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DRY HEATHLAND RESTORATION IN THE ZLATNICE NATURE RESERVE (CZECH REPUBLIC): AN ASSESSMENT OF THE EFFECTIVENESS OF GRAZING AND SOD-CUTTING

Jiří DOSTÁLEK[1,*] & Tomáš FRANTÍK[2]

Abstract

The vegetation of low-altitude dry heathlands in Central Europe (*Euphorbio cyparissiae-Callunion vulgaris*) has declined because the abandonment of traditional management has resulted in gradual overgrowth by woody species and because nutrient inputs have changed. Low-intensity grazing and sod-cutting, which are traditionally recommended to regenerate heather (*Calluna vulgaris*) vegetation from the seed bank, were introduced to restore stands of heather that had disappeared. The study was conducted in the Zlatnice Nature Reserve, located in the northwestern part of Prague (Czech Republic). A system of 1 m^2 permanent plots was used to collect the data. Both grazing and sod-cutting were effective for the restoration of the *Calluna vulgaris* vegetation. During the two years after the introduction of grazing, the greatest increase in the heather cover occurred in the grazed areas. The heather cover in the areas managed by sod-cutting started to increase significantly in the third year following the removal of sods and reached values comparable with the grazed areas. Regular grazing hindered the increase in the cover of herbs; the increase in the herb cover was higher after single sod-cutting. Sod-cutting facilitated the expansion of mosses. The experiment suggests that non-intensive sheep and goat grazing is most likely the most appropriate tool to restore dry heathland on shallow poor soils when more than 20 years have elapsed since the disappearance of the heathland. The use of sod-cutting itself is more demanding and brings a higher risk of overgrowth by unwanted herbs and woody species, resulting in repeated degradation of the *Calluna vulgaris* vegetation.

Keywords: *Calluna vulgaris*, heather, moss, open landscape, sheep grazing, woody encroachment.

Izvleček

Vegetacija nižinskih suhih vresav v srednji Evropi (*Euphorbio cyparissiae-Callunion vulgaris*) je v upadanju zaradi opuščanja tradicionalnega gospodarjenja in to se kaže v postopnem zaraščanju z lesnatimi rastlinami in spremenjenem vnosu hranil. Za obnovitev sestojev z vreso, ki so izginili, smo uporabili pašo z nizko intenzivnostjo in košnjo, ki sta tradicionalno priporočena načina za obnavljanje vegetacije z vreso (*Calluna vulgaris*) iz semenske banke. Raziskavo smo opravili v naravnem rezervatu Zlatnice, ki se nahaja v severozahodnem delu Prage (Češka republika). Vzpostavili smo sistem stalnih 1 m^2 ploskev. Za obnovitev vegetacije z vrsto *Calluna vulgaris* sta bila uspešna tako paša kot košnja. Pokrovnost vrese se je povečala dve leti po začetku poskusa s pašo, na površinah s košnjo pa se je značilno povečala tretje leto in vrednosti so bile primerljive s pašenimi površinami. Redna paša je ovirala povečanje pokrovnosti zelišč, medtem ko se je njihova pokrovnost povečala po posamezni košnji. Košnja je tudi vplivala na povečanje pokrovnosti mahov. Poizkus je pokazal, da je slabo intenzivna paša ovac in koz verjetno najbolj primeren način obnove suhih vresav na plitvih, s hranili revnih tleh, po več kot 20 let od uničenja vresave. Košnja je bolj zahtevna, pojavlja pa se tudi možnost razraščanja nezaželjenih zelišč in lesnatih rastlin, kar zopet vodi v degradacijo vegetacije z vrsto *Calluna vulgaris*.

Ključne besede: *Calluna vulgaris*, vresa, mahovi, odprta krajina, paša ovac, zaraščanje.

[1] Silva Tarouca Research Institute for Landscape and Ornamental Gardening, 252 43 Průhonice, Czech Republic, dostalek@vukoz.cz

[2] Institute of Botany, Academy of Sciences of the Czech Republic, 252 43 Průhonice, Czech Republic, tomas.frantik@ibot.cas.cz

* Corresponding author

1. INTRODUCTION

European heathlands were formed primarily as a result of the long-term effects of human activities, chiefly fire, pastoral and agricultural activities (Gimingham 1994, Antrop 2005, Plieninger et al. 2006). Depending on climatic conditions, a broad range of differentiated heathland communities arose (Fagúndez 2013). *Calluna vulgaris* (L.) Hull heathlands have become a major component of the cultural landscape in Europe (Gimingham 1972, Diemont et al. 2013). In connection with the changes in the agricultural landscape that occurred during the second half of the 20th century, a significant loss and degradation of these habitats has occurred due to abandonment. These changes have favored scrubland and forest expansion (Chauchard et al. 2007, Garbarino et al. 2011, Hooftman and Bullock 2012, Rego et al. 2013) as well as the accumulation of nutrients (Heil & Diemont 1983, van Rheenen et al. 1995). To maintain these threatened habitats, with their narrow specialist organisms and complex interactions (De Graaf et al. 2009), the importance of heathland conservation has been highlighted in recent decades and has received much attention by the European Union and individual countries in relationship to conservation management and restoration methods intended to counteract the negative effects of various drivers of biodiversity loss on habitat quality (Pywell et al. 2011, Diemont et al. 2013, Fagúndez et al. 2013).

Considerable attention has been devoted to the study of practices that maintain heathland community structure, such as grazing, burning, cutting, sod-cutting or sod-chopping and other factors affecting vegetation development (e.g., Pywell et al. 1995, 2011, Gallet & Roze 2001, Hulme et al. 2002, Pakeman et al. 2003, Niemeyer et al. 2007, Mitchell et al. 2008, Måren & Vandvik et al. 2009, Newton et al. 2009). Previous research has focused particularly on the parts of Western Europe where heathland occurs in extensive amounts. Only a few studies have addressed heathland restoration at the limits of the distribution area of heathlands (Sedláková & Chytrý 1999, Klein et al. 2009, Ascoli et al. 2013).

In contrast to the situation in Western Europe, low-altitude heathlands in Central Europe were, most likely, always restricted to small, more or less isolated areas (Sedláková & Chytrý 1999). The reason for this distribution is that *Calluna vulgaris* reaches its ecological and geographical limits in more continental climates (Schubert 1960).

Near the limits of its distribution, *Calluna* is less vigorous and competitive. These characteristics may result from drought stress and the effects of lower temperatures (Gimingham 1960, Rosén 1995). The vegetation of Central European dry heathland dominated by *Calluna vulgaris* (*Euphorbio cyparissiae-Callunion vulgaris* Schubert ex Passarge in Scamoni 1963) occurs on acidic and nutrient-poor soils in lowland and hilly landscapes characterized by low rainfall. These communities are often in contact with dry grassland (*Festuco-Brometea*) and contain several steppe species such as *Avenula pratensis*, *Carex humilis*, *Hypericum perforatum* and *Koeleria macrantha* (for details see Chytrý 2007). The vegetation of the *Euphorbio cyparissiae-Callunion vulgaris* alliance has declined due to the abandonment of traditional management (mostly extensive grazing), associated with gradual overgrowth by woody species and with nutrient inputs. As a result of such development, the stands of *Calluna vulgaris* have almost disappeared in a number of localities. The use of controlled fire is recognized to be one of the most effective tools for the conservation management of this type of vegetation (Sedláková & Chytrý 1999, Mohamed et al. 2006, Klein et al. 2009, Davies et al. 2010, Måren et al. 2010, Harris et al. 2011). Nevertheless, *Calluna* regeneration after fire may be modified by the local environment (Vandvik et al. 2005) and also by interactions with encroaching woody species (Manning et al. 2004). Several studies have noted that fire provides sites for aspen and birch seed germination (Chantal et al. 2005, Borghesio et al. 2009) and depletes allelopathic soil compounds (Mugion 1996). In addition, aspen post-fire stem mortality induces root suckering over sizeable areas. Consequently, the encroaching stands enlarge at each fire event until they merge and outcompete the heathland (Ascoli & Bovio 2010). Borghesio (2009) emphasizes that burning alone is insufficient to stop woodland expansion and that subsequent, prolonged grazing might be essential. This principle has been confirmed by Ascoli et al. (2013).

Although prescribed fire is considered a promising alternative management tool to maintain open landscapes, such as grasslands or heathlands, the application of this method is problematic in many parts of Europe because of the lack of specific knowledge and the legislative prohibition of prescribed burning in most of the countries (see Diemont et al. 2013). Valkó et al. (2014) emphasize that for the application of prescribed burning in Europe, the general findings of carefully designed case studies should be combined with the practical knowledge of conservation managers about the circumstances affecting the local application of fire to reach specific management objectives. It was not possible to apply fire treatments in our experiment because such treatments are strictly prohibited on the territory of the city of Prague; moreover, the vegetation did not contain sufficient dry matter to burn.

The aim of this study is to investigate to what extent the lost heathland can be restored following the introduction of non-intensive grazing. Low-intensity grazing is compared with sod-cutting, which is traditionally recommended for renewing *Calluna vulgaris* vegetation from the seed pool if burning cannot be used. Sod-cutting (i.e., removal of the top layer of soil) is a restoration management option that aims to enhance seedling establishment (Weijtmans et al. 2009). This technique is among the basic methods of heathland restoration (e.g., Sedláková & Chytrý 1999, Britton et al. 2000, Niemeyer et al. 2007, Diaz et al. 2008.).

2. STUDY SITE

The study was performed in the Zlatnice Nature Reserve in the northwestern part of Prague (Czech Republic; latitude 50° 06' 24'' N, longitude 14° 21' 59'' E). The Zlatnice Reserve is located on a westward-oriented steep rocky slope above a stream at 250–280 m a.s.l. The geological substratum is greywacke and shale of the Upper Proterozoic on which a shallow layer of soil of protoranker type has developed.

The climate is of the mild humid zone type, with a pronounced but not extremely cold winter, but features of a transition to a mild arid zone type with hot summers and cold winters are also present (Walter & Lieth 1960–1967). September is the driest month. The mean annual temperature on the slope with dry heathland is 9.0 °C. The mean temperature for the period of April to September ranges from 15.0 to 15.7 °C in the Prague Basin and from 14.2 to 14.6 °C on the surrounding plateau. A value of –29.9 °C was recorded as the absolute minimum temperature. The mean annual total precipitation is 476–487 mm in the Prague Basin and 521–575 mm on the Prague Plateau. The climatic data represent a 50 year average and were processed using information from the Czech Hydrometeorologic Institute climatologic database.

Previously, a considerable part of the slope was extensively grazed by livestock (especially by goats and sheep), which determined the formation of dry heathland communities (Kubíková et al. 2005). When the low-intensive farming of these areas stopped, shrubs and trees began to invade and overgrow the open habitat. More advanced stages of succession developed, heading toward woodland communities dominated primarily by *Quercus petraea*, a potential natural vegetation on rendzinas and rankers. In Prague, these advanced stages are, most frequently, xerothermic oak forests with *Cynanchum vincetoxicum* (*Cynancho-Quercetum*) and xerothermic downy oak forests (*Lathyro vesicoloris-Quercetum pubescentis*) (for details see Moravec & Neuhäusl 1991). As a result of the above-mentioned succession, the overall area of open space has become considerably smaller (approximately 0.2 ha).

Nevertheless, the preserved dry heathland that remains in this area is relatively extensive. These dry heathlands are represented by the association *Euphorbio cyparissiae-Callunetum vulgaris* Schubert 1960. This community is formed by characteristic species such as *Calluna vulgaris* (dominant), *Hieracium pilosella*, *Rumex acetosella*, *Cladonia uncinalis*, *Polytrichum piliferum*, *Avenella flexuosa*, *Euphorbia cyparissias*, *Festuca ovina*, *Dianthus carthusianorum*, *Hypericum perforatum*, *Potentilla arenaria*, *Pimpinella saxifraga* and *Jasione montana* (for more details on this type of vegetation see Chytrý 2007).

To protect the vegetation of the dry heathland, the nature reserve was established in 1968. In 1980, the heather was nearly overgrown by shrubs or replaced by stands of *Avenella flexuosa* and *Festuca ovina* (Kubíková 1982). By 2008, when the experiment was initiated, the population of *Calluna vulgaris*, including dry branches, had completely disappeared. The entire site was overgrown by shrubs, with the herb layer dominated by *Avenella flexuosa* and mosses, primarily *Hypnum cupressiforme*.

3. METHODS

At the beginning of 2008, the expanding woody plants were cut off in the entire area (0.2 ha), and the cut areas of their stumps were simultaneously smeared with the herbicide Roundup. In cases of surviving shoots, this procedure was repeated during August in 2009, 2010, 2011, 2012 and 2013. Annually since 2008, part of the area has been grazed by a herd of goats and sheep for a short time (1 week) in early spring (April). The grazing intensity, expressed as Animal-Days (AD) per unit area = stocking rate × days / area [ha] (see Hodgson 1979), was approximately 500 for the sheep and 50 for the goats. This grazing intensity is successfully used in Prague for dry grassland plant diversity conservation (see Dostálek & Frantík 2008, 2012).

In the early spring of 2008, on the part of the area that was not grazed, the sod was removed from the mineral soil on five randomly selected plots. An organic layer approximately 10 (5–15) cm thick was removed by hand using an iron rake. To collect the data, a system of permanent plots 1 m^2 in area was used. A system of permanent plots 1 m × 1 m in size is often used to sample vegetation data (e.g., Krahulec et al. 2001, Jacquemyn et al. 2011). During 2008–2013, we examined 14 plots. The following treatments were applied to individual plots: (1) grazing – each year in spring – 5 plots, (2) sod-cutting – at the beginning of the experiment only – 5 plots, and (3) control – only woody plants were cleared away when they appeared – 4 plots. A 3 × 3 grid was used to divide each plot into 9 smaller subplots. In each subplot, the percentage of vegetation cover of all species and each individual species was estimated in the middle of July. In this way, a more precise estimate of cover for each species was obtained for the entire plot, including the mean value and standard deviation. For *Calluna vulgaris*, the number of seedlings was also recorded in 2008–2010. After three years, it was not possible to distinguish individual plants because of the development of dense clusters. Bryophytes were not identified at the species level. The changes in the cover and numbers of individuals of *Calluna vulgaris* were tested using a Kruskal-Wallis test (Statistica v. 9 program). A Principal Component Analysis (PCA) was applied to examine the dependence of the changes in the cover of *Calluna vulgaris*, woody species, herbs and mosses on the treatment (CANOCO program; ter Braak & Šmilauer 1998).

The nomenclature of vascular plants follows Kubát et al. (2002).

4. RESULTS

4.1 Change in the cover and number of individuals of *Calluna vulgaris*

Changes in the heather cover in relation to the three treatment types are shown in Figure 1. Beginning in the second year, and in all subsequent years, the cover of heather was significantly higher in the grazed plots than in the control plots. However, the cover of heather in the sod-cut plots began to increase markedly beginning in the third year. In the fourth year, it reached a level at which the difference between the increase in cover in the sod-cut plots and grazed plots was not statistically significant. The favorable influence of grazing and sod-cutting on the increased cover of heather is also shown by a comparison of the lines indicating the successional processes occurring in the individual treatments (Figure 2 – the succession arrows for these treatments are

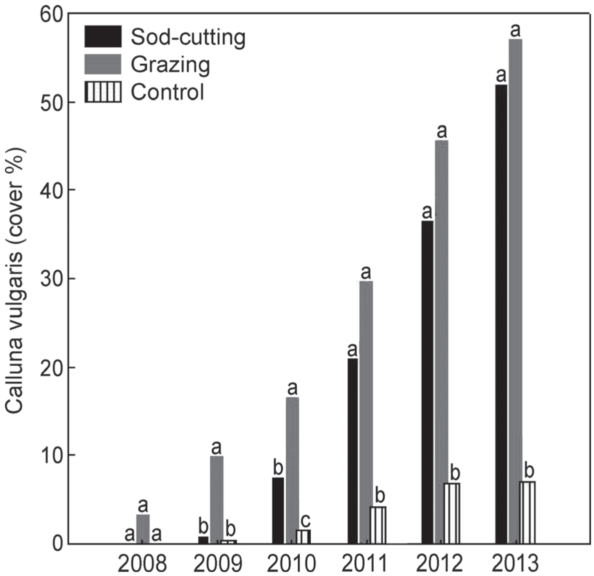

Figure 1: Heather cover in relationship to management intervention in 2008–2013 in the Zlatnice Nature Reserve. Means identified by identical letters are not significantly different ($p < 0.05$, Kruskal-Wallis test). Data on the plot level were used
Slika 1: Pokrovnost jesenske vrese v odvisnosti od gospodarjenja med letoma 2008 in 2013 v naravnem rezervatu Zlatnice. Povprečja, označena z enakimi črkami, niso statistično značilno različna ($p < 0,05$, Kruskal-Wallis test). Uporabili smo podatke posameznih poskusnih ploskev.

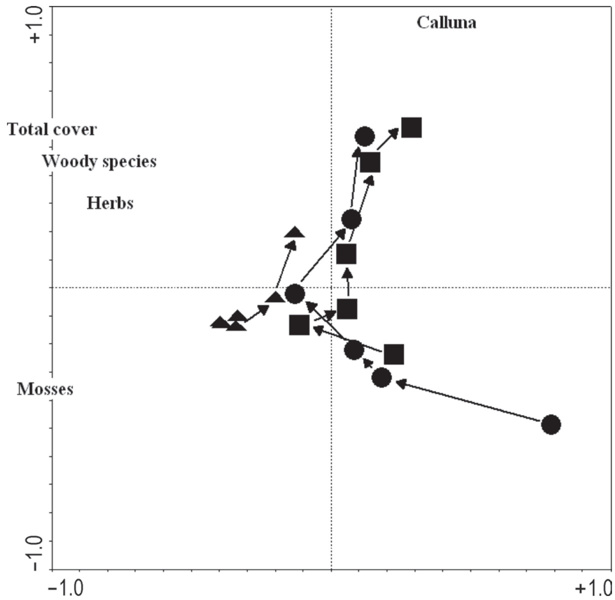

Figure 2: Ordination diagram for an indirect gradient analysis (PCA) showing successional changes on the monitored plots (average of all plots per management treatment per year and cover of *Calluna vulgaris* and other species groups were used) during 2008–2013 (circles – sod-cutting; squares – grazing; triangles – control). The arrows represent the direction of succession. The first two axes explained 89% of the total variability. Data on the plot level were used.

Slika 2: Ordinacijski diagram indirektne gradientne analize (PCA) kaže sukcesijske spremembe na poskusnih ploskvah (uporabili smo povprečje vseh ploskev z določenim gospodarjenjem v posameznem letu in pokrovnost jesenske vrese (*Calluna vulgaris*) in drugih skupin vrst) med letoma 2008 in 2013 (krog – košnja, kvadrat – paša, trikotnik – kontrola). Puščice predstavljajo smer sukcesije. Prvi dve osi pojasnjujeta 89% skupne variabilnosti. Uporabili smo podatke posameznih poskusnih ploskev.

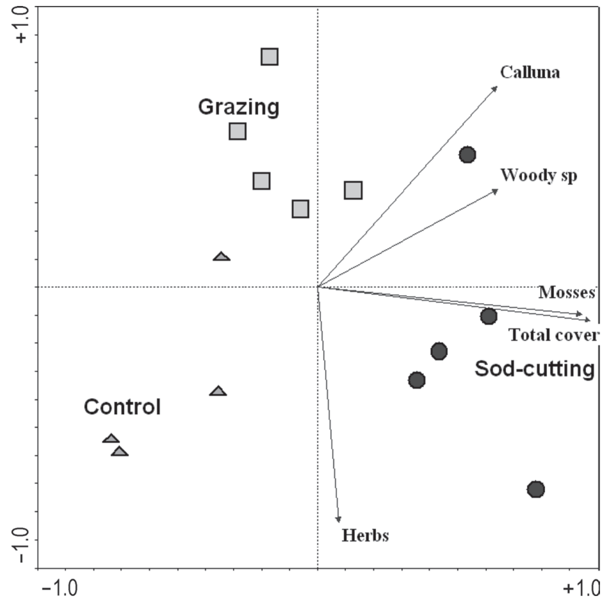

Figure 3: The results of an indirect gradient analysis (PCA) showing cover changes in *Calluna vulgaris* and groups of other species in relationship to restoration management. The difference between the cover in 2008 and 2013 was analyzed (circles – sod-cutting; squares – grazing; triangles – control). The first two axes explained 91% of the total variability. Data on the plot level were used.

Slika 3: Rezultati indirektne gradientne analize (PCA) kažejo spremembe pokrovnosti jesenske vrese in skupin drugih vrst v odvisnosti od načina obnove. Analizirali smo razlike v pokrovnosti med letoma 2008 in 2013 (krog – košnja, kvadrat – paša, trikotnik – kontrola). Prvi dve osi pojasnjujeta 91% skupne variabilnosti. Uporabili smo podatke posameznih poskusnih ploskev.

oriented to the maximum value of heather cover) and by the orientation of the *Calluna* vector to the grazed and to the sod-cut plots in Figure 3.

The impact of grazing and sod-cutting on the establishment of *Calluna* seedlings is shown in Figure 4. In the grazed plots, compared with the sod-cut plots and control plots, the number of

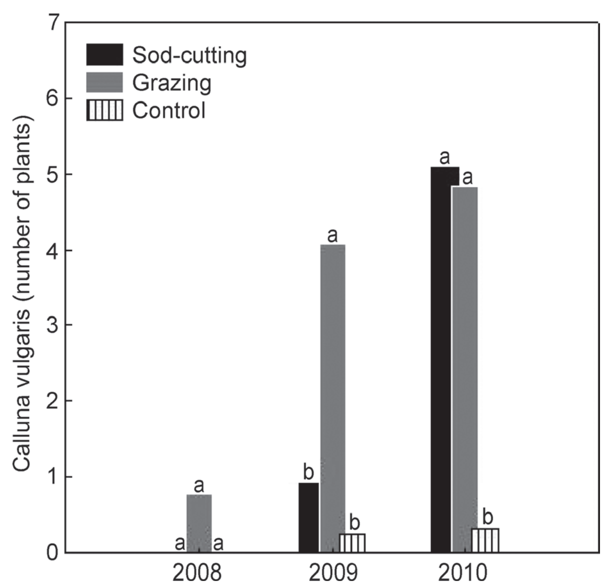

Figure 4: Number of heather individuals in relationship to management intervention in 2008–2010 on the monitored plots in the Zlatnice Nature Reserve. Means identified by different letters are significantly different ($p < 0.05$, Kruskal-Wallis test). Data on the plot level were used.

Slika 4: Število osebkov jesenske vrese v odvisnosti od načina gospodarjenja med letoma 2008 in 2010 na poskusnih ploskvah v naravnem rezervatu Zlatnice. Povprečja, označena z različnimi črkami, so statistično značilno različna ($p < 0,05$, Kruskal-Wallis test). Uporabili smo podatke posameznih poskusnih ploskev.

heather individuals increased significantly as early as the second year following the introduction of grazing. However, in the following year, 2010, a considerable increase in the number of heather individuals was found in the sod-cut plots. In 2010, the average number of heather individuals in the grazed plots and in the sod-cut plots was equal and was significantly higher than in the control plots.

The years 2010 and 2011, characterized by above-average precipitation, were generally favorable for the development of heath vegetation, showing a significant increase in heather cover in all monitored plots. In the course of six years of monitoring, the heather cover also continued to increase mildly in the control plots (see Figure 1).

4.2 Changes in the cover of other plant species

Figure 2 describes the successional process on the monitored plots. The succession arrows for the grazed plots and the sod-cut plots were more or less parallel and, compared with the control plots, indicated considerable successional changes. The effects of the restoration measures on the cover of functional species groups are shown in Figure 3. The overall cover of vegetation, as expected, increased primarily in the sod-cut plots. Figure 3 also shows that regular grazing significantly reduced the increase in the cover of herbs, whereas this increase was more marked after single sod-cutting. The cover of mosses increased markedly, especially in the sod-cut plots. As in the case of the herbs, this increase was related to the recovery of the dominant species of the original vegetation. The increased cover of *Ceratodon purpureus* was especially notable on the bare land. Woody species grew better on the plots after a single removal of sod, and their cover also increased in the grazed plots.

5. DISCUSSION

Grazing is recognized as an effective management option in heathland restoration under the assumption that its adverse impacts on the attributes of the habitat are eliminated (Newton et al. 2009, Fagúndez 2013). This study has shown that non-intensive grazing by sheep and goats during early spring is sufficient to restore stands of heather on dry-heathland habitats after more than 20 years following the disappearance of the heather. This effect is the result of the long viability of the seeds of heather and the disturbance of the organic litter layer due to trampling by animals on the shallow soils of dry habitats. If undisturbed, this layer prevents heather seeds from germinating (Bruggink 1993, Pywell et al. 2002, Bossuyt & Hermy 2003). Hulme et al. (2002) and Mitchell et al. (2008) have reported that reasonably intensive grazing favorably affects the restoration of degraded heath vegetation on habitats with prevailing *Nardus stricta* vegetation. These habitats are comparable to our habitat, with its prevailing *Avenella flexuosa* vegetation. However, grazing itself is most likely not effective for the restoration of aging or dying vegetation, as it is not effective in removing *Calluna* litter (Böhnert & Hempel 1987). Therefore, prescribed burning is often recommended as an appropriate management approach in addition to grazing (see, e.g., Sedláková & Chytrý 1999, Ascoli et al. 2013, Valkó et al. 2014).

In Western Europe, however, adverse effects have been observed in association with high grazing intensity. These adverse effects include declines in heather cover and increases in graminoids (e.g., Gallet & Roze 2001, Newton et al. 2009). In our case, no adverse impacts were observed after short-term grazing of the habitat; indeed, the introduction of grazing resulted in a marked decline in the cover of herbs, including graminoids. Grazing had also a positive influence, as it reduced the cover of undesirable woody species, as also documented by Ascoli et al. (2013), Bokdam & Gleichman (2000), Bullock & Pakeman (1997), Newton et al. (2009). However, this type of impact was not found in our study because grazing in our study lasted only for one week in April and was used mainly to produce a disturbance of the organic layer to help in *Calluna* seedling establishment.

Vegetation recovery following sod-cutting is generally reported as a promising but rather slow process (Werger et al. 1985, Diemont & Homan 1989, Gimingham et al. 1994). Sedláková & Chytrý (1999) state that under Central European conditions, recovery from seeds following sod-cutting occurs in the third year. We obtained similar results after evaluating our experiment. Our study also confirmed the hypothesis (Hobbs & Legg 1983, Mallik et al. 1984) that seeds were present in the plots immediately after the treatment, but seedling establishment was only possible after the spread of acrocarpous mosses, mainly *Ceratodon purpureus*, which allowed germination of *Calluna* by providing a suitable seedbed in the otherwise unsuitable area. An alternative explanation (Legg et al. 1992) is that *Calluna* seeds may have been absent after the treatment due to the effects of fire or because they were removed with the sod and that a length of time is necessary to allow the seed rain to compensate for these losses. In our case, this explanation can be excluded because fertile heather individuals were absent.

However, the bare soil patches present after sod-cutting supported the spread of undesirable woody species (in particular, *Betula pendula* and *Sorbus aucuparia*) and herbs, especially *Avenella flexuosa*, that may have outcompeted the developing heather vegetation. A similar problem has also been noted by Sedláková and Chytrý (1999).

The mild increase of *Calluna* in the control plots was caused by people employed in restoration management. The cover increased only in the parts of these plots that were randomly disturbed as a result of removing woody plants. The overall increase in the cover of light-demanding heather vegetation was also supported by the cutting of full-grown trees at the edge of the heath.

In general, it can be stated that extensive grazing is most likely the most appropriate tool to restore lost dry heathland on the shallow poor soils of the lowlands of Central Europe, even after more than 20 years following the disappearance of the heathland. In certain cases, however, it is possible to combine grazing with sod-cutting, and this combination represents another efficient method. The use of sod-cutting itself is more demanding and involves a higher risk of overgrowth by undesirable herbs and woody species, resulting in the repeated degradation of the *Calluna vulgaris* vegetation.

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7. REFERENCES

Antrop, M. 2005: Why landscapes of the past are important for the future. Landscape and Urban Planning 70(1): 21–34.

Ascoli, D. & Bovio, G. 2010: Tree encroachment dynamics in heathlands of North-west Italy: the fire regime hypothesis. iForest 3: 137–143.

Ascoli, D., Lonati, M., Marzano, R., Bovio, G., Cavallero, A. & Lombardi, G. 2013: Prescribed burning and browsing to control tree encroachment in southern European heathlands. Forest Ecology and Management 289: 69–77.

Böhnert, W. & Hempel, W. 1987. Nutzungs- und Pflegehinweise fuer die geschützte Vegetation des Graslandes und der Zwergstrauchheiden Sachsens. Naturschutzarbeit in Sachsen 29: 3–14.

Bokdam, J. & Gleichman, J. M. 2000: Effects of grazing by free ranging cattle on vegetation dynamics in a continental north west European heathland. Journal of Applied Ecology 37: 415–431.

Borghesio, L. 2009: Effects of fire on the vegetation of a lowland heathland in North-western Italy. Plant Ecology 201: 723–731.

Bossuyt, B. & Hermy, M. 2003: The potential of soil seedbanks in the ecological restoration of grassland and heathland communities. Belgian Journal of Botany 136: 23–34.

Britton, A. J., Marrs, R. H., Carey, P. D. & Pakeman, R. J. 2000: Comparison of techniques to increase *Calluna vulgaris* cover on heathland invaded by grasses in Breckland, south east England. Biological Conservation 95: 227–232.

Bruggink, M. 1993: Seed bank, germination, and establishment of ericaceous and gramineous species in heathlands. In Aerts, R. & Heil, G. W (eds.): Heathlands. Patterns and Processes in a Changing Environment. Springer Netherlands, pp. 153–180.

Bullock, J. M. & Pakeman, R. J. 1997: Grazing of lowland heath in England: management methods and their effects on healthland vegetation. Biological Conservation 79: 1–13.

Chantal, M., Kuuluvainen, T., Lindberg, H. & Vanha-Majamaa, I. 2005: Early regeneration of *Populus tremula* from seed after forest restoration with fire. Scandinavian Journal of Forest Research 20: 33–42.

Chauchard, S., Carcaillet, C. & Guibal, F. 2007: Patterns of land-use abandonment control tree-recruitment and forest dynamics in Mediterranean mountains. Ecosystems 10: 936–948.

Chytrý, M. (ed.) 2007: Vegetace České republiky. 1. Travinná a keříčková vegetace [Vegetation of the Czech Republic. 1 Grassland and Heathland Vegetation]. Academia, Praha, 526 pp.

Davies, G. M., Smith, A. A., MacDonald, A. J., Bakker, J. D. & Legg, C. G. 2010: Fire intensity, fire severity and ecosystem response in heathlands, factors affecting the regeneration of *Calluna vulgaris*. Journal of Applied Ecology 47: 356–365.

De Graaf, M. C. C., Bobbink, R., Smits, N. A. C., Van Diggelen, R. & Roelofs, J. G. M. 2009: Biodiversity, vegetation gradients and key biochemical processes in the heathland landscape. Biological Conservation 142: 2191–2201.

Diaz, A., Green, I. & Tibbett, M. 2008: Re-creation of heathland on improved pasture using top soil removal and sulphur amendments: Edaphic drivers and impacts on ericoid mycorrhizas. Biological Conservation 141: 1628–1635.

Diemont, W. H. & Homan, H. L. 1989: Re-establishment of dominance by dwarf shrubs on grass heaths. Vegetatio 85: 13–19.

Diemont, W. H., Heijman, W. J. M., Siepel, H. & Webb, N. R. (eds.) 2013: Economy and ecology of heathlands. KNNV Publishing, Zeist, The Netherlands, 462 pp.

Dostálek, J. & Frantík, T. 2008: Dry grassland plant diversity conservation using low-intensity sheep and goat grazing management: case study in Prague (Czech Republic). Biodiversity and Conservation 17:1439–1454.

Dostálek, J. & Frantík, T. 2012: The Impact of Different Grazing Periods in Dry Grasslands on the Expansive Grass *Arrhenatherum elatius* L. and on Woody Species. Environmental Management 49: 855–861.

Fagúndez, J. 2013: Heathlands confronting global change: drivers of biodiversity loss from past to future scenarios. Annals of Botany 111: 151–172.

Gallet, S. & Roze, F. 2001. Conservation of heathland by sheep grazing in Brittany (France): importance of grazing period on dry and mesophilous heathlands. Ecological Engineering 17: 333–344.

Garbarino, M., Lingua, E., Subira, M. M. & Motta, R. 2011: The larch wood pasture: structure and dynamics of a cultural landscape. European Journal of Forest Research 130: 491–502.

Gimingham, C. H. 1960: Biological flora of the British Isles. *Calluna* Salisb. A monotypic genus. *Calluna vulgaris* (L.) Hull. Journal of Ecology 40: 455–483.

Gimingham, C. H. 1972: Ecology of heathlands. Chapman and Hall, London.

Gimingham, C. H. 1994: Lowland heaths of West Europe: Management for conservation. Phytocoenologia 24: 615–626.

Harris, M. P. K., Allen, K. A., McAllister, H. A., Eyre G., Le Duc, M. G., & Marrs, R. H. 2011: Factors affecting moorland plant communities and component species in relation to prescribed burning. Journal of Applied Ecology 48: 1411–1421.

Heil, G. W. & Diemont, W. H. 1983: Raised nutrient levels change heathland into grassland. Vegetatio 53: 113–120.

Hobbs, R. J. & Legg, C. J. 1983: Markov models and initial floristic composition in heathland vegetation dynamics. Vegetatio 56: 31–43.

Hodgson, J. 1979: Nomenclature and definitions in grazing studies. Grass and Forage Science 34: 1–18.

Hooftman, D. A. P. & Bullock, J. M. 2012: Mapping to inform conservation: A case study of changes in semi-natural habitats and their connectivity over 70 years. Biological Conservation 145: 30–38.

Hulme, P. D., Merrell, B. G., Torvell, L., Fisher, J. M., Small, J. L. & Pakeman, R. J. 2002: Rehabilitation of degraded *Calluna vulgaris* (L.) Hull-dominated wet heath by controlled sheep grazing. Biological Conservation 107: 351–363.

Jacquemyn, H., Van Mechelen, C., Brys, R. & Honnay, O. 2011: Management effects on the vegetation and soil seed bank of calcareous grasslands: An 11-year experiment. Biological Conservation 144: 416–422.

Klein, S., Jäger, U. G. & Tischew, S. 2009: Anwendung von Feuer zur Pflege und Erhaltung von Heidekraut-Trockenrasen-Komplexen in der Porphyrkuppenlandschaft des unteren Saaletals. Hercynia N.F. 42: 217–238.

Krahulec, F., Skálová, H., Herben, T., Hadincová, V., Wildová, R. & Pecháčková, S. 2001: Vegetation changes following sheep grazing in abandoned mountain meadows. Applied Vegetation Science 4: 97–102.

Kubát, K., Hrouda, L., Chrtek, J. jun., Kaplan, Z., Kirschner, J. & Štěpánek, J. (eds.), 2002: Klíč ke květeně České republiky [Key to the Flora of the Czech Republic]. Academia, Praha.

Kubíková, J. 1982: Chráněná území Šáreckého

údolí a jejich současná vegetace [Nature reserves of Šárecké valley and their actual vegetation]. Natura Pragensis 1: 5–70.
Kubíková, J., Ložek, V., Špryňar, P. et al. 2005: Chráněná území ČR, XII. Praha. [Protected areas of Czech Republic, XII. Prague]. Agentura ochrany přírody a krajiny ČR, Praha, 304 pp.
Legg, C. J., Maltby, E. & Proctor, M. C. F. 1992: The ecology of severe moorland fire on the North York Moors: seed distribution and seedling establishment of *Calluna vulgaris*. Journal of Ecology 80: 737–752.
Mallik, A. U., Hobbs, R. J. & Legg, C. J. 1984: Seed dynamics in *Calluna-Arctostaphylos* heath in north-eastern Scotland. Journal of Ecology 72: 855–871.
Manning, P., Putwain, P. D. & Webb N. R. 2004: Identifying and modeling the determinants of woody plant invasion of lowland heath. Journal of Ecology 92: 868–881.
Måren, I. E. & Vandvik, V. 2009: Fire and regeneration: the role of seed banks in the dynamics of northern heathlands. Journal of Vegetation Science 20: 871–888.
Måren, I. E., Janovský Z., Spindelböck, J. P., Daws, M. I., Kaland, P. E. & Vandvik, V. 2010: Prescribed burning of northern heathlands, *Calluna vulgaris* germination cues and seed-bank dynamics. Plant Ecology 207: 245–256.
Mitchell, R. J., Rose, R. J. & Palmer, S. C. 2008: Restoration of *Calluna vulgaris* on grass-dominated moorlands: The importance of disturbance, grazing and seeding. Biological Conservation 141: 2100–2111.
Mohamed, A., Härdtle, W., Jirjahn, B., Niemeyer, T. & Oheimb, G. 2006: Effects of prescribed burning on plant available nutrients in dry heathland ecosystems. Plant Ecology 189: 279–289.
Moravec, J. & Neuhäusl, R. (eds.) 1991: Přirozená vegetace území hlavního města Prahy a její rekonstrukční mapa [Natural vegetation of the territory of the capital city Prague and its reconstruction map]. Academia, Praha, 200 pp.
Mugion, L. G. 1996: Vegetation aspects of *Calluna* heathlands in the western Po plain (Turin, NW Piedmont, Italy). Alliona 34: 343–348.
Newton, A. C., Stewart, G. B., Myers, G., Diaz, A., Lake, S., Bullock, J. M. & Pullin, A. S. 2009: Impacts of grazing on lowland heathland in north-west Europe. Biological Conservation 142: 935–947.
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.
Pakeman, R. J., Hulme, P. D., Torvell, L. & Fisher, J. M. 2003: Rehabilitation of degraded dry heather *Calluna vulgaris* (L.) Hull moorland by controlled sheep grazing. Biological Conservation 114: 389–400.
Plieninger, T., Höchtl, F. & Spek, T. 2006: Traditional land-use and nature conservation in European rural landscapes. Environmental Science & Policy 9: 317–321.
Pywell, R. F., Meek, W. R., Webb, N. R., Putwain, P. D. & Bullock, J. M. 2011: Long-term heathland restoration on former grassland: the results of a 17-year experiment. Biological Conservation 1445: 1602–1609.
Pywell, R. F., Pakeman, R. J., Allchin, E. A., Bourn, N. A. D., Warman, E. A. & Walker, K. J. 2002: The potential for lowland heath regeneration following plantation removal. Biological Conservation 108: 247–258.
Pywell, R. F., Webb, N. R. & Putwain, P. D. 1995: A comparison of techniques for restoring heathland on abandoned farmland. Journal of Applied Ecology 32: 400–411.
Rego, R. P., Rodríguez Guitián, M. A., López Castro, H., Ferreiro da Costa, J. & Muñoz Sobrino, C. 2013: Loss of European dry heaths in NW Spain: A case study. Diversity 5: 557–580.
Rosén, E. 1995: Periodic droughts and lon-term dynamics of alvar grassland vegetation on Öland, Sweden. Folia Geobotanica et Phytotaxonomica 30: 131–140.
Schubert, R. 1960: Die zwergstrauchreichen azidophilen Pflanzengesellschaften Mitteldeutschlands. Pflanzensoziologie 11: 1–235.
Sedláková, I. & Chytrý, M. 1999: Regeneration patterns in a Central European dry heathland: effects of burning, sod-cutting and cutting. Plant Ecology 143: 77–87.
ter Braak, C. J. F. & Šmilauer, P. 1998: CANOCO References Manual and Usery's Guide to Canoco for Windows. Software for Canonical Community Ordination (Version 4). Wageningen: Centre of Biometry.
Valkó, O., Török, P., Deák, B. & Tóthmérész, B. 2014: Prospects and limitations of prescribed burning as a management tool in European grasslands. Basic and Applied Ecology 15: 26–33.

Vandvik, V., Heedgaard, E., Maren, I. E. & Aarestad, P. A. 2005: Managing heterogeneity, the importance of grazing and environmental variation on post-fire succession in heathlands. Journal of Applied Ecology 42: 139–149.

Van Rheenen, J. W., Werger, M. J. A., Bobbink, R., Daniels, F. J. A. & Mulders, W. H. M. 1995: Short-term accumulation of organic matter and nutrient contents in two dry sand ecosystems. Vegetatio 120: 161–171.

Walter, H. & Lieth, H. 1960–1967: Klimadiagram-Weltatlas. Jena.

Weijtmans, K., Jongejans, E. & van Ruijven, J. 2009: Sod cutting and soil biota effects on seedling performance. Acta Oecologica 35: 651–656.

Werger, M. J. A., Prentice, I. C. & Helsper, H. P. H. 1985: The effect of sod-cutting to different depths on *Calluna* heathland regeneration. Journal of Environmental Management 20: 181–188.

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