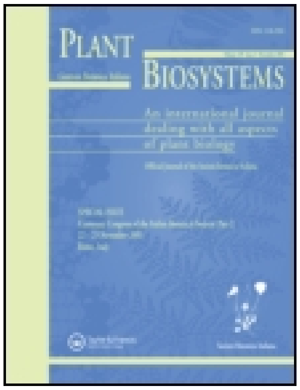

Plant Biosystems - An International Journal Dealing with all Aspects of Plant Biology
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tplb20

Successional changes of dry grasslands in southwestern Slovakia after 46 years of abandonment

K. Hegedüšováá [a] & D. Senko [a]
[a] Institute of Botany, Slovak Academy of Sciences, Dúúbravskáá cesta 9, SK-845 23 Bratislava, Slovak Republic

Available online: 14 Sep 2011

To cite this article: K. Hegedüšováá & D. Senko (2011): Successional changes of dry grasslands in southwestern Slovakia after 46 years of abandonment, Plant Biosystems - An International Journal Dealing with all Aspects of Plant Biology, 145:3, 666-687

To link to this article: http://dx.doi.org/10.1080/11263504.2011.601605

Plant Biosystems, Vol. 145, No. 3, September 2011, pp. 666–687

Taylor & Francis
Taylor & Francis Group

SUCCESSION, MANAGEMENT AND RESTORATION OF DRY GRASSLANDS

Successional changes of dry grasslands in southwestern Slovakia after 46 years of abandonment

K. HEGEDÜŠOVÁ & D. SENKO

Institute of Botany, Slovak Academy of Sciences, Dúbravská cesta 9, SK-845 23 Bratislava, Slovak Republic

Abstract

Dry grasslands are endangered by succession because of changes in management, soil conditions and abandonment. The successional changes in vegetation composition after 46 years of abandonment were subject of the study. The analyses were designed to minimize errors that could be caused by application of historical data. With the help of numerical classification, internal variation within the associations was evaluated. Using computer modeling in GIS, the suitable management model for dry grasslands was defined. The following impact of successional changes was observed: The cover of expansive woody species *Crataegus* sp., *Prunus* sp., *Rosa* sp.; non-native species *Pinus nigra*, *Prunus serotina*, *Robinia pseudoacacia*, *Syringa vulgaris*, *Fraxinus ornus*, and competitively strong species *Bromus erectus*, *Calamagrostis epigejos*, and *Peucedanum cervaria* increased. The covers of non-native species represent 29% of the total forested area. The *Poo badensis-Festucetum pallentis* communities are the most endangered. The species diversity, cover of *Festuco-Brometea* species and Red List species decreased significantly in this vegetation type. The area of grasslands has been reduced by 61.1% compared with 1949 levels. We defined the "core" zone with the highest abiotic potential for the conservation of the xero-thermophilous communities, where their long-term occurrence will not depend on the presence of the management interventions.

Keywords: *Dry grasslands, GIS, management, secondary succession, Slovakia*

Introduction

Species diversity remains one of the central topics in contemporary ecology and the object of various studies, from the community to landscape level and in all types of ecosystems. At the regional level, diversity has been related to various factors such as area, altitude, productivity, landscape heterogeneity, successional status and disturbance (Huston 1994). Afforestation and increasing shrub encroachment following the cessation of transhumance are the main causes of the drastic decline in species-rich dry calcareous grasslands in Central Europe during recent decades (Willems 2001; Poschlod & WallisDeVries 2002; Dierschke 2006). Dry calcareous grasslands on nutrient-poor sites in Central Europe have developed in most cases over centuries or even millennia due to traditional land use such as grazing and/or mowing (e.g. Hegg et al. 1992; Schumacher et al. 1995; Ellenberg 1996; Poschlod & WallisDeVries 2002). Semi-natural grassland communities on carbonate geologic soil belong to the most species-rich communities ever (Willems 1983; Bobbink et al. 1987; Schrautzer et al. 2009). They also contain a large number of rare and endangered species (Wolkinger & Plank 1981; Werner & Spranger 2000). The high species diversity of semi-natural calcareous grasslands is caused by a moderate disturbance regime combined with low nutrient availability of soils and a long history of species immigration (Poschlod & WallisDeVries 2002). In several European countries, successional changes in vegetation have been studied and field experiments have been set up to investigate the long-term influence of abandonment and different types of management on limestone grasslands (Willems 1985; Hansson & Fogelfors 2000; Köhler et al. 2005; Dierschke 2006; Dostálek & Frantík 2008; Bonanomi et al. 2009; Schrautzer et al. 2009; Jacquemyn et al. 2010; Ruprecht et al. 2010; Škornik et al. 2010; Török & Szitár 2010). Analysis of the vegetation–environment relationship also represents

Correspondence: Katarína Hegedüšová, Institute of Botany, Slovak Academy of Sciences, Dúbravská cesta 9, SK-845 23 Bratislava, Slovak Republic. Tel: +421 259 426 173. Fax: +421 2 54 771 948. Email: katarina.hegedusova@savba.sk

ISSN 1126-3504 print/ISSN 1724-5575 online
DOI: 10.1080/11263504.2011.601605

"the core" of predictive geographical modeling. A geographical information system (GIS) is a suitable tool for expressing complex botanical data in a spatio-temporal aspect. The application of GIS for spatial analysis and interpretation are now commonplace in landscape investigations (Izakovičová et al. 1997; Guisan & Zimmermann 2000; Münier et al. 2001). Equally important is the consequence of topoclimate in combination with other environmental factors, which has been much used to explain vegetation patterns (Van Hees 1994; Young & Mitchell 1994; Bennie et al. 2008). The amount of solar radiation received by a surface has been identified as an important factor in determining the ecological conditions at that site (Påhlsson 1974). Historical aerial photographs have long been recognized as an important source of information for studies of vegetation dynamics (Kadmon & Harari-Kremer 1999). Planar geometry can be used to characterize vegetation complexity and help to interpret aerial photographs.

The level of recorded change in the natural development of the plant associations (secondary succession) may be represented by empirically measurable characteristics. This can be used for spatial extrapolation of a landscape's potential for protection and subsequently the management of protected areas (Warren et al. 2002; Senko 2007).

The area of our case study is situated on Devínska Kobyla Mt., which is the most southern part of Malé Karpaty Mts, in Slovakia (Figure 1). Its unique geographical position has resulted in extraordinary environmental conditions. The occurrence of xerothermophilous grassland communities at Devínska Kobyla Mt. is in direct relationship with human's agricultural activity (Kaleta 1965; Hajdúk 1986; Hegedüšová et al. 2010). Unlike naturally forest-free areas, these communities formed after repeated massive deforestation. During the mid-20th century, the abandonment of traditional management (pasturing, mowing, and burning) resulted in the loss of area and degradation by shrub invasion. The present state of vegetation on Devínska Kobyla Mt. has been conditioned predominantly by succession, fragmentation and isolation of localities (Hegedüšová 2009). Part of the area is mainly affected by erosion hazards. In this case, a comprehensive understanding of the relationship between the forming vegetation and the abiotic environment indicates the need to know the sensitivity and vulnerability of the landscape.

The aims of this article were (1) to evaluate the succession and dynamics of vegetation changes based on a comparison of historical (1964) and recent (2009, 2010) phytosociological relevés (2) to determine overgrowth degrees (3) to predict successional changes in grasslands communities with respect to the abiotic ecological potential of the territory (ideal conditions for the occurrence of xerothermophilous communities) and (4) to suggest a suitable management model.

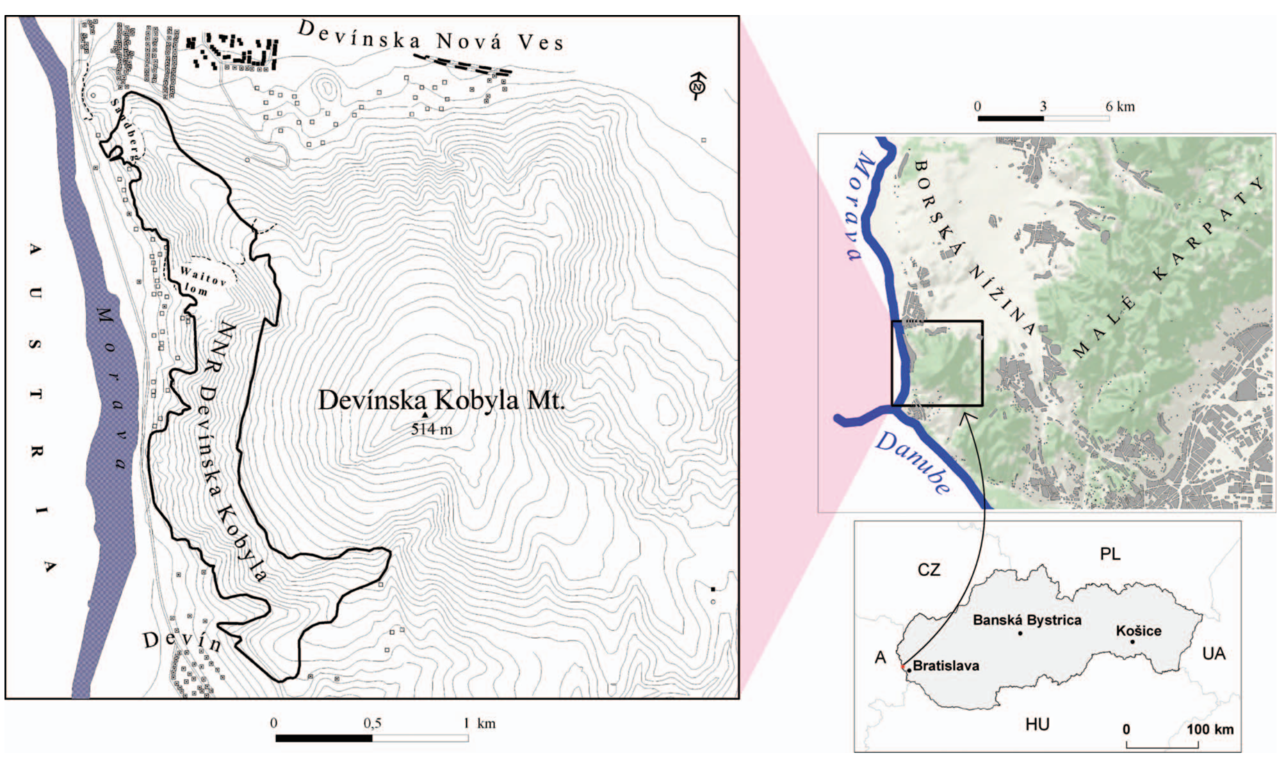

Figure 1. Localization of the National Nature Reserve Devínska Kobyla.

Materials and methods

Vegetation data set

As the core data source for the evaluation of the vegetation of Devínska Kobyla Mt. we used relevés stored in the Central Phytosociological Database of Slovakia (CDF: http://ibot.sav.sk/cdf/; Hegedüšová 2007). All phytosociological relevés were recorded according to the principles of the standard Central-European method (Zürich-Montpellier school; Braun-Blanquet 1921, 1928; Westhoff & van der Maarel 1973) and stored using the TURBOVEG database software (Hennekens & Schaminée 2001). Phytosociological relevés of Kaleta (1965) were sampled in 1964. No permanent plots had been marked during the first sampling period. Re-sampling was based on the historical description of sites. The second investigation took place between 2009 and 2010. For sampling, sites homogenous in species composition and environmental conditions were selected. The relevé plot size was 16 and 25 m^2 in most relevés. Records of juvenile trees and shrubs were deleted from the resulting data set (94 relevés; 43 historical, 51 recent). The data then were exported into the JUICE 7.0.58 software (Tichý 2002). For numerical analyses, some taxonomically problematic species, which were not distinguished in several relevés were classified within higher or broadly defined taxa. Narrowly defined species unified into a broader concept of species aggregates (agg.) according to Marhold & Hindák (1998) are listed in Appendix I. Species found in several layers (especially juvenile species of shrubs and trees) were merged into one layer in each relevé. For localization of the historical phytosociological relevés we developed an application in GRASS GIS, as a script written in Unix shell (Bash). We used a satisfactory range of values to minimize errors that could have been caused by iatrotechniques in 1964 (estimation of elevation, slope angle and slope aspect). The type of landcover was determined from aerial photographs, taken in 1966.

The nomenclature of vascular plants follows Marhold & Hindák (1998). The diagnostic species of the *Festuco-Brometea* class and nomenclature of syntaxa were unified according to Jarolímek et al. (2008).

Data analysis

Internal variation within the associations was assessed by cluster analysis of the relevés, using the PC-ORD 5.0 software package (McCune & Grace 2002), with Sorensen (Bray–Curtis) distance as a resemblance measure and Flexible Beta Method with logarithmic transformation $b = \log\ (Xi,j + 1)$. The optimal number of clusters was determined with the Crispness method using the JUICE (Tichý 2002). Diagnostic, constant and dominant species for the associations in the synoptic table were calculated by JUICE (Tichý 2002). Diagnostic species were statistically determined on the basis of the fidelity concept (Bruelheide 1995; Chytrý et al. 2002, 2006; Chytrý & Tichý 2003; Chytrý 2007), with a threshold value of $\phi \geq 0.30$. Fisher's exact test ($p < 0.001$) was used to eliminate the fidelity value of species with a non-significant pattern of occurrence. Dominant species were ordered according to the percentage of relevés in which their cover was over 25%. Non-parametrics statistic followed by Kruskal–Wallis ANOVA and Mann–Whitney U Test (Statica 8; http://www.statsoft.com/) were used to investigate whether the species richness (number of species, number of Red list species, and number of *Festuco-Brometea* species) in each similar association, respectively was different among historical and recent relevés.

Modeling in GIS

For interpolation and creation of a digital terrain model DTM we selected GRASS GIS v6.4, released under the GNU/GPL license (GRASS Development Team 2010). DTM development was calculated using *regularized spline with tension* (RST) (see Mitášová & Mitáš 1993) implemented as a *v.surf.rst* module. RST allows local spatial prediction to be performed in a flexible and robust way. The DTM was used to calculate the initial derivations of elevation, slope angle and slope aspect models in particular.

Solar energy was modeled with the *r.sun* routine in GRASS GIS (Hofierka & Šúri 2002). Solar geometry is based on the works of Krcho (1965), later improved by Scharmer & Grief (2000). We chose to use the annual cycle (from January 1 to December 31, 365 days = 8.760 h, with 15 min time increment in $Wh \cdot m^{-2}\ day^{-1}$). Topoclimatic research was based on digital meteorological stations (parallel measurements at equal time on different biotopes from 2005 to 2007). Our R script (in the R project environment) calculated the solar incidence angle for point locations on an inclined plane for particular days and time increments. A model of spatial differentiation of soil temperature was obtained by multiple linear regression and took the following form (TP – temperature difference of soils; TPa − TPb – Δ soil temperatures between two considered sites; a, b – sites; NV – altitude; UD – angle of incidence of solar radiation; UR – delta of angle of incidence of solar radiation, $R^2 = 81.1\%$):

$$\begin{aligned} \mathrm{TPa} - \mathrm{TPb} = {} & 0.532392 - 0.0311999 \times \mathrm{NVa} \\ & + 0.0172281 \times \mathrm{NVb} + 0.178537 \\ & \times \mathrm{UDa} - 0.115657 \times \mathrm{UDb} + 0.147367 \\ & \times \mathrm{URa} - 0.0885646 \times \mathrm{URb} \end{aligned}$$

Vertical atmospheric precipitation (48.198°, 16.976°, 220.5 m a s l.) was measured from June 17, 2003 to December 31, 2006. The measured data were compared with those of spatially proximate precipitation meteorological stations. The spatial differentiation of rainfall on large scales depends mainly on the properties of the terrain, according to the prevailing rainfall carrying winds. The *model of spatial differentiation of the vertical atmospheric precipitation* is based on a relationship derived by Minár et al. (2001). The precipitation–altitude relationship (we computed the pluviometric gradient to be $0.437\ \mathrm{mm} \cdot \mathrm{m}^{-1}$) often varies non-linearly.

Measured topoclimatic data (2,352,817 in total) were adjusted before their statistical processing by multiple regression analysis. The data files entered were selected on the basis of certain criteria (to eliminate a distorting effect on the resulting relationship).

The Gully erosion hazard model classifies the whole territory from the point of view of its predisposition to this type of erosion (see equations in Minár & Tremboš 1994). The evaluation of secondary succession was based on a chronological sequence of aerial photographs, taken in the years: 1949, 1966, 1985 and an orthophotomap from 2003. The criterion for digitalization of different types of vegetation to polygons was uniform vegetation physiognomy. The periods considered were 1949 to 1966 (17 years), 1966 to 1985 (19 years) and 1985 to 2003 (18 years).

Results

Based on studied data set, the numerical classification of the phytosociological relevés resulted in eight groups (Appendix II). They were assigned to the *Festuco-Brometea* class and three alliances within it (Appendix III) Kaleta (1965) distinguished the *Ranunculo illyrici-Festucetum valesiacae* association. Janišová et al. (2007) considered this association as syntaxonomic synonym of the *Festuco valesiacae-Stipetum capillatae* association. The synoptic table points out the differences in floristic composition between the groups on the basis of diagnostic, constant and dominant species (Appendix II). One hundred fifty six vascular plant species were recorded in historical relevés and 87 species in recent relevés in the analyzed data set. The significant differences in species richness (number of species, Red List species, *Festuco-Brometea* species) between the recent and historical relevés were demonstrated with respect to each vegetation type (Figures 2–4, Appendix I–III, Appendix Ia–IIIa). We defined the basic geoecological characteristics of the landscape, which are appropriate to extrapolation of the potential vulnerability and carrying capacity of the landscape. The polygons with overgrowth degrees are defined in Figure 5. With respect to the degree of succession we suggested appropriate management.

Description of the vegetation and changes in species composition during secondary succession

The *Poo badensis-Festucetum pallentis* (Appendix II; clusters 1 and 6) is the most xerophilous community at the western periphery of the Western Carpathians. Stands occur on rocky outcrops with the shallowest soils on warm SW-facing slopes. It forms species-poor, open stands with dominance of *Festuca pallens* and chamaephytes (e.g. *Fumana procumbens*, *Teucrium montanum*, and *Thymus praecox*). Recent relevés have been much worse when compared with historical relevés. Abandonment resulted in the most significant changes in floristic composition. Some chamaephytes and hemicryptophytes (e.g. *Alyssum montanum, Anthericum ramosum*, *Melica ciliata*, *Teucrium montanum*, *Sedum album*) occurred with lower abundance.

The stands of *Festuco pallentis-Caricetum humilis* (Appendix II; clusters 2 and 3) inhabit gentle and steep slopes with shallow soils, which are deeper than soils supporting the *Poo badensis-Festucetum pallentis* association. They include open dry grasslands dominated by *Carex humilis* with a high abundance of *Festuca pallens* and with constant occurrence of the sub-xerophilous grasses *Bothriochloa ischaemum*, *Stipa capillata*, and *Festuca rupicola*. The species, *Hesperis tristis*, *Stipa pulcherrima*, *Bothriochloa ischaemum*, and *Erysimum diffusum* agg., were less frequent in the recent relevés. The present occurrence of *Aster amelloides, Inula ensifolia*, and *Peucedanum cervaria* suggested on succession changes to the xerothermopilous fringe vegetation.

The *Festuco valesiacae-Stipetum capillatae* (Appendix II; clusters 7 and 4) is a very species-rich community dominated by the narrow-leaved tussock-forming grasses *Festuca valesiaca*, *F. rupicola*, *Stipa capillata* or *S. joannis*. Most sites of this community are located on moderate slopes with limited soil erosion. The association includes many common generalist species of Central European dry grasslands (e.g. *Asperula cynanchica*, *Eryngium campestre*, *Koeleria macrantha*, *Sanguisorba minor*, *Teucrium chamaedrys*, and *Tithymalus cyparissias*). Nowadays, the diagnostic species of the historical relevés, *Ranunculus illyricus*, is no longer present here. The species *Acosta rhenana*, *Allium flavum*, *Iris pumila*, *Prunella vulgaris*, *Pulsatilla pratensis* subsp. *bohemica*, and *Thesium linophyllon* occur with higher frequency. There has been a significant increase in the number of species, Red List species and *Festuco-Brometea* species in recent relevés compared with historical relevés (Figures 2–4).

The *Scabioso ochroleucae-Brachypodietum pinnati* and successional stages of *Bromion erecti* and *Cirsio-Brachypodion pinnati* transitional to *Geranion sanguinei* (Appendix II; 8 and 5) occur mainly in the steeper slopes exposed to intensive solar radiation. Nowadays, these communities include semi-closed to closed dry grasslands dominated by *Bromus erectus* and less commonly by *Brachypodium pinnatum*, *Inula ensifolia*, and *Adonis vernalis*. The abandonment becomes evident in the transitional character of stands between the *Onobrychido viciifoliae-Brometum erecti* and *Polygalo majoris-Brachypodietum pinati* associations. The absence of grazing, meadow cutting, and burning results in spreading of competitively strong grasses such as *Bromus erectus*, *Calamagrostis epigeios*, and *Arrhenatherum elatius*. The occurrence of the species *Geranium sanguineum* and *Peucedanum cervaria* signalize secondary succession to the xero-thermophilous fringe communities. Recently, many sites have become overgrown with shrubs (*Cerasus fruticosa*, *Cornus mas*, *Crataegus monogyna*, and *Prunus spinosa*). Due to soil erosion, succession is slower on steeper slopes. Compared with the relevés of Kaleta (1965), the grasses *Brachypodium pinnatum*, *Bromus inermis*, *Phleum phleoides*, and herbs *Origanum vulgare*, *Primula veris*, *Securigera varia*, *Thalictrum minus* are less frequent or even absent.

Changes in species richness and overgrowth degree

Our results show that the species richness of historical and recent relevés is significantly different. The results of the analysis indicated that there was a significant difference between the species richness of historical and recent relevés in the medians, χ^2 (7, $N = 94$) = 20.02628; $p = 0.0055$ (Appendix I). Because the overall test was significant, pairwise comparisons among the eight groups could be completed. Following the Mann–Whitney U test (Appendix Ia) species richness declined significantly after abandonment in recent relevés of the *Poo badensis-Festucetum pallentis* association from ca 43 species in 1964 to 33 species in 2009. In contrast, species richness in the *Festuco pallentis-Caricetum humilis* (on average 43 species per relevé) and *Scabioso ochroleucae-Brachypodietum pinnati* (on average 44 species per relevé) remained constant, whereas in the *Festuco valesiacae-Stipetum capillatae* it increased from 33 species in 1964 to 44 species in 2009, indicating that this type of vegetation is steadiest after abandonment and the least endangered by successional changes. Significant differences between groups of historical and recent relevés also occurred in the number of Red List species (Figure 3; Appendixes II, IIa) and the presence of the *Festuco-Brometea* species (Figure 4; Appendixes III, IIIa). With respect to successional changes there are various overgrowth degrees (Figure 5) in the studied area. Overgrowth has been categorized into three degrees. Degree I: stands with a 10–15% covering of shrubs forming 6.99 ha; degree II: stands overgrown by 30–35% forming 21.77 ha and degree III: stands which are

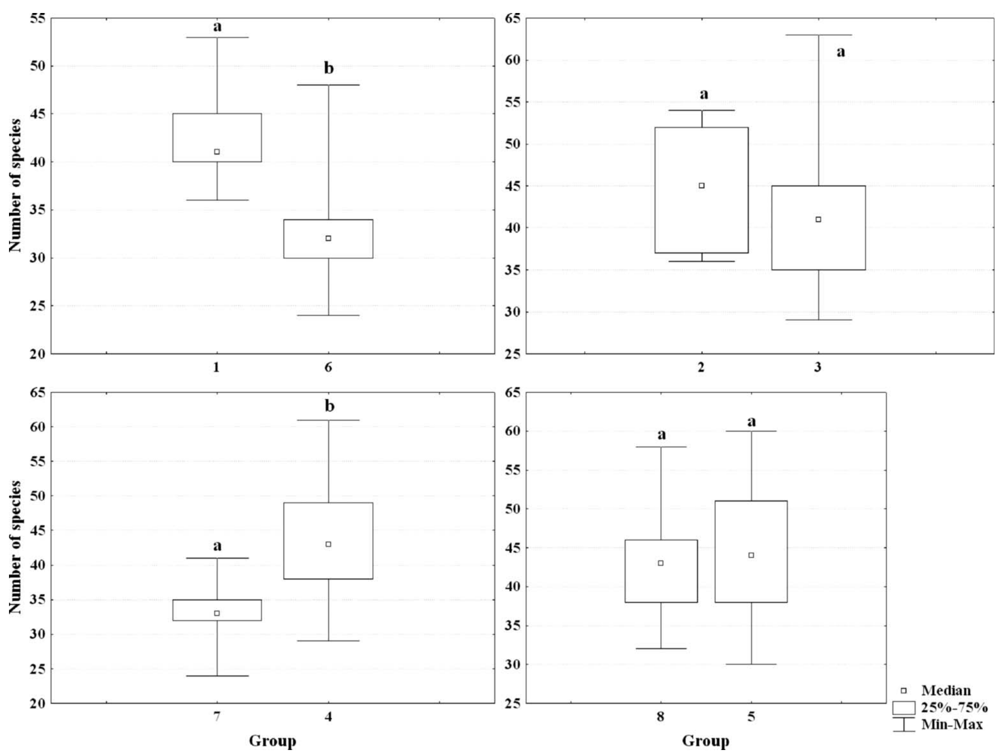

Figure. 2. Box & Whiskers diagrams showing the differences in number of species between historical (group 1, 2, 7, 8) and recent (group 3, 4, 5, 6) phytosociological relevés; 1-6. *Poo badensis-Festucetum pallentis*, 2-3. *Festuco pallentis-Caricetum humilis*, 7-4. *Festuco valesiacae-Stipetum capillatae*, 8. *Scabioso ochroleucae-Brachypodietum pinnati*, 5. successional stages of the *Bromion erecti* and *Cirsio-Brachypodion pinnati*. Different letters above the Box & Whiskers diagrams mean significant differences, $p < 0.05$.

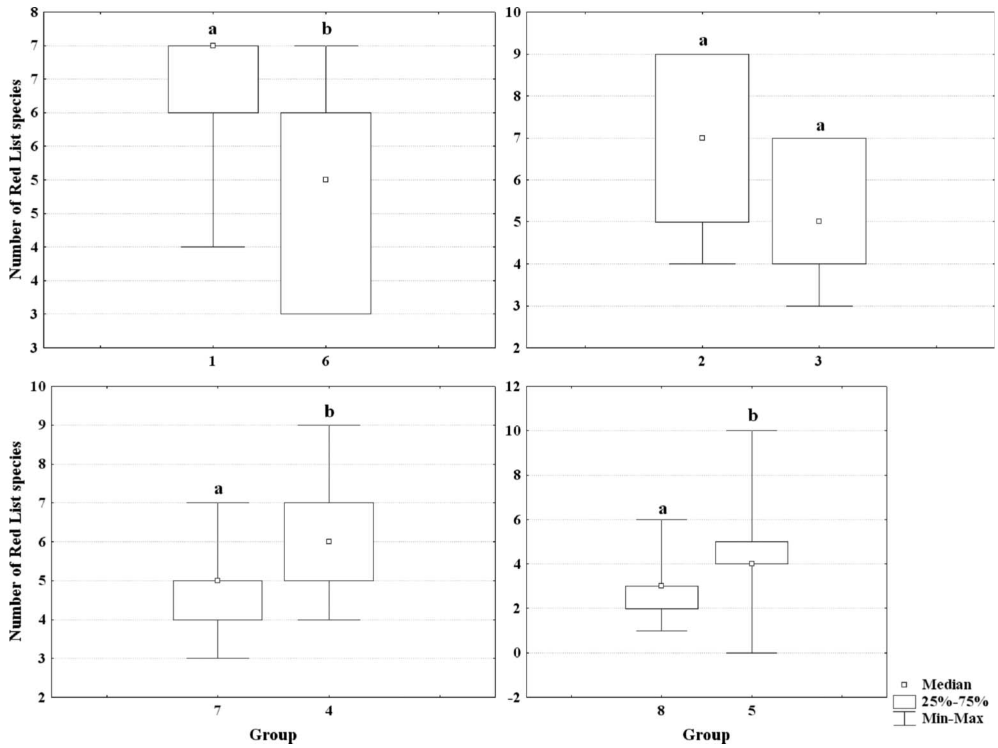

Figure 3. Box & Whiskers diagrams showing the differences in Number of Red list species between historical (group 1, 2, 7, 8) and recent (group 3, 4, 5, 6) phytosociological relevés; 1-6. *Poo badensis-Festucetum pallentis*, 2-3. *Festuco pallentis-Caricetum humilis*, 7-4. *Festuco valesiacae-Stipetum capillatae*, 8. *Scabioso ochroleucae-Brachypodietum pinnati*, 5. successional stages of the *Bromion erecti* and *Cirsio-Brachypodion pinnati.* Different letters above the Box & Whiskers diagrams mean significant differences, $p < 0.05$.

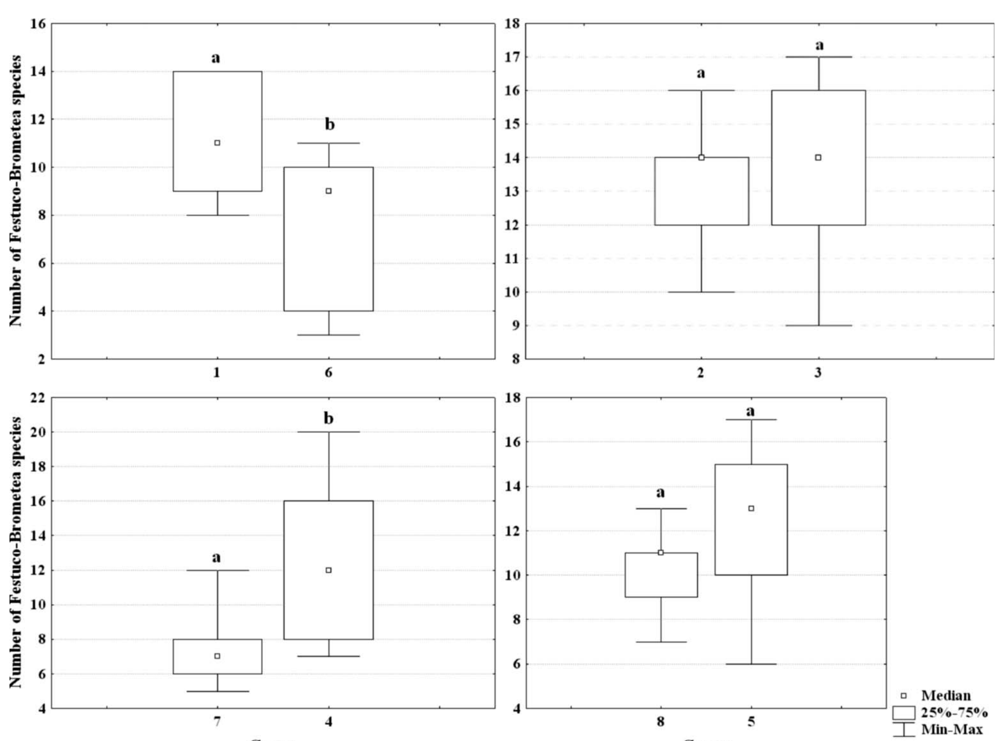

Figure 4. Box & Whiskers diagrams showing the differences in number of the *Festuco-Brometea* species between historical (group 1, 2, 7, 8) and recent (group 3, 4, 5, 6) phytosociological relevés; 1-6. *Poo badensis-Festucetum pallentis*, 2-3. *Festuco pallentis-Caricetum humilis*, 7-4. *Festuco valesiacae-Stipetum capillatae*, 8. *Scabioso ochroleucae-Brachypodietum pinnati*, 5. successional stages of the *Bromion erecti* and *Cirsio-Brachypodion pinnati.* Different letters above the Box & Whiskers diagrams mean significant differences, $p < 0.05$.

90–95% overgrown by trees and shrubs and form 44.44 ha.

Successional changes over 46 years

In 1949, grassland communities occupied 85.8% of the current reservation area (114.38 hectares). In the 1st reporting period (1949 to 1966) (Figure 6), successional changes were not strongly significant. Non-forest vegetation largely followed the edges of the forests and the area retained the character of the period before the end of grazing. Two years after abandonment of traditional farming, the decrease in the xero-thermophilous vegetation area, compared

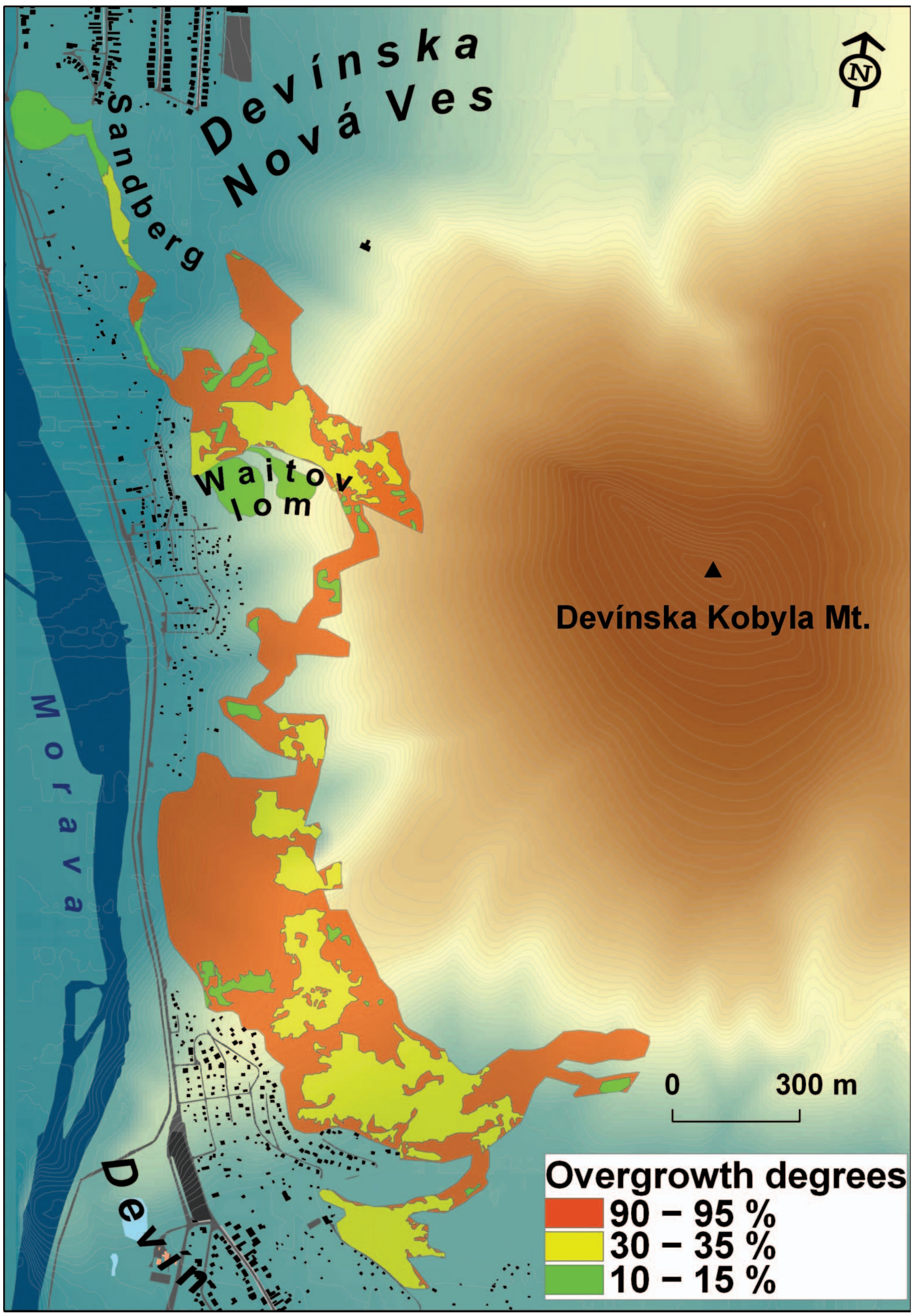

Figure. 5. Degree of overgrowth of grasslands by woody species representing different degrees of succession. Green colour represents 10–15% of overgrown of grasslands by woody plants (6.99 ha of NNR), yellow color represents 30–35% of overgrown of grasslands by woody plants (approximately 21.77 ha of NNR), red colour represents 90–95% of overgrown of grasslands by woody plants (44.44 ha of National Nature Reserve).

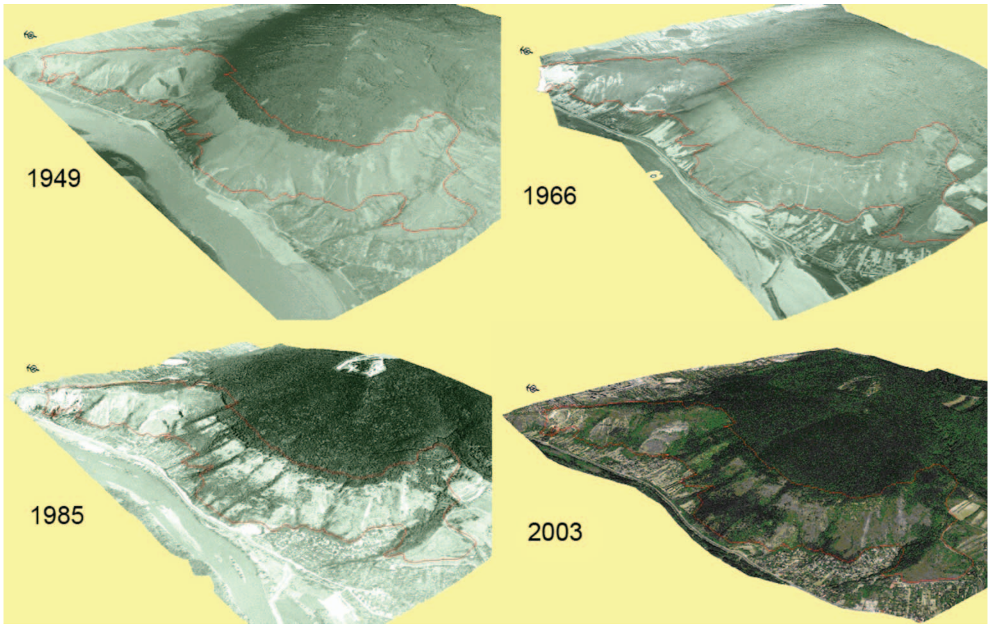

Figure 6. Successional changes in vegetation of the National Nature Reserve Devínska Kobyla derived from a chronological sequence of aerial photographs using geostatistics. Three reporting periods are displayed (1949 to 1966, 1966 to 1985 and 1985–2003).

with 1949, was 7.1%. The most significant changes were seen in the central part of the reservation during the years 1966 to 1985 (Figure 6) with the transition from compact, flat pastures to forest communities particularly visible. More advanced stages of succession, in the form of fringe thicket communities dominated by herbs and shrubs, were visible in some spots. The changeover to forest was visible in the succeeding period. In 1971, dry grasslands represented only 65% of the area. In 1985, an increase in xero-thermophilous stands fragmentation was seen throughout the whole reservation. Grasslands now occupy 53.8 ha, which is only 49.04% compared with 1949. Based on the abiotic ecological potential of landscape, this area is suitable for long-term preservation of xero-thermophilous grasslands. The third period (Figure 6) brought the fragmentation of the former wood-steppe communities into the present mosaic vegetation of rocky and dry grasslands. The change to the shrubs and trees was uniform across the board. Succession areas were not coherent. Nowadays, the area of grassland communities has been reduced by 61.1%, and makes up only 38.9% compared with 1949 levels. The temporal changes of the major types of vegetation are shown in Figure 7.

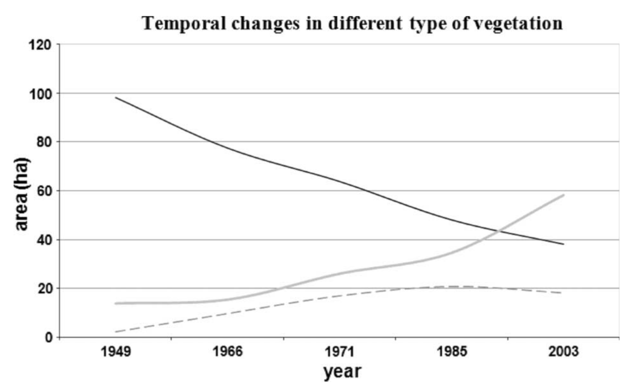

Figure 7. Temporal changes in different type of vegetation. Black line represents decrease of the grassland areas, grey line represents increase of the forest areas, and grey dash-curve represents the trends of shrublands.

Discussion

Disadvantage of the absence of permanent monitoring plots

We were not able to analyze significant differences in the influence of the ruderal species, aliens and competitors on recent vegetation because relevés were sampled with respect to the ideal conditions. Samples did not generally represent the sites with occurrence of the species mentioned above, but the parts of studied associations in the most typical conditions. According to Török & Szitár (2010), monitoring results based on standard protocols from permanent plots with qualitative and quantitative data would be the most suitable for the estimation of trends. Less accurate but still worth using are data with site indication (no permanent plots) and species lists of unknown plot sizes (Hédl 2004). Another major problem was the subjectivity of sampling methodology and lack of localization in historical relevés. For its localization, we had to develop an application in GRASS GIS. We have used an adequate range of values to minimize errors that could be caused by the author of relevés (estimation of elevation, slope angle, and slope aspect). In the first step, the script classifies the searching area to define geomorphological units and then calculates the parameters of DTM (elevation, slope angle, slope aspect models). The optimal approximation parameters for DTM surface are defined using smooth and tension with a cross-validation procedure. The type of landcover (habitat) is determined from aerial photographs, taken in 1966 (historical relevés were sampled in 1964). After this preparation stage, the script loads the input rasters (obtained from DTM) with the landcover raster. Then reclassified it and creates a new map layers whose category values are based on the reclassification of the categories in the existing raster map layer, and extracts the areas that meet given criteria from each of input maps. Afterward, the script overlays the partial maps and identifies areas that meet all given criteria in the raster form.

Despite these methodological drawbacks, however, our study has brought new information about management of dry grasslands using GIS.

Successional changes in dry grasslands

On the whole, the extent of Europe's semi-natural calcareous grasslands is in strong decline and they are under threat of abandonment (Riecken et al. 2002). The maintenance of high plant species diversity in calcareous grasslands cannot be guaranteed without some kind of disturbance (Willems 2001; Poschlod & WallisDeVries 2002). Similar to previous studies (Willems 1990; Kahmen et al. 2002), abandonment of traditional management resulted in a dramatic decline in species richness and a significant change in floristic composition. After abandonment, dry grassland areas decline due to gradual overgrowth by shrubs or woody species and the expansion of perennial tall grass species. Similar to other localities not only in Slovakia, traditional management of grasslands ended in the mid-20th century.

Our results pointed out the great impact of abandonment of traditional use of landscape, which is significant and visible in the succession of dry grasslands. Only areas in which xero-thermophilous meadows have been preserved up to the present have a high potential for long-term preservation in terms of the abiotic characteristics. Even if we do not consider all environmental changes (climatic conditions), it is obvious that long-lasting management affects the species richness of the semi-natural grasslands. The results of a comparison of recent and historical relevés (Figures 2–4, Appendixes I–II) demonstrate that the species richness of xero-thermophilous grasslands after abandonment of traditional use of landscape show the greatest tendency to decrease in the *Poo badensis-Festucetum pallentis* association. This is because of environmental conditions (shallow dry soils, steep slopes) as well as the response to abandonment. It is also in accordance with the results of Janišová (2007), Dostálek & Frantík (2008) and Bača (2010). On the other hand, throughout our observations, the abundance of non-xerothermic, competitively strong species (*Bromus erectus*, *Calamagrostis epigeios*, and *Arrhenatherum elatius*) and shrubs showed an increase over 46 years, which is obvious from the species composition of the successional stages of *Bromion erecti* and *Cirsio-Brachypodion pinnati*. Their strong dominance has led to a change in the abundance structure of the vegetation. Communities of the *Scabioso ochroleucae-Brachypodietum pinnati*, which developed on deeper soils, were the most noticeably affected by overgrowth. Over the long term, formerly grazed grasslands, dominated by *Brachypodium pinnatum*, in the absence of grazing, may transform into *Bromus erectus* and shrubs dominated types. On the other hand, endangered and rare species (Red List species) were equally represented in recent relevés and showed an increasing tendency in the number of species per relevé, though the relative abundance of some species was greater in the managed stands of the historical relevés (Appendix VII). By comparing chronological sequences of aerial photographs (Figure 6), we can see a mosaic-like transformation series and a shift to shrub and forest communities. It can be concluded that, in the long-term, following abandonment of grazing, the transformation of the xeric vegetation types into a woody type, which represents the final stage of the transformation series, is very probable.

Suggested management model

In many European countries, dry grasslands formed of *Festuco-Brometea* plant communities are receiving a great deal of attention in regard to conservation management (WallisDeVries 1999; WallisDeVries et al. 2002; Richter et al. 2003; Bąba 2004; Masé 2005; Bornkamm 2006; Dostálek & Frantík 2008; Janišová et al. 2010). The investigated communities underwent vascular species composition changes that resulted in decreasing species richness and overgrown by shrubs and woody species. According to Bucini & Lambin (2002) and Smit (2004), encroachment of woody species is a main sign of degradation or habitat alteration. This process was detected in each of the studied vegetation types, which is reason for suitable management. From the territory of Devínska Kobyla Mt. sheep goats and cattle grazing in particular, were all reported

(Ptačovský 1959; Kaleta 1965). After 1965, grazing gradually ended and the landscape was abandoned. In our case, restoring the traditional way of management, extensive grazing of grassland vegetation, is the best management model with attention to the impact of grazing animals on vegetation, which is usually considered as a single process, despite the knowledge that behaviors such as defoliation and trampling are likely to have different effects (Oom et al. 2008). The process, however, depends on the different types of animals (Pavlů et al. 2007) as well as on their abundance in a flock. Dostálek & Frantík (2008) also observed that after grazing was introduced, the cover of woody species decreased. The long-term decline in the cover of expansively spreading *Arrhenatherum elatius*, which is sensitive to grazing, was a positive finding with regard to pasture management. Their observations also showed that no significant changes occurred in the number and cover of Red List species. On the contrary, Krahulec et al. (2001) and Dostálek & Frantík (2008) pointed out that the main problem associated with sheep grazing is the increasing presence of nitrophilous tall herbs and grasses. Thanks to extraordinary competitive capabilities, resistance to distortion (creating resistant clones) and the ability to expand (CS strategist, Grime 1979) are also stands with *Brachypodium pinnatum* spread over by extensive grazing. The reason is that the animals avoid it (Gömöry et al. 2006). There is also fact that animals are capable of changing soil conditions. According to Török & Szitár (2010), it is assumed that physical soil disturbance, erosion and trampling by grazing animals induce the shift in the perennial-annual ratio and the establishment of annuals at temporarily open soil surfaces. Following these results, a management model should be created with respect to long-term planning in order to prevent overgrowth by trees and shrubs and to restore the species composition of vegetation which will be rich in species and close to the former pasture. As a first step, we recommend extensive low-intensity grazing by sheep, goats or small breeds of cows with respect to the effect of trampling, defoliation, lying, defaecation, and ruderalization. Low-intensity grazing can help to keep dry grassland vegetation in good conditions and conserve plant diversity. According to Oom et al. (2008), the impact of herbivores on vegetation is usually considered simply as the outcome of all these processes, implicitly assuming a linear spatial correlation between them. Because spatial heterogeneity is generally high in natural vegetation, mosaics and grazing-tolerant species may be intermixed with grazing-intolerant species, flocks should be dominated by sheep and goats. In systems where domestic herbivores are generally free-grazing, the spatial interactions between the various processes associated with the presence of grazing animals are more complex (Oom et al. 2008). Following previous studies, we would clearly predict a greater impact from both grazing and trampling activities on xerothermophilous grassland vegetation and we can assume a suitable management model. In most cases, it is crucial to remove shrubs (especially *Crataegus* sp., *Prunus* sp., *Rosa* sp.) and non-native species (*Pinus nigra*, *Prunus serotina, Robinia pseudoacacia, Syringa vulgaris*, and *Fraxinus ornus*) on which animals do not graze. At present, non-native species represent 29% of the total forested area (14.7% of reservation area). According to the overgrowth degrees (Figure 5), expected results of activities are tree elimination followed by grazing (69.10 ha, 60.41% of reservation area, Figure 8).

The second aim should be focused on removing and reducing the biomass of competitively strong species such as *Bromus erectus, Calamagrostis epigejos*, and *Peucedanum cervaria* through the use of mowing. Occasional or regular mowing of accessible spots or the impact of fire causes a positive influence on the development of dry grasslands. According to Ruprecht et al. (2010), the accumulation of biomass and of dead plant remains is a direct consequence of grassland abandonment. Litter can occupy potential microsites for seed germination and seedling establishment, and thus decreases species diversity in the long-term. One proposal would be to create management zones with the occurrence of *Orchidaceae,* 1.48 ha (1.29% of reservation area, Figure 8) and zones with/without mowing and grazing (Figure 8). Based on the abiotic characteristics, we defined "core" zone, 8.11 ha (7.09% of reservation area, Figure 8), which has the highest abiotic potential for the conservation of the xero-thermophilous communities. Their long-term occurrence will not depend on the presence of the management interventions. It is visible, that 1 year after mowing the permanent monitoring plots with the occurrence of *Ophrys sphegodes* (autumn 2004) the species richness of its population increased four times.

According to our results, it would be efficient to combine grazing with mowing; the ongoing clearing of shrubs and grass would remain.

Advantages of computer modeling in GIS

On the basis of our case study data, we have tried to develop an original methodological approach to the quantitative evaluation landscape method through a series of landscape potential geoecological fields (topoclimatic, terrain), computer modeling in GIS (solar radiation, gully erosion hazard), field research and subsequent processing using multidimensional

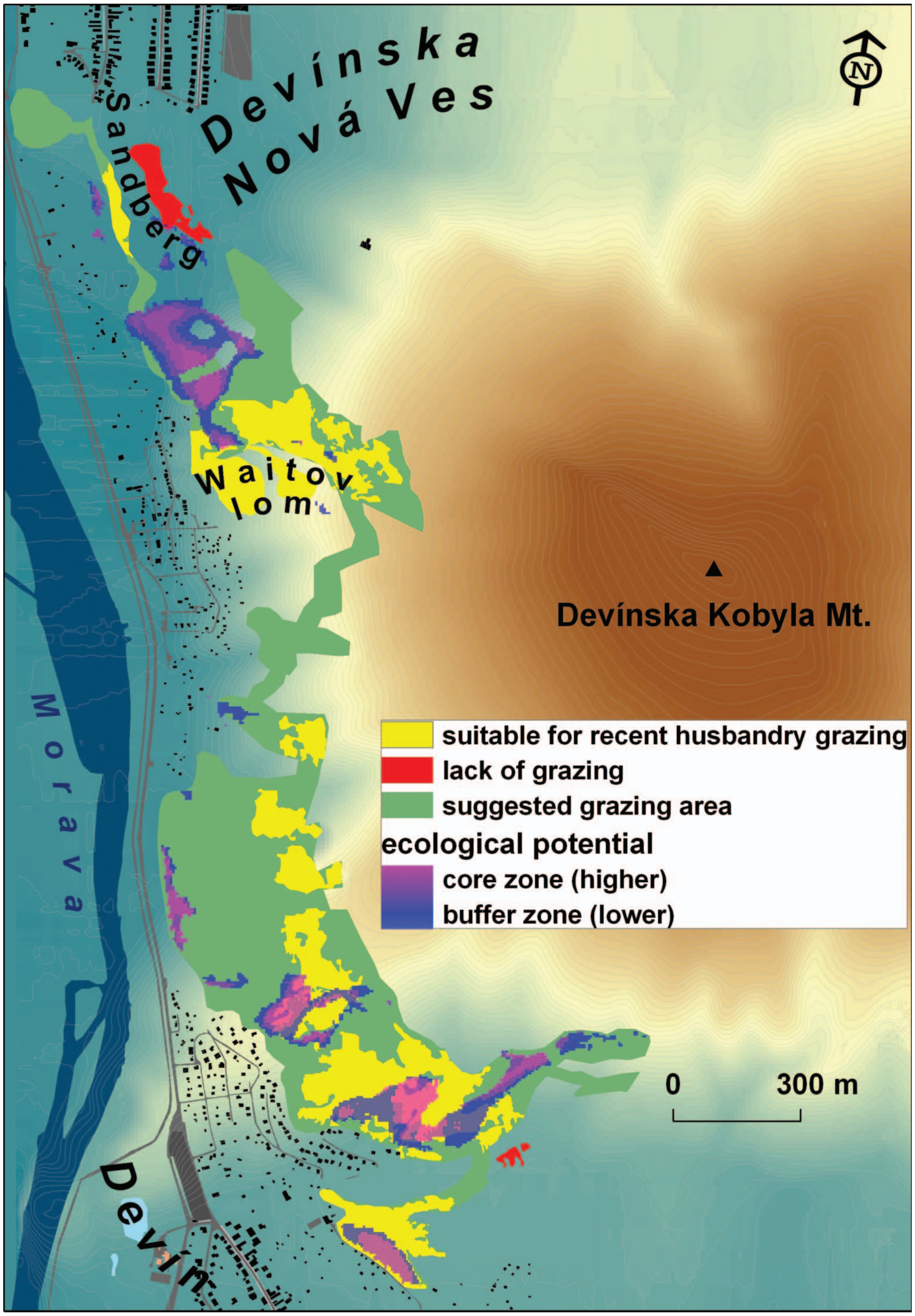

Figure 8. Management zones: (1) Suitable for pasture (yellow colour, 6.99 ha); (2) Lack of grazing (red colour, 1.48 ha, mowing and non-grazing regime), this zone includes management sites with the occurrence of *Orchidaceae*; (3) suggested grazing area for nature conservancy management (green colour, 60.41%, tree elimination followed by grazing). The violet colour (8.11ha, 7.09%) in the diffusion range of ecological potential represents a "core", which has the highest abiotic potential for the conservation of the xero-thermophilous communities. Their long-term occurrence will not depend on the presence of the management interventions.

statistics. The role of GIS was (1) to model spatial effects in the landscape (background data), (2) to synthesize these datas using spatial analysis, and (3) to integrate it to the final management model. The most important advantage of GIS is the effective and precise production of new information layers. The flexibility consists of modification of these tools. It brought us several methodical challenges and impetuses. Those ones we presented here via formulas (soil temperature, precipitation) or algorithms (solar radiation, incidence angle, localization of historical relevés). The usability of the input model relates closely to the quality of input data. Generalized inputs produce generalized outputs. Therefore, we had focused on the 3D input data of maximum precision in space accuracy. Plausibility of the management model depends on the time period considered. This credibility was growing with the complexity of the background input data.

The example of the analysis in Devínska Kobyla Mt. shows the advantages of complex approach in GIS, which has consequences in time extrapolation of the further region development (potential for long-term preservation). The model mentioned in this article has a potential of answering important questions, e.g. process development trajectory or identification of the most endangered areas. We have taken these parameters into account in the final model. We tried to emphasize the need of close connection between GIS and botanical methodology by outlining the selected aspects of simulating the landscape potential. The complete analysis of the problem exceeds far behind the scope of this article. In general framework, the ecological and geographical studies are very important and necessary for conservation planning, but some social aspects of former and recent land use must be considered as well. This can be applied to similar vegetation types not only in local conditions here in Slovakia. Traditional geobotanical approaches needs to adapt to the challenges for greater precision and spatial objectivity within a GIS environment. Modern geotechnologies brings a huge methodological impetus.

Acknowledgments

This publication is the result of the project implementation ''*The centre of excellency for biodiversity and land-use conservation*'' (ŠF OPVaV 26240120014) supported by the Research & Development Operational Program funded by the ERDF (50%) and grant VEGA 2/0181/09 (50%). The authors are grateful to Jozef Minár, Viera Feráková for their guidance during the early part of this work and Paolo Zuccarini for his constructive comments. We are grateful to David Jonathan Gresty (licensed interpreter of English-language papers in biological scientific journals), Katharine Bhattacharyya and Mary Fülöp for professional proofreading of the article. We would like to thank Daphne – Institute for Applied Ecology for enabling to use the program Statistica for our statistical analysis.

References

Bąba W. 2004. The species composition and dynamics in well-preserved and restored calcareous xerothermic grassland (South Poland). Biologia 59: 447–456.

Bača A. 2010. Vegetation types of the initial successional stages of grasslands in the Horné Požitavie region, Mid-Western Slovakia. In: Janišová M, Budzáková M, Petrášová M, editors. 7th European Dry Grassland Meeting. Succession, management and restoration of dry grasslands, 27–31 May 2010, Smolenice Congress Centre, Slovak Republic. Abstracts & Excursion Guides. Bratislava, Slovakia. 7 pp.

Bennie J, Huntley B, Wiltshire A, Hill MO, Baxter R. 2008. Slope, aspect and climate: Spatially explicit and implicit models of topographic microclimate in chalk grassland. Ecol Model 216/1: 47–59.

Bobbink R, During HJ, Schreurs J, Willems J, Zielman, R. 1987. Effects of selective clipping and mowing time on species diversity in chalk grassland. Folia Geobot et Phytotax 22: 363–376.

Bonanomi G, Caporaso S, Allegrezza M. 2009. Effects of nitrogen enrichment, plant litter removal and cutting on a species-rich Mediterranean calcareous grassland. Plant Biosyst 143/3: 443–455.

Bornkamm R. 2006. Fifty years vegetation development of a xerothermic calcareous grassland in Central Europe after heavy disturbance. Flora 201: 249–267.

Braun-Blanquet J. 1921. Prinzipien einer Systematik der Pflanzengesellschaften auf floristischer Grundlage. Jahrb St Gallischen Naturwiss Ges 57: 305–351.

Braun-Blanquet J. 1928. Pflanzensociologie. Grundzüge der Vegetationskunde. Berlin: Verlag von Julius Springer.

Bruelheide H. 1995. Die Grünlandgesellschaften des Harzes und ihre Standortsbedingungen. Mit einem Beitrag zum Gliederungsprinzip auf der Basis von statistisch ermittelten Artengruppen. Diss Bot 244: 1–338.

Bucini G, Lambin EF. 2002. Fire impacts on vegetation in Central Africa: A remote sensing-based statistical analysis. Appl Geogr 22: 225–245.

Chytrý M, editor. 2007. Vegetation of the Czech Republic 1. Grassland and Heathland Vegetation. Praha: Academia. 526 pp.

Chytrý M, Tichý L. 2003. Diagnostic, constant and dominant species of vegetation classes and alliances of the Czech Republic: A statistical revision. Folia Facultatis Scientiarum Naturalium Universitatis Masarykianae Brunensis 108: 1–231.

Chytrý M, Tichý L, Holt J. 2006. The fidelity concept. In: Tichý L, Holt J, editors. JUICE, program for management, analysis and classification of ecological data. First part of the program manual. Brno: Vegetation Science Group, Masaryk University. pp. 44–52.

Chytrý M, Tichý L, Holt J, Botta-Dukát Z. 2002. Determination of diagnostic species with statistical fidelity measures. J Veg Sci 13: 79–90.

Dierschke H. 2006. Sekundär-progressive Sukzession eines aufgelassenen Kalkmagerrasens. Dauerflächenuntersuchungen 1987–2002. Hercynia 39: 223–245.

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

Ellenberg H. 1996. Vegetation Mitteleuropas mit den Alpen in ökologischer, dynamischer und historischer Sicht. 5th ed. Stuttgart: Ulmer. 1095 pp.

Gömöry D, Dovčiak M, Gömöryová E, Hrivnák R, Janišová M, Ujházy K. 2006. Demecological, synecological and genetic aspects of the colonization of abandoned areas by trees. Zvolen: Technická univerzita vo Zvolene. 93 pp.

GRASS Development Team 2010. Geographic Resources Analysis Support System (GRASS) Software, Version 6.4.0. Open Source Geospatial Foundation. Available: http://grass.osgeo.org.

Grime JP. 1979. Plant strategies and vegetation processes. Chichester: J. Wiley & Sons. 222 pp.

Guisan A, Zimmermann NE. 2000. Predictive habitat distribution models in ecology. Ecol Model 135/2-3: 147–186.

Hajdúk J. 1986. Results of vegetation changes research on permanent trial plots and their importance for the management of the State Nature Reserve Devínska Kobyla. Ochrana prírody 7: 79–105.

Hansson M, Fogelfors H. 2000. Management of a seminatural grassland; results from a 15-year-old experiment in southern Sweden. J Veg Sci 11: 31–38.

Hédl R. 2004. Vegetation of beech forests in the Rychlebské Mounains, Czech Republic, re-inspected after 60 years with assessment of environmental changes. Plant Ecol 170: 243–265.

Hegedüšová K. 2007. Central database of phytosociological samples (CDF) in Slovakia (state to January 2007). Bull Slov Bot Spoločn 29: 124–129.

Hegedüšová K. 2009. Devínska Kobyla and Sandberg – National Nature Reserve (Slovak Republic). Bull Eur Dry Grassland Group [serial online]; 3. Available: http://www.edgg.org/publ/bulletin/Bulletin_EDGG_03.pdf.

Hegedüšová K, Senko D, Feráková V. 2010. Devínska Kobyla and Sandberg National Nature Reserve and Protected Site. In: Janišová M, Budzáková M, Petrášová M, editors. 7th European Dry Grassland Meeting. Succession, management and restoration of dry grasslands, 27–31 May 2010, Smolenice Congress Centre, Slovak Republic. Abstracts & Excursion Guides. Bratislava, Slovakia, pp. 112–122.

Hegg O, Béguin C, Zoller H. 1992. Atlas schutzwü rdiger Vegetationstypen in der Schweiz. Bern: BUWAL.

Hennekens SM, Schaminée JHJ. 2001. TURBOVEG, a comprehensive data base management system for vegetation data. J Veg Sci 12: 589–591.

Hofierka J, Šúri M. 2002. The solar radiation model for Open source GIS: Implementation and applications. In: Ciolli M, Zatelli P. editors. Proceedings of the ''Open Source Free Software GIS-GRASS Users Conference 2002''. Trento, Italy, 11–13 September 2002, CD-ROM.

Huston MA. 1994. Biological Diversity: The coexistence of species on changing landscape. Cambridge: Cambridge University Press. 681 pp.

Izakovičová Z, Miklós L, Drdoš J. 1997. Landscape conditions for sustainable development. Bratislava: Veda. 186 pp. In Slovak.

Jacquemyn H, Van Mechelen C, Brys R, Honnay O. 2010. Management effects on the vegetation and soil seed bank of calcareous grasslands: An 11-year experiment. biological conservation 144: 416–422.

Janišová M, editor. 2007. Grassland vegetation of Slovak Republic – electronic expert system for identification of syntaxa. Bratislava: Institute of Botany SAS. 265 pp.

Janišová M, Budzáková M, Petrášová M, editors. 2010. 7th European Dry Grassland Meeting. Succession, management and restoration of dry grasslands. 27–31 May 2010, Smolenice Congress Centre, Slovak Republic. Abstracts & Excursion Guides. Bratislava, Slovakia. 146 pp.

Jarolímek I, Šibík J, Hegedüšová K, Janišová M, Kliment J, Kučera P, et al. 2008. A list of vegetation units of Slovakia. In: Jarolímek I, Šibík J, editors. 2008. Diagnostic, constant and dominant taxa of the higher vegetation units of Slovakia. Bratislava: Veda. p. 295–329.

Kadmon R, Harari-Kremer R. 1999. Studying long-term vegetation dynamics using digital processing of historical aerial photographs. Rem Sens Environ 68/2: 164–176.

Kahmen S, Poschlod P, Schreiber KF. 2002. Conservation management of calcareous grasslands. Changes in plant species composition and response of functional traits during 25 years. Biol Conserv 104: 319–328.

Kaleta M. 1965. Vegetation of Devínskej Kobyla Mt. [Thesis]. Bratislava: Comenius University in Bratislava. 86 pp. Available from: Library of Department of Botany.

Köhler B, Gigon A, Edwards PJ, Krüsi B, Langenauer R, Lüscher A, et al. 2005. Changes in the species composition and conservation value of limestone grasslands in Northern Switzerland after 22 years of contrasting managements. Perspect Plant Ecol Evol Syst 7: 51–67.

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

Krcho J. 1965. Solar insolation at any angle and time and its representation in the map using isalumclines. Geogr J 17/1: 19–40.

Marhold K, Hindák F, editors. 1998. Checklist of non-vascular and vascular plants of Slovakia. Bratislava: Veda. 688 pp.

Masé G. 2005. The management of dry grassland in Switzerland. A Swiss federal program and its local practical application. Biotechnol Agron Soc Environ 2005 9/2: 133–138.

McCune B, Grace JB. 2002. Analysis of ecological communities. Gleneden Beach: MjM Software Design.

Minár J, Barka I, Bonk R, Bizubová M, Čerňanský J, Falt'an V, et al. 2001. Geoecological (complex physical–geographical) research and mapping in large scales. Geografické spektrum 3: 1–210.

Minár J, Tremboš P. 1994. Natural hazards – threats, some of their evaluation. Acta Geogr 35: 173–194.

Mitášová H, Mitáš L. 1993. Interpolation by regularized spline with tension: I. Theory and implementation. Math Geol 25/6: 641-655.

Münier B, Nygaardb B, Ejrnæsb R, Bruuna HG. 2001. A biotope landscape model for prediction of semi-natural vegetation in Denmark. Ecol Model 139/2-3: 221–233.

Oom SP, Sibbald AM, Hester A J, Miller DR, Legg CJ. 2008. Impacts of sheep grazing a complex vegetation mosaic: Relating behaviour to vegetation change. Agric Ecosyst Environ 124: 219–228.

Pavlů V, Hejcman M, Pavlů L, Gaisler, J. 2007. Restoration of grazing management and its effect on vegetation in an upland grassland. Appl Veg Sci 10: 375–382.

Påhlsson L. 1974. Relationship of soil, microclimate and vegetation on a sandy hill. Oikos 25: 21–34.

Poschlod P, WallisDeVries MF. 2002. The historical and socioeconomic perspective of calcareous grasslands. Lessons learnt from the distant and recent past. Biol Conserv 104: 361–376.

Ptačovský K. 1959. The contributions to the flora of Bratislava. Biol práce 5: 1–87.

Richter B, Partzsch M, Hensen I. 2003. Vegetation, Kultur- und Nutzungsgeschichte der xerothermen Hügellandschaft bei Mücheln/Wettin (Sachsen-Anhalt). Hercynia N F 36: 91–121.

Riecken U, Finck P, Schröder E. 2002. Significance of pasture landscape for nature conservation and extensive agriculture. In: Redecker B, Finck P, Härdtle W, Riecken U, Schröder E, editors. Pasture landscape and nature conservation. Berlin, Heidelberg. pp. 423–435.

Ruprecht E, Enyedi MZ, Eckstein RL, Donath TW. 2010. Restorative removal of plant litter and vegetation 40 years after abandonment enhances re-emergence of steppe grassland vegetation. Biol Conserv 143: 449–456.

Senko D. 2007. Geoecological analysis of the relationship between vegetation and its abiotic environment of the Devínska Kobyla region. Thesis [PhD]. Bratislava: Comenius University in Bratislava. 172 pp. Available from: Library of Department of Physical Geography and Geoecology.

Scharmer K, Greif J, editors. 2000. The European solar radiation atlas. 2. Database and exploitation software. Paris: Presses des Mines. 290 pp.

Schrautzer J, Jansen D, Breurer M, Nelle O. 2009. Succession and management of calcareous dry grasslands in the Northern Franconian Jura, Germany. Tuexenia 29: 339–351.

Schumacher W, Münzel M, Riemer S. 1995. Die Pflege der Kalkmagerrasen. Beih. Veröff. Naturschutz Landschaftspflege Bad. Württ 83: 37–63.

Smit GN. 2004. An approach to tree thinning to structure southern African savannas for long-term restoration from bush encroachment. J Env Manage 71: 179–191.

Škornik S, Vidrih M, Kaligarič M. 2010. The effect of grazing pressure on species richness, composition and productivity in North Adriatic Karst pastures. Plant Biosyst 144/2: 355–364.

Tichý L. 2002. JUICE, software for vegetation classification. J Veg Sci 13: 451–453.

Török K, Szitár K. 2010. Long-term changes of rock grassland communities in Hungary. Community Ecol 11: 67–76.

Van Hees WWS. 1994. A fractal model of vegetation complexity in Alaska. Landscape Ecol 9: 271–278.

WallisDeVries MF. 1999. The dilemma facing nature conservation and the role of large herbivores. In: Gerken B, Görner M, editors. The development of European landscapes with large herbivores-history, models and perspectives. Natur und Kulturlandschaft 3: 24–31.

WallisDeVries MF, Poschlod P, Willems JH. 2002. Challenges for the conservation of calcareous grasslands in northwestern Europe: Integrating the requirements of flora and fauna. Biol Conserv 104: 265–273.

Warren J, Christal A, Wilson F. 2002. Effects of sowing and management on vegetation succession during grassland habitat restoration. Agric Ecosyst Environ 93/1–3: 393–402.

Werner B, Spranger T. 2000. Manual on methodologies and criteria for mapping critical levels/loads and geographical areas where they are exceeded. UN ECE convention on long-range transboundary air pollution. Available: www.umweltdaten.de/uid/manual/manual_mapping.pdf.

Westhoff V, van der Maarel E. 1973. The Braun-Blanquet approach. In: Whittaker RH, editor. Ordination and 11 classification of communities. Hague: Dr. W. Junk Publishers. pp. 617–727.

Willems JH. 1983. Species composition and above-ground phytomass in chalk grassland with different management. Vegetatio 52: 171–180.

Willems JH. 1985. Growth form spectra and species diversity in permanent grassland plots with different management. Geogr Arb 20: 35–43.

Willems JH. 1990. Calcareous grasslands in Continental Europe. In Hillier SH, Walton DHW, Wells DA, editors. Calcareous grasslands. Ecology and management. United Kingdom: Bluntisham. pp. 3–10.

Willems JH. 2001. Problems, approaches and results in restoration of Dutch calcareous grasslands during the last 30 years. Restor Ecol 9: 147–154.

Wolkinger F, Plank S. 1981. Dry Grasslands of Europe. Nature and Environment Series. Strasbourg.

Young A, Mitchell N. 1994. Microclimate and vegetationnext term edge effects in a fragmented podocarp-broadleaf forest in New Zealand. Biol Conserv 67/1: 63–72.

Appendix I. List of species merged to aggregates (agg.) or broadly defined taxa (s. lat., sect.)

Taxon name	Included taxa
Achillea millefolium agg.	*A. millefolium*, *A. collina*, *A. pannonica*
Anthoxanthum odoratum agg.	*A. odoratum*, *A. alpinum*
Arenaria serpyllifolia agg.	*A. serpyllifolia*, *A. leptoclados*
Campanula rotundifolia agg.	*C. rotundifolia*, *C. moravica*
Dorycnium pentaphyllum agg.	*D. germanicum*, *D. herbaceum*
Erophila verna agg.	*E. verna*, *E. spathulata*
Festuca rubra agg.	*F. rubra*, *F. diffusa*, *F. nigrescens*
Galium mollugo agg.	*G. album*, *G. mollugo*
Galium verum agg.	*G. verum*, *G. wirtgenii*
Helianthemum nummularium agg.	*H. ovatum*, *H. grandiflorum*, *H. nummularium*
Lotus corniculatus agg.	*L. corniculatus*, *L. alpinus*, *L. borbasii*, *L. pedunculatus*, *L. tenuis*
Onobrychis viciifolia agg.	*O. viciifolia*, *O. arenaria*
Pimpinella saxifraga agg.	*P. saxifraga*, *P. nigra*
Poa pratensis agg.	*P. pratensis*, *P. angustifolia*, *P. humilis*
Potentilla arenaria agg.	*P. arenaria*, *P. tommasiniana*
Veronica chamaedrys agg.	*V. chamaedrys*, *V. vindobonensis*

Appendix II. A shortened combined synoptic table of the historical (group 1, 2, 7, 8, Kaleta 1965) and recent phytosociological relevés (group 3, 4, 5, 6, Hegedüšová 2009–2010) defined numerically with modified fidelity phi coefficient and frequency (%). The numbers given in the table are percentage values of species fidelity. Their upper indices are the frequency value of a species for a particular vegetation type; dashes mean negative phi values. Diagnostic species (DS) with phi-coefficient value higher than 0.30 (Fisher's exact test $p < 0.001$) are on a grey background, DS with phi-coefficient value higher than 0.40 are in bold. Constant species with frequency over 80% are printed in bold. 1-6. *Poo badensis-Festucetum pallentis*, -3. *Festuco pallentis-Caricetum humilis*, 7-4. *Festuco valesiacae-Stipetum capillatae*, 8. *Scabioso ochroleucae-Brachypodietum pinnati*, 5. successional stages of the *Bromion erecti* and *Cirsio-Brachypodion pinnati*.

Group No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
No. of relevés	**7**	**7**	**17**	**11**	**17**	**9**	**13**	**13**
Stipa species	**100.0**$^{\mathbf{100}}$	–	–	–	–	–	–	–
Campanula rotundifolia agg.	**79.0**^{71}	–	–	–	–^{6}	–	–	–
Asplenium ruta-muraria	**73.4**^{57}	–	–	–	–	–	–	–
Sedum album	**73.2**$^{\mathbf{100}}$	–^{14}	–^{12}	14.2^{36}	–^{6}	–	–	–
Sedum acre	**60.4**$^{\mathbf{100}}$	12.4^{43}	–^{12}	–^{9}	–^{6}	23.0^{56}	–	–
Verbascum austriacum	**56.8**^{43}	–	–	–	–	–	–	2.1^{8}
Poa badensis	**50.9**^{29}	–	–	–	–	–	–	–
Minuartia rubra	**50.5**^{43}	–	14.4^{18}	–	–	–	–	–
Polygonatum odoratum	**45.9**^{57}	–	3.4^{18}	–	3.4^{18}	–	–	9.3^{23}
Stipa capillata	**44.3**$^{\mathbf{100}}$	–^{43}	–^{41}	9.5^{55}	–^{12}	10.3^{56}	–^{31}	–
Allium senescens subsp. *montanum*	**42.2**$^{\mathbf{100}}$	–^{29}	–^{24}	7.6^{55}	–^{18}	25.3^{78}	7.1^{54}	–
Anthericum ramosum	39.0^{71}	2.1^{29}	12.9^{41}	–	–^{24}	15.7^{44}	–	–
Tragopogon orientalis	38.1^{57}	10.1^{29}	–^{18}	–	–^{12}	–	–^{8}	4.7^{23}
Salvia verticillata	35.7^{14}	–	–	–	–	–	–	–
Tithymalus amygdaloides	35.7^{14}	–	–	–	–	–	–	–
Xeranthemum annuum	33.9^{29}	12.0^{14}	–	4.0^{9}	–	–	–	–
Festuca pallens s.lat.	32.9$^{\mathbf{100}}$	–^{57}	15.0^{76}	26.0^{91}	–^{41}	24.5^{89}	–	–
Jurinea mollis	31.6$^{\mathbf{100}}$	9.6^{71}	27.1^{94}	10.6^{73}	–^{24}	–^{56}	–^{38}	–^{15}
Echium vulgare	31.1^{57}	–^{14}	–^{24}	4.1^{27}	–^{18}	–^{11}	7.3^{31}	–
Hesperis tristis	–	**69.1**^{57}	–	–	–^{6}	–	–	–
Viola ambigua	–	**58.1**^{43}	–^{6}	–	–	–	–	–
Pilosella officinarum	4.3^{29}	**55.1**$^{\mathbf{86}}$	5.0^{29}	–	–	–	19.9^{46}	–
Festuca pseudovina	–	**54.7**$^{\mathbf{86}}$	–^{6}	–	–	–	26.5^{54}	19.7^{46}
Pimpinella saxifraga agg.	18.0^{57}	**40.7**$^{\mathbf{86}}$	–^{29}	–^{18}	28.6^{71}	–	–^{15}	–
Pseudolysimachion spicatum	–	38.5^{29}	–	6.1^{9}	–^{6}	–	–	–
Stipa pulcherrima	–	37.1^{57}	–^{18}	–^{18}	–	–^{11}	26.5^{46}	–
Seseli annuum	–	35.7^{14}	–	–	–	–	–	–
Carex praecox	–	35.7^{14}	–	–	–	–	–	–
Botriochloa ischaemum	24.5^{86}	35.4$^{\mathbf{100}}$	17.5^{76}	28.5^{91}	–^{6}	–^{44}	–^{8}	–^{15}
Erysimum diffusum agg.	23.3^{86}	34.1$^{\mathbf{100}}$	–^{18}	–^{36}	–^{41}	–^{44}	22.4^{85}	–^{31}
Eryngium campestre	–	33.2$^{\mathbf{100}}$	1.8^{59}	–^{55}	19.7^{82}	–^{33}	3.8^{62}	3.8^{62}
Medicago falcata	–^{29}	30.8$^{\mathbf{86}}$	–^{24}	–^{18}	10.4^{59}	–	12.5^{62}	30.0^{85}
Carex supina	–	30.5^{29}	–	–	–	–	22.6^{23}	–^{8}
Bupleurum falcatum	–^{29}	–^{14}	**48.0**$^{\mathbf{94}}$	9.1^{45}	19.8^{59}	–	–^{8}	–^{23}
Inula ensifolia	–^{29}	–^{14}	**40.8**$^{\mathbf{82}}$	–^{27}	26.5^{65}	–	–^{8}	–^{31}
Globularia punctata	–^{43}	4.2^{57}	36.6$^{\mathbf{100}}$	22.9^{82}	–^{41}	11.4^{67}	–^{8}	–^{15}
Campanula glomerata	–	–	35.2^{24}	–	13.5^{12}	–	–	–
Aster amelloides	–	–	32.9^{18}	–	6.6^{6}	–	–	–
Ononis pusilla	–	–	32.9^{18}	–	6.6^{6}	–	–	–
Nonea pulla	–	–	–	**40.3**^{18}	–	–	–	–
Thesium linophyllon	–	–^{14}	9.4^{41}	35.5^{73}	28.9^{65}	–^{22}	–	–^{23}
Iris pumila	–^{29}	10.7^{43}	–^{29}	35.4^{73}	–^{24}	–^{11}	–^{31}	–
Prunella vulgaris	–	–	–	33.6^{18}	6.4^{6}	–	–	–
Koeleria macrantha	–^{57}	22.0^{86}	–^{41}	32.9$^{\mathbf{100}}$	–^{53}	–^{33}	–^{38}	–^{46}
Allium flavum	14.5^{43}	–	8.0^{35}	32.5^{64}	8.0^{35}	–	4.1^{31}	–
Acosta rhenana	–^{29}	13.1^{57}	9.9^{53}	32.2$^{\mathbf{82}}$	–^{29}	11.9^{56}	–^{15}	–
Fragaria viridis	–	–	4.4^{18}	–^{9}	**75.7**$^{\mathbf{82}}$	–	–	–
Chamaecytisus supinus	–	–	13.7^{24}	7.4^{18}	**48.1**^{53}	–	–	–
Peucedanum alsaticum	–	–	–	–	**46.1**^{24}	–	–	–
Campanula bononiensis	–^{14}	–^{14}	–^{12}	–	**44.2**^{65}	–	–^{8}	18.9^{38}
Colymbada scabiosa	–	–	17.6^{29}	5.1^{18}	**43.6**^{53}	–	–	–^{8}
Carex michelii	–	–	18.7^{24}	–^{9}	**41.7**^{41}	–	–	–

(*continued*)

Appendix II. (*Continued*).

Group No. **No. of relevés**	**1** **7**	**2** **7**	**3** **17**	**4** **11**	**5** **17**	**6** **9**	**7** **13**	**8** **13**
Festuca rubra agg.	–	–	–	–	39.7^{18}	–	–	–
Galium pycnotrichum	–	–	–^{6}	5.8^{9}	39.4^{29}	–	–	–
Galium glaucum	–	–	18.9^{18}	–	37.8^{29}	–	–	–
Peucedanum cervaria	–	–^{14}	17.3^{35}	–^{9}	34.7^{53}	–	–	12.8^{31}
Cerastium arvense	–	–	–	–	32.3^{12}	–	–	–
Arrhenatherum elatius	–	–	–	–	31.2^{18}	–	–	9.8^{8}
Peucedanum arenarium	–	–	–	–	–^{6}	**68.0**^{56}	–	–
Minuartia setacea	–	–	–^{6}	3.8^{18}	–	**67.5**^{78}	–^{15}	–
Peucedanum oreoselinum	–	–	–^{6}	3.4^{18}	2.9^{18}	**66.6**^{78}	–	–
Tithymalus seguierianus	–	–	–^{6}	22.6^{36}	–	**66.4**^{78}	–	–
Cerastium semidecandrum	–	–	–	15.7^{27}	–^{12}	**59.7**^{67}	–	–
Holosteum umbellatum	–	–	–	25.1^{36}	–^{6}	**58.5**^{67}	–	–
Thymus pannonicus	–	–	–	–	1.7^{6}	**49.8**^{33}	–	–
Camelina microcarpa	–	–	–	–	–	**44.7**^{22}	–	–
Salsola kali	–	–	–	–	–	**44.7**^{22}	–	–
Asperula tinctoria	–	–	8.3^{12}	–	–^{6}	**41.7**^{33}	–	–
Astragalus onobrychis	–	–^{29}	–^{24}	27.8^{91}	–^{53}	34.7$^{\mathbf{100}}$	–^{54}	23.0^{85}
Fumana procumbens	17.9^{57}	–^{29}	19.2^{59}	15.8^{55}	–	34.3^{78}	–	–
Bromus hordeaceus	–	–	–^{6}	26.0^{27}	–	34.3^{33}	–	–
Erophila verna agg.	–	–	–	26.0^{27}	–^{6}	34.3^{33}	–	–
Cerastium brachypetalum	–	–	–	–	–	31.4^{11}	–	–
Cotoneaster tomentosus	–	–	–	–	–	31.4^{11}	–	–
Cynodon dactylon	–	–	–	–	–	31.4^{11}	–	–
Cerastium glomeratum	–	–	–	–	–	31.4^{11}	–	–
Poa compressa	–	–	–	–	–	–	**52.9**^{31}	–
Veronica prostrata	–	–	–	–	–	–	**45.6**^{23}	–
Festuca rupicola	–	24.2^{71}	–^{12}	–^{9}	14.5^{59}	–	**40.3**$^{\mathbf{92}}$	28.4^{77}
Onobrychis viciifolia agg.	–	–	–^{6}	–	3.7^{12}	–	39.1^{38}	8.5^{15}
Genista pilosa	–	–^{14}	15.9^{35}	–^{9}	–^{12}	–^{11}	33.8^{54}	–^{15}
Galium verum agg.	–^{29}	–^{29}	–^{6}	–^{9}	–^{29}	–	33.5^{69}	27.1^{62}
Origanum vulgare	–	–	–^{6}	–	3.4^{18}	–	–	**83.6**$^{\mathbf{92}}$
Primula veris	–	–	–	–	9.8^{18}	–	–	**65.4**^{62}
Galium mollugo	–^{14}	–	–	–	–	–	22.8^{38}	**62.3**^{77}
Agrimonia eupatoria	–	–	–	–	11.5^{18}	–	–	**59.5**^{54}
Dactylis glomerata	–^{14}	–^{14}	–^{12}	–	13.0^{47}	–	24.8^{62}	**56.2**$^{\mathbf{100}}$
Anemone sylvestris	–	–	–^{6}	–	5.3^{12}	–	–	**53.3**^{46}
Thalictrum minus	–	–	–^{6}	–	–^{6}	–	–^{8}	**52.3**^{46}
Poa pratensis agg.	–	9.5^{43}	–	–^{18}	12.9^{47}	–^{11}	5.9^{38}	**49.8**^{92}
Silene vulgaris	–	–	–	–	2.4^{6}	–	–	**47.3**^{31}
Trifolium alpestre	–	1.6^{14}	–	–	–^{12}	–	11.5^{23}	**46.2**^{54}
Calamagrostis epigejos	–	–	–	–	–	–	–	**45.6**^{23}
Clematis recta	–	–	–	–	–	–	–	**45.6**^{23}
Trifolium pratense	–	–	–	–	–	–	–	**45.6**^{23}
Phleum phleoides	–	7.3^{29}	–^{12}	–	–^{18}	–	16.6^{38}	**45.3**^{69}
Ononis spinosa	–	–	–	–	–^{6}	–	11.4^{15}	**44.6**^{38}
Brachypodium pinnatum	10.6^{57}	–	11.9^{59}	–	7.4^{53}	–	25.7^{77}	**43.3**$^{\mathbf{100}}$
Viola hirta	–^{43}	10.3^{57}	16.0^{65}	–^{18}	11.5^{59}	–	–^{15}	37.1$^{\mathbf{92}}$
Clematis vitalba	–	–	–	–	–	–	–	37.0^{15}
Genista tinctoria	–	–^{14}	–^{18}	3.5^{27}	10.7^{35}	–	6.6^{31}	34.1^{62}
Hypericum perforatum	–	15.7^{43}	–^{12}	–^{9}	–^{18}	7.4^{33}	–^{23}	32.0^{62}
Betonica officinalis	–	–	4.8^{12}	–	21.0^{24}	–	–	30.9^{31}
DS common for two vegetation types								
Melica ciliata	**57.6**$^{\mathbf{100}}$	34.1^{71}	9.2^{41}	–^{9}	–	–^{11}	–	–
Rhamnus saxatilis subsp. *saxatilis*	**44.2**^{71}	31.2^{57}	–^{24}	–^{9}	–^{12}	–	–	–^{8}
Teucrium montanum	36.6^{100}	15.0^{71}	32.1$^{\mathbf{94}}$	2.2^{55}	–^{18}	–^{44}	–^{15}	–^{15}
Potentilla arenaria agg.	35.0^{100}	35.0^{100}	8.2^{65}	28.1^{91}	–^{53}	–^{22}	–	–
Inula oculus-christi	34.9^{43}	34.9^{43}	–^{6}	–	–	–	–^{8}	–
Convolvulus arvensis	–	30.5^{29}	–	–	–	–	–	33.7^{31}
Bromus erectus	–	–	42.4$^{\mathbf{82}}$	4.7^{36}	56.9$^{\mathbf{100}}$	–^{11}	–	–^{15}
Linum tenuifolium	–	–^{14}	30.2^{65}	36.9^{73}	–^{6}	22.6^{56}	–^{8}	–^{8}
Artemisia campestris	–	–^{14}	–^{12}	42.3$^{\mathbf{82}}$	4.0^{35}	57.2$^{\mathbf{100}}$	–	–
Linaria genistifolia	–	–	–^{18}	37.9^{64}	–^{18}	50.7^{78}	–	–

(*continued*)

Appendix II. (*Continued*).

Group No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
No. of relevés	**7**	**7**	**17**	**11**	**17**	**9**	**13**	**13**
Cerastium glutinosum	–	–	–^{6}	37.2^{45}	–^{6}	36.0^{44}	–	–
Silene otites	–	–	–	31.0^{36}	–^{6}	40.9^{44}	–	–
Geranium sanguineum	–	–	–^{6}	–	37.3^{41}	–	–	34.0^{38}
Securigera varia	–	–	–^{12}	–	–^{6}	–	51.3^{69}	36.0^{54}
Ranunculus illyricus	–	–	–	–	–	–	43.7^{46}	34.3^{38}
Fragaria moschata	–^{14}	23.3^{57}	–	–	–	–	39.8^{77}	46.2$^{\mathbf{85}}$
Plantago media	–	–^{29}	–^{6}	–^{27}	–^{6}	–^{22}	31.8^{69}	44.5$^{\mathbf{85}}$
Bromus inermis	–^{29}	37.8^{86}	–	–	–	–	48.9$^{\mathbf{100}}$	36.9$^{\mathbf{85}}$
Festuco-Brometea								
Teucrium chamaedrys	11.7^{86}	23.7^{100}	18.8^{94}	–^{73}	13.8^{88}	–^{33}	–	23.7^{100}
Campanula sibirica	5.0^{14}	–	–	21.1^{27}	9.2^{18}	–	–	15.9^{23}
Scabiosa ochroleuca	–^{57}	26.5^{100}	–^{65}	4.6^{73}	2.9^{71}	–^{56}	–^{31}	14.2^{85}
Acinos arvensis	–^{43}	–^{57}	–^{35}	23.5^{91}	–^{41}	13.4^{78}	12.7^{77}	–^{62}
Tithymalus cyparissias	–^{71}	–^{57}	19.8^{100}	19.8^{100}	3.6^{82}	–^{78}	–^{46}	12.8^{92}
Stachys recta	15.4^{43}	–	–^{24}	1.8^{27}	19.1^{47}	–^{22}	–	11.6^{38}
Anthyllis vulneraria	–^{14}	24.5^{57}	–^{18}	–^{27}	16.0^{47}	–^{22}	–^{8}	2.3^{31}
Asperula cynanchica	17.8^{71}	17.8^{71}	17.2^{71}	–^{36}	3.8^{53}	–^{11}	–^{23}	–^{46}
Salvia pratensis	18.0^{86}	–^{57}	6.2^{71}	7.9^{73}	6.2^{71}	–^{44}	–^{46}	–^{54}
Sanguisorba minor	–^{86}	11.5^{100}	11.5^{100}	–^{91}	–^{82}	–^{89}	11.5^{100}	–^{85}
Carex caryophyllea	–	–	24.6^{29}	21.9^{27}	2.3^{12}	1.5^{11}	–	–
Carex humilis	28.3^{100}	28.3^{100}	14.4^{82}	–^{55}	–^{65}	–^{11}	–^{54}	–^{46}
Festuca valesiaca	–	8.4^{29}	9.2^{29}	–^{18}	14.8^{35}	–	25.1^{46}	–
Other species with frequency $\geq$25% in at least one cluster								
Pyrethrum corymbosum	–	7.3^{14}	–^{6}	–	4.0^{12}	–	–^{8}	29.3^{31}
Chamaecytisus austriacus	–	–^{29}	15.3^{47}	–^{27}	5.5^{35}	–^{22}	–^{8}	27.4^{62}
Carlina vulgaris	–	–^{14}	4.1^{18}	–	4.1^{18}	–	10.0^{23}	26.9^{38}
Pilosella bauhinii	–^{14}	–	2.6^{18}	3.1^{18}	2.6^{18}	–	–^{15}	24.5^{38}
Dianthus pontederae	–	–	2.5^{18}	12.6^{27}	8.7^{24}	–	–^{15}	24.3^{38}
Achillea millefolium agg.	–^{57}	24.0^{100}	–^{47}	–^{64}	14.1^{88}	–^{22}	17.5^{92}	24.0^{100}
Cotoneaster integerrimus	19.8^{29}	19.8^{29}	–	–	–^{6}	–	–	22.4^{31}
Chrysopogon gryllus	8.1^{29}	8.1^{29}	–^{12}	–^{18}	–	–^{11}	2.9^{23}	17.5^{38}
Helianthemum nummularium agg.	–^{71}	2.5^{86}	11.0^{94}	7.7^{91}	5.0^{88}	–^{67}	–^{69}	16.9^{100}
Vincetoxicum hirundinaria	–	–	–^{12}	6.3^{18}	19.1^{29}	–^{11}	–^{8}	11.8^{23}
Adonis vernalis	–	5.9^{43}	–^{29}	–^{36}	18.6^{59}	–	26.8^{69}	8.5^{46}
Pulsatilla pratensis subsp. *bohemica*	–	18.9^{43}	–^{12}	29.5^{55}	6.6^{29}	–	–^{15}	–^{23}
Arabis hirsuta	28.8^{43}	–^{14}	2.4^{18}	–^{9}	8.6^{24}	–	–^{8}	–^{8}
Seseli osseum	1.1^{29}	13.2^{43}	16.8^{47}	7.7^{36}	–^{6}	–^{11}	3.0^{31}	–^{15}
Lotus corniculatus agg.	–^{14}	25.8^{71}	16.0^{59}	12.7^{55}	–^{35}	–^{33}	–^{15}	–^{23}
Seseli hippomarathrum	–	–^{14}	28.5^{53}	29.9^{55}	–^{12}	10.5^{33}	–	–^{8}
Medicago minima	–	–	–^{6}	28.4^{36}	13.5^{24}	12.0^{22}	–^{8}	–
Orthantha lutea	–^{14}	–	–^{12}	14.8^{27}	10.7^{24}	21.5^{33}	–	–
Thymus praecox	–^{71}	–^{71}	14.5^{94}	19.9^{100}	9.1^{88}	–^{78}	–^{62}	–^{62}
Elytrigia intermedia	28.3^{43}	13.4^{29}	–	21.5^{36}	2.0^{18}	–	–	–
Poa bulbosa	27.0^{43}	–	–	20.3^{36}	–	28.6^{44}	–^{8}	–
Scorzonera austriaca	24.1^{43}	–	28.2^{47}	8.8^{27}	–^{18}	–^{11}	–	–
Crinitina linosyris	–	9.8^{29}	4.9^{24}	26.3^{45}	–^{6}	25.3^{44}	–	–
Viola rupestris	29.7^{57}	17.0^{43}	–^{18}	–^{18}	–	–	26.8^{54}	–
Stipa joannis	21.6^{57}	–^{29}	3.7^{35}	27.0^{64}	–^{24}	–^{22}	–^{15}	–
Petrorhagia saxifraga	27.2^{100}	27.2^{100}	–^{41}	12.7^{82}	–^{35}	27.2^{100}	–^{62}	–^{8}
Dorycnium pentaphyllum agg.	26.2^{100}	3.1^{71}	26.2^{100}	–^{64}	7.2^{76}	–^{44}	13.8^{85}	–

Appendix III. A list of syntaxonomical units

Names of syntaxons	Clusters of historical relevés, Kaleta (1965)	Clusters of recent relevés, Hegedüšová 2009–2010
Class: *Festuco-Brometea*		
Alliance: *Festucion valesiacae*		
Association:		
Festuco valesiacae-Stipetum capillatae	7	4
Alliance: *Bromo pannonici-Festucion pallentis*		
Associations:		
Poo badensis-Festucetum pallentis	1	6
Festuco pallentis-Caricetum humilis	2	3
Alliance: *Cirsio-Brachypodion pinnati*		
Associations:		
Scabioso ochroleucae-Brachypodietum pinnati	8	
Vegetation type:		
Successional stages of *Bromion erecti* and *Cirsio-Brachypodion pinnati* transitional to *Geranion sanguinei*		5

Appendix IV. Summary of Kruskal–Wallis ANOVA showing the differences in number of species between vegetation units; group 1, 2, 7, 8 – historical phytosociological relevés; group 3, 4, 5, 6 – recent phytosociological relevés; 1-6. *Poo badensis-Festucetum pallentis*, 2-3. *Festuco pallentis-Caricetum humilis*, 7-4. *Festuco valesiacae-Stipetum capillatae, 8. Scabioso ochroleucae-Brachypodietum pinnati, 5. successional stages of the Bromion erecti and Cirsio-Brachypodion pinnati*

Kluskal–Wallis ANOVA (Number of species)
Median test, Overall median = 39.0000
Independent (grouping) variable: Group
Chi-Square = 20.02628, df = 7, $p = 0.0055$

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Total
≤Median: observed	2	3	8	3	6	8	12	6	48
Expected	3.57447	3.574468	8.68085	5.61702	8.68085	4.59574	6.63830	6.63830	
Obs.-exp.	−1.57447	−0.574468	−0.68085	−2.61702	−2.68085	3.40426	5.36170	−0.63830	
>Median: observed	5	4	9	8	11	1	1	7	46
Expected	3.42553	3.425532	8.31915	5.38298	8.31915	4.40426	6.36170	6.36170	
Obs.-exp.	1.57447	0.574468	0.68085	2.61702	2.68085	−3.40426	−5.36170	0.63830	
Total: observed	7	7	17	11	17	9	13	13	94

Appendix IVa. Summary of Mann–Whitney U test showing the differences in number of species between historical (group 1, 2, 7, 8) and recent (group 3, 4, 5, 6) phytosociological relevés, respectively. The significant differences are in bold. 1-6. *Poo badensis-Festucetum pallentis*, 2-3. *Festuco pallentis-Caricetum humilis*, 7-4. *Festuco valesiacae-Stipetum capillatae, 8. Scabioso ochroleucae-Brachypodietum pinnati, 5. successional stages of the Bromion erecti and Cirsio-Brachypodion pinnati*

Mann–Whitney U test (Number of species)
By variable Group
Marked tests are significant at $p < 0.05000$

	Rank Sum Group 1	Rank Sum Group 6	U	Z	p-level	Z adjusted	p-level	Valid N Group 1	Valid N Group 6	2*1sided exact p
Number of species	83.5	52.5	7.5	**2.540429**	**0.011072**	**2.549821**	**0.010778**	7	9	**0.007867**
	Rank Sum Group 2	Rank Sum Group 3	U	Z	p-level	Z adjusted	p-level	Valid N Group 2	Valid N Group 3	2*1sided exact p
Number of species	104	196	43	1.047927	0.294673	1.050213	0.293621	7	17	0.317592
	Rank Sum Group 7	Rank Sum Group 4	U	Z	p-level	Z adjusted	p-level	Valid N Group 7	Valid N Group 4	2*1sided exact p
Number of species	107.5	192.5	16.5	**−3.18651**	**0.001440**	**−3.19625**	**0.001392**	13	11	0.000707
	Rank Sum Group 8	Rank Sum Group 5	U	Z	p-level	Z adjusted	p-level	Valid N Group 8	Valid N Group 5	2*1sided exact p
Number of species	184	281	93	−0.732406	0.463922	−0.736017	0.461721	13	17	0.482564

Appendix V. Summary of Kruskal–Wallis ANOVA showing the differences in Number of Red List species between vegetation units; group 1, 2, 7, 8 – historical phytosociological relevés; group 3, 4, 5, 6 – recent phytosociological relevés; 1-6. *Poo badensis-Festucetum pallentis*, 2-3. *Festuco pallentis-Caricetum humilis*, 7-4. *Festuco valesiacae-Stipetum capillatae, 8. Scabioso ochroleucae-Brachypodietum pinnati, 5. successional stages of the Bromion erecti and Cirsio-Brachypodion pinnati*

Kruskal–Wallis ANOVA (Number of Red List species)
Median test, Overall median = 5
Independent (grouping) variable: Group
Chi-Square = 21.44700, df = 7, $p = 0.0032$

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Total
≤Median: observed	1	2	9	5	13	5	11	12	58
Expected	4.31915	4.31915	10.48936	6.78723	10.48936	5.553191	8.02128	8.02128	
Obs.-exp.	−3.31915	−2.31915	−1.48936	−1.78723	2.51064	−0.553191	2.97872	3.97872	
>Median: observed	6	5	8	6	4	4	2	1	36
Expected	2.68085	2.68085	6.51064	4.21277	6.51064	3.446809	4.97872	4.97872	
Obs.-exp.	3.31915	2.31915	1.48936	1.78723	−2.51064	0.553191	−2.97872	−3.97872	
Total: observed	7	7	17	11	17	9	13	13	94

Appendix Va. Summary of Mann–Whitney U test showing the differences in Number of Red List species between historical (group 1, 2, 7, 8) and recent (group 3, 4, 5, 6) phytosociological relevés, respectively. The significant differences are in bold. 1-6. *Poo badensis-Festucetum pallentis*, 2-3. *Festuco pallentis-Caricetum humilis*, 7-4. *Festuco valesiacae-Stipetum capillatae, 8. Scabioso ochroleucae-Brachypodietum pinnati, 5. successional stages of the Bromion erecti and Cirsio-Brachypodion pinnati*

Mann–Whitney U Test (Number of Red List species)
By variable group
Marked tests are significant at $p < 0.05000$

	Rank Sum Group 1	Rank Sum Group 6	U	Z	p-level	Z adjusted	p-level	Valid N Group 1	Valid N Group 6	2*1sided exact p
Number of Red List species	79	57	12	**2.064099**	**0.039009**	**2.144444**	**0.031998**	7	9	**0.041783**
	Rank Sum	Rank Sum Group 3	U	Z	p-level	Z adjusted	p-level	Valid N Group 2	Valid N Group 3	2*1sided exact p
Number of Red List species	115	185	32	1.746545	0.080717	1.776536	0.075646	7	17	0.086546
	Rank Sum Group 7	Rank Sum Group 4	U	Z	p-level	Z adjusted	p-level	Valid N Group 7	Valid N Group 4	2*1sided exact p
Number of Red List species	126	174	35	**−2.11468**	**0.034458**	**−2.23231**	**0.025595**	13	11	**0.035195**
	Rank Sum Group 8	Rank Sum Group 5	U	Z	p-level	Z adjusted	p-level	Valid N Group 8	Valid N Group 5	2*1sided exact p
Number of Red List species	150	315	59	**−2.15537**	**0.031134**	**−2.19125**	**0.028435**	13	17	**0.031282**

Appendix VI. Summary of Kruskal–Wallis ANOVA showing the differences in number of the *Festuco-Brometea* species between vegetation units; group 1, 2, 7, 8 – historical phytosociological relevés; group 3, 4, 5, 6 – recent phytosociological relevés; 1-6. *Poo badensis-Festucetum pallentis*, 2-3. *Festuco pallentis-Caricetum humilis, 7-4. Festuco valesiacae-Stipetum capillatae, 8. Scabioso ochroleucae-Brachypodietum pinnati, 5. successional stages of the Bromion erecti and Cirsio-Brachypodion pinnati*

Kruskal–Wallis ANOVA (Number of *Festuco-Brometea* species)
Median test, Overall median = 11.0000
Independent (grouping) variable: Group
Chi-square = 30.45710, df = 7, $p = 0.0001$

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Total
≤Median: observed	4	1	4	5	7	9	12	10	52
Expected	3.872340	3.87234	9.40426	6.08511	9.40426	4.97872	7.19149	7.19149	
Obs.-exp.	0.127660	−2.87234	−5.40426	−1.08511	−2.40426	4.02128	4.80851	2.80851	
>Median: observed	3	6	13	6	10	0	1	3	42
Expected	3.127660	3.12766	7.59574	4.91489	7.59574	4.02128	5.80851	5.80851	
Obs.-exp.	−0.127660	2.87234	5.40426	1.08511	2.40426	−4.02128	−4.80851	−2.80851	
Total: observed	7	7	17	11	17	9	13	13	94

Appendix VIa. Summary of Mann–Whitney U test showing the differences in number of the *Festuco-Brometea* species between historical (group 1, 2, 7, 8) and recent (group 3, 4, 5, 6) phytosociological relevés, respectively. The significant differences are in bold. 1-6. *Poo badensis-Festucetum pallentis*, 2-3. *Festuco pallentis-Caricetum humilis*, 7-4. *Festuco valesiacae-Stipetum capillatae*, 8. *Scabioso ochroleucae-Brachypodietum pinnati*, 5. *successional stages of the Bromion erecti and Cirsio-Brachypodion pinnati*

Mann–Whitney U Test (Number of *Festuco-Brometea* species)
By variable group
Marked tests are significant at $p < 0.05000$

	Rank Sum Group 1	Rank Sum Group 6	U	Z	*p*-level	Z adjusted	*p*-level	Valid N Group 1	Valid N Group 6	2*1sided exact *p*
Number of FB species	80	56	11	**2.169950**	**0.030011**	**2.200916**	**0.027743**	7	9	**0.031119**
	Rank Sum Group 2	**Rank Sum Group 3**	**U**	**Z**	***p*-level**	**Z adjusted**	***p*-level**	**Valid N Group 2**	**Valid N Group 3**	**2*1sided exact *p***
Number of FB species	80	220	52	−0.476331	0.633839	−0.483207	0.628949	7	17	0.664003
	Rank Sum Group 7	Rank Sum Group 4	U	Z	*p*-level	Z adjusted	*p*-level	Valid N Group 7	Valid N Group 4	2*1sided exact *p*
Number of FB species	106	194	15	**−3.27341**	**0.001063**	**−3.30372**	**0.000954**	13	11	**0.000534**
	Rank Sum Group 8	Rank Sum Group 5	U	Z	*p*-level	Z adjusted	*p*-level	Valid N Group 8	Valid N Group 5	2*1sided exact *p*
Number of FB species	158	308	67	−1.84148	0.065553	−1.86571	0.062083	13	17	0.064960

Appendix VII. Average cover table of Red List species. The species with decreasing average cover in recent relevés (group 3, 4, 5, 6) compare with historical relevés (group 1, 2, 7, 8) are printed in bold. 1-6. *Poo badensis-Festucetum pallentis*, 2-3. *Festuco pallentis-Caricetum humilis*, 7-4. *Festuco valesiacae-Stipetum capillatae, 8. Scabioso ochroleucae-Brachypodietum pinnati, 5. successional stages of the Bromion erecti and Cirsio-Brachypodion pinnati*

Groups	1	6	2	3	7	4	8	5
Adonis vernalis	2.9	6.3	2.8	8.8	4.6	6.0		
Anemone sylvestris			10.5	**1.0**	2.0	**0**		
Aster amelloides			0	2.3	2.0	**0**		
Campanula bononiensis	2.0	2.0	2.8	**2.5**	2.2	**0**	0	2
Cerasus fruticosa			0	53.0	1.0	**0**		
Chrysopogon gryllus	2.3	3.0	3.0	5.0	0	3.0	3	**2**
Clematis recta			2.0	**0**				
Erysimum diffusum agg.	2.4	**2.3**	2.0	6.0	1.7	**1.5**	2	2
Inula oculus-christi	3.0	**2.7**	0	3.0			0	3
Iris pumila	2.8	6.3	0	6.4	3.8	6.6	3	16
Jurinea mollis	2.0	9.0	2.0	2.1	1.5	2.4	1.8	2.3
Linum flavum	2.0	**0**	0	2.0				
Minuartia setacea	2.0	**0**	0	2.0	0	2.5	3.1	**0**
Minuartia viscose					2.0	**0**		
Ononis pusilla			0	1.7	3.0	**0**		
Orchis morio					0	3.0		
Orchis ustulata					0	2.0		
Orthantha lutea			0	2.0	3.3	**2.0**	1.7	2
Petrorhagia saxifrage	4.1	**2.9**	2.0	2.0	2.2	3.2	2.6	7.3
Peucedanum arenarium					2.0	**0**	9.8	**0**
Pulsatilla grandis	13.0	**0**	0	1.0	1.7	**0**	0	2
Pulsatilla pratensis subsp. *bohemica*	3.0	17.7	6.3	**2.0**	1.8	1.8		
Ranunculus illyricus	2.7	**0**	2.6	**0**				
Rhamnus saxatilis subsp. *saxatilis*	0	2.8	2.0	6.0	3.0	**2.0**	0	2.4
Scorzonera austriaca			0	2.3	2.0	2.3	2	2.3
Scorzonera purpurea			0	1.0	2.0	**0**		
Seseli hippomarathrum	0	13.0	3.0	5.0	2.0	2.5	2	0
Stipa joannis	2.5	3.0	0	4.3	2.5	5.9	20.5	**3**
Stipa pulcherrima	2.5	8.0	0	11.3	0	3	2	**0**
Tephroseris integrifolia			0	2.0	2.0	**0**		
Viola ambigua	0	2.7	0	3.0				
Xeranthemum annuum	0	2.0			0.0	3.0	0	2
Average cover of Red List species	**2.6**	**4.4**	**1.5**	**5.1**	**1.8**	**2.0**	**4.5**	**3.5**