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THE EFFECT OF TOPOGRAPHIC FACTORS AND LAND USE HISTORY ON GRASSLAND BIODIVERSITY IN THE POLISH CARPATHIANS

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Summary

Semi-natural, extensively managed grassland communities are among the most species-rich plant communities. The species number and floristic composition depend on numerous factors, both natural and associated with human activity, both present and past. In European countries, a system of subsidies for farmers is used to preserve extensive, usually unprofitable management of multi-species grassland communities. The development of specific recommendations requires knowledge of the main factors shaping grassland plant communities. A study was carried out in seven regions of the Polish Western Carpathians, in areas with traditional sheep grazing. Plant species composition (phytosociological relevés) of 517 plots were surveyed in different grassland types. For each plot, topographic parameters, i.e. slope, aspect and altitude, were recorded and land use in the past was read from historical maps. The aim of the study was to a) assess differences in the species composition of grassland vegetation between topographically and historically different regions of the Polish Carpathians, and b) to identify the main factors influencing species composition in each of these regions. Depending on the region, different factors contributed most to explaining the variation in the species composition and species numbers. Topographic factors played a decisive role. The type of past use (arable land or grassland) had little influence on current biodiversity. The results of the study indicate the need for a localised approach to developing principles for protection of grassland biodiversity.

Keywords

human impact • nature protection • grassland management • regional differences

1. Introduction

At present, the main goal of nature conservation is to preserve the biological diversity of both species and entire ecosystems [Millennium Ecosystem Assessment 2005]. An important reservoir of biodiversity is grasslands, which cover about 40% of the earth's surface (excluding Greenland and Antarctica) [White et al. 2000]. Grasslands and pastures also have significant landscape, cultural and environmental value, providing ecosystem services [Schills et al. 2022]. The social and economic transformations of the

20th century, however, caused changes in land use and management in agriculture. In Eastern Europe this process was particularly rapid following the political transformation at the beginning of the 1990s [Bakker et al. 2011, Bucała 2014]. Marginal areas of little use for agriculture are left unmanaged, enabling secondary forest succession and the loss of grassland communities [Tasser and Tappeiner 2002, Wesche et al. 2012, Zarzycki and Bedla 2017, Chabuz et al. 2019]. This is particularly unfavourable because the diversity of grassland communities is especially high in low-fertility habitats [Baumgartner and Hartmann 2001, Fischer and Wipf 2002, Tasser and Tappeiner 2002, Prangel et al. 2023].

To preserve extensive, usually unprofitable management of species in rich grassland communities in European countries, a system of subsidies for farmers is used [Darnhofer et al. 2017] and, in nature, protected area active conservation measures are introduced [Tokarczyk 2018]. Many of these programmes often do not take regional determinants into account. Developing specific recommendations adjusted to local conditions requires knowledge of the main factors shaping grassland plant communities [Dengler et al. 2014, Raduła et al. 2020]. Climatic, topographic and soil factors create the potential for the occurrence of plant species. The current species composition of grasslands is dependent on the presence of diaspores of species, largely due to historical factors, dispersal potential, and the type of agricultural use [Pärtel et al. 2005, Wellstein et al. 2007].

In our former paper [Zarzycki et al. 2022], we found out that species diversity was greater in grazing sites where grasslands developed on former arable land and the conservation status of a grassland was dependent on the present diversity of land use within a grazing site, rather than land use history 60 years ago. Our present hypothesis is that the regions differ in main environmental parameters that correlate with species richness and vegetation diversity.

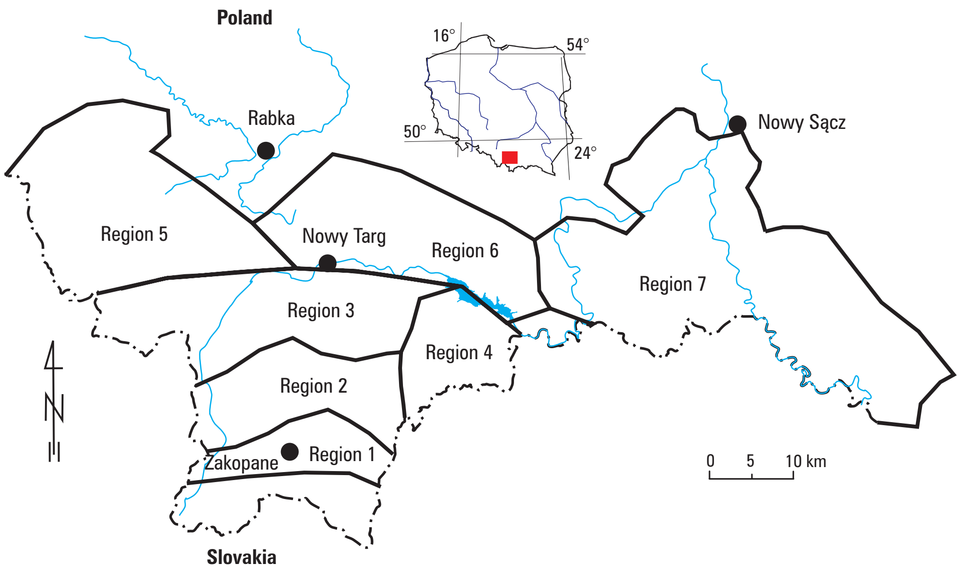
The aim of the study was to a) assess differences in the species composition of grassland vegetation between several topographically and historically different regions of the Polish Carpathians, and b) to identify the main factors influencing species composition in each of these regions.

2. Materials and methods

2.1. Study area

The study was carried out in 7 regions of the Polish part of the Western Carpathian Mountains (Fig. 1), distinguished mainly according to geographic criteria [Kondracki and Richling 1994]. The region of Pogórze Spisko-Gubałowskie was additionally divided into two subregions due to historical and ethnographic differences.

Within each region, research was carried out in 'grazing sites' used extensively by a single flock of sheep. The term 'grazing sites' may suggest land consisting of pastures alone; in fact, grazing may also take place in hay meadows, especially in autumn after mowing, and in former crop fields that have undergone spontaneous succession. The sheep flock moves about on the 'grazing site' every day and returns to a mobile pen at night. Due to diverse means of mowing and grazing management, many plant communities are of an intermediate character between pasture and hay meadow. The most widespread are pastures of the *Cynosurion* alliance, mainly *Festuco-Cynosuretum*, and mowed and grazed grasslands of the *Arrhenatherion* alliance. From 7 to 17 grazing sites in each region, 68 in total, were included in the study. The topographic conditions of the regions (Table 1) and the land use legacy (Fig. 2) varied.



Source: Authors' own study

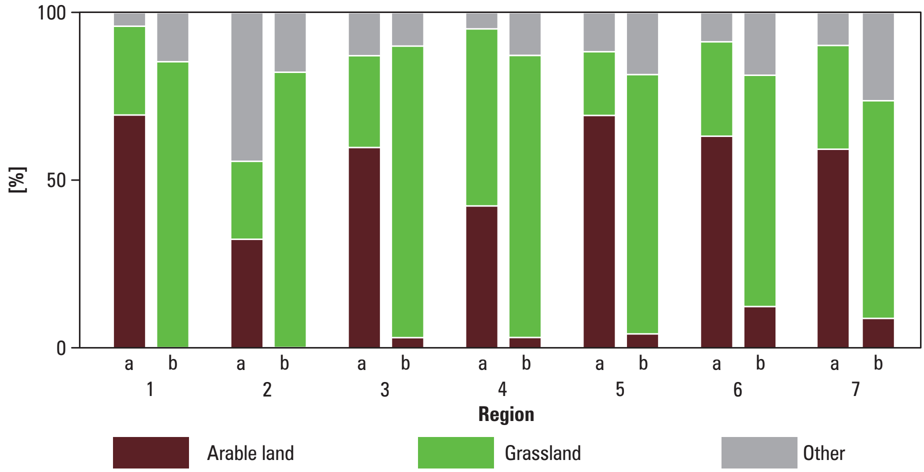
Fig. 1. Locations of regions in the Polish Carpathians. Region explanation as in Table 1

Table 1. Characteristic of regions based on relevés in individual regions

Region	Elevation [m] min–max (range)	Mean slope [°]	Number of grazing sites	Total area of grazing sites [ha]	Number of relevés
Region 1 Rów Podtatrzański	798–1133 (335)	8.81	17	1068	113
Region 2 Gubałówka	725–958 (233)	11.45	7	508	65
Region 3 Spisz	527–800 (273)	6.36	9	588	58
Region 4 Kotlina Orawsko-Nowotarska	584–689 (105)	1.82	10	847	69
Region 5 Beskid Żywiecki	491–887 (396)	9.38	7	256	56

Table 1. cont.

Region	Elevation [m] min–max (range)	Mean slope [°]	Number of grazing sites	Total area of grazing sites [ha]	Number of relevés
Region 6 Gorce	555–1200 (645)	8.28	8	669	61
Region 7 Beskid Sądecki and Kotlina Sądecka	410–945 (535)	9.88	10	1352	94



Source: Authors' own study

Fig. 2. Share [%] of area with different types of land use of grazing sites in each region in: a. 1960s and b. 2017. Region explanation as in Table 1

2.2. Data collection

A total of 517 plots (5 × 5 m) in mesic grassland communities were set up in such a way as to take into account the greatest possible floristic variation of each grazing site. The number of plots in each region varied and was associated with the number of grazing sites (Table 1). In 2017, a phytosociological relevé was designated on each plot using the Braun-Blanquett method (1964). For each relevé, mean Ellenberg Indicator Values (EIV) (Leuschner and Ellenberg, 2017) were calculated for soil temperature (T), moisture (F), reaction (R) and fertility (N).

2.3. Land use and topographic information

Using calibrated soil-agricultural maps from the 1960s with information on land use for each 'grazing site', the area of arable land and grassland during this period was calculated. The current area of arable land and area of grassland in the grazing sites were determined by field survey. Information on how each plot was used in the 1960s and 1980s (arable land or grassland) was read from soil-agricultural and topographic maps. For each plot, topographic parameters, i.e. slope, exposure and altitude, were recorded and potential annual direct radiation was calculated according to McCune and Keon [2002].

2.4. Data analysis

Data from the relevés were used to determine basic measures of the species diversity of the regions: average number of vascular plant species per relevé (alpha diversity), total number of vascular plant species in all relevés within a region (gamma diversity) and differences between communities within the region (beta diversity = gamma/(alpha – 1)) [Tuomisto 2010]. The effect of factors on vegetation was first assessed on the entire set of square-root-transformed species data in order to quantify and test the effect of three groups of explaining variables: topographic factors, legacy land use, and region. This was performed using redundancy analysis (RDA), and statistical significance ($p < 0.05$) was tested by a Monte Carlo permutation test. The topographic factors were altitude above sea level, exposure (expressed as degree deviation from northern exposure), and slope. The legacy land use factor comprised two variables: land use in the 1960s (arable land or grassland) and in the 1980s (arable land or grassland). For the data from each region separate analyses were carried out in the same way, using the same variables. Fraction of variation explained by topographic factors and past land use for the entire area and for each region separately was calculated by a partial RDA. The effect of environmental conditions on variation in species composition and species number in each region was determined by calculating Pearson's correlation coefficients between the values of topographic factors and indicator values (EIV) for a given plot with sample scores on the first and second detrended correspondence analysis (DCA) axes. The significance of differences in the number of species in plots used in different ways in the past was calculated using the Mann–Whitney U test. Analyses using multidimensional methods were carried out using the CANOCO 5 software, and the remaining statistical analyses were performed using the STATISTICA software.

3. Results

Analysis of the entire data set revealed that the factors considered explained 11.4% of the total variation in species composition. The largest proportion of the variation (6.1%) was caused by differences between regions (Table 2). In individual regions, the factors together explained from 12% in region 1 (Rów Podtatrzański) to even 20.8% in region 6 (Gorce). The topographic factors were significant in all regions and explained from 6.1% in region 1 (Rów Podtatrzański) to 12.2% in region 6 (Gorce) of the total variation. The type of past land use was significant in only three regions, with a maximum of 7.1% in region 5 (Beskid Żywiecki).

Table 2. Fraction of variation explained by topographic factors and past land use (RDA) for the entire area and for each region separately. The unique contribution of each set of variables is the variation accounted for when the effects of all other variables are removed in a partial RDA

	Set of variables	**Variation explained [%]**	**Unique contribution [%]**
All regions	Total	11.4**	
	Topographic	4.1	2.2**
	Land use legacy	1.5	1**
	Regions	7.8	6.1**
Region 1 Rów Podtatrzański	Total	12**	
	Topographic	6.9	6.1**
	Land use legacy	5	4.3*
Region 2 Gubałówka	Total	15.2*	
	Topographic	11.6	10.3*
	Land use legacy	4.8	3.5
Region 3 Spisz	Total	18.0**	
	Topographic	11.8	11.3*
	Land use legacy	6.7	6.2
Region 4 Kotlina Orawsko-Nowotarska	Total	16.9**	
	Topographic	10.8	10.4**
	Land use legacy	6.4	6.0**
Region 5 Beskid Żywiecki	Total	18.6**	
	Topographic	11.5	11.7**
	Land use legacy	6.9	7.1**
Region 6 Gorce	Total	20.8**	
	Topographic	15.1	12.2**
	Land use legacy	8.6	5.7
Region 7 Beskid Sądecki and Kotlina Sądecka	Total	13.8*	
	Topographic	10.1	7.8**
	Land use legacy	6	3.7

* $p < 0.05$, ** – $p < 0.01$ (Monte Carlo test, 999 permutations)

Variation in species composition expressed as the maximum length of the main gradient (1st or 2nd axis) in the DCA analysis was highest (4.51 SD) in region 6 (Gorce) and lowest (2.59 SD) in region 7 (Beskid Sądecki and Kotlina Sądecka) (Table 3). The main gradient of variation in species composition (DCA axis) was associated with various topographic parameters in the regions – in three regions with altitude; in three regions with exposure; and in three regions with radiation. In one region, no correlation was shown between the first two axes and the factors analysed. The correlations of the main gradients of variation with habitat conditions expressed as EIV varied (Table 3). In all regions there were correlations with fertility (*N*), but the correlation coefficients ranged from 0.34 ($r^2 = 0.12$) in region 1 (Rów Podtatrzański) to even 0.91 ($r^2 = 0.83$) in regions 3 (Spisz) and 6 (Gorce). Variation in species composition was also associated with soil reaction (*R*) in six regions and with soil moisture (*F*) in five regions, but the values of the correlation coefficients were much lower. In four regions, the first two axes were correlated with all the indicator values analysed, while in region 2 (Gubałówka) a significant correlation was noted with only one EIV.

Table 3. Length of the gradient of the first and second DCA axis in each region and Pearson correlation coefficients between the main gradient of variation in species composition and topographic factors and habitat conditions (EIV)

Region	1		2		3		4		5		6		7	
DCA axis	1	2	1	2	1	2	1	2	1	2	1	2	1	2
T	–0.01	0.00	–0.05	0.00	0.23	**0.48**	**0.24**	–0.08	–0.02	–0.18	**–0.58**	0.01	0.16	**–0.23**
F	0.03	–0.15	–0.14	0.19	**–0.67**	–0.21	**–0.28**	–0.01	**0.50**	**0.32**	**–0.40**	–0.17	**–0.57**	0.02
R	**0.35**	0.10	–0.18	–0.08	0.19	**0.40**	**0.72**	–0.07	**0.55**	0.03	**–0.84**	–0.06	**–0.22**	**0.62**
N	**0.34**	–0.14	**–0.44**	0.12	**–0.91**	0.25	**0.70**	–0.09	**0.51**	0.52	**–0.91**	–0.15	**–0.90**	0.14
Altitude	–0.08	–0.05	0.21	0.10	0.07	–0.20	–0.06	–0.16	**–0.29**	–0.10	**0.75**	0.26	**0.49**	**0.33**
Exposure	**–0.37**	0.11	0.23	–0.15	0.23	–0.02	0.01	–0.26	–0.16	**–0.39**	–0.08	–0.05	**0.27**	–0.11
Slope	–0.06	**0.35**	**0.36**	–0.01	**0.38**	0.13	–0.20	–0.01	–0.25	–0.02	0.15	0.22	0.00	0.04
Radiation	**–0.31**	0.12	0.07	–0.14	0.19	0.10	–0.15	–0.20	–0.09	**–0.45**	0.01	**0.28**	0.10	–0.04

Statistically significant coefficients at $p < 0.05$ in bold

There were 267 plant species recorded in the entire study area. The most species (Table 4) were recorded in regions 6 (Gorce) and 7 (Beskid Sądecki and Kotlina Sądecka), 172 and 171 species, respectively, and the fewest (only 113) in region 2 (Gubałówka). The average species number per relevé was highest in regions 3 (Spisz) and 7 (Beskid Sądecki and Kotlina Sądecka), 28 and 30, respectively and was significantly different from that in other regions. Beta diversity, i.e. differences between plots, was lowest (5.0) in region 2 (Gubałówka) and highest (8.1) in region 4 (Kotlina Orawsko-Nowotarska).

Table 4. Number of species in grassland communities in each region

Region	1	2	3	4	5	6	7
Number of all species (gamma)	143	113	150	169	148	172	171
Average number of species/plot	23.1a	22.6a	28.2b	20.7a	22.8a	24.4a	29.9b
Beta diversity	6.2	5.0	5.3	8.1	6.5	7.1	5.7

Significant differences ($P < 0.05$) between species number per plot in the region are indicated by different letters.

Species richness was associated with various factors, depending on the region (Table 5). The correlation of the number of species correlated with the altitude above sea level was positive (0.33) in region 2 (Gubałówka) and negative (–0.37) in region 6 (Gorce). An effect of slope was also noted for two regions, and an effect of radiation for one, while exposure did not affect the number of species in any region. Species number was correlated negatively with soil fertility (*N*) in three regions. Soil moisture (*F*) also had a significant correlation in three regions – a positive correlation in two and a negative correlation in one. Positive significant correlations of species number with EIV were noted for soil reaction (*R*) in two regions and for temperature (*T*) also in two regions.

Table 5. Pearson correlation coefficients between species number per plot and topographic and habitat factors (EIV)

Region	Altitude	Exposure	Slope	Radiation	*T*	*F*	*R*	*N*
1	–0.09	–0.05	**0.27**	–0.03	–0.12	–0.09	0.03	–0.04
2	**0.33**	0.04	0.10	–0.10	0.10	**–0.25**	–0.05	**–0.36**
3	0.06	–0.01	0.13	0.07	**0.30**	–0.24	0.03	**–0.51**
4	0.30	0.04	**0.40**	0.06	0.02	–0.27	0.06	–0.15
4	0.13	0.07	0.17	**0.37**	0.25	**–0.40**	0.02	–0.21
6	**–0.37**	–0.02	0.10	0.14	**0.37**	**0.31**	**0.36**	0.09
7	0.16	0.11	0.10	–0.09	–0.15	–0.11	**0.39**	**–0.24**

Statistically significant coefficients at $p < 0.05$ in bold

The type of land use in the 1960s did not affect the average species number per relevé. The species number per plot was higher in areas that were used as grassland in the 1980s, but this relationship was not significant. Only in region 1 (Rów Podtatrzański) species numbers were significantly higher in plots that were arable land in the 1980s compared to those that were used as grassland at that time.

4. Discussion

The main factor influencing the species composition of grassland vegetation was the region itself, which is the combined result of all habitat factors as well as the effect of past human impact and current management [Kalusova et al. 2009]. The altitude above sea level is the main topographic factor influencing habitat conditions in mountains [Marini et al. 2007, Halada et al. 2017, Korzeniak 2016]. As the altitude increases, the average air temperature decreases, the growing period becomes shorter, and precipitation totals increase [McCain and Grytnes 2010]. Altitude was shown to significantly influence species composition in the regions with the greatest differences in altitude (regions 5, 6 and 7). However, the number of species was shown to depend on altitude in only two regions. In region 8 the correlation was negative, due to the high maximum altitude and its large range. Slope was positively correlated with species number, but the correlation was significant in only two regions. Slope influences microclimate conditions and reduces nutrient accumulation [Pittarello et al. 2020], which results in differences in species composition [Janišova et al. 2010, Marini et al. 2007, Klimek et al. 2007]. Habitat determinants expressed as EIV were strongly correlated with species composition. The strongest correlation, significant for all regions, was noted in the case of fertility (*N*). Nutrient availability, which is closely linked to biomass, is one of the main factors determining the species composition and diversity of most plant communities [Janssens et al. 1997, Celeumans et al. 2013]. Soil acidity (*R*) and moisture content (*F*) were also correlated with the main gradient of changes in species composition in most of the regions. Temperature conditions (*T*) showed the least differentiating effect, most likely due to the small variation in this parameter in the study area.

In our study, past land use (arable land vs grassland) had a relatively minor effect on species composition, and only in certain regions. This factor was also not shown to affect species diversity. In the study area, the type of land use 60 and 40 years prior was taken into account, and thus use as grassland had already been ongoing for several decades. The time needed for typical grassland communities to be formed can vary widely depending on local determinants [Bruun et al. 2001, Cousins et al. 2002, Lunt and Spooner 2005]. Grassland and arable land in the Polish Carpathians have always formed a spatial mosaic, and there have always been species-rich grassland communities providing a potential source of diaspores in the vicinity of arable fields. Temporary ploughing of meadows was also practiced in the past. After the return to mowing, multi-species communities usually re-formed in a short time [Włodarczyk 1956]. Despite the minor role of land use legacy, variables associated with past land use may contribute to explaining the differences in the local pool of species [Bruun et al. 2001].

Also, biodiversity cannot be explained by a single factor but is the result of a unique combination of historical factors, local abiotic factors, migration limitation, neutral ('random') processes and management [Merunková et al. 2012]. In effect, the importance of individual factors is different in different areas. Factors significant on the local and regional scale [Zobel et al. 2000, Korzeniak 2016, Dembicz et al. 2020, Riibak et al.

2020] are usually different from the factors found to be significant in analyses of large areas [Bailey et al. 2017].

5. Conclusions

1. The main factors correlating with the diversity of grassland vary by region.
2. Factors that are positively correlated with the species richness of grassland in one region can be negatively correlated in another region.
3. The factors influencing species richness in regions may be different from those influencing the diversity of species composition.
4. Use of present grassland as arable land in the past (60 and 40 years ago) has little influence on the current biodiversity of grasslands.
5. A thorough comparison of environmental conditions and historical determinants should be made before extrapolating results and recommendations regarding management in different regions.

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