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# Soil zoology I: arthropod communities in open landscapes of former brown coal mining areas

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## Abstract

In different habitat types of the former coal mining area of Lower Lusatia, distribution and abundance of species of various arthropod groups was studied as to the colonization dynamics and the formation of community patterns. Heteroptera, Auchenorrhyncha, different groups of Coleoptera, Araneida, and Orthoptera were included in the study. In total, about 850 species were captured by pitfall trapping and sweepnet sampling. A detailed analysis of species–environment-relations was performed by means of gradient and eigenvector analysis (DCA, CCA). It is shown that colonization of bare sand habitats, pioneer vegetation with ruderal herbs, short grass prairie with *Corynephorus* and xerophytic herbs, tall grass prairie with *Calamagrostis*, and shrubs takes place rather quickly. In all the analysed habitats an adequate degree of the colonization was attained by the studied groups. Both the formation of patterns of species assemblages and population dynamics in upper layers of vegetation mainly depend on the patterns of plant communities and vegetation architecture. In lower layers micro-climatic conditions as well as abiotic soil parameters were shown to be of special importance. Differences of community patterns between predators and mainly phytophagous arthropod groups were discussed.
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*Keywords:* Arthropoda; Araneida; Carabidae; Heteroptera; Auchenorryncha; Staphylinidae; Scarabaeidae; Orthoptera; Lower Lusatia; Germany; Community patterns

## 1. Introduction

Animal colonization and the formation of spatial patterns of animal communities have been studied in the framework of numerous ecological theories, the most important one being the general theory of island biogeography (MacArthur and Wilson, 1963; Connor and McCoy, 1979; Coleman, 1981). Time and size dependency as well as habitat features and different properties of sites like heterogeneity have been stressed to explain both species–area-relations (Whittaker, 1972; Williamson, 1981; Nielsson et al., 1988; Seagle and Shugart, 1985) and species-abundance relations (Williams, 1964; May, 1975). Assembly rules have been proposed to explain patterns of

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species distribution in animal communities (Diamond, 1975; Connor and Simberloff, 1979; Wilson, 1994; Palmer and White, 1994) and the importance of environmental filters have been stressed (Keddy, 1992; Niemelä, 1993). The role of interspecific competition is often considered as weak (Connor and Simberloff, 1979; Connell, 1980; Strong et al., 1979; Simberloff, 1983).

In order to analyse both patterns of colonization and community formation under different environmental conditions and their variation in time, we investigated open landscapes of former opencast brown coal mining areas. Open mining leaves great areas of devasted land after dumping requiring all species to invade into the area again and recolonize it. The following questions will be adressed in what follows:

1. What are the main environmental factors which determine colonization processes of invertebrate animals and community pattern formation of open sites?
2. Which mechanisms determine the colonization, and is there any evidence for time dependence of the formation of spatial community pattern?
3. Are there any differences among certain taxocoenoses and functional animal groups?

Compared to biogeographic investigations carried out in order to analyse colonization mechanisms on islands the former mining area is less isolated from the colonization source. Former investigations have often been restricted to certain taxocoenoses (see references in Connor and McCoy, 1979), while we tried to include different groups of animals, at least predatory and non-predatory as well as groups restricted to vertical different layers. In the framework of the present study, the following procedure is applied:

- Selection of study sites in former opencast mining areas including different habitats in open landscapes, inventarisation of arthropods of different groups with different collecting methods and data sampling including different biotic and abiotic environmental factors.
- A priori classification of the landscape according to the general vegetation architecture, selecting study sites.
- Application of different gradient analyses (Detrended Correspondence and Canonical Correspondence Analysis) to different animal groups in order to classify habitats in relation to environmental parameters, occurrence of species and the effect of time.
- Detection of environmental parameters as to their relative importance for the formation of animal communities and comparison of effects for different groups of arthropods.

## 2. Study area and study sites

Investigations on the distribution and abundance of terrestrial organisms in former coal mining areas of Lower Lusatia were carried out since 1995 in the framework of different research projects. The mining region of Lusatia comprises the area of Southern Brandenburg and Northeastern Saxonia, approximately 130 km southeast of Berlin and 100 km north of Dresden, respectively (Fig. 1). It is situated at the southeastern edge of the north German lowlands area. Mining sites were situated both in glacial valleys and ground moraine areas which results in a different hydrological situations. Most glacial deposits resulted in sandy soils except in the north western part of the region. Predominant land use in the non-mining areas is forestry which covers approximately 70% of the total area. Agriculture is traditionally weak in Lusatia as the soils are generally nutrient poor and infertile.

For detailed account on the ecological and socioeconomical problems of the area see Wiegleb (1996), Blumrich et al. (1998), and Wiegleb and Felinks (2001a,b). The opencast lignite mining-activities leaves destroyed large areas with bare substratum and without any vegetation, so that all organisms have to recolonize the area anew. Subsequently, anthropogenous activities are addressed to reclamation and restoration in order to use the landscape for farming, forestry or nature conservation. Reclamation techniques as amelioration, pine afforestation, or sowing of commercial grass mixtures are used. Several methods for compaction of substratum and solification are applied.

In total, 24 sites from which 20 sites are located on mined land and four sites on undisturbed land have been included into the present study (Table 1). The time of the natural development, partly after reclamation activities, is indicated as "age" here. The sites can be regarded as representative for the habitat and vegetation conditions of the Lusatian mining region. They are situated in four mining areas, namely Schlabendorf–Nord (1), Schlabendorf–Süd (2) (larger and younger, 5–20-year old sites), Koyne/Grünewalde (3), and Plessa (4) (smaller and older, 35–70-year old sites) in the western part of the Lusatian region. The first cipher in the sampling site number denotes the respective mining area and can be used for spatial orientation in the diagrams. In total, between 5- and 70-year old sites were investigated. Information about dominant vegetation type

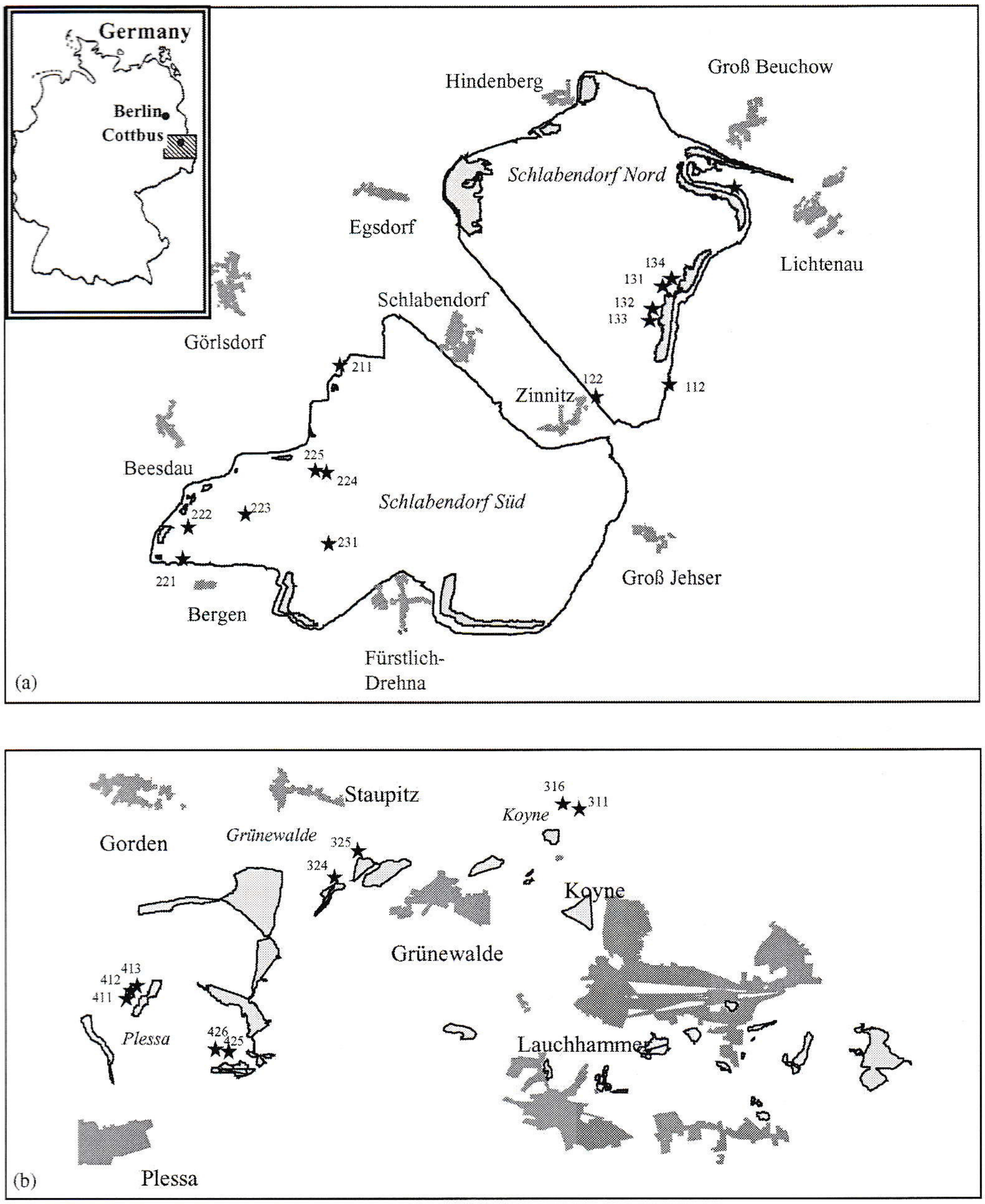

Fig. 1. Study area and location of the sampling sites (a) Schlabendorf–Nord, Schlabendorf–Süd; (b) Koyne/Grünewalde, Plessa, (★) investigated sites, (■) villages, (□) mining lakes (rest-holes)).

Table 1
List of studied sites in four former coal mining areas

| No. of site | Mining site | Vegetation resp. habitat type | Age |
|---|---|---|---|
| *Young sites* | | | |
| 111 ■ | Schlabendorf–Nord | Calamagrostis epigejos stand | Undisturbed land |
| 112 ▲ | Schlabendorf–Nord | Dwarf shrub heath | Undisturbed land |
| 122 ● | Schlabendorf–Nord | Dense sown grassland | 20 years |
| 131 ▽ | Schlabendorf–Nord | Sparse vegetation on bare sand | 20 years |
| 132 ● | Schlabendorf–Nord | Species-rich psammophytic grassland | 20 years |
| 133 ■ | Schlabendorf–Nord | Calamagrostis epigejos stand | 20 years |
| 134 ○ | Schlabendorf–Nord | Moss-rich psammophytic grassland | 20 years |
| 211 ■ | Schlabendorf–Süd | Calamagrostis epigejos stand | Undisturbed land |
| 221 ■ | Schlabendorf–Süd | Calamagrostis epigejos stand | Undisturbed land |
| 212 ▽ | Schlabendorf–Süd | Sparse vegetation on bare sand | 6 years |
| 222 ○ | Schlabendorf–Süd | Sparse sown grassland | 7 years |
| 223 ◇ | Schlabendorf–Süd | Failed pine afforestation | 7 years |
| 224 ▨ | Schlabendorf–Süd | Dense sown grassland | 5 years |
| 225 ▽ | Schlabendorf–Süd | Free of vegetation | 15 years |
| 231 ○ | Schlabendorf–Süd | Scarce Corynephorus canescens stand | 10 years |
| *Old sites* | | | |
| 311 ○ | Koyne | Bare sand with bulk ripples, surrounded by psammophytic grassland | 45 years |
| 312 ■ | Koyne | Calamagrostis epigejos stand | 45 years |
| 316 ■ | Koyne | Sparse Calamagrostis epigejos stand | 45 years |
| 324 ▨ | Grünewalde | Dense, sown grassland | 35 years (recultivated 5 years ago) |
| 325 ◆ | Grünewalde | Mature psammophytic grassland | 35 years |
| 411 ▽ | Plessa | Free of vegetation | 50 years |
| 412 ● | Plessa | Psammophytic grassland | 50 years |
| 413 ■ | Plessa | Calamagrostis epigejos stand | 50 years |
| 426 ▽ | Plessa | Free of vegetation | 70 years |

Dominant vegetation and age of the sample sites according to Felinks, 2000.

and age is provided by Weichelt et al. (1997), Felinks et al. (1999a), Wiegleb and Felinks (2001a,b). Four areas from undisturbed land were also included in the study for comparative purpose. As for some groups of species data are missing for single sites in some of the analyses several sites are neglected.

A priori classification of sites was based on general features of habitat, mainly the patterns of the vegetation structure. Openland habitats included were the following:

- bare sand habitats;
- pioneer vegetation with ruderal herbs;
- short grass prairie with *Corynephorus* and xerophytic herbs;
- tall grass prairie with *Calamagrostis*;
- seeded grasslands;
- heath land.

## 3. Material and methods

### 3.1. Faunistic data sampling

Arthropods in the lower vegetation layer were collected in 24 sampling sites by pitfall-trapping (8 cm diameter, 50% ethylene glycol) every 2 weeks from May 1995 to December 1996. Six traps arranged in a regular pattern (three pairs of traps of 1 m distance being 10 m away from each other) within an uniformous vegetation architecture were set up at each site (see also Mrzljak and Wiegleb, 2000; Mrzljak et al., 2000). Araneida, Coleoptera Caraboidea (including Cicindellidae and Carabidae), Coleoptera Staphylinidae, and Coleoptera Scarabaeidae were included into the present study. Auchenorryncha and terrestrial Heteroptera of the upper vegetation layer were sampled by quantitative sweepnet sampling (50 sweeps on 100 qm, five sam-

Table 2
List of environmental parameters studied and abbreviations used

| Variable | Shortcut |
|---|---|
| General features of sites | |
| Age after dumping | AGE |
| Landcover class | LANDCOV |
| Exposition of site (1 = south, 4 = north) | EXPOS |
| Inclination of site | INCLIN |
| Structural heterogenity of site | SH195 |
| Structural heterogenity of site | SH45 |
| Soil | |
| Heat output of soil | HEAT |
| Substrate respiration | SUBSTRES |
| Soil respiration | SOILRESP |
| Conductivity of soil | CONDUCT |
| PH-value of soil | SOILPH |
| Moisture content in soil | MOICONT |
| Water capacity of substratum | WATCAP |
| Clay content of soil | CLAY |
| Ammonification | AMMONIF |
| N-total content of soil | NTOT |
| C total content of siol | CTOT |
| SO4 content of soil | SO4CONT |
| S total of soil | STOT |
| Vegetation | |
| Number of plant species | PLSPEC |
| Vegetation height | VEHEIGHT |
| Vegetation density | VEDENS |
| Vegetation cover in total | VECOV |
| Species abundance of herbs | HERBM |
| Number of herb-species | HERBS |
| Cover of herbs (%) | HERBCOV |
| Species abundance of grass | GRASM |
| Cover of grass | GRASCOV |
| Cover of shrubs (%) | SHRUBCOV |

plings in the vegetation period of 1995 and 1996). Additionally data for Coleoptera Coccinellidae (sweepnet and pitfall trapping) from seven sampling sites are included in some analyses.

### 3.2. Environmental/habitat data sampling

In total, 29 environmental variables are included into the study (Table 2). Landscapes variables referring to general features as age after dumping, habitat heterogeneity, exposition and inclination of sites. Thirteen soil parameters and 10 parameters referring to the vegetation structure are included. The range of the variables has already been discussed by Mrzljak and Wiegleb (2000).

#### 3.2.1. Vegetation data

Methods are described in Felinks et al. (1999a) and Wiegleb and Felinks (2001a,b). For the purpose of the present study, the following parameters were taken into account in multivariate analysis: vegetation density (stems/leaves per meter above ground), average vegetation height, total vegetation cover, and number of plant species. Vegetation types as defined by Felinks (2000) and Wiegleb and Felinks (2001a,b) are used for description of the sites.

#### 3.2.2. Remote sensing data

Location and assignment of the studied sites to land cover classes was ascertained by satellite imagery (LANDSAT$^{TM}$) and high resolution scanning data (CASI, see Felinks et al., 1999b). The data are also used to generate GIS maps and to generalize data to special units, respectively. For multivariate analysis land cover class (Weichelt et al., 1997) and two heterogeneity indices were used (small scale [45 qm] and medium scale [195 qm] around the sample sites according to Mrzljak and Wiegleb, 2000).

#### 3.2.3. Soil data

Soil chemical and physical data were sampled repeatedly during the summer season. The method of sampling and sample processing is described in detail by Hahn and Fromm (2000). For the present purpose water content, water capacity, pH, electric conductivity, total carbon, total nitrogen, total sulfur, and sulfate sulfur from the soil depth of 0–10 cm were used as variables in the multivariate analyses. An average of seven sampling times was calculated. Biotic soil parameters such as heat output of microorganisms, soil respiration, and substrate induced respiration (SIR) are also included in analyses (see Hahn and Fromm, 2000).

### 3.3. Data analysis

Eigenvector ordinations (direct and indirect gradient analyses, (detrended) (canonical) correspondence analyses) were carried out with CANOCO (Ter Braak and Šmilauer, 1998; Jongman et al., 1995) and DECORANA (Hill, 1979) and MSVP (Kovach, 1999). Marginal and conditional effects in CCA were also calculated with CANOCO: the marginal effects (lambda-1) of variables in CCA denote the share of explained variance they explain singly, i.e. when that

Table 3
Taxa of Arthropoda studied, number of species, number of species in Brandenburg, sampling methods and authors

| Taxon | No. of species | Brandenburg | Sampling method | Authors |
|---|---|---|---|---|
| Heteroptera | 138 | 520 | Sweepnet, pitfall trap | Bröring |
| Auchenorryncha | 92 | 363[a] | Sweepnet | Niedringhaus |
| Carabidae | 172 | 300 | Pitfall trap | Grondke |
| Staphylinidae | 219 | 820 | Pitfall trap | Rusch |
| Scarabaeidae | 23 | 100 | Pitfall trap | Kalz |
| Coccinellidae | 12 | 40[b] | Sweepnet, pitfall trap | Schuster |
| Orthoptera | 35 | 60[b] | Sweepnet, pitfall trap | Borries |
| Arachnida | 263 | 560 | Pitfall trap | Mrzljak |

All investigated sites included, otherwise data according to Ministry of Environment, Nature Conservation and Spatial Planning (MUNR) Brandenburg.

[a] Rough estimation.

[b] According to Nickel and Remane in literature.

particular variable is used as the only environmental variable, while the conditional effects (lambda-A) shows the environmental variables in the order of their inclusion into the model, together with the additional variance they explain at the time when they were included after stepwise inclusion (Ter Braak and Šmilauer, 1998; 98f.). Ordination plots according to CANOCO results were drawn by means of CanoDraw 3.1, and CanoPost 1.0 (Šmilauer, 1992; Ter Braak and Šmilauer, 1998). Other analyses were performed with SPSS 10.0.

## 4. Results

### 4.1. Inventory of colonization state

An inventory of species from 8 Arthropod groups yield 919 species in total, where true bugs (Heteroptera), leafhoppers (Auchenorryncha), ground beetles (Coleoptera Carabidae), rove beetles (Staphylinidae), scarabaeid beetles (Scarabaeidae), ladybird beetles (Coccinellidae), grasshoppers and related (Orthoptera: Saltatoria, Dermaptera, Blattodea),

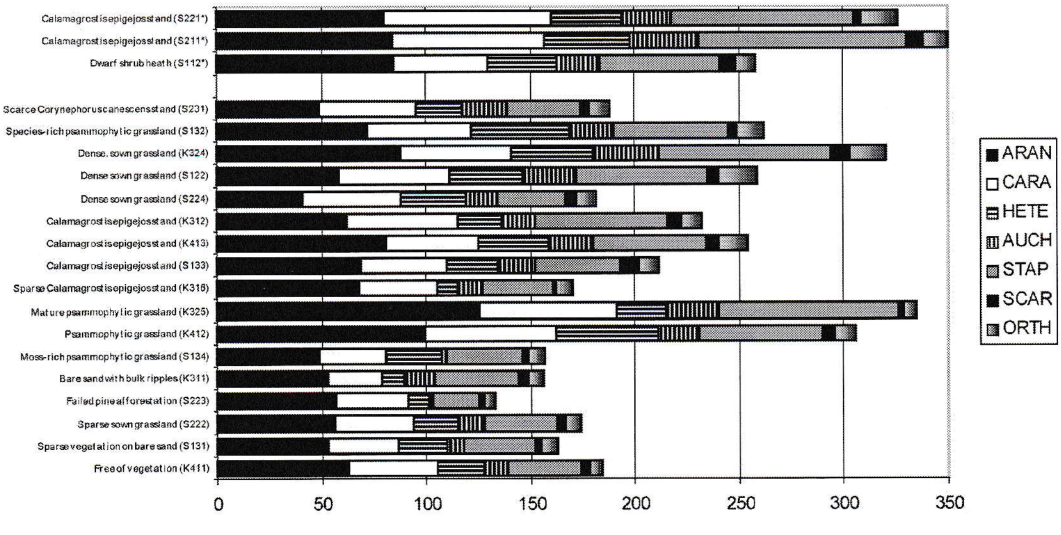

Fig. 2. Number of species of different groups of Arthropoda in the studied sites ((*) indicating undisturbed sites, ARAN: Araneida, CARA: Carabidae, HETE: Heteroptera, AUCH: Auchenorryncha, STAP: Staphylinidae, SCAR: Scarabaeidae, ORTH: Orthoptera).

and spiders (Arachnidae) are included (Table 3). Compared to the total numbers of species occurring in the state of Brandenburg the numbers of species found are remarkably high. It is assumed that a high degree of colonisation was attained by the different groups of arthropods in different mining areas.

Species numbers for different sampling sites are presented in Fig. 2. A rough comparison between the results for the undisturbed sites and former mining sites shows no significant differences. In several study sites in former mining areas, especially in dense sown grasslands and psammophytic grasslands, high numbers of species could be found, *Calamagrostis* stands were also very species rich.

The arthropod groups studied are different as to the feeding, preference of different layers, dispersal potential, and other biological features. Moreover, within the species groups, biological properties of species are distributed more or less heterogenously. Spiders, rove beetles, and most of the ground beetles are predators mainly occurring in ground layers. Leafhoppers, grasshoppers and scarabaeid beetles are feeding on plants and live in different layers. Biological features of true bugs are different to a high extent. No significant differences in species numbers of the different guilds within certain habitats can be assumed.

### 4.2. Species assemblages and classification of sites

In total, 824 species of Arthropoda are included (Arachnida, Carabidae, Staphylinidae, Heteroptera, Auchenorryncha, Scarabaeidae, Orthoptera) in indirect gradient analyses (detrended correspondence analyses) and cluster analyses. The ordination plots based on 19 sites (with undisturbed) and 17 sites (without undisturbed), respectively, are given in Fig. 3, the result of cluster analysis is shown in Fig. 4. The restriction is due to the fact that not for all studied sites a complete data set is available. About 28.3% and 27.4% of the variance of species data, respectively, is explained by the first two canonical axes of the ordination plot after running DCA.

According to the distribution of species a classification of habitats is given by the DCA, which partly correspondents with an a priori classification according to vegetation structure. The results of the analysis for undisturbed sites only is similar to that for all studied sites, undisturbed sites are obviously not separated. Habitats with sparse vegetation are grouped together, *Calamagrostis* sites and partly the psammophytic grasslands, respectively. It seems to be obvious, that the first axis correlates with vegetation density and the second with vegetation height, respectively, both of which being variables referring to vegetation architecture.

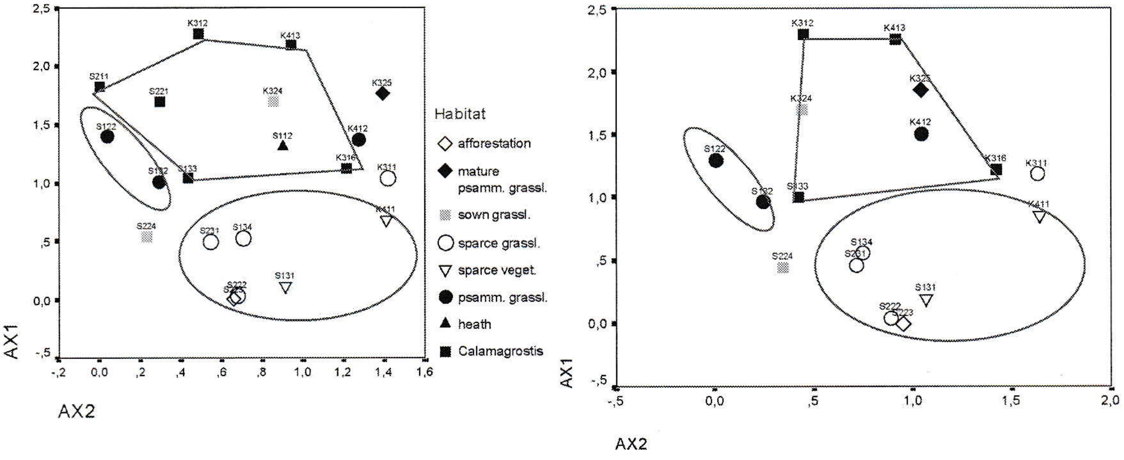

Fig. 3. DCA ordination plot based on 824 species of Arachnida, Carabidae, Staphylinidae, Heteroptera, Auchenorryncha, Scarabaeidae, Orthoptera (left: undisturbed sites included; right: undisturbed sites excluded).

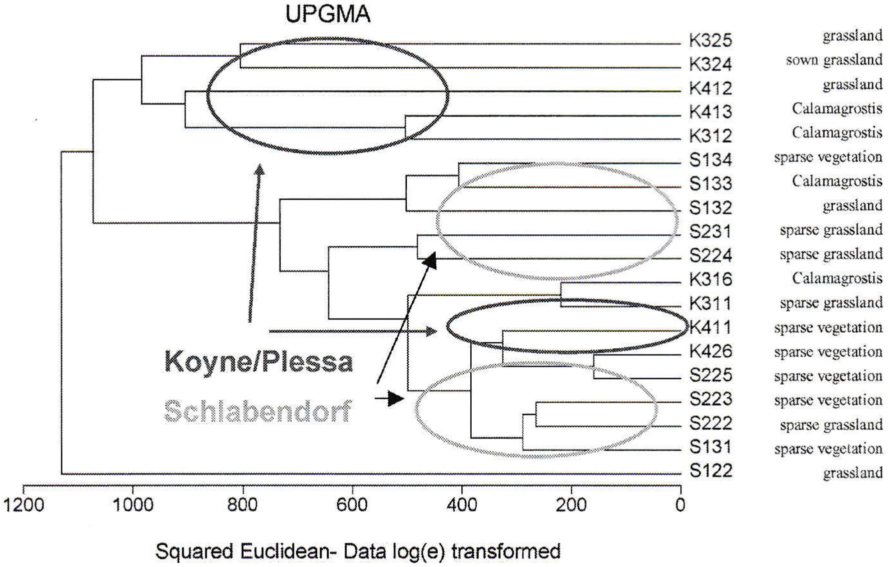

Fig. 4. Result of a cluster analysis based on 824 species of Arachnida, Carabidae, Staphylinidae, Heteroptera, Auchenorryncha, Scarabaeidae, Orthoptera.

Cluster analysis revealed a comparable result as to classification of sites, but the mean classification property is obviously the position of sites in a certain mining area (Koyne/Plessa-sites on top of the plot, Schlabendorf-North-sites, Koyne/Plessa-sites, and Schlabendorf-South-sites at the bottom). By this it can be concluded that spatial autocorrelation is an important factor for actual species compositions.

### *4.3. Relation between species assemblages and environmental characteristics*

Direct gradient analyses were carried out in order to detect influences of different environmental variables and to analyse community pattern of the actual perceived species assemblages. At first, marginal and conditional effects of the variables are calculated (Table 4). Stepwise inclusion of variables in the CCA for all studied sites revealed that age after dumping is the variable which explains the highest share of variance in species abundances. Heat output as a reflection of microbiological activity in the soil, share of clay content, number of plant species, carbon content and soil-pH is significant as to conditional effects. Excluding the undisturbed sites the result is different, age is not significant in this case, although included at 10th position. Different variables referring to vegetation patterns are obviously important, and also some of the soil parameters.

Table 4
Marginal and conditional effects of environmental variables after CCA

| All species | | | | All species, all sites | | | |
|---|---|---|---|---|---|---|---|
| Marginal | $\lambda 1$ | Conditional | $\lambda A$ (*P*) | Marginal | $\lambda 1$ | Conditional | $\lambda A$ (*P*) |
| AGE | 0.25 | AGE | 0.25 (0.005) | HERBCOV | 0.20 | HERBCOV | 0.20 (0.005) |
| HEAT | 0.25 | HEAT | 0.20 (0.005) | HEAT | 0.20 | SOILPH | 0.13 (0.005) |
| SHRUBCOV | 0.22 | CLAY | 0.13 (0.015) | SHRUBCOV | 0.19 | SUBSTRES | 0.11 (0.010) |
| NTOT | 0.21 | PLSPEC | 0.12 (0.015) | NTOT | 0.19 | WATCAP | 0.11 (0.005) |
| HERBCOV | 0.21 | CTOT | 0.11 (0.035) | AMMONIF | 0.18 | PLSPEC | 0.10 (0.025) |
| SOILRESP | 0.19 | SOILPH | 0.10 (0.035) | VECOV | 0.18 | INCLIN | 0.09 (0.055) |

About 824 species of Arachnida, Carabidae, Staphylinidae, Heteroptera, Auchenorryncha, Scarabaeidae, Orthoptera included, for abbreviations of variables see Table 2.

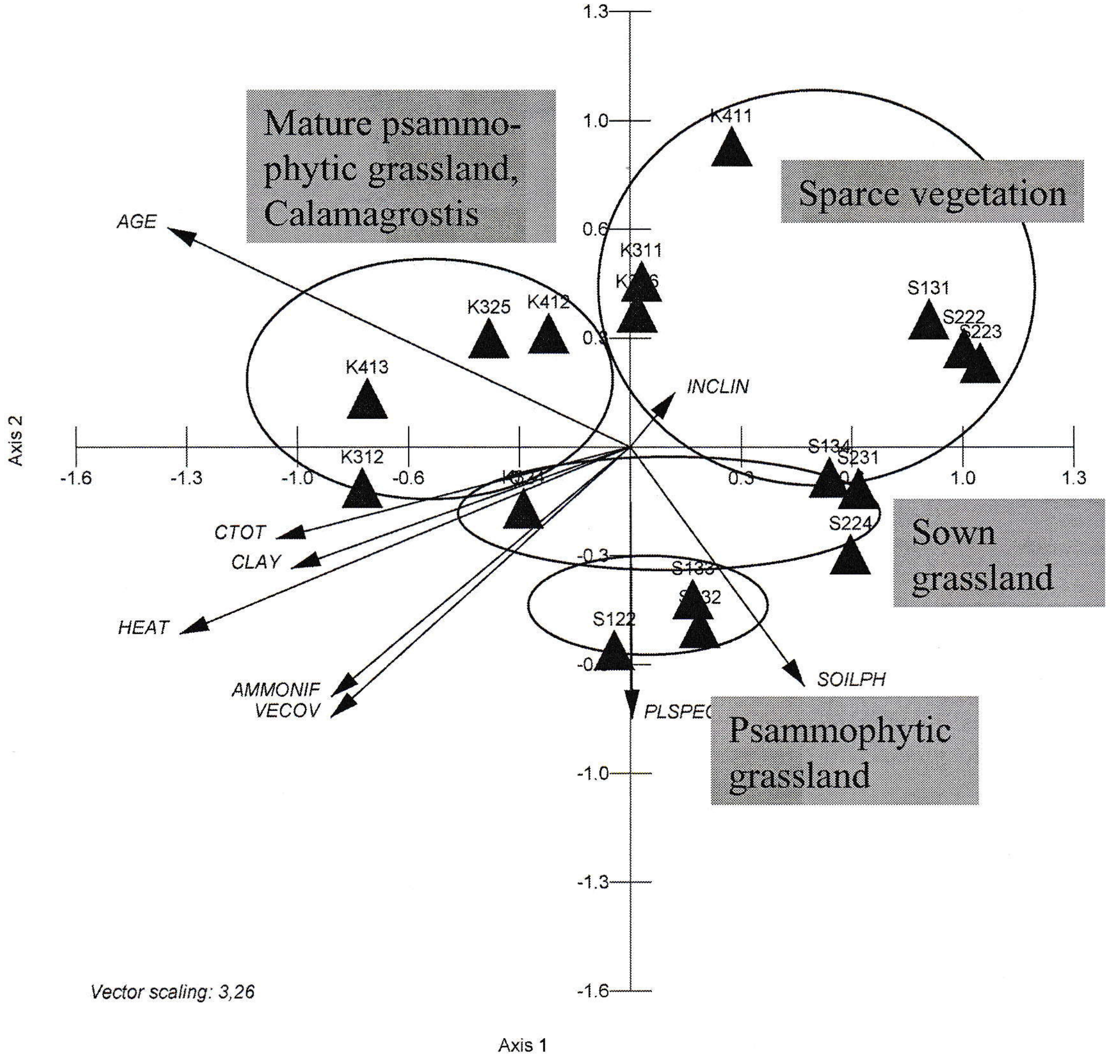

Fig. 5. Ordination plot after CCA for 17 dumped sites based on 824 species of Arachnida, Carabidae, Staphylinidae, Heteroptera, Auchenorryncha, Scarabaeidae, Orthoptera.

The best fitting variables were included into the ordination plot (Fig. 5). A priori classification is reflected again by the arrangement of the studied sites. Mature psammophytic grassland is separated from sown grassland, and psammophytic grassland, respectively, while sparse vegetation occurs as a cluster in the right upper part of the ordination plot. Variances of the sites with sparse vegetation could not be explained by the variables chosen. The first axis is correlated so some extent with age and soil parameters, the second with number of plant species, respectively.

In order to detect differences for different groups of species, CCA was applied for each of the eight studied groups separately. The marginal and conditional effects of environmental variables on species abundances at dumped are calculated, significant conditional effects are given in Table 5, where feeding type and layer of occurrence of species groups are indicated. Except in Scarabaeidae and Orthoptera age after dumping is one of the main factors to explain variances in species abundances. Besides age, heat output explains variances to a huge extent. While there is no obvious difference be-

Table 5
Patterns of influences of environmental variables on different species groups according to conditional effects in CCA

| Parameters | ARAN | CARA | STAP | COCC | HETE | AUCH | SCAR | ORTH |
|---|---|---|---|---|---|---|---|---|
| Feeding | Zooph | (Zooph) | Zooph | Zooph | Different | Phytoph | Phytoph | Phytoph |
| Occurrence | Ground | Ground | Ground | Upper | Different | Upper | Different | Different |
| Age | 0.19 (0.005) | 0.10 (0.045) | 0.21 (0.005) | 0.26 (0.015) | 0.18 (0.015) | 0.28 (0.005) | | |
| Vegetation cover | 0.07 (0.260) | | | | | | 0.38 (0.005) | |
| Vegetation density | | | 0.09 (0.120) | | 0.21 (0.040) | 0.18 (0.035) | | 0.10 (0.040) |
| Vegetation height | | | | | 0.16 (0.010) | 0.19 (0.030) | 0.13 (0.125) | |
| Shrub cover | | | | | 0.18 (0.010) | | | |
| Herbs | | | | | | 0.15 (0.045) | | |
| Plant species | | | | 0.20 (0.050) | | | | |
| Heterogeneity | | 0.11 (0.015) | 0.10 (0.070) | | | | 0.21 (0.010) | |
| Heat output | 0.21 (0.005) | 0.29 (0.005) | 0.23 (0.005) | | 0.27 (0.005) | | | 0.48 (0.005) |
| Water capacity | | 0.13 (0.010) | 0.14 (0.015) | | | | | 0.20 (0.005) |
| Soil pH | | 0.16 (0.005) | | | | | | |
| Conductivity | | | 0.14 (0.005) | | | | | 0.17 (0.005) |
| Soil respiration | | | | 0.10 (0.390) | 0.17 (0.010) | 0.21 (0.030) | 0.12 (0.365) | |
| Clay content | 0.12 (0.015) | | | | | | 0.11 (0.375) | |
| Ammonification | 0.12 (0.015) | | | | | 0.24 (0.005) | | |
| NTOT | | 0.10 (0.020) | | | | | | 0.11 (0.030) |

Zooph: zoophagous, phytoph: phytophagous, ground: mainly living in lower layer, recorded by pitfall traps, upper: mainly living in upper layers, recorded by sweepnet sampling, diverse: living in different layers, but recorded by sweepnet sampling, ARAN: Araneida, CARA: Carabidae, HETE: Heteroptera, AUCH: Auchenorryncha, STAP: Staphylinidae, SCAR: Scarabaeidae, ORTH: Orthoptera.

tween zoophagous and phytophagous group, it is evident that mainly for ground living groups different soil parameters are important, for species groups mainly living in herb and grass layer parameters referring to the vegetation architecture (vegetation height, cover, and density, respectively) explain high shares of variances.

Ordination plots after CCA including the most important variables are given for spiders, rove beetles, true bugs, and leafhoppers, respectively (Fig. 6).

At least for spiders and rove beetles the a priori classification of sites is partly reflected, for true bugs and leafhoppers no clear separation is possible, in these cases the distribution of species could not be explained by the included environmental variables for a huge share of investigated sites (for Heteroptera in the upper part of the ordination plot sites with sparse vegetation).

## 5. Discussion

For different groups of animals the colonization of dumped sites after mining activities have recently been studied (Landeck, 1996; Durka et al., 1997; Dunger, 1998; Mrzljak et al., 2000; Mrzljak and Wiegleb, 2000), especially as to the development of species numbers. Generally, it was concluded that initial animal colonization of former brown coal mining areas occurs very rapidly during the first years after dumping. Species turnover have been proposed, which takes place according to the succession of habitats, but detailed analysis of change in species abundance relations is rare so far.

A detailed analysis of possible plant succession pathways are given by Felinks et al. (1999b), Felinks (2000), and Wiegleb and Felinks (2001a,b). It was shown that changes in biotic features of the plant communities are neither linear nor predictable. The duration of a given stage is often unknown. In some cases, the stage of pioneer vegetation is reached after 70 years, in other cases, however, the subsequent stages are reached after 20 years, and generally the change of vegetation types is slow. Some stages may be skipped, some others may occur several times. Initially, the natural development progresses from the early stage of bare sand areas to stages of pioneer vegetation with ruderal herbs or short grasses and xerophytic herbs, and subsequently to tall grass prairies or shrubs.

By including different groups of Arthropoda it was shown in the present framework that colonization of the studied habitats takes place rather quickly, obviously an adequate degree of colonization as to species numbers

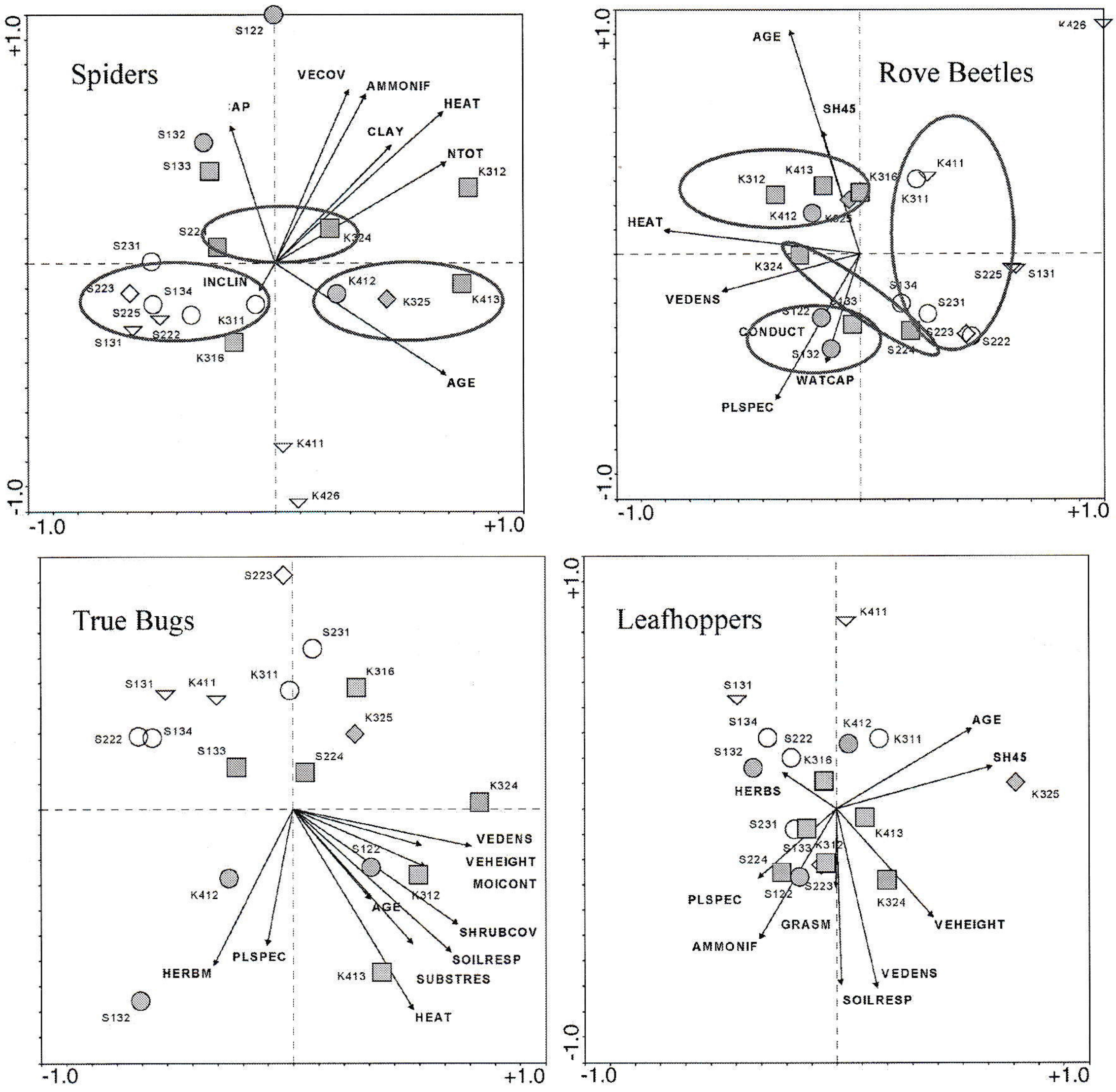

Fig. 6. Ordination plots for different groups of species including best fitting environmental variables).

was attained after short time. In this respect zoophagous and phytophagous groups of species, respectively, do not differ. By this it can be concluded that the influence of time is low as to species numbers, but reasonable as to variation of community patterns (species abundance relations), as it was shown by gradient analyses.

The change within species assemblages are due to different environmental factors and their variation in time (see Table 5). Response models for different groups revealed, that age after dumping is obviously important for the formation of communities of different taxocoenoses. By this it can be concluded that species turnover and fluctuations in population densities occurs to a reasonable extent. These fluctuations are due to different environmental parameters which also change in the course of time. Parameters referring to the vegetation architecture might be interpreted as noncausal (indirect), abiotic soil parameters as causal effects, as the soil parameters have a direct influence of the succession of the vegetation. For plant communities multivariate analysis revealed that some environmental factors influence the species composition, mainly pH, organic carbon, phosphate and water capacity of the soil (Wiegleb and Felinks, 2001a,b).

Combinations of the decisive environmental factors are different for different groups of species. Only slight differences of community patterns between predators and mainly phytophagous feeding arthropod groups could be detected. For zoophagous species groups soil parameters are more important, while phytophagous species are influenced by the vegetation structure. No evidence could be given for a subsequent influence on zoophagous communities on phytophagous, as the phytophagous are the preys for the arthropod predators. The formation of patterns of species assemblages and population dynamics in upper layers mainly depend on the patterns of plant communities while in lower layers micro-climatic conditions and abiotic soil parameters are important.

As there are causal and non-causal effects on species communities, mechanistical explanation of the development of patterns of species assemblages in animal communities is difficult or impossible. On the other hand, it is possible to describe community patterns for each of the habitat-types studied, as we can assign sets of species to each of the studied openland habitat types of the Lusatian coal mining area.

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