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Status and restoration potential of heathlands and sand grasslands in the southwest of Luxembourg

Zustand und Renaturierungspotential von Heiden und Sandmagerrasen im Südwesten Luxemburgs

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Abstract

In Europe, semi-natural nutrient-poor ecosystems such as sand grasslands and heathlands have shown extreme declines in surface area and species richness within the last century. The remaining sites are hence of high conservation value. This study analysed the vascular plant species inventory of established and recently restored heathlands and sand grasslands in the southwest of Luxembourg. Analyses to explain differences in vegetation composition between "old" (remnant sites or sites restored a long time ago) and "new" (recently restored) sites in relation to environmental variables were carried out with DCAs and ANOVA/Mann-Whitney-U tests, respectively. The vegetation of old heathlands had few character species of typical heathland communities (*Calluno-Ulicetea*, *Nardetalia*), whereas new heathland sites were preponderantly marked by taxa of meso- or eutrophic grasslands and ruderal communities. New heathland sites mainly differed from old sites by higher soil phosphorus contents. Sand grassland vegetation was species-rich and composed by species of the *Sedo-Scleranthetea* and *Festuco-Brometea*. With increasing age of the sites, vegetation composition shifted to grass dominance with species of the *Molinio-Arrhenateretea*. New sand grasslands differed from old sand grasslands by higher soil pH, higher soil potassium content and lower graminoid cover. The differences between new and old sites of both habitat types could mainly be explained by successional processes or were a result of topsoil removal. In some cases, former anthropogenic impact at or in close proximity of restored sites resulted in unsuitable conditions, such as alkaline soil on former landfill sites or highly eutrophic soil due to intensive agriculture. Future management options for the study sites are discussed.

Keywords: *Calluna vulgaris*, *Calluno-Ulicetea*, conservation, habitat management, *Sedo-Scleranthetea*, topsoil removal

Erweiterte deutsche Zusammenfassung am Ende des Artikels

1. Introduction

In Europe, semi-natural nutrient-poor ecosystems such as heathlands and sand grasslands have sharply declined over the last century due to either conversion into arable land or abandonment of grazing with subsequent afforestation or tree encroachment (POSCHLOD & SCHUMACHER 1998, BAKKER & BERENDSE 1999). In Luxembourg, these changes have led to

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a decrease of dry heathlands from 32,500 ha in the 19th century (COLLING & SCHOTEL 1991) to currently 19 ha of heathlands (spread over 37 locations) and ca. 9 ha of sand grasslands (spread over 60 sites) (MINISTÈRE DU DÉVELOPPEMENT DURABLE ET DES INFRASTRUCTURES 2014a). At these small remnant sites, the characteristic vegetation is often negatively affected by soil acidification and nitrogen input from atmospheric depositions and from surrounding agriculture (BOBBINK et al. 1998, ROEM et al. 2002, DUPRÈ et al. 2010, DISE et al. 2011). The high soil nitrogen input often leads to a shift in the floristic composition, shrub encroachment and consequently a loss of endangered species (MÅRTENSSON & OLSSON 2010, FAUST et al. 2012). In Luxembourg, most of the remnant heathlands and sand grasslands are in a bad ecological status (SCHNEIDER & NAUMANN 2013, MINISTÈRE DU DÉVELOPPEMENT DURABLE ET DES INFRASTRUCTURES 2014a).

As they are valuable habitats with a high number of specific plant species, heathlands are protected under the Habitats Directive and sand grasslands under the Luxembourgish law for the protection of nature and natural resources (LOI DU 19 JANVIER 2004, COUNCIL OF EUROPEAN COMMUNITIES 1992). To actively counteract the loss of these valuable habitats, heathlands and sand grasslands have been subject to conservation and restoration efforts for decades across Central Europe (BAKKER & BERENDSE 1999, HÄRDTLE et al. 2009, SCHWABE & KRATOCHWIL 2009). Within the framework of the "National plan for nature protection 2" ([original in French: Plan National concernant la Protection de la Nature 2] MINISTÈRE DU DÉVELOPPEMENT DURABLE ET DES INFRASTRUCTURES 2017), the extension of the national heathland sites through restorative measures by up to a total of 200 ha is envisaged.

Although target species might successfully re-establish from the seed bank (e.g. GILHAUS et al. 2015), natural re-colonisation is often restricted by seed availability (BOSSUYT & HONNAY 2008) - particularly on formerly abandoned or agriculturally managed sites. Moreover, the high degree of habitat fragmentation in Western Europe (ENVIRONMENTAL AGENCY 2010) hampers seed dispersal between sites, thus preventing spontaneous regeneration of target communities even further (DONATH et al. 2003). Finally, high soil nitrogen and phosphorus residues on formerly fertilized sites hamper the restoration of plant communities adapted to nutrient-poor conditions (HÖLZEL 2009, DISE et al. 2011, CEULEMANS et al. 2014).

However, several restorative measures for heathlands and sand grasslands have been proven successful in overcoming these limitations: both topsoil removal and topsoil inversion proved to be extremely efficient to counteract the effects of elevated soil nutrient contents and low pH values (HÖLZEL & OTTE 2003, TÖRÖK et al. 2011, GILHAUS et al. 2015). Similarly the transfer of seed bearing vegetation cuts or rakings from donor sites was shown to be adequate methods to overcome limited seed dispersal (EICHBERG et al. 2010, PYWELL et al. 2011). Subsequently, the introduction of an appropriate long-term management regime on restored sites is crucial for the long-term success (BAKKER & BERENDSE 1999, GILHAUS et al. 2015).

In order to expand heathlands and sand grasslands in Luxembourg, several restoration projects were initiated over the last years. However, a recent in depth evaluation of the restored habitats, potentially highlighting the factors that influence restoration success, is still missing, as well as a phytosociological classification of the local associations of the two habitats. Our study attempts to close these gaps by assessing a variety of factors on established and recently restored sites in the southwest of Luxembourg and performing a syntaxonomic classification of the two habitats. The study focussed on vegetation compostion, but butterfly and *Orthoptera* communities were recorded as well and the respective results will be published later.

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Species richness and vegetation were analysed in several study sites in an intensively used landscape with strongly fragmented remnants of semi-natural grassland habitats. We differed between "new" sites, which were restored only recently (within the last ten years), and "old" sites, which were either restored over ten years ago, or persisted over decades through continuous low-intensive management. All restoration projects, as well as the current management on all the sites bar one, were carried out by the local nature conservation syndicate SICONA. The study aims specifically at answering the following questions: (1) What is the plant species composition of the studied heathland and sand grassland sites in the southwest of Luxembourg? (2) Does this composition differ between old and newly restored sites? (3) Which environmental variables can explain any observed differences in species composition in general and after restoration in particular? (4) Is the vegetation in the two habitats characterized by clearly definable associations?

2. Study area and sites

The study was conducted in the Eisch-Mamer-Gutland (250–400 m a.s.l.) which is situated in the southwest of Luxembourg (Fig. 1A). This area harbours some old sites of heathland and sand grassland ecosystems and is characterised by its bedrock, Luxembourg sandstone (hard yellow Liassic sandstone with calcareous binder). The rivers, which have given rise to the name of the area, have cut steep and narrow valleys into the sandstone. The plateau areas with sandy, permeable and thus nutrient-poor soils (which often are podzolic) are mostly afforested, while areas where the soils developed from loamy and clayey marne or loess layers are used agriculturally. The climate is Atlantic with mean annual temperatures of 8–9 °C (15 °C during summer) and mean annual precipitations of 800–850 mm (320–340 mm during summer) (EFOR 1995).

The study was carried out on 12 sites (Fig. 1B). Detailed information on the study sites is given in Table 1. Eleven of the sites are currently being managed by SICONA and one site is managed by the national administration for nature and forests. All sites but two were smaller than 1 ha. Five sites were heathlands (H) and seven sites characterised by sand grassland (S). The H and S sites were split up into two categories, namely old and new sites. Old sites have been in a similarly favourable ecological state for at least 10 years. These sites have either been created by traditional management over the course of the last century and then been taken over by SICONA for management, or they have been subject to restorative measures over 10 years ago and were consecutively managed by SICONA. New sites, on the other hand, were restored less than 10 years ago. In the context of this study, the designations "restoration" or "restorative measure" always stand for removal of the upper soil layers (topsoil removal) followed by transfer of freshly mown plant material (sensu HÖLZEL & OTTE 2003). The plant material used for the restoration process was obtained on the old sites at the moment of seed maturity of most of the characteristic species. Often the plant material was applied as a mixture from different old sites. The restored site S7* was the only exception to this, because topsoil was not removed but sealed with a layer of deep sand substrate.

All sites except H1 were managed by mowing once a year in July. On H2 and H3, this regime intended to negatively affect species undesired from a nature conversation perspective, such as *Pteridium aquilinum* and *Calamagrostis epigejos*. H1 was grazed once a year (late summer - autumn) by a 300–400 strong sheep flock for 3–4 days.

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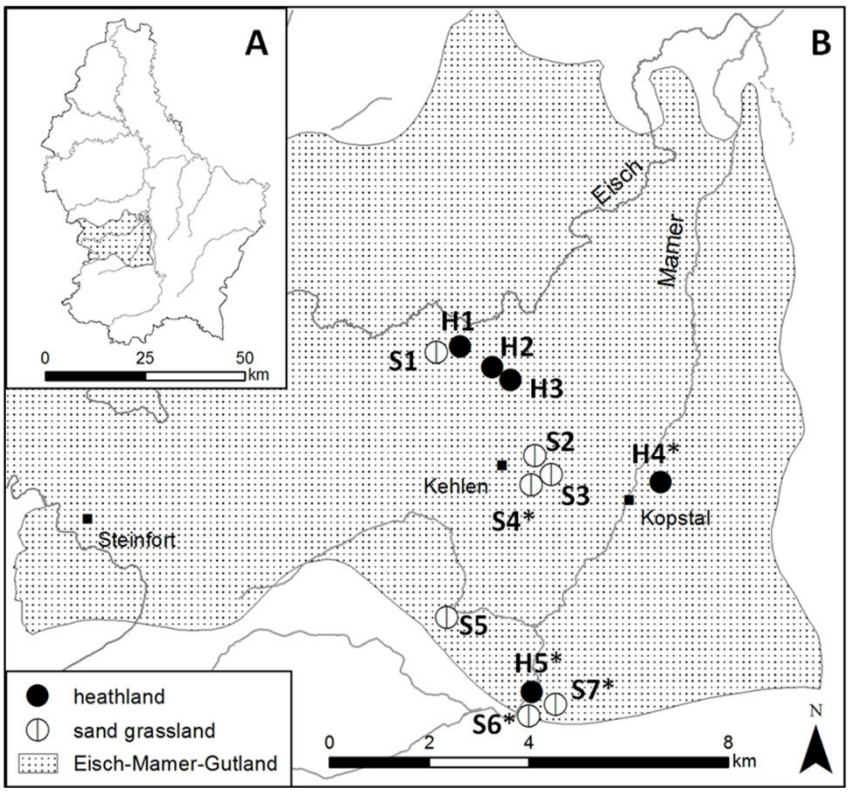

Fig. 1. Map of the study area "Eisch-Mamer Gutland" in the southwest of Luxembourg **A)** and the location of the study sites **B)**. "H" is the abbreviation for heathland and "S" for sand grassland. New sites are marked with *. These sites have been restored less than 10 years ago. The other heathland and sand grassland sites have been restored over 10 years ago or are a result of long-lasting extensive management. (Source of the digital data base: ADMINISTRATION DU CADASTRE ET DE LA TOPOGRAPHIE LUXEMBOURG 2000).

Abb. 1. Karte des Untersuchungsgebietes im Südwesten Luxemburgs **A)** und die Lage der Untersuchungsflächen **B)**. „H" steht für Heide und „S" für Sandmagerrasen. Neue Flächen sind mit einem * markiert und wurden vor weniger als 10 Jahren renaturiert. Die restlichen „H"- und „S"-Flächen wurden vor mehr als 10 Jahren renaturiert oder sind das Ergebnis jahrzehntelanger traditioneller Bewirtschaftung. (Quelle der digitalen Kartengrundlage: ADMINISTRATION DU CADASTRE ET DE LA TOPOGRAPHIE LUXEMBOURG 2000).

The vegetation of the old heathland sites was mainly characterised by a high cover of the shrub *Calluna vulgaris* and a dense cover of bryophytes (Fig. 2a). However, many woody species had already invaded the sites. Moreover, *Pteridium aquilinum* formed a dense cover in some parts of the old sites. The new heathland sites had been restored two years prior to the sampling and did not yet resemble the old sites. However, *Calluna vulgaris* plants were already present, but just as seedlings. Species of mesophile grassland and ruderals dominated the new heathland sites (Fig. 2b).

The old sand grassland sites ranged from grass-dominated to herb-dominated stands (Fig. 2c). Overall, they had a denser vegetation and a lower amount of bare soil than new sites. The latter presented a high diversity of species and were rich in flowers (Fig. 2d).

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Table 1. Information on the study sites. For abbreviations check Fig. 1.

Tabelle 1. Informationen zu den Untersuchungsflächen. Abkürzungen siehe Abb. 1.

designation	field-name	coordinates Gauss-Luxembourg	(target) vegetation	size [ha]	year of restoration	use before restoration
heathlands						
H1	Telpeschholz 1	69572 E, 84006 N	H	1.47	.	.
H2	Heedchen 1	70399 E, 83651 N	H	0.44	.	.
H3	Heedchen 2	70423 E, 83563 N	H	0.15	2002	overgrown heathland
H4*	Fënnef Buchen	73761 E, 81428 N	H	0.50	2013	spruce forest
H5*	Bertrange	71178 E, 76941 N	H	0.15	2013	spruce forest
sand grasslands						
S1	Telpeschholz 2	69385 E, 83970 N	S	1.48	partially 2003–2004	grassland
S2	Schéimerech	71242 E, 81930 N	S	0.50	1999	fallow grassland
S3	Stëllerstrachen 1	71517 E, 81515 N	S	0.11	1999	fallow grassland
S4*	Stëllerstrachen 2	71384 E, 81431 N	S	0.28	2010	spruce forest
S5	Kazefiels	69460 E, 78690 N	S	0.09	1999	fallow grassland
S6*	Tossebierg	70990 E, 76600 N	S	0.34	partially 2012	sandstone quarry/illegal waste disposal
S7*	Gaaschtgronn	71646 E, 76948 N	S	0.25	2012	waste landfill

3. Methods

3.1 Vegetation sampling

Vegetation was sampled in April 2015 for early flowering species and repeated in June, respectively July. At each site, the cover of vascular plants of 4 plots (except S6* with 3 and H3 with 2 plots), each measuring 4 m x 4 m (GILHAUS et al. 2015), was sampled by means of relevés using the Braun-Blanquet scale, as modified by WILMANNS (1998). The following vegetation variables were recorded: cover [%] of herbs, bryophytes and lichens, grasses, litter, bare soil and mean vegetation height [cm]. Due to the heterogeneity of some of the study sites, the locations of the plots within the study sites were selected by preferential stratified sampling in order to ensure that the majority of species found within these rare habitats were sampled and recording of edge effects was minimized. Since all sites, except for H5*, were situated on plateaus, aspect and slope data was not taken. H5* was situated on a terrace on a north slope. Nomenclature of vascular plant species followed LAMBINON & VERLOOVE (2012). In deviation to this, following aggregates of difficultly distinguishable species were used: *Carex muricata* agg., *Festuca ovina* agg., *Galium mollugo* agg., *Galium verum* agg. and *Festuca rubra* agg.

3.2 Soil nutrient sampling

Soil samples were taken in May 2015 by combining 20 single soil cores of 10–12 cm depth to one bulk sample on each site. One additional sample was taken on S6* because vegetation differed strongly on this site. The samples were analysed for pH, phosphorus (P), potassium (K), nitrate (NO_3) and organic matter (Corg) content by the pedological laboratory of the administration for technical services in agriculture, according to their standard guidelines (pH: VDLUFA A5.1.1 1991; P_2O_5 & K_2O: VDLUFA A 6.2.1.1 2012; NO_3: VDLUFA A 6.1.4.; Corg: ISO 10694:1995). Unfortunately, ammonium analysis could not be performed by the laboratory.

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Fig. 2. Pictures of the study sites. **a)** Old heathland site (H3) in August 2016 with *Calluna vulgaris* (Photo: S. Schneider). **b)** New heathland site (H5*) with *Trifolium repens* and *Agrostis capillaris* in June 2015 (Photo: C. Wolff). **c)** Old sand grassland site (S2) with faded *Hypochaeris radicata* and *Arrhenatherum elatius* in July 2015 (Photo: C. Wolff). **d)** New sand grassland site (S4*) with dense lichen cover and blooming *Jasione montana* in July 2015 (Photo: C. Wolff).

Abb. 2. Bilder der Untersuchungsflächen. **a)** Alte Heide-Fläche (H3) im August 2016 mit *Calluna vulgaris* (Foto: S. Schneider). **b)** Neue Heidefläche (H5*) mit *Trifolium repens* und *Agrostis capillaris* im Juni 2015 (Foto: C. Wolff). **c)** Alter Sandmagerrasen mit verblühtem *Hypochaeris radicata* und *Arrhenatherum elatius* im Juli 2015 (Foto: C. Wolff). **d)** Neuer Sandmagerrasen (S4*) mit hoher Flechten-Deckung und Blühaspekt von *Jasione montana* im Juli 2015 (Foto: C. Wolff).

3.3 Statistical analysis

For all statistical analysis, the cover scale of the vegetation relevés was transformed as follows: r = 0.1%, + = 0.1%, 1 = 1%, 2m = 2%, 2a = 8%, 2b = 18%, 3 = 33%, 4 = 58% and 5 = 83%. The percentage values are always the lower third values between the percentage cover values of each class (e.g. 3 = 25–50% cover = 33% cover after transformation). In addition to environmental and structural variables, diversity measures and soil nutrients, red list species, indicator values and the seed longevity index were used in statistical analyses. Data on Red List species were taken from COLLING (2005). For each relevé, mean Ellenberg indicator values (ELLENBERG et al. 2001) for soil moisture (EIV-M), soil reaction (EIV-R) and soil nutrients (EIV-N) (KLAUS et al. 2012) were calculated, weighted by species cover (ELLENBERG et al. 2001). For species that were only determined to genus level, the genus means were calculated in consideration of only those species occurring in Luxembourg, as given by COLLING (2005). The LEDA-database by KLEYER et al. (2008) provided the information for the seed longevity index. It uses three seedbank categories to classify species, which are based upon the absolute index values by THOMPSON et al. (1997). Because of the occasional occurrence of numerous diverging database records for a same species, we categorized seed bank longevity as follows: if ≥ 50% of the records classified a species as building a transient short-term seedbank, it was treated as having a "short-lived seed bank". Contrarily, if in ≥ 50% of the records the species had been assigned to the summed-up categories of "short-term persistent" and "long-term persistent", the species was treated as building

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a "long-lived seed bank". Missing values for species that were only determined to genus level were assigned the genus weighted mean of those species occurring in Luxembourg (COLLING 2005). Species without an entry in the database were not included in the analysis ($n = 9$).

Vegetation was also classified phytosociologically, based on prevailing character species (DIERSCHKE 1994), which were determined with OBERDORFER (2001). Only the detailed classification of the heath specific communities followed PEPPLER-LISBACH & PETERSEN (2001), with the exception that, locally, *Luzula campestris* cannot be rated as a *Nardetalia*-character species (SCHNEIDER 2011). Moreover, the local differentiation between character species of *Arrhenatheretalia* and *Molinio-Arrhenateretea* followed the classification of SCHNEIDER (2011).

The species composition of vascular plants in the relevés were analysed by Detrended Correspondence Analysis (DCA) using PCORD 6 (MjM Software Design, Gleneden Beach, OR, USA) with an overlay of the respective recorded environmental variables. For the DCA of the heathland and sand grassland relevés, plant species abundances were square root transformed, species with an occurrence of less than three in the entire dataset excluded and rare species down-weighted prior to the calculation.

Further settings of the DCAs were: rescale axes and 26 segments. With gradient lengths of the two 1st axes being 4.25 and 2.7, DCA was an adequate ordination method (LEYER & WESCHE 2008).

Univariate statistics to determine significant differences between old and new sites in structural variables, soil nutrients and seed bank characteristics were calculated in SPSS 23 (IBM Corp., Armonk, NY, USA). Where the requirements of homogeneity of variance and normal distribution of the residuals was given (for some variables after logarithmical or square root transformation), one-way ANOVA was used. When data was not distributed normally (even after transformation), differences were calculated with Mann-Whitney-U tests. The significance level was set at $p = 0.05$.

4. Results

4.1 Floristic composition

A total of 180 vascular plant species, 13 of which were classified as endangered in Luxembourg, were recorded in the heathlands (18 relevés) and sand grasslands (27 relevés). The syntaxonomical classification of heathland and sand grassland vegetation of the study sites could only be done to class or order level. The vegetation lacked character species, so that further identification of alliances, let alone associations, was not possible. The classified records of the plots are given in Supplement S1 for heathlands and Supplement S2 for sand grasslands, both added as loose inserts.

4.1.1 Heathland syntaxonomy

The old heathland sites were primarily generally species-poor and characterised by the abundant dwarf-shrub *Calluna vulgaris*, which is a character species of the *Calluno-Ulicetea* (Supplement S1). Height and vitality of the *Calluna* shrubs varied strongly among sites. However, even where they had been damaged by beetles or a plant disease, the defoliated stems and branches still had quite high cover values (H2). Two other character species of the *Calluna-Ulicetea*, *Deschampsia flexuosa* and *Genista pilosa*, were found on the sites. Two sites additionally harboured character species of the *Nardetalia* order (H2 & H3). However, those sites also showed signs of encroachment by different by woody species such as *Cytisus scoparius*, *Pinus sylvestris* and *Populus tremula*, as well as grass encroachment by *Deschampsia flexuosa*, *Holcus mollis* and *Calamagrostis epigejos*. Furthermore, some individuals of *Pteridium aquilinum* were present on H2 and H3. Site H1 was dominated by *Calluna vulgaris*, but was species poor in general.

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As a result of restoration measures, *Calluna vulgaris* and *Deschampsia flexuosa* were the only character species of the *Calluno-Ulicetea* transferred to the new sites whereas *Genista pilosa* or *Nardetalia* species were mostly absent. The newly restored sites were characterised by species of mesotrophic or eutrophic grasslands. Especially *Holcus lanatus* and *Trifolium repens* overgrew the restoration sites. The high abundance of species indicative of moist and nutrient-rich conditions distinguished the new site H5* from H4*. Common species on all heathland sites were acidophilic species such as *Rumex acetosella* and *Agrostis capillaris* with high constancy on both site categories.

4.1.2 Sand grassland syntaxonomy

The sand grasslands were overall species-rich with 16 to 51 species per relevé. A total of nine endangered herbaceous species was recorded. The old sand grassland sites could be divided into two categories (Supplement S2). The first category consisted of two old sites (S5 and S3), which had a diverse vegetation composed of character species of the *Sedo-Scleranthetea* Br.-Bl. 1955 em. Th. Müller 1961 and the *Festuco-Brometea* Br.-Bl. et Tx. 1943, as well as typical species of those classes. The weak character species of the *Festuco-Brometea*, *Euphorbia cyparissias* and the *Brometalia* species *Potentilla neumanniana*, were abundant only on these sites and could not be found on the other old sites. Sites of the second category (S1 and S2) were mostly characterised by the lack of species of the former classes and by a dense vegetation cover of more common grassland species, such as *Agrostis capillaris, Anthoxanthum odoratum*, *Luzula campestris* and *Holcus lanatus.* One of these two sites (S1) also showed relatively high cover of species indicating weakly acid and nutrient-poor conditions such as *Ornithopus perpusillus* and *Hieracium pilosella*.

The new sand grassland sites had species in common with both categories of the old sites, but were similarly distinguished by either the predominance of *Sedo-Scleranthetea* taxa or by the presence of grassland species. Some very threatened species, such as *Vulpia myuros* and *Jasione montana,* were growing at one site (S4*). The other sites (S6* & S7*) were outstandingly diverse with species indicative of base-rich soil (e.g. *Bromus erectus*), as well as some pioneer species (e.g. *Echium vulgare*).

Common species on the species-rich old sites and the new sites were character species of the *Arrhenateretalia* (*Achillea millefolium*, *Saxifraga granulata*), which were less frequent in the grass-dominated sites.

4.2 Relationship between vegetation and environmental variables

4.2.1 Heathlands

The DCA of the heathland plots showed a clear differentiation of the old and the new sites along the 1st axis (eigenvalue: 0.785) (Fig. 3). Cover of bryophytes and lichens, cover of shrubs and content of soil organic matter were strongly positively, and soil nutrients, soil reaction and cover of grasses negatively correlated with the 1st axis (Table 3). Old sites had higher cover of bryophytes, lichens and shrubs and less cover of grasses than new sites (Fig. 3, Table 4). Moreover, they had significantly lower pH values and EIV-R values, lower P in the soil and a lower EIV-N (Fig. 3, Table 2). With a mean pH of 3.7 they were very acidic, corresponding well to the lower nutrient availability. Additionally, the higher amount of species building a long-lived seed bank distinguished the new sites from the old ones. The plots of the old heathland sites themselves split up along the 2nd axis (eigenvalue: 0.227).

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Table 2. Mean values (± standard deviation) of soil variables of the study sites. Differences between the old and new sites were tested with ANOVA if requirements were met (in some cases after logarithmical or square root transformation), otherwise with Mann-Whitney-U tests. NO_3 = nitrate and Corg = soil organic matter. Significance level was set at $p = 0.05$.

Tabelle 2. Mittelwerte (± Standardabweichung) von den Bodenvariablen der Untersuchungsflächen. Unterschiede zwischen den alten und neuen Flächen wurden mit ANOVA getestet, wenn die Voraussetzungen erfüllt waren (manchmal nach logarithmischer oder Wurzeltransformation), ansonsten mit Mann-Whitney-U Test. NO_3 = Nitrat und Corg = organischer Kohlenstoff. Signifikanzniveau wurde auf $p = 0{,}05$ festgelegt.

	heathland		ANOVA/ Mann-Whitney	sand grassland		ANOVA/ Mann-Whitney
	old sites $n = 3$	new sites $n = 2$		old sites $n = 4$	new sites $n = 4$	
pH	3.70 ± 0.10	4.30 ± 0.14	0.011	4.15 ± 0.54	7.03 ± 0.83	0.001
P_2O_5 [mg/100 g]	2.91 ± 1.76	15.8 ± 5.98	0.032	10.80 ± 10.50	7.50 ± 4.18	0.581
K_2O [mg/100 g]	1.00 ± 0.00	4.00 ± 1.41	0.128	1.75 ± 0.95	12.50 ± 10.40	0.029
NO_3 [kgNitrate/ha]	1.27 ± 0.19	1.18 ± 0.06	0.605	1.14 ± 0.23	1.50 ± 0.59	0.306
C_{org} [%]	1.06 ± 0.05	0.8 ± 0.00	0.008	0.93 ± 0.22	1.03 ± 0.62	0.879

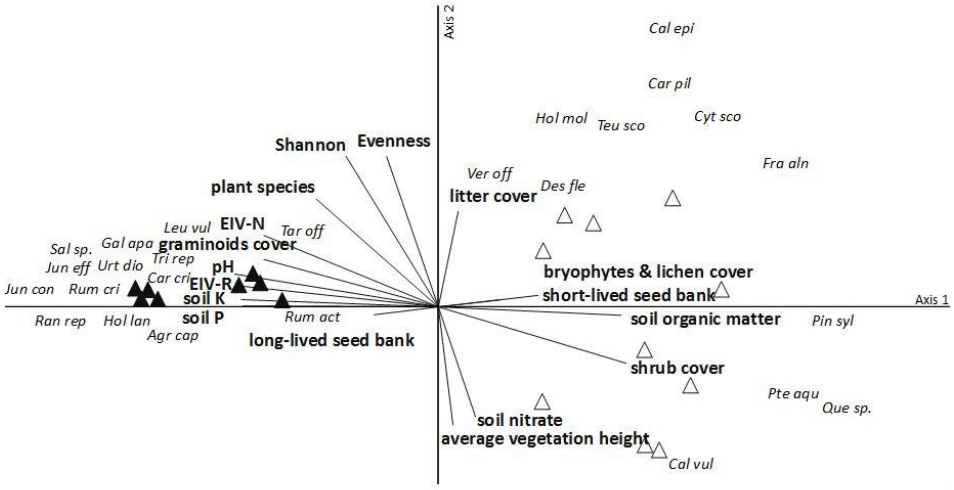

Fig. 3. Detrended correspondence analysis of the vegetation relevés of the old and the new heathland sites. $n = 18$. Species occurring less than three times in the whole data set were excluded, abundances square root transformed and rare species down-weighted. Only some representative species of the syntaxonomical classes of chapter 4.1.1 are displayed. Gradient length of Axis 1 = 4.25 S.D. Percentage of explained variance: Axis 1: 35.4%, Axis 2: 10.2%. For abbreviations check chapter 3.2 & 3.3, as well as Supplement S1.

Abb. 3. DCA-Diagramm der Vegetationsaufnahmen der alten und neuen Heiden. $n = 18$. Arten, die weniger als dreimal im Datensatz vorkamen, wurden ausgeschlossen, Abundanzen wurden wurzeltransformiert und seltene Arten heruntergewichtet. Nur einige repräsentative Arten der syntaxonomischen Klassen aus Kapitel 4.1.1 sind dargestellt. Gradientenlänge der 1. Achse = 4,25 S.D. Anteil erklärter Varianz: Axis 1: 35,4 %, Axis 2: 10,2 %. Abkürzungen in Kapitel 3.2 & 3.3 sowie in Beilage S1.

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Table 3. Pearson's correlation of the second matrix (environmental variables) with the 1st and the 2nd Axis of the two DCAs. Cut-off value was set as > 0.2, thus only *r* values > 0.2 are shown.

Tabelle 3. Pearson-Korrelationskoeffizient *r* von der zweiten Matrix (Umweltparameter) mit der ersten und zweiten Achse der zwei DCAs. Cut-off-value > 0,2; nur *r*-Werte > 0,2 aufgeführt.

	heathland		sand grassland	
	Axis 1	Axis 2	Axis 1	Axis 2
Number of plant species	-0.75	0.70	0.71	-
Number of endangered species	0.34	0.38	0.39	0.29
Vegetation parameters				
average vegetation height	-	-0.72	-0.25	-
Cover				
shrub	0.93	-0.51	-	-
graminoid	-0.89	0.47	-0.60	-0.27
herbs	-0.24	-	0.23	-
litter	0.30	0.66	-0.24	-0.30
bare ground	-	-	0.45	-
bryophytes & lichens	0.68	0.23	-	-0.20
Relative abundance of				
species with short-lived seed bank	0.54	-	0.73	-
species with long-lived seed bank	-0.54	-	-0.40	-
Ellenberg IV				
M	-0.28	-	-	-
N	-0.89	0.57	-0.24	-0.27
R	-0.96	0.31	0.28	-0.48
Biodiversity indices				
Evenness	-0.49	0.83	0.34	-0.20
Shannon	-0.65	0.83	0.74	-
Soil nutrients				
Corg	0.91	-	-	-0.27
K	-0.95	-	0.58	-
NO_3	0.41	-0.71	0.38	-
P	-0.95	-	-0.41	-
pH	-0.96	0.39	0.69	0.26

The resulting clusters represent the different old sites well. The plots situated in the upper right quadrant in Figure 3 belong to site H2 and had smaller growing vegetation, higher litter cover, a higher Shannon index, and lower soil nitrate contents than the plots of H1 (located in the lower right quadrant in Fig. 3). This aspect is reflected in the results of the syntaxonomic analysis (see above; Supplement S1): site H2 harbours most of the typical heathland species and the plots of site H1 are dominated by tall *Calluna vulgaris* shrubs. The two plots of H3 mediate between H1 and H2, being situated between both sites in Figure 3. Moreover, Figure 3 shows that, in line with plant sociological classification, old heathland sites distinguished themselves through the presence of heathland species as well as woody species, and new sites were located within the ruderal and grassland species.

Table 4. Mean values (± standard deviation) of several environmental variables for old and new heathland and sand grassland sites. Differences between old and new sites were tested with ANOVA if requirements were met (in some cases after logarithmical or square root transformation), otherwise with Mann-Whitney-U tests. For explanations of categories "old" and "new", check Figure 1. Significance level was set at $p = 0.05$.

Tabelle 4. Mittelwerte (± Standardabweichung) verschiedener Umweltvariablen alter und neuer Heiden, sowie alter und neuer Sandmagerrasen. Unterschiede zwischen den alten und neuen Flächen wurden mit ANOVA getestet, wenn die Voraussetzungen erfüllt waren (manchmal nach logarithmischer oder Wurzeltransformation), ansonsten mit Mann-Whitney-U Test. Für Definition der Kategorie „old" und „new", siehe Abbildung 1. Signifikanzniveau wurde auf $p = 0{,}05$ festgelegt.

	heathland		ANOVA/ Mann-Whitney	sand grassland		ANOVA/ Mann-Whitney
	old sites $n = 10$	new sites $n = 8$		old sites $n = 16$	new sites $n = 11$	
Number of (per plot)						
plant species	12.90 ± 0.67	25.00 ± 3.34	0.001	24.38 ± 5.16	32.82 ± 8.06	0.030
endangered species	0.50 ± 0.53	0.25 ± 0.46	0.408	2.06 ± 1.24	2.45 ± 1.04	0.481
Vegetation parameters						
average vegetation height [cm]	42.50 ± 27.71	40.00 ± 9.26	0.811	33.12 ± 9.98	26.36 ± 18.72	0.026
Cover [%]						
shrub	63.60 ± 17.84	0.00 ± 0.00	0.000	2.13 ± 5.031	3.00 ± 9.95	0.753
graminoid	16.60 ± 13.82	58.75 ± 18.07	0.003	48.43 ± 23.07	36.36 ± 14.50	0.368
herbs	16.63 ± 22.87	26.75 ± 15.77	0.304	39.68 ± 17.55	37.27 ± 16.63	0.723
litter	29.10 ± 28.83	13.75 ± 6.41	0.161	20.31 ± 10.07	19.09 ± 3.75	0.827
bare ground	3.20 ± 5.27	7.63 ± 8.75	0.202	5.06 ± 6.01	7.09 ± 6.30	0.368
bryophytes & lichens	63.00 ± 28.88	20.00 ± 14.88	0.002	47.81 ± 25.75	51.81 ± 22.16	0.790
Relative abundance of						
species with transient seedbank	65.08 ± 10.52	54.43 ± 10.19	0.046	79.11 ± 6.01	81.82 ± 0.20	0.265
species with persistent seedbank	32.48 ± 11.32	44.10 ± 10.80	0.042	18.67 ± 4.81	18.17 ± 4.02	0.780
Ellenberg IV						
R	1.50 ± 0.57	6.08 ± 1.42	0.000	4.91 ± 0.80	5.12 ± 1.07	0.576
N	1.90 ± 0.93	4.57 ± 0.34	0.000	3.18 ± 0.75	3.18 ± 0.82	0.990
Biodiversity index						
Shannon	1.74 ± 0.86	2.71 ± 0.20	0.007	2.77 ± 0.27	3.02 ± 0.29	0.030

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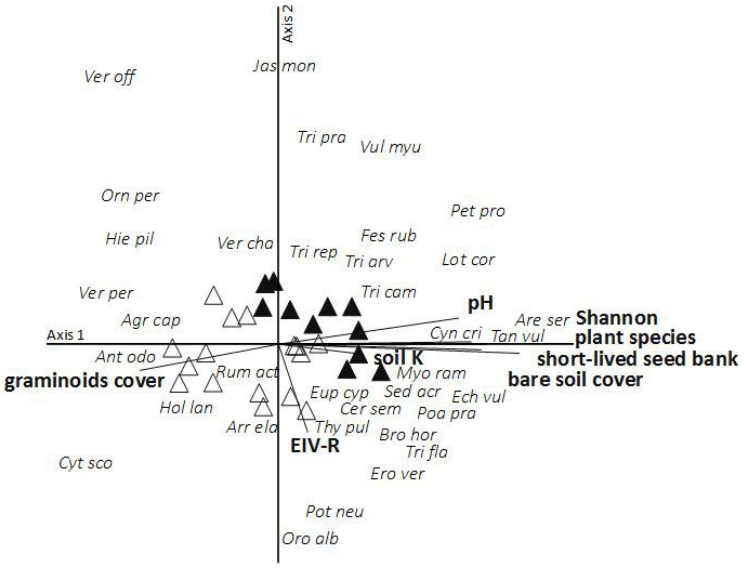

Fig. 4. Detrended correspondence analysis of the vegetation relevés of the old and the new sand grassland sites. *n* = 27. Species occurring less than three times in the whole data set were excluded, abundances square root transformed and rare species down-weighted. Only some representative species of the syntaxonomical classes of chapter 4.1.2 are displayed. Gradient length of Axis 1 = 2.7 S.D. Percentage of explained variance: Axis 1: 18.9%, Axis 2: 9.3%. For abbreviations check chapter 3.2 & 3.3, as well as Supplement S2.

Abb. 4. DCA-Diagramm der Vegetationsaufnahmen der alten und neuen Sandmagerrasen. *n* = 27. Arten, die weniger als dreimal im Datensatz vorkamen, wurden ausgeschlossen, Abundanzen wurden wurzeltransformiert und seltene Arten heruntergewichtet. Nur einige repräsentative Arten der syntaxonomischen Klassen aus Kapitel 4.1.2 sind dargestellt. Gradientenlänge der 1. Achse = 2,7 S.D. Anteil erklärter Varianz: Axis 1: 18,9 %, Axis 2: 9,3 %. Abkürzungen in Kapitel 3.2 & 3.3 sowie in Beilage S2.

4.2.2 Sand grasslands

The old and new sand grassland relevés differed in their position along the 1st axis (eigenvalue: 0.361) of the DCA (Fig. 4). However, they were all relatively clustered, meaning that their vegetation composition was quite similar. Additionally, there were only few significant differences in soil and structural variables between new and old sand grassland sites (Table 2, Table 4). The graminoid cover tended to be higher on the old sites, whereas the cover of bare soil, pH, species richness, vegetation height and the Shannon index tended to be higher on new sites (Fig. 4, Table 3). However, only the latter three were significantly different between the site categories (Table 4). Finally, soil K was correlated with the 1st axis and was also significantly higher on new sites. However, the high standard deviation for the mean value of K, as well as for the mean value of P, indicates that there were relatively high differences in the data set (Table 2). The outlier data were the following: S1 had elevated P contents of 26.43 mg 100 g^{-1} and both samples of S6* had high K contents around 20 mg 100 g^{-1}.

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Some of the new and old plots were distributed along the gradient represented by the 2nd axis (eigenvalue: 0.179). This axis was best represented by EIV-R (Table 3).

As shown in chapter 4.1.2, and also depicted in Figure 4, the old sites tended to be dominated by several grass species. Nevertheless, some of the plots of old sites presented a more diverse vegetation with typical sand grassland species belonging to *Sedo-Scleranthetea* or *Festuco-Brometea,* such as *Vulpia myuros* and *Cerastium semidecandrum*. As shown in Supplement S2, some plots of the new sites held species adapted to higher pH values (plots situated on the outer right in Fig. 4).

5. Discussion

5.1 Heathlands

Heathlands develop in a typical cycle depending on their management and age (GIMINGHAM 1972, KVAMME et al. 2004). The two investigated types of heathlands clearly differed in their current development status. Whereas the old sites H1 and H2 were already in the degeneration phase, the site H3, which was restored in 2002, was vital and the recently restored sites were in the pioneer phase. Old and new heathlands differed in structural variables, soil nutrient content and vegetation composition.

The old heathlands were quite poor in typical heathland species, except for the dominant *Calluna vulgaris*. Only 3 of the 16 indicator species for heathlands, as listed in the national action plan for Luxembourg by SCHNEIDER & NAUMANN (2013), were recorded in the relevés of this study (*Calluna vulgaris*, *Genista pilosa* and *Vaccinium myrtillus*).

The dense cover of ruderal and grassland species on the new sites, with an increased amount of plants indicating nutrient-rich conditions, questions the future success of restoration measures. Additionally, the low insolation on the north-facing slope in site H5* also seems to be detrimental for the establishment of the light-dependent germinator *Calluna vulgaris* (OBERDORFER 2001). The high amounts of P in the soil have probably already prevented and will continue to counteract the establishment of the target species of nutrient-poor environments by favouring fast-growing species, especially grasses (CEULEMANS et al. 2014, HORROCKS et al. 2016). Hence, the germination and growth of light-demanding species such as *Calluna vulgaris* are worsened (FLEISCHER et al. 2013). However, as restoration measures were implemented only 2 years prior to the sampling, it may be too early to make a statement about the successful, respectively unsuccessful establishment of heathland species because this process may take up to 9 years (VERHAGEN et al. 2001).

To diminish the eutrophication and resulting acidification, topsoil removal has been proven to be a powerful tool (HÖLZEL & OTTE 2003, GEISSEN et al. 2013). However, at the investigated restored sites, the technique seems to have been unsuccessful. Topsoil removal was either not deep enough, or P has been imported onto the sites after the restoration by surface run-off from neighbouring arable land (SMITH et al. 2001). A depth-graded analysis of P distribution in soil prior to restoration by topsoil removal could be a solution to the first problem if a specific nutrient level is desired (GILHAUS et al. 2015). Several studies showed that P depletion can be reinforced by increasing removal depth (SÜSS et al. 2004, EICHBERG et al. 2010, GILHAUS et al. 2015).

Nitrate content was similarly low on old and new heathland sites. However, in such acidic conditions ammonium may become the dominant form of mineral nitrogen due to decreased activity of nitrifying bacteria (BLUME et al. 2010). The high amount of perennial

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grasses and ruderals supports the assumption of an increased nitrogen supply, which often prevents the success of restoration measures (BAKKER & BERENDSE 1999, DUPRÈ et al. 2010).

Lower soil pH values on the old heathlands are surely a result of progressed leaching of base-cations with age (BLUME et al. 2010). Furthermore, atmospheric N depositions could have contributed to increased soil acidification.

Acidification leads to species-loss in weakly-buffered sand soils (ROEM et al. 2002, CEULEMANS et al. 2014). Whilst *Calluna vulgaris* has adapted to low pH, most other heathland species need a pH > 5 to germinate (ROEM et al. 2002). Furthermore, in such acidic conditions, plants suffer from N-deficiency caused by an inhibited uptake through Al-toxicity (ROEM et al. 2002).

The difference in vegetation composition among the old sites might not only relate to soil properties, but can also be explained by the different management regimes. H1 was grazed by sheep which could have led to the observed decrease in litter coverage (PEPPLER-LISBACH & PETERSEN 2001, RUPPRECHT et al. 2016) as well as to the higher growing *Calluna vulgaris* plants. However, the dense moss cover on site H1 might prevent many light-demanding species from germinating (JESCHKE & KIEHL 2008, FLEISCHER et al. 2013). In opposition to this, the yearly mowing regime on H2 and H3 prevented the heather from gaining its typical aspect. Moreover, the vegetation canopy on H2 was opened 3 years prior to the sampling due to a bug infestation or other disease of the heather shrubs. This probably favoured a higher number of *Nardetalia*, but also woody species to establish themselves (PEPPLER-LISBACH & PETERSEN 2001). The higher number of species building a short-lived seedbank on the new sites suggests that many of the abundant species such as *Trifolium repens* or *Agrostis capillaris* result from the former fallow vegetation of the site. They could establish and spread easily after topsoil removal, as they found ideal low-competitive conditions (HÖLZEL & OTTE 2003). The high occurrence of non-target species on the new sites suggests that, in line with the high P content, topsoil removal had not been done to a sufficient depth and that the soil seed bank of "undesired" vegetation was not entirely removed (HÖLZEL & OTTE 2003).

5.2 Sand grasslands

The composition of the vegetation in the sand grassland sites was mainly characterized by species belonging to the *Sedo-Scleranthetea.* Two old sand grasslands were additionally marked by the presence of two species belonging to the *Festuco-Brometea*. Given the facts that *Euphorbia cyparissias* is only a weak character species of this class (SCHNEIDER 2011) and *Potentilla neumanniana* is a weak base indicator (ELLENBERG et al. 2001), we could say that these species are differential species for the local type of sand grasslands occuring on base-rich locations. We can confirm the statement of STEINBACH & PFEIFFENSCHNEIDER (2001), that the remaining sand grasslands of the study area cannot be classified into the *Koelerion glaucae* Volk 1931 (FFH 6210). However, it was not possible to classify the present relevés as belonging to a "*Corynephorion*-community" as did the afore-mentioned authors, because the diagnostic species *Corynephorus canescens* and other typical species could not be found in any of the study sites. In fact, there are only 3 known locations of *Corynephorus canescens* left in Luxembourg, and the last records date from 2010 (MUSÉE NATIONAL D'HISTOIRE NATURELLE LUXEMBOURG 2016). Nevertheless, the high conservation value of this habitat is certain, given the diversity of plants and especially the number of threatened species.

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The high species number in the species-rich sites can be explained by the surplus in basophilic species and the higher number of pioneer species in comparison to the other sites. The initial stages of succession of sand grasslands with high amounts of bare soil are the richest in target species, with an overall decline in species when shifting to consolidated grassland (SCHWABE et al. 2013, GILHAUS et al. 2015, RUPPRECHT et al. 2016). These initial stages could be found on two old sites, where soil was strikingly shallow and on the new sites S6* and S7*, where even parts of the bedrock surfaced. At site S6* the alien species *Cotoneaster* cf. *horizontalis* occurred, which probably was imported by green waste disposal. The mixture of acidophilic and basophilic species in the latter sites may result from their former use as landfills, which can possess high pH values (TOWNSEND et al. 1999, FRĄCZEK et al. 2014). The higher K content in the soil of site S6* might be a result of deposited fertilized soil. The low pH values on the old sand grasslands can be seen as a result of successional processes, as explained earlier for the heathlands (see chapter 5.1).

The later successional stages on the old sites with dense graminoid cover and high vegetation height might be related to a higher N and P content (STORM & SÜSS 2008, SÜSS et al. 2010, CEULEMANS et al. 2014, HORROCKS et al. 2016) and/or a higher moisture degree in the soil (SÜSS et al. 2010). Cumulative N deposition can have the effect of lower dicotyledon and higher grass species proportions in acidic grasslands (DUPRÈ et al. 2010, FAUST et. al 2012), as was the case in these old sites.

Topsoil removal and transfer of freshly mown plant material as well as diaspore inoculation of deep sand material seem to be adequate restoration measures for the local type of sand grasslands, given the similar set of vascular plants on new and old sites. Both techniques have formerly been proven as successful for sand grassland restoration (JENTSCH & BEYSCHLAG 2003, EICHBERG et al. 2010). However, *Euphorbia cyparissias* and *Potentilla neumanniana* were only abundant on two of the old sites and were scarcely represented in the new sites. As they both are early-flowering species, the transfer of freshly mown plant material in June or July was probably not suitable for their transfer (KIEHL & WAGNER 2006).

6. Management proposals

Management of both habitat types should include measures that ensure a sufficient nitrogen output and recreate initial stages of succession. To counteract the eutrophication effects of atmospherical N depositions, the one-cut regime of the existing sand grasslands should be continued (HÖLZEL 2009), whereas on the old heathland sites a cutting regime of the *Calluna* shrubs with a frequency of one or two cuts in 5 years would be sufficient (KEIENBURG & PRÜTER 2006, HÄRDTLE et al. 2006, MINISTÈRE DU DÉVELOPPEMENT DURABLE ET DES INFRASTRUCTURES & MINISTÈRE DE L'AGRICULTURE, DE LA VITICULTURE ET DE LA PROTECTION DES CONSOMMATEURS 2014b). On the grass and ruderal-dominated new heathland sites, early mowing in spring with removal of the cuts should be continued to weaken the non-target species, as well as to enhance nitrogen output (HUHTA et al. 2001). The mowing should be combined with extensive sheep grazing at all sites, as grazing creates a diverse micro-structure, counteracts grass-encroachment and is beneficial to overall plant diversity by creating open soil patches (KOOIJMAN & VAN DER MEULEN 1996, RUPPRECHT et al. 2016). Thus, periodical intensive shepherding for 2–3 days with a night pen outside of the sites would be a solution, whereas year-round grazing cannot be recommended as sites are smaller than 10 ha (BUNZEL-DRÜKE et al. 2008).

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In addition to mowing and grazing, occasional high-intensity measures such as sod-cutting or choppering should be included in the management plan of the old heathland sites to maintain long-term balanced nutrient budgets (HÄRDTLE et al. 2006). If sites are infested with grasses, sod-cutting should be chosen over choppering, which is more efficient on overaged or damaged shrubs (NIEMEYER et al. 2007, FARTMANN et al. 2015). If applied in a spatially and temporally heterogeneous manner, the resulting mosaic of successional stages contributes to the overall plant species diversity (RUPPRECHT et al. 2016).

For future restorations, measures that transfer inoculation material with soil should be used, e.g. choppering or raking. Firstly, the material obtained contains mycorrhizal fungi which enhance the establishment of target species (EICHBERG et al. 2010). Moreover, such procedures create open soil patches on the donor sites, which is necessary for the recruitment of sand grassland and heathland species (NIEMEYER et al. 2007, EICHBERG et al. 2010).

7. Conclusion

The continued conservation and restoration of the two studied habitats is indisputable. Although the old heathlands are not rich in species, their floristic composition is very unique and constitutes an important cultural heritage. The local sand grasslands stand out through their high plant diversity, including many endangered species. All in all, the study sites represent important refuges for many species, because similarly nutrient-poor open habitats are scarce in the surrounding landscape.

However, some criteria should be respected to ensure successful conservation and restoration in the future: restoration sites should be chosen in respect to low or at least removable N and P contents in the soil, so that levels similar to the reference sites can be reached. Furthermore, the soils of the restoration sites should not be too loamy, in order to ensure xeric conditions as well as poor nutrient availability (BLUME et al. 2010). It should be avoided to purchase sites with a high cover of problematic species such as *Pteridium aquilinum* or *Calamagrostis epigejos*. After restoration and on existing sites, the introduction or continuation of a management regime creating and preserving early successional stages is important.

Beneath the restoration of the heathlands and sand grasslands, further future tasks should be the improvement of the habitat quality (HEINKEN 2009, KUUSSAARI et al. 2009) and the connectivity between existing sites (LINDBORG & ERIKSSON 2004, HEINKEN 2009, HAENEL 2015), as well as the regular monitoring of the restoration sites to follow the development of the target species.

All in all the results of the present study should be beneficial to reaching the Luxembourgish nationwide aim to restore total heathland area up to 200 ha, as projected by the second national plan for nature protection ("Plan National concernant la Protection de la Nature 2", MINISTÈRE DU DÉVELOPPEMENT DURABLE ET DES INFRASTRUCTURES 2017).

Erweiterte deutsche Zusammenfassung

Einleitung – Nährstoffarme Ökosysteme wie Heiden und Sandmagerrasen sind in den letzten Jahrzehnten in Europa stark zurückgegangen und noch vorhandene Flächen sind vor allem durch Versauerung und Stickstoffeinträge gefährdet (z. B. BAKKER & BERENDSE 1999, HÄRDTLE et al. 2009). In Luxemburg ist der Großteil der Heiden und Sandmagerrasen in einem schlechten ökologischen Zustand (SCHNEIDER & NAUMANN 2013, MINISTÈRE DU DÉVELOPPEMENT DURABLE ET DES INFRASTRUC-

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TURES 2014a). Aufgrund dessen und wegen des starken Rückgangs werden hier seit einigen Jahren gezielt Renaturierungsmaßnahmen durchgeführt. Allerdings fehlt bisher eine Evaluierung dieser Maßnahmen und des Managements, weshalb in dieser Studie die Vegetation bestehender Flächen erfasst wurde.

Untersuchungsgebiet – Die Studie wurde im Südwesten Luxemburgs, im Eisch-Mamer-Gutland, durchgeführt (Abb. 1A). Dort herrschen sandige, nährstoffarme Böden vor; das Klima ist atlantisch. Es wurden insgesamt 12 Flächen, davon fünf Heiden und sieben Sandmagerrasen untersucht (Abb. 1B). Dabei unterschieden wir jeweils zwischen „alten" (gleicher ökologischer Zustand seit mind. zehn Jahren) und „neuen" Flächen (vor weniger als zehn Jahren renaturiert). Bis auf eine Heidefläche, auf der Schafbeweidung stattfand, werden alle Flächen generell einschürig im Juli gemäht (Tab. 1).

Methoden – Pro Fläche wurden in der Regel je vier Vegetationsaufnahmen (4 x 4 m^2) durchgeführt und strukturelle Parameter erfasst. Pro Fläche ist eine Bodenprobe genommen, auf pH-Wert sowie die Gehalte an Phosphor, Kalium, Nitrat und organischer Substanz untersucht worden.

Für die statistische Auswertung wurden die Rote Liste-Arten verwendet. Außerdem wurden pro Aufnahme Ellenberg-Zeigerwerte und Werte zur Langlebigkeit der Samenbank berechnet.

Die Vegetationsaufnahmen wurden pflanzensoziologisch nach Vorhandensein von Kennarten sortiert und eingeordnet (DIERSCHKE 1994). Für den Vergleich zwischen alten und neuen Flächen wurden Ordinationen berechnet und Signifikanztests durchgeführt.

Ergebnisse – Floristische Zusammensetzung/Syntaxonomie: Auf den alten Heideflächen dominierte *Calluna vulgaris*, Charakterart der *Calluno-Ulicetea* (Beilage S1). Auf zwei alten Heideflächen haben sich verstärkt Gehölze und Gräser ausgebreitet.

Auf den neuen Heideflächen waren vor allem Arten des mesophilen und eutrophen Grünlands zu finden (Beilage S1). An typischen Heidearten konnten nur *Calluna vulgaris* und *Deschampsia flexuosa* mit den Renaturierungsmaßnahmen übertragen werden.

Mit 16 bis 51 Arten pro Aufnahme waren die Sandmagerrasen insgesamt artenreich. Auf zwei der alten Sandmagerrasen-Flächen waren vorwiegend Charakterarten und typische Arten der *Sedo-Scleranthetea* und der *Festuco-Brometea* zu finden (Beilage S2). Arten dieser Klassen fehlten auf den anderen beiden alten Sandmagerrasen-Flächen. Hier dominierten typische Arten des mesophilen Grünlands (*Molinio-Arrhenateretea*), insbesondere Gräser. In neuen Sandmagerrasen konnten Arten aller genannten Klassen gefunden werden.

Beziehung zwischen Vegetation und Umweltparametern: Alte und neue Heideflächen konnten anhand der erfassten Umweltparameter und der Vegetation klar voneinander differenziert werden. Auf alten Heideflächen war die Deckung an Moosen, Flechten und Gehölzen höher und die Deckung an Gräsern geringer (Abb. 3, Tab. 3, 4). Der pH-Wert, Phosphor im Boden und der Ellenberg N-Zeigerwert waren niedriger (Tab. 2, 4). Auf neuen Flächen waren mehr Arten mit einer langlebigen Samenbank zu finden (Abb. 3).

Die Artenzusammensetzung und auch die Vegetationsstruktur der alten und neuen Sandmagerrasen waren recht ähnlich (Abb. 4). Lediglich die Artenzahl, der Shannon-Index und die Vegetationshöhe waren signifikant höher auf den neuen Flächen (Tab. 4).

Diskussion – Heiden: Die untersuchten Heiden befanden sich in unterschiedlichen Entwicklungsstadien. Während sich zwei der alten Heiden in der Degenerationsphase befanden, war die dritte alte Heide vital und die zweijährigen Renaturierungsflächen im Pionierstadium. Die alten Flächen waren daher recht artenarm mit nur wenigen Zielarten (SCHNEIDER & NAUMANN 2013). Da auf den neuen Flächen bislang kaum heidetypische Arten, sondern vielmehr Nährstoffzeiger und Grünlandarten zu finden waren, scheinen die Renaturierungsmaßnahmen nach jetzigem Kenntnisstand und nach der kurzen Beobachtungszeit hier nicht ausreichend gewesen zu sein. Um ein endgültiges Urteil fällen zu können, muss dies in den kommenden Jahren weiterhin beobachtet werden, da die erfolgreiche Ansiedlung von Heide-Arten bis zu neun Jahren betragen kann (VERHAGEN et al. 2001). Trotz vorherigem

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Oberbodenabtrag, war der Phosphor-Gehalt im Boden auf den neuen Flächen relativ hoch und sorgte für ein starkes Wachstum an Gräsern und hochwüchsigen Arten, die für das Fehlen von Lichtkeimern, wie u. a. *Calluna vulgaris*, verantwortlich sein können. Demnach ist es vor allem wichtig, vor dem Abtrag die Tiefe des Phosphor-Anreicherungshorizonts und damit die nötige Abtragstiefe zu bestimmen (SÜSS et al. 2004, EICHBERG et al. 2010, GILHAUS et al. 2015).

Sandmagerrasen: Die Vegetation der Sandmagerrasen war vor allem von Arten der *Sedo-Scleranthetea* und - wegen der teils basenreichen Sande auch - *Festuco-Brometea* gekennzeichnet. Aufgrund ihrer Diversität und insbesondere der Vielzahl an gefährdeten Arten sind sie schützenswert. Gerade Sandmagerrasen im Pionierstadium mit einem großen Offenbodenanteil sind in der Regel sehr artenreich (z. B. SCHWABE et al. 2013, GILHAUS et al. 2015). Eine hohe Diversität wiesen auch die Flächen auf, die vorher als Schuttablageflächen (kleine Müll-/Bauschuttdeponien) dienten und wo aufgrund des heterogenen Bodensäuregrads neben Säurezeigern auch basophile Arten vorkamen (z. B. FRĄCZEK et al. 2014).

Die alten Sandmagerrasen-Flächen wiesen eine hohe Gräserdeckung und eine hohe Vegetation auf, wie es typisch ist für Sandmagerrasen in späteren Sukzessionsstadien (erhöhte Nährstoffgehalte, feuchtere Bodenverhältnisse) (STORM & SÜSS 2008, SÜSS et al. 2010, HORROCKS et al. 2016).

Alte und neue Sandmagerrasen unterschieden sich insgesamt floristisch kaum. Unsere Studie konnte somit zeigen, dass Oberbodenabtrag und Artentransfer mittels Mahdgut geeignete Renaturierungsmaßnahmen für den lokalen Sandmagerrasen-Typ sind.

Management-Empfehlungen – Für den Erhalt der Heiden und Sandmagerrasen ist eine langfristige Nutzung notwendig. Um dem Stickstoffeintrag entgegenzuwirken, sollten die bestehenden Sandmagerrasen weiterhin einschürig gemäht werden (HÖLZEL 2009). Für die Heiden sollte eine Mahd alle fünf Jahre ausreichen (HÄRDTLE et al. 2006, KEIENBURG & PRÜTER 2006). Auf alten Flächen sollen durch Schoppern oder Plaggen auf den Heiden (NIEMEYER et al. 2007, FARTMANN et al. 2015), sowie durch Rechen auf den Sandmagerrasen (JENTSCH et al. 2002, EICHBERG et al. 2010) zusätzlich kleinere Bereiche geschaffen werden. Der gleiche Effekt auf kleinerer Ebene könnte durch das Entstehen offener Bodenstellen bei extensiver Schafbeweidung sichergestellt werden (SÜSS & SCHWABE 2007, EICHBERG et al. 2010).

Schlussfolgerung – Die untersuchten Heiden und Sandmagerrasen sind bedeutsam als Refugien für viele unter nährstoffarmen Bedingungen vorkommende Arten, da ähnlich nährstoffarme Flächen im Untersuchungsgebiet nicht vorkommen. Für den langfristigen Erhalt ist ein geeignetes Management, das Eutrophierungseffekten entgegenwirkt und frühe Sukzessionsstadien erhält, unabdingbar. Besonders auf den vergrasten Flächen sollte die Nutzung daher entsprechend angepasst werden. Für erfolgreiche Renaturierungen ist es wichtig, ein geeignetes Nährstoffniveau zu schaffen und Zielarten über z. B. Mahdgutübertragung einzubringen.

In Zukunft sollten erstens die bestehenden Flächen vergrößert und zweitens ihre Qualität verbessert werden (HEINKEN 2009, KUUSSAARI et al. 2009). Außerdem sollten neue Heide- und Sandmagerrasen-Flächen geschaffen werden, um die Konnektivität der Habitate zu verbessern (LINDBORG & ERIKSSON 2004, HAENEL 2015, MINISTÈRE DU DÉVELOPPEMENT DURABLE ET DES INFRASTRUCTURES 2017).

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Supplements

Supplement S1. Syntaxonomically classified vegetation relevés of heathlands.

Beilage S1. Syntaxonomisch geordnete Vegetationsaufnahmen der Heiden.

Supplement S2. Syntaxonomically classified vegetation relevés of sand grasslands.

Beilage S2. Syntaxonomisch geordnete Vegetationsaufnahmen der Sandmagerrasen.

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Supplement S1. Syntaxonomically classified vegetation relevés of heathlands, N=18. Plot size = 4 m x 4 m. Cover abundance values of species are coded in the Braun-Blanquet scale modified by Wilmanns (1998). Weighted mean Ellenberg's indicator values for moisture (mEIV-M), reaction (mEIV-R) and nutrients (mEIV-N) are given for each relevé. The absolute Ellenberg's indicator values are given for each species (M, R, N), where "x" indicates indifferent behaviour regarding the respective parameter. Red List status is abbreviated as following: NT=near threatened, VU=vulnerable, CR=critically endangered. H is the abbreviation for heathland and * indicates new sites. Coordinates, site abbreviations and other information upon the sites are given in Table 1.

Beilage S1. Syntaxonomisch geordnete Vegetationsaufnahmen der Heiden, N=18. Aufnahmefläche= 4 m * 4 m. Deckungsgrade der Arten sind in der Skala von Braun-Blanquet verändert nach Wilmans (1998) angegeben. Gewichtete Mittelwerte der Indikatorwerte nach Ellenberg für Feuchte (mEIV-M), Reaktion (mEIV-R) und Nährstoffe (mEIV-N) sind für jede Aufnahme angegeben. Die absoluten Indikatorzahlen sind für jede Art angebenen, wobei "X" für indifferentes Verhalten der Art je nach Parameter steht. Die Rote Liste Kategorien sind wie folgt abgekürzt: NT= potenziell gefährdet, VU=gefährdet, CR= vom Aussterben bedroht. "H" steht für Heiden und neue Flächen sind mit * markiert. Koordinaten, Flächenkürzel und andere Informationen zu den Flächen sind in Tabelle 1 aufgeführt.

relevé number						1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
site designation						**H2**	**H2**	**H2**	**H2**	**H3**	**H3**	**H1**	**H1**	**H1**	**H1**	**H4***	**H4***	**H4***	**H4***	**H5***	**H5***	**H5***	**H5***	
mEIV-M						4,1	4,4	4,3	4,6	4,5	4,9	5,0	5,0	4,0	3,9	4,5	4,1	4,5	4,5	5,7	5,1	4,5	4,8	
mEIV-R						2,3	2,2	2,3	1,4	1,3	1,0	1,0	1,0	1,0	1,3	5,0	4,2	5,3	5,0	6,0	7,6	7,7	7,8	
mEIV-N						2,3	3,0	2,6	3,6	1,4	1,0	1,8	1,0	1,0	1,4	4,3	4,1	4,6	4,8	5,2	4,8	4,4	4,6	
bare soil cover [%]						5	1	0	0	15	10	0	0	1	0	25	5	15	0	5	10	1	0	
bryophytes & lichen cover [%]						80	85	90	80	50	35	90	25	80	15	50	25	15	15	30	15	5	5	
litter cover [%]						60	30	75	70	15	25	5	5	1	5	25	15	5	15	5	15	15	15	
graminoid cover [%]						20	40	30	30	5	5	15	1	0	20	40	50	60	30	60	70	80	80	
herb cover [%]						20	30	20	10	5	5	0	1	0	1	30	40	30	60	25	20	25	20	
shrub cover [%]						34	42	51	48	74	74	75	75	80	83	0	0	0	0	0	0	0	0	
no. vascular plants						20	24	21	15	18	11	4	5	4	7	21	20	28	25	31	25	25	24	
						old heathlands										new heathlands								
						Calluno-Ulicetea																		
						Nardetalia						species poor												
						grass/bush encroachment																		
	abbreviation (figure 3)	**Ellenberg's indicator value**			**Red List status**											grassland species								**constancy (number)**
																				moisture indicators				
		M	**R**	**N**																				
character species Calluno-Ulicetea																								
Calluna vulgaris	Cal vul	x	1	1	-	3	3	3	3	4	4	4	4	5	5	1	+	r	.	1	1	.	.	15
Deschampsia flexuosa	Des fle	x	x	3	-	2a	2b	2b	2b	r	.	2a	r	.	2a	+	2a	2m	1	.	.	.	.	12
Genista pilosa		x	2	1	-	2b	.	.	.	2a	.	.	.	.	.	.	.	.	.	.	.	.	.	2
character species Nardetalia																								
Veronica officinalis	Ver off	4	3	4	-	+	1	1	.	.	.	.	.	.	.	1	+	.	1	.	.	.	.	6
Carex pilulifera	Car pil	5	3	3	-	2a	1	2b	2a	+	+	.	.	.	.	.	.	.	.	.	.	.	.	6
Luzula multiflora		5	5	3	-	.	2a	2m	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2
species of forests, encroachment indicators																								
Cytisus scoparius	Cyt sco	4	3	4	-	.	2a	2b	2a	2a	+	.	.	r	.	+	.	.	.	.	.	.	.	7
Teucrium scorodonia	Teu sco	4	2	3	-	2a	2b	2a	1	+	.	.	.	+	.	.	.	.	.	.	.	.	.	6
Frangula alnus	Fra aln	8	4	x	-	1	.	r	2a	r	.	2a	+	.	.	.	.	.	.	.	.	.	.	6
Poa nemoralis		5	5	4	-	.	1	2a	.	+	+	.	.	.	.	.	.	r	.	.	.	.	.	5
Pinus sylvestris (juv.)	Pin syl	x	x	x	CR	r	.	r	r	1	1	.	.	.	.	.	.	.	.	.	.	.	.	5
Quercus spec. (juv.)	Que sp.	5	x	x	-	.	.	r	+	r	+	.	+	.	.	.	.	.	.	.	.	.	.	5
Holcus mollis	Hol mol	5	2	3	-	1	2a	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3
Calamagrostis epigejos	Cal epi	x	x	6	-	2a	2b	.	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3
Betula pendula (juv.)		x	x	x	-	.	.	.	1	2a	+	.	.	.	.	.	.	.	.	.	.	.	.	3
Populus tremula (juv.)		5	x	x	-	.	.	.	2a	2a	1	.	.	.	.	.	.	.	.	.	.	.	.	3
Pteridium aquilinum	Pte aqu	5	3	3	-	.	+	.	.	+	+	.	.	.	.	.	.	.	.	.	.	.	.	3
species of meso-/eutrophic grassland and ruderals																								
Holcus lanatus	Hol lan	6	x	5	-	.	.	.	.	.	.	.	.	.	.	2b	2b	2b	2b	2b	3	1	2a	8
Trifolium repens	Tri rep	5	6	6	-	.	.	.	.	.	.	.	.	.	.	2b	4	3	5	2a	2b	2b	2a	8
Vicia sativa subsp. nigra		x	x	x	-	.	.	.	.	.	.	.	.	.	.	1	1	1	+	1	1	+	+	8
Taraxacum sect. Ruderalia	Tar off	5	x	8	-	.	r	.	.	.	.	.	.	.	.	+	+	+	1	+	r	+	.	8
Luzula campestris		4	3	3	-	1	.	.	+	.	.	.	.	.	2a	2a	+	+	+	.	.	+	.	8
Poa trivialis		7	x	7	-	.	.	.	.	.	.	.	.	.	.	1	1	1	.	2m	1	1	2a	7
Vicia hirsuta		4	x	4	-	.	.	.	.	.	.	.	.	.	.	+	+	2m	1	.	.	+	r	6
Leucanthemum vulgare	Leu vul	4	x	3	-	.	.	.	.	.	.	.	.	.	.	.	1	1	.	.	.	.	r	3
Galium aparine	Gal apa	x	6	8	-	.	.	.	.	.	.	.	.	.	.	.	.	+	+	+	.	+	+	5
Carduus crispus	Car cri	6	7	9	-	.	.	.	.	.	.	.	.	.	.	2a	1	2a	2a	.	.	.	.	4
moisture and nutrient indicators																								
Poa annua		6	x	8	-	.	.	.	.	.	.	.	.	.	.	.	.	.	+	2a	1	1	1	5
Ranunculus repens	Ran rep	7	x	7	-	.	.	.	.	.	.	.	.	.	.	.	.	r	.	1	2a	1	1	5
Rumex crispus	Rum cri	7	x	6	-	.	.	.	.	.	.	.	.	.	.	.	.	r	.	2b	2a	1	2a	5
Salix spec. (juv.)	Sal sp.	8	6	5	-	r	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	2a	2a	5
Juncus effusus	Jun eff	7	3	4	-	.	.	.	.	.	.	.	.	.	.	.	.	.	r	r	+	+	.	4
Urtica dioica	Urt dio	6	7	9	-	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	r	r	+	4
Cerastium fontanum		5	x	5	-	.	.	.	.	.	.	.	.	.	.	+	.	.	.	1	2m	.	.	3
Silene latifolia subsp. alba		4	x	7	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	1	+	3
Stellaria media		x	7	8	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	.	1	3
Epilobium montanum		5	6	6	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	+	+	3
Juncus conglomeratus	Jun con	7	4	3	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	1	+	3
Juncus bufonius		7	3	4	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2a	2m	.	.	2
Trifolium hybridum		6	7	5	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2a	.	2a	.	2
common species																								
Hypericum perforatum		4	6	4	-	1	1	1	r	r	r	.	.	.	.	2a	1	1	2a	1	1	1	2m	14
Rumex acetosella	Rum act	3	2	2	-	1	1	1	.	r	.	.	.	.	1	2b	3	2b	2b	1	1	1	.	12
Rubus sect. Rubus		/	/	/	-	+	2b	+	.	.	.	r	.	r	+	2a	2a	2a	2a	1	1	.	.	12
Agrostis capillaris	Agr cap	x	4	4	-	2a	.	+	.	.	.	.	.	.	2m	2b	2b	2b	2a	2b	4	5	5	11
endangered species																								
Aira praecox		2	2	1	VU	.	.	.	.	.	.	.	.	.	.	.	1	1	.	.	.	.	.	2
Convallaria majalis		4	x	4	NT	r	.	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2
companion species																								
Hypochaeris radicata		5	4	3	-	.	r	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	3
Epilobium angustifolium		5	5	8	-	.	+	.	.	.	.	.	.	.	.	.	.	+	1	.	.	.	.	3
Anthoxanthum odoratum		x	5	x	-	.	r	1	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	3
Fagus sylvatica (juv.)		5	x	x	-	.	.	.	.	+	r	.	.	.	.	.	.	.	.	.	.	.	.	2
Hieracium maculatum		4	5	2	-	+	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2
Crepis capillaris		5	6	4	-	.	.	r	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	2
Cerastium brachypetalum		3	8	2	-	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	2
Veronica chamaedrys		5	x	x	-	.	1	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	2
Trifolium campestre		4	6	3	-	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	+	.	.	2
Veronica arvensis		x	6	x	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	+	2
Tanacetum vulgare		5	8	5	-	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	+	2
Cardamine hirsuta		5	5	7	-	.	.	.	.	.	.	.	.	.	.	.	.	+	+	.	.	.	.	2
Veronica agrestis		6	7	7	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	1	.	.	2
Acer spec. (juv.)		6	7	7	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1	.	.	2
Silene dioica		6	7	8	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	+	2
Arabidopsis thaliana		4	4	4	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	+	.	2
Scrophularia nodosa		6	6	7	-	.	.	.	.	.	.	.	.	.	.	.	r	.	r	.	.	.	.	2
Matricaria recutita		5	5	5	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	+	.	2
Festuca ovina agg.		x	3	1	-	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Achillea millefolium		4	x	5	-	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	.	1
Trifolium pratense		5	x	x	-	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	1
Plantago lanceolata		x	x	x	-	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	1
Campanula rapunculus		3	7	4	-	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	1
Picea abies		x	x	x	-	.	.	.	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	1
Bromus hordeaceus		x	x	3	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	1
Arrhenatherum elatius		x	7	7	-	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	1
Senecio jacobaea		4	7	5	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	1
Phleum pratense		5	x	7	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	1
Erodium cicutarium		4	x	x	-	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	1
Daucus carota		4	x	4	-	.	.	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	1
Cirsium vulgare		5	7	8	-	.	.	.	.	.	.	.	.	.	.	.	r	.	.	.	.	.	.	1
Viola arvensis		x	x	x	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	1
Cirsium arvense		x	x	7	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	1
Viola riviniana		4	4	x	-	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Solanum dulcamara		8	x	8	-	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	1
Equisetum arvense		x	x	3	-	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	1
Lonicera xylosteum		5	7	6	-	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Centaurea jacea		x	x	x	-	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	1
Agrimonia eupatoria		4	8	4	-	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Carpinus betulus (juv.)		x	x	x	-	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Conyza canadensis		4	x	5	-	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	1
Polygonum aviculare		4	x	6	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	1
Ajuga reptans		6	6	6	-	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Fragaria vesca		5	x	6	-	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Silene vulgaris		4	7	4	-	.	+	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Vicia tetrasperma		5	5	5	-	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Vicia villosa		4	6	5	-	.	.	.	.	.	.	.	.	.	.	.	.	.	2a	.	.	.	.	1
Vaccinium myrtillus		x	2	3	-	.	.	.	.	r	.	.	.	.	.	.	.	.	.	.	.	.	.	1
Carex ovalis		7	3	3	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	1
Myosotis arvensis		5	x	6	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	+	.	.	.	1
Poa pratensis		5	x	6	-	.	.	.	.	.	.	.	.	.	+	.	.	.	.	.	.	.	.	1

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Supplement S2. Syntaxonomically classified vegetation relevés of sand grasslands, N=27. Plot size=4 m x 4 m. Cover abundance values of species are coded in the Braun-Blanquet scale modified by Wilmanns (1998). Weighted mean Ellenberg's indicator values for moisture (mEIV-M), reaction (mEIV-R) and nutrients (mEIV-N) are given for each relevé. The absolute Ellenberg's indicator values are given for each species (M, R, N), where "x" indicates indifferent behaviour regarding the respective parameter. Red List status is abbreviated as following: EN=endangered, NT=near threatened, VU=vulnerable, CR=critically endangered. "S" is the abbreviation for sand grassland and * indicates new sites. Coordinates, site abbreviations and other information upon the sites are given in Table 1.

Beilage S2. Syntaxonomisch geordnete Vegetationsaufnahmen der Sandmagerrasen, N=37. Aufnahmefläche= 4 m * 4 m. Deckungsgrade der Arten sind in der Skala von Braun-Blanquet verändert nach Wilmans (1998) angegeben. Gewichtete Mittelwerte der Indikatorwerte nach Ellenberg für Feuchte (mEIV-M), Reaktion (mEIV-R) und Nährstoffe (mEIV-N) sind für jede Aufnahme angegeben. Die absoluten Indikatorzahlen sind für jede Art angebenen, wobei "X" für indifferentes Verhalten der Art je nach Parameter steht. Die Rote Liste Kategorien sind wie folgt abgekürzt: NT= potenziell gefährdet, VU=gefährdet, CR= vom Aussterben bedroht. "S" steht für Sandmagerrasen und neue Flächen sind mit * markiert. Koordinaten, Flächenkürzel und andere Informationen zu den Flächen sind in Tabelle 1 aufgeführt.

relevé number																															
site designation																															
mEIV-F																															
mEIV-R																															
mEIV-N																															
bare soil cover [%]																															
bryophytes & lichen cover [%]																															
litter cover [%]																															
graminoid cover [%]																															
forb cover [%]																															
no. of vascular plants																															

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