



Montane heathland rejuvenation by chopperring—Effects on vascular plant and arthropod assemblages

Thomas Fartmann ^{a,*}, Fabian Borchard ^a, Sascha Buchholz ^b

^a Department of Community Ecology, Institute of Landscape Ecology, University of Münster, Heisenbergstraße 2, D-48149 Münster, Germany

^b Department of Ecology, TU Berlin, Rothenburgstr. 12, 12165 Berlin, Germany



ARTICLE INFO

Article history:

Received 12 April 2015

Received in revised form 29 July 2015

Accepted 21 August 2015

Keywords:

Biodiversity
Conservation management
Dwarf shrub
Microclimate
Semi-natural habitat
Succession

ABSTRACT

Land-use changes and atmospheric nitrogen deposition have negatively affected heathland biota. Active habitat management is one possible way of counteracting the biodiversity loss associated with these habitat alterations. However, management practices for lowland heathlands often have been transferred to montane heathlands, irrespective of the differences in environmental conditions or assemblage composition. The objective of this study was to evaluate the effects of so-called chopperring for the rejuvenation of montane heathland. Chopperring involves chaffing and removing the largest part of the organic layer down to the mineral soil. In this study, we compared montane heathlands that were rejuvenated through the application of chopperring (CHOPPER) to old-growth montane heathlands (CONTROL). Thirteen years after the rejuvenation measures had been conducted, the environmental conditions between CHOPPER and CONTROL still differed. CHOPPER was characterised by shorter vegetation (herbs/grasses and dwarf shrubs), more bare soil, less litter and higher temperatures. Although, the vascular plants and all studied arthropod groups were affected by the environmental changes, their responses were somewhat different. CHOPPER had a unique assemblage of each taxonomic group that included at least a few heathland species that mainly occurred in this treatment. However, chopperring was most beneficial for vascular plants, grasshoppers and carabid beetles. As shown for lowland heathlands, chopperring is also a suitable management measure for montane heathland to rejuvenate vegetation with its characteristic arthropod fauna. Due to the intact seed banks and Ericaceae root systems with their mycorrhizas, in combination with the availability of bare soil, heathland vegetation can rapidly regenerate after chopperring. The key-stone structures that explain the high relevance of CHOPPER, especially for vascular plants, grasshoppers and carabid beetles, are low-growing vegetation and bare soil, which result in light and warm microclimatic conditions. Based on the results of our study, we recommend chopperring as a regular management measure to rejuvenate montane heathland.

© 2015 Elsevier GmbH. All rights reserved.

1. Introduction

Habitat management provides valuable and important opportunities for the protection of biodiversity (Dobson, Bradshaw, & Baker, 1997; Maron et al., 2012). Consequently, it is increasingly implemented throughout the world into conservation strategies (Clewell & Aronson, 2007). In Central Europe, mainly semi-natural ecosystems such as heathlands have been the focus of conserva-

tion management activities (Chapin et al., 2000; Plieninger, Höchtl, & Spek, 2006; Webb, 1998). Heathlands harbour many rare plant and animal species (Buchholz, 2010; Buchholz, Hannig, & Schirmel, 2013; Schirmel & Fartmann, 2014; Schirmel, Mantilla-Contreras, Blindow, & Fartmann, 2011; Usher, 1992; Usher and Thompson, 1993); some of these rare species are even restricted to heathlands (Symes & Day, 2003). Due to their high relevance for biodiversity conservation (Thompson & MacDonald, 1995; Usher, 1992), heathlands are protected under the EU Habitats Directive (European Community 1992; Ssymank et al., 1998; Thompson & MacDonald, 1995). Apart from its specialised wildlife, heathlands are also known for their beauty and high cultural value (Haaland, 2003).

However, land-use change, the most important driver of global biodiversity loss (Sala et al., 2000; Wessel et al., 2004), has

* Corresponding author. Present address: Ecology, Department of Biology/Chemistry, University of Osnabrück, Barbarastrasse 11, 49069 Osnabrück, Germany. Fax: +49 541 969 2815.

E-mail address: Thomas.Fartmann@biologie.uni-osnabrueck.de (T. Fartmann).

negatively affected heathland biota (Thompson & MacDonald, 1995). The dramatic decline of heathlands began in the middle of the 19th century (Keienburg & Prüter, 2004; Symes & Day, 2003). Lowland heathlands have been converted to arable fields, whereas montane heathlands have become degraded by the abandonment of traditional management practices such as sheep grazing, sod cutting and burning (Hahn, 2007), which was followed by partial afforestation (Symes & Day, 2003; Walker et al., 2004). Recently, atmospheric nitrogen deposition has become a further threat to heathlands. It reduces the regeneration of heather and favors the encroachment of grasses and mosses (Bobbink, Hornung, & Roelofs, 1998; Lindemann, 1993; Wessel et al., 2004).

Montane heathlands are restricted to areas with a cold and wet mountain climate (Britton, Pearce, & Jones, 2005). Hence, their flora and fauna are exceptionally rich in arctic-alpine and boreal-montane species (Thompson & MacDonald, 1995). In addition to *Calluna vulgaris*, two other Ericaceae dwarf shrubs, *Vaccinium myrtillus* and *Vaccinium vitis-idaea*, dominate these heathland stands (Geringhoff & Daniëls, 2003). In Central Europe, the 'Rothaargebirge' low mountain range is one of the last regions where larger montane heathlands remain (Geringhoff & Daniëls, 2003). Due to their extent and biodiversity, these montane heathlands are of European relevance (Frede, 1998).

Whereas many aspects of lowland heathland management have been studied in detail (e.g., Bullock & Pakeman, 1996; Gimmingham, 1992; Keienburg & Prüter, 2004; Michael, 1993; Symes & Day, 2003), montane heathlands have been widely neglected. Management practices applied in lowland heathlands often have been transferred and applied to montane heathlands (Hoffmann, 1998), irrespective of differences in climatic and edaphic conditions or assemblage composition (Breder & Schubert, 1998). Felton and Marsden (1990) have already suggested that there is a need to better understand montane heathland management techniques.

The objective of this study is to evaluate the effects of so-called chopperring for the rejuvenation of montane heathland. Chopperring involves chaffing and removing the largest part of the organic layer (O-horizon) down to the mineral soil with a specifically designed machine (Keienburg & Prüter, 2004; Niemeyer et al. 2007; Borchard & Fartmann, 2014; Borchard, Schulte, & Fartmann, 2013; Borchard, Buchholz, Helbing, & Fartmann, 2014). The result is the creation of bare ground with a thin layer of organic material (approximately 0.5 cm high) at the surface. Chopperring has been successfully applied to lowland heathlands (Niemeyer et al., 2007). Except for the first descriptive data collected on the establishment of vascular plant species on sites where this rejuvenation measure was applied (Breder & Schubert, 1998; Schubert, Trappman, & Gräf, 2008), a detailed assessment of the effects of chopperring on plant and arthropod assemblages of montane heathlands is still missing. In addition to using vascular plants, we use four different arthropod groups (grasshoppers, leaf-/planthoppers, carabid beetles, and spiders) as indicators in our study. All taxa (i) contain typical heathland species, (ii) respond quickly to environmental changes, (iii) have a high diversity and abundance and (iv) are important elements of the food chain in open habitats (Borchard & Fartmann, 2014; Borchard et al., 2013, 2014; Buchholz, 2010; Fartmann et al., 2012; Nickel & Hildebrandt, 2003; Noordijk et al., 2011; Rainio & Niemelä, 2003; Schirmel & Buchholz, 2011). To evaluate the effects of heathland rejuvenation management, we compared montane heathlands that were rejuvenated through the application of chopperring (CHOPPER) in old-growth montane heathlands (CONTROL). In particular, we address the following questions: do the three Ericaceae species that are characteristic of montane heathlands establish on sites where chopperring was applied? Can chopperring generally be recommended for the management of montane

heathlands with their characteristic plant and arthropod assemblages?

2. Materials and methods

2.1. Study area and study plots

Field work was carried out on the largest existing montane heathland (Niedersfelder Hochheide, 73.9 ha) in the 'Rothaargebirge' low mountain range at the eastern edge of the German Federal State of North Rhine-Westphalia (51°15'N, 8°33'E). The study area is situated at an altitude of 800 m a.s.l. It has a montane climate with a mean annual temperature of 5 °C, a mean annual precipitation of 1,450 mm (Borchard et al., 2013) and snow cover for 100 days/year (German Weather Service, pers. comm.). In the late 1980s, tree and shrub removal on the formerly abandoned montane heathland took place, and sheep grazing (shepherding) was re-introduced (Schubert et al., 2008).

In the montane heathlands of the study area, chopperring was conducted in 1997/1998 on five patches with a total area of 2 ha. After the application of chopperring, the CHOPPER area was grazed in the same way as the CONTROL (see above).

In total, we established seven randomly selected study plots with an area of 500 m² (20 × 25 m) on the CONTROL ($N=3$) and CHOPPER ($N=4$) sites. To avoid edge effects, each plot was located at least 20 m away from the treatment border (Schirmel, Blindow, & Fartmann, 2010). CONTROL was dominated by old-growth plants of *Calluna vulgaris*, *Vaccinium myrtillus* and *Vaccinium vitis-idaea*, whereas CHOPPER was mainly covered by young *Calluna vulgaris* plants and, to a much lower extent, *Nardus stricta*.

3. Sampling design

3.1. Environmental parameters

We sampled environmental parameters on three randomly chosen subplots per study plot twice in July 2011 and September 2012. Each subplot had a size of 16 m² (4 × 4 m). We recorded vegetation cover for the herb/grass, dwarf shrub, and the moss and lichen layer in 5% steps. Moreover, we recorded the cover of bare soil and litter. The average heights of the aforementioned vegetation layers were determined by using a ruler.

In addition, we recorded microclimatic parameters (temperature and humidity) from the beginning of August to the end of September 2011 on each of the study plots with a Hygrochron temperature/humidity logger (iButton, DS1923, Maxim, Dallas, TX, USA). The Hygrochron sensor was placed in a radiation shield (cf. Borchard & Fartmann, 2014) and installed 10 cm above the ground. Temperature and humidity were measured and recorded every hour.

3.2. Vascular plants and arthropods

All vascular plants were identified on each of the three subplots per study plot in July 2011 and September 2012 (see above), according to Oberdorfer (2001) and Jäger & Werner (2001). The scientific nomenclature follows Wisskirchen and Haeupler (1998).

Orthopterans (Ensifera and Caelifera; from now on referred to as grasshoppers) were sampled from mid-July to the end of July 2011 using a box quadrat (Gardiner, Hill, & Chesmore, 2005; Ingrisch & Köhler, 1998). The box quadrat was 0.8 m high and had an area of 2 m² (1.41 × 1.41 m). During sampling, the box quadrat was randomly dropped over the vegetation at 10 different points per study plot (total area: 20 m²; cf. Fartmann, Behrens, & Loritz, 2008; Poniatowski & Fartmann, 2011). Grasshopper species were

identified according to [Bellmann \(2006\)](#). Scientific nomenclature follows [Coray and Lehmann \(1998\)](#).

Leaf- and planthoppers (Cicadomorpha and Fulgoromorpha; from now on referred to as leafhoppers) were sampled twice in August 2011 and June 2012. We walked over each study plot in loops, doing 100 strokes with a sweep net of 30 cm diameter. As with the grasshoppers, all leafhopper surveys were conducted under warm and sunny weather conditions between 10:00 and 18:00. The individuals collected with the sweep net were transferred to plastic bags and frozen. In addition to analysing the sweep net catches, we analysed pitfall trap catches (see below). Pitfall trap catches and sweep net samples were pooled for each site. We determined all adult leafhoppers to the species level (or genus level if species could not be separated, such as with *Psammotettix* females) using [Biedermann and Niedringhaus \(2004\)](#) and [Kunz, Nickel, & Niedringhaus \(2011\)](#).

Carabid beetles and spiders were sampled from mid-August until mid-October 2011 (62 days) and from mid-May until the beginning of July 2012 (66 days) using pitfall traps. Therefore, we randomly set out three traps per study plot. The traps were 7.5 cm deep, 9 cm in diameter and half filled with Renner solution (40% ethanol, 30% water, 20% glycerine, and 10% acetic acid). To avoid overflow and trampling of the pitfall traps, we installed a roof (2 cm above each trap) and a wire netting (15 cm above each trap). The traps were emptied every three weeks during the sampling period. We determined all carabid beetles to the species level according to [Müller-Motzfeld \(2006\)](#) and [Trautner and Geigenmüller \(1988\)](#). The nomenclature follows [Müller-Motzfeld \(2006\)](#). Spiders were identified according to [Roberts \(1987, 1998\)](#) and [Nentwig et al. \(2013\)](#). Only adult spiders were included in the analysis. The nomenclature follows [Platnick \(2013\)](#).

3.3. Classification of heathland species

The classification of heathland plant and arthropod species was based on the literature. A species was classified as a heathland species if heathlands are among the most important habitat types for this species. The classification of typical heathland plants followed [Peppler \(1992\)](#) ([Appendix A](#)). Grasshoppers were classified according to [Detzel \(1998\)](#); leafhoppers, according to [Biedermann and Niedringhaus \(2004\)](#); carabid beetles, according to [Gesellschaft für angewandte Carabidologie \(2009\)](#); and spiders, according to [Kreuels and Buchholz \(2006\)](#) ([Appendix B](#)).

3.4. Statistical analysis

For statistical evaluation, all subplot data were pooled per study plot, incorporating both sampling periods (2011/2012). Differences between CONTROL and CHOPPER were analysed using a *t*-test. If

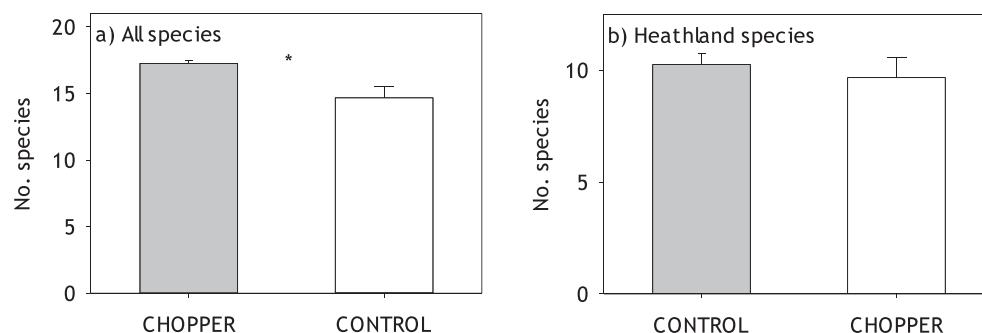


Fig. 1. Mean values (+SE) of all (a) and heathland vascular plant species richness (b) for CHOPPER ($N=4$) and CONTROL ($N=3$). (a) *t*-test, $t=-3.25$, $P<0.05$; (b) *t*-test, $t=0.63$, $P=0.56$. * $P<0.05$.

Table 1

Mean values \pm SE of environmental parameters for CHOPPER ($N=4$) and CONTROL ($N=3$). Differences between treatments were analysed by *t*-test in case of normal distribution and homogeneity of variance, otherwise by the Mann–Whitney *U*-test.

Parameter	CHOPPER	CONTROL	P
Cover (%)			
Total vegetation	82.7 ± 7.1	97.3 ± 0.7	<i>t</i> , n.s.
Herbs/grasses	9.2 ± 2.9	8.0 ± 6.9	<i>t</i> , n.s.
Dwarf shrubs	65.0 ± 5.7	80.7 ± 6.0	<i>t</i> , n.s.
Mosses	6.7 ± 1.9	8.5 ± 1.7	<i>t</i> , n.s.
Lichens	2.2 ± 0.4	0.0 ± 0.0	MWU, n.s.
Bare soil	5.6 ± 3.3	0.0 ± 0.0	MWU, *
Litter	0.1 ± 0.1	1.6 ± 0.3	<i>t</i> , **
Height (cm)			
Herbs/grasses	48.6 ± 2.6	72.9 ± 1.7	<i>t</i> , ***
Dwarf shrubs	24.8 ± 2.2	52.6 ± 3.6	<i>t</i> , ***
Mosses	2.7 ± 0.5	3.7 ± 0.2	<i>t</i> , n.s.
Lichens	1.1 ± 0.3	0.0 ± 0.0	MWU, n.s.
Temperature (°C)	13.7 ± 0.1	12.8 ± 0.2	<i>t</i> , **
Humidity (%)	91.9 ± 1.1	96.6 ± 1.5	<i>t</i> , n.s.

n.s.: Not significant; *** $P<0.001$; ** $P<0.01$; * $P<0.05$.

data were not normally distributed with equal variance, we performed a Mann–Whitney *U*-test.

Community structure of vascular plants, leafhoppers, carabid beetles and spiders with environmental parameters were analysed ecologically using non-metric multidimensional scaling (NMDS) (R packages: VEGAN, MASS). NMDS ordination was based on the Bray–Curtis distance measure and a maximum number of 100 random starts were used to search for a stable solution. To avoid multi-collinearity, we only included environmental parameters with Spearman correlations of $|r_s|<0.8$. Rare species with fewer than three individuals were excluded from the analyses. The environmental parameters were fitted afterwards onto the ordination.

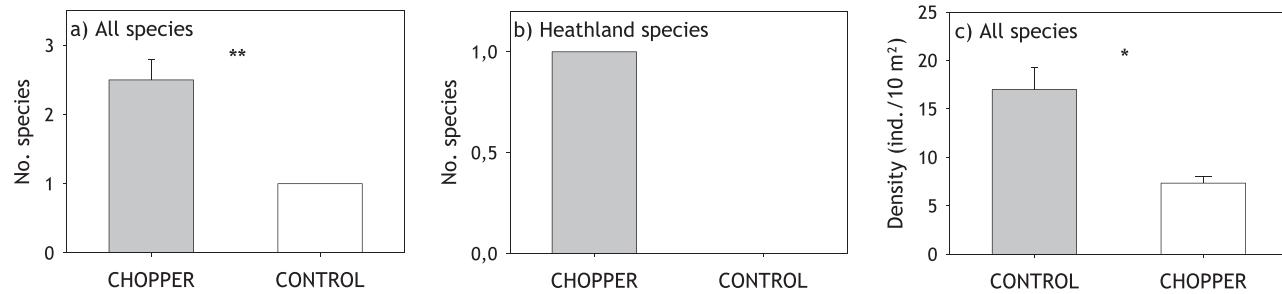
To evaluate whether chipping significantly affects community composition, we applied a permutational multivariate analysis of variance (permutational MANOVA, function: adonis) using the Bray–Curtis distance measure for community data. The statistical analyses were performed using the software packages R-3.1.1 ([R Development Core Team, 2014](#)) including library VEGAN ([Oksanen et al., 2008](#)) and SigmaPlot 12.5.

4. Results

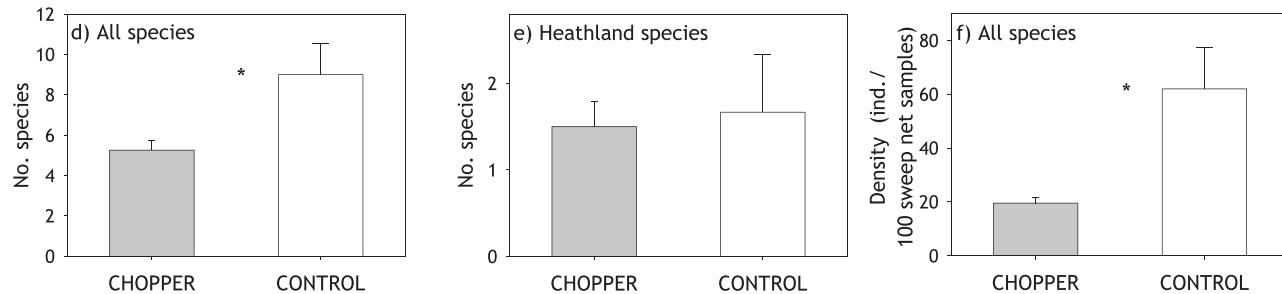
4.1. Environmental parameters

Even thirteen years after chipping, differences in vegetation structure between CHOPPER and CONTROL are still visible. Of the 13 analysed environmental parameters, five parameters significantly differed between the two treatments ([Table 1](#)). CHOPPER was characterised by shorter vegetation (herbs/grasses and dwarf shrubs), more bare soil, less litter and higher temperatures.

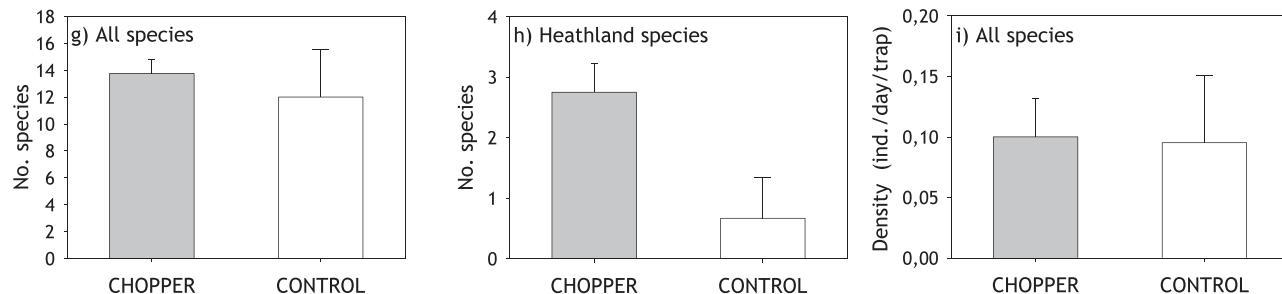
Grasshoppers



Leafhoppers



Carabid beetles



Spiders

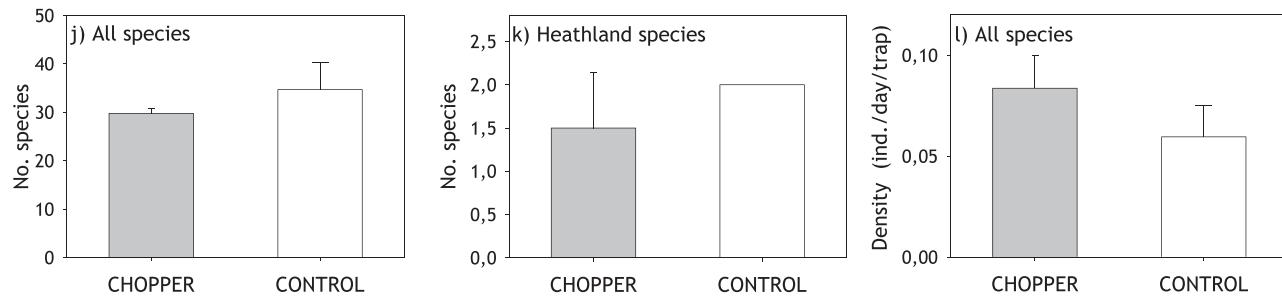


Fig. 2. Mean values (+SE) of species richness (all species and heathland species) and density of grasshoppers (a–c), leafhoppers (d–f), carabid beetles (g–i) and spiders (j–l) for CHOPPER ($N=4$) and CONTROL ($N=3$). Grasshoppers: (a) t-test, $t = -4.39$, $P < 0.01$; (b) U-test, $U = 0.00$, $P = 0.06$; (c) t-test, $t = -3.52$, $P < 0.05$; leafhoppers: (d) t-test, $t = 2.69$, $P < 0.05$; (e) t-test, $t = 0.26$, $P = 0.81$; (f) t-test, $t = 3.23$, $P < 0.05$; carabid beetles: (g) t-test, $t = -0.55$, $P = 0.61$; (h) U-test, $U = 1.00$, $P = 0.14$; (i) t-test, $t = -0.08$, $P = 0.94$; spiders: (j) t-test, $t = 1.00$, $P = 0.360$; (k) t-test, $t = 0.66$, $P = 0.54$; and (l) U-test, $U = 2.00$, $P = 0.23$. *** $P < 0.001$; ** $P < 0.01$; * $P < 0.05$. ind. = individuals.

4.2. Species richness and abundance of vascular plants and arthropods

Altogether, we identified 24 vascular plant species on the study plots (Appendix A). Grasshoppers were identified as belonging to three species, of which *Myrmeleotettix maculatus* was the most

frequently observed with 62% of the 89 total individuals (Appendix B). Moreover, *M. maculatus* was the only heathland species detected and was restricted to CHOPPER. The 261 captured leafhoppers belonged to 22 species. *Jassargus allobrogicus* was the most abundant species (31% of all individuals), followed by *Psammotettix helvolus* (22%) and *Psammotettix nodosus* (11%). In total, we sampled

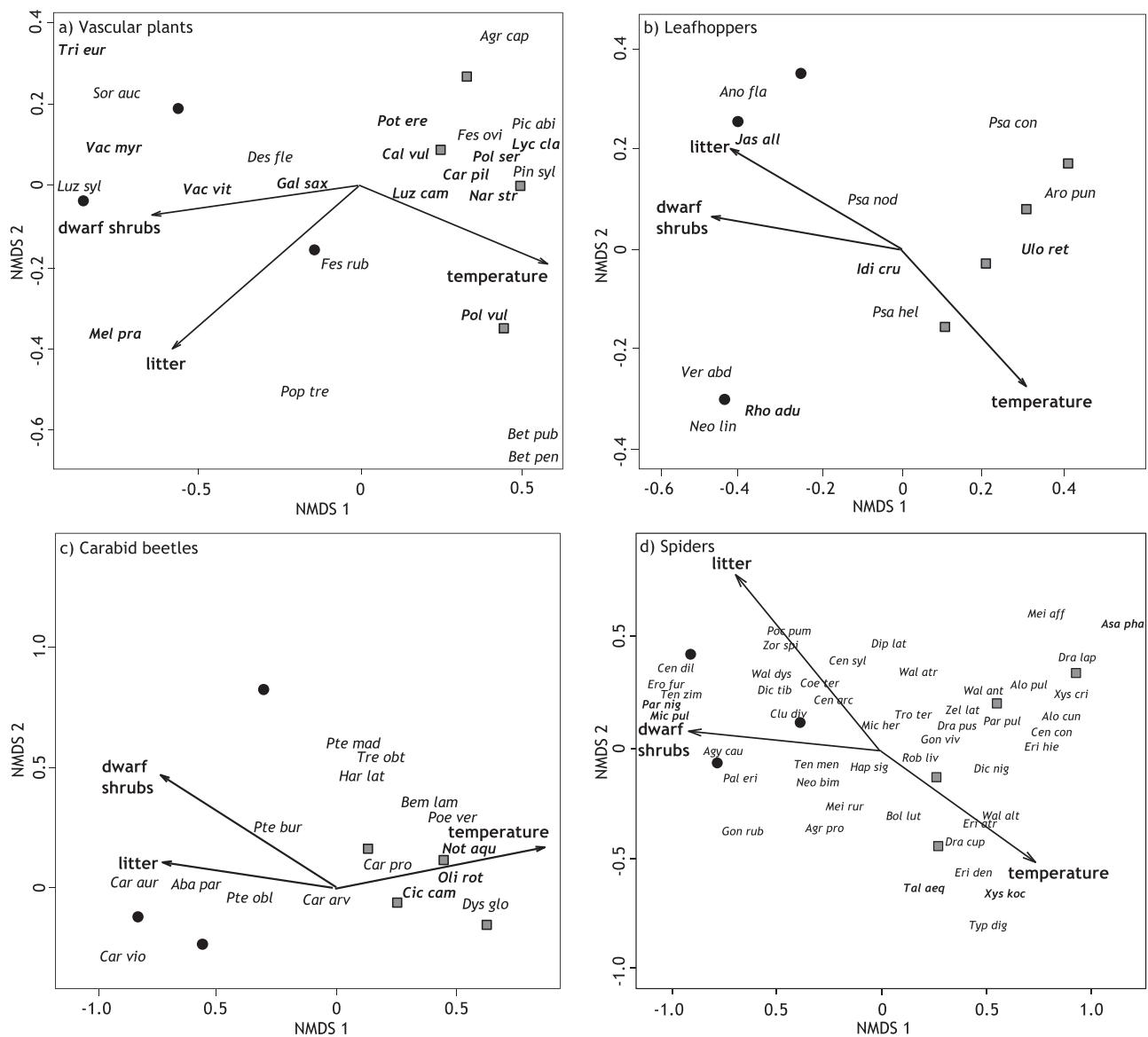


Fig. 3. Results of non-metric multidimensional scaling (NMDS) ordination based on vascular plant (a) (stress = 3.8, 3 dimensions), leafhopper (b) (stress = 2.6, 3 dimensions), carabid (c) (stress = 2.5, 3 dimensions) and spider species (d) (stress = 2.5, 3 dimensions) and environmental parameters. Squares symbolize CHOPPER and circles symbolize CONTROL. Heathland species are highlighted in bold type. For abbreviations of the species names see Appendices A and B.

1844 carabid beetles belonging to 29 species. The most common was *Pterostichus burmeisteri*, representing 52% of the total catch followed by *Carabus problematicus* (12%). Spiders were represented by 1379 individuals belonging to 82 different species. The most frequent species were *Pardosa pullata* (50% of all individuals), *Coelotes terrestris* (6%) and *Trochosa terricola* (4%).

Species richness and the abundance of vascular plants, grasshoppers and leafhoppers significantly responded to chopperring, the first two positively and the latter negatively (Figs. 1 and 2). In contrast, the number of heathland species of all taxonomic groups, as well as carabid beetle and spider diversity and density in general, were not affected by the rejuvenation measurement.

4.3. Vascular plant and arthropod assemblage response to chopperring

The NMDS ordination based on the vascular plant, leafhopper, carabid beetle and spider data revealed a clear separation of the two treatments along the first NMDS axis (Fig. 3). Thereby, the cover of

dwarf shrubs, the cover of litter and the temperature significantly contributed to the segregation of CHOPPER and CONTROL. CHOPPER was characterised by a lower cover of dwarf shrubs ($P < 0.05$) and litter ($P < 0.01$) and, thus, higher temperatures ($P < 0.05$) in comparison to CONTROL. Permutational MANOVA revealed that chopperring significantly influenced the distribution of vascular plant ($F = 10.059$, $df = 1$, $R^2 = 0.67$, $P < 0.05$), leafhopper ($F = 9.529$, $df = 1$, $R^2 = 0.66$, $P < 0.05$), carabid ($F = 2.923$, $df = 1$, $R^2 = 0.40$, $P < 0.05$) and spider ($F = 4.314$, $df = 1$, $R^2 = 0.46$, $P < 0.05$) species. Hence, each treatment had a unique assemblage and, except for carabid beetles, each treatment was characterised by at least some heathland species. For carabid beetles, heathland species were only associated with CHOPPER.

5. Discussion

Thirteen years after rejuvenation measures had been conducted on montane heathlands, the environmental conditions between CHOPPER and CONTROL still differed. CHOPPER was characterised

by shorter vegetation (herbs/grasses and dwarf shrubs), more bare soil, less litter and higher temperatures. Although vascular plants and all of the studied arthropod groups were affected by the environmental changes, their responses were somewhat different. CHOPPER had a unique assemblage of each taxonomic group with at least some heathland species that mainly occurred in this treatment. However, chopperring was the more beneficial management for vascular plants, grasshoppers and carabid beetles. Species richness of vascular plants, as well as grasshopper species richness and density, were highest on the CHOPPER sites. Moreover, all the observed threatened plant species (*Luzula campestris*, *Lycopodium clavatum*, *Nardus stricta*, *Polygala serpyllifolia*, *Polygala vulgaris* and *Potentilla erecta*) except for *Vaccinium vitis-idaea* (LANUV, 2011, Fig. 3) and all heathland grasshopper and carabid beetle species were associated with CHOPPER.

Our study clearly showed that chopperring is a suitable measure to rejuvenate montane heathland vegetation and to create open heathland stands that will have bare ground for more than ten years. The three ericaceous dwarf shrub species, *Calluna vulgaris*, *Vaccinium myrtillus* and *Vaccinium vitis-idaea*, which are characteristic of montane heathlands (Geringhoff & Daniëls, 2003), successfully colonised CHOPPER (Appendix A). In contrast to other rejuvenation measures such as sod-cutting, chopperring does not destroy the root system of the Ericaceae species with their ericoid mycorrhizas (cf. Vergeer et al., 2006) or the soil seed bank. Under such conditions, *Calluna vulgaris* is able to re-establish rapidly from the seed bank, and the two *Vaccinium* species, by vegetative regeneration (Schwabe-Braun, 1980; Geringhoff & Daniëls, 2003; Grime, Hodgson, & Hunt, 2007). According to a descriptive study by Schubert et al. (2008), all three species were present on chopper sites no later than three years after the application of rejuvenation measures.

The keystone structures (cf. Tews et al., 2004) that explain the high relevance of CHOPPER, especially for vascular plants, grasshoppers and carabid beetles, are low-growing vegetation and the bare soil (cf. Chritchley et al., 2013), which result in light and warm microclimatic conditions (cf. Stoutjesdijk & Barkman, 1992). Microsite limitation is one of the driving forces controlling the establishment of species (Münzbergová & Herben, 2005). Less competitive plants with light-germinating seeds, as the observed threatened species, depend on disturbance and the availability of gaps with bare soil (Fleischer, Streitberger, & Fartmann, 2013; Grime et al., 2007; McIntyre, Lavorel, & Tremont, 1995). The three detected grasshopper species (*Chorthippus biguttulus*, *Myrmeleotettix maculatus*, and *Omocestus viridulus*) also rely on bare soil as they oviposit into or near the ground (Fartmann & Mattes, 1997; Wünsch, Schirmel, & Fartmann, 2012). Even the heathland species *Myrmeleotettix maculatus* is restricted to sparse vegetation with bare ground and a warm microclimate (Fartmann et al., 2012; Poniatowski & Fartmann, 2008; Schirmel et al., 2011; Wünsch et al., 2012). The cool montane climate with high precipitation generally offers adverse conditions for cold-blooded organisms that require high ambient temperatures. Consequently, the heathland carabid beetles largely avoid dense heath stands in our study area and are restricted to patches with short turf and bare ground, which offer warm microclimatic conditions (Borchard et al., 2014).

6. Conclusion

In summary, as shown for lowland heathlands (Niemeyer et al., 2007), chopperring is a suitable management measure for use in montane heathland to rejuvenate vegetation with its characteristic arthropod fauna. Due to the intact seed banks and Ericaceae root systems with their mycorrhizas, in combination with the availability of bare soil, heathland vegetation can rapidly regenerate after

chopperring. Although, chopperring resulted in unique assemblages of each studied taxonomic group with at least some heathland species, it was most beneficial for vascular plants, grasshoppers and carabid beetles. The keystone structures explaining the high relevance of CHOPPER, especially for these groups, are low-growing vegetation and bare soil, which result in light and warm microclimatic conditions.

Based on the results of our study, we recommend chopperring as a regular management measure to rejuvenate montane heathland. In addition to the rapid vegetation recovery (cf. Section 5), it has several advantages over sod-cutting, including smaller amounts of waste material, lower costs and a higher removal of nitrogen per unit due to higher nitrogen contents in the organic layer compared to the A-horizon (Niemeyer et al., 2007). Even under the current atmospheric nitrogen deposition rates of 15–20 kg ha⁻¹ y⁻¹ in the study area (Wichink Kruit et al., 2014), which is at the level of the critical loads for heathlands (10–20 kg ha⁻¹ y⁻¹, Achermann & Bobbink, 2003), chopperring creates open heathland stands that will have bare ground for more than ten years.

Borchard et al. (2013) have already noted the lack of early and partly mid-successional stages within the montane heathlands of the study area. Several previously widespread species of the early seral stages of montane heathlands are extinct in heathlands or have strongly declined. This is, for example, the case for the clubmoss species *Diphasiastrum alpinum*, *Diphasiastrum tristachyum*, *Diphasiastrum issleri* and *Lycopodium clavatum* (Geringhoff & Daniëls, 2003; Nieschalk & Nieschalk 1983) and the woodlark (*Lullula arborea*) (Legge, 2009). Moreover, most threatened heathland plant species (this study) and the majority of heathland grasshopper and carabid beetle species are associated with these successional stages in the study area (this study; Borchard et al., 2013, 2014). Chopperring exactly creates these seral stages, which have vital importance to montane heathland conservation. However, there are also some heathland species that depend on later successional stages (this study, Borchard & Fartmann, 2013; Borchard et al., 2013, 2014) or even on mosaics of different stages (Wünsch et al., 2012). Consequently, the management of montane heathland should aim at creating sufficient early successional patches and mosaics of the different seral stages (Schirmel et al., 2010). We suggest that chopperring should be applied to all montane heathlands in a rotational manner and not only for parts of the sites Neuer Hagen and Kahle Pön (cf. Borchard et al., 2013). However, as most montane heathlands in the study area are small, enlargement of the heathlands will be necessary to allow rotational management and the occurrence of several seral stages at one site.

Acknowledgements

We are very grateful to H. Nickel for the identification of difficult leafhoppers and K. Hannig for the determination of critical carabid species. Furthermore, K. Hannig provided helpful support for the classification of heathland carabid beetles. Many thanks to P. Ahlders, M. Borchard, I. Fischer, F. Helbing and T. Hermann who provided help during field work. The study was funded by the Deutsche Bundesstiftung Umwelt (DBU) as part of the research project "Restoration of montane heathland ecosystems in Central Europe". Moreover, we are grateful to two anonymous reviewers for valuable comments on an earlier version of the manuscript.

Appendix A.

List of observed plant species on the study plots. Classification of heathland species is according to Peppler (1992).

Plant species	Abbreviation	Heathland species	CHOPPER	CONTROL	<i>Planaphrodes bifasciata</i>	<i>Pla bif</i>	.	.	2	2
<i>Agrostis capillaris</i>	<i>Agr cap</i>	.	x	x	<i>Psammotettix confinis</i>	<i>Psa con</i>	.	7	5	12
<i>Betula pendula</i>	<i>Bet pen</i>	.	x	.	<i>Psammotettix helvolus</i>	<i>Psa hel</i>	.	19	39	58
<i>Betula pubescens</i>	<i>Bet pub</i>	.	x	x	<i>Psammotettix nodosus</i>	<i>Psa nod</i>	.	10	18	28
<i>Calluna vulgaris</i>	<i>Cal vul</i>	x	x	x	<i>Rhopalopyx adumbrata</i>	<i>Rho adu</i>	x	.	9	9
<i>Carex pilulifera</i>	<i>Car pil</i>	x	x	x	<i>Rhopalopyx preyssleri</i>	<i>Rho pre</i>	.	.	1	1
<i>Deschampsia flexuosa</i>	<i>Des fle</i>	.	x	x	<i>Streptanus marginatus</i>	<i>Str mar</i>	x	.	1	1
<i>Festuca ovina</i>	<i>Fes ovi</i>	.	x	x	<i>Ulopa reticulata</i>	<i>Ulo ret</i>	x	26	1	27
<i>Festuca rubra</i>	<i>Fes rub</i>	.	x	x	<i>Verdanus abdominalis</i>	<i>Ver abd</i>	.	4	4	4
<i>Galium saxatile</i>	<i>Gal sax</i>	x	x	x	No. individuals	.	.	79	182	261
<i>Luzula campestris</i>	<i>Luz cam</i>	x	x	x	No. species	.	6	9	19	22
<i>Luzula sylvatica</i>	<i>Luz syl</i>	.	.	x	Carabid beetles					
<i>Lycopodium clavatum</i>	<i>Lyc cla</i>	x	x	.	<i>Abax parallelepipedus</i>	<i>Aba par</i>	.	13	42	55
<i>Melampyrum pratense</i>	<i>Mel pra</i>	x	.	x	<i>Amara convexior</i>	.	.	1	1	2
<i>Nardus stricta</i>	<i>Nar stri</i>	x	x	x	<i>Amara lunicollis</i>	.	.	.	1	1
<i>Picea abies</i>	<i>Pic abi</i>	.	x	.	<i>Bembidion lampros</i>	<i>Bem lam</i>	.	35	1	36
<i>Pinus sylvestris</i>	<i>Pin syl</i>	.	x	.	<i>Bradycellus caucasicus</i>	.	x	1	.	1
<i>Polygala serpyllifolia</i>	<i>Pol ser</i>	x	x	x	<i>Carabus arvensis</i>	<i>Car arv</i>	.	16	7	23
<i>Polygala vulgaris</i>	<i>Pol vul</i>	x	x	x	<i>Carabus auronitens</i>	<i>Car aur</i>	.	.	4	4
<i>Populus tremula</i>	<i>Pop tre</i>	.	.	x	<i>Carabus glabratus</i>	.	.	.	1	1
<i>Potentilla erecta</i>	<i>Pot ere</i>	x	x	x	<i>Carabus problematicus</i>	<i>Car pro</i>	.	203	20	223
<i>Sorbus aucuparia</i>	<i>Sor auc</i>	.	x	x	<i>Carabus violaceus</i>	<i>Car vio</i>	.	.	3	3
<i>Trientalis europaea</i>	<i>Tri eur</i>	x	.	x	<i>Cicindela campestris</i>	<i>Cic cam</i>	x	97	.	97
<i>Vaccinium myrtillus</i>	<i>Vac myr</i>	x	x	x	<i>Clivina fassor</i>	.	.	1	.	1
<i>Vaccinium vitis-idaea</i>	<i>Vac vit</i>	x	x	x	<i>Cychrus caraboides</i>	.	.	.	1	1
No. species		13	20	19	<i>Dyschirius globosus</i>	<i>Dys glo</i>	.	36	.	36

Appendix B.

List of observed arthropod species on the study plots.

Classification of heathland species: grasshoppers—[Detzel \(1998\)](#); leafhoppers—[Biedermann and Niedringhaus \(2004\)](#); carabid beetles—[Gesellschaft für angewandte Carabidologie \(2009\)](#), [Hannig and Hartmann \(2006\)](#); spiders—[Kreuels and Buchholz \(2006\)](#).

Taxonomic group	Abbreviation	Heathland species	CHOPPER	CONTROL	Sum						
Grasshoppers											
<i>Chorthippus biguttulus</i>	.	.	7	.	7						
<i>Myrmeleotettix maculatus</i>	.	x	56	.	56						
<i>Omocestus viridulus</i>	.	.	4	22	26						
No. individuals	.	.	67	22	89						
No. species	.	1	3	1	3						
Leafhoppers											
<i>Anoscopus flavostriatus</i>	<i>Ano fla</i>	.	.	5	5						
<i>Aphrodes diminuta</i>	<i>Aph dim</i>	.	1	1	2						
<i>Arocephalus punctum</i>	<i>Aro pun</i>	.	12	.	12						
<i>Errhomenus brachypterus</i>	<i>Err bra</i>	.	.	2	2						
<i>Hyledelphax elegantula</i>	<i>Hyl ele</i>	.	.	1	1						
<i>Idiodonus cruentatus</i>	<i>Idi cru</i>	x	2	4	6						
<i>Jassargus allobrogicus</i>	<i>Jas all</i>	x	.	81	81						
<i>Javesella dubia</i>	<i>Jav dub</i>	.	1	.	1						
<i>Laodelphax striatella</i>	<i>Lao stri</i>	.	.	1	1						
<i>Macustus grisezens</i>	<i>Mac gri</i>	.	.	1	1						
<i>Muellerianella brevipennis</i>	<i>Mue bre</i>	.	.	1	1						
<i>Neophilaenus lineatus</i>	<i>Neo lin</i>	.	.	5	5						
<i>Ophiola russeola</i>	<i>Oph rus</i>	x	1	.	1						
						<i>Planaphrodes bifasciata</i>	<i>Pla bif</i>	.	.	2	
						<i>Psammotettix confinis</i>	<i>Psa con</i>	.	7	5	
						<i>Psammotettix helvolus</i>	<i>Psa hel</i>	.	19	39	
						<i>Psammotettix nodosus</i>	<i>Psa nod</i>	.	10	18	
						<i>Rhopalopyx adumbrata</i>	<i>Rho adu</i>	x	.	9	
						<i>Rhopalopyx preyssleri</i>	<i>Rho pre</i>	.	.	9	
						<i>Streptanus marginatus</i>	<i>Str mar</i>	x	.	1	
						<i>Ulopa reticulata</i>	<i>Ulo ret</i>	x	26	1	
						<i>Verdanus abdominalis</i>	<i>Ver abd</i>	.	4	4	
						No. individuals	.	.	1076	768	1,844
						No. species	.	5	21	22	29

Spiders	Spiders									
<i>Agroeca proxima</i>	<i>Agr pro</i>	.	2	2	4	<i>Meioneta affinis</i>	<i>Mei aff</i>	.	6	.
<i>Agyrta cauta</i>	<i>Agy cau</i>	.	.	11	11	<i>Meioneta innotabilis</i>	.	1	1	6
<i>Agyrta conigera</i>	.	.	1	1		<i>Meioneta rurestris</i>	<i>Mei rur</i>	4	3	7
<i>Aloppecosa cuneata</i>	<i>Alo cun</i>	.	5	.	5	<i>Meioneta saxatilis</i>	.	.	2	2
<i>Aloppecosa pulverulenta</i>	<i>Alo pul</i>	.	12	2	14	<i>Mermessus trilobatus</i>	.	1	1	2
<i>Araneus quadratus</i>	.	.	.	1	1	<i>Micaria fulgens</i>	.	x	1	1
<i>Asagena phalerata</i>	<i>Asa pha</i>	x	3	.	3	<i>Micaria pulicaria</i>	<i>Mic pul</i>	x	4	4
<i>Bathyphantes gracilis</i>	.	.	.	2	2	<i>Micrargus herbigradus</i>	.	.	1	1
<i>Bathyphantes parvulus</i>	.	.	.	1	1	<i>Minyriolus pusillus</i>	.	.	1	1
<i>Bolyphantes luteolus</i>	<i>Bol lut</i>	.	3	3	6	<i>Neottiura bimaculata</i>	<i>Neo bim</i>	.	1	3
<i>Centromerita concinna</i>	<i>Cen con</i>	.	18	.	18	<i>Ozyptila trux</i>	.	.	2	0
<i>Centromerus arcarius</i>	<i>Cen arc</i>	.	12	28	40	<i>Pachygnatha degeeri</i>	.	.	1	1
<i>Centromerus dilutus</i>	<i>Cen dil</i>	.	.	5	5	<i>Palliduphantes ericaeus</i>	.	.	1	1
<i>Centromerus pubulator</i>	.	.	.	2	2	<i>Pardosa amentata</i>	.	.	1	1
<i>Centromerus sylvaticus</i>	<i>Cen syl</i>	.	2	5	7	<i>Pardosa lugubris</i>	.	.	1	1
<i>Ceratinella brevis</i>	.	.	1	1	2	<i>Pardosa nigriceps</i>	<i>Par.nig</i>	x	6	6
<i>Clubiona diversa</i>	<i>Clu div</i>	.	2	6	8	<i>Pardosa pullata</i>	<i>Par pul</i>	.	561	127
<i>Clubiona subtilis</i>	.	.	1	.	1	<i>Pelecopsis parallela</i>	.	.	1	1
<i>Clubiona trivialis</i>	.	.	.	1	1	<i>Pocadicnemis pumila</i>	<i>Poc pum</i>	.	28	31
<i>Cnephalocotes obscurus</i>	.	.	2	.	2	<i>Robertus lividus</i>	<i>Rob liv</i>	.	8	6
<i>Coelotes terrestris</i>	<i>Coe ter</i>	.	11	73	84	<i>Robertus scoticus</i>	.	.	2	2
<i>Dictyna arundinacea</i>	.	.	.	1	1	<i>Talavera aequipes</i>	<i>Tal aeq</i>	x	3	.
<i>Dicymbium nigrum brevisetosum</i>	<i>Dic bre</i>	.	3	.	3	<i>Tapinocyba insecta</i>	.	.	1	1
<i>Dicymbium tibiale</i>	<i>Dic tib</i>	.	.	3	3	<i>Tenuiphantes alacris</i>	.	.	1	1
<i>Diplocephalus latifrons</i>	<i>Dip lat</i>	.	3	5	8	<i>Tenuiphantes mensei</i>	<i>Ten men</i>	.	4	31
<i>Drassodes cupreus</i>	<i>Dra cup</i>	.	20	.	20	<i>Tenuiphantes zimmermanni</i>	<i>Ten zim</i>	.	6	6
<i>Drassodes lapidosus</i>	<i>Dra lap</i>	.	13	1	14	<i>Tiso vagans</i>	.	.	1	1
<i>Drassyllus pusillus</i>	<i>Dras pus</i>	.	33	3	36	<i>Trochosa terricola</i>	<i>Tro ter</i>	.	34	24
<i>Erigone atra</i>	<i>Eri atr</i>	.	6	.	6	<i>Typhochrestus digitatus</i>	.	x	5	.
<i>Erigone dentipalpis</i>	<i>Eri den</i>	.	4	.	4	<i>Walckenaeria alticeps</i>	.	.	6	7
<i>Erigonella hiemalis</i>	<i>Eri hie</i>	.	6	.	6	<i>Walckenaeria antica</i>	.	.	2	3
<i>Ero furcata</i>	<i>Ero fur</i>	.	.	3	3	<i>Walckenaeria atrotibialis</i>	.	.	1	1
<i>Euophrys frontalis</i>	.	.	.	2	2	<i>Walckenaeria cucullata</i>	.	.	1	1
<i>Evansia merens</i>	.	.	1	.	1	<i>Walckenaeria dysderoides</i>	.	.	1	1
<i>Floronia bucculenta</i>	.	.	.	1	1	<i>Walckenaeria furcillata</i>	.	.	1	1
<i>Gonatium rubens</i>	<i>Gon rub</i>	.	4	14	18	<i>Walckenaeria monoceros</i>	.	.	1	1
<i>Gongylidiellum latebricola</i>	.	.	.	1	1	<i>Xysticus bifasciatus</i>	.	x	2	.
<i>Gongylidiellum vivum</i>	<i>Gon viv</i>	.	15	5	20	<i>Xysticus cristatus</i>	<i>Xys cri</i>	.	5	1
<i>Haplodrassus signifer</i>	<i>Hapl sig</i>	.	12	2	14	<i>Xysticus kochi</i>	<i>Xys koc</i>	x	4	4
<i>Heliophanus dampfi</i>	.	.	.	1	1	<i>Zelotes latreillei</i>	<i>Zel lat</i>	.	20	3
						<i>Zora spinimana</i>	<i>Zor spi</i>	.	3	12
						No. individuals	.	.	899	480
						No. species	.	8	53	59
								.	82	1,379

References

- Achermann, B., & Bobbink, R. (2003). Empirical critical loads for nitrogen. *Proceedings of an expert workshop, 11–13 November 2002, Berne. Environmental Documentation No. 164. Berne: Swiss Agency for the Environment, Forests and Landscape.*
- Bellmann, H. (2006). *Der Kosmos Heuschreckenführer*. Stuttgart: Kosmos: Die Arten Mitteleuropas sicher bestimmen.
- Biedermann, R., & Niedringhaus, R. (2004). *Die Zikaden Deutschlands. Bestimmungstafeln für alle Arten*. Schäfer: WABV.
- Bobbink, R., Hornung, M., & Roelofs, G. M. (1998). The effects of air-borne nitrogen pollutants on species diversity in natural and semi-natural European vegetation: a review. *Journal of Ecology*, 86, 717–738.
- Borchard, F., Buchholz, S., Helbing, F., & Fartmann, T. (2014). Carabid beetles and spiders as bioindicators for the evaluation of montane heathland restoration on former spruce forests. *Biological Conservation*, 178, 185–192.
- Borchard, F., & Fartmann, T. (2014). Effects of montane heathland restoration on leafhopper assemblages (Auchenorrhyncha). *Restoration Ecology*, 22, 749–757.
- Borchard, F., Schulte, A. M., & Fartmann, F. (2013). Rapid response of Orthoptera to restoration of montane heathland. *Biodiversity Conservation*, 22, 687–700.
- Breder, C., & Schubert, W. (1998). Hochheide-management am Beispiel des Naturschutzgebietes "Neuer Hagen" (Hochsauerlandkreis). *Jahrbuch Natursch Hessen*, 3, 208–215.
- Britton, A. J., Pearce, I. S. K., & Jones, B. (2005). Impacts of grazing on montane heath vegetation in Wales and implications for the restoration of montane areas. *Biological Conservation*, 125, 515–524.
- Buchholz, S. (2010). Ground spider assemblages as indicators for habitat structure in inland sand ecosystems. *Biodiversity Conservation*, 19, 2565–2595.
- Buchholz, S., Hannig, K., & Schirmel, J. (2013). Losing uniqueness—shifts in carabid species composition during dry grassland and heathland succession. *Animal Conservation*, 16, 661–670.
- Bullock, J. M., & Pakeman, R. J. (1996). Grazing of lowland heath in England: management methods and their effects on heathland vegetation. *Biological Conservation*, 79, 1–13.
- Chapin, F. S., Zavaleta, E. S., Eviner, V. T., Naylor, R. L., Vitousek, P. M., Reynolds, H. L., et al. (2000). Consequences of changing biodiversity. *Nature*, 405, 234–242.
- Chritley, C. N. R., Mitchell, R. J., Rose, R. J., Griffiths, J. B., Jackson, E., Scott, H., et al. (2013). Re-establishment of *Calluna vulgaris* (L.) Hull in an eight-year grazing experiment on upland acid grassland. *Journal of Nature and Conservation*, 21, 22–30.
- Clewell, A. F., & Aronson, J. (2007). *Ecological restoration: principles, values, and structure of an emerging profession*. Washington: Island Press.
- Coray, A., & Lehmann, A. W. (1998). Taxonomie der Heuschrecken Deutschlands (Orthoptera): formale Aspekte der wissenschaftlichen Namen. *Articulata Beiheft*, 7, 63–152.
- Detzel, P. (1998). *Die Heuschrecken Baden-Württembergs*. Stuttgart: Ulmer.
- Dobson, A. P., Bradshaw, A. D., & Baker, A. J. M. (1997). Hopes for the future: restoration ecology and conservation biology. *Science*, 277, 515–522.
- European Community (1992). The habitats directive 92/43/EEC. Brussels, European Community.
- Fartmann, T., Behrens, M., & Loritz, H. (2008). Orthopteran communities in the conifer-broadleaved woodland zone of the Russian far east. *European Journal of Entomology*, 105, 673–680.
- Fartmann, T., & Mattes, H. (1997). Heuschreckenfauna und Grünland-Bewirtschaftungsmaßnahmen und Biotopmanagement. *Arbian Institut Landschaftsökologie*, 3, 179–188.
- Fartmann, T., Krämer, B., Stelzner, F., & Poniatowski, D. (2012). Orthoptera as for succession in steppe grassland. *Ecological Indicators*, 20, 337–344.
- Felton, M., & Marsden, L. (1990). *Heather regeneration in England and Wales: a feasibility study for the Department of the Environment*. Petersborough: Nature Conservancy Council.
- Fleischer, K., Streitberger, M., & Fartmann, T. (2013). The importance of disturbance for the conservation of a low-competitive herb in mesotrophic grasslands. *Biologia*, 68, 398–403.
- Frede, A. (1998). Erfahrungen mit der Heidebiotoppflege im Landkreis Waldeck-Frankenberg aus Sicht der Unteren Naturschutzbehörde. *Jahrbuch Natursch Hessen*, 3, 205–207.
- Gardiner, T., Hill, J., & Chesmore, D. (2005). Review of the methods frequently used to estimate the abundance of Orthoptera in grassland ecosystems. *Journal of Insect Conservation*, 9, 151–173.
- Geringhoff, H. J. T., & Daniëls, F. J. A. (2003). Zur Syntaxonomie des *Vaccinio-Callunetum* Büker 1942 unter besonderer Berücksichtigung der Bestände im Rothaargebirge. *Abhandlungen Westfälischen Museum Naturkunde*, 65, 1–80.
- Gesellschaft für angewandte Carabidologie, 2009. Lebensraumpräferenzen der Laufkäfer Deutschlands. Wissensbasierter Katalog. Angew. Carabidologie Suppl., V, 1–48.
- Gimmingham, G. H. (1992). *The lowland heathland management handbook*. Peterborough: English Nature Science 8.
- Grime, J. P., Hodgson, J. G., & Hunt, R. (2007). *Comparative plant ecology* (2nd ed.). Dalbeattie: Castlepoint Press.
- Haaland, S. (2003). *Feuer und Flamme für die Heide: 5000 Jahre Kulturlandschaft in Europa*. Bremen: Hauschild.
- Hahn, V. (2007). Neubegründung von Bergheideflächen auf dem Kahlen Asten. *Natur in NRW*, 2, 42–44.
- Hannig, K., & Hartmann, V. (2006). Die Laufkäferfauna (Col., Carabidae) ausgewählter hochmontaner Standorte im sauerländischen Rothaargebirge. *Nature Heimat*, 66, 1–12.
- Hoffmann, A. (1998). "Hochheide"—eine Heide mit eigenen Gesetzmäßigkeiten. *Jahrbuch Natursch Hessen*, 3, 216–218.
- Ingrisch, S., & Köhler, G. (1998). *Die heuschrecken mitteleuropas*. Magdeburg: Westarp Wissenschaften.
- Jäger, E., & Werner, K. (2001). *Rothmaler—exkursionsflora von Deutschland* (10th ed.). Heidelberg: Berlin: Spektrum: Gefäßpflanzen: Atlasband.
- Keienburg, T., & Prüter, J. (2004). Conservation and management of Central European lowland heathlands. Case study: Lüneburger Heide nature reserve, North-West Germany. *Mitt Alfred Toepper Academy Naturschutz*, 15, 1–64.
- Kreuels, M., & Buchholz, S. (2006). Ecology, distribution and status of endangerment of spiders of North Rhine-Westphalia. First revised version of the Red Data Book of the spiders (Arachnida: Araneae) including additional ecological information, their distribution in North Rhine-Westphalia and the new guidelines of the BfN (Bundesamt für Naturschutz) regarding the status of endangerment. Havixbeck-Hohenholte: Wolf & Kreuels.
- Kunz, G., Nickel, H., & Niedringhaus, R. (2011). *Fotoatlas der Zikaden Deutschlands. Fründ*: WABV.
- LANUV—Landesamt für Natur, Umwelt und Verbraucherschutz (2011). Rote Liste der gefährdeten Pflanzen, Pilze und Tiere in Nordrhein-Westfalen. Fachbericht 36. Vol. 1: Pflanzen und Pilze. Recklinghausen: LANUV.
- Legge, H. (2009). Zur Brutverbreitung der Heideleiche *Lullula arborea* im Hochsauerlandkreis. *Charadrius*, 45, 213–218.
- Lindemann, K.-O. (1993). Die Rolle von *Deschampsia flexuosa* in *Calluna*-Heiden mitteleuropas. *NNA-Berichte*, 5, 20–39.
- Maron, M., Hobbs, R. J., Moilanen, A., Matthews, J. W., Christie, K., Gardner, T. A., et al. (2012). Faustian bargains? Restoration realities in the context of biodiversity offset policies. *Biological Conservation*, 155, 141–148.
- McIntyre, S., Lavorel, S., & Tremont, R. (1995). Plant life-history attributes: their relationship to disturbance response in herbaceous vegetation. *Journal of Ecology*, 83, 1–44.
- Michael, N. (1993). *The lowland heathland management booklet*. Peterborough: English Nature Science 11.
- Müller-Motzfeld, G. (2006). Die Käfer Mitteleuropas. Adephaga 1: Carabidae (Laufkäfer). In H. Freude, K. W. Harde, & G. A. Lohse (Eds.), *Die Käfer Mitteleuropas* (Vol. 2). Heidelberg: Spektrum.
- Münzbergová, M., & Herben, T. (2005). Seed, dispersal, microsite, habitat and recruitment limitation: identification of terms and concepts in studies of limitation. *Oecologia*, 145, 1–8.
- Nentwig, W., Hänggi, A., Kropp, C., & Blick, T. (2013). Central European spiders –determination key version 09.2013. <<http://www.araneae.unibe.ch/index.html>> (accessed 01.10.14.).
- Nickel, H., & Hildebrandt, J. (2003). Auchenorrhyncha communities as indicators of disturbance in grasslands (Insecta, Hemiptera)—a case study from the Elbe flood plains (northern Germany). *Agriculture Ecosystems and Environment*, 98, 183–199.
- Niemeyer, M., Niemeyer, T., Fottner, S., Härdtle, W., & Mohamed, A. (2007). Impact of sod-cutting and choppering on nutrient budgets of dry heathlands. *Biological Conservation*, 134, 344–353.
- Nieschalk, A., & Nieschalk, C. (1983). Hochheiden im Waldecker Upland und angrenzenden westfälischen Sauerland. *Philippia*, 2, 127–150.
- Noordijk, J., Schaffers, A. P., Heijerman, T., & Sýkora, K. V. (2011). Using movement and habitat corridors to improve the connectivity for heathland carabid beetles. *Journal of Nature Conservation*, 19, 276–284.
- Oberdorfer, E. (2001). *Pflanzensoziologische Exkursionsflora für Deutschland und angrenzende Gebiete* 8. Aufl. Stuttgart: Ulmer.
- Oksanen, J., Kindt, R., Legendre, P., O'Hara, B., Simpson, G.L., Solymos, et al. (2008). The vegan Package Version 2.0–6. <<http://cran.r-project.org/>>, <<http://vegan.r-forge.r-project.org/>> (accessed 01.10.14.).
- Peppler, C. (1992). Die Borstgrasrasen (Nardetalia) Westdeutschlands. *Diss Botany*, 192, 1–404.
- Platnick, N.I. (2013). The world spider catalog, Version 14. American Museum of Natural History. <<http://research.amnh.org/iz/spiders/catalog/>> (accessed 01.10.14.).
- Plieninger, T., Höchtl, F., & Spek, T. (2006). Traditional land-use and nature conservation in European landscapes. *Environmental Science and Policy*, 9, 317–321.
- Poniatowski, D., & Fartmann, T. (2008). The classification of insect communities: lessons from orthopteran assemblages of semi-dry calcareous grasslands in central Germany. *European Journal of Entomology*, 105, 659–671.
- Poniatowski, D., & Fartmann, T. (2011). Dispersal capability in a habitat specialist bush cricket: the role of population density and habitat moisture. *Ecological Entomology*, 36, 717–723.
- R Development Core Team, 2014. R: a language and environment for statistical computing. R Foundation for statistical computing. <<http://www.R-project.org>> (accessed 01.10.14.).
- Rainio, J., & Niemelä, J. (2003). Ground beetles (Coleoptera: Carabidae) as bioindicators. *Biodiversity Conservation*, 12, 487–506.
- Roberts, M. J. (1987). *.. The spiders of Great Britain and Ireland, linyphiidae and checklist* (Vol. 2). Colchester: Harley Books.
- Roberts, M. J. (1998). *Spinnen gids*. Baarn: Tirion.

- Sala, O. E., Chapin, F. S., Armesto, J. J., Berlow, E., Bloomfield, J., Dirzo, R., et al. (2000). Biodiversity—global biodiversity scenarios for the year 2100. *Science*, *287*, 1770–1774.
- Schirmel, J., & Buchholz, S. (2011). Response of carabid beetles (Coleoptera: Carabidae) and spiders (Araneae) to coastal heathland succession. *Biodiversity Conservation*, *20*, 1469–1482.
- Schirmel, J., & Fartmann, T. (2014). Coastal heathland succession influences butterfly community composition and threatens endangered species. *Journal of Insect Conservation*, *18*, 111–120.
- Schirmel, J., Blindow, I., & Fartmann, T. (2010). The importance of habitat mosaics for Orthoptera (Caelifera and Ensifera) in dry heathlands. *European Journal of Entomology*, *107*, 129–132.
- Schirmel, J., Mantilla-Contreras, J., Blindow, I., & Fartmann, T. (2011). Impacts of succession and grass encroachment on Orthoptera in heathlands. *Journal of Insect Conservation*, *15*, 633–642.
- Schubert, W., Trappman, R., & Gräf, B. (2008). Erhalt und restitution von heiden im östlichen hochsauerlandkreis. *Abhandlungen Westf Museum Naturkde*, *70*(3/4), 261–276.
- Schwabe-Braun, A. (1980). Eine pflanzensoziologische modelluntersuchung als grundlage für naturschutz und planung. Weidfeld-vegetation im Südschwarzwald: Geschichte der Nutzung-Gesellschaften und ihre Komplexe-Bewertung für den Naturschutz. *Urbs et Regio*, *18*, 1–212.
- Ssymank, A., Hauke, U., Rückriem, C., & Schröder, E. (1998). Das europäische schutzgebietssystem NATURA. BfN-Handbuch zur umsetzung der fauna-flora-habitat-richtlinie und der Vogelschutz-Richtlinie. *Schriftenreihe für Landschaftspflege und Naturschutz*, (53), 1–560.
- Stoutjesdijk, P., & Barkman, J. J. (1992). *Microclimate, vegetation and fauna*. Uppsala: Opulus Press.
- Symes, N., & Day, J. (2003). *A practical guide to the restoration and management of lowland heathland*. Sandy: RSPB.
- Tews, J., Brose, U., Grimm, V., Tielbörger, K., Wichmann, M. C., Schwager, M., et al. (2004). Animal species diversity driven by habitat heterogeneity/diversity: the importance of keystone structures. *Journal of Biogeography*, *31*, 79–92.
- Thompson, D. B. A., & MacDonald, A. J. (1995). Upland heather moorland in Great Britain: a review of international importance, vegetation change and some objectives for nature conservation. *Biological Conservation*, *71*, 163–178.
- Trautner, J., & Geigenmüller, K. (1988). Sandlaufkäfer. Laufkäfer. Illustrierter Schlüssel zu den Cicindeliden und Carabiden Europas. Aichtal: Margraf.
- Wichink Kruit, R., Schaap, M., Segers, A., Heslinga, D., Builtjes, P., Banzhaf, S., & Scheuschner, T. (2014). Modelling and mapping of atmospheric nitrogen and sulphur deposition and critical loads for ecosystem specific assessment of threats to biodiversity in Germany—PINETI (Pollutant INput and EcosyTem Impact). Substudy Report 1. Texte Umweltbundesamt, 60/2014, 1–170.
- Usher, M. B. (1992). *Management and diversity of arthropods in Calluna heathland*. *Biodiversity Conservation*, *1*, 63–79.
- Usher, M. B., & Thompson, D. B. A. (1993). Variation in the upland heathlands of Great Britain: conservation importance. *Biological Conservation*, *66*, 69–81.
- Vergeer, P., Van den Berg, L. J. L., Baar, J., Ouborg, N. J., & Roelofs, J. G. M. (2006). The effect of turf cutting on plant and arbuscular mycorrhizal spore recolonisation: implications for heathland restoration. *Biological Conservation*, *129*, 226–235.
- Webb, N. R. (1998). The traditional management of European heathlands. *Journal of Applied Ecology*, *35*, 987–990.
- Wessel, W. W., Tietema, A., Beier, C., Emmett, B. A., Penuelas, J., & Riis-Nielsen, T. (2004). A qualitative ecosystem assessment for different shrublands in Western Europe under impact of climate change. *Ecosystems*, *7*, 662–671.
- Wisskirchen, R., & Haeupler, H. (1998). *Standardliste der Farn- und Blütenpflanzen Deutschlands*. Stuttgart: Ulmer.
- Wünsch, Y., Schirmel, J., & Fartmann, T. (2012). Conservation management of coastal dunes for Orthoptera has to consider oviposition and nymphal preferences. *Journal of Insect Conservation*, *16*, 501–510.