Biochem. **25**, 11: 1491–1497.

SKUBAŁA P. 1995. Moss-mites (Acarina: Oribatida) on industrial dumps of different ages. Pedobiologia **39**: 170–184.

SKUBAŁA P. 1996. Moss-mites communities (Acarida, Oribatida) on galena-calamine mining wastelands. Acta Biol. Sil. **28**, 45: 147–169.

SKUBAŁA P. 1997a. Oribatid mite communities (Acari, Oribatida) on postindustrial dumps of different kinds. I: Abundance and species richness. Abh. Ber. Naturkundemus. Görlitz **69**, 6: 63–68.

SKUBAŁA P. 1997b. The structure of oribatid mite communities (Acari, Oribatida) on mine dumps and reclaimed land. Zool. Beitr., N.F. **38**, 1: 1–22.

SKUBAŁA P. & MADEJ G. 1997. Oribatid and mesostigmatid mites (Acari) of the beech forest on the abandoned galena-calamine wastelands in the "Segiet" reserve. In: BOCZEK J., IGNATOWICZ S. (eds.). Proceedings of the Symposium on "Advances of Acarology in Poland", Siedlce, September 26–27, 1995: 84–87.

SKUBAŁA P. 1998. Oribatid mite communities (Acari, Oribatida) on postindustrial dumps of different kinds. II. Zoocenological analysis. Fragm. Faun. **41**,14: 193–207.

SKUBAŁA P. 1999. Colonization of a dolomitic dump by oribatid mites (Acari, Oribatida). Pedobiologia **43**: 145–159.

SKUBAŁA P. 2002a. Development of oribatid mite communities (Acari, Oribatida) on a mine dump. In: BERNINI F., NANNELLI R., NUZZACI G., DE LILLO E. (eds.). Acarid Phylogeny and Evolution. Adaptations in mites and ticks. Kluwer Academic Publishers: 209–215.

SKUBAŁA P. 2002b. Biodiversity of oribatid mites (Acari: Oribatida) on postindustrial dumps. In: IGNATOWICZ S. (ed.). Postępy polskiej akarologii. Wyd. SGGW. Warszawa: 194–202.

SKUBAŁA P. 2002c. Development of oribatid mite fauna (Acari, Oribatida) in a sedimentation tank. In: TAJOVSKÝ K., BALIK V. & PIŽL V. (eds.). Studies on Soil Fauna in Central Europe. ISB AS CR, České Budějovice: 177–184.

SKUBAŁA P. 2003. Oribatid Fauna (Acari: Oribatida) of Abandoned Galena-calamine Wastelands. Archives of Environmental Protection **29**: 67–75.

SKUBAŁA P. & DZIUBA S. 1995. Soil mites (Acarida) of urban green in Katowice. Fragm. Faun. **37**, 22: 485–504.

SKUBAŁA P., DZIUBA S., STODÓŁKA A. 1998. Acari and Collembola in the "Żabie Doły" protected area or how nature struggles with industry. Zesz. Nauk. ATR. Ochrona Środowiska. Bydgoszcz **2**: 251–257.

SKUBAŁA P. & NIEMI R. 1998. Oribatid mites (Acari: Oribatida) new to the Polish fauna from galena-calamine mining wastelands. Ann. of the Upper Silesian Museum, Natural History **15**: 31–44.

SKUBAŁA P. & CIOSK M. 1999. Oribatid mites (Acari, Oribatida) colonizing the zinc metallurgic dump. Fragm. Faun. **42**, 6: 41–45.

SKUBAŁA P. & BIELSKA A. 2000. Oribatid fauna (Acari; Oribatida) in biotopes of the "Góra Chełm" Reserve. In: IGNATOWICZ S. (ed.). Akarologia polska u progu nowego tysiąclecia. Wyd. SGGW. Warszawa: 135–141.

SMRŽ J. 1992. Some microanatomical aspect of parthenogenesis in oribatid mites (Acari: Oribatida). In: BENNETOVÁ B., GELBIČ I. & SOLDÁN T. (eds.). Advances in regulation of insect reproduction. Inst. Entomol. Czech Acad. Sci. České Budějovice: 279–280.

SMRŽ J. & JUNGOVÁ E. 1989. The ecology of a field population of *Tyrophagus putrescentiae* (Acari: Acaridida). Pedobiologia **33**: 183–192.

SMRŽ J. & STARÝ J. 1995. Acarina: Oribatida. Folia Fac. Sci. Nat. Univ. Masarykianae Brunensis, Biologia **92**: 79–85.

SOUTHWOOD T.R.E. 1988. Tactics, strategies and templets. Oikos **52**: 3–18.

SØVIK G. & LEINAAS H.P. 2002. Variation in extraction efficiency between juvenile and adult oribatid mites: *Ameronothrus lineatus* (Oribatida, Acari) in a MacFadyen high-gradient canister extractor. Pedobiologia **46**: 34–41.

STAMOU G.P. & ARGYROPOULOU 1995. A preliminary study on the effect of Cu, Pb and Zn contamination of soils on community structure and certain life-history traits of oribatids from urban areas. Exp. & Appl. Acarol. **19**: 381–390.

STANTON N.L. 1979. Patterns of species diversity in temperate and tropical litter mites. Ecology **60**: 295–304.

STARÝ J. 1999. Changes of oribatid mite communities (Acari: Oribatida) during secondary succession on abandoned fields in South Bohemia. In: TAJOVSKÝ K. & PIŽL V. (eds.). Soil Zoology in Central Europe. České Budějovice: 315–323.

STARÝ J. & BLOCK W. 1998. Distribution and biogeography of oribatid mites (Acari: Oribatida) in Antarctica, the sub-Antarctic islands and nearby land areas. J. Nat. History **32**: 861–894.

STEBAEVA S.K. & ANDRIEVSKII V.S. 1997. Collembola and Oribatei of Brown Coal Dumps in Siberia. Rus. J. Zool. **1**, 3: 292–301.

STEFANIAK O. & SENICZAK S. 1981. The effect of fungal diet on the development of *Oppia nitens* (Acari, Oribatei) and on the microflora of its alimentary tract. Pedobiologia **21**: 202–210.

STEINBERGER Y. ALDON E.F. & WHITFORD W.G. 1990. Soil microarthropod fauna of four habitats of the Rio Puerco watershed, New Mexico. Southwestern Naturalist **35**: 279–284.

STEINER W.A. 1995. Influence of air pollution on moss-dwelling animals. 3: Terrestrial fauna, with emphasis on Oribatida and Collembola. Acarologia **36**, 2: 149–173.

STENSETH N.C. 1979. Where have all the species gone? The nature of extinction and the Red Queen Hypothesis. Oikos **33**: 196–227.

STREIT B., BUEHLMANN A. & REUTIMANN P. 1985. Mite succession in compost communities: Studies with Oribatei, Gamasina, and Uropodina. Pedobiologia **28**: 1–12.

STROJAN C.L. 1978. The impact of zinc smelter emissions on forest litter arthropods. Oikos **31**: 41–46.

STRENZKE K. 1952. Untersuchungen über die Tiergeminschaften des Bodens: Die Oribatiden und ihre Synusien in der Böden Norddeutschlands. Zoologica, Stuttgart **1104**: 1–173.

STRÜEVE-KUSENBERG R. 1982. Succession and trophic structure of soil animal communities in different suburban fallow areas. The Second European Ecological Symposium, Berlin: 89–98.

SUBIAS L.S. & BALOGH J. 1989. Identification keys to the genera of Oppiidae Grandjean, 1951 (Acari: Oribatei). Acta zool. Hung. **35**, 3–4: 355–412.

Systematyka gleb Polski 1989. In: Roczniki Gleboznawcze **40**, 3/4, pp. 150.

TAGAMI K., ISHIHARA T., HOSOKAWA J.-I., ITO M. & FUKUYAMA K. 1992. Occurrence of aquatic oribatid and astigmatid mites in swimming pools. Water Res. **26**: 1549–1554.

TAJOVSKÝ K. 1990. Diplopoda in a secondary succession row. In: MINELLI A. (ed.). Proceedings of the 7th International Congress of Myriapodology, New York. E.J. Brill.: 229–234.

TAKEDA H. 1988. A 5 year study of pine needle litter decomposition in relation to mass loss and faunal abundances. Pedobiologia **32**: 221–226.

TER BRAAK C.J.F. 1988. CANOCO – a FORTRAN program for canonical community ordination by (partial) (detrended) (canonical) correspondence analysis, principle component analysis and redundancy analysis. Groep Landbouwwiskunde. Wageningen, pp. 95.

THIENEMANN A. 1939. Grundzüge einer allgemeinen Oekologie. Archiv. für Hydrobiologie **35**, 267–285.

THOMAS J.O.M. 1979. An energy budget for a woodland population of oribatid mites. Pedobiologia **19**, 5: 346–378.

TOKARSKA-GUZIK B., ROSTAŃSKI A. & KLOTZ S. 1991. Vegetation of the zinc smelter spoil heap in Katowice-Wełnowiec (in Polish). Acta Biol. Sil. **19**, 36: 94–102.

TOKARSKA-GUZIK B. & ROSTAŃSKI A. 2001. Prospects and limitations of natural management of post-industrial areas (in Polish). Natura Silesiae Superiors. Supplement: 5–17.

TOPP W., GEMESI O., GRÜNING C., TACH P. & ZHOU H. 1992. Fortstlische rekultivierung mit altwaldboden in Rheinischen Braunkohlenrevier. Die sukzession der bodefauna. Zool. Jahrb. Syst. **119**: 505–533.

TOUSIGNANT S. & CODERRE D. 1992. Niche partitioning by soil mites in a recent hardwood plantation in Southern Québec, Canada. Pedobiologia **36**: 287–294.

TRAVÉ J. 1963. Écologie et biologie des Oribates (Acariens) saxicoles et arboricoles. Vie et Milieu Suppl. **14** (IX): 1–267.

TRAVÉ J., ANDRÉ H.M., TABERLY G. & BERNINI F. 1996. Les Acariens Oribates. Éditions AGAR and SIALF. Wavre. Belgique.

TROJAN P. 2000. The meaning and measurement of species diversity. Fragm. Faun. **43**, 1: 1–13.

TRUEMAN I.C., COHN E.V., TOKARSKA-GUZIK B., ROSTAŃSKI A. & WOŹNIAK G. 2001. Calcerous waste slurry as wildlife habitat in England and Poland. GREEN 3. The exploitation of natural resources and the consequences. Thomas Telford, London: 527–534.

USHER M.B. 1975. Some properties of the aggregations of soil arthropods: Cryptostigmata. Pedobiologia **15**: 355–363.

USHER M.B. 1976. Aggregation responses of soil arthropods in relation to the soil environment. In: ANDERSON J.M. & MACFADYEN A. (eds.). The role of terrestrial and aquatic organisms in decomposition processes. Oxford. Blackwell Scientific Publications: 61–94.

USHER M.B. 1979. Natural communities of plants and animals in disused quarries. J. Environ. Managem. **8**: 223–236.

USHER M.B., DAVIS P., HARRIS J. & LONGSTAFF B. 1979. A profusion of species? Approaches towards understanding the dynamics on the populations of microarthropods in decomposer communities. In: ANDERSON R.M., TURNER B.D., TAYLOR L.R. (eds.). Population Dynamics. Oxford. Blackwell Scientific Publications: 359–384.

USHER M.B., BOOTH R.G. & SPARKES K.E. 1982. A review of progress in understanding the organization of communities of soil arthropods. Pedobiologia **23**: 126–144.

VALIX M., TANG J.Y. & MALIK R. 2001. Heavy metal tolerance of fungi. Minerals Engineering **14**, 5: 499–505.

VAN STRAALEN N.M. 1998. Evaluation of bioindicator systems derived from soil arthropod communities. Appl. Soil Ecol. **9**: 429–437.

VAN STRAALEN N.M., KRAAK M.H.S. & DENNEMAN C.A.J. 1988. Soil microarthropods as indicators of soil acidification and forest decline in the Veluwe area, the Netherlands. Pedobiologia **32**: 47–55.

VAN STRAALEN N.M., SCHOBBEN J.H.M. & de GOEDE R.G.M. 1989. Population consequences of cadmium toxicity in soil microarthropods. Ecotoxicol. Environ. Safety **17**: 190–204.

VAN STRAALEN N.M. & VERHOEF H.A. 1997. The development of a bioindicator system for soil acidity based on arthropod pH preferences. J. Appl. Ecol. **31**, 1: 217–232.

VANEK J. 1967. Industrieexhalate und Moosmilbengemeinschaften in Nordböhmen. In: GRAFF O. & SATCHELL J.E. (eds.). Progress in Soil Biology: 331–339.

VEERESH G.K. & RAJAGOPAL D. 1988. Applied Soil Biology and Ecology. Oxford–New Delhi. IBH Publishing Co. Bombay. PVT. Ltd. Calcutta, pp. 375.

VERHOEF H.A. & BRUSSARD L. 1990. Decomposition and nitrogen mineralization in natural and agroecosystems: the contribution of soil animals. Biogeochemistry **11**: 175–211.

VERSCHOOR B.C. & KREBS B.P.M. 1995. Successional changes in a saltmarsh carabid beetle (Coleoptera, Carabidae) community after embankment of the Markiezaat area. Pedobiologia **39**: 385–404.

VOGEL J. & DUNGER W. 1991. Carabiden und Staphyniden als Besiedler rekultivierter Tagebau-Halden in Ostdeutschland. Abh. Ber. Naturkundemus, Görlitz **65**: 1–31.

WALKER B.H. 1992. Biodiversity and ecological redundancy. Conservation Biology **6**: 18–23.

WALLWORK J.A. 1970. Ecology of soil animals. McGraw-Hill. London, pp. 283.

WALLWORK J.A. 1976. The Distribution and Diversity of the Soil Fauna. Academic Press. London, pp. 355.

WALLWORK J.A. 1983. Oribatids in forest ecosystems. Ann. Rev. Entomol. **28**: 109–130.

WALTER D.E., KRANTZ G. & LINDQUIST E.E. 1996. Tree of life, Acari. <phylogeny.arizona.edu/tree/eukaryotes/animals/arthropoda/arachnida/acari/acari.html> (4 November 1998).

WALTER D.E. & PROCTOR H.C. 1999. Mites. Ecology, Evolution and Behaviour. CABI Publishing. New York. USA, pp. 322.

WANNER M., DUNGER W., SCHULZ H.-J. & VOIGTLÄNDER K. 1998. Primary immigration of soil organisms on coal mined areas in Eastern Germany. In: PIŽL V. & TAJOVSKÝ K. (eds.). Soil Zoological Problems in Central Europe. České Budějovice: 267–275.

WARDLE D.A. & LAVELLE P. 1997. Linkages between soil biota, plant litter quality and decomposition. In: CADISCH G. & GILLER G.E. (eds.). Driven by Nature: Plant Litter Quality and Decomposition. CAB International. Wallingford: 107–124.

WARDLE D.A., BONNER K.I. & NICHOLSON K.S. 1997. Biodiversity and plant litter – experimental evidence which does not support the view that enhanced species richness improves ecosystem function. Oikos **79**, 2: 247–258.

WARDLE D., NILSSON M.C., GALLET C. & ZACKRISSON O. 1998. An ecosystem-level perspective of allelopathy. Biol. Rev. **73**: 305–319.

WATKINSON A.R. 1998. The role of the soil community in plant population dynamics. TREE **13**, 5: 171–172.

WAUTHY G. 1981. Synecology of forest soil oribatid mites of Belgium (Acari, Oribatida). II: Zoosociological uniformity. Acta Oecologia. Oecol. gener. **2**: 31–47.

WAUTHY G., NOTI M.-I. & DUFRÊNE M. 1989. Geographic ecology of soil oribatid mites in deciduous forests. Pedobiologia **33**: 399–416.

WEBB N.R. 1994. Post-fire succession of cryptostigmatic mites (Acari, Cryptostigmata) in a *Calluna*-heathland soil. Pedobiologia **38**, 2: 138–145.

WEIDEMANN G., KOEHLER H. & SCHRIEFER Th. 1982. Recultivation: a problem of stabilization during ecosystem development. In: BORNKAMM R., LEE J.A. & SEAWARD M.R.D. Urban Ecology. Blackwell. Oxford: 305–313.

WEIGMANN G. 1982. The colonization of ruderal biotopes in the city of Berlin by arthropods. In: BORNKAMM R., LEE J.A. & SEAWARD M.R.D. (eds.). Urban Ecology. Blackwell. Oxford: 75–82.

WEIGMANN G. & STRATIL H. 1979. Bodenfauna im Tiergarten. In: SUKOPP H. (Hrsg.). Ökologisches Gutachten über die Auswirkungen von Bau und Betrieb der BAB Berlin (West) auf den Großen Tiergarten. Senator für Bau- und Wohnungswesen **1**: 54–71.

WEIGMANN G. & KRATZ W. 1987. Oribatid mites in urban zones of West Berlin. Biol. Fertil. Soils **3**: 81–84.

WEST C. 1984. Micro-arthropod and plant species associations in two subantarctic terrestrial communities. Oikos **42**: 66–73.

WHELAN J. 1978. Acarine succession in grassland on cutway raised bog. Scientific Proceedings of the Royal Dublin Society **A**, **6**: 175–183.

WHITTAKER R.H. 1972. Evolution and measurement of species diversity. Taxon **21**: 213–251.

WIEGLEB G., BRÖRING U., MRZLJAK J. & SCHULZ F. 2000. Naturschutz in Bergbaufolgelandschaften. Landschaftsanalyse und Leitbildentwicklung. Physica-Verlag. Heidelberg.

WIERZBICKA M. & ROSTAŃSKI A. 2002. Microevolutionary changes in ecotypes of calamine waste heap vegetation near Olkusz, Poland. A Review. Acta Biol. Crac. **44**: 7–19.

WILLIAMSON P. & EVANS P.R. 1973. A preliminary study of the effect of high levels of inorganic lead on soil fauna. Pedobiologia **13**: 16–21.

WILSON E.O. 1988. The current state of biological diversity. In: WILSON E.O. & PETER F.M. (eds.). Biodiversity. National Academy Press. Washington, DC: 3–17.

WILSON E.O. 1992. The diversity of life. Belknap Press. Harvard.

WILSON M.V. & SHMIDA A. 1984. Measuring beta diversity with presence–absence data. J. Ecol. **72**: 1055–1064.

WINCHESTER N.N. 1997. Canopy arthropods of coastal Sitka spruce trees on Vancouver Island, British Columbia, Canada. In: STORK N.E., ADIS J. & DIDHAM R.K. (eds.). Canopy Arthropods. Chapman & Hall. London: 151–168.

WITKAMP M. 1971. Soils as components of ecosystems. Ann. Rev. Ecol. Syst. **2**: 85–110.

Wood T.G. 1971. The distribution and abundance of *Folsomides deserticola* Wood (Collembola: Isotomidae) and other microarthropods in arid and semiarid soils in southern Australia with a note on nematode populations. Pedobiologia **11**: 446–468.

Wolf G. (ed.). 1985. Primäre Sukzession auf kiesig-sandigen Rohböden im Rheinischen Braunkohlenrevier. Schriftenreihe für Vegetationskunde **16**: 1–203.

Woodring J.P. & Cook E.F. 1962. The biology of *Ceratozetes cisalpinus* Berlese, *Scheloribates laevigatus* Koch, and *Oppia neerlandica* Oudemans (Oribatei) with a description of all stages. Acarologia **4**: 101–137.

Zachvatkin A.A. 1947. Nekotorye itogi i perspektivy razvitija sel'skochozjajstvennoj i obščej akarologii v SSSR. Zool. Zh. **26**, 5: 437–450.

Zaitsev A.S. 1998. Populations of oribatid mites in the surroundings of Kosaya Gora near a metallurgic plant. In: Butovsky R.O. & Van Straalen N.M. (eds.). Pollution-induced Changes in Soil Invertebrate Food-Webs. Amsterdam and Moscow **3**: 45–53.

Zaitsev A.S. 1999. Metal accumulation by oribatid mites in the surroundings of the Kosogorsky metallurgical plant. In: Butovsky R.O. & Van Straalen N.M. (eds.). Pollution-induced Changes in Soil Invertebrate Food-Webs. Amsterdam and Moscow **4**: 51–70.

Zaitsev A.S. & Krivolutsky D.A. 1999. Responses of oribatid mite communities to the impact of a metallurgical plant in the Netherlands (Ijmuiden). In: Butovsky R.O. & Van Straalen N.M. (eds.). Pollution-induced Changes in Soil Invertebrate Food-Webs. Amsterdam and Moscow **2**, 3: 43–50.

Zalewska M. 1989. Moss-mites (Oribatida, Acarida) of the eastern part of the forest-steppe reserve in Bielinek on the Oder (in Polish). Acta Biol. et Marin. Univ. Stettin. **1**: 53–143.

Zalewska M. & Rajski A. 1990. Mechowce (Oribatida, Acarida) gołoborzy w Świętokrzyskim Parku Narodowym. Fragm. Faun. **33**, 13: 191–201.

Zar J.H. 1999. Biostatistical analysis. Prentice Hall, Upper Saddle River. New Jersey, USA, pp. 786.

Żbikowska-Zdun K. 1988. Species diversity and biomass of communities of moss-mites (Oribatida, Acarida) of three different biotopes in the Upper Silesian Region. Acta Biol. Sil. **10**, 27: 46–61.

Żyromska-Rudzka H. 1976. The effect of mineral fertilization of a meadow on the oribatid mites and other soil mesofauna. Pol. ecol. Stud. **2**, 4: 157–182.

Piotr Skubała

Kolonizacja i rozwój zgrupowań mechowców (Acari: Oribatida) na zwałach poprzemysłowych

Streszczenie

W pracy analizowano sukcesję zgrupowań glebowych roztoczy z rzędu Oribatida na sześciu zwałach poprzemysłowych różnego typu (zwały kopalniane, zwał hutnictwa żelaza, zwał pocynkowy, osadnik wód kopalnianych) oraz na rekultywowanych zwałach kopalnianych. Ponadto badano faunę Oribatida w przylegającym do zwału biotopie. Na 28 stanowiskach badawczych pobrano ogółem 5260 prób glebowych wykorzystanych do analizy zoocenologicznej, 224 próby służące do analiz glebowych i 1444 próby do oceny względnej wilgotności. Ogółem zebrano ponad 133 tysiące przedstawicieli mezofauny glebowej (roztoczy i skoczogonków), w tym ponad 73 tysiące reprezentantów rzędu Oribatida.

Wyróżniono 3 stadia sukcesyjne w rozwoju zgrupowań Oribatida – „pionierskie", „łąkowe" i „przedleśne". Mechowce, mimo cech charakterystycznych dla „*K*-strategów", możemy uznać za grupę, która z powodzeniem zasiedla hałdy. Mogą one osiągnąć zagęszczenie około 12 000 osobników/m^2 po kilku latach i stają się dominującą grupą wśród mezofauny glebowej po 10–15 latach. Wśród gatunków zasiedlających zwały wyróżniono wczesnych kolonizatorów, a wśród nich tzw. „sprinterów" (np. *Brachychochthonius cricoides*, *Liochthonius piluliferus*, *Scutovertex sculptus*) oraz „długodystansowców" (np. *Oppiella nova*, *Peloptulus phaenotus*, *Tectocepheus velatus*), a także gatunki „późnej" sukcesji (np. *Eupelops tardus*, *Punctoribates punctum*, *Tectocepheus minor*). Do cech zoocenotycznych, które z największym prawdopodobieństwem pozwalają określić stadium rozwoju zgrupowania, należą między innymi: struktura dominacji, udział określonych kohort systematycznych, czy stadiów młodocianych wybranych gatunków.

Bardzo różne czynniki środowiskowe (w pracy analizowano oddziaływanie ponad 20 parametrów glebowych i dotyczących roślin) w znaczący sposób wpływają na rozwój zgrupowań znajdujących się na poszczególnych stanowiskach na zwałach różnego typu. Zawartość niektórych pierwiastków, np. magnezu i sodu, najczęściej odnotowywano jako mającą największy wpływ na kształtowanie się zgrupowań. Ogólną charakterystykę zgrupowania mechowców (z wyjątkiem składu gatunkowego) można stosunkowo najłatwiej określić, opierając się na cechach roślinności występującej na danej powierzchni. Rodzaj składowanych odpadów nie wpływa w istotny sposób na strukturę czy skład gatunkowy zgrupowań mechowców.

Oddziaływanie otaczających biotopów na skład gatunkowy i tempo rozwoju zgrupowań mechowców na zwałach było słabo zaznaczone. Zwykle połowa i więcej gatunków pojawiających się na hałdach była nieobecna w ich najbliższym otoczeniu. Pozytywny wpływ rekultywacji prowadzonej na zwałach jest zauważalny tylko w początkowym etapie rozwoju zgrupowań Oribatida. Po około 20 latach obserwuje się negatywne trendy w rozwoju fauny roztoczy, np. spadek zagęszczenia i liczby gatunków. Żaden z modeli sukcesji („ułatwiania", „hamowania" czy „tolerancji") nie wyjaśnia w sposób bezpośredni i pełny rozwoju fauny Oribatida. Niemniej jednak wydaje się, że model „ułatwiania" najlepiej opisuje większość zjawisk obserwowanych w odniesieniu do tej grupy zwierząt na zwałach poprzemysłowych.

Zebrane mechowce należały do 172 gatunków Oribatida (co stanowi ponad 30% fauny Oribatida Polski), w tym 8 gatunków i 1 podgatunek były nowe dla fauny Polski, a 37 to gatunki nowe dla fauny Górnego Śląska.

Piotr Skubała

Ansiedlung und Entwicklung der Moostiereansammlungen (Acari: Oribatida) auf postindustriellen Haufen

Zusammenfassung

In der vorliegenden Arbeit wurde die Sukzession der Ansammlungen von Bodenmilben (Ordnung: Oribatida) auf sechs verschiedenartigen, postindustriellen Haufen (Grubenhaufen, Eisenhüttenhaufen, Postzinkhaufen, Grubenwasserabsetzbecken) und auf rekultivierten Bergwerkhaufen untersucht. Außerdem untersuchte man die Fauna Oribatida in dem an den Haufen angrenzenden Biotop. An 28 Forschungsstellen wurden insgesamt 5260 Bodenproben entnommen, die bei der zoozönologischen Analyse verwandt wurden; 224 Proben dienten der Bodenanalyse und 1444 der Beurteilung von relativer Feuchtigkeit. Alles in Allem wurden über 133 Tausend Vertreter der Bodenmesofaune gesammelt (Milben und Springschwänze), darunter über 73 Tausend Vertreter der Ordnung: Oribatida.

Es wurden 3 Sukzessionsstadien in der Entwicklung der Ansammlungen von Oribatida unterschieden: „Pionierstadium“-, „Wiesenstadium“- und „Vorwaldstadium“. Trotz ihrer für „*K*-Strategen“ typischen Eigenschaften kann man die Mosstiere für eine solche Gruppe halten, die mit Erfolg die Haufen besiedelt. Nach einigen Jahren können sie die Verdichtung von etwa 12 000 Einzelwesen pro Quadratmeter erreichen und nach 10–15 Jahren werden sie eine dominierende Gruppe in der Bodenmesofaune. Unter den die Haufen besiedelten Gattungen wurden frühe Kolonisatoren unterschieden, und darunter sog. Sprinter (z.B.: *Brachychochthonius cricoides, Liochthonius piluliferus, Scutovertex sculptus*) und sog. Langstreckenläufer (z.B.: *Oppiella nova, Peloptulus phaenotus, Tectocepheus velatus*) als auch Gattungen der „späten“ Sukzession (z.B.: *Eupelops tardus, Punctoribates punctum, Tectocepheus minor*). Zu zoozönotischen Eigenschaften, die mit höchster Wahrscheinlichkeit das Entwicklungsstadium der Ansammlung bestimmen lassen, gehören u.a.: die Dominanzstruktur, der Anteil von bestimmten systematischen Kohorten oder jugendlichen Stadien der ausgewählten Gattungen.

Ganz unterschiedliche Umweltfaktoren (in der vorliegenden Arbeit wurde die Einwirkung von über 20 Boden- und Pflanzenparametern untersucht) beeinflussen wesentlich die Entwicklung der Ansammlungen an den einzelnen Stellen auf verschiedenartigen Haufen. Der Gehalt von manchen Elementen, z.B. Magnesium und Natrium sollte den größten Einfluss auf die Bildung von Ansammlungen haben. Die allgemeine Charakteristik der Moostiereansammlungen (mit Ausnahme von der Gattungszusammensetzung) kann am schnellsten anhand der Charakteristik von den, auf der bestimmten Fläche auftretenden Pflanzen bezeichnet werden. Die Art der angehäuften Abfälle übt keinen wesentlichen Einfluss auf die Struktur oder auf die Gattungszusammensetzung der Moostiereansammlungen aus.

Die Einwirkung der umgebenden Biotope auf die Gattungszusammesetzung und das Entwicklungstempo der Moostiereansammlungen auf den Haufen war nur schwach abgezeichnet. Meist die Hälfte oder mehrere auf den Haufen auftretenden Gattungen waren in ihrer nächsten Umgebung nicht vorhanden. Der positive Einfluss von der auf den Haufen geführten Rekultivierung war nur in der ersten Entwicklungsetappe von Oribatida bemerkbar. Nach ungefähr 20 Jahren beobachtet man negative Trends in der Entwicklung der Milbenfauna, wie z.B. sinkende Verdichtung, und wenigere Gattungen. Kein von den Sukzessionsmodellen

(„Erleichterung“, „Hemmung“ oder „Toleranz“) kann die Entwicklung der Oribatida – Fauna direkt und vollständig erläutern. Doch das „Erleichterungsmodell“ scheint die meisten, auf den Haufen beobachteten Erscheinungen am besten beschreiben zu können.

Die gesammelten Moostiere gehörten zu 172 Oribatida – Gattungen (was über 30% der polnischen Oribatida-Fauna bildet), darunter waren 8 Gattungen und eine Untergattung für die Fauna Polens, und 37 Gattungen für die oberschlesische Fauna ganz neu.

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This book describes a thorough ecological study of oribatid mite communities on seven different post-industrial dumps, which appear to be an excellent experimental field to study succession. Space-for-time and direct long-term observations were used to analyse the colonization by and development of oribatids in specific technogenic habitats. Saprophagous oribatid mites in the soil prove to be successful colonizers of this new environment created by human activity. Remarks on the ecological features of many species, driving factors influencing oribatid fauna, ways of migration, and the effectiveness of reclamation measures are included.

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