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BIODIVERSITY OF GRASSLANDS OF STOŁOWE MOUNTAINS NATIONAL PARK

Magdalena Szymura[1], Tomasz H. Szymura[2], Agnieszka Dradrach[1], Zygmunt Mikołajczak[1]

[1] Wrocław University of Environmental and Life Sciences
[2] Wrocław University in Wrocław

Abstract. Biodiversity of grasslands depend on several factors, like abiotic conditions, management history of vegetation and landscape structure. Region of Stołowe Mountains National Park is mainly forested, the grasslands cover only 8% of the area, that is about 500 ha. Meadows are distributed in four distinctive complexes: Darnków, Pasterka east, Pasterka west, and Łężyce. The grasslands form discrete patches in forest landscape. In spite of relatively high species richness, only a few grass species (mainly *Agrostis capillaris* and *Festuca rubra*) dominated in the vegetation of grasslands. The species richness was influenced mainly by beta diversity (both among relevés and complexes), whereas Snannon-Wiener index by alpha diversity. Basic factors influencing beta diversity seems to be soil pH and affinity of particular relevé to grassland complex. Differences between old and young grasslands in species richness and Shannon-Wiener index were statistically not significant. On the area of grasslands of Stołowe Mountains National Park numerous protected and rare plant species occurred, e.g.: *Traunsteinera globosa*, *Colchicum autumnale*, *Platanthera bifolia*, *Listera ovata*, *Gladiolus imbricatus*, *Carlina acaulis*, *Trollius europaeus*, *Lilium bulbiferum*.

Key words: old meadows, dissimilarity analysis, α, β, γ diversity, species richness, Shannon-Wiener index, Ellenberg's indicator values.

INTRODUCTION

Landscape is defined as a heterogeneous land area composed of a cluster of interacting ecosystems [Forman 1995]. In order to describe the structures and relationships occurring at the landscape level a model of patches and corridors was created. In the model the mosaic of ecosystems is described as the arrangement of the

Corresponding author: dr Magdalena Szymura, Department of Agroecosystems and Green Areas Management of Wrocław University of Environmental and Life Sciences, pl. Grunwaldzki 24A, 53-363 Wrocław, e-mail: magdalena.szymura@up.wroc.pl

"friendly" habitats (patches and corridors), placed on a background of matrix "hostile" to particular plants and animals taxa [Forman and Godron 1986]. Patches in this model are referred as habitat islands, comparable to oceanic islands, where main factors influencing number of species are the size of island and its distance to continent. Among main processes shaping biodiversity are species immigration and local extinction [MacArthur and Wilson 1967]. This similarity can be used in order to asses biodiversity of vegetation patches, placed in contrast surrounding [Helm *et al.* 2006, Vondrák and Prach 2006].

In mosaic landscape age of patch is known as important factor to biodiversity [Waesch and Becker 2009]. In general, the absence or presence of plant species can be a result of limitation of propagule dispersal and recruitment limitation [Stein *et al.* 2008]. Numerous studies have described the importance of patch age for species composition in forest vegetation. There are designed group of species typical to old forests [Hermy and Verheyen 2007]. In contrast, effect of patch age in grasslands is poorly investigated [Waesch and Becker 2009]. The results of studies in forests cannot be directly applied to meadows, because of differences between these habitats in many attributes, e.g. wind influence, management intensity, and hence probably in importance of wind and human dispersal [Luftensteiner 1982].

The decay of grassland species, observed in last years is mainly caused by degradation of meadows habitats [Kącki and Szymura 2010]. Reason of this process is intensification of management regime, through drainage of moist areas, excessive fertilization, over utilization and overgrazing or transformation of meadows and pastures into arable lands. Also the process of succession of shrubs and trees on abandoned grasslands cause loss of grasslands biodiversity [Bischoff 2002]. There are numerous papers describing influence of field management intensity, mainly fertilizing [e.g. Garcia 1992, Janssens *et al.* 1998, Marini *et al.* 2007], management regime as grazing or cutting [Gough *et al.* 2000, Maurer *et al.* 2006], or local environmental factors [Wright *et al.* 2003] on grasslands biodiversity. Till now only few studies analysed together environmental factors, landscape structure and history of management together [Klimek *et al.* 2007]. Furthermore, only limited number of studies tried to examine different components of the diversity, in order to better understanding the processes shaped species composition as well as to elaborate efficient methods of nature conservation [Gering *et al.* 2003, Klimek *et al.* 2008].

In this paper we show the results of our examination of grasslands of Stołowe Mountains National Park. They create a system of meadows patches placed in matrix of forest and differ with respect to their history of management. The grasslands, due to biodiversity which they support, have an important role in system of nature protection of Sudety Mountain Massif (S-W Poland, border region between Poland and Czech Republic).

The detailed aims of our study were to partition the overall diversity of studied grasslands into alpha and beta level, and to determine which factors: a) environmental conditions, b) local species poll of isolated patches, or c) origin and history of management of grassland had significant influence on biodiversity of grassland on the Stołowe Mountains National Park.

MATERIAL AND METHODS

The Stołowe Mountains National Park was created in 1993, it covers an area of 63 square kilometres with the culminations of Szczeliniec Wielki (919 m a.s.l.) and Skalniak (915 m). Stołowe Mountains are situated in the middle of Sudety Masiff, on the Polish-Czech border. Geological settings of Stolowe Mountains represent sandstones and marls, and predominant types of soils are brown soils and leached brown soils. The average temperature of year is 6°C, with maximum in July (average 15.4°C), and minimum in January (average − 3.2°C). The vegetation period lasts no longer, than 27 weeks. Annual sum of precipitation in valleys is 800-1000 mm, and on upper parts of mountains above 1100 mm. Dominant direction of winds is south-west.

The area of Stołowe Moutains National Park is mainly covered by forests. Grasslands covered only 8% of the area, that is about 500 ha. The meadows are placed in four distinctive complexes: K1 – Darnków (area approximately 80 ha), K2 – Pasterka east (140 ha), K3 – Pasterka west (160 ha), and K4 – Łężyce (100 ha). The complexes are separated by forests and urbanised areas. Studied grasslands are relatively similar and or uniform according to altitude (600-750 m. a.s.l) and slope inclination. Before II World War the majority of grasslands were managed as arable lands, and today's meadows and pastures are of post-agricultural origin. However, due to relatively long period of farming by mowing and pasturing (about 15-20 years), as well as presence of patches, managed permanently as hay-pasture grasslands (old meadows), these grasslands have a relatively high biodiversity.

The vegetation was recorded using classical Braun-Blanquet [1964] method. 115 phytosociological relevés, each sized 25 m^2, were recorded in the first half of July, before the first mowing of grassland. The location of each relevés was marked using a GPS receiver. The nomenclature of plant names was given according to Mirek *et al.* [2002].

A basic overview of the compositional gradient of the species data was obtained by correspondence analysis (CA), using Canoco software [Ter Braak and Smilauer 1997]. The average Ellenberg's indicator values (EIV), were used as a help during the interpretation of the ordination diagrams [Persson 1981, Ellenberg *et al.* 1992]. The EIVs were calculated using presence/absence data. The plant species diversity was analyzed using additive partitioning procedure following Crist *et al.* [2003]. It assumes that diversity at relevé level (α – diversity) and diversity at level of meadows complex (β1) and between complex (β2) add up to whole diversity (γ), thus β diversity was measured in the same dimensions as α and γ [Lande 1996]. In order to test whether there is significant difference between groups of plots in their species composition analysis of similarities (ANOSIM) was used [Clarke 1993]. For this two calculation package "vegan" in R platform was used [Oksanen *et al.* 2008]. The dissimilarity matrix was constructed using Bray-Curtis indices.

In order to study the effect of management history on species composition and richness, information derived from historical Messtischblatt maps [Krüger and Schnadt 2000] current for year 1919 was used. The Messtischblatt maps were calibrated and registered in Polish State Coordinate System 1992, using control points method [Rumsey and Williams 2002]. Calculated mean error of transformation (RMS) was 15 m. Around all phytosociological relevés a buffer with diameter 15 meters was established. Than those relevés which without a doubt was placed in grassland patches mapped in 1919 year (i.e. whole area of the buffer was placed in patch marked as grassland) were selected. For each relevés classified as old grassland, (11 relevés) three nearest relevés classified without a doubt as young grassland (24 relevés) was founded. Whether the two data sets differ in species richness, S-W diversity indices and overall species composition was checked. For species richness and S-W indices U Man – Whitney test [Legendre and Legendre 1998] was used, while for species composition the ANOSIM method [Clarke 1993].

RESULTS

On the studied area 139 species of vascular plants were found. Grasslands were mainly formed by two grass species: common bent (*Agrostis capillaris* L.) and red fescue (*Festuca rubra agg.* L.). Numerous relevés were fragmented with more shallow soil, where the dominant species were: creeping soft grass (*Holcus mollis* L.), sweet vernal grass (*Anthoxanthum odoratum* L.), as well as wavy hair-grass (*Deschampsia flexuosa* (L.) Trin.) (Table 1). Small patches, with characteristic physiognomy occupied mat grass (*Nardus stricta* L.). In more fertile sites, with higher soil moisture, vegetation with domination of kentucky bluegrass (*Poa pratensis agg.* L.), meadow foxtail (*Alopecurus pratensis* L.), and tufted hairgrass (*Deschampsia caespitosa* (L.) P. Beauv.) was developed. From dicotyledonous species most frequently occured: *Hypericum maculatum* Crantz, *Rumex acetosa* L., *Veronica chamaedrys* L., *Ranunculus acris* L., and *Campanula patula* L. With lower frequency, but in higher ground cover on moist habitats predominantly occurred: common cottongrass (*Eriophorum angustifolium* Honck.) and *Juncus filiformis* L., and on patches, not mowed at all, maple (*Acer platanoides* L.).

Diversity alpha, expressed in species richness in particular relevé, was relatively low, on average 20 species per relevé (Fig. 1). The total biodiversity (gamma) was mainly determined by beta diversity, which is diversity among relevés within the complex (β1, approx. 70 species) and among different complexes (β2, approx. 50 species). To the contrary Shannon-Wiener diversity index was mainly determined by alpha diversity (Fig. 2).

When numbers of species in particular relevés were presented in the map, we got visible patterns, showing grasslands in complex K1 (Darnków) were the most rich in species, while the grasslands of large complex (K2 and K3) in Pasterka had the lowest number of species per relevé (Fig. 3).

More detailed analysis of factors, shaping beta diversity was conducted using canonical analysis (CA). On the right site of diagram, along the first axis, the species related to acidic soils were grouped. There were mainly patches of swards with *Nardus stricta* (*Nardetalia* order), with presence of common heather (*Calluna vulgaris* (L.) Hull), blueberry (*Vaccinium myrtillus* L.) and cowberry (*V. vitis-idaea* L.), as well as *Hieracium pilosella* L., *Potentilla erecta* (L.) Raeusch. and *Molinia caerulea* (L.) Moench) (Fig. 4). Axis 1 was connected mainly with soil reaction (correlation with EIV r = -0,8362), while axis 2 was connected with light and fertility indices, however the gradient of these two factors was very short. For explanation of relevés ordination along to axis 2, spatial distribution of the relevés (that is affinity to different complexes) was meaningful (Fig. 5). In upper part of diagram the species rich grasslands were grouped, which were placed in complexes K1 (Darnków), and K4 (Łężyce), whereas in the lower part of diagram grasslands of Pasterka (K2 and K3) with poor plant species composition were found.

Table 1. Dominant species with % frequency and mean non-zero cover
Tabela 1. Gatunki dominujące z % frekwencją z średnią pokrycia (nie zero)

No Lp.	Species Gatunek	% frequency Frekwencja	Mean non-zero cover Średnia (nie zero)	No Lp.	Species Gatunek	% frequency Frekwencja	Mean non-zero cover Srednia (nie zero)
1	*Festuca rubra*	93.9	10.15	27	*Leucanthemum vulgare*	27.0	1
2	*Agrostis capillaris*	91.3	13.42	28	*Potentilla erecta*	27.0	1.26
3	*Hypericum maculatum*	72.2	3.84	29	*Trisetum flavescens*	24.3	1.43
4	*Poa pratensis*	65.2	4.09	30	*Centaurea jacea*	21.7	1.48
5	*Holcus mollis*	63.5	6.7	31	*Nardus stricta*	21.7	15.24
6	*Rumex acetosa*	63.5	1.66	32	*Lathyrus pratensis*	19.1	1.18
7	*Veronica chamaedrys*	55.7	1.75	33	*Lotus corniculatus*	19.1	1.91
8	*Deschampsia caespitosa*	54.8	10.96	34	*Taraxacum officinale*	19.1	1.36
9	*Ranunculus acris*	53.0	1.79	35	*Knautia arvensis*	17.4	1
10	*Anthoxanthum odoratum*	51.3	2.22	36	*Trifolium pratense*	17.4	2.2
11	*Campanula patula*	50.4	1.21	37	*Cirisium helenioides*	15.7	1
12	*Alopecurus pratensis*	47.0	7.15	38	*Leontodon autumnalis*	15.7	1.44
13	*Deschampsia flexuosa*	45.2	5.63	39	*Pimpinella saxifraga*	14.8	1
14	*Galium mollugo*	44.3	1.94	40	*Arrhenatherum elatius*	13.9	4.5
15	*Alchemilla monticola*	42.6	1.65	41	*Cerastium holosteoides*	13.9	1.5
16	*Dactylis glomerata*	42.6	2.96	42	*Festuca pratensis*	13.9	4
17	*Campanula rotundifolia*	38.3	1.18	43	*Leontodon hispidus*	13.9	1.25
18	*Lychnis flos-cuculi*	38.3	1.09	44	*Veronica officinalis*	13.9	1
19	*Stellaria graminea*	38.3	1.18	45	*Rhinanthus minor*	13.0	1.67
20	*Achillea millefolium*	35.7	1.1	46	*Vicia angustifolia*	13.0	1.27
21	*Phleum pratense*	33.0	1.42	47	*Holcus lanatus*	12.2	2.71
22	*Hieracium murorum*	32.2	2.73	48	*Angelica sylvestris*	11.3	1.31
23	*Luzula multiflora*	30.4	1.23	49	*Plantago lanceolata*	11.3	1
24	*Cirsium rivulare*	29.6	1.24	50	*Ranunculus repens*	10.4	1
25	*Vicia cracca*	29.6	2.18	51	*Rumex crispus*	10.4	1.33
26	*Trifolium repens*	27.8	2.5	52	*Veratrum lobelianum*	10.4	1
123	*Eriophorum angistifolium*	0.9	37				
127	*Juncus filiformis*	0.9	37				
104	*Acer platanoides*	1.7	31.5				

The species with frequency above 10% were shown. Additionally species with high cover were shown.
Przedstawiono gatunki, których frekwencja wystąpień wynosiła powyżej 10%, a dodatkowo, gatunki charakteryzujące się dużym pokryciem

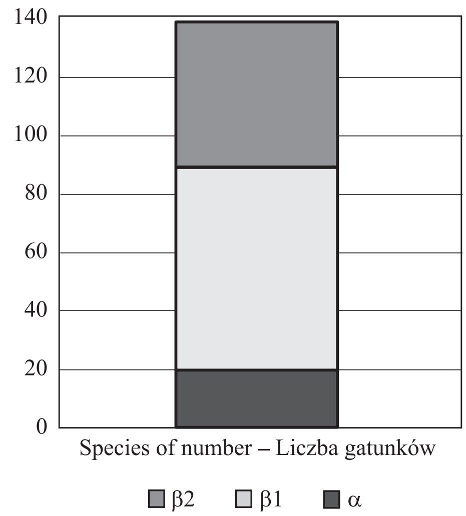

Fig. 1. Species richness influencing α, β1 and β2 diversity
Rys. 1. Liczba gatunków wpływająca na różnorodność α, β1 i β2

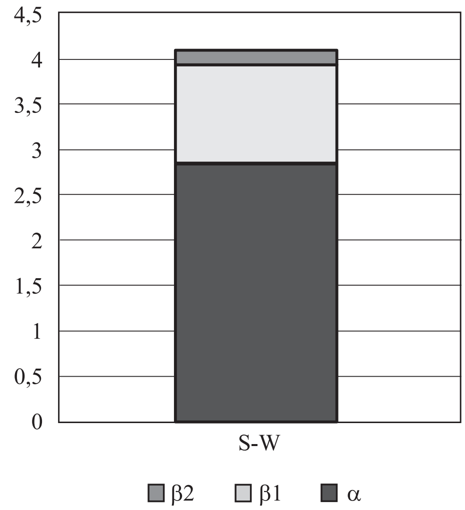

Fig. 2. Shannon-Wienner index influencing α, β1 and β2 diversity
Rys. 2. Wskaźnik Shannona-Wiennera wpływający na różnorodność α, β1 i β2

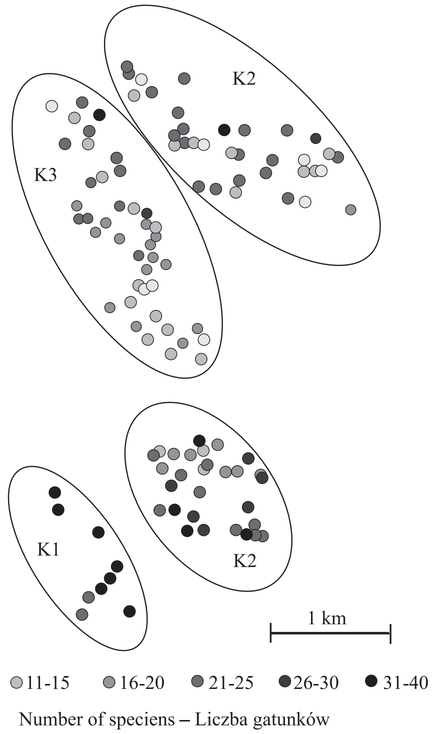

Fig. 3. Diagram of location relevés within complexes with six classes of species number
Rys. 3. Diagram lokalizacji zdjęć fitosocjologicznych w obrębie kompleksów z podziałem na sześć klas w zależności od liczby gatunków

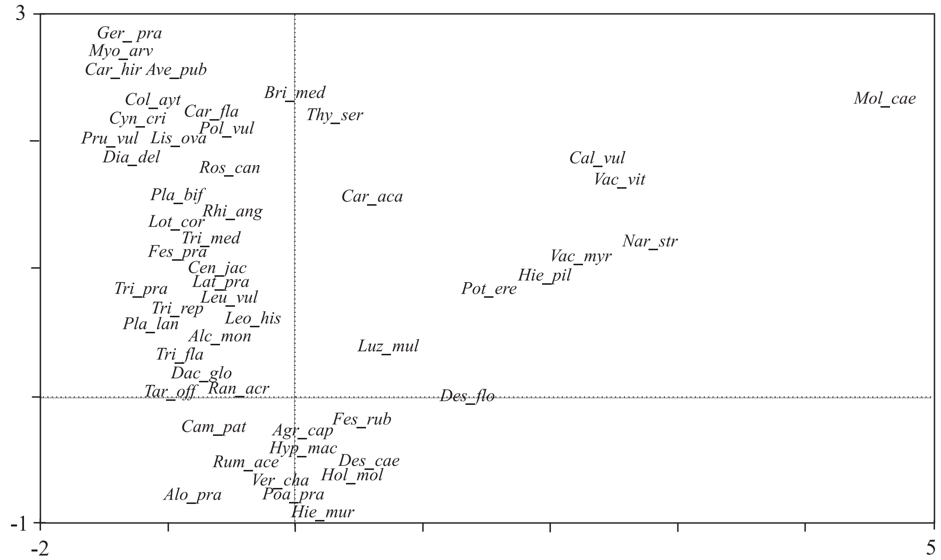

Fig. 4. Canonical analysis (CA) of species composition of analysed meadows
Rys. 4. Analiza kanoniczna (CA) składu gatunkowego obserwowanych łak

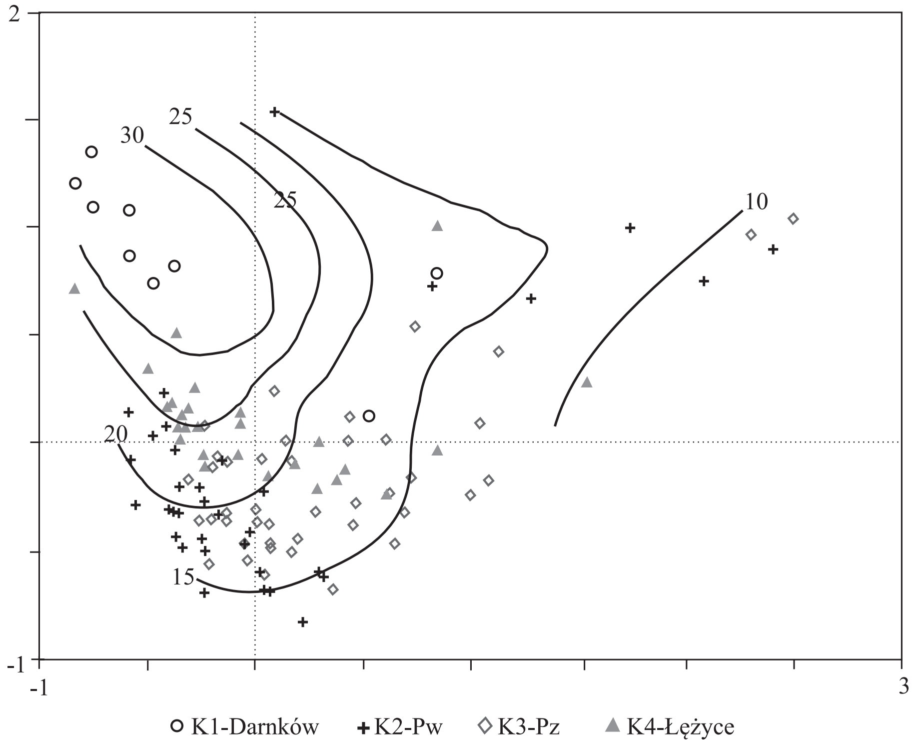

Fig. 5. Canonical analysis (CA) of affiliation of particular plots and species richness of analysed meadows

Rys. 5. Analiza kanoniczna (CA) przynależności poszczególnych poletek badawczych i różnorodności gatunkowej obserwowanych łąk

The analysis of vegetation dissimilarity showed significantly higher differentiation among the particular grassland complexes, than the differentiation within the complexes (Fig. 6). Particularly low diversity of vegetation occurred on complexes of K4 (Łężyce), and K1 (Darnków).

In analysis of historical land uses, from 115 relevés, 19 were excluded since we were not able to undoubtedly define the past land use. From the remaining ones, the most of relevés (85) were found on young grasslands, which on map from 1919 were marked as arable lands, or, rarely as forests or as brushwood. Only 11 relevés occurred in such areas, which on the historical map were grasslands. On old grasslands a slightly higher average number of species was found (22,5), in comparison with young grasslands (20,5), as well as slightly higher value of Shannon-Wiener index (2,98 and 2,95, respectively). However U Mann-Whitney test did not show that the differences were statistically significant (Z = -85, p = 0.39). The analysis of dissimilarity of vegetation using Bray-Curtis indices between young and old grasslands showed the lack of significant differences, too (Fig. 7).

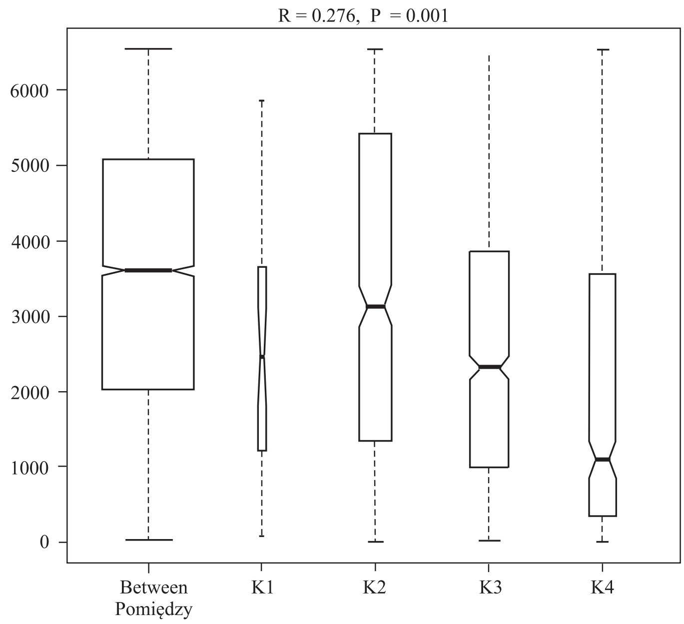

Fig. 6. Dissimilarity ranks between and within classes: K1 – Darnków, K2 – Pw., K3 – Pz., K4 – Łężyce

Rys. 6. Miara niepodobieństwa w obrębie i pomiędzy klasami: K1 – Darnków, K2 – Pw., K3 – Pz., K4 – Łężyce

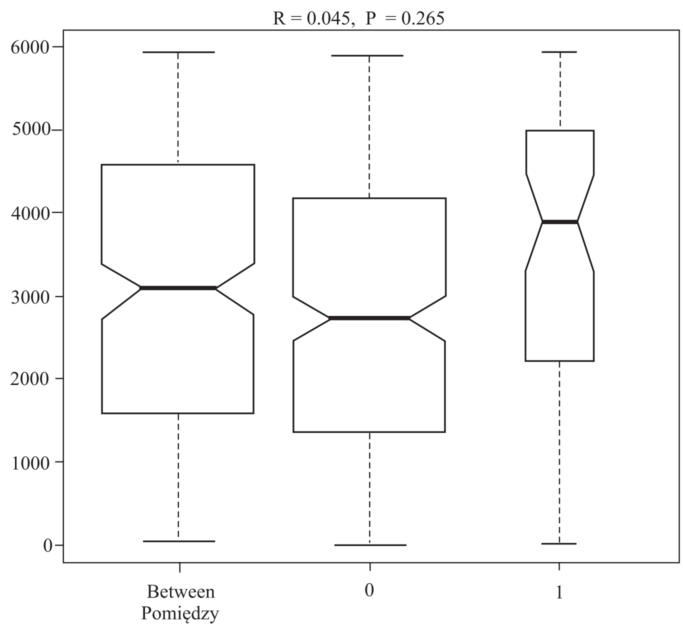

Fig. 7. Dissimilarity ranks between and within classes: 0 – "new" meadows, 1 – "old" meadows

Rys. 7. Miara niepodobieństwa w obrębie i pomiędzy klasami: 0 – „nowe" łąki, 1 – „stare" łąki

On the area of grasslands of Stołowe Mountains National Park the presence of numerous protected and rare species were recorded. Some of them were considered as interesting ones, e.g.: *Traunsteinera globosa* (L.) Rchb., *Colchicum autumnale* L., *Platanthera bifolia* (L.) Rich., *Dactylorhiza majalis* s.l. (Rchb.) P.F. Hunt et Summerh., *Listera ovata* (L.) R. Br., *Gladiolus imbricatus* L., *Carlina acaulis* L., *Veratrum lobelianum* Bernh., *Trollius europaeus* L. s. str., *Lilium bulbiferum* L., *Phyteuma orbiculare* L.

DISCUSSION

Species richness and composition of vascular plants in grasslands are mainly determined by local factors [Wright *et al.* 2003], including strong effects of management [Marini *et al.* 2007]. However the results of recent studies underline also the effect of landscape scale and regional processes on grasslands species richness [Michalcová *et al.* 2014].

In grasslands of Stołowe Mountains National Park we have found low level of alpha diversity expressed in terms of species richness (average 20 species per *relevé*). The main component of species richness was beta diversity: β1 (approx. 70 species), connected with differentiation of relevés in one complex, as well as β2 (approx. 50 species), showing the diversity among grasslands complexes. Therefore it could be stated, that species richness in particular relevés was strongly determined by local species pool of given grassland complex. To contrast, the Shannon-Wiener index of diversity was highest at the alpha level, while the β diversity was lower. It is the result of specific species composition of meadows in this area [Nadolna and Żyszkowska 2011]. Only a few species (*Festuca rubra*, *Agrostis capillaris*, *Nardus stricta*, *Deschampsia caespitosa*, *Alopecurus pratensis*, *Deschampsia flexuosa*) dominated the vegetation, occurring with high ground cover values, and these species existed constantly in all the grassland complexes. Therefore the quantitative relationships between dominant species differed within particular relevés (resulting high alpha diversity), but there were still limited number of dominant species in studied grasslands, resulting in low beta diversity.

The biodiversity of the most species-rich grasslands on the world (White Carpathian Mountains grasslands) is caused mainly by high level of alpha diversity, whereas beta diversity is low. This pattern could be caused by various factors, e.g.: large total area of grasslands, long history of management, low geological diversity, and high land-cover diversity, which supports mixing of species from different vegetation types [Michalcová *et al.* 2014]. The observed by us grasslands reveal different pattern (low alpha, high beta diversity), which we attributed to short history of management, dispersal limitation, and differences in soil characteristics.

Ellenbers's indicator values (EIV's) are commonly used to describe the existing environmental conditions on grasslands on the basis of species composition [Diekmann 2003]. However, comparison of measured values with bioindicators sometimes shows low correlations between results of bioindicators and real values [Szymura *et al.* 2014]. The main environmental factor influencing the beta diversity of grasslands of Stołowe Mountains National Park seems to be soil reaction. The pH gradient is considered as main driver of vascular plants species richness in Central Europe, because relative low species number adapted to low pH [Chytrý *et al.* 2003, Ewald 2003]. In studied meadows the bioindication suggest, that soils varied from acidic to neutral (average values of EIV 3.0 up to 6.4, detailed results not shown), thus the local variation of soil substrate was strong enough to shape the plant composition. Other factors, connected with second axis of ordination had very short gradient, especially the light values, and can hardly be used to explain the results of CA analysis. Particular in the case of EIV for light, it seems highly impossible, that open meadows really differ in light conditions. To the contrary, it seems that affinity to given complex was crucial to the ordination. Therefore we argue that the differences of local species pool, not related to any environmental gradient, are main determinant of beta diversity, according to second ordination axis.

Higher numbers of vascular plant species in old than in young grasslands were found in subalpine pastures in Norway [Austrheim *et al.* 1999], and also in low mountain region, in Thuringian Forest in Germany [Waesch and Becker 2009]. On the other hand the old meadows may not be species-rich if they have been intensively managed [Gustavsson *et al.* 2007]. In our opinion the lack of differences between old and young meadows in Stołowe Mountains National Park is a result of long period of the same management regime and the mosaic character of landscape causing homogenisation of species composition within meadow complex.

CONCLUSIONS

Grasslands in Stołowe Mountains National Park form patches in forest landscape. Relatively uniform, post-war management resulted only in few grass species dominating the meadows communities. Species richness in these grasslands was influenced mainly by beta diversity, whereas Snannon-Wiener index by alpha diversity. Important factor influencing beta diversity of the vegetation was affinity of relevés to particular grassland complex. From the environmental conditions the soil pH seems to determine the beta diversity. Differences between old and young grasslands in species richness and Shannon-Wiener index were statistically not significant. The results emphasize the role of local species pool as influencing the overall grasslands diversity.

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RÓŻNORODNOŚĆ BIOLOGICZNA ŁĄK PARKU NARODOWEGO GÓR STOŁOWYCH

Streszczenie. Bioróżnorodność łąk zależy od szeregu czynników, jak: warunki abiotyczne, historia użytkowania roślinności i struktura krajobrazu. Obszar Parku Narodowego Gór Stołowych porastają głównie lasy; zbiorowiska trawiaste zajmują zaledwie 8% powierzchni, czyli około 500 ha. Obszary łąkowe są rozmieszczone w czterech odrębnych kompleksach: Darnków, Pasterka wschodnia, Pasterka zachodnia i Łężyce. Łąki tworzą odrębne płaty na tle krajobrazu zdominowanego przez lasy. Pomimo stosunkowo wysokiej różnorodności biologicznej roślinność łąk jest zdominowana przez zaledwie kilka gatunków traw (głównie *Agrostis capillaris* i *Festuca rubra*). Różnorodność gatunkowa jest kształtowana głównie przez różnorodność beta (zarówno pomiędzy zdjęciami fitosocjologicznymi, jak i pomiędzy kompleksami), podczas gdy wskaźnik Shannona-Wiennera przez różnorodność alfa. Głównymi czynnikami wpływającymi na różnorodność beta były odczyn podłoża i przynależność poletka badawczego do konkretnego kompleksu łąk. Różnice pomiędzy starymi a nowymi łąkami w odniesieniu do różnorodności biologicznej i wskaźnika Shannona-Wiennera nie były istotne statystycznie. Na obszarze łąk Parku Narodowego Gór Stołowych zostały odnotowane liczne gatunki objęte ochroną prawną i uznane za cenne, np.: *Traunsteinera globosa*, *Colchicum autumnale*, *Platanthera bifolia*, *Listera ovata*, *Gladiolus imbricatus*, *Carlina acaulis*, *Trollius europaeus*, *Lilium bulbiferum*.

Słowa kluczowe: analiza niepodobieństwa, liczby wskaźnikowe Ellenberga, różnorodność α, β, γ, stare łąki, wskaźnik Shannona-Wienera

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