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Diversity of surface dwelling beetle assemblages in open-cast lignite mines in Central Germany

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Abstract. We investigated species richness of ground dwelling beetle assemblages in two non-reclaimed lignite mines and a dump in Central Germany by means of pitfall trapping. During a period of five months, a total of 203 beetle species within 27 families represented by 4099 individuals were trapped. This included 75 species of ground beetles represented in a sample of 957 individuals from which 10 species are regionally endangered. The number of individuals, species richness, as well as the proportions of endangered species did not differ between successional stages whereas species composition of sites could be related well to a set of environmental variables. High values of beta-diversity between sites indicated that the total number of species recorded is caused by habitat diversity. From the viewpoint of nature conservation, we conclude that postmining areas can play a key role in conservation of beetle diversity in agricultural areas since they harbour threatened species whose original habitats are now rare due to human impact. An important task for future management of postmining areas is to maintain successional processes and to prevent loss of habitat diversity through afforestation. Areas with extreme soil conditions should also be preserved for long-term availability of bare soil and pioneer vegetation and associated fauna.

Key words: beetles, conservation, diversity, open-cast lignite mining, restoration, succession

Introduction

Restoration of surface-mined land is a major goal in lignite districts in order to attain sustainable land use (Bradshaw and Chadwick 1980; Pflug 1998). In the Central German lignite district, the largest part of restored land are arable fields, forests and lakes (Berkner 1998). From the viewpoint of nature conservation, however, a thorough assessment has to reveal whether unreclaimed successional mining areas may be important for species diversity and for conservation of rare and endangered species (Bruns 1988; Kendle 1995).

One centre of mining activity is located south of Leipzig in Saxony, Germany (Figure 1). Large open-cast lignite mines are imbedded in agricultural areas which are bare of woodlands, hedges and other structural elements. After 1990, most of these mines were closed and restoration started including afforestation and flooding of mining pits. However, some mines were left unreclaimed and were previously

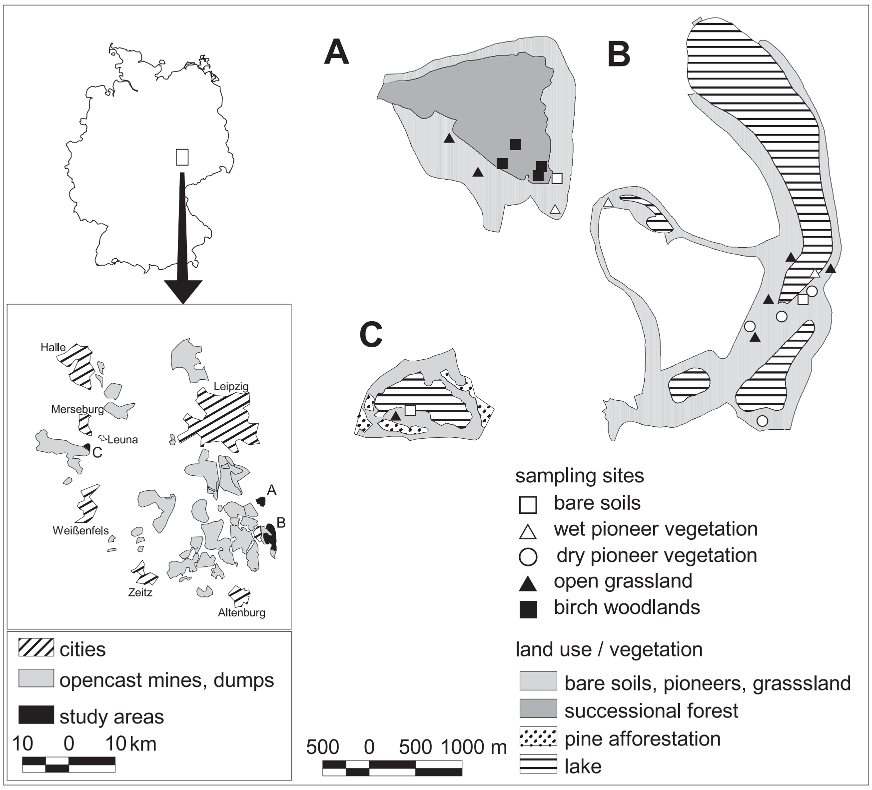

Figure 1. Map of study area and sampling sites. A = 'Halde Trages', B = 'Tagebau Bockwitz/Borna-Ost', C = 'Restloch Beuna'.

surveyed for different taxonomic groups of plants and animals (Durka et al. 1997). This survey revealed a highly structured area that included a mosaic of contrasting habitat types reaching from bare soils and wetlands to early birch-woodlands. Thus, in intensively used agricultural areas, such areas may play a key role in the maintenance of biodiversity (Altmoos and Durka 1998; Bradshaw 1989). The protection of certain areas and future management is now discussed by local government and nature conservation organisations (e.g. Geißler-Strobel et al. 1997; Meyer and Große 1997). In addition to their importance for species conservation, successional mining areas are among the rare cases of primary succession in Central Europe. Thus, they provide a good opportunity to study how the assembly of communities changes during succession and which parameters affect species diversity and composition of different successional stages (Dunger 1989).

In this paper, we present a survey of the surface dwelling beetle fauna of two unreclaimed open cast mines and a dump with special reference to ground beetles (Coleoptera, Carabidae). Ground beetles are one of the best known beetle taxa and are often used as indicator group for site assessment in nature conservation (reviews in

Thiele 1977; Lövei and Sunderland 1996). Furthermore, the ecological requirements as well as the distribution and endangering of most species in Germany are well known (Koch 1989; Arndt and Richter 1995; Trautner and Müller-Motzfeld 1995). Thus, ground beetles are a group well suited to study patterns of diversity and mechanisms of colonisation processes along a successional gradient. The objective of this study is firstly to characterise the surface dwelling beetle assemblages of successional lignite mines and to compare species diversity among typical habitats. Secondly, we relate species composition to habitat conditions in order to test whether beetle assemblages can be predicted from environmental parameters. Thirdly, in an attempt to explain the distribution pattern of ground beetles, we correlate the occurrence of species with some of their ecological attributes such as flight ability and body size. Fourthly, we discuss the consequences of our results for species and habitat conservation and give recommendations for future management of the mining sites.

Methods

Study areas

The study was carried out in the Central German lignite district in the South of Leipzig (Figure 1). Open-cast brown coal mining started on a large scale at the beginning of the 20th century. Prior to 1990, reclamation focussed primarily on the establishment of agricultural fields and afforestation without significant consideration of natural succession and conservation issues. Nevertheless, a large part of the total area excavated in the study region until 1990, (200 km^2) was unreclaimed. After 1990, most of the mines were closed and restoration started.

In contrast to the surrounding agricultural area, successional mining sites are often vertically and horizontally highly structured areas including dumps, pits, steep slopes and erosion channels. Soil substrates consist of tertiary or quaternary deposits and are essentially free of nutrients ($N \leq 0.17\%$) and seed banks after dumping. pH ranges from pH < 3 to pH = 7.5 (Durka et al. 1997; Hildmann and Wünsche 1996).

In three areas, within this lignite district, a total of 21 sites were selected (Figure 1): 11 sites at the ‘Tagebau Bockwitz/Borna-Ost’; with a maximum age of 25 years, two sites at the ‘Restloch Beuna’ with a maximum age of 20 years, and eight sites at the dump ‘Halde Trages’ with a maximum age of 50 years. These sites were selected since the protection of the three areas is discussed by local government and because the sites represent all typical habitats of the natural succession on lignite sites. Note that not all habitat types were found in all three areas (see Figure 1). Early birch-woodlands, for instance were until now rare successional habitats in the postmining area and only found at the dump. We, therefore, test for differences in diversity only among the habitat types and not among the three areas.

The 21 sites were classified as (i) dry bare soils without vegetation (3 sites), (ii) dry soils with pioneer vegetation (4 sites), (iii) wet soils with pioneer vegetation (3 sites), (iv) grassland (7 sites), and (v) early birch-woodlands (4 sites).

Beetle sampling

The surface dwelling beetle fauna was sampled with pitfall traps. The use of pitfall traps for studying the surface dwelling fauna has been criticised by various authors (references in Lövei and Sunderland 1996). In general, however, existing differences in species richness and composition among sites could be detected. Pitfall traps are selective in that they reflect species activity. Thus, the use of abundance data in numerical analyses is problematic and some authors suggested to restrict analyses to the presence or absence of a species from a habitat. Abundance data are biased by differences in activity among species as well as differences in habitat structure affecting mobility of species (e.g. Greenslade 1964; Pollard 1968; Halsall and Wratten 1988). On the other hand, much information is lost which would be able to compare sites by reducing abundance data to presence/absence form (Maelfait and Desender 1990). We will consider this problem by analysing data in both ways and then comparing the respective results.

On each site, five pitfall traps (plastic cups of 6.5 cm diameter, set 9 cm deep into the ground) were placed 5 m apart in a straight line in the centre of the selected site. Five to ten traps are the most frequent number of traps used to sample a single habitat type (e.g. Neumann 1971; Maelfait and Desender 1990; de Vries et al. 1996; Crisp et al. 1998; Petit and Usher 1998). Stein (1965) showed that five traps per habitat are sufficient to sample all dominant, subdominant and even the less common species within a habitat. The distance of 5 m was chosen to avoid edge effects since due to the highly structured physiognomy of the areas, size of some sites were rather small (see also de Vries et al. 1996). To avoid attraction of species, we used a saturated NaCl solution for preservation of trapped specimen. Each site was sampled in 1996 between March and August 1996 and every two weeks the traps were emptied and replaced by pitfalls with fresh NaCl solution. We stopped the sampling in September because wild boars increasingly dug out the traps. However, it is unlikely that this will influence results since our major goal was site assessment which is even possible when sampling is restricted to only one season (Maelfait and Desender 1990; Petit and Usher 1998). Since the number of individuals captured was low compared with e.g. agriculture areas, the samples of all five traps of each site were pooled over the whole trapping period.

Ground beetles were identified using Freude et al. (1976), species of other families were determined at least to the family level using Freude et al. (1965–1983) and further classified according to the morphospecies concept as recommended by Olivier and Beattie (1996). The nomenclature of species and families follows Köhler and Klausnitzer (1998).

Ecological attributes due to habitat choice of species were taken from Koch (1989). To estimate species, colonisation ability ground beetles were classified according to hide wing morphology into three groups using data from Lindroth (1986) and Hejkal (1985): (i) macropterous (ii) polymorphic or dimorphic and (iii) brachypterous, micropterous or apterous species. Body size of each species was estimated using the midpoint of body length (in mm) reported in Freude et al. (1976).

Environmental variables

The following soil characteristics were considered: soil pH (H_2O) and soil moisture (gravimetrically) were measured on five samples (0–5 cm depth) distributed randomly at each site. The mean of the samples was used in the statistical analyses. Soils were further categorised as into loam–sand (LS), sand (S), sand–loam (SL), clay (T) or humus soils (H). We estimated the vegetation cover (in %) of (i) bare soil, (ii) moss layer, (iii) herb layer between 0–20 cm above ground, (iv) herb layer between 20–50 cm above ground, (v) shrub layer between 50–400 cm above ground, and (vi) tree layer higher than 400 cm above ground. Additionally, since some members of the phytophagous families are restricted to certain plant species (e.g. Curculionidae, Chrysomelidae), we determined the number of plant species at each site.

Statistical analysis

Due to problems of interpreting abundance data using pitfall trapping (see above), species diversity of sites was calculated simply by counting the number of species recorded at each site, henceforth called species richness. To test for differences in means of individuals and species richness among habitat types we computed One-way ANOVAs. Beta-diversity was analysed calculating Jaccard-indices and a species accumulation curve across sites. The composition of the assemblages was analysed by ordination. We used Detrended Correspondence Analysis (DCA) as implemented in the CANOCO-software (Ter Braak and Smilauer 1998) to ordinate the sites. The program produces a biplot in which sites and species are ordinated simultaneously. We are aware that DCA and related ordination techniques assume (i) the activity of all species to be the same in all sites and (ii) the efficiency of the traps to be site independent (Maelfait and Desender 1990). Due to the very different habitats selected both assumptions were not fulfilled in our study. To elevate the robustness of ordination patterns we analysed the data set as presence/absence and as abundance data. Prior to analysis, species abundance data were $\log_{10}(x+1)$-transformed. Results of both ordination analyses were qualitatively identical. Thus, we present only the results of the presence/absence ordination.

To relate species composition to the environmental variables we ordinated the data using a DCA (see above). Prior to ordination, environmental variables were standardised to proportions. The resulting ordinations of species and environmental variables were compared using a Procrustes analysis. The observed sum of squared distances was tested for significance against 1000 random comparisons using a Monte Carlo simulation implemented in the SYN-TAX-package (Podani 1994).

Analysing proportional data of endangered species and flight morphs we applied generalised linear modelling (GLM) using GLIM statistical software package (Francis et al. 1994). This method is advocated when there are substantial differences in sample size (i.e. the number of species trapped) among sites or habitat types (Crawley 1993).

Results

In total, we trapped 4099 beetle individuals of 203 species from 27 families. The ground beetles made up 957 individuals representing 75 species (see Appendix). The most numerous species were the small sized, eurytopic *Microlestes minutulus* and *Bembidion lampros* which predominately were found at sites with pioneer vegetation or grasses. These two species made up 30% of the total ground beetle catch. Stenoecious species like *Syntomus foveatus*, which prefer sandy soils, or *Omophron limbatum* and *Oodes helopioides* that are restricted to wet soils were also found. Within the other beetle families a few medium-sized species of grass-root feeding Curculionidae species were most abundant, which probably exploit the dominant grass species *Calamagrostis epigejos* and *Festuca rubra*. Consequently, these species dominated at the grassy sites. Other dominant species were the small-sized *Zorochrus dermestoides* (Elateridae) and *Throscus dermestoides* (Throscidae) which were most abundant at sites with pioneer vegetation.

There was no difference among types of habitat in the number of individuals as well as in species richness. This is because the number of individuals as well as the number of species trapped differed considerably among sites within types of habitats (Table 1). There was, however, no habitat type in which proportions of endangered species (only ground beetles) are larger than in others (ANOVA with binomial error:

Table 1. One-way ANOVA table among five habitat types testing for differences in number of individuals and species richness. Note that data were $\log_{10}$-transformed prior to analysis.

Source	*df*	*SS*	*MS*	*F*	*P*
Individuals					
Between groups	4	0.25	0.06	0.32	0.86
Within groups	16	3.17	0.19		
Total	20	3.42			
Species					
Between groups	4	0.21	0.05	1.15	0.37
Within groups	16	0.73	0.04		
Total	20	0.96			

$n = 21$, $df = 4$, $\chi^2 = 2.0$, $P > 0.05$). The strong rise of the species accumulation curve (Figure 2) revealed high values of beta-diversity between sites as indicated by a low Jaccard value [0.12 ± 0.14 (mean + SD)] comparing species composition of all sites. Ordination of species discriminated the successional gradient on the first DCA-axis reaching from bare soils and pioneer vegetated sites to grassy sites and early birch-woodlands (Figure 3a,b). The second DCA-axis discriminated the sites of wet soils with pioneer vegetation from all other sites. Typical species of the bare soils and the pioneer vegetation were the small detritivorous *Throscus dermestoides* and the Elateridae *Zorochrus dermestoides* whereas the grassy sites supported many Curculionidae species. The two tiger beetle species *Cicindela hybrida* and *Cicindela campestris* are typical predators of the sandy soils where they prey upon other insects and spiders. *C. hybrida* was found to live predominantly on the bare soils without vegetation whereas *C. campestris* preferred sites with pioneer vegetation and grassy sites. In the woodland sites, both species were missing. Typical species of the wet soils were *Omophron limbatum* and *Demetrias monostigma*. Fully winged eurytopic ground beetle species, e.g. *Bembidion lampros*, *Microlestes minutulus*, dominated at early successional stages and grassy sites whilst at the early woodlands large, flightless species, e.g. *Cychrus caraboides*, *Carabus convexus*, *C. hortensis* and *C. nemoralis*, were predominantly found. Ordination of sites using environmental variables reflected the successional gradient along the first DCA-axis (Figure 3c). The most important variables were loamy soil (score = 3.6), cover of bare soil (score = 2.8) and shrub cover (score = 2.8). The second DCA-axis weakly discriminated the wet soils. The most important variables were sandy/loamy soil (score = 3.5), soil moisture (score = 2.6) and moss cover (score = 2.2). Ordination of sites across species was closely related to the ordination of sites across environmental variables (Procrustes rotation of ordinations: $d^2 = 0.84$, $P = 0.001$), despite low values of explained variance of DCA-axes.

Frequency of macropterous species decreased from bare soil sites to early birch-woodlands (regression analysis with binomial error: $n = 21$, $df = 1$, $\chi^2 = 16.4$, $P < 0.001$), whereas the frequency of polymorphic and brachypterous species increased in later successional stages (regression analysis with binomial error: polymorhphic species: $n = 21$, $df = 1$, $\chi^2 = 4.7$, $P < 0.05$, brachypterous species: $n = 21$, $df = 1$, $\chi^2 = 11.4$, $P < 0.001$). We found also a correlation of body size and wing morphology: brachypterous species are on average larger than polymorphic and macropterous spcies (One-way ANOVA: $n = 72$, $F_{2,70} = 7.0$, $P = 0.001$, body size was $\log_{10}$-transformed prior to analysis).

Discussion

Species richness

This study reveals a high diversity of surface dwelling beetles in unreclaimed brown-coal mining areas. We recorded a total of 203 species including 75 ground beetle

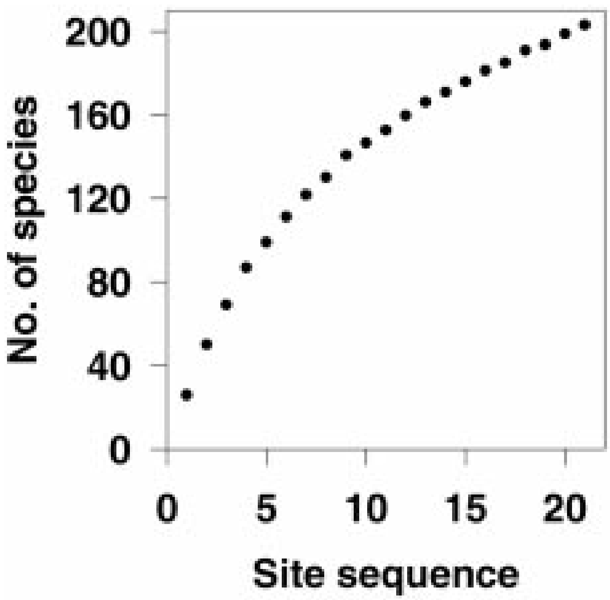

Figure 2. Species accumulation curve across sites. The curve was obtained calculating the mean number of cumulative species obtained from 20 random combinations across sites within each cumulative step (all species included into the analysis).

species (957 individuals) which is high compared with agricultural areas. For example, in a study on set-aside fields surrounding the sites of our study only 58 ground beetles in a sample of 10555 individuals were recorded during a complete year (M. Frenzel, unpublished data). On set-aside fields of arable land on sandy soil in Flanders (Belgium), Desender and Bosmans (1998) recorded only 53 ground beetle species in a sample of 3650 individuals during a complete year. The high number of species trapped in our study probably results from the high habitat diversity found in the postmining area indicated by high values of beta-diversity between sites. Because the sampling period disregarded species which are active in autumn we believe that the actual number of ground beetle species in our study area would reach more than 100 species if trapping had been conducted over a whole year.

The ground beetles recorded comprised 19% of the total ground beetle species pool in Saxony (Trautner and Müller-Motzfeld 1995). Ten of the 75 ground beetle species recorded were endangered species according to the red data book for Saxony (Arndt and Richter 1995). Four of these were either found in more than one site or were dominant at this site (see Appendix). Two ecological groups representing different environmental requirements can be distinguished: (i) eurytopic species which use the postmining area as an extension of their typical habitat e.g. *Microlestes minutulus*, *Bembidion lampros*, *Poecilus cupreus* and *Amara communis*, (ii) specialised species of wet habitats which use this area as a surrogate of their original

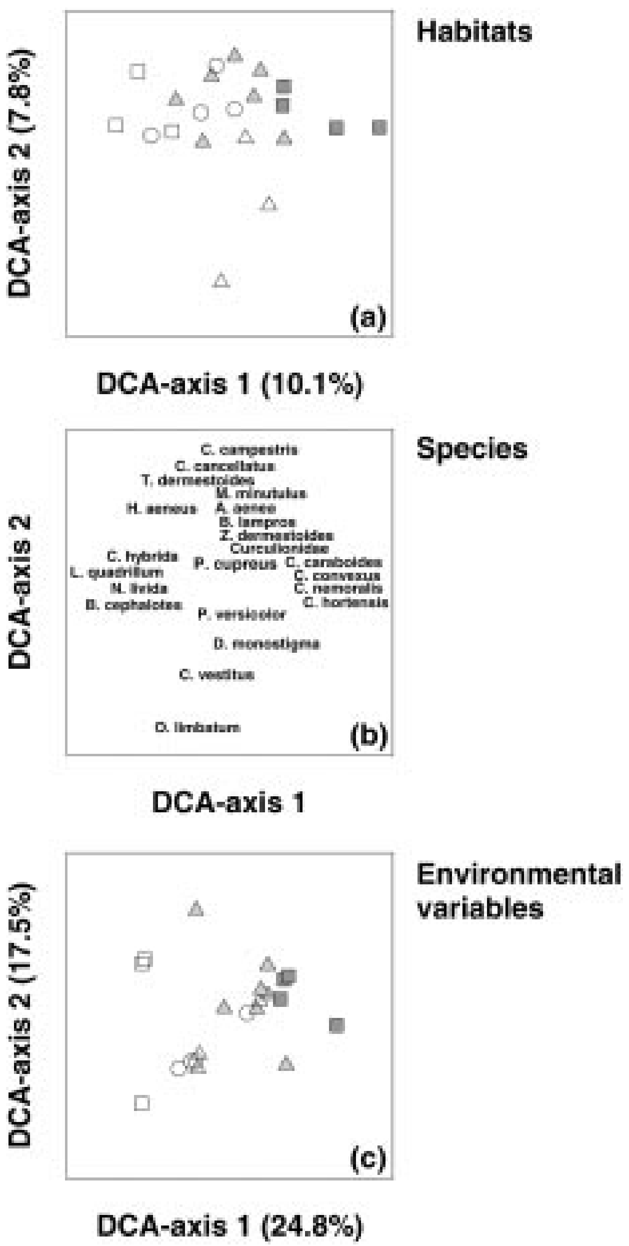

Figure 3. Ordination diagram of the first two axes of Detrended Correspondance Analysis (DCA) of (a) sites and (b) species. (c) Ordination of sites using environmental variables. Explained variance of axes in brackets. Open quadrates = bare soils, open circles = dry soils with pioneer vegetation, open triangles = wet soils with pioneer vegetation, filled triangles = sites with grassy vegetation, filled quadrates = early birch-woodlands (all species included into the analysis).

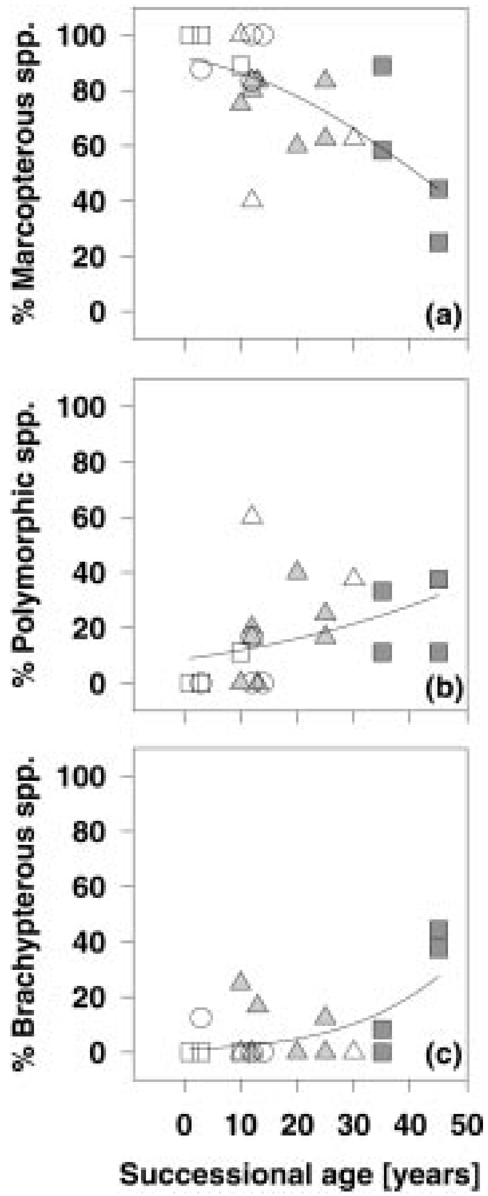

Figure 4. Proportions of (a) macropterous, fully winged (b) polymorphic and (c) brachypterous ground beetle species *versus* successional age of habitats. Statistics see text. Symbols indicate habitat types (see Figure 1).

habitat, e.g. *Lyonichus quadrillum*, *Omophron limbatum* and *Demetrias monostigma*. For some of these, the postmining area is now the only suitable habitat in the region, e.g. *Nebria livida* (Arndt and Richter 1995). The high species diversity and the occurrence of specialised species demonstrates that unreclaimed brown-coal mining sites are of high conservation value of ground beetles in intensively used agricultural areas. It emphasises the importance to protect these sites to ensure the preservation of high diversity of different habitats. Species that are restricted to sandy or loamy banks of large, natural rivers or lakes find adequate habitat in such areas. Their original, 'natural environments' are now rare in Central Europe due to human impact.

Species composition

We found that species composition of assemblages reflects different environmental conditions of the study sites. Ordination of sites across species as well as across environmental variables distinctly reflected the successional gradient. This reveals that assemblages change in a predictable manner when one successional stage is replaced by another. During succession not only species composition but also species traits changed: macropterous ground beetles dominated on bare soils and soils with pioneer vegetation. During succession, the proportion of fully winged pioneer species decreases while the proportion of polymorphic and flightless species increases. This seems to be a general pattern and our results are in concordance with other studies in open-cast lignite mines or spoil banks (e.g. Neumann 1971; Hejkal 1985; Mader 1986; Tietze and Eppert 1993; Kielhorn et al. 1998).

In intraspecific comparisons of polymorphic ground beetles Den Boer et al. (1980) found that macropterous individuals inhabited open areas whereas in older forests short-winged individuals dominated. They take this as an evidence that the more 'stable' or predictable a habitat occupied (stable in the sense that such habitats are only little affected by random fluctuations), the more will natural selection reduce relative wing size (see also Denno 1991). This conclusion encompasses the *r* and *K* selection theory of populations (e.g. Southwood 1977). The dominance of macropterous species in early successional habitats is explained by the ability to immigrate and exploit ephemeral, highly heterogeneous resources and to emigrate from such habitats (*r*-selected populations). Consequently in later successional stages, dominance of brachypterous species is expected whose ability to immigrate is reduced due to efficient utilisation of resources (*K*-selected populations).

However, wing morphology is confounded with body size, brachypterous species being larger than polymorphic and macropterous. Larger species could be forced to live in more predictable environments (*K*-selected species, sensu Southwood 1977) because (i) for energetic reasons they must utilise more productive environments to build up viable populations and/or (ii) a structurally more complex habitat (e.g. woodlands) allows larger species to find better refuges from predators. Thus, they reduce or lose the ability to fly as a consequence of being adapted to productive habitat and they are restricted in colonising new environments (DenBoer et al. 1980). However, further research is needed to test the causal relationship between flight ability, body size and species distribution.

Recommendations for conservation management

As we have shown for ground beetles, unreclaimed successional lignite mines are important centres of diversity in agricultural areas of Central Germany. For future management policy there are several points which are important in maintaining diversity of beetles and possibly other organisms in the postmining area. (1) The high diversity of unreclaimed mines is based on the diversity of soil substrates, hydrology and successional age. For conservation of biodiversity a representative sample of habitats should be preserved (Altmoos and Durka 1998). (2) The ongoing succession of sites produces a highly dynamic area with a variety of different habitats. These successional processes are key factors determining diversity and should be maintained. (3) Bare soil and pioneer vegetation, which are important habitats of endangered beetle species, will constantly be replaced by later successional stages. For long-term availability of bare soil and pioneer vegetation sites with extreme soil conditions should be included into conservation networks. Thus, sites with acidic tertiary sands (pH $<$ 3) which are colonised very slowly and may remain unvegetated for 50 years are potential conservation areas of the future and should be left unreclaimed. (4) Restoration by afforestation or flooding of mining areas would result in a loss of habitat diversity. Thus, a balanced restoration management is needed to bridge the gap between social and economic interests and nature conservation.

Appendix

List of ground beetle species recorded in the study area. Number of individuals trapped of a species (*n*) and number of sites (sites) in which the species was recorded (total 21 sites) are also given

Species	*n*	Sites	Species	*n*	Sites
Acupalpus parvulus	3	2	*Clivina fossor*	1	1
Acupalpus meridianus	2	2	*Cychrus caraboides*	3	3
Agonum marginatum	2	1	*Demetrias monostigma*	1	1
Agonum mülleri	1	1	*Dromius linearis*	1	1
Agonum sexpunctatum	5	1	*Dyschirius globosus*	1	1
Agonum viduum	2	1	*Harpalus aeneus*	27	7
Amara aenea	34	1	*Harpalus anxius*	3	2
Amara aulica	1	1	*Harpalus distinguendus*	14	4
Amara brunnea[a]	1	1	*Harpalus modestus*[a]	1	1
Amara communis	25	8	*Harpalus rubripes*	38	6
Amara consularis	1	1	*Harpalus rufitarsis*	1	1
Amara fulva	5	3	*Leistus ferrugineus*	1	1
Amara lunicollis	2	1	*Loricera pilicornis*	5	4
Amara similata	5	3	*Lionychus quadrillum*[a]	57	2
Anisodactylus binotatus	2	1	*Metophonus rufibarbis*	1	1
Asaphidion flavipes	3	2	*Microlestes minutulus*	181	13
Asaphidion pallipes[a]	3	1	*Nebria brevicollis*	6	4
Badister lacertosus	3	1	*Nebria livida*[a]	1	1
Bembidion bruxellense	1	1	*Notiophilius aquaticus*	1	1
Bembidion femoratum	6	4	*Notiophilus aesthuans*[a]	1	1

Appendix Continued.

Species	*n*	Sites	Species	*n*	Sites
Bembidion illigeri	47	3	*Notiophilus biguttatus*	1	1
Bembidion lampros	107	7	*Notiophilus palustris*	6	2
Bembidion lunulatum[a]	1	1	*Omophron limbatum*[a]	64	1
Bembidion obtusum	5	3	*Oodes helopioides*	1	1
Bembidion pygmaeum	16	4	*Platynus assimilis*	1	1
Bembidion quadrimaculatum	13	8	*Poecilus cupreus*	53	11
Broscus cephalotes[a]	5	2	*Poecilus versicolor*	20	3
Calathus ambiguus	1	1	*Pseudoophonus rufipes*	5	3
Calathus erratus	10	6	*Pterostichus niger*	1	1
Calathus fuscipes	1	1	*Pterostichus nigrita*	2	1
Calathus mollis	1	1	*Pterostichus oblongopunctatus*	1	1
Carabus cancellatus[a]	11	4	*Stenolophus mixtus*	36	1
Carabus convexus	9	3	*Stenolophus teutonus*	2	1
Carabus hortensis	8	2	*Stomis pumicatus*	1	1
Carabus nemoralis	7	1	*Syntomus foveatus*	1	1
Chlaenius vestitus	14	2	*Syntomus truncatellus*	1	1
Cicindela campestris	23	11	*Trechus quadristriatus*	2	2
Cicindela hybrida	28	4			

[a] Species listed in the regional red data book of Saxony by Arndt and Richter (1995). Nomenclature of ground beetles follows Köhler and Klausnitzer (1998).

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