SHORT-TERM EFFECTS OF MODERN HEATHLAND MANAGEMENT MEASURES ON CARABID BEETLES (COLEOPTERA: CARABIDAE)

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Abstract. For the maintance of dry heathland ecosystems the implementation of adequate conservation measures is required. Besides traditional land use practices (e.g. mowing) several modern management measures (e.g. sod-cutting, choppering) were developed and applied. In the present study the carabid beetle fauna of three different managed heathland sites in a coastal heathland on the Baltic isle of Hiddensee, Germany, was analysed. Pitfall trapping yielded a total of 4,018 carabid beetles belonging to 48 species. Species and individual richness was highest in the sod-cutted site followed by choppering and mowing. Diversity was highest on the mown site, due to the most even distribution of species. Species composition differed clearly among sites indicated by RDA ordination and Jaccard´s similarity index. The application of sod-cutting and mowing present two important habitats for specialised carabid beetles: Sod-cutting creates secondary, highly dynamical habitats suitable for several dune species while mowing seemed to preserve a typical (*Calluna*) heathland carabid fauna. The use of different management measures could lead to a more heterogeneous heathland, create suitable habitats for several specialised carabid beetle species and therefore might enhance diversity.
Keywords: *Choppering, coastal heathland, mowing, restoration ecology, sod-cutting*

Introduction

The main object of the European Habitats Directive is the maintenance of biodiversity by the conservation of certain habitats and of wild fauna and flora (EC Habitats Directive 92/43/EEC). For semi-natural habitats, such as dry heathlands, the implementation of adequate conservation measures is therefore required and necessary. In North-West Europe heathlands were traditionally used as grazing ground for sheep in addition with sod-cutting (also known as turf cutting or plaggen) (Webb, 1998). By such land use practices, nutrients were continuously depleted and natural succession to shrub or forest is arrested (Gimingham, 1972; Webb, 1998). In former times, this cultural landscape developed in large areas throughout the Atlantic region of Europe mainly on dry, acid, and nutrient-poor soils (Gimingham, 1972). Nowadays, heathlands are restricted to small and mainly fragmented areas (Webb, 1998). The main reasons for this decrease are changes in land-use (e.g. afforestation, agricultural intensification) and high rates of atmospheric nitrogen deposition (Heil and Diemont, 1983; Webb, 1998). Both, the abandonment of traditional land use and eutrophication, enhance successional processes including negative effects such as accumulation of soil organic matter, decreasing biodiversity and the loss of a typical heathland fauna (Marrs and Le Duc, 2000; Roem and Berendse, 2000; Irmler, 2004). Especially for invertebrates, such as carabid beetles or spiders, heathlands present an important ecosystem with higly specialised species (Usher, 1992; Buchholz, 2010).

To preserve heathlands and counteract the negative effects of succession and eutrophication, several modern management measures were developed and applied (Barker et al., 2004; Härdtle et al., 2006). Besides mowing and burning, especially sod-cutting and choppering, two methods that are highly intensive and require the use of specialised machines, are seen as highly effective in reducing nutrient loads (Härdlte, 2006). By sod-cutting the total above ground biomass and most of the humus-rich topsoil layer (O- and A-horizon) is removed down to the mineral and sandy soil layer. Because sod-cutting is cost-intensive and results in high amounts of waste material, choppering has been applied as an alternative method (Niemeyer et al., 2007) which takes an intermediate position of intensity between sod-cutting and mowing. Thereby the above ground biomass is totally removed as well as (much of) the O-horizon, while the A-horizon remains unaffected (Maes et al., 2004). A more detailed description of both measures is given by Niemeyer et al. (2007).

All management measures aim at preserving a vital heathland landscape on a long-term basis as well as preserving a typical heathland flora and fauna. Carabid beetles are a highly usefull indicator taxon for assessing management practices or restoration effects (e.g. Buchholz et al., 2009; Malfait and Desender, 1990; Mossakowski et al., 1990), and in many studies the (short-term) response of carabid beetles to different heathland management schemes like cutting/mowing, burning or grazing has been analysed (Usher and Thompson, 1993; Usher, 1992; Gardner, 1991; Garcia et al., 2009). But especially with respect of animal conservation, not only the long-term preservation of a (homogenous) heathland vegetation but also the creation of a vegetation mosaic might be of great importance, too, as a heterogeneous heathland might enhance insect diversity (Gardner, 1991; Schirmel et al., 2010). Therefore, management measures are not only important for vegetation recovery and development on a long-term basis, but could also contribute to a high insect diversity by forming a heathland mosaic with different habitats suitable for several species.

The aim of the present study was to analyse the carabid beetle fauna of three different managed heathland sites in a coastal heathland on the Baltic isle of Hiddensee, Germany. The applied management measures were sod-cutting, choppering and mowing and an analysis of the short-term effects of these management measures (up to 3 years after realisation) on the carabid beetle fauna was done. In particular the following research questions were addressed: (i) How do species richness, diversity and abundance patterns differ among the three different managed sites? (ii) Does the carabid species composition differ? (iii) What can be concluded for nature conservation and management practices in heathlands?

Materials and methods

Study area

The study area is a coastal dune heathland on the Baltic Sea island of Hiddensee (Mecklenburg-Western Pomerania, Northeastern Germany). The island is situated west of Rügen in the National Park “Vorpommersche Boddenlandschaft” (Western Pomeranian Bodden landscape). The north-south extent of Hiddensee is about 19 km with a maximum width of about 3 km (total area of approx. 16 km^2). The island is divided geomorphologically into a Pleistocene hilly landscape in the north (up to 72.5 m a.s.l.) and an adjacent lowland in the south formed by Holocene sandy deposits (Möbus, 2000). Hiddensee has an average annual precipitation of 547 mm and an average annual temperature of 7.5 C (Reinhard, 1962). In the centre of Hiddensee an anthropo-zoogenically influenced coastal dune heathland is situated with a size of about 250 ha (54°32´N, 13°5´E). The heathland is dominated by dwarf-shrubs (mainly *Calluna vulgaris* (L.) Hull, but also *Empetrum nigrum* L. s. str., *Salix repens* L. and *Erica tetralix* L.). The extensive and rather homogeneous heath-stands are interrupted by sparsely vegetated grey dunes dominated by *Corynephors canescens* (L.) P. Beauv., *Carex arenaria* L. and cryptogams, grassy heath-stands (*Deschampsia flexuosa* (L.) Trin., *Molinia caerulea* (L.) Moench, *C. arenaria*), and shrub encroached stands (mainly *Betula pendula* Roth and *B. pubescens* Ehrh.).

The heathland area was traditionally used as grazing ground for domestic animals and as fuel and building material until about the second World War (Umweltministerium Mecklenburg-Vorpommern, 2003). In recent times the heathland has been kept open by several conservation measures. Manual shrub clearing has been applied sporadically since 1978 (Umweltministerium Mecklenburg-Vorpommern, 2003) and regularly since 2000 (Blindow, pers. comm.). In 2004 sheep grazing with up to 550 individuals and herd by a shepard was reintroduced. On three sites within the heathland the mechanical techniques sod-cutting, choppering and mowing were conducted.

Experimental set-up

Choppering (size: around 16,700 m^2) and mowing (around 6,500 m^2) were done in November 2006 and sod-cutting (20,500 m^2) in November 2007 (*Table 1*). All measures were accomplished by the company Meyer-Luhdorf with specialised maschines.

Carabid beetles were sampled continuously from 09 May 2008 to 22 October 2009, i.e., 0.5 to 2 years after sod-cutting and 1.5–3 years after choppering and mowing, respectively. On each site two transects were arranged from the border to the centre, each consisting of four sampling locations at +5m, +10m, +15m, and +20m. At each sampling location one pitfall trap was installed. Pitfall traps consisting of white plastic cups (6.5 cm in diameter and 7.5 cm deep) were set flush with the soil surface. To protect the traps from precipitation a 15 × 15 cm transparent plastic roof was installed a few centimeters above each trap. Ethylenglycol and a few drops of detergent were filled up to about the half of the traps and used as a killing and preservation fluid. The traps were emptied every two (2008) or four (2009) weeks in summer and every four weeks in winter. Vegetation sampling took place at each sampling location in a 1 × 1m square once in July 2008. The densities of field layer (DFL), cryptogams (DCR) and litter (DLI) as well as the proportion of bare soil (DBS) were estimated in %. The height of field layer (HFL) was measured in cm.

Table 1. *Charactersitics of the study sites with the different management schemes a) sod-cutting, b) choppering and c) mowing in the coastal heathland on the Baltic isle of Hiddensee, Germany*

Management	Size [m²]	Date of measure	Description
Sod-cutting	20,500	Nov 2007	Dominated by new shoots of *Calluna vulgaris*, *Rumex acetosella*, *Carex arenaria* and *Rubus fruticosus* agg. Very high proportion of bare and sandy soil.
Choppering	16,700	Nov 2006	Domination of *Carex arenaria*, *Calluna vulgaris*, *Deschampsia flexuosa* and cryptogams. High proportion of bare soil rich in humus.
Mowing	6,500	Nov 2006	Domination of *Calluna vulgaris*, *Carex arenaria*, *Deschampsia flexuosa* and cryptogams. High proportion of dead woody *Calluna*-sprouds and cryptogams (e.g. *Pleurozium schreberi*).

Data analyses

Müller-Motzfeld (2006) was used for species identification and nomenclature of carabid beetles. Vegetation parameters (log(x+1) transformed) among the three managed sites were compared using Kruskal-Wallis-ANOVA (SPSS 11.5). Species richness estimation of carabid beetles was done using the bias-corrected Chao1 (Chao, 1984, 2005), ACE (Chao and Lee, 1992) and the second order Jacknife (Burnham and Overton, 1978) index with the software SPADE. As diversity measures the Shannon index ($H' = \sum p_i \ln p_i$), the reciprocal Simpson index ($1 / (D = \sum p_i^2)$) and the reciprocal Berger-Parker index ($1 / (d = N_{max} / N)$) were used. Rarefied species richness (down to n = 780 individuals) and rarefaction curves were calculated and created with the software PAST. Differences between rank abundance-plots were tested using the Kolmogorov-Smirnov two-sample test where D_{max} represents the largest unsigned difference between the cumulative relative abundances of two sites. The critical value D_α was calculated as $D_\alpha = K_\alpha \sqrt{[(n_1 + n_2) / (n_1 * n_2)]}$, where $K_\alpha = \sqrt{[1/2 (-\ln (\alpha/2))]}$ (see Magurran, 2004). The Jaccard´s similarity index (C_J) where used as a measure of species overlap between managed sites. To analyse carabid assemblage response to habitat parameters of the three sites RDA ordination was performed, because preliminary conducted DCA yielded a gradient length of < 2 (Leyer and Wesche, 2006). For scaling we chose inter-species correlations and species scores were divided by deviation. For ordination analyses the four pitfall traps of one transect were treated as a unit, and number of individuals were standardised to individuals/transect/day. Only species with > 3 individuals per transect were used, and data was log transformed prior analyses. RDA ordination was done using the software package Canoco 4.5.

Results

Vegetation characteristics

Density of field layer and of cryptogams differed significantly among the three sites increasing from sod-cutting over choppering to mowing (*Table 2*). Also the proportion of bare soil differed significantly and was by far highest in the sod-cutted site followed by the choppered site. No differences could be detected in density of litter and height of field layer. However, for the latter a trend could be observed showing the highest vegetation on the mown site mainly due to the occurrence of grasses such as *D. flexuosa* and *Festuca rubra* L.

Table 2. *Comparison of vegetation parameters of different managed heathland sites a) sod-cutting, b) choppering and c) mowing. Significant differences are shown in bold (Kruskal-Wallis-ANOVA)*

	Abbreviation	Sod-cutting	Choppering	Mowing	Chi²	p
Density [%]						
Field layer	DFL	13.3 ± 4.1	39.6 ± 11.0	72.5 ± 7.4	12.611	**0.002**
Cryptogams	DCR	0	2.9 ± 1.6	21.3 ± 6.3	16.809	< **0.001**
Litter	DLI	6.0 ± 0.5	9.0 ± 2.5	10.0 ± 1.3	3.485	0.175
Bare soil	DBS	80.3 ± 5.4	53.8 ± 11.8	18.1 ± 7.4	11.908	**0.003**
Height of field layer [cm]	HFL	17.4 ±2.9	13.1 ± 2.0	23.6 ± 4.0	5.144	0.076

Capture statistics and diversity

In total 4,018 carabid beetles belonging to 48 species were sampled. *Calathus fuscipes* Goeze (1,523 individuals, 37.9 % of total catch) and *Nebria salina* Fairmaire & Laboulbène (1,264 ind., 31.5 %) were the dominant species in all sites. Frequent species were *Calathus erratus* C.R. Sahlberg (259 ind., 6.4 %), *Poecilus versicolor* Sturm (146 ind., 3.6 %) and *Amara lunicollis* Schiödte (110 ind., 2.7 %).

Species richness (observed and estimated) and individual richness was highest in the sod-cutted site followed by choppering and mowing (*Table 3, Fig. 1*). In contrast, diversity measures indicate a higher diversity on the mown site compared to the choppered and sod-cutted sites, which both had very similar values. Rarefaction curves showed for all three management schemes no reaching of an asymptote (*Fig. 1*).

Table 3. *Species richness and diversity measures of carabid beetles in three different managed heathland sites a) sod-cutting, b) choppering and c) mowing.*

	Sod-cutting	Choppering	Mowing
Individuals	1,738	1,497	783
Species richness			
Observed	37	30	29
Chao1	40.5	32.5	31.0
ACE	44.0	32.9	32.1
2^{nd} order Jackknife	46.0	37.0	35.0
Rarefied (n=780)	29.6	26.3	29.0
Diversity			
Shannon *H´*	1.6	1.6	2.2
Simpson (1/*D*)	3.0	3.0	6.2
Berger-Parker (1/*d*)	1.9	2.0	3.6

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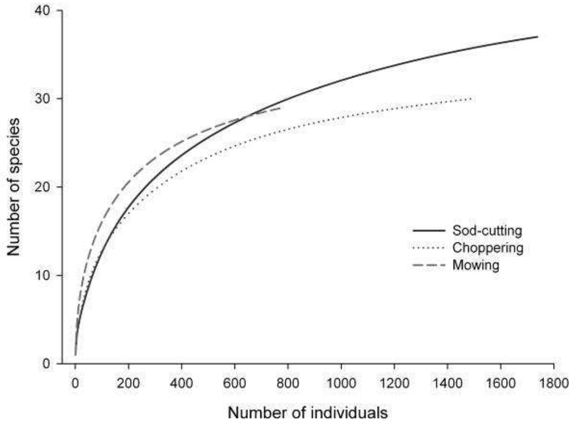

Figure 1. *Individual-based rarefaction curves based on carabid beetle data of three different managed heathland sites a) sod-cutting, b) choppering and c) mowing*

Rank-abundance plots of carabids (*Fig. 2*) did not differ significantly among sites (Komogorov-Smirnof two-sample test; sod-cutting vs. choppering: D_{max} = 0.054, D_{α} = 0.334, $p > 0.05$; sod-cutting vs. mowing: D_{max} = 0.241, D_{α} = 0.337, $p > 0.05$; choppering vs. mowing: D_{max} = 0.276, D_{α} = 0.354, $p > 0.05$). However, rank-abundance plot of the mown site showed a more even distribution of species while the sod-cutted and choppered sites were dominated by three or two species, respectively.

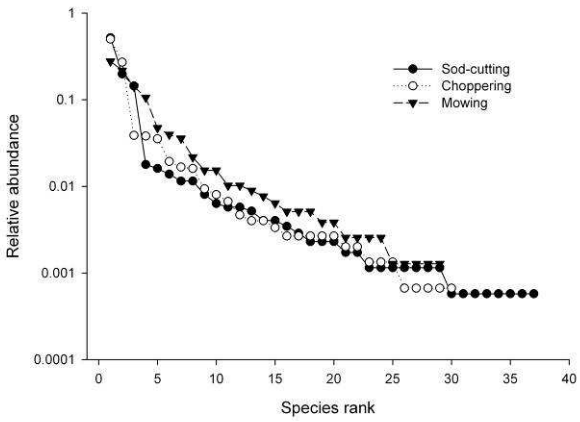

Figure 2. *Rank-abundance plots based on carabid beetle data of three different managed heathland sites a) sod-cutting, b) choppering and c) mowing.*

Species composition

The similarity index of Jaccard showed a weak similarity between carabid beetle species inventory of sod-cutting and choppering (C_J = 0.523) and sod-cutting and mowing (C_J = 0.404). The choppered site and the mown site shared 23 species of 34 and had a moderately similar species inventory (C_J = 0.676).

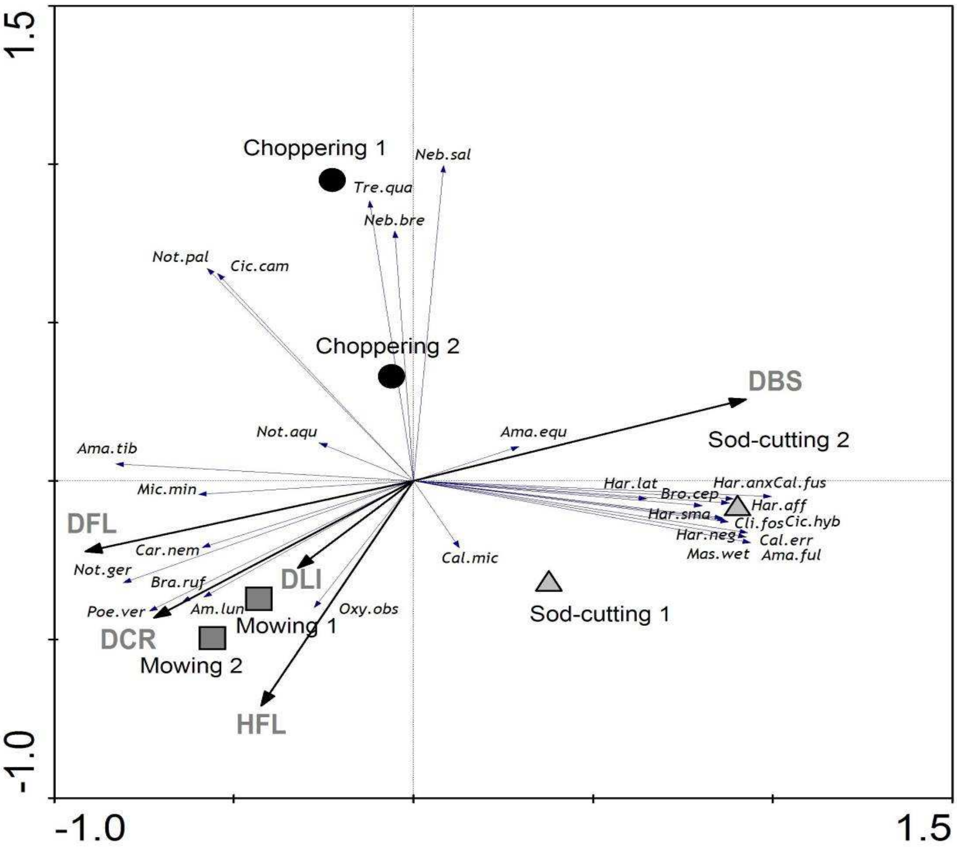

Figure 3. *RDA-ordination of carabid beetles (species > 3 ind. per transect, two transects per site) and vegetation parameters of three different managed heathland sites a) sod-cutting, b) choppering and c) mowing during the whole catching period from May 2008 until October 2009. Abbreviation of species names: Ama.equ = Amara equestris, Ama.ful = A. fulva, Ama.lun= A. lunicollis, Ama.tib = A. tibialis, Bra.ruf = Bradycellus ruficollis, Bro.cep = Broscus cephalotus, Cal.err = Calathus erratus, Cal.fus = C. fuscipes, Cal.mic = C. micropterus, Car.nem = Carabus nemoralis, Cic.cam = Cicindela campestris, Cic.hyb = C. hybrida, Cli.fos = Clivina fossor, Har.aff = Harpalus affinis, Har.anx = H. anxius, Har.lat = H. latus, Har.neg = H. neglectus, Har.sma = H. smaragdinus, Mas.wet = Masoreus wetterhallii, Mic.min = Microlestes minutulus, Neb.bre = Nebria brevicollis, Neb.sal = N. salina, Not.aqu = Notiophilus aquaticus, Not.ger = N. germinyi, Not.pal = N. palustris, Oxy.obs = Oxypselaphus obscurus, Poe.ver = Poecilus versicolor, Tre.qua = Trechus quadristriatus*

RDA ordination of carabid data showed a separation of the six transects mainly along two axis (eigenvalues of axis: 1. = 0.569, 2. = 0.375, 3. = 0.029, 4. = 0.018; *Fig. 3*). Axis 1 showed a separation along a vegetation density gradient while the second axes showed a gradient from high to low vegetation. The sod-cutting transects could be found on the right end of the ordination plot and were positively correlated with a high proportion of bare soil (DBS) and negatively with the density of total vegetation (DTV). Typical species exclusively occurring at this site were *Cicindela hybrida* Linnaeus, *Masoreus wetterhallii* Gyllenhal, *Broscus cephalotus* Linnaeus, *Amara fulva* O.F. Müller, *Clivina fossor* Linnaeus, *Harpalus neglectus* Audinet-Serville and *Harpalus smaragdinus* Duftschmid. Most frequent species were *C. fuscipes* (52%), *N. salina* (20%) and *C. erratus* (14%). An intermediate position along this gradient took the choppering transects. This site was characterised by the dominance of *N. salina* (50%),

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less abundant *C. fuscipes* (27%) and the frequent occurrence of *Nebria brevicollis* Fabricius (4%) and *Trechus quadristriatus* Schrank (4%). Other species preferring this site were *Cicindela campestris* Linnaeus and *Notiophilus palustris* Duftschmid. On the left side of the ordination plot and positively correlated with vegetation density (DTV, DCR, DLI) were the mown transects situated. Typical species in this site were *P. versicolor*, *Notiophilus germinyi* Fauvel in Grenier, *A. lunicollis*, *Amara tibialis* Paykull and *Bradycellus ruficollis* Stephens. Again *C. fuscipes* (28%) and *N. salina* (22%) were the dominant species, but also *P. versicolor* (14%), *A. lunicollis* (11%) and *B. ruficollis* (5%) were common.

Discussion

In order to preserve heathlands several different measurements were used but with different success (Power et al., 2001). As shown by (den Boer and de Vries, 1994), even by the application of the very intensive measurement sod-cutting, a typical heathland carabid beetle fauna developed on a long-term view. But besides the aim of a long-term preservation of a typical heathland vegetation and faunal composition, the use of different management measures might furthermore create a more heterogenous heathland. (Gardner, 1991) proposed, that the occurrence of different heathland successional stages could enhance carabid beetle diversity and (Schirmel et al., 2010) showed, that habitat mosaics within a heathland were of great importance for Orthoptera. So in which way do the three different managed sites differ and which value do the management measures have for carabid beetles?

Since the sites were closely related (max. distance about 250 m), were not divided by any barriers, and had a similar vegetation prior management (Blindow, pers. comm.), we assume a similar carabid beetle composition of the sites prior the the management measures. Detected differences in this study among sites, could therefore mainly be returned to the effect of each of the applied management measures. Differences were detected in species and individual richness and in species composition of carabid beetles. The site with the most intensive measure sod-cutting showed clearly both the highest species and individual richness. High individual numbers can be explained by the frequent occurrence of *Calathus fuscipes*. Individual richness was also relatively high on the choppered site while on the mown site only about the half of the individual number could be detected. Species richness between the choppered and the mown site showed similar results.

Species composition of the different managed sites differed clearly indicated by the RDA ordination and the Jaccard index. Especially composition of the sod-cutted site could be well separated. On this site several species occur exclusively. To these species belong mainly typical “dune” species such as *Harpalus smaragdinus*, *H. neglectus*, *Broscus cephalotus*, *Masoreus wetterhallii*, *Amara fulva* and *Cicindela hybrida* (Turin, 2000). On the other hand typical “heath” species such as the locally threatened *Bradycellus ruficollis* or *Notiophilus germinyi* (Turin, 2000) were very frequent on the mown site. Also species depending on higher vegetation (*Poecilus versicolor*, *Oxypselaphus obscurus*) found suitable habitat conditions on this site. The occurrence of these species reflects the low intensity of this management measurement and indicates a low impact on the typical heathland carabid beetle fauna. Choppering, which take an intermediate position in management intensity, also showed an intermediate position referring to species composition. However, neither typical dune nor heath species occurred frequently in this site and the assemblage mainly consist of eurytopic species (e.g. *Nebria salina*, *Notiophilus palustris*) (Turin, 2000).

From a carabid beetle conservation point of view, the application of sod-cutting and mowing therefore present two important habitats for specialised carabid beetles. Thereby sod-cutting creates secondary, highly dynamical (e.g. sand blow) habitats similar to younger and more pristine successional stages. In contrast, mowing seemed to preserve a typical (*Calluna*) heathland carabid fauna which found suitable habitat conditions shortly after application. This should mainly be caused by the fact, that the topsoil is not affected and torphobiont species (such as *B. ruficollis*) are still able to find approbiate habitat conditions which seemed not to be true for the choppered site.

By applying management for nature conservation one has always to keep in mind the costs: While sod-cutting (or topsoil removal in general) is extremely expensive (e.g. Klimkowska, in press), mowing have relatively low costs. For the conservation of heath carabid beetles species mowing seems to be an appropriate management scheme and should be preferred compared to choppering which is more expensive. But of course the future perspective and the vegetation development of these sites are of outstanding importance. If nutrient loads in heathland habitats became to high, mowing might be an unsuitable measure and e.g. choppering might be more successfull.

In conlusion, the use of different management measures have a great short-term effect on carabid beetles. While sod-cutting creates a highly dynamic habitat important for several and often threatened dune species, mowing preserve a typical heathland carabid fauna. Choppering seemd to be of low relevance on a short-term basis, because of the quasi absence of dune and heath species. The use of different managements can led to a more heterogenous heathland which might be important not only for carabid beetles but for several arthropods and might enhance biodiversity in general.

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