Collembola in Landscape Ecology

Collembolen in der Landschaftsökologie

Dissertation
Zur Erlangung des Doktorades
An der Universität für Bodenkultur

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Tag der Einreichung: 10. Oktober 2008
Tag der mündlichen Verteidigung: 31. Oktober 2008

Summary

The aim of this thesis is to summarize the current knowledge of landscape scale patterns in the ecology of the soil fauna, to investigate some effects of landscape heterogeneity and change on Collembola communities, and to optimize sampling methods for soil microarthropods to use them in biodiversity assessments or landscape ecological projects.

In the Introduction, an overview of landscape-level patterns and processes relevant for soil zoology is given. Issues like landscape heterogeneity, fragmentation, metapopulation processes, land use history and dispersal are discussed for Collembola, Oribatida, Gamasida, terrestrial nematodes and Lumbricidae. Few publications were found focusing specifically on soil animals in landscape ecology. Springtails and earthworms were found to be affected by habitat fragmentation, land use history and landscape structure. Additionally, metapopulation processes, active movement or passive dispersal across the landscape are discussed for the animal groups in a landscape context.

To use Collembola in biodiversity assessments or landscape ecological projects, their sampling needs to be optimized. We combined pitfall traps and soil cores to collect both eu- and epedaphic species. Identifying five replicates each collected a high total species number with a low sampling, sorting and identification effort.

To investigate the effects of a natural forest fire and the following succession on the Collembola in a subalpine habitat (dwarf-pine forest), communities of a recently burned, a fifty year burned and a reference site were compared. The results show that the recently burned site had an equally high abundance and species richness as the reference site, but that the composition of the communities differed. The fifty year old burned site exhibited much lower abundance, species richness and different community composition and than the two other sites. These results indicate that the Collembola communities need much longer than fifty years to recover from a natural and large scale landscape change like a forest fire in harsh subalpine environments.

The final part of the thesis addresses effects of landscape heterogeneity on Collembola communities in agricultural fields. I found that both the eu- and epedaphic species were influenced by the composition of the landscape surrounding the investigated sites. Site variables like soil index, soil moisture or vegetation cover had low explanatory power for the Collembola diversity. Landscape diversity at a 1,500 m radius around the fields was the best predicting landscape variable. Other relevant landscape variables were percentage of woody area, oilseed rape field area or isolation of open habitats. We found two spatial scales relevant for the landscape variables around the investigated fields, namely small scale effects at close radii and large scale effects at 1,000-2,000 m radii around the sites. Active migration and passive dispersal with wind might be responsible for this spatial differentiation. Probably both processes frequently take place in open landscapes.

Keywords: Collembola; Soil animals; Landscape ecology; Fire; Biodiversity; Sampling

Zusammenfassung

Ziel dieser Arbeit ist es, den aktuellen Wissensstand über die Landschaftsökologie von Bodentieren zusammenzufassen, Einflüsse von Landschaftsstruktur und Landschaftsveränderung auf Collembolen zu untersuchen und gängige Sammelmethoden für die Bodenmesofauna zu optimieren, um diese vermehrt in Biodiversitäts- und landschaftsökologischen Untersuchungen einsetzen zu können.

Die Einleitung gibt einen Überblick über landschaftsökologische Prozesse und Muster, die für Bodentiere relevant sein können. Themen wie Landschaftsheterogenität, Habitatfragmentierung, Metapopulationsprozesse, Landnutzungsgeschichte und Ausbreitung werden für Collembolen, Oribatiden, Gamasinen, terrestrische Nematoden und Regenwürmer diskutiert. Nur wenige Arbeiten wurden zu Bodentieren und Landschaftsökologie gefunden; es zeigt sich aber, dass die Gemeinschaften von Springschwänzen und Regenwürmern von Landschaftsstruktur, Nutzungsgeschichte und Fragmentierung beeinflusst werden. Weiters werden Metapupolationsprozesse, aktive Migration und passive Verdriftung von Bodentieren in der Landschaft in einem landschaftsökologischen Kontext besprochen.

Um Collembolen in Biodiversitätsuntersuchungen und landschaftsökologischen Projekten besser untersuchen zu können, müssen die gängigen Sammelmethoden optimiert werden. Ich habe Bodenproben mit Barberfallen kombiniert, um die epigäischen und endogäischen Arten gleichermassen adäquat zu besammeln und konnte zeigen, dass damit ein Großteil der Arten mit einem stark reduzierten Sammel-, Sortier- und Bestimmungsaufwand gefunden werden kann.

Um die Effekte eines natürlichen Feuers und die darauffolgende Sukzession der Collembolen in einem subalpinen Latschenbestand zu untersuchen, wurden die Gemeinschaften einer frischen, einer fünfzigjährigen und einer Referenzfläche verglichen. Die Ergebnisse zeigen, dass die kürzlich abgebrannte Fläche ähnliche Artenzahlen und Individuendichten wie die Referenzfläche aufweist, die Gemeinschaften sich aber unterscheiden. Die fünfzigjährige Brandfläche ist durch eine geringe Artenzahl, Abundanz und eine spezifische Gemeinschaft charakterisiert. Diese Ergebnisse weisen darauf hin, dass Collembolengemeinschaften subalpiner Lagen weit mehr als fünfzig Jahre brauchen können, um sich von einer großflächigen Landschaftsveränderung wie einem Feuer zu erholen.

Der abschließende Teil der Arbeit untersucht den Effekt der Struktur von Landschaften auf Collembolen in Rapsfeldern. Sowohl die epigäischen als auch die endogäischen Arten sind von der Struktur der die untersuchten Flächen umgebenden Landschaft beeinflusst. Standortsparameter wie Bodenzahl, Bodenfeuchte und Deckung haben einen geringen

Erklärungswert für die Diversität der Collembolengemeinschaften. Die Heterogenität der Landschaft in einem Radius von 1500 m um die Flächen hatte den besten Erklärungswert, andere relevante Landschaftsfaktoren waren die Fläche von Gehölzen und anderen Rapsfeldern und der Isolationsgrad offener Habitate. Wir konnten zwei räumliche Skalen von Landschaftseinflüssen unterscheiden, nämlich einen nahen Radius und 1000-2000 m um die Flächen. Aktive Migration und passive Verdriftung von Tieren mit Wind sind vermutlich verantwortlich für diese Differenzierung. Beide Prozesse kommen wahrscheinlich in einer offenen Landschaft häufig vor und prägen die Collembolengemeinschaften.

Schlagwörter: Collembola; Bodentiere; Landschaftsökologie; Feuer; Biodiversität, Sammelmethode

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Overview of the thesis

Soil animal communities are rarely considered by landscape ecologists, although they are an important component of terrestrial ecosystems, due to their high local biodiversity, high abundance and pivotal ecosystemal functions. Processes acting on landscape scales influence their communities probably to a much larger extent than commonly assumed by most soil ecologists. The aim of this thesis is to summarize current knowledge of landscape scale patterns in soil fauna ecology, investigate some effects of landscape heterogeneity and change on Collembola communities, and to optimize large scale sampling methods for soil microarthropods.

Chapter I. gives an overview of landscape-level patterns and processes relevant for soil zoology. Issues cutting across both scientific disciplines are identified and discussed, like landscape heterogeneity, fragmentation, metapopulation processes, land use history and dispersal; the problem of how to adequately sample soil faunas at large spatial scales is addressed.

Chapter II. deals with the combination of two sampling methods (pitfall traps and soil cores) to collect epigeic (surface active) and endogeic (soil living) Collembola species in biodiversity assessments, biodiversity monitorings and landscape ecology projects.

Chapter III. investigates the effects of a natural forest fire and the following succession on the Collembola communities in a subalpine habitat.

Chapter IV. addresses effects of landscape heterogeneity on Collembola communities in agricultural fields.

Chapter I.

1. The landscape ecology of soil animals

1.1 Introduction

The aim of this contribution is to discuss landscape-level patterns and processes relevant for various groups of soil animals and to suggest potential benefits for landscape ecology research in the future. Landscape ecology is a young field of ecology, although typical "landscape-issues" have a prominent place in this discipline: landscape composition effects, metapopulation processes, habitat fragmentation and animal distribution and dispersal in space all belong here. To investigate these topics, vascular plants, mammals, birds and selected arthropod groups (butterflies, spiders, ground beetles) are used. Much less is known on the landscape ecology of the vast majority of other organisms, and this is also true for all soil animals. What we have, is highly fragmentary and scattered knowledge of the biology and ecology of these creatures that is relevant at the landscape scale - pieces of information which have rarely been seen under the heading of landscape ecology. As a consequence, only vague ideas may be formulated on how the composition of landscapes may affect soil communities, and what the effects of landscape-level environmental changes might be.

Each soil organism inhabits a specific space which is probably not independent from the surrounding landscape. This landscape can vary from structurally simple with extensive agricultural fields to diverse and well-structured with many different habitats. At what special scale soil animals are affected by the landscape and if a more diverse landscape contains more species, is still not known. Processes like fragmentation of natural habitats could influence the soil animals by reducing their populations and isolating them from neighboring populations. This could have a direct effect on rare and remnant dependant species, living for example in small dry grasslands patches (islands) surrounded by agricultural fields. Metapupolation processes, the extinction and recolonization of populations, might also occur in soil animal ecology.

Soil animals should also be considered in landscape ecology because of their high local biodiversity, high abundance and pivotal ecosystem functions. Up to hundreds of species can be found in one site, most of them with a body size of 0.2-2 cm or even smaller and total abundances up to 10 million individuals*m^{-2}. Their role in the ecosystem can be assumed as important, as decomposition, soil development and nutrient cycles are all related to the activity of soil animals.

In the following text we use the term “landscape” from a human perspective (*i.e.* at a scale of 10^3 meters), as the “landscape perception” of a soil animal of 0.5 mm body length is still poorly studied (maybe 10^{-2} to 10^{-3} meters). This “human” landscape is composed of different patches resulting in a patch mosaic, each large enough to contain various animal and plant communities. Each of these patches might contain many different microhabitats for soil animals but these are not considered here.

1.2 The landscape ecology of soil microarthropods (Collembola, Oribatida and Gamasida)

Collembola (springtails), Oribatida (oribatid or beetle mites) and Gamasida (predatory mites) belong to the soil mesofauna with a body size of 0.2-2 mm. They are the dominant group of arthropods in temperate forests, grasslands and agricultural fields, have high abundances (10^4-10^5 individuals*m^{-2}), and all together may build up rich communities with several hundreds of species. Collembola and Oribatida are mainly fungi- or detritivorous and Gamasida are predatory (for example on Collembola).

Landscape composition and land use intensity

Collembola were one of the indicator groups used to investigate the effects of land use intensity on soil biodiversity in 6 countries across Europe. Six land use units (from natural forests to agricultural fields) were sampled in each country and Ponge et al. (2003, 2006) and Sousa et al. (2004, 2006) found a decrease of species richness and total abundance towards more intensively managed land. Vanbergen et al. (2007) correlated Collembola species richness with proportion of forest cover, habitat richness and patchiness at the landscape (1 km^2) and local (up to 200 m^2) scale. They found no effect of habitat richness on the Collembola richness, but a negative correlation to landscape spatial patchiness at the landscape scale. Collembola diversity was independent from local habitat variables like habitat richness, tree cover, plant species richness, litter cover, soil pH or depth of organic horizon. Querner et al. (Chapter IV in this volume) investigated the effects of landscape composition and diversity on epedaphic (surface active) and endogeic (soil living) Collembola species richness in 29 oilseed rape fields in Eastern Austria. They found a positive relationship between landscape structure (for example landscape diversity, forest and field areas within a 1,500 m radius) on the species richness in the investigated fields.

The presented studies show that the landscape composition seems to affect the diversity and community composition of the soil mesofauna in a range of habitats. The patters behind these relationships are not yet understood and could be related to the dispersal of soil animals, or to land use history.

Land use history

In 1975, the German soil zoologist Dunger introduced the idea of animal communities representing a “long term memory” of the soil: “It is obvious, that the epedaphic (=aboveground) synusiae (=communities), in connection with changes in vegetation, will be altered much more quickly and intensively than in the case of the “conservative” edaphic (=belowground) synusia” (Dunger 1975, p. 46). He deduced this from the succession of epedaphic and the euedaphic Collembola communities on an afforested coal dump site over 14 years. As this was a purely observational study, Dungers hypothesis has yet never been tested experimentally. Using a similar approach, Filser et al. (2002) investigated effects of changes in arable land management over a period of 8 years and found that the Collembola communities of deeper soil layers (>10 cm) reflected the historical management. The fauna of the upper soil layers (0-10 cm), on the contrary, closely followed the actual land use.

Ruf (personal communication, 2004) also found that the soil Gamasid fauna reflect the past land use, but only two forest sites were compared in this experiment. A large scale project with adequate replication of treatments testing this hypothesis is still missing.

The field of land use history still needs to be investigated further to be of any practical use. But if the soil mesofauna turns out to be a good indicator for past land use, however, it could be used to monitor and evaluate the success of restoration ecology measures.

Fragmentation

Chust et al. (2002, 2003 a, b) investigated the effect of forest fragmentation on soil Collembola communities in the Pyrenees. They correlated landscape heterogeneity to the composition of all species present and to the richness of endemic species (the Pyrenees contain a high number of endemic Collembola, Deharveng 1996) at several spatial scales and levels of contrast (satellite image resolution) using satellite image data. They found a negative relationship between landscape heterogeneity and richness of the endemic species, indicating that landscape fragmentation is a potential threat to the endemic component of soil assemblages.

Querner (2002) sampled surface active Collembola in 50 fragmented dry grassland islands in Eastern Austria. He found significant positive correlations between the number of remnant dependant species (in this case, typical dry grassland species) and (i) the minimum distance of large dry grassland patches (>15 ha) and (ii) the total grassland area within a 1x1 km^2 area around the sampled sites. These results indicated that the presence of neighbouring grasslands in close vicinity to the sites influenced the number of remnant dependant species. Size and shape of the islands, in contrast, were poor predictors of Collembola species richness. Overall, forest and grassland Collembola seem to be susceptible to landscape fragmentation. Remnant dependant or endemic species might especially be endangered by habitat destruction and fragmentation.

Metapopulations

Studies investigating metapopulation dynamics of soil microarthropods are lacking, therefore it is still unknown if metapopulation processes are occurring in the soil. As these taxa have very high abundance and therefore large populations even within a small patch in the landscape, only rare species might be affected by these processes. If a population gets extinct, for example because of a disturbances, recolonization from distant patches is probably a rare phenomenon. Experiments of metapopulation processes at the landscape scale will be hard to undertake since it is very difficult to be sure that a soil animal species got extinct in a site and is not still occurring in some microhabitat in the patch.

Dispersal across the landscape

Two pathways of dispersal can be distinguished in Collembola: (1) passive dispersal, and (2) active movement, the latter of which is probably limited to a few metres for the endogeic species and to a few hundred meters for the epigeics species. Directed movement of Collembola was described by Hagvar (1995) over a few hundred meters for the surface active species *Hypogastrura socialis*. Migration of springtails from hedges into adjacent agricultural fields was described by Alvarez et al. (1997, 2000), Frampton (2002), Frampton & van den Brink (2002) and Frampton et al. (2007). These studies showed that landscape structures like hedges can have an influence on the species richness and composition occurring within a field.

Passive dispersal with wind can also be an important factor for soil micoarthropods. Wind dispersal of Collembola was first described by Glick in 1939 (p. 89) when collecting animals by an airplane in 3,000 m height, and again demonstrated several times later (Freeman 1952, Johnson 1957, Gressitt et al. 1960). Other known vectors for passive dispersal for Collembola are runoff water (Usher 1985, Christiansen 1964), and birds and small mammals for oribatid mites (Krivolutsky et al. 2003, Krivolutsky & Lebedeva 2004, Lebedeva & Krivolutsky 2004).

Another strong evidence for the passive dispersal of Collembola in the landscape is the natural succession on coal mine pits (Dunger 1989, Dunger et al. 2001, 2002, 2004). Dunger & Voigtländer (2005) described 8 waves of colonizing Collembola which occur one after the other in the succession. In each group, previously undetected species occurred. They must have been passively dispersed onto the coal mine pits.

Passive dispersal with wind, birds or other vectors, is probably a common phenomenon for soil microarthropods. However, details of dispersal distance, direction and if dispersal is more frequent in open than in structured habitats, are still not known.

1.3 The landscape ecology of terrestrial nematodes

Soil living nematodes also belong to the soil microfauna and have a body size of 0.15 to 5 mm. Their communities can be very diverse with up to 60 species in deciduous temperate forests and abundances of 10 million individuals*m^{-2}. Nematode species feed on bacteria, roots, hyphae, and other animals.

So far, few studies have investigated the effects of landscape processes on nematode communities. With such high population sizes, any effects of fragmentation and metapupulation dynamics don’t seem likely to have a role at the landscape scale.

Because of their small body size, active migration of nematodes is probably limited to a few centimetres in the soil. Passive transportation with water and air currents was described by Carroll & Viglierchio (1981), Janiec (1996) and Prot & VanGundy (1981) and can disperse species over large distances across the landscape.

1.4 The landscape ecology of Lumbricidae

Temperate Lumbricidae (earthworms) have a body size of 2-50 cm and belong to the soil macrofauna. Their diversity varies between 1-15 species per site, with most assemblages consisting of 3-6 species. Although they are less numerous than soil mesofauna taxa, their abundance can reach up to 2,000 individuals*m^{-2}, and their biomass is orders of magnitude higher than that of any arthropod group. Earthworms are usually the dominant soil macrofauna detritivores and can be considered *the* most important group of soil animals in many temperate ecosystems.

Land use intensity and land use change

Like many other invertebrates, earthworms are affected by landuse changes, and there is a rich literature on that. In contrast, studies focusing on landscape heterogeneity are still lacking. Vanbergen et al. (2007) correlated lumbricid species richness with proportion of forest cover, habitat richness and patchiness at the landscape (1 km^2) and local (up to 200 m^2) scale. They found positive correlations between habitat richness and lumbricid diversity and between landscape spatial patchiness and lumbricid abundance at the landscape scale. Lumbricid diversity was positively related to local-scale variables like vascular plant species richness, and negatively to the tree canopy density.

Fragmentation and metapopulation dynamics

If and at which scale habitat fragmentation may affect earthworms is still unknown. Because of their larger body size, earthworm populations are smaller then the above mentioned soil mesofauna and patches need to be sufficiently extended to contain a durable earthworm population. Therefore habitat destruction and fragmentation at the landscape scale could affect them directly since they are sensitive to land use intensification, and especially the deep borrowing species get extinct in agricultural fields due to deep plowing, chiseling, and harrowing. In remaining natural habitats surrounded by inhabitable fields, populations of earthworms might get extinct and recolonized over time, making them a potential candidate for metapopulation processes in the landscape.

Dispersal in the landscape

Alien (newly introduced) earthworm species have dramatically changed the local soil properties and vegetation in North America. Due to their rapid spread (4-9 m per year; van Rhee 1969 a, b, Hoogerkamp et al. 1983), large areas are affected by now (Hale et al. 2006, Scheu & Parkinson 1994). Passive dispersal via vertebrate predators, vehicles or along waterways may even be much faster (Cameron et al. 2007). Cocoons of earthworms can also be transported in soil remains on plant roots, hooves of ungulates, feet of birds or in running waters (Edwards & Bohlen 1996, p. 103) and result in a fast passive dispersal of species.

1.5 Sampling soil animals at the landscape scale

To investigate soil animals at landscape scales, the usually employed sampling methods need to be modified. Sampling a large number of sites is usually required to answer questions in landscape ecology using multivariate statistical methods. The traditional sampling methods for the soil mesofauna (soil cores and pitfall traps) or soil macrofauna (hand sorting, formol and mustard extraction) should therefore be optimised (size, number of replicates) to reduce the effort for sorting and identification. A combination of methods might also give better results than using only a single method (see Querner & Bruckner; Chapter II in this volume). Abundances of soil animals generally vary greatly within a site, as the soil fauna is very heterogeneously distributed in space. To reduce the resulting high variation of microarthropod numbers in soil cores, Bruckner et al. (2000) proposed to pool a large number of soil samples, and sort and identify the animals out of aliquots. This improved the precision of abundance and species richness estimates considerably and would allow to confidently characterising a large number of sites in a landscape. Composites are already frequently used for collection of nematodes (Carter & Lowe 1986, McSorley & Walter 1991, Peterson & Calvin 1986, Schouten 1995).

In chapter II of this volume, the methods for sampling Collembola with pitfall traps and soil cores are modified to collect communities at the landscape scale. Similar sampling protocols can be applied for the other groups of the soil mesofauna (Oribatida and Gamasida).

1.6 Conclusion

All the above mentioned organisms contribute to the decomposition of dead organic matter (Petersen 1994), nutrient cycling (Petersen and Luxton 1982), the development of the soil microstructure (Rusek 1975, 1985) and the function of ecosystems (Copley 2000). The soil and its organisms are part of nearly all terrestrial ecosystems and can not be separated from the aboveground system, as both depend on each other and interact closely (Hooper et al. 2000, Wolters et al. 2000). This system is also influenced by landscape-level parameters and therefore also applies to soil animals. Anthropogenic impacts taking place at the landscape level, like habitat fragmentation or reduction of the landscape diversity, directly or indirectly influence soil animals. These effects could result in a lower soil animal diversity and reduce the stability of the communities and affect decomposition and nutrient cycles in the soil. Further, ecosystem services provided by soil animals, in particular by earthworms (Copley 2000, Lavelle et al. 1997) could be influenced, if landscape changes negatively affect these animals. Earthworms are considered one of the most important ecosystem engineers in temperate terrestrial ecosystems (Lavelle et al. 1997, Costanza et al. 1997) by burrow formation, transportation, fragmentation, breakdown and incorporation of organic matter. They affect the soil microorganisms by dispersing and stimulating them and enhancing the soil fertility, plant productivity and nutrient uptake (Edwards & Bohlen 1996, p. 197 and 212, Curry 1987, Lee & Foster 1991). If landscape changes are affecting earthworms in a negative way (for example by reducing their populations), this would result in a reduction of the ecosystem services they provide.

Landscape ecology could also profit from a closer look at soil organisms. Firstly considering all organisms in the soil (animals, bacteria, fungi), we get hundreds of species (Wall & Virgina 2000) within a few cm^3 and this high diversity should be included in studies investigating the effects of landscape processes on biodiversity. Secondly the combination of animals of different body size classes in landscape ecology might help us to better understand scale dependant patterns and processes. Most investigated arthropods in landscape ecology are larger then 0.5 cm (ants, spiders and beetles). By including the soil mesofauna, we could investigate landscape effects at a smaller scale. Thirdly soil animals have particular life histories and represent the group of detritivors, which, because of their importance in terrestrial ecosystems, should not be neglected in landscape ecology.

We believe that the effects of landscape scale processes on soil animals are much larger than currently assumed in soil ecology and should therefore be considered more closely in the future. Soil organism communities are traditionally seen as regulated by habitat features (vegetation cover, soil pH, soil temperature, humus type), and the surrounding landscape is not taken into account. The results presented here show that the landscape composition influences various soil animal groups. The surrounding landscape composition and the landuse history of an investigated site should also be taken into account, to better understand the patterns we encounter in the distribution, community composition and diversity of soil animals. Further research should focus for example on aspects like passive dispersal of soil animals across the landscape, as it is probably a common phenomenon. Other potential research fields are habitat fragmentation, metapopulation processes and landscape composition that could be investigated for the various soil animal groups.

1.7 References

Alvarez, T., Frampton, G.K. & Goulson, D. (1997) Population dynamics of epigeic Collembola in arable fields: The importance of hedgerow proximity and crop type. Pedobiologia 41 (1-3), 110-114.

Alvarez, T., Frampton, G.K. & Goulson, D. (2000) The role of hedgerows in the recolonisation of arable fields by epigeal Collembola. Pedobiologia 44 (3-4), 516-526.

Bruckner, A., Barth, G. & Scheibengraf, M. (2000) Composite sampling enhances the confidence of soil microarthropod abundance and species richness estimates. Pedobiologia 44 (1), 63-74.

Cameron, E.K., Bayne, E.M. & Clapperton, M.J. (2007) Human-facilitated invasion of exotic earthworms into northern boreal forests. Ecoscience 14 (4), 482-490.

Carroll, J.J. & Viglierchio, D.R. (1981) On the transport of nematodes by the wind. Journal of Nematology 13 (4), 476-483.

Carter, R.E. & Lowe, L.E. (1986) Lateral variability of forest floor properties under second-growth Douglas-fir stands and the usefulness of composite sampling techniques. Canadian Journal of Forest Research 16 (5), 1128-1132.

Christiansen, K. (1964) Bionomics of Collembola. Annual Review of Entomology 9, 147-178.

Chust, G., Lek, S., Deharveng, L., Ventura, D., Ducrot, D. & Pretus, J. (2000) The effects of the landscape pattern on arthropod assemblages: an analysis of scale-dependence using satellite data. Belgian Journal of Entomology 2 (1), 99-110.

Chust, G., Pretus, J.L., Ducrot, D., Bedòs, A. & Deharveng, L. (2003 a) Response of Soil Fauna to Landscape Heterogeneity: Determining Optimal Scales for Biodiversity Modeling. Conservation Biology 17 (6), 1712-1723.

Chust, G., Pretus, J.L., Ducrot, D., Bedòs, A. & Deharveng, L. (2003 b) Identification of landscape units from an insect perspective. Ecography 26 (3), 257-268.

Copley, J. (2000) Ecology goes underground. Nature 406, 452-454.

Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P. & van den Belt, M. (1997) The value of the world's ecosystem services and natural capital. Nature 387, 253-260.

Curry, J.P. (1987) The invertebrate fauna of grassland and its influence on productivity. 1. The composition of the fauna. Grass and Forage Science 42 (2), 103-120.

Deharveng, L. (1996) Soil Collembola diversity, endemism, and reforestation: a case study in the Pyrenees (France). Conservation Biology 10 (1), 74-84.

Dunger, W. (1975) On the delimitation of soil microarthropod coenoses in time and space. In: Vanek, J. (Ed.) Progress in Soil Zoology. Proceedings of the 5th International Colloquium on Soil Zoology, Prague, 17-22 September 1973, 43-49.

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. Cambridge University Press, 307-337.

Dunger, W., Wanner, M., Hauser, H., Hohberg, K., Schulz, H.J., Schwalbe, T., Seifert, B. & Zulka, K.P. (2001) Development of soil fauna at mine sites during 46 years after afforestation. Pedobiologia 45 (3), 243-271.

Dunger, W., Schulz, H.J. & Zimdars, B. (2002) Colonization behaviour of Collembola under different conditions of dispersal. Pedobiologia 46 (3-4), 316-327.

Dunger, W., Schulz, H.J., Zimdars, B. & Hohberg, K. (2004) Changes in Collembolan species composition in Eastern German mine-sites over fifty years of primary succession. Pedobiologia 48 (5-6), 503-517.

Dunger, W. & Voigtländer, K. (2005) Assessment of biological soil quality in wooded reclaimed mine sites. Geoderma 129 (1-2), 32-44.

Edwards, C.A. & Bohlen, P.J. (1996) Biology and Ecology of earthworms. Third edition. Chapman and Hall, London, 426pp.

Frampton, G.K. (2002) Long-term impacts of an organophosphate-based regime of pesticides on field and field-edge Collembola communities. Pest Management Science 58 (10), 991-1001.

Frampton, G.K., Gould, P.J.L., van den Brink, P.J. & Hendy, E. (2007) Type 'A' and 'B' recovery revisited: The role of field-edge habitats for Collembola and macroarthropod community recovery after insecticide treatment. Environmental Pollution 145 (3), 874-883.

Frampton, G.K. & van den Brink, P.J. (2002) Influence of cropping on the species composition of epigeic Collembola in arable fields. Pedobiologia 46 (3-4), 328-337.

Freeman, J.A. (1952) Occurence of Collembola in the air. Proceedings of the Royal Entomological Society of London, 27A, 28.

Filser, J., Mebes, K.H., Winter, K., Lang, A. & Kampichler, C. (2002) Long-term dynamics and interrelationships of soil Collembola and microorganisms in an arable landscape following land use change. Geoderma 105 (3-4), 201-221.

Gressitt, J.L., Leech, R.E., Leech, T.S., Sedlacek, J. & Wise, K.A.J. (1961) Trapping of air-borne insects in the Antarctic area (Part 2). Pacific Insects 3, 559-562.

Glick, PA. (1939) The distribution of insects, spiders and mites in the air. Technical Bulletin No. 673, U.S. Department of Agriculture. 150pp.

Hale, C., Frelich, L.E. & Reich, P.B. (2006) Changes in hardwood forest understory plant communities in response to European earthworm invasions. Ecology 87 (7), 1637-1649.

Hagvar, S. (1995) Long distance, directional migration on snow in a forest Collembolan *Hypogastrura socialis* (Uzel). Acta Zoologica Fennica 196, 200-205.

Hoogerkamp, M., Rogaar, H. & Eijsackers, H. (1983) Effect of earthworms on grassland on recently reclaimed polder soils in the Netherlands. In: Satchell, J.E. (Ed.) Earthworm ecology from Darwin to vermiculture. Chapman and Hall, London, 85-107.

Hooper, D.U., Bignell, D.E., Brown, V.K., Brussaard, L., Dangerfield, M.J., Wall, H., Wardle, D.A., Coleman, Giller, K.E., Lavelle, P., van der Putten, W.H., de Reiter, P., Rusek, J., Silver, W.L., Tide, J.M. & Walters, V. (2000) Interactions between aboveground and belowground biodiversity in terrestrial ecosystems: patterns, mechanisms, and feedbacks. BioScience 50 (12), 1049-1061.

Hopkin, S.P. (1997) Biology of the Springtails. Oxford University Press, Oxford, 330p.

Janiec, K. (1996) Short distance wind transport of microfauna in maritime Antarctic (King George Island, South Shetland Islands). Polish Polar Research 17 (3-4), 203-211.

Johnson, C.G. (1957) The distribution of Insects in the Air and the Empirical Relation of Density to Height. Journal of Animal Ecology 26 (2). 479-494.

Krivolutsky, D.A. & Lebedeva N.V. (2004) Oribatid mites (Oribatei, Acariformes) in bird feathers: non-Passerines. Acta Zoologica Lituanica 14 (1), 26-47.

Krivolutsky, D.A., Lebedeva, N.V. & Matyukhin, A.V. (2001) The oribates (Oribatei) in the lumage of birds. Parazitologiya 35 (4), 282-283.

Lavelle, P., Bignell, D., Lepage, M., Wolters, V., Roger, P., Ineson, P., Heal, O.W. & Dhillion, S. (1997) Soil function in a changing world: The role of invertebrate ecosystem engineers. European Journal of Soil Biology 33 (4), 159-193.

Lebedeva, N.V. & Krivolutsky, D.A. (2003) Birds spread soil microarthropods to arctic islands. Doklady Biological Sciences 391 (1-6), 329-332.

Lee, K.E. & Foster, R.C. (1991) Soil fauna and soil structure. Australian Journal of Soil Research 29, 745-775.

McSorley, R. & Walter, D.E. (1991) Comparison of soil extraction methods for nematodes and microarthropods. Agriculture, Ecosystems and Environment 34 (1-4), 201-207.

Petersen, H. (1994) A review of collembolan ecology in ecosystem context. In: Vilkamaa, P. (Ed.) VIII International Colloquium on Apterygota, Helsinki 17 - 19 Aug. 1992. Acta Zoologica Fennica 195, 111-118.

Petersen, R.G. & Calvin, L.D. (1986) Sampling. In: Klute, A. (Ed.) Soil Analysis. Part 1, Physical and Mineralogical Methods, ASA & SSSA, Madison, Wisconsin, 33-51.

Petersen, H. & Luxton, M. (1982) A comparative analysis of soil fauna populations and their role in decomposition processes. Oikos 39, 288-309.

Prot, J.C. & VanGundy, S.D. (1981) Effect of soil texture and clay component on migration of *Meloidogyne incognita* Second-stage juvenile. Journal of Nematology 13 (2), 213-217.

Ponge, J.F., Gillet, S., Dubs, F., Fedoroff, E., Haese, L., Sousa, J.P. & Lavelle, P. (2003) Collembolan communities as bioindicators of land use intensification. Soil Biology and Biochemistry 35 (6), 813-826.

Ponge, J.F., Dubs, F., Gillet, S., Sousa, J.P. & Lavelle, P. (2006) Decreased biodiversity in soil springtail communities: the importance of dispersal and landuse history in heterogeneous landscapes. Soil Biology and Biochemistry 38 (5), 1158-1161.

Querner, P. (2002) Biodiversität von Collembolen auf fragmentierten Trockenrasen. Diplomarbeit an der Universität Wien, 35pp.

Querner, P. & Bruckner, A. (in this volume) Combining pitfall traps and soil cores to collect Collembola for biodiversity assessments. 21-38.

Querner, P., Bruckner, A., Drapela, T. & Moser, D. (in this volume) Effects of site and landscape parameters on Collembola diversity in 29 winter oilseed rape fields. 58-83.

van Rhee, J.A. (1969) Development of earthworm populations in polder soils. Pedobiologia 9, 133-140.

van Rhee, J.A. (1969) Inoculation of earthworms in a newly drained polder. Pedobiologia 9, 128-132.

Rusek, J. (1975) Die Bodenbilde Function von Collembolen und Acarina. Pedobiologia 15, 299-308.

Rusek, J. (1985) Soil microstructures-contributions on specific soil organisms. Quaestiones Entomologicae 21, 497-514.

Scheu, S. & Parkinson, D. (1994) Effects of invasion of an Aspen forest (Canada) by *Dendrobaena octaedra* (Lumbricidae) on plant growth. Ecology 75 (8), 2348-2361.

Schouten, A.J. (1995) Recovery of nematodes from Scots pine soil- and litter bulk samples: Effects of mixing and addition of water. Pedobiologia 39 (3), 277-288.

Sousa, J.P., Da Gama, M.M., Pinto, C., Keating, A., Calhoâ, F., Lemos, M., Castro, C., Luz, T., Leitão, P. & Dias, S. (2004) Effects of land-use on Collembola diversity patterns in a Mediterranean landscape. Pedobiologia 48 (5-6), 609-622.

Sousa, J.P., Bolger, T., da Gama, M.M., Lukkari, T., Ponge, J.-F., Simón, C., Traser, G., Vanbergen, A.J., Brennan, A., Dubs, F., Ivitis, E., Keating, A., Stofer, S. & Watt, A.D. (2006) Changes in Collembola richness and diversity along a gradient of land-use intensity: A pan European study. Pedobiologia 50 (2), 147-156.

Usher, M.B. (1985) Population and community dynamics in the soil ecosystem. In: Atkinson, D., Read, D.J. & Usher, M.B. (Eds.) Ecological interactions in soil. Blackwell Scientific Publications, Oxford, 243-265.

Vanbergen, A.J., Watt, A.D., Mitchell, R., Truscott, A.-M., Palmer, S.C.F., Ivits, E., Eggleton, P., Jones, T.H. & Sousa, J.P. (2007) Scale-specific correlations between habitat heterogeneity and soil fauna diversity along a landscape structure gradient. Oecologia 153 (3), 713-725.

Wall, D.H. & Virginia, R.A. (2000) The world beneath our feet: soil biodiversity and ecosystem functioning. In: Raven, P.R. & Williams, T. (Eds.) Nature and human society: the quest for a sustainable world. National Academy of Sciences and National Research Council, Washington DC, 225-241.

Wolters, V., Silver, W.L., Bignell, D.E., Coleman, D.C., Lavelle, P., van der Puten, W.H., de Ruiter, P., Rusek, J., Wall, D.H., Wardle, D.A., Brussaard, L., Dangerfield, M.J., Brown, V.K., Giller, K.E., Hooper, D.U., Sala, O., Tiedje, J.M. & van Veen, J.A. (2000) Effects of global changes on above- and belowground biodiversity in terrestrial ecosystems: implications for ecosystem functioning. BioScience 50, 1089-1098.

Chapter II.

2. Combining pitfall traps and soil cores to collect Collembola for biodiversity assessments

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Type of contribution: regular paper
Journal: Applied Soil Ecology

2.1 Abstract

Collembola are rarely implemented in landscape-level biodiversity assessments, large-scale surveys and monitoring projects because huge numbers of specimens would accumulate even in moderately sized programmes. Budgets are always limited, so sampling methods and identification need to be optimised. As no single sampling method collects all Collembola species equally well, we tested the efficiency of a combination of 6 pitfall traps and 5 soil samples in 30 oil seed rape fields in Eastern Austria. Work effort in man hours for sampling, sorting and identification was quantified for each method and related to the collected species richness. Total identification effort was four times higher for the soil cores than the pitfall traps, however, cores also collected more species (53 and 34, respectively). Out Of the 70 species collected in total, an average of 13 species was found in the pitfall samples, 17 in the soil samples and 25 when combining both methods. Using more than 6 pitfall samples would not have collected considerably more species. For the soil samples, still more species can be expected with the identification of more than 5 aliquots, but this would also result in higher costs. When implementing Collembola in large scale biodiversity assessments, surveys or monitoring projects, we therefore propose to combine both methods. Two to five replicates of each method gave a good estimate of both the ep- and euedaphic species and collected more species than a higher number of replicates of each method alone. Combining both methods yields also a more complete picture of the Collembola community of a site.

Keywords: Collembola; Biodiversity assessments; Monitoring; Sampling; Pitfall traps; Soil cores; Species richness

2.2 Introduction

In landscape-level biodiversity assessments, large-scale surveys and monitoring projects, huge amounts of animal or plant specimens have to be processed. Especially arthropods are quickly collected in large numbers, however, the identification of most taxa is very time consuming and therefore costly. As budgets are always limited, sampling and identification need to be optimized, in order to collect a sufficient number of sample units with the lowest possible effort. Collembola have rarely been considered in large-scale projects (Black et al. 2003, Sousa et al. 2006, Vanbergen et al. 2007), as they are found in extra high abundance in most terrestrial habitats, and their identification is especially intricate and labour and cost intensive.

As Collembola live in the soil pores, on the soil surface, in the litter layer and the vegetation, no single sampling method collects all species appropriately. The eu- and hemiedaphic species are normally extracted from soil and litter samples using Berlese-Tullgren or Macfadyen extractors. Between one to ten soil cores are usually collected per site and extracted unit by unit (see for example Derharveng 1996, Black et al. 2003, Palacios-Vargas et al. 2007, Cole et al. 2008, Salmon et al. 2008). Alternatively, Bruckner et al. (2000) proposed to collect a large number of soil samples and to identify aliquots after pooling all extracted animals. This reduces the large variation of abundance and species richness found in most sample units which is due to their aggregated spatial distribution in soil (Hopkin 1997; p. 163).

The epedaphic or surface active species are best collected in pitfall traps; suction sampling (Stewart & Wright 1995) is less frequently applied. Up to ten pitfall traps are placed per site and exposed for a few days to a few months (see for example Durbešić et al. 2006, Fountain et al. 2007). Comparing results from pitfall catches of different places or periods is difficult, because trap number size, material, and conservation fluid all influence the catch considerably (Adis 1979), and sampling is not yet standardized.

Few ecological studies combine coring and trapping (Jakel & Roth 1998, Fountain & Hopkin 2004, Bitzer et al. 2005) to adequately represent all life forms in the sample. However, combining both methods with a lower total number of sampling units may yield a more complete picture of community structure and composition than one method alone. To test this hypothesis, we sampled the Collembola assemblages from 30 agricultural fields and compared the (i) pitfall trap, (ii) soil core and (iii) pooled species richness. Additionally, we quantified the man hours spent for collecting, sorting and identifying the catch of each method to identify the most efficient sampling strategy.

2.3 Material and methods

Site description

As part of a larger project on the landscape ecology of plant parasites and pest predators, (Drapela et al. 2008, Zaller et al. 2008 a, b, c), we designated an agricultural study region of 240 km^2 size approximately 40 km east of Vienna, Austria (central coordinates: 16°57'E, 48°04'N). The main soil type of the region is chernozem; the climate is pannonian (continental). Within this region, 30 winter oilseed rape fields were selected, embedded in differently structured landscapes ranging from structurally simple to structurally complex (details in Zaller et al. 2008 b). Oilseed rape was sown in August and September 2004 and the fields were fertilized and treated with herbicides, fungicides, and insecticides following common agricultural practice. In January 2005, an area of 1 ha within each field was excluded from pesticide applications and this area was used for sampling the surface active and soil living Collembola later on.

Collembola sampling

Pitfall traps

Six unroofed pitfall traps of 1.7 cm diameter were used to collect the surface active Collembola at each site. Traps were placed along a 50 m transect with a spacing of 10 m between each trap, filled with ethylene glycol and a drop of odorless detergent. After an exposure of 14 days in April of 2005, the traps were removed and the Collembola specimens determined to species level and counted.

Soil core collection and extraction

In April 2005, 20 soil cores were taken along two parallel transects (each 50 m long and 10 m apart) with a spacing of 5 m between samples. 57 x 57 mm steel tubes (Bruckner 1998) were used to a depth of 100 mm, the soil was stored in plastic bags and cooled until extraction. All samples were extracted in a modified Berlese-Tullgren extractor for seven days into 10% benzoic acid solution. In each field, 20 cores were collected, extracted and pooled, and 5 aliquots processed further (see Bruckner et al. (2000) for a detailed description of this method).

Collembola identification

The Collembola were identified using the keys of Gisin (1960), Stach (1960, 1963), Babenko et al. (1994), Zimdars & Dunger (1994), Pomorski (1998), Bretfeld (1999), Potapow (2001) and Thibaud et al. (2004).

Man hours were noted for all procedures of both sampling methods for the 30 sites, that is: (1) field collection, (2) extraction (for coring method), (3) sorting Collembola from the samples, (4) slide preparation and (5) identification to species level.

Statistical analysis

We computed rarefaction curves (Mao Tau) per sample unit and per individual for (i) the 6 pitfall samples, (ii) the 5 per soil samples and for (iii) the pooled samples (5 pitfall traps and 5 soil cores). A nonparametric incidence coverage estimator (ICE; Colwell el at. 2004) was calculated to see how many samples have to be identified to adequately estimate the species richness for the pitfall samples, soil samples and the pooled data. All calculations were computed in EstimateS for Windows (version 8.00; Colwell 1994-2008) with 1000 randomizations.

2.4 Results

We collected 35,981 Collembola in total, 8,042 from soil and 27,939 from pitfall samples. The activity density in the pitfalls varied between 82 and 3,048 individuals (6 samples pooled) and the abundance in the soil samples between 55 and 1,200 individuals per site (5 aliquots pooled). 70 species were yielded in total; 34 in the pitfall samples and 53 in the soil samples (Table 1). The site frequency of most species varied greatly between the two methods. 18 species were collected with both methods; 10 of these were found in equal frequency (for example *Ceratophysella succinea*, *Cryptopygus thermophilus*, *Isotoma viridis*, *Lepidocyrtus cyaneus* and *Pseudosinella alba*). Species like *Entomobrya handschini* and *Sminthurinus aureus* are typical epedaphic and were found with very low frequency in the soil samples. In contrast, species like *Protaphorura armata* are typically euedaphic and were found with a low frequency in the pitfall traps. An average of 13 species was found in the pitfall samples, 17 in the soil samples and 25 when combining both methods.

The rarefaction curves per sampling unit (Fig. 1) and per captured individual (Fig. 2) both showed that the pitfalls yielded the lowest species richness, followed by the cores and the both methods pooled. The curve of the pitfall samples is levelling out at about 14 species with 900 individuals identified on average. This indicates that a large part of the species was found and identifying more individuals would not collect substantially more epedaphic species. In contrast, the cuve of soil cores is steeper, indicating that more species can be expected if more than 5 soil samples (aliquots) would be identified. This would, however, also result in a much higher effort (man hours) for sorting and identification. When combining both methods, the identification of only two pitfalls and two soil samples already collects more than the average number of species in 5 soil samples or 6 pitfalls, respectively. Thus, the combination of both methods is the most efficient sampling strategy.

The incidence coverage estimator values (Fig. 3) are very similar between all three data sets (pitfalls, soil and pooled samples). Identifying two to three samples is sufficient to get a good estimate of the three species numbers.

We performed a Pearson regression between the species richness of the pitfall and soil samples and found a significant and positive relationship between the two methods (r = 0.41, P = 0.025; Fig 4): Sites with a high diversity of euedaphic species also contain a high epedaphic richness. Both diversities are related.

Sampling, sorting and identifying the Collembola of the soil samples took 1,350 man hours and 345 h for the pitfall samples (Table 2). Total work effort for the pitfalls was four times higher for the soil samples, but also collected more total (53 compared to 34) and average species numbers (17 compared to 13). 46.9 % of the total time was spent for the identification of the species (600 h or 44.4 % for the soil samples, compared to 195 h or 56.5 % for the pitfalls). The identification needs expert knowledge, must remain with trained scientists, and is therefore very expensive. Field work, extraction of the soil samples and sorting all samples also consumed a considerable effort (43.5 % for pitfall traps and 55.5 % for soil samples). These activities can be done by technical assistants and are less costly.

The man hour per identified species was 10.15 h for the pitfall samples, 25.47 h for the soil samples and 24.21 h for both methods. The man hour per identified individual was 0.74 min for the pitfall samples, 10.07 min for the soil samples and 2.83 min for both methods.

2.5 Discussion

In this study, most epedaphic species were confined to the pitfall traps and euedaphic species to the soil cores. However there were some epedaphic species which also occurred in the soil samples and vice versa. These results show that the classification of Collembola in “ep- and euedaphic” life forms proposed by Gisin (1943) and Peterson (2002) is not fully reproduced in collected samples from the field. The epedaphic species occurring in the soil samples are mostly juveniles or surface active ones migrate into deeper soil layers, when the conditions are unfavorable at the surface (for example during drought; Hopkin 1997; p. 168). Similarly, euedaphic species may coincidentally appear in pitfall traps. These were possibly attracted by the disturbances of trap placement (“digging in effect”, Greenslade 1973) and were active on the surface. Most studies investigating Collembola communities use either soil cores or pitfall traps and use all collected species in the analysis, irrespective if they are appropriately sampled by the method. Instead, we propose to critically evaluate all species when only one sampling method is used, as the inclusion of specimens only collected by chance could bias analyses of community structure and composition.

Combining both methods yield a more complete picture of the Collembola community of a site. However, few recent studies on Collembola made the effort of using both pitfall trapping and soil core extraction (Jakel & Roth 1998, Fountain & Hopkin 2004, Bitzer et al. 2005).

This is more frequently done for other arthropod groups. Missa et al. (2008), Souza et al. (2007), Groc et al. (2007) and Ellison et al. (2007) combined pitfall traps with Winkler extractor and litter samples, manual collection in the field and baited pitfall traps to collect ants. For sampling spiders, Hovemeryer & Stippich (2000), Nobre et al. (2000), Jiménez-Valverde & Lobo (2005) and Kapoor (2006) combined pitfall trapping with vegetation beating, leaf litter extraction, manual collection and emergence traps. For other arthropods, Kitching et al. (2001), Druce et al. (2004) and Missa et al. (2008) combined pitfall traps with Malaise flight traps and quadrate searching. All these studies clearly show that combining sampling methods yields more species and is more efficient.

Both methods, soil core extraction and pitfall trapping, collected large numbers of individuals and species of Collembola in this study. Because of the low species overlap between the two methods, combining both methods collected the highest species richness. Using more than 6 pitfall samples would not have collected considerably more species. Placing, sorting and identification of pitfalls requires a reasonably low effort, therefore this sampling method should be favoured in low budget investigations. For the soil samples, still more species can be expected with the identification of more than 5 aliquots. The field work would be the same, but sorting and identifying more aliquots also results in higher cost. When implementing Collembola in large scale biodiversity assessments, surveys or monitoring projects, we therefore propose to combine both methods. Two to five replicates of each method gave a good estimate of both the ep- and euedaphic species and collected more species than a higher number of replicates of each method alone.

We found a significant and linear relationship between the number of species collected with pitfall traps and soil cores. If the budget is very limited in a large-scale study and only the richness of communities is of interest, sampling could be restricted to the pitfall method and the soil core and total richness extrapolated from the results. This would substantially save time and cost, however, as the correlation between the methods is not close (r = 0.41), this would introduce considerable error into the data. Thus, this relationship needs to be investigated further before applying it in practical work. For example, the applicability of pitfall richness as a proxy for soil and total richness may be enhanced by including site or sampling parameters (weather conditions, vegetation structure, etc.) in the regression model to increase the correlation coefficient.

Acknowledgements

We thank Alex Bandion, Bettina Ibera and Thomas Drapela for their help in the field. This project was funded by a scholarship of the University of Natural Resources and Applied Life Sciences, Vienna.

2.6 References

Adis, J. (1979) Problems of Interpretating Arthropod Sampling with Pitfall Traps. Zoologischer Anzeiger 202, 177-184.

Babenko, A.B., Chernova, N.M., Potapov, M.B. & Stebaeva, S.K. (1994) Collembola of Russia and adjacent countries: Family Hypogastruridae. Nauka, Moscow. 336pp.

Bitzer, R.J., Rice, M.E., Pilcher, C.D., Pilcher, C.L. & Lam, W.K.F. (2005) Biodiversity and community structure of epedaphic and euedaphic springtails (Collembola) in transgenic rootworm Bt corn. Environmental Entomology 34 (5), 1346-1376.

Bretfeld, G. (1999) Synopses on Palaearctic Collembola. Volume 2. Symphypleona. Abhandlungen und Berichte des Naturkundemuseums Görlitz 71 (1), 318pp.

Black, H.I.J., Parekh, N.R., Chaplow, J.S., Monson, F., Watkins, J., Creamer, R., Potter, E.D., Poskitt, J.M., Rowland, P., Ainsworth, G. & Hornung, M. (2003) Assessing soil biodiversity across Great Britain: National trends in the occurrence of heterotrophic bacteria and invertebrates in soil. Journal of Environmental Management 67 (3), 255-266.

Bruckner, A. (1998) Augers may bias field sampling of soil mesofauna. Pedobiologia 42 (4), 309-315.

Bruckner, A., Barth, G. & Scheibengraf, M. (2000) Composite sampling enhances the confidence of soil microarthropod abundance and species richness estimates. Pedobiologia 44 (1), 63-74.

Coddington, J.A., Griswold, C.E., Davila, C.E., Penaranda, D.S. & Larcher, S.F. (1991) Designing and testing sampling protocols to estimate biodiversity in tropical ecosystems. In: Dudley, E.C. (ed.). The Unity of Evolutionary Biology: Proceedings of the Fourth International Congress of Systematic and Evolutionary Biology, Dioscordes Press, Portland, Oregon, USA, 44-60.

Cole, L., Buckland, S.M. & Bardgett, R.D. (2008) Influence of disturbance and nitrogen addition on plant and soil animal diversity in grassland. Soil Biology and Biochemistry 40 (2), 505-514.

Colwell, R.K., (1994-2008) EstimateS, Version 8: Statistical Estimation of Species Richness and Shared Species from Samples (Software and User's Guide) Freeware for Windows and Mac OS, http://viceroy.eeb.uconn.edu/EstimateS

Colwell, R.K., Mao, C.X. & Chang, J. (2004) Interpolating, extrapolating, and comparing incidence-based species accumulation curves. Ecology 85 (10), 2717-2727.

Deharveng, L. (1996) Soil Collembola diversity, endemism, and reforestation: a case study in the Pyrenees (France). Conservation Biology 10, 74-84.

Drapela, T., Moser, D., Zaller, J.G., Frank, T. (2008) Spider assemblages in winter oilseed rape affected by landscape and site factors. Ecography 31 (2), 254-262.

Druce, D., Hamer, M. & Slotow, R. (2004) Sampling strategies for millipedes (Diplopoda), centipedes (Chilopoda) and scorpions (Scorpionida) in savanna habitats. African Zoology 39 (2), 293-304.

Durbešić, P., Vujčić-Karlo, S., Jelaska, L.Š. & Pintarić, K. (2006) Abundance and seasonal dynamics of arthropods in the meadow community Arrhenatheretum elatioris near Varaždin, Croatia. Periodicum Biologorum 108 (1), 3-10.

Ellison, A.M., Record, S., Arguello, A. & Gotelli, N.J. (2007) Rapid inventory of the ant assemblage in a temperate hardwood forest: Species composition and assessment of sampling methods. Environmental Entomology 36 (4), 766-775.

Fountain, M.T. & Hopkin, S.P. (2004) A comparative study of the effects of metal contamination on collembola in the field and in the laboratory. Ecotoxicology 13 (6), 573-587.

Fountain, M.T., Brown, V.K., Gange, A.C., Symondson, W.O.C. & Murray, P.J. (2007) The effects of the insecticide chlorpyrifos on spider and Collembola communities. Pedobiologia 51 (2), 147-158.

Gisin, H. (1943) Ökologie und Lebensgemeinschaften der Collembolen im Schweizerischen Exkursionsgebiet Basels. Revue Suisse de Zoologie 50, 131-224.

Gisin, H. (1960) Collembolenfauna Europas. Museum d´Histoire Naturelle, Genève, 312pp.

Greenslade, P.J.M. (1973) Sampling ants with pitfall traps: Digging-in effects. Insectes Sociaux 20 (4), 343-353.

Groc, S., Delabie, J.H.C., Céréghino, R., Orivel, J., Jaladeau, F., Grangier, J., Mariano, C.S.F. & Dejean, A. (2007) Ant species diversity in the 'Grands Causses' (Aveyron, France): In search of sampling methods adapted to temperate climates. Comptes Rendus - Biologies 330 (12), 913-922.

Hagvar, S. (1983) Collembola in Norwegian coniferous forest soils. II. Vertical distribution. Pedobiologia 25 (6), 383-401.

Hopkin, S.P. (1997) Biology of the Springtails. Oxford University Press, Oxford, 330pp.

Hovemeyer, K. & Stippich, G. (2000) Assessing spider community structure in a beech forest: Effects of sampling method. European Journal of Entomology 97 (3), 369-375.

Jakel, A. & Roth, M. (1998) Effects of insecticides (Diflubenzuron, *Bacillus thuringiensis* var. *kurstaki*) on non-target organisms (soil arthropods) in pine stands. Verhandlungen der Gesellschaft fur Ökologie 29, 237-246.

Jimének-Valverde, A. & Lobo, J.M. (2005) Determining a combined sampling procedure for a reliable estimation of Araneidae and Thomisidae assemblages (Arachnida, Araneae). Journal of Arachnology 33 (1), 33-42.

Kapoor, V. (2006) An assessment of spider sampling methods in tropical rainforest fragments of the Anamalai hills, Western Ghats, India. Zoos' Print Journal 21 (12), 2483-2488.

Kitching, R.L., Li, D. & Stork, N.E. (2001) Assessing biodiversity 'sampling packages': How similar are arthropod assemblages in different tropical rainforests? Biodiversity and Conservation 10 (5), 793-813.

Missa, O., Basset, Y., Alonso, A., Miller, S.E., Curletti, G., De Meyer, M., Eardley, C., Mansell, M.W. & Wagner, T. (2008) Monitoring arthropods in a tropical landscape: relative effects of sampling methods and habitat types on trap catches. Journal of Insect Conservation (in press).

Nobre, T., Meierrose, C., De Oliveira, N.G. (2000) Comparison of sampling techniques for vineyard foliage spiders (Araneae). In: Gardoš, P. & Pekár, S. (Eds.) Proceedings of the 18th European Colloquium of Arachnology, Stará Lesná, 1999. Ekológia Bratislava 19 (supplement 3/2000), 201-206.

Palacios-Vargas, J.G., Castaño-Meneses, G., Gómez-Anaya, J.A., Martínez-Yrizar, A., Mejía-Recamier, B.E. & Martínez-Sánchez, J. (2007) Litter and soil arthropods diversity and density in a tropical dry forest ecosystem in Western Mexico. Biodiversity and Conservation 16 (13), 3703-3717.

Pomorski, J. (1998) Onychiurinae of Poland (Collembola: Onychiuridae). Polish Taxonomical Society, Wrocklaw, 201pp.

Potapov, M. (2001) Synopses on Palaearctic Collembola. Volume 3. Isotomidae. Abhandlungen und Berichte des Naturkundemuseums Görlitz 73 (2), 603pp.

Salmon, S., Frizzera, L. & Camaret, S. (2008) Linking forest dynamics to richness and assemblage of soil zoological groups and to soil mineralization processes. Forest Ecology and Management 256 (9), 1612-1623.

Schouten, A.J. (1995) Recovery of nematodes from Scots pine soil- and litter bulk samples: Effects of mixing and addition of water. Pedobiologia 39 (3), 277-288.

Souza, J.L.P. , Moura, C.A.R. , Harada, A.Y. & Franklin, E. (2007) Diversity of species of the genera Crematogaster, Gnamptogenys and Pachycondyla, (Hymenoptera: Formicidae) and complementarity of sampling methods during the dry season in an ecological station in the Brazilian state of Pará. Acta Amazonica 37 (4), 649-656.

Stach, J. (1960) The Apterygotan Fauna of Poland in Relation to the World-Fauna of this group of Insects. Tribe: Orchesellini. Polska Akademia Nauk, Kraków. 151pp.

Stach, J. (1963) The Apterygotan Fauna of Poland in Relation to the World-Fauna of this group of Insects. Tribe: Entomobryini. Polska Akademia Nauk, Kraków. 126pp.

Stewart, A.J.A. & Wright, A.F. (1995) A new inexpensive suction apparatus for sampling arthropods in grassland. Ecological Entomology 20 (1), 98-102.

Thibaud, J.M., Schulz, H.J. & da Gama Assalino, M.M. (2004) Synopses on Palaearctic Collembola. Volume 4. Hypogastruridae. Abhandlungen und Berichte des Naturkundemuseums Görlitz 75 (2), 287pp.

Vanbergen, A.J., Watt, A.D., Mitchell, R., Truscott, A.-M., Palmer, S.C.F., Ivits, E., Eggleton, P., Jones, T.H. & Sousa, J.P. (2007) Scale-specific correlations between habitat heterogeneity and soil fauna diversity along a landscape structure gradient. Oecologia 153 (3), 713-725.

Zaller, J.G., Moser, D., Drapela, T., Schmöger, C. & Frank, T. (2008 a) Effect of within-field and landscape factors on insect damage in winter oilseed rape. Agriculture, Ecosystem and Environment 123 (1-3), 233-238.

Zaller, J.G., Moser, D., Drapela, T., Schmöger, C. & Frank, T. (2008 b) Insect pests in winter oilseed rape affected by field and landscape characteristics. Basic and Applied Ecology 9 (6), (in press).

Zaller, J.G., Moser, D., Drapela, T., Frank, T. (2008 c) Ground-dwelling predators can affect within-field pest insect emergence in winter oilseed rape fields. Biocontrol (in press).

Zimdars, B. & Dunger, W. (1994) Synopses on Palaearctic Collembola. Volume 1. Tullberginae. Abhandlungen und Berichte des Naturkundemuseums Görlitz 68, 70pp.

Collembola species	**frequency in the pitfall traps**	**frequency in the soil core**
Anurophorus sp	-	5
Arrhopalites caecus (Tullberg, 1871)	-	3
Axenyllodes bayeri (Kseneman, 1935)	-	1
Bourletiella (B.) hortensis (Fitch, 1863)	1	-
Bourletiella sp	-	7
Ceratophysella sigillata (Uzel, 1891)	-	1
Ceratophysella succinea (Gisin, 1949)	28	29
Cryptopygus ponticus (Stach, 1947)	1	-
Cryptopygus thermophilus (Axelson, 1900)	27	25
Deuterosminthurus sulphureus (Koch, 1840)	9	-
Deutonura conjuncta (Stach, 1926)	1	-
Entomobrya handschini Stach, 1922	19	1
Entomobrya marginata (Tullberg, 1871)	30	-
Entomobrya multifasciata (Tullberg, 1871)	3	1
Entomobrya sp	-	18
Folsomia sensibilis Kseneman, 1936	-	10
Folsomia sp	-	1
Folsomia spinosa Kseneman, 1936	3	-
Folsomides parvulus Stach, 1922	14	20
Friesea afurcata (Denis, 1926)	11	-
Heteromurus major (Moniez,1889)	4	-
Heteromurus nitidus (Templeton, 1835)	18	-
Heteromurus sp	-	2
Hypogastrura assimilis (Krausbauer, 1898)	5	-
Hypogastrura neglecta cf Börner, 1901	1	-
Hypogastrura sensilis cf (Folsom, 1919)	-	4
Hypogastrura sp	-	2
Isotoma viridis Bourlet, 1839	29	28
Isotomiella minor (Schäffer, 1896)	-	1
Isotomodes sexsetosus Da Gama, 1963	-	1
Lepidocyrtus cyaneus Tullberg, 1871	30	25
Lepidocyrtus lanuginosus (Gmelin, 1788)	5	1
Lepidocyrtus paradoxus Uzel, 1891	2	-
Mesaphorura critica Ellis, 1976	-	29
Mesaphorura florae Simon, Ruiz, Martin & Luciañez, 1994	-	5
Mesaphorura hylophila Rusek, 1982	-	22
Mesaphorura italica (Rusek, 1971)	-	13
Mesaphorura jarmilae Rusek, 1982	-	15
Mesaphorura krausbaueri Börner, 1901	-	1
Mesaphorura macrochaeta Rusek, 1976	-	28
Mesaphorura sp	-	10
Mesaphorura sylvatica (Rusek; 1971)	-	2
Mesaphorura yosii (Rusek, 1967)	-	10
Metaphorura affinis (Börner, 1902)	-	3
Neotullbergia ramicuspis (Gisin, 1953)	-	15
Oncopodura crassicornis Shoebotham, 1911	-	2
Onychiurus juv.	-	5
Onychiurus sp 1	-	3
Onychiurus sp 2	-	5
Orchesella cincta (Linnaeus, 1758)	11	4

Parisotoma notabilis (Schäffer, 1896)	11	21
Pogonognathellus flavescens (Tullberg, 1871)	2	-
Polyacanthella sp	-	1
Proisotoma minuta (Tullberg, 1871)	-	10
Protaphorura armata (Tullberg, 1869)	3	20
Protaphorura tricampata (Gisin, 1956)	1	1
Pseudachorutes dubius Krausbauer, 1898	10	-
Pseudosinella alba (Packard, 1873)	18	17
Pseudosinella sexoculata Schött, 1902	29	17
Pseudosinella sp	-	12
Schoettella ununguiculata (Tullberg, 1869)	3	-
Sminthurinus aureus (Lubbock, 1862)	21	3
Sminthurinus elegans (Fitch, 1863)	2	3
Sminthurus multipunctatus Schäffer, 1896	16	3
Sphaeridia pumilis (Krausbauer, 1898)	29	19
Stenacidia violacea (Reuter, 1881)	3	-
Stenaphorura denisi Bagnall, 1935	-	16
Symphypleaona	-	2
Willemia anophthalma Börner, 1901	-	29
Willemia sp	-	9

Table 1: Species list and site frequency of the Collembola in pitfall traps and soil cores in 30 oilseed rape fields.

Activity	**Effort per site [h]**	**Total**
Field work for 6 pitfall traps	1.5	45
Sorting specimens from the pitfall traps	3.5	105
Slide preparation, identification	6.5	195
Pitfall trap total	11.5	**345**
Field work for 20 soil cores	4	120
Extraction of soil cores, pooling, aliquot preparation	6	180
Sorting specimens from the soil cores	15	450
Slide preparation, identification	20	600
Soil core total	45	**1350**

Table 2: Man hours spent sampling, processing, sorting and identifying the Collembola collected with pitfall traps and soil samples in oilseed rape fields.

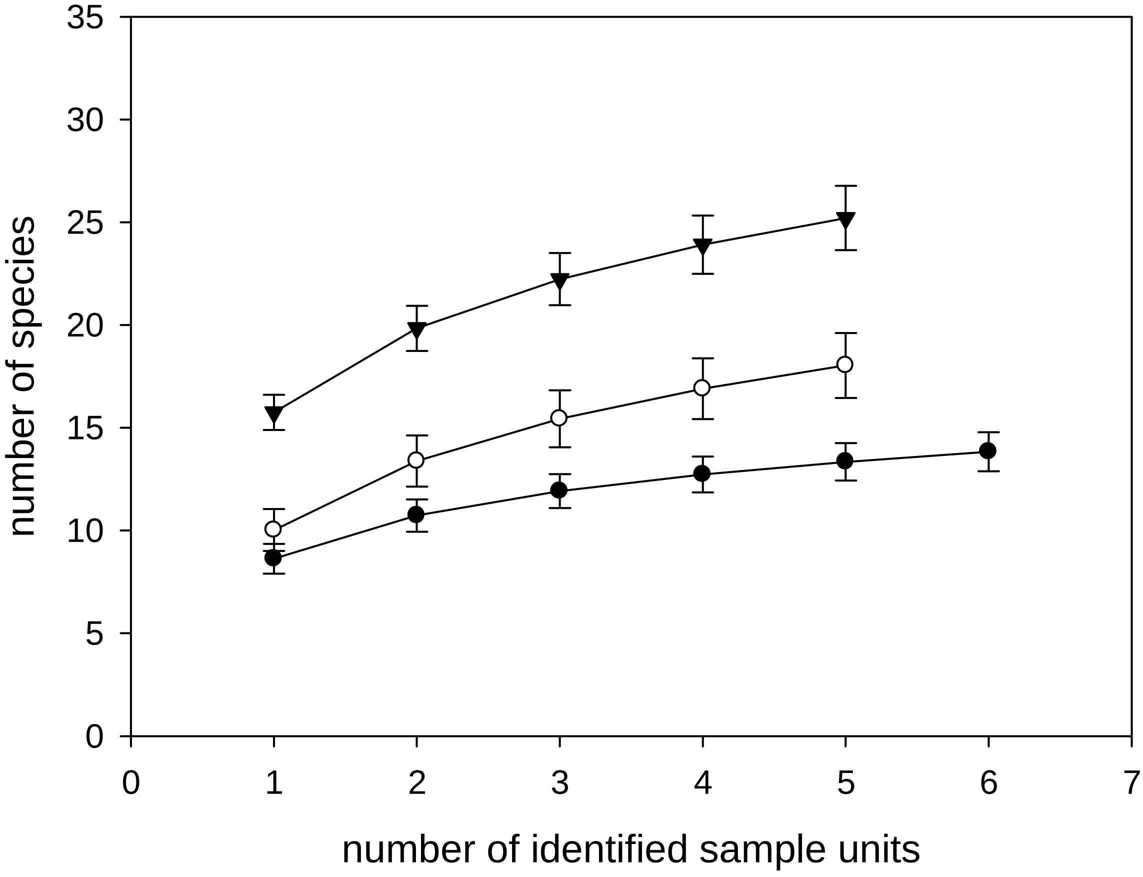

Fig. 1: Species rarefaction curves per sample unit for the Collembola collected with pitfall traps (●), soil samples (○) and pooled samples (▼); points are arithmetic means of 30 sites with 95 % confidence interval.

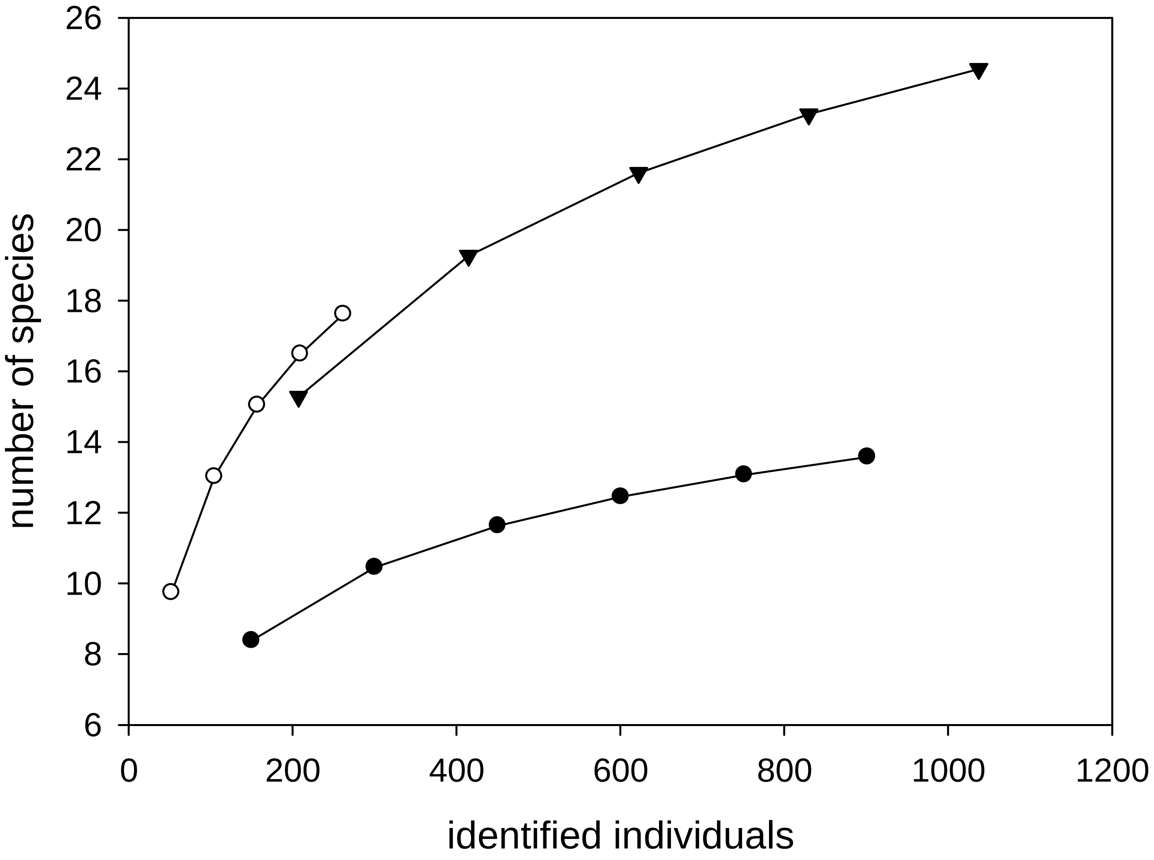

Fig. 2: Species rarefaction curves (Mao Tau) per individual (average) for the Collembola collected with pitfall traps (●), soil samples (○) and pooled samples (▼).

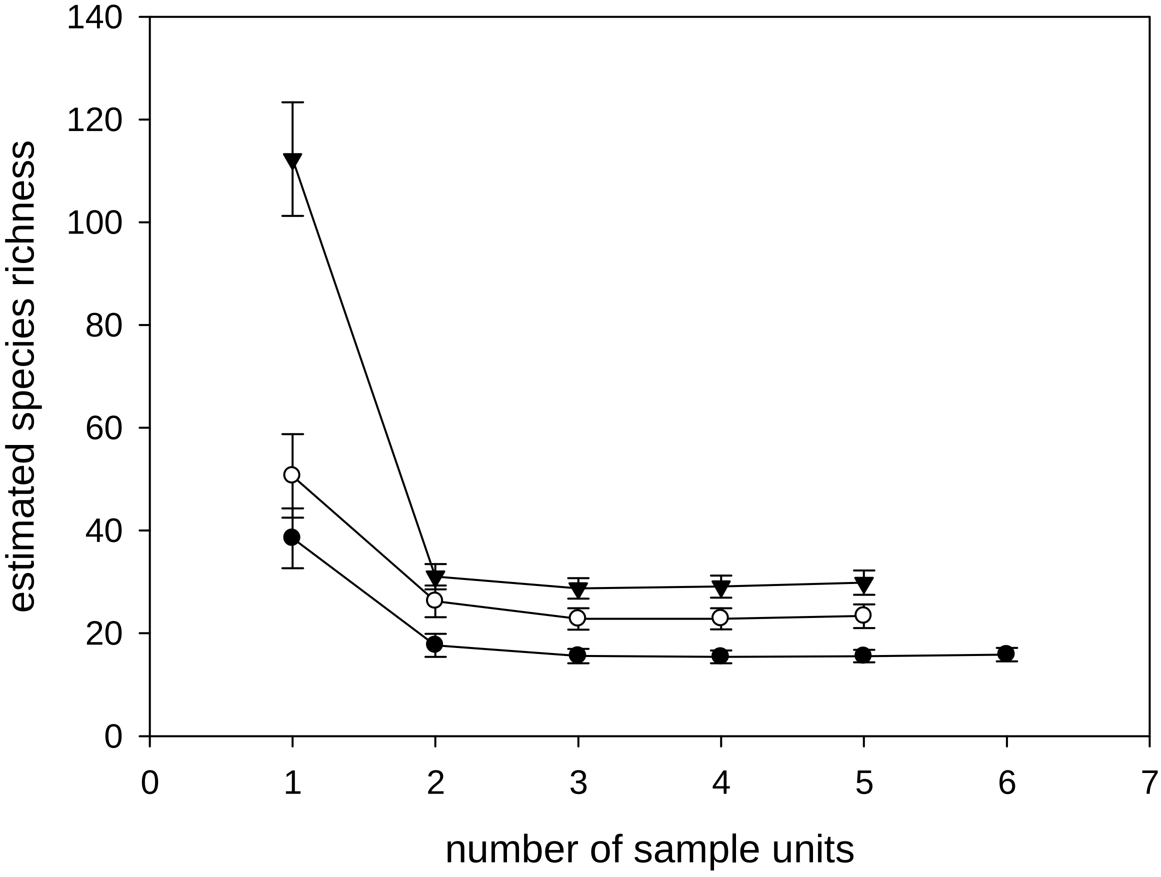

Fig. 3: Incidence coverage estimator (ICE) for the Collembola collected with pitfall traps (●), soil samples (○) and pooled samples (▼); points are arithmetic means of 30 sites with 95 % confidence interval.

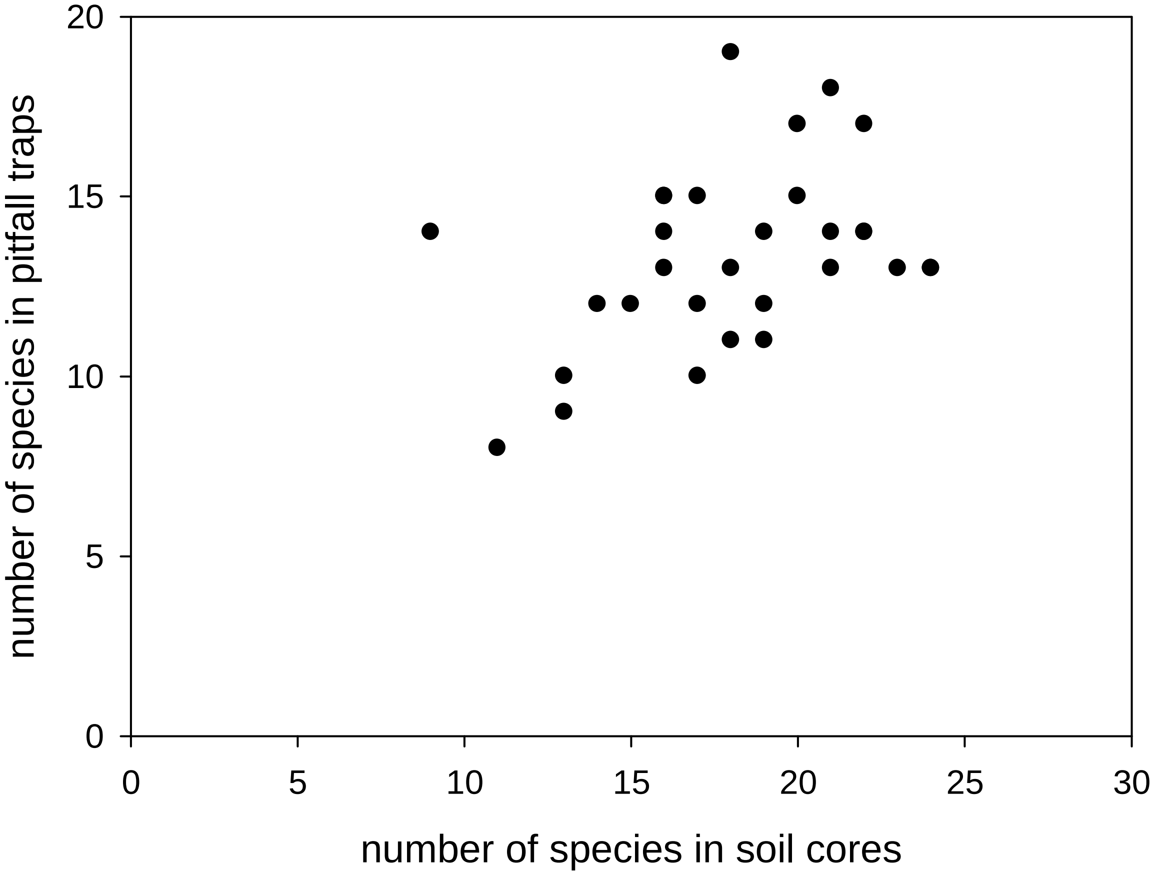

Fig. 4: Relationship between the Collembola species richness from pitfall traps and soil samples in oilseed rape fields.

Chapter III.

3. Short- and long-term effects of fire on the Collembola communities of a sub-alpine dwarf-pine ecosystem in the Austrian Alps

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Type of contribution: regular paper
Journal: Forest Ecology and Management

3.1 Abstract

We compared the Collembola communities of three sub-alpine sites in the Limestone Alps (National Park Kalkalpen; Upper Austria) to evaluate the short- and long-term effects of large natural forest fires. SITE 1 was burned for 10 days in August 2003 and represented the first stage of the succession. SITE 2 was burned 50 years ago and sampled to assess the long-term effects of fire and the recovery of soil animals within 50 years. A reference site (REF) nearby was sampled to represent the undisturbed dwarf-pine community without the influence of fires. All sites are close to each other on a steep slope between 1,400 and 1,650 m above sea level. We found a total of 41 species of Collembola, as well as, clear differences in the species composition and abundance between the sites: Most species (30) were found on the REF site in high abundance (43,080 ind.*m^{-2}). The highest abundance was found on SITE 1 (48,960 ind.*m^{-2}, 22 species). We assume that some species survived the fire in deeper soil layers and others migrated or were passively dispersed from unburned patches and surrounding sites. The lowest abundance and species number (8,160 ind.*m^{-2}, 18 species) were found on the 50 year old site (SITE 2). This site was covered with a typical community for moving substratum, consisting mainly of alpine grasses, yet the dwarf-pine vegetation had not yet recovered. The soil layer was still very thin and we therefore assume that a recovery of the Collembola community will take much longer than 50 years. We predict an impoverishment of the communities of SITE 1 toward that of SITE 2 within the next 50 years.

Keywords

Fire; Collembola; short-term effects; long-term effects; indicators; Austrian Alps

3.2 Introduction

Fire is a common and destructive disturbance in terrestrial ecosystems. Large wildfires can destroy the aboveground vegetation and also change the belowground physical, chemical and biological properties. Secondary effects like enhanced erosion may result in a further loss of plant biomass and soil nutrients. However, fire is not deleterious for all organisms: some animals and plants are well adapted to this disturbance, for example in the Mediterranean regions and Australia. Pyrophilous species of insects or fungi may even depend on it to thrive. Certini (2005) reviews the effects of fires on the forest soil and distinguishes between (1) low to moderate fires and (2) severe fires. Most prescribed fires are of low intensity and can be used as a management tool without long-term effects on organism density and composition. Wildfires, on the contrary, are often of high intensity, occur during dry periods and have much larger and even irreversible effects on the ecosystem. Certini (2005) concludes that if plants succeed in recolonizing a burned site soon after the fire, the pre-fire conditions can recover within a short time. Neary et al. (1999) give a general review on the effects of fire on belowground systems and describe the physical, biogeochemical and biological effects: Low-impact fires can promote a herbaceous flora, increase plant available nutrients and thin overcrowded forests. Severe fires, on the contrary, change the mineralisation rate, alter C : N ratios, influence above- and below-ground species composition, decrease the micro- and macrofauna and alter the microbial population. Recovery time depends on fire intensity, the effects on key ecosystem processes and components, but also on previous land-use practices. Neary et al. (1999) conclude that the impact of fires can vary greatly and therefore are not predictable.

In the Alps although wildfires are rare, some species profit from the disturbance: Early successional or ruderal species are able to colonize burned sites and species-rich mosaics of spatial patches may develop. Very few species are truly fire-dependent, but the rare carabid beetle *Agonum bogemanni* is an example (Peter Zulka, Univ. Vienna, oral comm., September 2006).

Collembola (springtails) are small, soil-inhabiting, wingless insects. Like other edaphic arthropods, they may be especially affected by fires because they cannot escape the heat and generally depend on moist and cool conditions in the litter and upper soil layers. The high temperatures of an intense fire usually reach these strata and may destroy the life therein. Most studies investigating the effects of fire on Collembola have been conducted in habitats where fires are a common disturbance, *e.g.* in Australia (Greenslade 1997, Driessen & Greenslade 2004) or Finland (Koponen 1988, 1989, 1995, Huhta et al. 1967, 1969). They found recovery times varying between a few to over 20 years depending on the intensity of the fire.

In the central Alps fires are less frequent and a seldom studied disturbance. Gimmi et al. (2004) investigated the fire frequency and Wohlgemuth et al. (2002, 2005) the ecological resilience of the plant and animal communities in the Swiss Alps after a large fire of 300 ha in 2003. A recent wildfire in the Austrian Alps gave us the opportunity to investigate the short and long term effects of high intensity burning on a sub-alpine habitat and compare the recovery times of the vegetation and the Collembola to studies in other parts of the world. We also developed indicator values of the springtail species as a reference for the age classification of burned sites.

3.3 Material and Methods

Study area

The study area is situated in the North-eastern Limestone Alps in the Sengsengebirge (National park Kalkalpen; Upper Austria). This mountain range stretches in a roughly east-west direction and rises up to 2,000 m above sea level. Sub-alpine dwarf-pine vegetation (*Erico-Pinion mugi* Leibundgut, 1948) covers its steep south facing slopes above the timber line. Dwarf-pines (*Pinus mugo)* are dominant here and form an impenetrable thicket, with Winter Heath (*Erica carnea*) and Hairy Alpine Rose (*Rhododendron hirsutum*) underneath. Individual larch (*Larix decidua*) and Norway spruce trees (*Picea abies)* are interspersed among the dwarf-pines. The soil is a Tangelrendzina (Austrian soil classification: Kilian 2002), covered with a 15-20 cm layer of raw humus. We selected three sites on the slope, all close to each other between 1,400 and 1,650 m above sea level.

SITE 1

In August 2003, an area of 15 ha (centre of the site: 14°18' E, 47°46' N; SW exposition; slope: 35°) burned for 8 days (August 17 to 24) during a very dry weather period, probably due to natural lightning. The fire was fought from the ground and with helicopters, but no retardant was used. During the fire all the dwarf-pines, most of the larch trees and large parts of the raw humus layer burned. The rainfall of autumn 2003 and the snow melt in spring 2004 eroded large parts of the remaining soil and ash. The result was a patchy mosaic of soil remnants, rock and scree. At the time of sampling (10 months after the fire) the vegetation was very sparse and consisted of only a few remaining or colonizing species (*Funaria hygrometrica, Campanula cochleariifolia, Calamagrostis villosa, Erica carnea, Galium anisophyllon, Heleborus niger*).

SITE 2

Close to SITE 1 a similar dwarf-pine stand of 12 ha burned on June 29, 1950 for 3 weeks. This area we designated SITE 2 (S exposition; slope 30-40°) to investigate the long-term effects of fire and the subsequent biotope succession on Collembola after 50 years.

The plant community was dominated by grasses, all other plants appeared in low coverage. Sociologically, it belonged to the association of *Athamanto-Trisetum distichophylli* (Jenny-Lips, 1930) which is typical for moving limestone scree (Seibert 1974, Englisch et al. 1993). In addition, *Carex sempervierens* and *Sesleria albicans* were also found in high coverage. These two species are typical of the formation of *Seslerio-Caricetum sempervirentis* (Beger,

1922) (Grabherr et al. 1993, Oberdorfer 1974/76) which grows on reposing limestone scree and is often associated and interspersed with the *Athamanto-Trisetum distichophylli* (Ellenberg 1996).
The dwarf-pines, larch trees and Norway spruce trees were not fully recovered and in general the vegetation was patchier than SITE 1. The soil layer was still shallow, probably due to heavy erosion over the last 50 years and the movements of the limestone scree.

SITE 3

A reference site (REF) north of SITE 1 was sampled to represent the undisturbed Collembola fauna. We assume that the Collembola fauna of the REF site was identical to the fauna of SITE 1 and SITE 2 prior to the fire.
The tree, shrub and herb layers were well developed at the site. A sparse moss layer was also found. The tree layer consisted of two species, *Picea abies* and *Larix decidua* (2.35 stems *100 m^{-2}). The shrub-layer was dominated by *Pinus mugo.* Within the herb layer, the acidophilus species *Vaccinium myrtillus, V. vitis-idea* and *Erica carnea* dominated in high coverage and constancy. The plant association was a *Homogyno-Piceetum* (Zukrigl 1973), which is often found along the timberline in the northern Alps (Seibert 1988, Mertz 2002).

Field sampling

Collembola were sampled at the three sites on June 26, 2004, shortly after snowmelt. On each site, ten soil cores were taken with a 57 x 57 mm steel tube (Bruckner 1998) to a depth of 100 mm, stored in plastic bags and cooled until extraction. The cores were taken at random positions with a minimum spacing of 5 m, wherever sufficient substratum was available and within an area of 1,000 m^2 each site. The samples were taken to the laboratory and extracted in a modified Macfadyen-Extractor for seven days into 10% benzoic acid solution. The Collembola were transferred to 70 % ethanol, counted and identified using the keys of Gisin (1960), Babenko et al. (1994), Bretfeld (1999), Stach (1960, 1963) and Potapow (2001).

Data treatment

With the full data set, the species similarity of the three sites faunas was calculated with the Sørensen Index, and similarity of the dominant species with the Bray-Curtis index. The dominance structure of the communities was compared graphically with rank-abundance plots.

Prior to the multivariate data analyses, species with less than three individuals per core were removed from the data (25 species remained); accordingly, two samples (one in SITE 1 and one in REF) were classified as outliers and not included in the analysis. A non-metric multidimensional scaling (NMDS, Bray-Curtis-similarity, McCune & Grace 2002, 125ff) was performed to ordinate the individual samples along axes in multidimensional species space and separate the three sites. We tested for significant differences between the three faunas in ordination space with a nonparametric procedure (MRPP; multi-response permutation procedure, McCune & Grace 2002, 188ff).

Indicator species analysis (McCune & Grace 2002, 198ff) was used to find indicative species for the three investigation sites, and, more general, for the respective post-fire succession stage. In this analysis, a species is considered most useful, if it is both faithful to a site (present in all cores from the site) and exclusive (never occurring at the other sites).

We used PRIMER 5.2.9 (Clarke & Gorley 2001) for the calculation of the Sørensen and Bray-Curtis Index, and PC-ORD 4.25 (McCune & Mefford 1999) for the multivariate analyses.

3.4 Results

We collected 2,505 Collembola specimens in the soil samples which belonged to 41 species (Tab. 1). Clear differences were found in total Collembola abundance and species richness among the three sites: SITE 1 had the highest abundance of 48,960 individuals * m^{-2} and 22 species. *Hypogastrura cf assimilis, Parisotoma notabilis* and *Mesaphorura hylophila* were the most abundant species.

SITE 2 showed the lowest number of individuals (8,160 * m^{-2}) and also the lowest species richness (18). *Folsomia penicula, Mesaphorura hylophila* and *Parisotoma notabilis* were the most abundant species.

The highest species richness was found on the REF site with 30 species and a high abundance with 43,080 individuals * m^{-2}. *Mesaphorura sylvatica, Xenylla sp.* and *Isotomiella minor* were the most abundant species.

Species similarity (Sørensen Index, Tab. 2) was moderately high between the REF and SITE 1 faunas; lower between the SITE 1 and SITE 2 faunas; and lowest between REF and SITE 2. The similarity of the dominants (Bray-Curtis Index, Tab. 2) was low between REF and SITE 2 and between SITE 1 and SITE 2; and slightly higher between REF and SITE 1.

The rank-abundance plots of the three sites are approximately linear and very similar (Fig. 1). Few dominant species make up a large proportion of the catch, and most other species occur in intermediate to low abundance. Therefore, the fire did not affect the dominance structure of the site faunas.

The ordination of the 28 samples with the non-metric multidimensional scaling (NMDS) did not reveal a strong multivariate gradient separating the three sites along any of the axes. Indistinct site clusters are evident, however, in plots of the first three axes (Fig. 2). This clustering was significant (MRPP; $T = -11.17$, $p = 2*10^{-8}$).

We found a total of 8 species of high indicator value for the investigation sites (2 for REF, 3 for each SITE 1 and SITE 2, respectively; Tab. 3).

3.5 Discussion

We found substantial compositional differences between the Collembola faunas of the three investigated sites. This shows that fires may have significant short- and long-term effects on the Collembola communities in sub-alpine habitats.

The result of low abundance and species richness at SITE 2, compared to the reference site, is surprising at first sight, since we expected extensive recovery of the Collembola community after 50 years of post-fire succession. Other authors found much faster recovery times: Sgardelis & Margaris (1993), Majer (1984), Metz & Farrier (1973) and Seastedt (1984) estimated short recovery times (3-4 years) after controlled and less destructive fires. Jahn et al. (1970) investigated the succession of Collembola on another burned alpine site (Tyrol, Austria, 1,600 - 2,137 m above sea level), the only other study investigating the effect of fire on Collembola in the Alps. They found that the number of individuals and species declined in the first year and was still lower 11 years after the fire, but had recovered after 20 years. Koponen (1988, 1989 and 1995) found lower densities of springtails and mites, instable and divergent communities 4 years after a fire in Finland. Similar results were presented by Huhta et al. (1967, 1969) in central Finland, where 7 years were not sufficient for the communities to recover. But Koponen and Huhta et al. only investigated short-term effects and did not sample after longer recovery times. Long-term effects (8-11 and 27 years) were investigated by Driessen & Greenslade (2004) in Australian lowland grasslands, and they found some differences in the species composition in the younger regrowth site, but not in the older site. Shaw (1997) found depauperate communities on two sites that burned 20 year ago and again 5 years prior to sampling. He also described a strong rise of Collembola densities 3 months after a shallow fire, and accounted for this with enhanced egg germination due to the fire. The recovery times of Collembola communities found by other authors varied greatly and probably depended mainly on the intensity of the fire, but also on the seasonality of the fire and the local adaptation of the habitat to this disturbance.

However, if secondary effects of the fire are considered, the reasons for the slow recovery of the fauna of SITE 2 are obvious and are in accordance with the vegetation. The soil was probably denuded after the fire of 1950 and, due to the steep inclination, strong rains and intensive snow melting in each spring, the soil developing processes were retarded afterwards. A shallow soil layer hinders the development of larger plants, which by itself would stop erosion more effectively. As a result of the missing humus-layer the rocks become destabilized (Conedera 2005) creating a moving substratum on the steep slopes. This also prevented the original vegetation from recolonizing the site. Limestone and the small humus body below the rock contain sufficient nutrients (Zöttl 1952) but only few plant species can survive on moving rubble. This substratum can only be colonized by species that can dam up moving rocks, wander downward or overgrow the moving scree. A change to alpine grassland and later to the original dwarf-pine is only possible, when rock fall has stopped. This succession is not expected within the next centuries due to the very short vegetation period each year (June to September). The low plant cover and shallow soil layer have a different microclimate than the dwarf-pine stand. The patchy short grass vegetation of SITE 2 has a more extreme microclimate and can affect the Collembola community indirectly: (1) higher temperatures in summer because of the steep and southern exposition, (2) colder temperatures in winter due to lack of a buffering dwarf-pine layer, and (3) extreme drought because the soil layer is too thin to store significant amounts of humidity and limestone by itself does not hold water. (4) Wind action can be expected to be another intense factor. This also coincides with the hypothesis of Certini (2005) and Webb (1994) that the recovery time of the animal assemblages after fires depends very much on the recovery of the vegetation. Due to these secondary effects, we predict a decline of the number of species and abundance for SITE 1 over the next 50 years toward a community similar to that of SITE 2. These results contradict those of Wolgemuth et al. (2005) and Schönenberger & Wasem (1997) who reported a rather fast recovery of the plant cover of burn sites in Wallis (southern Switzerland). Especially *Calamagrostis varia* was found within one year in their sites. This plant can be derived from surviving rhizomes below the ash-layer (Wolgemuth et al. 2005). In the site in Austria the soil layer was nearly completely destroyed by the fire of 2003, and we do not expect a recovery from the seed-bank or surviving rhizomes.

The recently burned SITE 1 exhibited high abundance and high species number. This was unexpected, since the fire severely reduced the humus layer, and we expected it to have a devastating impact on the soil fauna. Our findings can be explained with the probable survival and immigration of individuals: (1) Collembola may have survived the fire in deeper soil layers. They are known to migrate into deeper soil layers (up to 10 cm) during unfavorable conditions, for example heat or drought (Hopkin 1997, p. 168). As the fire occurred in a very dry and hot summer period, animals might have survived within the site. Webb (1994) showed in experimental fires that the heat doesn’t penetrate deeper than 5 cm into the soil and that microarthropods can survive. (2) Active migration/recolonization over short distances from the small unburned patches within the site (as proposed by Bellido 1987 or Shaw 1997) and/or also from the surrounding unharmed dwarf-pine stands is possible, since microarthropods can migrate a few meters within a short time (Hågvar 1995). (3) Passive dispersal of animals with water and soil substrate after heavy rains and snowmelt from higher lying areas was probably the most important factor. As Collembola can be active under the snow cover (Aitchison 1979, 1984) and reproduce fast (Hopkin 1997, p. 133), they had enough time to recover during the ten months after the fire.

Our results provide a good example for the fact that the identification to species level provides much deeper ecological insight than the sheer counting of individuals. We found similar abundances on SITE 1 and the REF site, but the species compositions were significantly different. Conclusions in the literature on the recovery times, based on the abundance only, do not account for the potential extinction of certain species, recolonization by others and compositional changes in the community as a whole. Even the identification of morpho-species, as done in Australia by Greenslade & Driessen (1999), can give a better resolution.

We are aware of the pseudoreplication of our experimental design in only three sites. Larger studies with a detailed resolution of chronosequences are needed to investigate further the long-term effects of fires on Collembola in the Alps and to test the prediction of a species loss within 50 years after the fire. Sites older than 50 years could reveal the time needed to reach an ecological climax. The only study in the Alps sampling a large number of sites of different successional stages was done by Moretti et al. (2004), who sampled 22 sites in the southern Alps of Switzerland to investigate the effects of single and repeated forest fires on the species richness of ground beetles, hoverflies, bees, wasps, spiders, bugs and lacewings. In Australia, Greenslade & Driessen (1999) sampled 27 Buttongrass moorland sites for the Collembola communities with a chronosequence ranging from one month to 64 years since the last fire. Friend (1996) suggested in his review six invertebrate groups (spiders, butterflies, isopods, Isoptera, Thysanoptera and Blattodea) as indicator groups for fire disturbances. We suggest that Collembola should be included in this list so that soil microarthropods will also be covered.

3.6 Conclusion

A recent fire in a high Alpine dwarf-pine forest resulted in a compositional shift of the Collembola community. Densities were slightly higher than in the reference site and the species composition was significantly different. The long-term effects (50 years) of a fire were even more dramatic and resulted in much lower abundance and impoverished species composition. We therefore assume that in this high Alpine habitat recovery after a fire toward the climax community may take much longer than 50 years and the species richness and abundances on the burned site of 2003 will reduce over time.

Acknowledgements

The project was funded by the “Theodor Körner Fond” of the City of Vienna (2004). We also thank Cristina Lazcano for help in the field and Richard Hobbs and Sandrine Petit for their comments on the manuscript.

3.7 References

Aitchison, C.W. (1979) Winter-active subnivean invertebrates in central, southern Canada. I. Collembola. Pedobiologia 19, 113-120.

Aitchison, C.W. (1984) The phenology of Collembola from south central Canada. Pedobiologia 27, 405-423.

Babenko, A.B., Chernova, N.M., Potapov, M.B. & Stebaeva, S.K. (1994) Collembola of Russia and adjacent countries: Family Hypogastruridae. Nauka, Moscow, 336pp.

Bellido, A. (1987) Field experiment about direct effect of a heathland prescribed fire on microarthropod community. Revue d’Écologie et de Biologie du sol 24, 603-622.

Bretfeld, G. (1999) Synopses on Palaearctic Collembola. Volume 2. Symphypleona. Abhandlungen und Berichte des Naturkundemuseums Görlitz 71 (1), 318pp.

Bruckner, A. (1998) Augers may bias field samples of soil mesofauna. Pedobiologia 42, 309-315.

Certini, G. (2005) Effects of fire on properties of forest soils: a review. Oecologia 143, 1-10.

Clarke, K.R. & Gorley, R.N. (2001) PRIMER v5: User Manual/Tutorial. PRIMER-E, Plymouth.

Conedera, M. (2005) Erosion und Oberflächenabfluss nach Bränden. Bündnerwald 58, 6, 75-76.

Driessen, M.M. & Greenslade, P. (2004) Effect of season, location and fire on Collembola communities in buttongrass moorlands, Tasmania. Pedobiologia 48, 631-642.

Ellenberg, H. (1996) Vegetation Mitteleuropas mit den Alpen in ökologischer, dynamischer und historischer Sicht. 5. Auflage, E. Ulmer, Stuttgart, 1096pp.

Englisch, T., Valachovič, M., Mucina, L., Grabherr, G. Ellmauer, T. (1993) *Thlaspietea rotundifolii*. In: Grabherr, G., Mucina, L. (Eds.), Die Pflanzengesellschaften Österreichs. Teil II. Gustav Fischer Verlag, Jena. 276-342.

Friend, G. (1996) Fire ecology of invertebrates: implications for nature conservation, fire management and future research. In Fire and Biodiversity: the Effects and Effectiveness of Fire Management: Proceedings of the Conference Held 8-9 October, 1994, Footscray, Melbourne, Department of the Environment, Sport and Territories, Australia, 155-162.

Gimmi, U., Bürgi, M. & Wohlgemuth, T. (2004) Wie oft brannte der Walliser Wald im 20. Jahrhundert? Schweizerische Zeitschrift für Forstwesen 155 (10), 437-440.

Gisin, H. (1960) Collembolenfauna Europas. Museum d´Histoire Naturelle, Genève, 312pp.

Grabherr, G., Greimler, J. & Mucina, L. (1993) *Seslerietae albicantis*. In: Grabherr, G., & Mucina, L. (Eds.), Die Pflanzengesellschaften Österreichs. Teil II. Gustav Fischer Verlag, Jena. 402-446.

Greenslade, P. (1997) Short term effects of a predescribed burn on invertebrates in grassy woodland in South-Eastern Australia. Memoirs of the Museum of Victoria 65(2), 305-312.

Greenslade, P. & Driessen, D. (1999) The effect of fire on epigaeic arthropods in Buttongrass moorlands in Tasmania. In: Ponder, W., Lunney, D., (Eds.), The Other 99%. The Conservation and Biodiversity of Invertebrates. Transactions of the Royal Zoological Society of New South Wales, Mosman 2088, 82-89.

Hågvar, S. (1995) Long distance, directional migration on snow in a forest collembolan, *Hypogastrura socialis* (Uzel). Acta Zoologica Fennica 196, 200-205.

Hopkin, S.P. (1997) Biology of the Springtails. Oxford University Press, Oxford, 330pp.

Hutha, V., Karppinen, E., Nurminen, M. & Valpas, A. (1967) Effect of silvicultural practices upon arthropod, annelid and nematode populations in coniferous forest soil. Annales Zoologici Fennici 2, 87-145.

Huhta, V., Nurminen, M. & Valpas, A. (1969) Further notes on the effect of silvicultural practices upon the fauna of coniferous forest soil. Annales Zoologici Fennici 6, 327-334.

Jahn, E., Schmiechtl, H.M. & Schimitschek, G. (1970) Möglichkeiten der natürlichen und künstlichen Regeneration einer Waldbrandfläche in den Tiroler Kalkalpen. Berichte der Naturhistorischen und Medizinischen Vereinigung Innsbruck 58, 355-388.

Kilian, W. (2002) Schlüssel zur Bestimmung der Böden Österreichs. Mitteilungen der Österreichischen Bodenkundlichen Gesellschaft 67, 1-96.

Koponen, S. (1988) Effects of fire on spider fauna in subarctic birch forest, northern Finland. Techische Universität Berlin. Dokumentation Kongresse Tagungen 38, 148-153.

Koponen, S. (1989) Effect of fire on ground layer invertebrate fauna in birch forest in the Kevo Strict Sature Reserve, Finnish Lappland. Folia forestalia 736, 75-80.

Koponen, S. (1995) Postfire succession of soil arthropod groups in a subarctic birch forest. Acta Zoologica Fennica 196, 243-245.

Lippert, W. (1966) Die Pflanzengesellschaften des Naturschutzgebietes Berchtesgaden. Berichte der Bayerischen Botanischen Gesellschaft 39, 67-122.

Lussenhop, J.F. (1976) Soil arthropod responce to prairie burning. Ecology 57, 88-98.

McCune, G. & Mefford. M. J. (1999) PC-ORD. Multivariate analysis of ecological data, v4.0. MjM Software Design, Gleneden Beach, Oregon, USA.

McCune, B. & Grace, J.B. (2002) Analysis of Ecological Communities. MjM Software Design, Gleneden Beach, OR, USA.

Majer, J.D. (1984) Short term responses of soil and litter invertebrates to a cool autumn burn in Jarrah (*Eucalyptus marginata*) forest in Western Australia. Pedobiologia 26, 229-247.

Metz, L.J. & Farrier, M.H. (1973) Prescribed burning and populations of soil mesofauna. Environmental Ecology 2, 433-440.

Mertz, P. (2002) Pflanzengesellschaften Mitteleuropas und der Alpen, Erkennen, Bestimmen, Bewerten, Ein Handbuch für die vegetationskundliche Praxis. Nicol VerlagsGesmbH, Hamburg, 511pp.

Moretti, M., Obris, K.M. & Duelli, P. (2004) Arthropod biodiversity after forest fires: winners and losers in the winter fire regime of the southern Alps. Ecography 27, 173-186.

Neary, D.G., Klopatek, C.C., DeBano, L.F. & Ffolliott, P.F. (1999) Fire effects on belowground sustainability: a review and synthesis. Forest Ecology and Management 122, 51-71.

Oberdorfer, E. (1974/76) *Seslerietae variae*. In: Oberdorfer, E., (Hrsg.) 1993. Süddeutsche Pflanzengesellschaften, Teil II. 3. Auflage, G. Fischer Verlag, Stuttgart, New York, 194-203.

Potapow, M. (2001) Synopses on Palaearctic Collembola. Volume 3. Isotomidae. Abhandlungen und Berichte des Naturkundemuseums Görlitz 73 (2), 603pp.

Schönenberger, W. & Wasem, U. (1997) Die Wiederbewaldung der Brandfläche Müstair. Cratschla 2/97, 9-14.

Seastedt, T.R. (1984) Microarthropods of burned and unburned tallgrass prairie. Journal of the Kansas Entomological Society 57, 468-476.

Seibert, P. (1974) *Thlaspietea rotundifolii*. In: Oberdorfer, E., (Hrsg.) 1977. Süddeutsche Pflanzengesellschaften, Teil I. 2. Auflage, G. Fischer Verlag, Stuttgart, New York, 42-66.

Seibert, P. (1988) *Vaccinio-Piceetea*. In: Oberdorfer, E., (Ed.) 1992. Süddeutsche Pflanzengesellschaften, Teil IV. 2. Auflage, G. Fischer Verlag, Stuttgart, New York, 53-80.

Sgardelis, S.P. & Margaris, N.S. (1993) Effects of fire on soil microarthropods of a phryganic ecosystem. Pedobiologia 37, 83-94.

Shaw, P.J.A. (1997) Post-fire successions of Collembola in lowland heaths in South-Eastern UK. Pedobiologia 41, 80-87.

Stach, J. (1960) The Apterygotan Fauna of Poland in Relation to the World-Fauna of this group of Insects. Tribe: Orchesellini. Polska Akademia Nauk, Kraków, 151pp.

Stach, J. (1963) The Apterygotan Fauna of Poland in Relation to the World-Fauna of this group of Insects. Tribe: Entomobryini. Polska Akademia Nauk, Kraków, 126pp.

Webb, N.R. (1994) Post-fire succession of Cryptostigmatic mites (Acari, Cryptostigmata) in a *Calluna*-heathland soil. Pedobiologia 38, 138-145.

Wohlgemuth, T., Bürgi, M., Scheidegger, C. & Schütz, M. (2002) Dominance reduction of species through disturbance - a proposed management principle for central European forests. Forest Ecology and Management 166, 1-15.

Wohlgemuth, T., Duelli, P., Ginzler, C., Gödickmeier, I., Hadorn, S., Hagedorn, F., Küttel, P., Lüscher, P., Moretti, M., Schneiter, G., Sciacca, S. & Wermelinger, B. (2005) Ökologische Resilienz nach Feuer: Die Waldbrandfläche Leuk als Modellfall. Schweizerische Zeitschrift für Forstwesen 156 (9), 345-352.

Zöttl, H. (1952) Beitrag zur Ökologie alpiner Kalkschuttstandorte. Phyton 4, 160-175.

Zukrigl, K. (1973) Montane und subalpine Waldgesellschaften am Alpenostrand. Mitteilungen der Forstlichen Bundesversuchsanstalt 101, 1-387.

Species	**SITE 1**	**SITE 2**	**REF**
Allacma fusca (Linnaeus, 1758)	0	0	80
Anurophorus laricis Nicolet, 1842	0	0	40
Bourletiella (B.) pistillum Gisin, 1946	0	0	40
Ceratophysella sp.	40	0	0
Entomobrya nivalis (Linnaeus, 1758)	0	0	40
Entomobrya sp.	240	0	560
Folsomia penicula Bagnall, 1939	1680	1880	3440
Heterosminthurus sp.	160	240	0
Hypogastrura cf assimilis (Krausbauer, 1898)	17320	560	0
Isotomiella minor (Schäffer, 1896)	2360	320	7040
Pseudisotoma sensibilis (Tullberg, 1876)	0	0	160
Isotoma sp.	0	440	0
Desoria sp.	1520	0	0
Lepidocyrtus cyaneus Tullberg, 1871	2880	0	40
Lepidocyrtus sp.	120	0	200
Mesaphorura sylvatica Rusek, 1971	3280	1640	15720
Mesaphorura sp.	200	0	1 120
Neanura parva (Stach, 1951)	0	40	0
Odontella armata Axelson, 1903	360	0	0
Oligaphorura absoloni (Börner 1901)	0	360	0
Kalaphorura burmeisteri (Lubbock, 1873)	520	0	480
Onychiurus fimetarius (L. 1767)	920	0	0
Onychiurus juv.	2440	40	80
Onychiuroides pseudogranulosus (Gisin, 1951)	1760	280	80
Onychiurus vontoernei (Gisin 1957)	1040	40	2040
Orchesella montana Stach, 1960	0	160	0
Parisotoma notabilis (Schäffer, 1896)	10040	1280	2320
Pseudachorutes subcrassus Tullberg, 1871	0	240	80
Pseudanurophorus boerneri Stach, 1922	200	0	1520

Ceratophysella sp.	0	480	0
Seira sp.	0	0	40
Sminthurides sp.	40	80	120
Lipothrix lubbocki (Tullberg, 1872)	0	0	120
Sminthurus maculatus Tömösvary, 1883	0	0	40
Tetracanthella stachi Cassagnau, 1959	560	0	1040
Thaumanura oniscoides (Latzel, 1917)	0	0	120
Tomocerus minor (Lubbock, 1862)	1280	40	800
Tullbergiinae sp.	0	40	0
Willemia anophthalma Börner, 1901	0	0	160
Willemia denisi Mills, 1932	0	0	200
Xenylla sp.	0	0	5360
Total number of individuals * m^{-2}	48960	8160	43080
Total number of species per site	22	18	30

Table 1: Species abundance table of the Collembola found in soil samples of three investigation sites of a wildfire experiment. SITE 1 is a disturbed site that burned in 2003, SITE 2 burned in 1950 and REF is an undisturbed reference site. Values are individuals * m^{-2}.

Bray-Curtis Index		
	REF	SITE 2
SITE 2	21.39	-
SITE 1	29.38	21.29
Sørensen Index		
	REF	SITE 2
SITE 2	42.55	-
SITE 1	62.75	55.00

Table 2: Species (Sørensen Index) and dominance similarity (Bray-Curtis Index) of the Collembola faunas in soil samples of three investigation sites of a wildfire experiment. Refer to Table 1 for site codes.

REF	Indication value	significance
Pseudanurophorus boerneri	79 %	p = 0.004
Willemia aspinata	100 %	p = 0.043
SITE 1		
Isotoma sp.	100 %	p = 0.002
Oligophorura absoloni	100 %	p = 0.007
Hypogastrura cf assimilis	89 %	p = 0.001
SITE 2		
Desoria sp.	100 %	p = 0.004
Lepidocyrtus cyaneus	100 %	p = 0.001
Tomocerus minutus	72 %	p = 0.001

Table 3: Collembola species of significant indicator value for three investigation sites of a wildfire experiment. The indicator value is the percentage of perfect indication (100%) for a specific site. Refer to Table 1 for site codes.

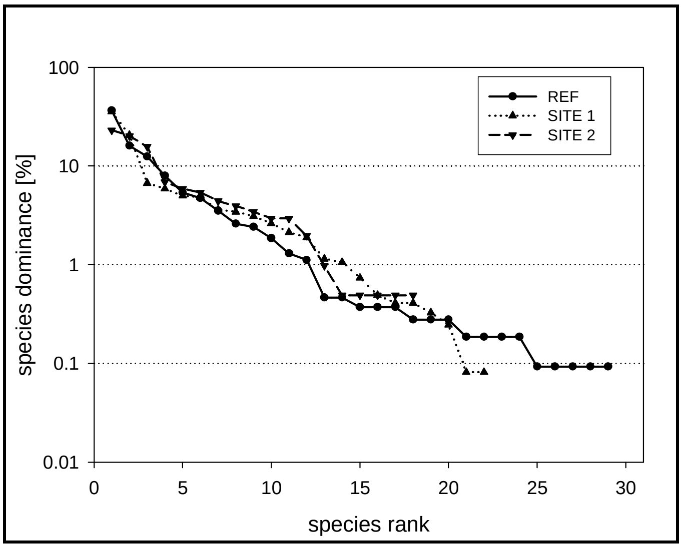

Figure 1: Rank-abundance curve for the Collembola from three investigation sites of a wildfire experiment. Refer to Table 1 for site codes.

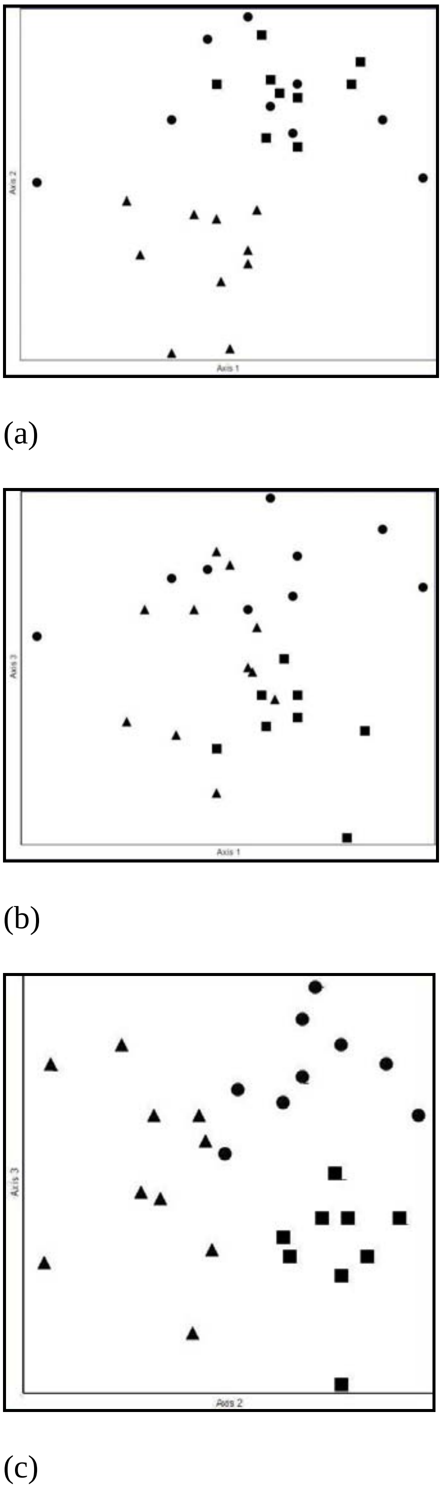

Figure 2: Ordination of 25 samples along (a) axes 2 and 1, (b) axis 3 and 1 and (c) axis 3 and 2 in a multidimensional space (Non-metric multidimensional scaling; NMDS). SITE 1 (▲) is a disturbed site that burned in 2003, SITE 2 (■) burned in 1950 and REF (●) is an undisturbed reference site.

Chapter IV.

4. Effects of site and landscape parameters on Collembola diversity in 29 winter oilseed rape fields

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Type of contribution: regular paper
Journal: Landscape ecology

4.1 Abstract

Soil animals are rarely considered in landscape ecology although recent findings show that landscape composition and habitat fragmentation may exert strong influence on their communities. We assessed at which spatial scales landscape parameters affect Collembola diversity in agricultural fields. We hypothesized that epigeic (surface active) species are influenced more in this respect than endogeic (soil living) species. We used pitfall traps and soil cores to collect the species richness and abundance of the two life forms in 29 oilseed rape fields in Eastern Austria that were situated in differently structured landscapes (fields, forests, hedges, grasslands, fallows). We found that both epi- and endogeic species were influenced by landscape structure. Site parameters like soil index, soil moisture and site cover also affected their diversity but to a lower extent. The epigeic species richness was positively related to different landscape parameters like landscape diversity, proportion of woody area, isolation of open habitats and area of oilseed rape fields at small to medium (250-1,000 m) and at larger (1,000-1,750 m) scales around the investigated sites. The endogeic species richness was also influenced by landscape parameters like landscape diversity and road strip length. Total species richness was affected by landscape diversity at a larger scale, isolation of open habitats and proportion of woody area at a smaller spatial scale. Our results demonstrate that landscape parameters affected Collembola at two spatial scales: At small scales, probably due to active migration from bordering hedges, forests or grasslands; and at larger scales, possible due to passive dispersal. Dispersal of animals with wind may be a relevant factor in the landscape ecology of soil animals.

Keywords: Collembola; Euedaphic and epedaphic species; Diversity; Landscape ecology, Oilseed rape; Wind dispersal; Migration

4.2 Introduction

The soil is part of most terrestrial ecosystems and is closely linked to the above ground system. A broad variety of animals inhabit the soil and contribute considerably to the decomposition of dead organic matter (Petersen 1994), nutrient cycles (Petersen and Luxton 1982), the development of soil microstructure (Rusek 1975, 1985) and thus to the functioning of the ecosystem as a whole (Copley 2000). Considering all soil organisms together the soil is hyper diverse (Wall & Virgina 2000) with hundreds of species within a few cubic centimeter. In temperate regions, Collembola (springtails) are the most abundant insects in the soil (10^4-10^5 individuals*m^{-2}; Peteterson & Luxton 1982). They belong to the soil mesofauna (body size of 0.2-2 mm) with a species richness up to 60 species in a site of ½ ha (Petersen 2002). They live in the soil pores, the litter layer, on the soil surface, and on vegetation (Hopkin 1997). The diversity and community composition are usually related to abiotic and biotic site parameters. Soil type, temperature, moisture, acidity, the presence or absence of a litter layer and the fungal community influence the communities (Betsch 1991, Betsch & Cancela da Fonseca 1995, Hashimoto & Tamura 1994, Klironomos & Kendrick 1995, Kovác 1994, Ponge et al. 1993). Site parameters that seem to have the most influence are soil acidity, vegetation type and humus form (Ponge 1993, Ponge & Prat 1982). However, it is yet not fully understood to what extent these parameters regulate the structure and compostion of Collembola communities of particular sites.

Landscape or regional parameters could also affect Collembola, but are rarely considered in soil ecology. The landscape structure and variety around a site may have an influence, as they may determine the animals' dispersal rates in the landscape matrix. In recent years, some studies have investigated the effects of the landscape structure on springtail diversity and communities. Chust et al. (2002, 2003 a, b) studied the effect of fragmentation in Pyrenean forests on soil Collembola communities and found a negative relationship between landscape heterogeneity and richness of the endemic species, indicating that landscape fragmentation is a potential threat to the endemic component of soil assemblages. Querner (2002) found positive correlations between the diversity of surface active Collembola and the landscape composition around 50 fragmented dry grassland islands in Eastern Austria. This points to the importance of neighbouring grasslands in close vicinity to the sites, which influence the number of remnant dependant species. The effects of land use intensity and landscape structure on the Collembola biodiversity and communities were investigated by Ponge et al. (2003, 2006), Sousa et al. (2004, 2006) and Vanberger et al. (2007). All these studies showed an effect of the landscape structure on the Collembola.

But at which spatial scale the landscape structure affects springtails and whether the euedaphic (soil living) and epedaphic (surface active) species are influenced in the same way, has not yet been studied. To answer these questions, we collected the eu- and epedaphic Collembola communities in 29 oilseed rape fields situated within variously structured landscapes, ranging from structurally simple to complex. We hypothesized (1) that the epedaphic species are influenced more by the landscape structure because they are larger, live on the soil surface and are more mobile. Active movement from one patch to another seems more likely; (2) that the euedaphic species in contrast are influenced more by site parameters because they are smaller, live in the soil pores and are less mobile, than the euedaphic species;

(3) that a more diverse landscape comprised of small fields, grasslands, fallows, forests and hedges, contains a higher total Collembola diversity, than a structurally simple landscape with large fields and fewer natural habitats.

4.3 Material and methods

Site description

As part of a larger project on the landscape ecology of plant parasites and pest predators, (Drapela et al. 2008, Zaller et al. 2008 a, b, c), we designated an agricultural study region of 240 km^2 size approximately 40 km east of Vienna, Austria (central coordinates: 16°57'E, 48°04'N). The main soil type of the region is chernozem; the climate is pannonian (continental). Within this region, 29 winter oilseed rape fields were selected, embedded in differently structured landscapes ranging from structurally simple to structurally complex (details in Zaller et al. 2008 b). Oilseed rape was sown in August and September 2004 and the fields were fertilized and treated with herbicides, fungicides, and insecticides following common agricultural practice. In January 2005, an area of 1 ha within each field was excluded from pesticide applications and this area was used for sampling the surface active and soil living Collembola later on.

Collembola sampling

Pitfall traps

Six unroofed pitfall traps of 1.7 cm diameter were used to collect the surface active Collembola at each site. Traps were placed along a 50 m transect with a spacing of 10 m between each trap, filled with ethylene glycol and a drop of odorless detergent. After an exposure of 14 days in April of 2005, the traps were removed and the Collembola specimens determined to species level and counted.

Soil core collection and extraction

In April 2005, 20 soil cores were taken along two parallel transects (each 50 m long and 10 m apart) with a spacing of 5 m between samples. 57 x 57 mm steel tubes (Bruckner 1998) were used to a depth of 100 mm, the soil was stored in plastic bags and cooled until extraction. All samples were extracted in a modified Berlese-Tullgren extractor for seven days into 10% benzoic acid solution. In each field, 20 cores were collected, extracted and pooled, and 5 aliquots processed further (see Bruckner et al. (2000) for a detailed description of this method).

Collembola identification

The Collembola were identified using the keys of Gisin (1960), Stach (1960, 1963), Babenko et al. (1994), Zimdars & Dunger (1994), Pomorski (1998), Bretfeld (1999), Potapow (2001) and Thibaud et al. (2004).

Each species was classified as “euedaphic” or “epedaphic” (Gisin 1943, Petersen 2002), according to its frequency in the sampling methods: Species collected in higher frequency in the pitfall traps than in the soil samples were classified as epedaphic, and vice versa with the euedaphic species. If a species was found in both methods equally frequently, the species was kept in both lists for further analysis.

Collembola data

As dependent parameters we used the number of species from the pitfall traps (surface species richness), from the soil samples (soil species richness) and the pooled species richness (total species richness) and the abundance from the pitfall trap (surface abundance) and the soil samples (soil abundance). Abundance data were $\log_{10}+1$ transformed prior to the analysis to meet criteria for regression analyses.

Landscape parameters

The landscape surrounding each study field was analyzed in eight circular radii of 250, 500, 750, 1000, 1250, 1500, 1750, 2000 m regarding the total area of oilseed rape fields, total non crop area (woody structures and open habitats), total woody area (pooled area of dry forests, alluvial forests, riverine forests, copses, woody fallows and hedges), total open habitats area (grassy fallows and dry grasslands, but not linear structures) and total length of road-side strips using the software packages ArcGIS 9.1 and Arc View GIS 3.3 (ESRI Redlands, CA, USA). Isolation of open habitats (grassy fallows, dry grasslands, vineyards) in the landscape was calculated by using a negative exponential weighting function: Isolation was calculated based on the distances of the nearest open habitat to each study field and the area of the open habitat in each spatial scale. We used the formula: $\text{Isolation}_i = -\Sigma(e^{-\text{distance}} \times \text{open habitat area}_j) / \Sigma\, e^{-\text{distance}}$ (Kruess 2003). Additionally, the minimum distance to the nearest oilseed rape field, forest, hedgerow, woody structure (forest or hedgerow), dry grassland and open habitat (grassland or fallows) was calculated. To estimate landscape diversity, we calculated the Shannon-Wiener landscape diversity index (Krebs 1994) and landscape habitat richness, based on 14 habitat types (arable fields, grassy fallows, woody fallows, copses, dry grasslands, dry shrub lands, dry forests, alluvial forests, riverside forests, hedges, settlements, water bodies, roads, and vineyards) for the eight radii around each study field. The calculations of landscape parameters based on a detailed land use map elaborated by field surveys in 2005 using real color orthophotos (minimum resolution 0.25 m). All parameters are listed in Table 1.

Site parameters

Information on several site parameters (Table 1.) was gathered by a questionnaire among farmers. Soil index is a measure of soil quality representing the natural yield capacity of a field in relation to the highest yielding capacity of the country (values from 0 to 100, where 100 stands for the highest yield capacity) integrating soil type, humus content, soil depth, texture, density, structure, lime content, gleying, and soil congregation (ÖBG 2001). The soil moisture (values from 1 to 10; 1 stands for dry) was obtained from the Austrian soil map (eBOD 2008). Based on the farmers' information on cultivation practices (ploughing, harrowing, milling, grubbing), we calculated an index of soil cultivation intensity. Furthermore, the farmers provided information on nitrogen fertilizer and pesticide applications. Vegetation cover of oilseed rape (%) was estimated in November 2004 at three randomly positioned 1-m^2 plots in each study field. As a measure of structural complexity, we assessed oilseed rape stand density (plants m^{-2}) within two 1-m^2 frames per field a couple of days before harvest in the third week of June 2005. Averaged values of vegetation cover and stand density for each study field were used for statistical analyses.

Data analysis

We used ordinary least-squares regression (OLS) for the species richness and abundance data, as all dependent parameters were normally distributed after transformation (Kolmogorov-Smirnov-test). To detect scale-dependent effects, we compared the predictive power of each landscape parameter at each of the eight radii, if at least one of the radii revealed a significant result for this landscape parameter. If more than one significantly fitting function (linear, quadratic or cubic) was found, we selected the one explaining the largest part of the variance and compared the explained variance for this parameter across the radii.

We performed a multivariate regression for the (i) surface species richness, (ii) soil species richness and (iii) total species richness by using a forward stepwise selection and backward elimination procedure. At each step of the parameter selection, the significance of the partial effects of predictors was tested by dropping them sequentially from the model (Wald test, F-statistics; because of normal distributed data, $p<0.05$). We selected a maximum of three significant predicting parameters for each model. Each additional parameter enhanced the explanatory power of the howl model. All regression analyses were performed with S-PLUS 7.0 for Windows (Insightful, Seattle, USA).

4.4 Results

We collected 35,048 Collembola in total. The activity density in the pitfall traps varied between 82 and 3,048 and the abundance in the soil samples between 451 and 9,837 individuals per square meter. Out of the 70 species collected in total (Table 2), 16 species were found only in the pitfall traps, 36 only in the soil samples and 18 species were about equally frequently collected with both methods. Species richness in the fields varied between 8 and 19 in the pitfall traps and between 8 and 24 in the soil cores. According to their frequency in all the samples, 38 Collembola species were classified as epedaphic and 22 as euedaphic species. Two species were removed from the pitfall trap list and 8 from the soil sample list because they were yielded very infrequently with these methods. 10 species were collected with both methods equally well and no preferred method was found (Table 2).

All significant linear, quadratic and cubic regressions are listed in Table 3. For the significant site parameters, epigeic species richness was positively related to soil index (Fig. 1 a) and soil moisture (Fig. 1 b); endogeic species richness to oilseed rape cover (Fig. 1 c); total species richness was negatively to N-fertility (Fig. 1 d); and endogeic abundance positively to oilseed rape cover (Fig. 1 e). However, despite the significance of the relationships, the correlations between site and faunal parameters were not close and simple (Fig. 1 a-e). For epigeic abundance, no significant correlation to any of the site parameters was found.

The landscape parameters woody area (Fig. 2 a), isolation of open habitats (Fig. 2 b) and habitat richness (Fig. 2 c) were positively related to the epigeic species richness and had the highest explained variance between 250, 500 and 250 - 1,250 m radius, respectively. For the landscape parameters landscape diversity (Fig. 2 d) and oilseed rape area (Fig. 2 e) the explained variance was highest at larger radii (1,500 - 1,750 m and 750 - 1,500 m, respectively). The single most important variable for the epigeic species richness was landscape diversity at 1,500 m (Tab. 3). In the multivariate regression model, landscape diversity at 1,500 m, soil index and open habitat isolation at 500 m and explained 66% of the variance (Tab. 4).

The landscape parameters landscape diversity was positively and road-side strip length negatively related to the endogeic species richness. The explained variance for the landscape diversity was highest at 1,500-1,750 m (Fig. 3 a), and at 1,000 m (Fig. 3 b) for road-side strip length, respectively. The single most important parameter was landscape diversity at large radii (1,500 - 1,750 m; Tab. 3). In the multivariate regression model for the endogeic species richness, landscape diversity at 1,500 m, open habitat isolation at 500 m and habitat richness at 250 m explained 65 % of the variation (Tab. 4).

The landscape parameters landscape diversity, woody area and open habitat isolation were positively related to total species richness. The explained variance for landscape diversity was highest at 1,500-1,750 m (Fig. 4 a), for woody area at 500-1,000 m (Fig. 4 b) and for open habitat isolation over shorter radii (500 m; Fig. 4 c), respectively. The single most important variable was landscape diversity at 1,500 m (Tab. 3). In the multivariate regression model for total species richness, landscape diversity at 1,500 m, soil cultivation index and open habitat isolation at 500 m explained 80.85 % of the variation (Table 4).

The surface activity abundance was positively related to the landscape parameters oilseed rape area at 250 m (Fig. 5 a) and negatively to woody areas at 750-1,000 m (Fig. 5 b). The single most important explaining variable for the surface activity abundance was oilseed rape area at 250 m (Table 4).

4.5 Discussion

Our results clearly show that both the eu- and epedaphic Collembola species richness are influenced by the structure of the landscape surrounding the investigated sites. In agreement with our assumptions, we found the closest relationships between the richness of the epigeic Collembola and landscape parameters. Site parameters like soil index and soil moisture also affected their diversity, but to a lower extent and no simple form of the correlations was found.

We could distinguish between landscape parameters affecting the epigeic Collembola over two spatial scales. Woody area, habitat richness and isolation of open habitats affected the diversity over short and medium ranges (250-1,250 m) and Shannon landscape diversity and oilseed rape field area over larger ranges (750-1,750 m). All relations were positive indicating that a more diverse landscapes, consisting of larger areas of wood or oilseed rape fields, lead to higher epigeic species richness in the fields. In contradiction to our assumptions, we found that also the soil living species were mainly influenced by landscape structure, namely landscape diversity and road-side strips length over large radii (>1,000 m).

The influence of landscape parameters at a small scale or short range can be explained through active migration of animals into the fields from surrounding habitats. Short range effects were only found for the epigeic and total species richness. Active migration of surface Collembola was described by Hågvar (1995, 2000) and Mebes & Filser (1997) and is probably taking place only over shorter distances and from bordering habitats. Hågvar (2000) described directed migration of epigeic Collembola over a few hundred meters within a day, navigating by the position of the sun. Migration of surface active springtails from bordering hedges into fields was described by Frampton (2002), Frampton & Van den Brink (2002), Frampton et al. (2007) and Alvarez et al. (1997, 2000). These studies show that bordering or close landscape structures like hedges within a few hundred meter distance, can influence the Collembola diversity in fields. We did not find hedges as a relevant landscape structure at our sites, but woody areas, that probably have the same effects.

The influence of landscape structure on the eu-, epedaphic and total species richness at large scales is probably not related to active migration, as this is limited to 10^{-2} and 10^{-1} meters (Ojala & Huhta 2001). We suppose that passive dispersal of all species is an important factor for the patters we found in our study. Various vectors of passive dispersal in Collembola are possible. Wind dispersal was already described by Glick in 1939 in an experiment collecting animals by airplane at a height of 3,000 m. Freeman (1952), Johnson (1957), Gressitt et al. (1960) also showed that passive dispersal with wind is a common phenomenon and can transport Collembola over longer distances. Other vectors for passive dispersal of soil arthropods are runoff water (Usher 1985, Christiansen 1964) and birds (described for soil mites; Krivolutsky & Lebedeva 2004, Krivolutsky et al. 2003, Lebedeva & Krivolutsky 2004).

Another evidence that even epedaphic Collembola are passively dispersed by wind is the natural succession taking place at reclaimed sites. Long term studies of the colonization of coal mine dumps was described by Dunger (1989) and Dunger et al. (2001, 2002, 2004). Dunger & Voigtländer (2005) described 8 colonizing groups for Collembola, each with a number of previously undetected species. They must have been passively dispersed onto the coal mine dumps.

We hypothesize that short-range passive transport of animals might occur predominantly close to the soil surface. In this study, the oilseed rape fields could have functioned as a sieve or filter and collected the transported animals from the air currents. During the time of the sampling and also the previous months, the oilseed rape fields had a much denser and higher vegetation cover than most fields in the surrounding agricultural landscape.

No faunal variable was influenced by landscape parameters at radii larger than 1750 meters. This contrasts to literature on large-scale transport (see above) demonstrating that passive dispersal is also taking place above this scale. A possible explanation for this discrepancy (and for the humped shape of some of the graphs) might be the way we progressively included data from peripheral radii into the analysis: At smaller scales, the parameters of the landscapes surrounding the investigated fields were progressively better described (and became better descriptors of faunal variables), the more radii we included in the regression. Between these and the maximum range considered (2,000 m), landscape parameters were no longer scale dependant, that is, did not change further with increasing distance from the investigated fields, and their relative influence on the regressions decreased again.

The multivariate regression model for the total species richness explained 80 % of the variation with the landscape factors landscape diversity and open habitat isolation and the site factor soil cultivation index. This high value shows how important landscape parameters are for the Collembola diversity of agricultural fields. Therefore, we strongly suggest to include parameters at landscape scales and of landscape composition in studies on the composition and regulation of soil microarthropod assembalges, as these may significantly improve our understanding of community patterns.

4.6 Conclusion

Considering the evidences from the literature about migration and dispersal and the results from our project, we believe that the surface active and the soil living Collembola species are both affected by the landscape structure. This might be a wide spread phenomenon, especially in open and divers landscapes. Active migration over short distances and passive dispersal over longer distances are probably both taking place. We believe that soil ecologists should take a closer look at the landscape surrounding their investigated site in the future and used also landscape parameters in their analysis. Studying the distance, frequency and methods of active migration and passive dispersal of Collembola or other soil animals across the landscape, could be new and very interesting research fields in soil or landscape ecology, helping to understand the patterns we find in soil fauna communities.

Acknowledgements

We would like to thank Alex Bandion and Bettina Iberer for their help in the field.

4.7 References

Alvarez, T., Frampton, G.K. & Goulson, D. (1997) Population dynamics of epigeic Collembola in arable fields: The importance of hedgerow proximity and crop type. Pedobiologia 41 (1-3), 110-114.

Alvarez, T., Frampton, G.K. & Goulson, D. (2000) The role of hedgerows in the recolonisation of arable fields by epigeal Collembola. Pedobiologia 44 (3-4), 516-526.

Babenko, A.B., Chernova, N.M., Potapov, M.B. & Stebaeva, S.K. (1994) Collembola of Russia and adjacent countries: Family Hypogastruridae. Nauka, Moscow, 336pp.

Betsch, J.M. (1991) Effets de la privation des apports annuels de litière sur les collemboles symphypléones épigés d'une forêt sur rendzine. Revue d'écologie et de biologie du sol 28 (1), 41-49.

Betsch, J.M. & Cancela da Fonseca, P. (1995) Changes in edaphic factors and microarthropod communities after clearing and burning in a tropical rain forest in French Guyana. Acta Zoologica Fennica 196, 142-145.

Bretfeld, G. (1999) Synopses on Palaearctic Collembola. Symphypleona. Volume 2. Abhandlungen und Berichte des Naturkundemuseums Görlitz 71 (1), 318pp.

Bruckner, A. (1998) Augers may bias field sampling of soil mesofauna. Pedobiologia 42 (4), 309-315.

Bruckner, A., Barth, G. & Scheibengraf, M. (2000) Composite sampling enhances the confidence of soil microarthropod abundance and species richness estimates. Pedobiologia 44 (1), 63-74.

Christiansen, K. (1964) Bionomics of Collembola, Annual Review of Entomology 9, 147-178.

Chust, G., Lek, S., Deharveng, L., Ventura, D., Ducrot, D. & Pretus, J. (2000) The effects of the landscape pattern on arthropod assemblages: an analysis of scale-dependence using satellite data. Belgian Journal of Entomology 2 (1), 99-110.

Chust, G., Pretus, J.L., Ducrot, D., Bedòs, A. & Deharveng, L. (2003 a) Response of Soil Fauna to Landscape Heterogeneity: Determining Optimal Scales for Biodiversity Modeling. Conservation Biology 17 (6), 1712-1723.

Chust, G., Pretus, J.L., Ducrot, D., Bedòs, A. & Deharveng, L. (2003 b) Identification of landscape units from an insect perspective. Ecography 26 (3), 257-268.

Copley, J. (2000) Ecology goes underground. Nature 406, 452-454.

Drapela, T., Moser, D., Zaller, J.G. & Frank, T. (2008) Spider assemblages in winter oilseed rape affected by landscape and site factors. Ecography 31 (2), 254-262.

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. Cambridge University Press, 307-337.

Dunger, W., Wanner, M., Hauser, H., Hohberg, K., Schulz, H.J., Schwalbe, T., Seifert, B. & Zulka, K.P. (2001) Development of soil fauna at mine sites during 46 years after afforestation. Pedobiologia 45 (3), 243-271.

Dunger, W., Schulz, H.J. & Zimdars, B. (2002) Colonization behaviour of Collembola under different conditions of dispersal. Pedobiologia 46 (3-4), 316-327.

Dunger, W., Schulz, H.J., Zimdars, B. & Hohberg, K. (2004) Changes in Collembolan species composition in Eastern German mine-sites over fifty years of primary succession. Pedobiologia 48 (5-6), 503-517.

Dunger, W. & Voigtländer, K. (2005) Assessment of biological soil quality in wooded reclaimed mine sites. Geoderma 129 (1-2), 32-44.

eBOD (2008) Österreichische (digitale) Bodenkarte. Bundesforschungs- und Ausbildungszentrum für Wald, Naturgefahren und Landschaft (BFW). www.bodenkarte.at.

Frampton, G.K. (2002) Long-term impacts of an organophosphate-based regime of pesticides on field and field-edge Collembola communities. Pest Management Science 58 (10), 991-1001.

Frampton, G.K. & van den Brink, P.J. (2002) Influence of cropping on the species composition of epigeic Collembola in arable fields. Pedobiologia 46 (3-4), 328-337.

Frampton, G.K., Gould, P.J.L., van den Brink, P.J. & Hendy, E. (2007) Type 'A' and 'B' recovery revisited: The role of field-edge habitats for Collembola and macroarthropod community recovery after insecticide treatment. Environmental Pollution 145 (3), 874-883.

Freeman, J.A. (1952) Occurence of Collembola in the air. Proceedings of the Royal Entomological Society of London 27A, 28.

Gisin, H. (1960) Collembolenfauna Europas. Museum d´Histoire Naturelle, Genève, 312pp.

Gisin, H. (1943) Ökologie und Lebensgemeinschaften der Collembolen im Schweizerischen Exkursionsgebiet Basels, Revue suisse de Zoologie 50, 131-224.

Glick, P.A. (1939) The distribution of insects, spiders and mites in the air. Technical Bulletin No. 673 U.S. Department of Agriculture, 150pp.

Gressitt, J.L., Leech, R.E., Leech, T.S., Sedlacek, J. & Wise K.A.J. (1961) Trapping of air-borne insects in the Antarctic area (Part 2). Pacific Insects 3, 559-562.

Hågvar, S. (1995) Long distance, directional migration on snow in a forest Collembolan *Hypogastrura socialis* (Uzel). Acta Zoologica Fennica 196, 200-205.

Hågvar, S. (2000) Navigation and behavior of four Collembola species migrating on the snow surface. Pedobiologia 44 (3-4), 221-233.

Hashimoto, H. & Tamura, H. (1994) Change in collembolan community during litter breakdown. Acta Zoologica Fennica 195, 67-68.

Hopkin, S.P. (1997) Biology of the springtails (Insecta: Collembola), Oxford University Press, Oxford, 330pp.

Johnson, C.G. (1957) The distribution of insects in the air and the empirical relation of density to height. Journal of Animal Ecology 26 (2). 479-494.

Klironomos, J.N. & Kendrick, W.B. (1995) Stimulative effects of arthropods on endomycorrhizas of sugar maple in the presence of decaying litter. Functional Ecology 9 (3), 528-536.

Kovác, L. (1994) Effects of soil type on collembolan communities in agroecosystems. Acta Zoologica Fennica 195. 89-93.

Krebs, C.J. (1994) Ecology: the experimental analysis of distribution and abundance. 4th edition, Harper Collins, New York. 801 pp.

Kruess, A. (2003) Effects of landscape structure and habitat type on a plant-herbivore parasitoid community. Ecography 26 (3), 283-290.

Krivolutsky, D.A. & Lebedeva N.V. (2004) Oribatid mites (Oribatei, Acariformes) in bird feathers: non-Passerines. Acta Zoologica Lituanica 14 (1), 26-47.

Krivolutsky, D.A., Lebedeva, N.V. & Matyukhin, A.V. (2001) The oribates (Oribatei) in the lumage of birds. Parazitologiya 35 (4), 282-283.

Lebedeva, N.V. & Krivolutsky, D.A. (2003) Birds spread soil microarthropods to arctic islands. Doklady Biological Sciences 391 (1-6), 329-332.

Mebes, K.H. & Filser, J. (1997) A method for estimating the significance of surface dispersal for population fluctuations of Collembola in arable land. Pedobiologia 41 (1-3), 115-122.

ÖBG. (2001) Bodenaufnahmesysteme in Österreich. Mitteilungen der Österreichischen Bodenkundlichen Gesellschaft Heft 62, Österreichische Bodenkundliche Gesellschaft, 43pp.

Ojala, R. & Huhta, V. (2001) Dispersal of microarthropods in forest soil. Pedobiologia 45 (5), 443-450.

Petersen, H. (1994) A review of collembolan ecology in ecosystem context. In: Vilkamaa, P. (ed.) VIII International Colloquium on Apterygota, Helsinki 17-19 August 1992. Acta Zoologica Fennica 195, 111-118.

Petersen, H. (2002) General aspects of collembolan ecology at the turn of the millennium. Pedobiologia 46 (3-4), 246-260.

Peterson, H. & Luxton, M. (1982) A comparative analyses of soil fauna population and their role in decomposition processes. Oikos 39, 287-388.

Pomorski, J. (1998) Onychiurinae of Poland (Collembola: Onychiuridae). Polish Taxonomical Society, Wrocklaw, 201pp.

Ponge, J.F. (1993) Biocenoses of Collembola in Atlantic temperate grass-woodland ecosystems. Pedobiologia 37 (4), 223-244.

Ponge, J.F. & Prat, B. (1982) Collembola, indicators of the humification process in the resinous, deciduous and mixed plantings: results obtained in the forest d'Orleans, France. Revue d'Ecologie et de Biologie du Sol 19 (2), 237-250.

Ponge, J.F., Arpin, P. & Vannier, G. (1993) Collembolan response to experimental perturbations of litter supply in a temperate forest ecosystem. European Journal of Soil Biology 29 (3-4), 141-153.

Ponge, J.F., Gillet, S., Dubs, F., Fedoroff, E., Haese, L., Sousa, J.P. & Lavelle, P. (2003) Collembolan communities as bioindicators of land use intensification. Soil Biology and Biochemistry 35 (6), 813-826.

Ponge, J.F., Dubs, F., Gillet, S., Sousa, J.P. & Lavelle, P. (2006) Decreased biodiversity in soil springtail communities: the importance of dispersal and landuse history in heterogeneous landscapes. Soil Biology and Biochemistry 38 (5), 1158-1161.

Potapov, M. (2001) Synopses on Palaearctic Collembola. Volume 3. Isotomidae. Abhandlungen und Berichte des Naturkundemuseums Görlitz 73 (2), 603pp.

Querner, P. (2002) Biodiversity of Collembola on fragmented dry grasslands. Master Thesis at the University of Vienna. 35pp.

Querner, P. & Bruckner, A. (in this volume) Combining pitfall traps and soil cores to collect Collembola for biodiversity assessments. 21-38.

Rusek, J. (1975) Die Bodenbilde Function von Collembolen und Acarina. Pedobiologia 15, 299-308.

Rusek, J. (1985) Soil microstructures-contributions on specific soil organisms, Questiones Entomologicae 21, 497-514.

Sousa, J.P., da Gama, M.M., Pinto, C., Keating, A., Calhôa, F., Lemos, M., Castro, C., Luz, T., Leitão, P. & Dias, S. (2004) Effects of land-use on Collembola diversity patterns in a Mediterranean landscape. Pedobiologia 48 (5-6), 609-622.

Sousa, J.P., Bolger, T., da Gama, M.M., Lukkari, T., Ponge, J.F., Simón, C., Traser, G., Vanbergen, A.J., Brennan, A., Dubs, F., Ivitis, E., Keating, A., Stofer, S. & Watt, A.D. (2006)

Changes in Collembola richness and diversity along a gradient of land-use intensity: A pan European study. Pedobiologia 50 (2), 147-156.

Stach, J. (1960) The Apterygotan Fauna of Poland in Relation to the World-Fauna of this group of Insects. Tribe: Orchesellini. Polska Akademia Nauk, Kraków, 151pp.

Stach, J. (1963) The Apterygotan Fauna of Poland in Relation to the World-Fauna of this group of Insects. Tribe: Entomobryini. Polska Akademia Nauk, Kraków, 126pp.

Thibaud, J.M., Schulz, H.J. & da Gama Assalino, M.M. (2004) Synopses on Palaearctic Collembola. Volume 4. Hypogastruridae. Abhandlungen und Berichte des Naturkundemuseums Görlitz 75 (2), 287pp.

Usher, M. B. (1985) Population and community dynamics in the soil ecosystem. In: Atkinson, D., Read, D.J. & Usher, M.B. (eds.) Ecological interactions in soil. Blackwell Scientific Publications, Oxford, 243-265.

Vanbergen, A.J., Watt, A.D., Mitchell, R., Truscott, A.M., Palmer, S.C.F., Ivits, E., Eggleton, P., Jones, T.H. & Sousa, J.P. (2007) Scale-specific correlations between habitat heterogeneity and soil fauna diversity along a landscape structure gradient. Oecologia 153 (3), 713-725.

Wall, D.H. & Virginia. R.A. (2000) The world beneath our feet: soil biodiversity and ecosystem functioning. In: Raven, P.R. & Williams, T. (eds.) Nature and human society: the quest for a sustainable world. National Academy of Sciences and National Research Council, Washington, DC, 225-241.

Yee, T.W. & Mitchell, N.D. (1991) Generalized additive models in plant ecology. Journal of Vegetation Science 2, 587-602.

Zaller, J.G., Moser, D., Drapela, T., Schmöger, C. & Frank, T. (2008 a) Effect of within-field and landscape factors on insect damage in winter oilseed rape. Agriculture, Ecosystem and Environment 123 (1-3), 233-238.

Zaller, J.G., Moser, D., Drapela, T., Schmöger, C. & Frank, T. (2008 b) Insect pests in winter oilseed rape affected by field and landscape characteristics. Basic and Applied Ecology 9 (6), (in press).

Zaller, J.G., Moser, D., Drapela, T., Frank, T. (2008 c) Ground-dwelling predators can affect within-field pest insect emergence in winter oilseed rape fields. Biocontrol (in press).

Zimdars, B. & Dunger, W. (1994) Synopses on Palaearctic Collembola. Volume1. Tullberginae. Abhandlungen und Berichte des Naturkundemuseums Görlitz 68 (3), 70pp.

Site parameters	
Soil index	1 to 100
Soil moisture	1 to 10
Soil cultivation intensity	0 to 15
Oilseed rape stand density	plants * m^{-2}
Vegetation cover of oilseed rape	in %
Nitrogen fertilization in 2005	in kg N ha^{-1}
Insecticide application	in kg ha^{-1}
Landscape parameters	
Non crop area	250-2000 m radius
Grass not linear area	250-2000 m radius
Woody area	250-2000 m radius
Road side strip length	250-2000 m radius
Isolation of open habitats	250-2000 m radius
Oilseed rape area	250-2000 m radius
Landscape diversity	250-2000 m radius
Habitat richness	250-2000 m radius
Nearest oilseed rape field	min. distance
Nearest dry grassland site	min. distance
Nearest open habitat (hedges or dry grasslands)	min. distance
Nearest forest site	min. distance
Nearest hedge	min. distance
Nearest woody structure (forests or hedges)	min. distance

Table 1: Site and landscape parameters used to model the influence of local and regional factors on the Collembola communities of oilseed rape fields.

Collembola species	**Frequency in the pifall trap**	**Frequency in the soil cores**	**Selected sampling method**
Anurophorus sp	-	5	s
Arrhopalites caecus (Tullberg, 1871)	-	3	s
Axenyllodes bayeri (Kseneman, 1935)	-	1	s
Bourletiella (B.) hortensis (Fitch, 1863)	1	-	p
Bourletiella sp	-	7	s
Ceratophysella sigillata (Uzel, 1891)	-	1	s
Ceratophysella succinea (Gisin, 1949)	28	29	both
Cryptopygus ponticus (Stach, 1947)	1	-	p
Cryptopygus thermophilus (Axelson, 1900)	27	25	both
Deuterosminthurus sulphureus (Koch, 1840)	9	-	p
Deutonura conjuncta (Stach, 1926)	1	-	p
Entomobrya handschini Stach, 1922	19	1	p
Entomobrya marginata (Tullberg, 1871)	30	-	p
Entomobrya multifasciata (Tullberg, 1871)	3	1	p
Entomobrya sp	-	18	-
Folsomia sensibilis Kseneman, 1936	-	10	s
Folsomia sp	-	1	s
Folsomia spinosa Kseneman, 1936	3	-	p
Folsomides parvulus Stach, 1922	14	20	both
Friesea afurcata (Denis, 1926)	11	-	p
Heteromurus major (Moniez,1889)	4	-	p
Heteromurus nitidus (Templeton, 1835)	18	-	p
Heteromurus sp	-	2	s
Hypogastrura assimilis (Krausbauer, 1898)	5	-	p
Hypogastrura neglecta cf	1	-	p
Hypogastrura sensilis cf	-	4	s
Hypogastrura sp	-	2	s
Isotoma viridis Bourlet, 1839	29	28	both
Isotomiella minor (Schäffer, 1896)	-	1	s
Isotomodes sexsetosus Da Gama, 1963	-	1	s
Lepidocyrtus cyaneus Tullberg, 1871	30	25	both
Lepidocyrtus lanuginosus (Gmelin, 1788)	5	1	p
Lepidocyrtus paradoxus Uzel, 1891	2	-	p
Mesaphorura critica Ellis, 1976	-	29	s
Mesaphorura florae Simon, Ruiz, Martin & Luciañez, 1994	-	5	s
Mesaphorura hylophila Rusek, 1982	-	22	s

Mesaphorura italica (Rusek, 1971)	-	13	s
Mesaphorura jarmilae Rusek, 1982	-	15	s
Mesaphorura krausbaueri Börner, 1901	-	1	s
Mesaphorura macrochaeta Rusek, 1976	-	28	s
Mesaphorura sp	-	10	s
Mesaphorura sylvatica (Rusek; 1971)	-	2	s
Mesaphorura yosii (Rusek, 1967)	-	10	s
Metaphorura affinis (Börner, 1902)	-	3	s
Neotullbergia ramicuspis (Gisin, 1953)	-	15	s
Oncopodura crassicornis Shoebotham, 1911	-	2	s
Onychiurus sp (juv)	-	5	s
Onychiurus sp1	-	3	s
Onychiurus sp2	-	5	s
Orchesella cincta (Linnaeus, 1758)	11	4	p
Parisotoma notabilis (Schäffer, 1896)	11	21	s
Pogonognathellus flavescens (Tullberg, 1871)	2	-	p
Polyacanthella sp	-	1	s
Proisotoma minuta (Tullberg, 1871)	-	10	s
Protaphorura armata (Tullberg, 1869)	3	20	s
Protaphorura tricampata (Gisin, 1956)	1	1	both
Pseudachorutes dubius Krausbauer, 1898	10	-	p
Pseudosinella alba (Packard, 1873)	18	17	both
Pseudosinella sexoculata Schött, 1902	29	17	both
Pseudosinella sp	-	12	s
Schoettella ununguiculata (Tullberg, 1869)	3	-	p
Sminthurinus aureus (Lubbock, 1862)	21	3	p
Sminthurinus elegans (Fitch, 1863)	2	3	both
Sminthurus multipunctatus Schäffer, 1896	16	3	p
Sphaeridia pumilis (Krausbauer, 1898)	29	19	both
Stenacidia violacea (Reuter, 1881)	3	-	p
Stenaphorura denisi Bagnall, 1935	-	16	s
Symphypleaona sp	-	2	s
Willemia anophthalma Börner, 1901	-	29	s
Willemia sp	-	9	s

Table 2: Species list, frequency in the pitfall traps and soil cores and selected sampling method for the Collembola collected in the oilseed rape fields.

Parameters	Radius [m]	Relationship	Explained variance in %	P
Epigeic species richness				
Soil index	site	1	20.56	0.013
Soil dry point	site	1	17.84	0.022
Landscape diversity	1500	3	42.17	0.003
Oilseed rape area	1500	3	41.82	0.003
Oilseed rape area	1000	3	33.17	0.016
Landscape diversity	1750	3	32.05	0.02
Oilseed rape area	1250	3	31.67	0.021
Isolation open habitats	500	2	25.81	0.021
Oilseed rape area	750	2	24.93	0.024
Oilseed rape area	1000	2	21.18	0.045
Habitat richness	1250	1	20.10	0.015
Woody area	250	1	18.18	0.021
Woody area	250	1	17.44	0.024
Habitat richness	500	1	17.33	0.025
Habitat richness	750	1	15.55	0.034
Woody area	500	1	14.77	0.04
Habitat richness	1000	1	14.62	0.041
Woody area	750	1	14.48	0.042
Landscape diversity	250	1	14.15	0.044
Landscape diversity	1500	1	13.72	0.048
Epigeic abundance				
Oilseed rape area	250	3	31.91	0.02
Min. distance dry grassland	Min. dist.	3	29.55	0.03
Woody area	750	3	27.18	0.044
Oilseed rape area	500	2	24	0.028
Min. distance dry grassland	Min. dist.	1	14.18	0.044
Endogeic species richness				
Site cover	site	2	29.24	0.011
Landscape diversity	1500	3	32.76	0.018
Landscape diversity	1750	3	32.47	0.018
Road side strip length	1000	1	18.77	0.019
Endogeic abundance				
Site cover	site	1	20.23	0.014
Total species richness				
N-fertility 2005	site	1	16.29	0.03

Landscape diversity	1500	3	37.53	0.007
Landscape diversity	1750	3	33.75	0.015
Isolation open habitats	500	2	20.73	0.049
Woody area	750	1	17.51	0.024
Woody area	500	1	16.34	0.03
Landscape diversity	1500	1	13.59	0.049

Table 3: Significant regressions between site and landscape parameters and epigeic, endogeic and total species richness and epigeic and endogeic abundacne on the Collembola communities of oilseed rape fields (1 = linear; 2 = quadratic; 3 = cubic function).

Factor	d.f.	Partial SS	F	P	Partial r2
Surface SR					
Landscape diversity at 1500 m	3	74.898	9.35	0.0003	0.419
Soil index	1	19.006	7.12	0.0137	0.106
Isolation at 500 m	1	17.371	6.50	0.0179	0.097
Full	5	117.266	8.78	0.0001	0.656
Residual	23	61.424			
Soil SR					
Landscape diversity at 1500 m	3	168.772	9.52	0.0004	0.481
Isolation at 500 m	1	57.307	9.69	0.0053	0.163
Habitat richness at 250 m	3	54.761	3.09	0.0493	0.156
Full	7	226.602	5.48	0.0011	0.646
Residual	21	124.157			
Total SR					
Landscape diversity at 1500 m	3	164.718	9.61	0.004	0.29
Soil cultivation	3	119.632	6.98	0.0024	0.211
Isolation at 500 m	3	115.179	6.72	0.0028	0.203
Full	9	458.43	8.91	<0.0001	0.809
Residual	19	108.605			

Table 4: ANOVA table for the site and landscape parameters used in the multivariate regression models on the Collembola communities of oilseed rape fields.

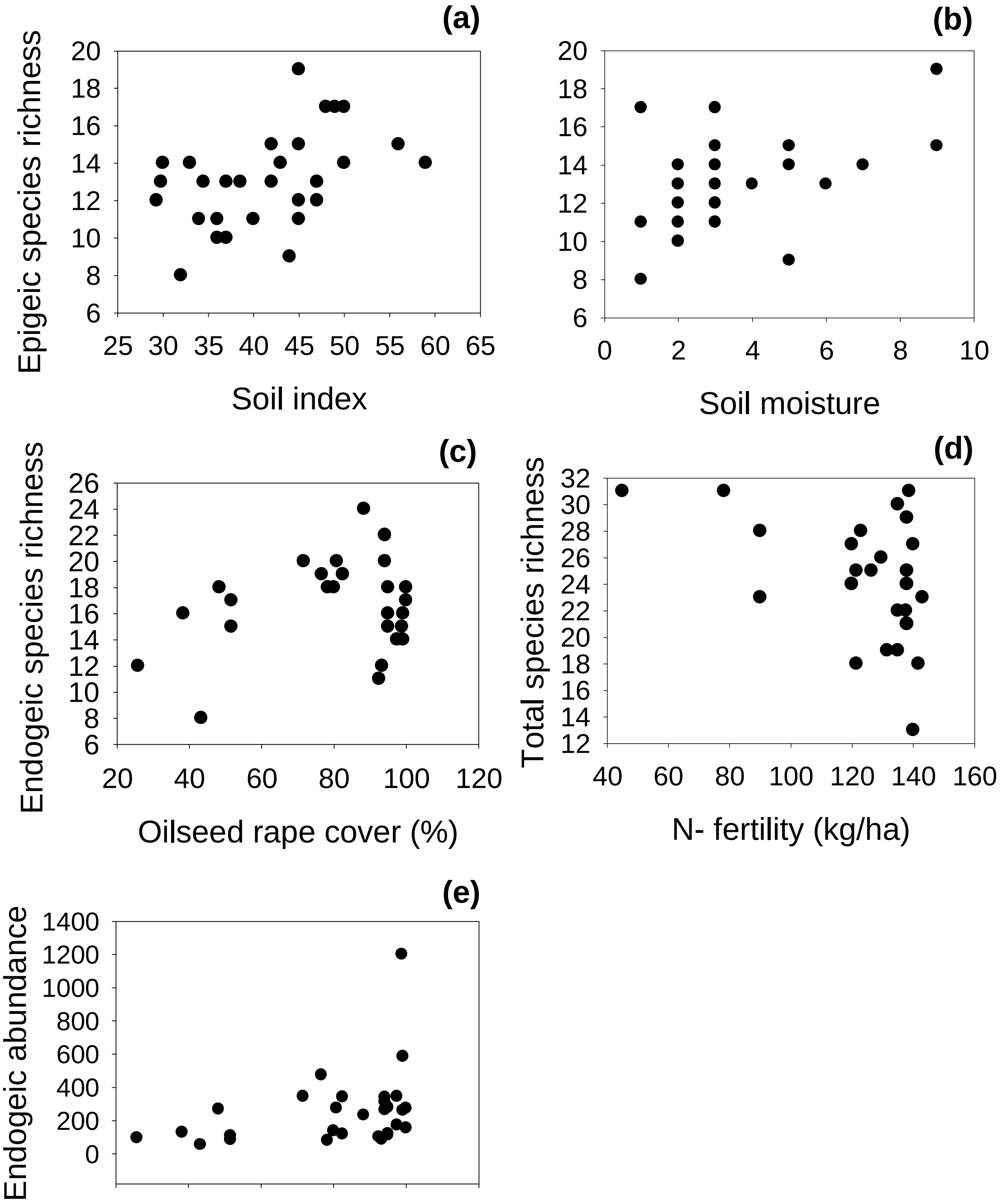

Fig. 1

Fig. 1: Relationship between site variables and epigeic (a, b), endogeic (c) and total Collembola species richness (d) and endogeic abundance (e) of the Collembola in oilseed rape fields (n = 29).

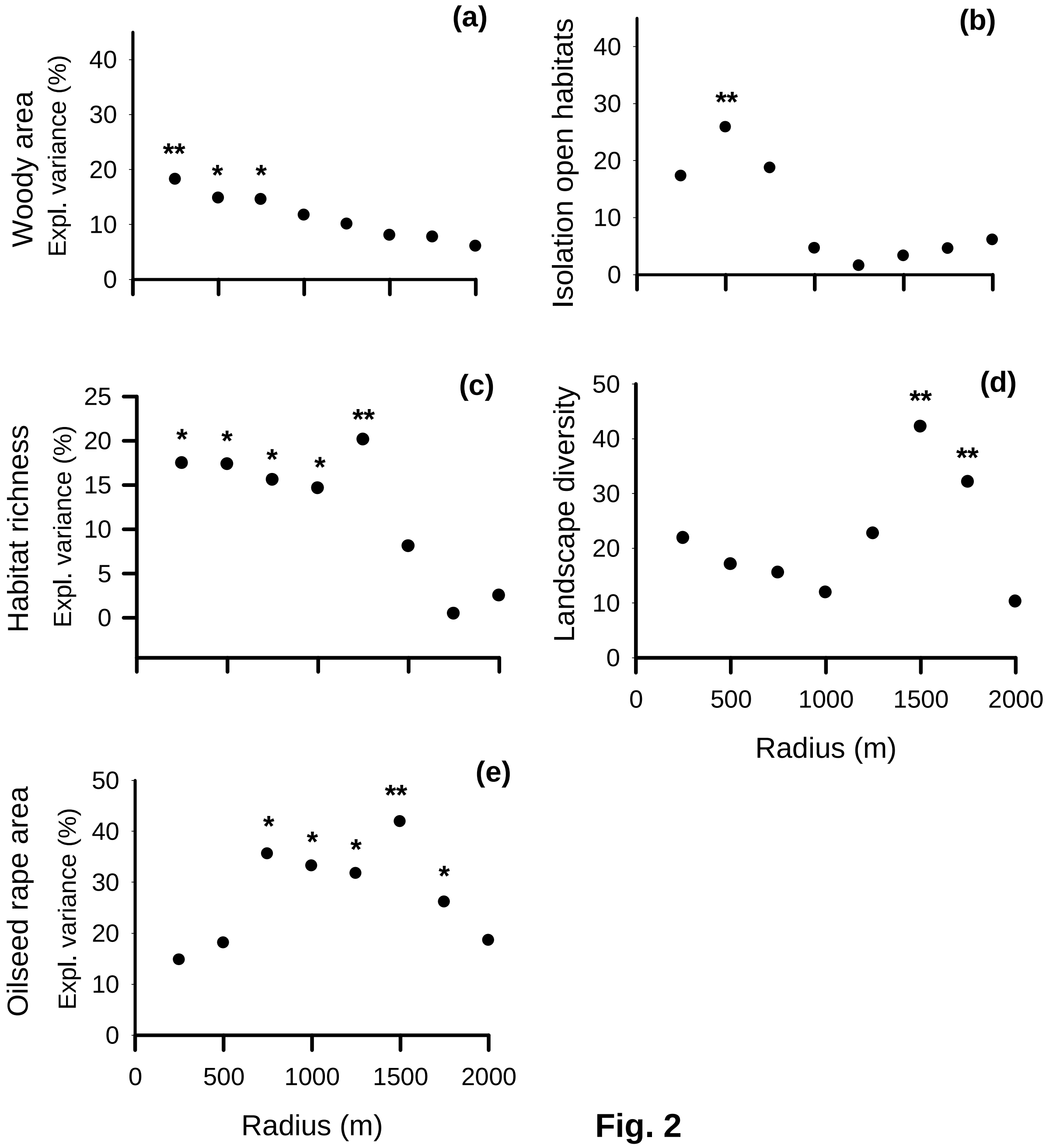

Fig. 2

Fig. 2: Relationship between epigeic Collembola species richness and landscape factors (a = woody area, b = isolation open habitats, c = habitat richness, d = landscape diversity, e = oilseed rape area) across the 8 radii (250 - 2000 m) in oilseed rape fields. Explained variance was derived from univariate ordinary least square regression analysis; ** $P < 0.01$, * $P < 0.05$.

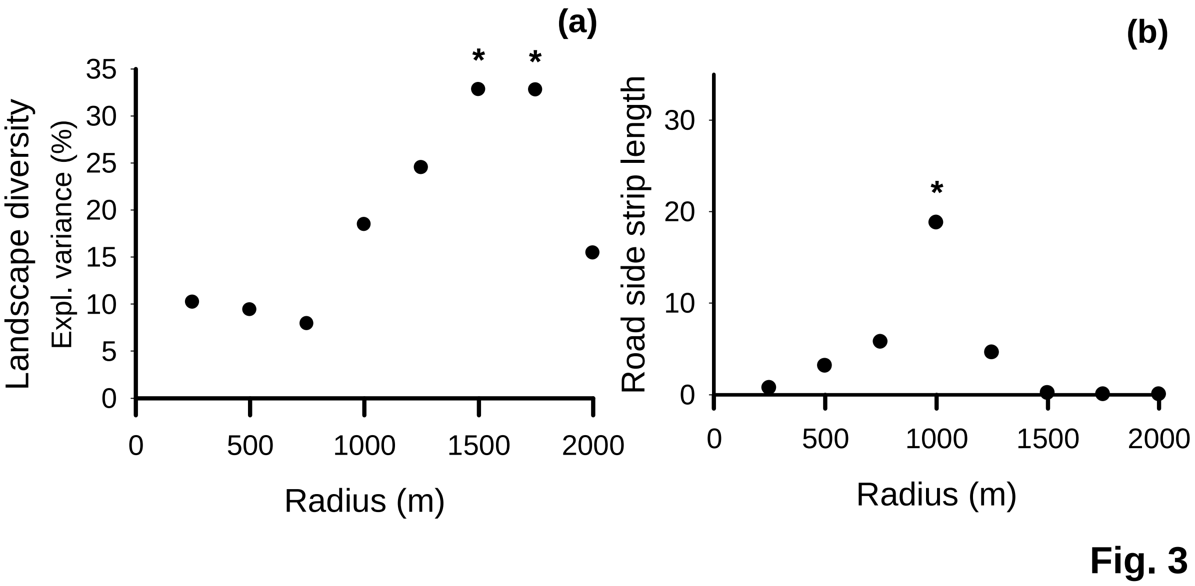

Fig. 3: Relationship between endogeic Collembola species richness and landscape factors (a = landscape diversity, b = road side strip length) across the 8 radii (250 - 2000 m) in oilseed rape fields. Explained variance was derived from univariate ordinary least square regression analysis; * $P < 0.05$.

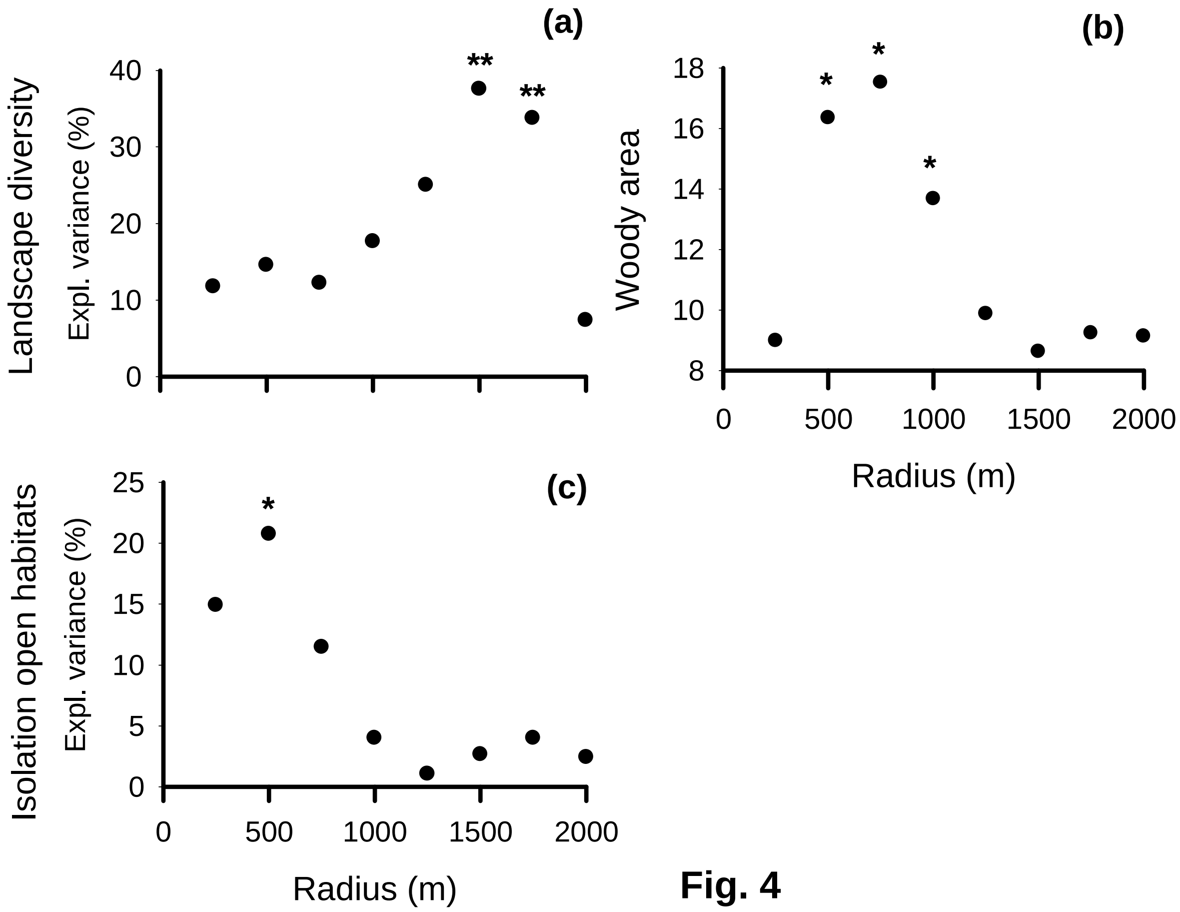

Fig. 4

Fig. 4: Relationship between total Collembola species richness and landscape factors (a = landscape diversity, b = woody area, c = isolation open habitats) across the 8 radii (250 - 2000 m) in oilseed rape fields. Explained variance was derived from univariate ordinary least square regression analysis; ** $P < 0.01$, * $P < 0.05$.

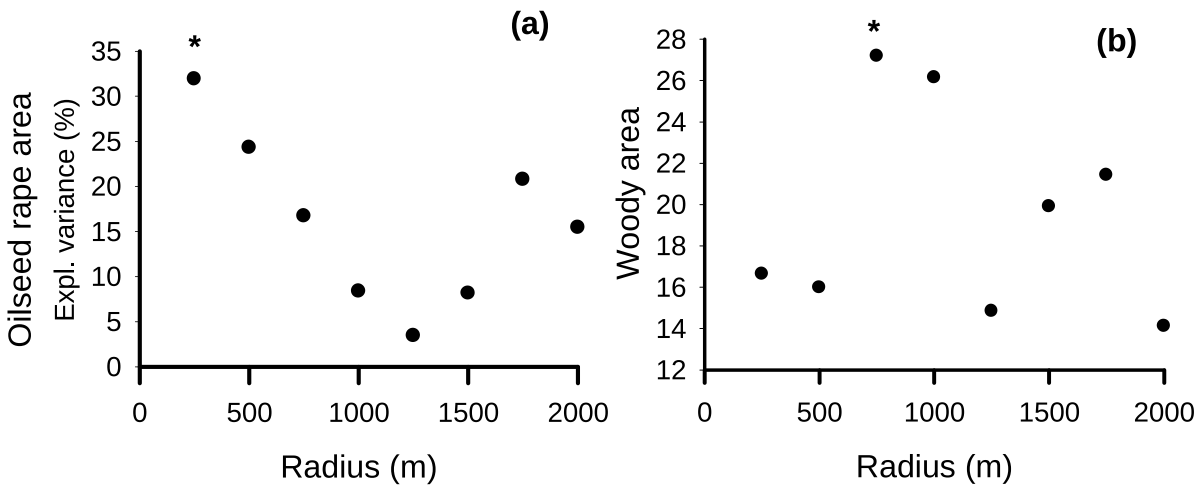

Fig. 5

Fig. 5: Relationship between epigeic Collembola abundance and landscape factors (a = oilseed rape area, b = woody area) across the 8 radii (250 - 2000 m) in oilseed rape fields. Explained variance was derived from univariate ordinary least square regression analysis; * $P < 0.05$.

Danksagung

Ich danke ganz besonders Alexander Bruckner für die jahrelange Unterstützung und Betreuung der Dissertation und die vielen Projekte die mich finanziert und interessiert haben. Über die Jahre ist eine Freundschaft gewachsen, die über Bodentiere und die Landschaft hinausgeht.

Prof. Dr. Thomas Wrbka danke ich für die Begutachtung der Dissertation und das Interesse an meinem Thema.

Danke an die Projektgruppe Thomas Frank, Thomas Drapela, Johann G. Zaller und Dietmar Moser, dass ich in dem Rapsprojekt mitarbeiten durfte.

Erich Weigand danke ich für die jahrelange Unterstützung und Motivation in der Wissenschaft tätig zu bleiben und dem Nationalpark Kalkalpen für die Unterstützung vor Ort und die Möglichkeit, die Brandfläche zu untersuchen.

Peter Zulka and Norbert Milasowszky danke ich für den Vorschlag mit Collembola zu arbeiten und mein Interesse für die Landschaftsökologie zu wecken.

Erhard Cristian danke ich für die jahrelange Unterstützung in allen erdenklichen Fragen zu Collembolen.

Franz für die jahrelange Unterstützung in allen PC Fragen…

Danke an den Mittagstisch in der Zoologie für die lustigen und entspannenden Gespräche über Gott und die Welt…

Danke auch allen Professoren und Studenten der PhD Kurse über Landschaftsökologie in Laggan (Schottland) und Faro (Portugal) und Jorge Domínguez Martín und Josefina Garrido González für den Arbeitsplatz in Vigo (Spanien).

Thomas Drapela, Alex Bandion, Bettina Iberer und Cristina Lazcano für die Hilfe im Freiland.

Danke an den Theodor Körner Fond, dem Nationalpark Kalkalpen und dem BOKU Stipendium für die finanzielle Unterstützung der Arbeit.

Natürlich auch besonderen Dank an meiner Familie, Jessica Szturmann und allen meinen Freundin, die mich in meinem Studium und meiner Arbeit immer unterstützt haben.

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Publikationsliste

Querner, P. (2003): Diversität von Collembolen auf fragmentierten Trockenrasen. Entomologica Austriaca 9, p 3-7.

Querner, P. (2003) Mesofauna als Indikator für Landschaftsveränderungen. 19. Jahresbericht der AG Bodenmesofauna, Wien. p 50-54.

Querner, P. (2004) Collembolen – Die kleinsten und häufigsten Insekten im Nationalpark Kalkalpen. Natur im Aufwind, Die Nationalpark Kalkalpen Zeitschrift 48, p 14-15.

Querner, P. (2004) Epigäische Springschwänze (Collembola) des Naturschutzgebietes Staninger Leiten, Oberösterreich. Beiträge zur Entomofaunistik 4, p 27-32.

Querner, P. (2004) Epigäische Springschwänze (Collembola) von Trockenrasenstandorten in Wien, Niederösterreich und Burgenland. Beiträge zur Entomofaunistik 4, p 17-26.

Querner, P., Uteseny, K., Bruckner, A, & Coja, T. (2004) Boden-Microarthropoden (Collembola, Oribatida, Gamasina, Uropodina) des Botanischen Gartens der Universität Wien. In: Pernstich, A. & Krenn, H.W. (Eds.) Die Tierwelt des Botanischen Gartens der Universität Wien. p 17-30.

Querner, P. & Gereben-Krenn, B.-A. (2005) Subterranean traps in two high alpine habitats. - In: Tajovsky, K., Balik, V., Pizl, V. (Eds.): 7th Central European Workshop Soil Zoology, České Budějovice; Studies on Soil Fauna in Central Europe, České Budějovice. p 119-122.

Querner, P. (2007) Befall von Holzpaletten in Depots durch zwei Holzschädlinge (Gemeiner Nagekäfer *Anobium puctatum* und Hausbockkäfer *Hylotrupes bajulus*). Restauno 3, p 188-190.

Querner, P. (2008): Collembola (Insecta). Checkliste der Fauna Österreichs No.3. Akademie der Wissenschaften, Wien. p 1-26.

Querner, P., Bruckner, A., Čoja, T. & Peham, T. (in Druck) Effect of mulching and irrigation on the soil biota in a garden lawn. Contribution to Soil Ecology in Central Europe.

Querner, P. & Morelli, M. (eingereicht) Integrierte Schädlingsbekämpfung in Museen: Erfahrungen und Präsentation eines Leitfadens für eine Umstellung. Zeitschrift für Kunsttechnologie und Konservierung.

Querner, P. & Morelli, M. (eingereicht) Nachweis von Museumsschädlingen in Schmutz. Restauno.