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Ground beetle communities on reclaimed mine spoil: Effects of organic matter application and revegetation

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Abstract

On a study site in the Lusatian lignite mining region (Germany), sandy mine spoil was ameliorated with either sewage sludge, compost or mineral fertilizer. Plots were sown with the grass *Secale multicaule* and planted with pine seedlings except for a control that was not meliorated and not revegetated. Pitfall catches of ground beetles in 1996/97 yielded high numbers of species and individuals directly after revegetation. The dominant beetles were xerophilic species, known to prefer open sandy sites. Catches in different plots were positively correlated with the amount of vegetation cover and declined as follows: amelioration with sewage sludge > compost > mineral fertilizer > untreated control. Even beetles characteristic of open sandy sites showed a distinct preference for plots with high vegetation cover treated with organic waste. For the dominant species, an attraction to shelter and a more balanced, humid microclimate is assumed. A year-to-year comparison showed an increase in beetles typical of dry grasslands and ruderal sites in the second year, while characteristic species of open sandy sites decreased. Application of organic waste combined with revegetation led to an immediate increase in beetle numbers. In the long term, revegetation would be expected to reduce suitable habitats for endangered ground beetles which prefer open sites with poor sandy soils.

Introduction

The Lusatian mining district is the largest lignite mining region in Germany with a history of mining which dates back to the 18th century. About 75,000 ha of land have been used for open-cast mining. A large proportion of this area has not yet been reclaimed (Hüttl, 1998). To a great extent, the top layer of the spoil contains Tertiary substrate with fossil organic carbon. This spoil type is characterized by low nutrient content and low recent organic matter, as well as low pH values and water retention capacity. As a consequence, natural succession on this substrate is extremely slow. Therefore, the common reclamation practice includes an application of lignite ash and mineral fertilizer. About 60% of the reclaimed area has been afforested with mostly pine (*Pinus sylvestris* L.) or red oak (*Quercus rubra* L.).

Ground beetles (Carabidae) are among the first epigeic arthropods to colonize fresh mine spoil (Neumann, 1971; Hejkal, 1985; Mader, 1986; Parmenter and MacMahon, 1987). Predatory ground beetles play a major role in the natural control of pest organisms in agricultural fields (Luff, 1987) and woods (Weidemann, 1972), and are generally regarded as beneficial arthropods. They are an important food source for many vertebrates, e. g. birds, bats and shrews (Barndt et al., 1991). The widespread occurrence of ground beetles in a broad range of biotopes and their well-known autecological demands (Thiele, 1977) are the basis for their value as bioindicators in monitoring environmental change (Müller-Motzfeld, 1989; Trautner, 1992; Heijerman and Turin, 1994).

The immigration and succession of ground beetles on reclaimed strip-mining areas in Germany has received considerable attention (Neumann, 1971; Mader, 1986; Dunger, 1989; Vogel and Dunger, 1991; Topp et al., 1992; Haag and Depenbusch, 1995; Skam-

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bracks et al. 1997). However, little data is available for the Lower Lusatia region and for the influence of local soil conditions and reclamation techniques on the composition and development of beetle communities.

The ground beetle fauna on plots in a recently reclaimed experimental site in Lower Lusatia, which have been ameliorated differently, has been monitored since 1996. The present work is part of a study investigating the effects of organic waste on the re-establishment of ecological soil functions in afforested mine spoil carried out at the Brandenburg University of Technology in Cottbus (cf. Vetterlein et al., 1997). The objectives of the current study are: (1) the ecological characterization of the immigrating ground beetles in revegetated sites on sandy mine spoil, (2) the possible effects of different organic amelioration substances on the ground beetle fauna, and (3) a description of trends in the future development of the fauna.

Materials and methods

The ground beetle fauna was investigated on the study site 'Weißagker Berg' in the lignite mining area 'Jänsch-walde' near Cottbus (State of Brandenburg, Germany). The substrate of the site was dumped in 1991 and mainly consists of Tertiary marine-brackish sands containing fossil organic carbon. Four main test plots (size 40×25 m), each with 2 smaller replicate plots (25×20m), were ameliorated in April 1996 with a basic treatment of ash (about 120–150 t/ha). In addition, either sewage sludge (19 t/ha), compost (22 t/ha) or mineral fertilizer (120 kg N, 100 kg P, 80 kg K) was applied on three of the plots. After amelioration, all plots were sown with the test crop *Secale multicaule* and planted with two-year old Scots pine seedlings (*Pinus sylvestris* L.). An additional control plot was left completely untreated and not planted. The pH value of the top soil was highly variable, ranging from 2.5 to 3.5 before amelioration and from 3.5 to 4.5 after amelioration with ash (Vetterlein et al., 1997). No noticeable change in pH values occurred after the application of organic waste and mineral fertilizer.

Ground beetles were monitored on three of the main test plots at the study site: amelioration with sewage sludge, compost, mineral fertilizer, and the untreated control (no amelioration or revegetation). Replicate plots were not monitored, as they were small and hence edge effects were expected to be too large. In summer 1996, the main visible difference between the various test plots was the amount of cover of the test crop. Vegetation cover was high on the sewage sludge plot (50–75% total cover), lower but still homogeneous on the compost plot (50–75%), low and heterogeneous with unvegetated areas on the mineral fertilizer plot (5–25%), and almost non-existent on the untreated control plot (< 5%).

Ground beetles were sampled using funnel traps (Müller, 1984). The traps were protected against rain and litter-fall by a transparent plastic roof (15×15 cm). A 3.5% formaldehyde solution with added detergent was used as the preservation fluid. Sets of five traps (trap-to-trap distance at least 4 m), as well as an additional spare trap to compensate for any possible catch losses should one of the other traps fill with sand, were installed in May 1996 on each of the plots. The traps were emptied at two-week intervals with the exception of longer intervals in July 1996 and winter 1996/97. Catches from each trap were dealt with separately, and single-trap catches were calculated (see Figure 4).

Due to a slight slope on the study site and erosion of the substrate after heavy rainfall, the traps frequently filled with sand, causing losses of complete catches, in particular on the control plot without vegetation cover. Consequently, calculations of catch numbers are based only on time periods where catches from all plots were available.

Results

Structure and development of ground beetle communities

During a catch period of 288 days, a total of 14,129 individuals and 70 species of beetles was caught on the study site. The species number represents about 20% of the ground beetle fauna in the State of Brandenburg. The ecological characterization shows a clear dominance of xerophilic species and individuals: over 70% of the species recorded and 92% of the individuals preferred dry habitats (Figure 1, top row).

Most of the ground beetles were species associated with arable land, dry grassland, open sandy sites and ruderal sites (Figure 1, bottom row). Despite the low number of species which prefer open sandy sites, these beetles constituted 50% of the recorded individuals. Compared to the fauna of similar habitats on naturally grown soil (e. g. inland sand dunes), the number of common field species on the study site was rather high. Soil cultivation during reclamation apparently favors these ground beetles.

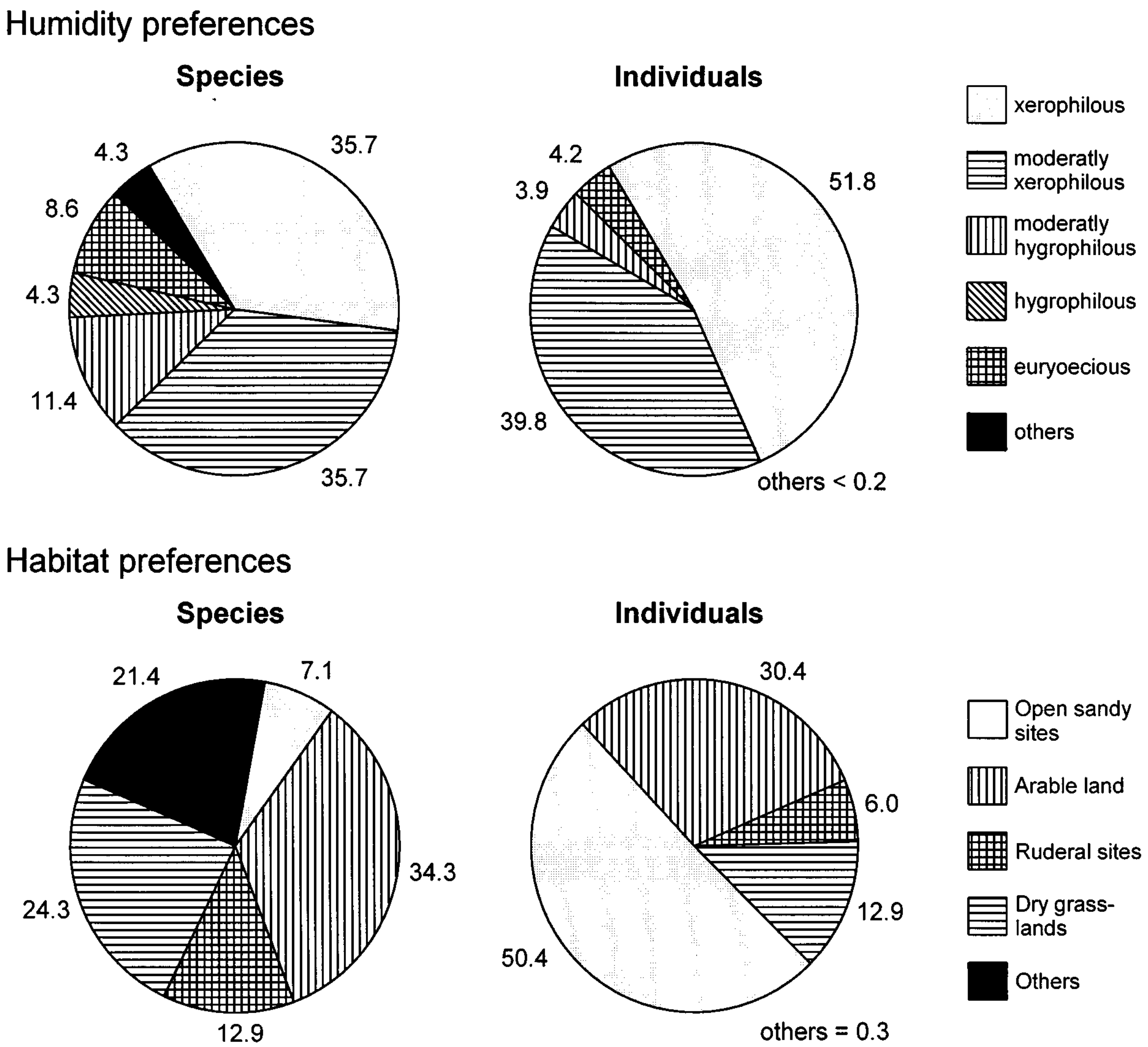


Figure 1. Distribution of carabid species and individuals from the study site by humidity preference (top row) and habitat preference (bottom row), in % of total catch with 20 pitfall traps over 288 days; ecological characterization of beetles modified and simplified from the scheme of Barndt et al., 1991.

The high catch numbers recorded directly after re-vegetation indicate a rapid immigration of beetles onto the study site. The examination of about 10 liters of the sewage sludge and compost used for the application treatment yielded no ground beetles or remains of beetles. Thus, the import of ground beetles via the applied amelioration materials seems unlikely. About 74% of the sampled species and 93% of the individuals were macropterous (fully winged) with good dispersal abilities. The dominance of ground beetles typical of open sandy sites points to an immigration from areas adjacent to the plots. Catches of larvae demonstrate that in general, beetle populations were reproducing on the site (Figure 3).

Total catch numbers differed little between 1996 and 1997 on the ameliorated plots (catch periods around 130 days, Figure 2). Ground beetles with a preference for open sandy sites decreased on the

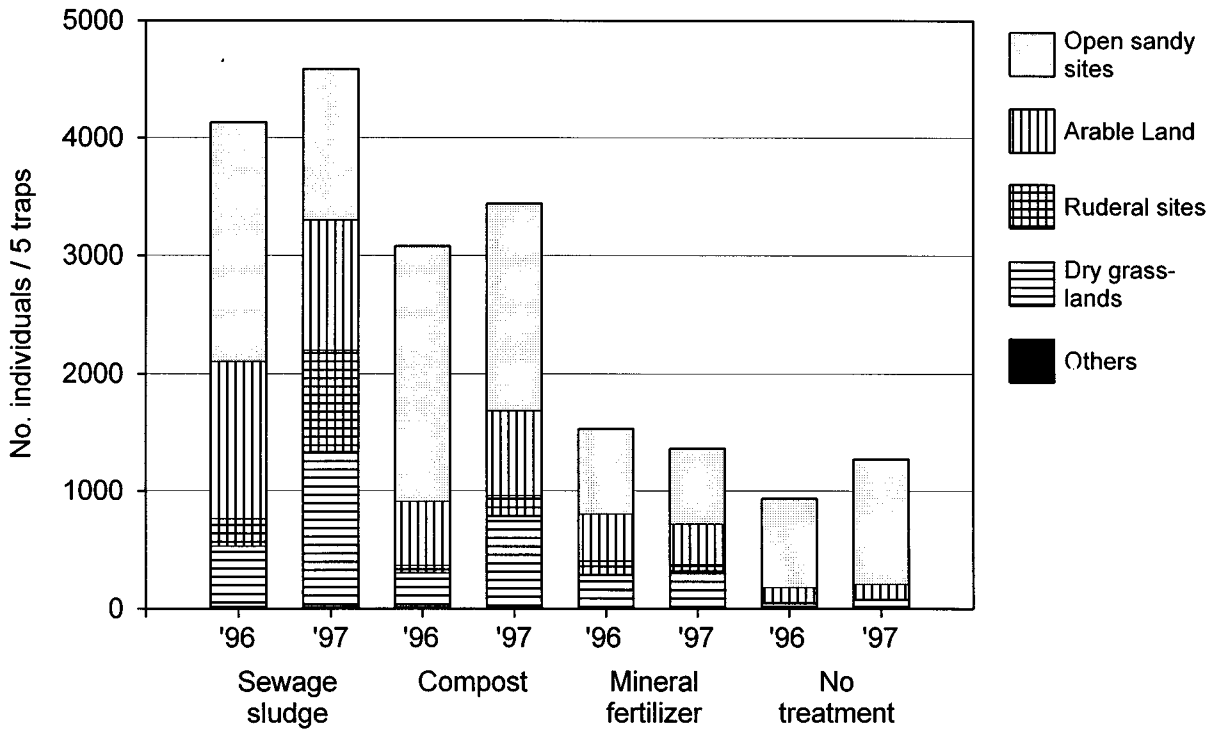


Figure 2. Changes in distribution of carabid individuals by habitat preference from the year of revegetation (1996) to the following year (1997) on differently ameliorated plots of the study site (total catch from 5 traps, catch period in untreated control 126 days (1996) and 133 days (1997), in all other plots 139 days (1996) and 133 days in 1997; habitat preference of beetles modified and simplified from the scheme of Barndt et al., 1991).

compost and sewage sludge plots (40 and 20%, respectively), while individuals of species inhabiting dry grasslands and ruderal sites were caught in much higher numbers in 1997 compared to 1996. No major changes in the faunal composition occurred on the mineral fertilizer plot. On the untreated plot, only the number of characteristic beetles of open sandy sites increased by about 40% due to higher catches of *Amara fulva*.

The main reason for lower numbers of beetles which prefer open sandy sites on the compost and sewage sludge plots was a reduction in catches of *Harpalus flavescens* – the dominant species on all plots. On the contrary, *Amara fulva* – another typical beetle of open sandy sites – showed an increase in catch numbers on all plots. In 1997, *Calathus ambiguus* – a characteristic species of dry grasslands – was also caught in higher numbers on all plots, especially in the sewage sludge and compost plots. In addition, the number of partly spermophagous (seed eating) beetles (*Pseudoophonus rufipes*, *Amara* spp.) increased on these plots in 1997.

Effects of different amelioration materials

The applied amelioration materials strongly affected the total number of beetles. The numbers declined as follows: amelioration with sewage sludge > compost > mineral fertilizer > untreated control (Figure 3). This observation correlates with the cover of the test crop *Secale multicaule* on the various plots of the study site. Species numbers and catches of larvae followed a similar trend (Figure 3) with highest catch numbers on the sewage sludge plot.

Most of the abundant ground beetle species showed this preference for the plots with dense grass vegetation. Even species that usually prefer open sites with little or no vegetation were caught in higher numbers on these plots. However, these species had a different pattern of preferences for the various plots. While characteristic beetles of open sandy sites were

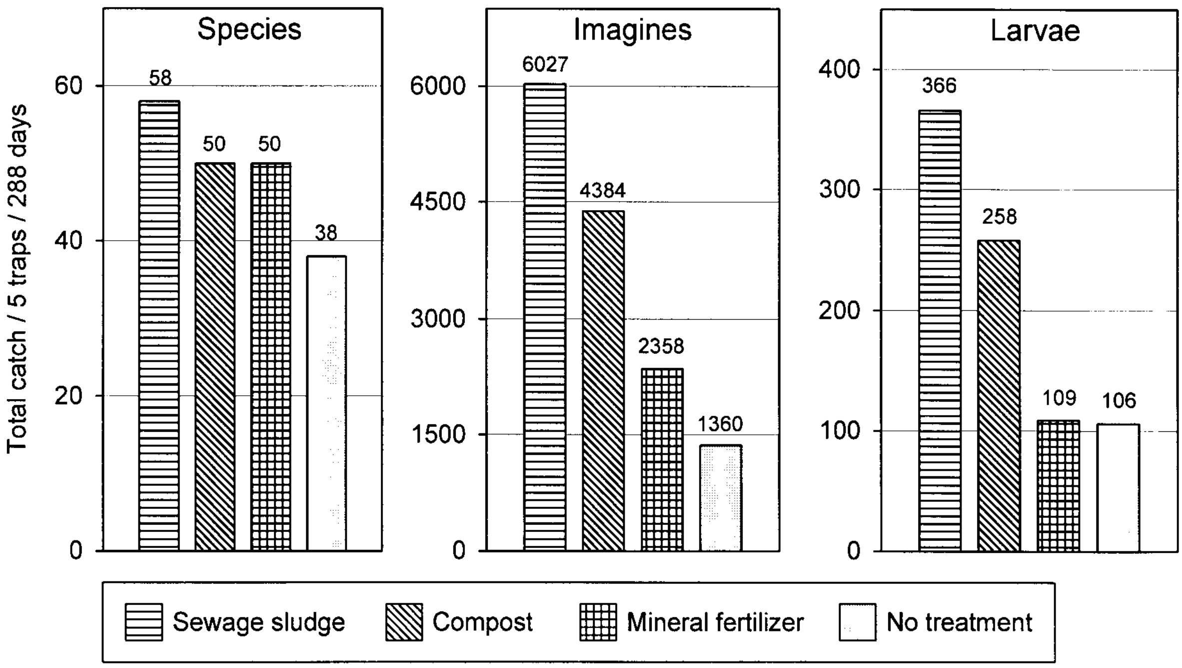


Figure 3. Total catch of ground beetle species, imagines, and larvae on differently ameliorated plots of the study site (sums from 5 traps and 288 days).

caught in comparable numbers on the compost plot and on the sewage sludge plot (Figure 4, top row), species typical of arable land (*Bembidion quadrimaculatum*, *Poecilus cupreus*) and ruderal sites (*Microlestes minutulus*) clearly had a maximum number of catches on the sewage sludge plot (Figure 4, bottom row). A similar distribution of catch numbers was found in common species of dry grasslands (*Calathus ambiguus*, *C. cinctus*).

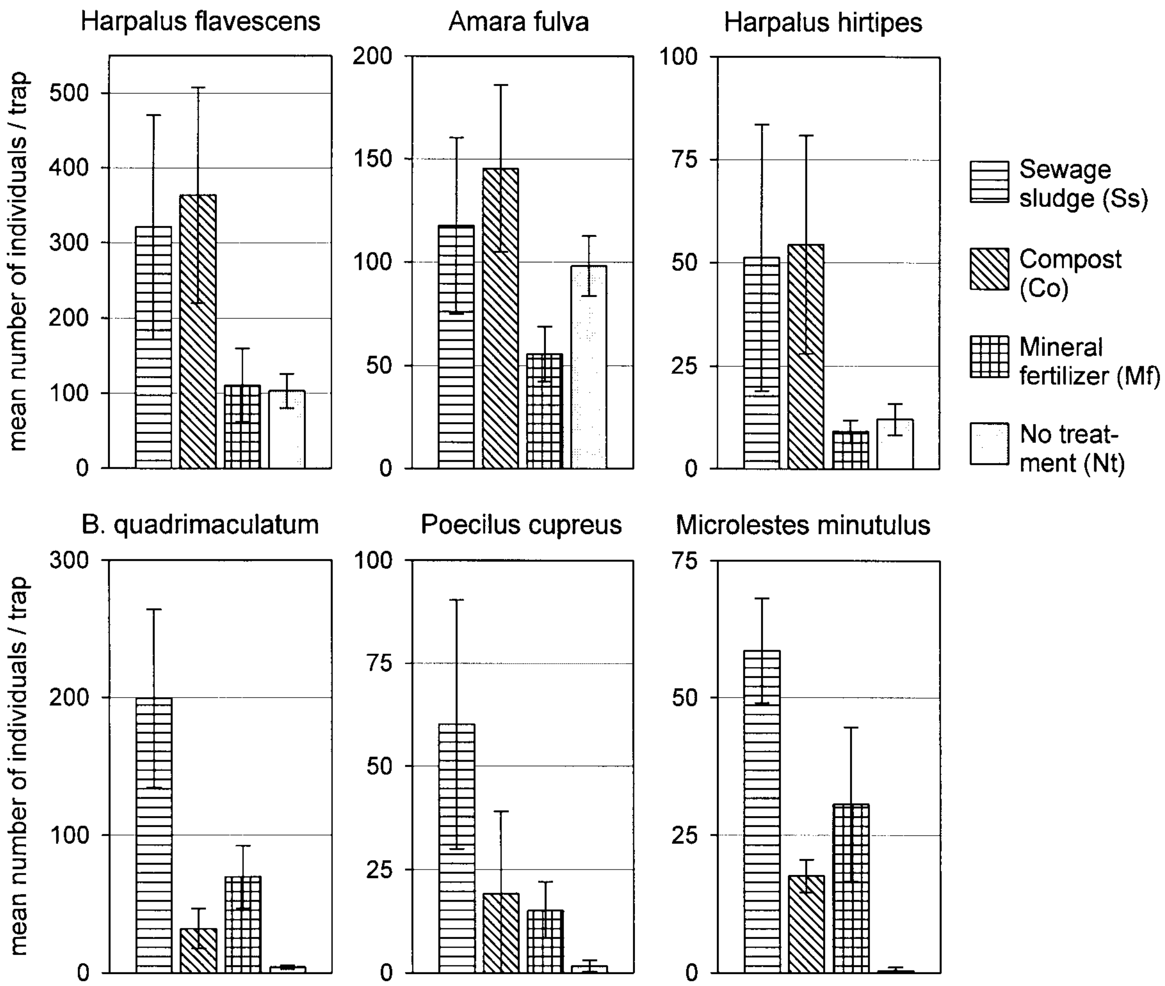
Discussion

The addition of organic waste to soil increases populations of detritivorous arthropods in soil and litter and initiates improved plant growth (Pimentel and Warneke, 1989). Ground beetles can benefit from these developments as a result of a larger food supply of detritivorous and herbivorous invertebrate prey (Larsen et al., 1996).

Treatment with sewage sludge or manure in different field cultures led to an increase in numbers of carabid species and/or individuals (Pietraszko and de Clercq, 1982; Purvis and Curry, 1984; Humphreys and Mowat, 1994; Larsen et al., 1996). Studies in a beech forest directly after the application of sewage sludge (Kobel-Lamparski et al., 1985) and on a lignite mining dump 10 years after treatment with sewage sludge (Vowinkel, 1990) failed to show changes in ground beetle abundance.

The application of organic waste resulted in an increase in ground beetles of between 10 and 80% in the above-cited studies. A similar effect was found in our current study, with numbers of beetles increasing by more than 200% on the compost plot and over 300% on the sewage sludge plot compared to the control. This might be an effect of the larger difference between the control plot, with nearly no vegetation, and the revegetated plots, as opposed to variance in vegetation cover between treatments in field cultures. A dense vegetation cover can offer a more favorable microclimate for both the beetles (Thiele 1964) and the potential prey (Basedow, 1994).

On the other hand, a dense vegetation is thought to impede carabid surface activity by increased habitat resistance (Heydemann, 1957; Greenslade, 1964) and therefore to lower catch numbers of beetles in pitfall traps. Some authors have reported a positive correlation between numbers of ground beetles and vegetation cover (Speight and Lawton, 1976; Cardwell et al., 1994), while others found no effects from different



	Ss/Co	Ss/Mf	Ss/Nt	Co/Mf	Co/Nt	Mf/Nt
Harpalus flavescens	ns	★★	★★	★★★	★★★	ns
Amara fulva	ns	★★	ns	★★★	★	★★★
Harpalus hirtipes	ns	★★★	★	★★★	★★★	ns
Bem. quadrimaculatum	★★★	★★★	★★★	★	★★★	★★★
Poecilus cupreus	★	★★★	★★★	ns	★	★★★
Microlestes minutulus	★★★	★★★	★★★	ns	★★★	★★★

Figure 4. Mean catches of selected ground beetle species on differently ameliorated plots of the study site. Mean and standard deviation of five single-trap catches (catch period 288 days) and significance levels of differences between plots (Mann-Whitney-U-test; ns $P > 0.05$, ★ $P \leq 0.05 > 0.01$, ★★ $P \leq 0.01 > 0.005$, ★★★ $P \leq 0.005$).

vegetation densities (Purvis and Curry, 1984; Basedow, 1994) or even an inverse relationship (Honek 1988). Vermeulen (1994) showed ground beetles from open sandy sites to move more slowly in dense grass vegetation and in forests. Mitchell (1963) and Wallin (1985) found that preferences for dense or sparse vegetation cover differed between species.

In the present study, most beetles on the revegetated plots are believed to have immigrated from the direct surroundings because species typical of open sandy sites were dominant here as well as in the control plot, which was similar to the adjacent area. Evidently, the revegetated plots were very attractive even for beetles with an adverse habitat preference. This is remarkable, as Vermeulen (1994) demonstrated a strong tendency to avoid dense grassland in stenotopic carabids from open sandy habitats. The dominant species in all plots was *Harpalus flavescens*. This extremely xerophilic species lives on loose sand with scattered vegetation (Lindroth, 1986). In the daytime it remains buried in the sand at the roots of plants. The revegetated plots might have acted as a vegetation island for this beetle, offering better shelter. However, higher numbers of ground beetle larvae on the ameliorated plots indicated increased breeding and not merely a short-term preference by individual beetles.

Species commonly found in fields and ruderal sites seemed to depend much more on the revegetated plots and to avoid the open control plot, where characteristic beetles of open sandy sites were still caught in considerable numbers (Figure 4). In the case of the former, the improved microclimate in the dense grass stands with more litter and larger populations of prey might have been the main attraction encouraging immigration.

Evidence in the literature of an increase in beetle numbers as result of higher prey density is inconclusive. In contrast to Speight and Lawton (1976), both Basedow (1994) and Purvis and Curry (1984) have reported no change in beetle numbers despite an increase in the abundance of potential prey. On reclaimed sites with acidic nutrient-poor sandy soils, the numbers of Collembola and other prey are rather low in the first years after reclamation (Dunger 1989, 1998a). Many of the beetles on the study site belonged to the tribes Harpalini and Amarini. Both are known to be mixed feeders and to include a higher proportion of seeds and plant material in their food compared to other ground beetles (Hengeveld, 1980; Goldschmidt and Toft, 1997). Thus the revegetation might have directly provided them with an additional food source.

The development of the fauna in the second year showed a decrease in characteristic ground beetles of open sandy sites and an increase in beetles typical of dry grasslands and ruderal sites on the plots with high vegetation cover. This could be seen as the start of the retreat of pioneer species found in open, disturbed habitats and the replacement by species of a later successional phase. Mader (1986) and Dunger (1998b) have described a sequence of stages in the succession of ground beetle communities on mine spoil.

In the present study, the application of organic waste led to a greater increase in the abundance of potentially beneficial ground beetle populations on revegetated poor sandy soils as opposed to treatment with mineral fertilizer. Therefore, based on this fairly limited study, treatment with organic waste could be recommended for reclamation purposes. Afforestation of the site did not affect the ground beetle community in this early stage of development, but will almost certainly change its structure considerably within a few years (Kielhorn et al., 1998). In terms of conservation, revegetation leads ultimately to a loss in habitats for endangered beetles typical of open sandy sites (Mader, 1986; Trautner et al., 1997).

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