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GROUND BEETLE ASSEMBLAGES (COLEOPTERA, CARABIDAE) IN A DRIFT SAND AREA SYSTEM IN EASTERN LOWER AUSTRIA

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Abstract — The ground beetle (Coleoptera, Carabidae) assemblage at four different sites in a 1 ha-sized post-glacial sand dune area near the March River in Lower Austria on the Slovakian border was sampled by pitfall trapping. After removal of topsoil in the investigation area in 2004, 33 ground beetle species represented by 838 individuals were trapped during a period of seven months. Remarkable species such as *Harpalus flavescens* (new to Austria) and *H. picipennis, H. politus, Cryptophonus melancholicus,* and *Masoreus wetterhalli* (very rare in Austria) were recorded. Generally, the majority of carabid beetles in this area are xerophilous and psammophilous with a high dispersal power, which is typical of early successional stages. These four sites are dissimilar regarding species composition, dominance structure, diversity, and evenness, presumably due to different soil types and vegetation.

Key words: Ground beetles (Coleoptera: Carabidae), drift sand, open sand habitats, succession, Lower Austria, Drösing

INTRODUCTION

Drifting sand areas and sand dunes are among the most threatened habitats in Central Europe. Reforestation and intensive agriculture lead to deterioration and violent reduction of these areas.

The drifting sand areas of Lower Austria are located between the city limits of Vienna and the March River south of the village Drösing. These sand dune areas cover only small parts of a belt east of the March River in Slovakia, which is about 40 km in length. In fact they have a total size of about 25 to 30 km^2 (Wiesbauer and Mazzucco, 2002). This special kind of ecosystem is unique for Austria and only sand dunes along the eastern border of Lake Neusiedl in Eastern Austria are comparable, although 70% of the carabid community and the vegetation cover are different (Agnezy, 2003).

The dune areas in Lower Austria were formed during and after the last ice-age (from 35,000 to 10,000 years ago). Harsh climate, low cover of vegetation, and vast deposition of fine sediments along rivers were important for this process (Küster 1995). When rivers run low with water, shelf and sand are split and dried up; as a consequence, wind can transport fine-grained material over wide ranges and deposit it as dunes. About 10,000 years ago, the climate improved in Central Europe – it became warmer and wetter. The natural cover therefore increased, drifting sands were gradually overgrown with forests, and consequently the mobility of the dunes was limited and the sand became stable (Wiesbauer and Mazzucco, 2002).

The drifting sand was stabilized by the cover of vegetation for thousands of years until man cleared forests beginning in the Neolithic period. In the 11th and 12th centuries, the population density greatly increased in the March Valley, and new farm and pasture land had to be gained. Fields were formed at the expense of woodlands. However, the soils of these arable fields were highly at risk of eolian erosion, wind removed the topsoil and uncovered the sand, and the dunes were mobilized again. Because of that, fields yielded more and more poorly, and man started to afforest the dune areas to stabilize the sand at the end of the 18th century. At the beginning of the 20th century, large parts of these areas were afforested (Wiesbauer and Mazzucco, 2002).

Recently, only small patches of sand lawn areas are left, owing to the above-mentioned reasons (Wiesbauer and Mazzucco, 1997). One of these patches is a field of about 5 ha called "In den Sandbergen" near the township of Drösing, and it served as the investigation area in the present work. Although different vegetational and faunistic research has been carried out in this area over the last few years (Wiesbauer and Mazzucco, 1997; Wiesbauer and Mazzucco, 1999; Kohla, 2001; Zolda, 2001; Wiesbauer, 2002), ground beetles have not yet been investigated. In this paper, a survey of the ground beetle (Coleoptera, Carabidae) fauna is presented. Carabid beetles are one of the best examined beetle taxa, and their ecological requirements as well as their distribution in Europe are well known (e.g., Koch, 1989; Trautner and Geigenmüller, 1987; Müller-Motzfeld, 2004; Hurka, 1996). Moreover, they are often used as an indicator group for site assessment in nature conservation (Thiele, 1977). Only a few works have dealt with Carabidae in open sand or sand lawn areas in Austria (Mitter, 1991; Agnezy, 2003), but more studies were performed in Germany, Slovakia, Belgium, and the Netherlands (Majzlan and Rychlík, 1993; Vermeulen, 1994; Falke and Assmann, 1997; Schüle, 1997; Majzlan and Rychlík, 1999; Schwarzwälder, 2004).

The purpose of this study was to survey the ground beetle fauna and compare species composition, species richness, abundance, diversity, and similarity of carabid communities at four different investigation sites "In den Sandbergen". In addition to this, ecological attributes such as ecological valence and preference as well as flight ability of the detected Carabidae are discussed. Finally, aspects of nature conservation and management methods for preserving the investigation site are considered.

MATERIAL AND METHODS

Area of research

The investigation area is located "In den Sandbergen" near the township of Drösing in the northeastern part of Lower Austria (geographical position: N 48°31', E 16° 55', 158 m above sea level). The district around Drösing contains a former dune region with a size of about 20 ha (Wiesbauer and Mazzucco 2002). This area is afforested with Scotch pine (*Pinus sylvestris*), except for a clearing of about 5 ha, which served as the study area (Fig. 1A). The mean annual temperature is 9°C, the mean temperature in July is above 20°C, and mean annual precipitation is 540-600 mm (Steinhauser, 1952; Cepuder et al., 1998; http://www.droesing.at/).

Fig. 1. A - Investigation area with completely open sand dune character after topsoil removal in 2003 (photo by K. Kugler). B - Investigation area after sowing with gray hairgrass (*Corynephorus canescens*) in 2004, by 2007 transformed into a sandy steppe ecosystem (photo by W. Waitzbauer).

The dune land in Lower Austria has a sub-Pannonic climate with hot summers, cold winters, and low annual precipitation (540-600 mm per year on the average) (Steinhauser, 1952; Wendelberger, 1964; Hadatsch et al., 2000).

The dunes of Drösing are based on post-glacial drifting sand. The mean grain size is between 0.63 and 0.2 mm; the pH-value is 4.7 (Wiesbauer and Mazzucco, 1999). The sand lies on terraces with Quaternary rubble as well as traces of loess, and it is covered by para-chernozem soil (Wendelberger, 1964; Hadatsch et al. 2000).

The typical plant community of the moderately to highly acidic soil is the "Marchtaler Silbergrasflur" community (*Thymo angustifolii-Corynephoretum*). These anciently widespread gray hairgrass (*Corynephorus canescens*) meadows disappeared because of successive afforestation beginning approximately in the year 1920. In Austria, this special plant association can only be found in small patches in the March and Thaya Valleys (Wiesbauer and Mazzucco, 2002). Besides *Corynephorus canescens*, the plant communities in these acidic sand areas are characterized by some rare species as *Filago vulgaris* Lam. (Asteraceae), *Herniaria glabra* L. (Illecebraceae), *Spergula morisonii* Bor. (Caryophyllaceae), *Thymus serpyllum* L. (Lamiaceae), and *Viola tricolor* ssp. *curtisii*.

In 1993 the topsoil of the above-mentioned clearing was removed, and the typical gray hairgrass meadow could therefore take root again. However, this plant association was destroyed once more by reforestation. In May 2003 the area was stubbed, and in autumn of the same year the topsoil was partly removed for the second time (Wiesbauer, 2004). Extensive sowing of *Corynephorus* seeds and of other autochthonous species changed the situation of vegetation cover and diversity greatly within a few years. Now, five years after restoration, the area is densely covered again with gray hairgrass (Fig. 1B).

The present work discusses the resettlement of carabid beetles in this newly created dune habitat. Four study sites were selected (for descriptive sketches of the investigation area, see Figs. 2 and 3):

• The top edge of the acclivity (trap row or habitat A), covered with ruderal vegetation

• The bottom of the acclivity (trap row or habitat Aa), covered with ruderal vegetation

• The wind exposed free sand area (trap row or habitat B), without any vegetation

• The adjacent area pastured by sheep (trap row or habitat D), an extremely disturbed parachernozem soil area, covered only with scarce wood small-reed (*Calamagrostis epigejos*).

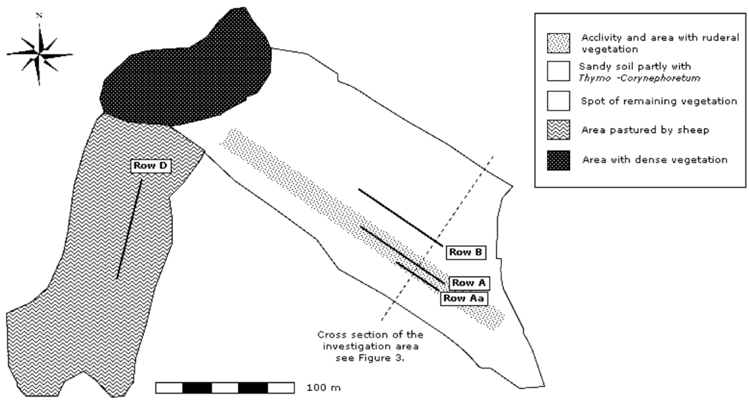

Fig. 2. Investigation area at Drösing, Lower Austria.

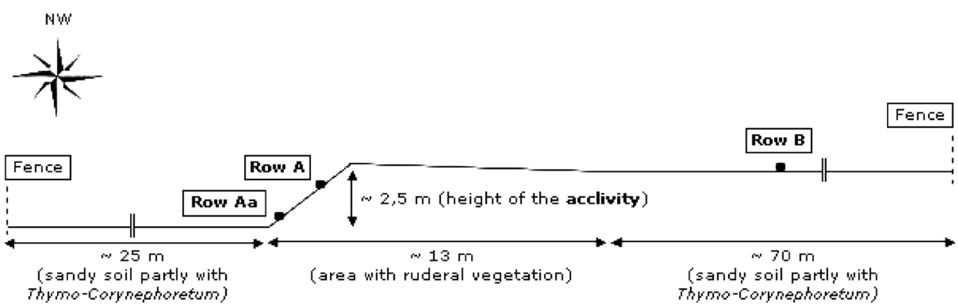

Fig. 3. Sketch of investigation area. For explanations of abbreviations, see text.

Additional habitat investigations

Four commercially available thermometers detecting minimum and maximum temperature were installed in the investigation area as follows: three thermometers at the bottom of the acclivity (habitat Aa), one of which was hidden under a small white table (dimensions: 35 x 20 x 15 cm) in order to avoid direct solar irradiation, one was positioned on the soil without any protection, and one was buried in the sand to a depth of 20 cm. The last thermometer was installed at a spot of remaining vegetation shaded by a young pine. Additionally, one ombrometer (based on the model of Prof. Hellmann) and one anemometer (Lambrecht, type 1440) were also positioned at this spot of remaining vegetation; a second anemometer was installed at the bottom of the acclivity. The reading of each gauge was taken every time the traps were emptied. In addition, the temperature of the soil surface and that of soil at depths of 5 and 10 cm were measured with a temperature sensor (Testo 635) at every study site (except site A) each time the traps were emptied.

Period of investigation and method of trapping

Arthropods were sampled by means of pitfall traps. All traps were plastic jars (top brim diameter of 6.5 cm, height of 10 cm), which were covered with white round plastic lids (diameter of 10 cm). The lids were situated about three centimeters above the jar to protect the trap from evaporation and rain. The traps contained ethylene glycol, which was diluted with water in a ratio 1 to 1.

Twenty-five traps were installed in four rows with a distance of five meters between two traps in each row: 10 in the free sand area (B), 10 at the top edge of the acclivity (A), and five at its bottom (Aa). The acclivity is an accumulation of the topsoil removed at the beginning of the investigation period.

The period of investigation began on 31 March 2004 and lasted till 26 October 2004. The traps were emptied in a 10 to 14 day rhythm.

Identification of Carabidae

Nearly all Carabidae were identified using Trautner and Geigenmüller (1987) and Müller-Motzfeld (2004). Wolfgang Paill (Ökoteam Graz) identified all species of *Amara* and *Trechus,* while Srećko Ćurčić examined and determined many *Harpalus* species. The nomenclature of species follows Hurka (1996).

Data analyses

Beetle communities are qualitatively described with the species present and their biological and ecological characteristics on the one hand. On the other hand, community structure parameters such as species richness or species abundance measured by means of different indices give quantitative information about the community. Analysis of pitfall captures allows comparisons between diverse species composition at different study sites. Dominance, diversity, and similarity of these communities were calculated and evaluated as important ecological indices.

Dominance

Dominance describes the relative abundance of one species in comparison to all other species living in the same biocoenosis (Mühlenberg, 1993). This index ranges from 0, where all taxa are equally present, to 1, where one species dominates the community completely (Hammer et al., 2001).

Abundance

The Berger-Parker index, an index of abundance, expresses the relative abundance of the dominant species (Southwood, 1978); since it measures inverse dominance, the more dominant the most abundant species, the lower the index.

Species abundance plots

Species abundance plots or species abundance curves can be used as an empirical description of a sample from a community (Krebs, 1998) by plotting relative abundance of species on a logarithmic scale against their rank in abundance, arrayed from commonest to rarest.

Diversity

Species richness is the simplest measure of diversity of a biocoenosis; it is the count of the number of different species in a given area. Diversity indices relate the number of species to the number of individuals of each species.

In this work the Shannon-Weiner function is used (Magurran, 1988).

Evenness

Evenness measures the similarity of abundances of different species in a group or community. The index expresses the ratio of observed diversity to the maximum diversity that could possibly occur (Mühlenberg, 1993). One of the most often used diversity indices for calculating an evenness index is Shannon's index of diversity, expressed after Magurran (1988).

Similarity indices

Although there are many measures of similarity available, only four indices are calculated in this work: the coefficient of Jaccard, the coefficient of Sørensen, the Renkonen index, and Morisita's index of similarity.

The Jaccard coefficient is a binary similarity coefficient and used when only presence/absence data are available for the species in a community. The index can be calculated using the following formula (Krebs, 1998).

The Sørensen coefficient is very similar to that of Jaccard, but it weights matches in species composition between two samples more heavily than mismatches (Krebs, 1998).

The Renkonen index or the measure of percentage similarity is a quantitative similarity coefficient and requires the measure of relative abundance of each species in the community. It is expressed as follows (Krebs, 1998).

Morisita's index of similarity is calculated according to Krebs (1998). This index varies from 0 to 1.0 – from no similarity to complete similarity.

Hierarchical cluster analysis was applied to demonstrate similarities between the four habitats observed. Morisita's index of abundance data and single linkage grouping strategy were chosen. To make comparison possible, only data as of July 1 were used. This statistical analysis was carried out using the PAST program, version 1.42 (Hammer et al., 2001).

Species richness - Rarefaction

The rarefaction method offers the possibility of comparing community samples based on different sample sizes. This method standardizes all samples from different communities to a common sample size with the same number of individuals, since a greater sampling effort would yield a larger sample and therefore more species. Thus, comparison of different communities with respect to species richness – the number of species in the single communities – is possible. The rarefaction algorithm reads as follows (Krebs, 1998).

Biology and ecology of Carabidae

Ecological valences based on habitat choice of Carabidae were taken from Koch (1989), Marggi (1992), Hurka (1996), and Müller-Motzfeld (2004). Ground beetles were classified according to their wing morphology into three groups using data from Hurka (1996) to estimate their colonization ability: macropterous species and species observed in flight; dimorphic or polymorphic species; and brachypterous, micropterous, or apterous species (m, di, and b, respectively).

Red Lists

Species found at an investigation site and mentioned in The Red List of Threatened Species may help to assess this site's faunistic value and importance for nature conservation. Since the Austrian Red List of Coleoptera is more than 10 years old (Jäch et al., 1994), the Red List of Slovakia (Holecová and Franc, 2001) and Red List of Bavaria (Lorenz, 2003) were consulted.

RESULTS

Additional habitat investigations

Precipitation

Measured precipitation measurement in the investigation period had two peaks - one in late spring/early summer and one in autumn. In total, nearly 300 mm precipitation was recorded.

Temperature

Temperature measurements were conducted at each site investigated. Comparison between temperatures at the soil surface and in soil at a depth of 5 or 10 cm

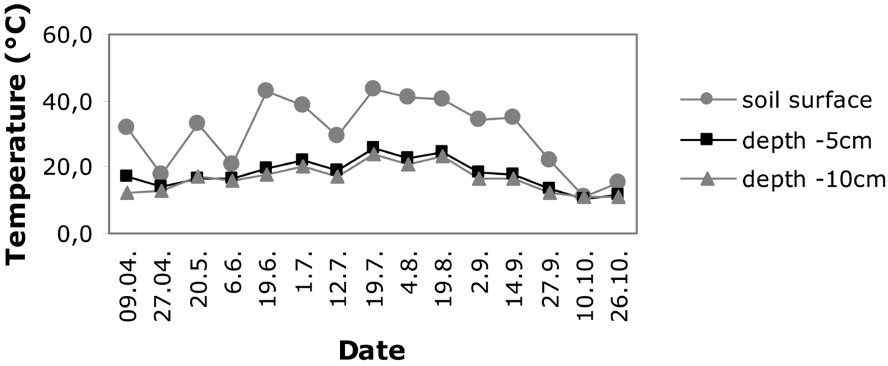

Fig. 4. Temperature measurements in habitat Aa. Temperature gauged at soil surface and at depths of 5 cm and 10 cm. All measurements took place around noon.

shows that fluctuation was already balanced even at a shallow depth. In contrast, temperatures at the soil surface fluctuated greatly. For example, the sandy soil was warmed to a maximum temperature of 43°C on a sunny day in June (Fig. 4). But its temperature values did not differ much from those measured in deeper soil on a cloudy day in April or October.

Ecological indices

Dominance

Habitat A shows the highest dominance index, with 0.48 or 0.55 when only data of July 1 are used to make a comparison between all four sites. *Pseudophonus rufipes* is the species occurring with the highest number of individuals by far in this area (68% or 73% when the investigation period is shortened). In contrast, habitat Aa has the most balanced ground beetle community composition, with a dominance index of only 0.25 or 0.29. This conspicuous difference is interesting because the two habitats are situated close to each other. Obviously, proximity to the open sand area at the bottom of the acclivity abets this balanced community composition.

Abundance

The highest value of the Berger-Parker index (0.68 or 0.73) is exhibited by habitat A, since only one eudominant species occurs, as mentioned before. The remaining ground beetle communities show a value of around 0.45 in each case.

Diversity

When considering the whole as well as the shortened investigation period, the Shannon-Weiner diversity index has its highest values in habitat Aa (H'=1.98 or 1.73). It is followed by habitat D, with an index value of 1.39. The habitat with the least diverse ground beetle community is area B (H'=1.32) or habitat A (H'=1.15) (when only half of the investigation period is taken into account).

Table 1. Ecological indices of the carabid communities at the four study sites. Numbers of species and individuals are given as integers. Data of total investigation period as well as data as of July 1 2004 are presented.

Habitat	A	Aa	B	D
		Total investigation period		
No. Taxa	21	24	10	8
No. Individuals	266	268	258	41
Dominance D	0.484	0.247	0.338	0.334
Berger-Parker	0.684	0.444	0.457	0.439
Shannon H’	1.358	1.984	1.320	1.386
Evenness	0.446	0.624	0.573	0.667
		Research as of 01/07/2004		
No. Taxa	19	18	9	8
No. Individuals	248	242	255	41
Dominance D	0.553	0.294	0.341	0.334
Berger-Parker	0.734	0.448	0.463	0.439
Shannon H’	1.152	1.732	1.301	1.386
Evenness	0.391	0.599	0.592	0.667

Evenness and Similarity

The carabid cenosis in habitat D shows the most equal distribution (0.67), followed by the community in habitat Aa (0.62). The most unequal distribution can be found in habitat A, with an index of 0.45. The ground beetle communities in habitats A and Aa show the highest similarity (68.6%), followed by the cenoses in habitats A and D (43.8%). Habitats Aa and B accommodate 19.4% mutual species.

A summary of the indices mentioned above is given in Table 1. A dendrogram based on cluster analyses illustrates the comparison graphically (Fig. 5).

The Carabid fauna in Drösing

In total 838 individuals of 33 species from 11 genera were found (see Appendix). In this study *Amara* and *Harpalus* are the most abundant genera. The most numerous forms are the rather large-sized and eurytopic *Pseudoophonus rufipes* and the species *Harpalus flavescens*. These two species make up more than half (57%) of the total ground beetle fauna.

Pseudoophonus rufipes is very common in Europe and prefers dry to moderately moist, unshaded habitats like fields, meadows, or ruderals. This species is macropterous and when observed in flight it can thus easily disperse (Hurka, 1996).

The eurytopic and macropterous species *Harpalus flavescens* is an extremely xero- and psammophilous species that prefers loose and nearly sterile sand and is therefore a typical pioneer in open sand habitats. This ground beetle in Europe is rare and sporadic except in large sandy areas of Eastern Germany. According to Müller-Motzfeld (2004), *Harpalus flavescens* has not been found in Austria so far.

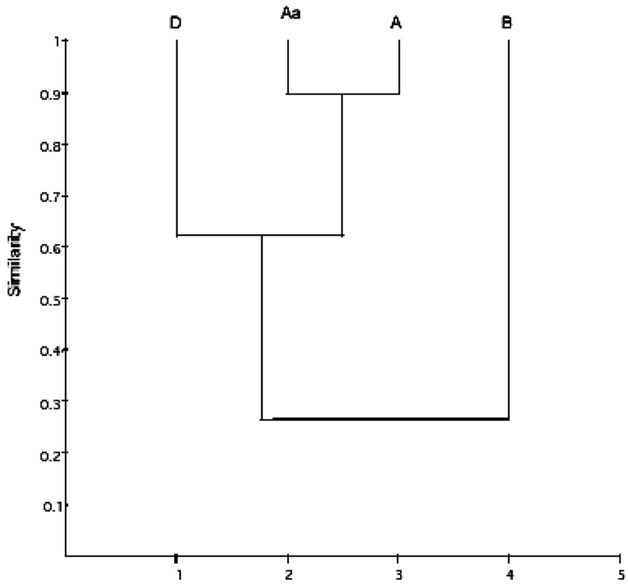

Fig. 5. Dendrogram of all habitats under investigation, based on Morisita's index of similarity. Only data as of July 1 2004 are used.

Nearly all species are eurytopic except for the recedent taxa *Masoreus wetterhalli* and *Harpalus picipennis*, as well as the sporadic *Cryptophonus melancholicus*. These species are stenotopic. *Masoreus wetterhalli* and *Harpalus picipennis* prefer dry to very dry, unshaded habitats like steppes and sand dunes, *Harpalus picipennis* being found almost exclusively on sandy soils. Both of them are xerophilous. *Cryptophonus melancholicus* also occurs in very dry, unshaded habitats like sandy grassland or inland dunes and is very rare in Austria (Hurka, 1996).

Most of the carabid beetles found are xerophilous and/or psammophilous or at least campicolous, except for *Carabus coriaceus* and *Pterostichus anthracinus*. They have completely different habitat requirements, *Carabus coriaces* being common in forests and *Pterostichus anthracinus* prefering damp habitats (Hurka, 1996). They both can be assumed to be vagrants, since only one individual was found in each case. A detailed record is given in Appendix I.

Comparison of investigation areas

We recorded 266 individuals belonging to 21 species in habitat A, 268 individuals of 24 species in habitat Aa, 258 individuals of 10 species in habitat B, and 41 individuals of eight species in habitat D. Five additional individuals (one *Amara fulva*, one *Harpalus froelichi*, one *Masoreus wetterhalli*, and two individuals of *Pseudoophonus rufipes*) were identified, but could not be allocated to any of these habitats; they are therefore not incorporated in comparisons of investigation areas or used in calculation of indices.

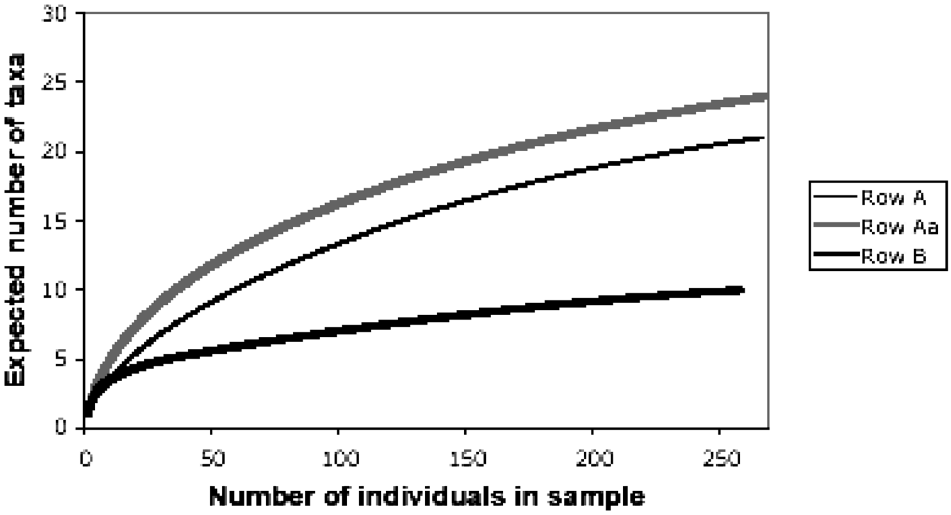

Fig. 6. Rarefaction curves for ground beetle communities of the three habitats A, Aa, and B. Data for total investigation period.

Rarefaction curves for these four ground beetle communities (Fig. 6) indicate that habitat Aa contains slightly more species than habitat A and many more than habitat B. The curve progressions of habitats A and Aa are very similar due to their short distance apart along the acclivity. These curves are rising and do not yet reach a flat progression, which means that the carabid community has not been recorded completely. The open sand area (habitat B) has much lower species richness and a flatter curve progression – apparently, this ground beetle cenosis was recorded more completely.

Structure of carabid cenoses

The four investigation areas differ with respect to dominance structures of their carabid communities. Nevertheless, habitats A and Aa are quite similar in species composition and dominance structures. In both habitats, *Pseudoophonus rufipes* is eudominant, *Harpalus froelichi* dominant, and *Harpalus tardus* subdominant. The other subdominant species (*Harpalus rufipalpis* in habitat A and *Harpalus flavescens*, *Harpalus picipennis*, and *Harpalus autumnalis* in habitat Aa) differ, occuring in both areas, though not in the same class of dominance. A relatively high number of recedent species (three in habitat A versus five in habitat Aa) and a high number of subrecedent species (14 versus 13) are present in both habitats. However, *Pseudoophonus rufipes* represents 68% of all individuals in habitat A, but only 44% in habitat Aa. Habitat A is characterized by high abundance of one eudominant species, by few dominant and subdominant taxa, and by many conductive species.

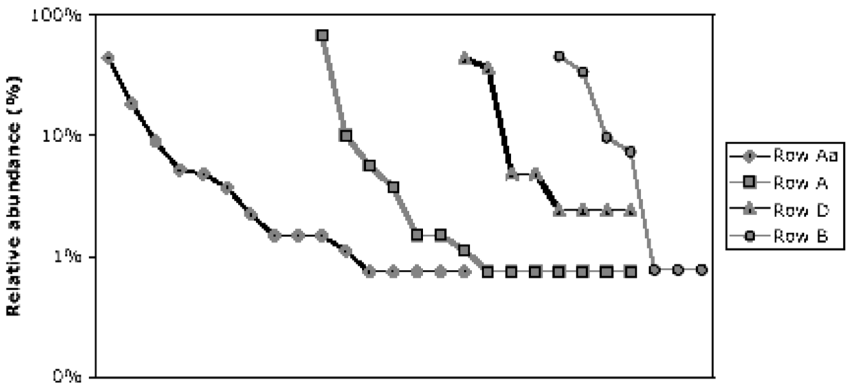

Fig. 7. Species abundance curves for ground beetle cenoses of all four habitats A, Aa, B, and D. Data for total investigation period.

The species abundance curve is therefore steeper than the one resulting from data collected in habitat Aa (see Fig. 7).

The open sand habitat (B) differs greatly from the two habitats on the acclivity in both dominance structure and species composition. The main species, *Harpalus flavescens* and *Cicindela hybrida* (eudominant; 46 and 34%) as well as *Pseudoophonus rufipes* and *Amara fulva* (subdominant; 10 and 7%), are fairly different from those found in habitats A and Aa. Additionally, habitat B exhibits relative species-poorness and a steep species abundance curve; the indicated two eudominant species make up more than three quarters of the total abundance, and dominant as well as recedent species are missing. Specialists on sandy soil like *Harpalus picipennis* or *Cryptophonus melancholicus*, which occur on the acclivity, are absent in habitat B. *Masoreus wetterhalli*, an important species in steppes, appears only subrecedently.

All data for the first half of the study period are missing in the case of habitat D; for this reason, only a few individuals (41) belonging to a small number of species (eight) were recorded.

The stenotopic species *Masoreus wetterhalli* in particular and the hemerophilous species *Pseudoophonus rufipes* together nevertheless make up 80% of the total ground beetle catch in this area. Apparently, *Masoreus wetterhalli* has found an adequate habitat there. The remaining species appear with low frequency (only one or two individuals per species). Table 2 gives summary of carabid communities and their structures of dominance.

Biology and ecology of Carabidae

Ecological valence

The vast majority (>87%) of ground beetle species in every habitat observed are eurytopic. As mentioned before, only three stenotopic species occur in the whole investigation area, all three of them appearing in habitat Aa. Only one stenotopic

Table 2. Comparison of carabid cenosis of investigation areas: dominance structures, number of individuals (Ind.), and relative abundance (Rel. Abund.). Classification of classes of dominance according to Engelmann (1978). If available, grades of threats as quoted in the Red Lists of Coleoptera of Bavaria (Lorenz 2003) are mentioned: Species*...endangered; Species** ...vulnerable; Species***…near threatened.

Habitat A		
Species	**Ind.**	**Rel. Abund.**
eudominant (32-100%)		
Pseudoophonus rufipes	182	68.42%
dominant (10-31.9%)		
Harpalus froelichi**	27	10.15%
subdominant (3.2-9.9%)		
Harpalus tardus	15	5.64%
*Harpalus rufipalpis****	10	3.76%
recedent (1-3.1%)		
*Amara consularis****	4	1.50%
Harpalus autumnalis	4	1.50%
Amara similata	3	1.13%
subrecedent (0.32-0.99%)		
*Amara apricaria****	2	0.75%
Harpalus affinis	2	0.75%
Harpalus flavicornis	2	0.75%
Harpalus picipennis**	2	0.75%
Harpalus politus	2	0.75%
Harpalus serripes**	2	0.75%
*Pseudoophonus griseus****	2	0.75%
Amara bifrons	1	0.38%
Carabus coriaceus	1	0.38%
Cicindela hybrida	1	0.38%
Harpalus flavescens*	1	0.38%
Harpalus pumilus**	1	0.38%
Ophonus azureus	1	0.38%
Poecilus cupreus	1	0.38%

Habitat Aa		
Species	**Ind.**	**Rel. Abund.**
eudominant (32-100%)		
Pseudoophonus rufipes	119	44.40%
dominant (10-31.9%)		
Harpalus froelichi**	49	18.28%
subdominant (3.2-9.9%)		
Harpalus flavescens*	24	8.96%
Harpalus picipennis**	14	5.22%
Harpalus autumnalis**	13	4.85%
Harpalus tardus	10	3.73%
recedent (1-3.1%)		
*Harpalus rufipalpis****	6	2.24%
*Amara consularis****	4	1.49%
Amara similata	4	1.49%
Harpalus pumilus**	4	1.49%
Amara fulva	3	1.12%
subrecedent (0.32-0.99%)		
Amara bifrons	2	0.75%
Cicindela hybrida	2	0.75%
*Cryptophonus melancholicus***	2	0.75%
Ophonus azureus	2	0.75%
*Pseudoophonus griseus****	2	0.75%
*Amara apricaria****	1	0.37%
Harpalus politus	1	0.37%
Harpalus rubripes	1	0.37%
Harpalus serripes**	1	0.37%
Harpalus servus	1	0.37%
Harpalus tenebrosus	1	0.37%
Masoreus wetterhalli**	1	0.37%
*Ophonus puncticeps****	1	0.37%

Habitat B		
Species	**Ind.**	**Rel. Abund.**
eudominant (32-100%)		
Harpalus flavescens*	118	45.74%
Cicindela hybrida	87	33.72%
subdominant (3.2-9.9%)		
Amara fulva	25	9.69%
Pseudoophonus rufipes	19	7.36%
subrecedent (0.32-0.99%)		
*Amara apricaria****	2	0.78%
*Harpalus smaragdinus****	2	0.78%
Masoreus wetterhalli**	2	0.78%
Amara familiaris	1	0.39%
Harpalus affinis	1	0.39%
Pterostichus anthracinus	1	0.39%

Habitat D		
Species	**Ind.**	**Rel. Abund.**
eudominant (32-100%)		
Masoreus wetterhalli**	18	43.90%
Pseudoophonus rufipes	15	36.59%
subdominant (3.2-9.9%)		
Harpalus tardus	2	4.88%
Harpalus signaticornis	2	4.88%
recedent (1-3.1%)		
*Amara consularis****	1	2.44%
Poecilus cupreus	1	2.44%
*Pseudoophonus griseus****	1	2.44%
Trechus quadristriatus	1	2.44%

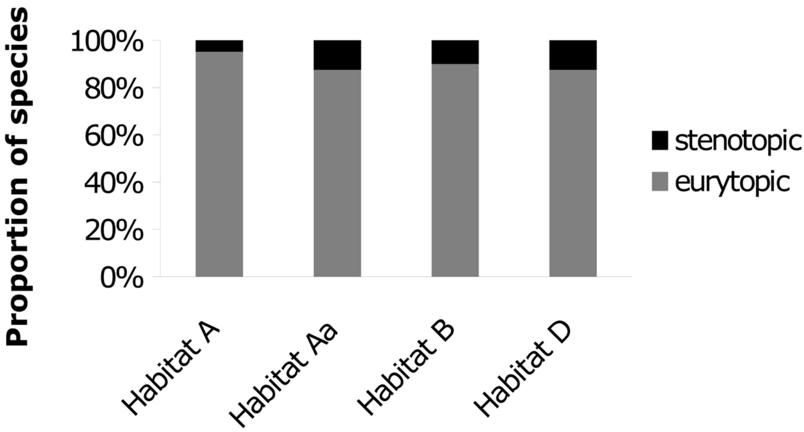

Fig. 7. Species abundance curves for ground beetle cenoses of all four habitats A, Aa, B, and D. Data for total investigation period.

species was found in each remaining habitat: *Harpalus picipennis* in habitat A and *Masoreus wetterhalli* in habitats B and D. A graphic illustration is given in Fig. 8.

Ecological preference

As shown in Fig. 9, the vast majority of carabid species are xerophilous and/or psammophilous in each habitat (85.71% in habitat A, 95.83% in habitat Aa, 90% in habitat B, and 75% in habitat D). Species with other ecological preferences are very rare: *Carabus coriaceus*, *Pterostichus anthracinus*, and *Trechus quadristriatus* are represented by one individual each, *Poecilus cupreus* by two individuals.

Wing morphology

Macropterous ground beetle species are represented by a large number in every habitat. Carabidae found in habitat D are exclusively macropterous. The dimorphic species *Pterosticus anthracinus* occurred only in area B. *Harpalus autumnalis* and *Ophonus azureus*, which are also dimorphic, could be found in habitats A and Aa with representation of 9.52 and 8.33%, respectively. The brachypterous species *Harpalus picipennis* and *Harpalus pumilus* are represented with a proportion of 8.33% in area Aa. Together with *Harpalus flavicornis* and *Carabus coriaceus*, they make up 19.05% of the ground beetle catch in habitat A.

Red Lists

Species found in Drösing were not mentioned in either the Red List of Coleoptera of Austria (Jäch, et al., 1994) or the Red List of Coleoptera of Slovakia (Holecová and Franc, 2001). However, 14 out of 33 carabid species found in the whole investigation area appear in the Bavarian Red List (Lorenz, 2003): *Harpalus flavescens* and *Cryptophonus melancholicus* are mentioned in the category “endangered”, six species are mentioned in the category “vulnerable” (*Harpalus autumnalis, H. froelichi, H.*

picipennis, H. pumilus, H. serripes, and *Masoreus wetterhalli*), and six species are mentioned in the category "near threatened" (*Amara apricaria, A. consularis, Pseudoophonus griseus, Harpalus rufipalpis, H. smaragdinus,* and *Ophonus puncticeps*). Four different geographical classifications of natural landscapes are distinguished in Bavaria in the context of the Red List (Voith, 2003). However, only the grades of threat in the region "Schichtstufenland" are cited in the present work because this region has several xerothermic sites that are similar to the area observed herein.

The four habitats observed "In den Sandbergen" have different numbers of Red List species: eight such carabid species were found at the top of the acclivity (site A), 10 at its bottom (Aa), five in the open sand area (B), and just three in the adjacent area pastured by sheep (D). For details, see Table 2.

DISCUSSION

The Carabid fauna in Drösing – Species composition

The occurrence of xerophilous and/or specialized psammophilous carabid species such as *Harpalus froelichi, H. flavescens, Masoreus wetterhalli, Cicindela hybrida*, and *Amara fulva* characterizes the investigation area.

Already in the first year of succession after removal of the soil surface, typical inhabitants of open sand areas and species of *Corynephoretum* could become established. According to Tietze (1973), *Harpalus picipennis, H. servus, H. flavescens, Amara fulva*, and *Masoreus wetterhalli* belong to a carabid cenosis charasteristic of sand pioneer grasslands. Majzlan and Rychlík (1999) cite *Harpalus picipennis* and *H. froelichi* as typical indicator species of sandy and warm habitats in the south of Slovakia. *Amara fulva, Harpalus autumnalis, H. flavescens*, and *H. smaragdinus* are considered pioneer species after (Plachter, 1985). Nevertheless, some xerophilous and typical species found on sandy soils in Austria or Germany are missing, for example: *Calathus fuscipes, C. erratus, C. melanocepalus, C. ambiguus,* and *Harpalus distinguendus* (Tietze, 1973; Bernhardt and Handke, 1989; Handke, 1995; Falke and Assmann, 2001; Agnezy, 2003; Schwarzwälder, 2004); and *Panagaeus bipustulatus* (Majzlan and Rychlík, 1999; Falke and Assmann, 2001; Agnezy, 2003; Schwarzwälder, 2004). The work of Agnezy (2003) in the "Neusiedlersee – Seewinkel" National Park is the only comparable examination of carabid beetles in open sand areas in Austria. Although these investigation areas differ in their plant communities, soil composition, and the proportions of open sandy soils, the most abundant specialized ground beetle species detected there can also be found in Drösing. Only the above-mentioned species of the genus *Calathus* and some halophilous species are missing. In Bavaria, Schwarzwälder (2004) discovered a continuous increase in the number of thermophilous, rare, and stenotopic ground beetle species with no increase in total number of species over the years of succession. It follows that the investigation area has unquestionable potential for future colonization by carabid species, and successional studies would certainly be interesting and appreciated.

Other Carabidae, especially those now still inhabiting adjacent sandy paths and sandpits, might migrate to the study area in the future.

Comparison of different carabid cenoses in Drösing

The investigation site at the top of the acclivity (site A) is characterized by a high dominance index, low diversity, and low evenness, attrubutes consistent with typical early successional stages (Southwood et al., 1979; Hejkal, 1985; Molles, 1999; Brändle et al., 2000). By far the most abundant species is *Pseudoophonus rufipes,* a hemerophilous ground beetle. The recedent *Amara consularis* and subrecedent *Amara apricaria, Harpalus picipennis, Pseudoophonus griseus*, and *Harpalus flavescens* are species characteristic of sand pioneer swards or (semi-) dry meadows (Tietze, 1973). The carabid fauna of site A is in keeping with its ruderal vegetation, with several eurytopic xerophilous species and some typical sand species. It should be noted that eight taxa found at site A are mentioned in the Red List of Bavaria, and the acclivity accommodates species not detected in the adjacent open sand area (habitat B). Apparently, some factors different at site B (vegetation cover, slope, or soil composition) contribute to the fact that certain species prefer the acclivity to the exposed open sandy soils. The acclivity, at first glance only a ruderal site, still appears to be a valuable habitat due to the presence *Harpalus polites*, which is very rare in Austria and which was found only here.

Investigation site Aa, the bottom of the acclivity, is only one and a half meters below habitat A, and the two cenoses are therefore very similar. Nevertheless, unlike site A, habitat Aa shows the highest diversity and the most balanced ground beetle community composition of all sites examined. This is certainly due to nearness of an open sand area similar to investigated site B at the bottom of the acclivity, but not so exposed to the influence of wind. This nearness may lead to the immigration of species that mainly prefer open habitats into an area covered with vegetation but with similar soil – an ecotope rich in species, as it includes species from both communities and is characterized by a plurality of environmental conditions on a small space (Kratochwil and Schwabe, 2001; Magura, 2002; Nentwig et al., 2004). The fact that nearly 20% of species were found in both habitats Aa and B also supports this thesis. In contrast, sites A and B do not even accommodate 10% shared species because habitat A is situated at a greater distance from open sandy soils than site Aa. Seven species characteristic of sandy pioneer grasslands or (semi-) dry meadows (Tietze, 1973) were detected at the bottom of the acclivity.

As many as 10 species found at site Aa are mentioned in the Red List of Bavaria. For all these reasons, this habitat can be regarded as very valuable.

Certainly the most interesting investigation site is habitat B, the open sand area. Five species (half of all species detected at this site) – among others including *Harpalus flavescens*, whose occurrence could not be proved so far in Austria (Müller-Motzfeld, 2004) are “indicator species” of sandy pioneer swards or steppes (Tietze, 1973). Four species are mentioned in the Bavarian Red List.

Although data were gathered throughout the whole vegetation period, less than half the number of species detected on the acclivity (sites A and Aa) could be found in the open sand area. Considering the rarefaction curve for the ground beetle community at habitat B, we can assume that the cenosis was recorded more or less completely, so species richness is in fact rather low there. Extreme environmental conditions on bare sandy soils (aridity, high temperatures, and intense solar irradiation), and absence of vegetation lead to low species richness and high densities of well-adapted species (Kratochwil and Schwabe, 2001). The carabid community at site B shows little diversity, which is typical of initial successional stages (see above), but it is conspicuously dominated by the typical sand species *Harpalus flavescens.* This alone makes the open sand site definitely worth protecting. Noteworthy is the occurrence of *Cicindela hybrida* ssp. *hybrida,* a typical species of sandy riversides. The sand dunes of Drösing are a "locus classicus" (Mandl, 1936).

It is a pity that the area pastured by sheep (site D) was not investigated until July 2004, and the ground beetle community could therefore be recorded only fragmentarily. The majority of all species were captured between the middle of August and middle of September at every site. During this period, only about 14% of the species that were found at every other site were detected in area D. This habitat has definitely not yet recovered from removal of the topsoil and plowing, a situation also evident from the composition of ground beetles: although both investigation areas B and D are unshaded and dry with high insolation, they share only a few species, probably due to different soil types (nearly sterile sandy soil versus disturbed and plowed soil). The presence of the eudominant and hemerophilous *Pseudoophonus rufipes,* as well as *Harpalus tardus, Poecilus cupreus,* and *Trechus quadristriatus* (species often prevailing in ruderals or on cultivated land), indicates site D to be a rather disturbed habitat. This is supported by the fact that site D is quite similar to site A in regard to species composition. Conversely, *Masoreus wetterhalli*, mentioned in the vulnerable category in the Bavarian Red List and according to Tietze (1973) indicating intact sandy pioneer grasslands and dry meadows, makes up nearly half of all carabid beetles in area D. Why does *Masoreus wetterhalli* occur in much greater numbers at this disturbed site than in the open sand area (only two specimens were found in habitat B and one in habitat Aa)? At this time, it is hard to explain that. It is difficult to predict whether if area D will turn into a valuable steppe or a ruderal in the future; a follow-up examination would be important and certainly interesting.

Ecological valence and preference

All ground beetle species found in the whole investigation area are eurytopic except for three stenotopic ones (*Cryptophonus melancholicus, Harpalus picipennis,* and *Masoreus wetterhalli*) (Koch, 1989). This is in agreement with Brändle et al. (2000) – species able to adapt to a wide range of environmental conditions dominate at early successional stages.

Nearly all the carabid beetles found are xerophilous and/or psammophilous and therefore well-adapted to the habitat. It seems that all three sites with sandy soil (A, Aa, and B) accommodate mostly species that immigrated from habitats like adjacent sandpits or sandy paths. Only habitat D appears to be an exception, as discussed above.

The few species having other ecological preferences (*Poecilus cupreus, Pterostichus anthracinus,* and *Carabus coriaceus*) may be vagrants from water meadows or the neighboring pine forest.

Wing morphology

Habitats at the beginning of succession or pioneer habitats usually accommodate mostly macropterous carabid species (Hejkal, 1985; Brändle et al., 2000; Handke, 2002), as could be observed at all four investigation sites. Since ground beetles with flight ability can cover a distance of at least several kilometers (De Vries et al., 1996) some carabids of the extensive sand dune locality Závod-Borová, which is only 5 km (linear distance) east of Drösing on the other side of the March River in Slovakia, could theoretically have contributed to resettlement of the "Sandberge". However, in the work of Majzlan and Rychlík (1993) treating faunistic research in the Borová sand dune area, not a single ground beetle species occurring at the study site in Drösing was mentioned. Although the substratum of the Borová sand dunes is very similar to that in Drösing [(acidic, silicate sands with a plant community of the *Thymo angustifolii-Corynephoretum canescentis* type (Stanová and Seffer, 1994)], the ground beetle community is completely different: the occurrence of mainly hygrophilous carabid species at Borová can be related to the surrounding moist flood meadows and high flood during spring of the year of investigation.

The other Pannonic sand dune areas in Lower Austria (e.g., Weikendorfer Remise or Obersiebenbrunn) are more than 20 km distant (as the crow flies) from Drösing and consequently for ground beetles too far away for dispersal.

Thus, only ground beetles species occurring in nearby cultivated areas, fields, adjacent sandpits, or sandy paths are able to migrate to the investigation area. In particular, both of the last mentioned habitats certainly provide shelter areas for brachypterous, well-adapted species like *Harpalus flavicornis, H. picipennis,* or *H. pumilus,* since most ground beetles can cover distances of up to 500 meters by walking (Baars, 1979).

Another important aspect is the size of an area. The smaller the area, the more will its species composition be dominated by species with high dispersal abilities (de Vries et al. 1996). De Vries et al. (1996) demonstrated that the number of ground beetle species with low power of dispersal is significantly smaller in small heathland habitats (<10 ha) than in larger areas (>100 ha). Since the whole investigation site in Drösing has a size of only five hectares, it would be interesting to learn if the ratio between macropterous and brachypterous carabid species in the future changes in favor of brachypterous ones or remains at its current level.

Red Lists

Red Lists of Threatened Species are an important tool for nature conservation and species protection. Species found at an investigation site and mentioned in a Red List may help to assess this site.

None of the ground beetles found in Drösing is mentioned in the currently available Red List of Coleoptera of Austria (Jäch, 1994). This is not very surprising since the list is more than 10 years old. However, it was the same with the more recent Red List of Coleoptera of Slovakia (Holecová and Franc, 2001). The most recent Red List of Austria's neighboring states is the one of Bavaria (Lorenz, 2003). Although Bavaria is a fair distance away from the investigation area, a comparison with its Red List species makes sense. In Germany 84% of all ground beetle species occurring in dry and semi-dry meadows or heath lands are endangered due to deterioration of these habitats, reforestation, eutrophication, or natural rareness (http://www.bfn.de/0322_tiere.html). Open inland dunes and drifting sand areas are even critically endangered in Germany, as in Austria. In fact, dry meadows on sandy substrates are threatened with totall extinction in Austria (Essl, 2004). It should be noted that "Schichtstufenland", one of the four geographical regions distinguished in the context of the Red List of Bavaria, has several xerothermic areas similar to our investigation site.

Altogether, 14 species out of the 33 found at our site are registered in the Red List of Bavaria. This is nearly half of all species recorded at the investigation site. Considering the small size of the investigation area (5 ha), the number is very high once more emphasizes its importance.

Aspects of nature conservation

This work again underlines out the uniqueness of the former drift sand area near Drösing. In both botanical and zoological respects, the given site exceptionally valuable, as was already demonstrated in previous works (Wiesbauer, 1997 and 1999; Kohla, 2001; Zolda, 2001; Wiesbauer, 2002). A proposal for establishing "In den Sandbergen" as a nature reserve is currently under consideration. In the meantime, management measures such as extensive pasturing with sheep or mechanical (harrow, disk harrow, or finger weeder) treatment are used to inhibit *Calamagrostis epigeios* from spreading into the open sand areas. In general, pasturing with sheep or cattle is an often-applied management tool. It shows good results (e.g., Bokdam 2002; Siebel and Piek, 2002; Bakker, 2003), and its implementation certainly makes sense in the investigation area.

Bare soil and pioneer vegetation, both essential habitats for many endangered species, will constantly be replaced by later successional stages (Brändle et al., 1999). It is therefore important to keep sandy soils open. An effective method is the removal of topsoil, which has already been applied and will be used in the future as an additional management tool. This method has been utilized for 25 years for purposes of nature conservation in different regions of Central Europe (Reutemann-Gerster, et al. 2005), and good results can be realized with this practice in many projects (e.g., Ochse and Michels, 1999; Meinecke, 2000). However, one problem involves disposal of the removed topsoil (Reutemann-Gerster et al., 2005). In Drösing, it was heaped onto the acclivity, with the effect that ruderal vegetation instead of gray hairgrass sprouted. Since the acclivity is home to many valuable carabid species (as discussed above), it would be preferable not to deposit this soil in the open sand area.

The sand dune area in Drösing is unique in Austria with respect to its size, openness of its landscape, and its soil composition. It would therefore be very important to establish a nature reserve to protect and preserve this threatened habitat for the future.

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Appendix

List of Taxa (Coleoptera, Carabidae), species nomenclature after Hurka (1996)

Carabus (Procrustes) coriaceus (Linnaeus, 1758)
Cicindela (C.) hybrida hybrida (Linnaeus, 1758)
Trechus quadristriatus (Schrank, 1781)
Poecilus (P.) cupreus (Linnaeus, 1758)
Pterostichus (Melanius) anthracinus (Illiger, 1798)
Amara (A.) familiaris (Duftschmid, 1812)
Amara (A.) similata (Gyllenhal, 1810)
Amara (Celia) bifrons (Gyllenhal, 1810)
Amara (Bradytus) apricaria (Paykull, 1790)
Amara (Bradytus) consularis (Duftschmid, 1812)
Amara (Bradytus) fulva (O. F. Müller, 1776)
Ophonus (O.) azureus (Fabricius, 1775)
Ophonus (Metophonus) puncticeps Stephens, 1828
Cryptophonus melancholicus (Dejean, 1829)
Cryptophonus tenebrosus centralis (Schauberger, 1929)
Pseudoophonus (P.) griseus (Panzer, 1797)
Pseudoophonus (P.) rufipes (De Geer, 1774)
Harpalus (Semiophonus) signaticornis (Duftschmid, 1812)
Harpalus (H.) affinis (Schrank, 1781)
Harpalus (H.) autumnalis (Duftschmid, 1812)
Harpalus (H.) flavescens (Piller et Mitterbacher, 1783)
Harpalus (H.) flavicornis Dejean, 1829
Harpalus (H.) froelichi Sturm, 1818
Harpalus (H.) picipennis (Duftschmid, 1812)
Harpalus (H.) politus Dejean, 1829
Harpalus (H.) pumilus Sturm, 1818
Harpalus (H.) rubripes (Duftschmid, 1812)
Harpalus (H.) rufipalpis Sturm, 1818
Harpalus (H.) serripes (Quensel in Schönherr, 1806)
Harpalus (H.) servus (Duftschmid, 1812)
Harpalus (H.) smaragdinus (Duftschmid, 1812)
Harpalus (H.) tardus (Panzer, 1797)
Masoreus wetterhalli (Gyllenhal, 1813)