POLISH JOURNAL OF NATURAL SCIENCES
Abbrev.: Pol. J. Natur. Sc., Vol 24(1) 43-59, Y. 2009

DOI 10.2478/v10020-009-0005-y

SPECIES DIVERSITY IN GRASSLAND COMMUNITIES UNDER DIFFERENT HABITAT CONDITIONS

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Key words: grasslands, plant communities, species diversity, ecological indicator values.

Abstract

Two hundred species of vascular plants were identified in grasslands on the Popielno Peninsula, in the part used for agricultural purposes. Species diversity in plant communities, measured by the Shannon-Wiener index, was found to depend on soil type, land use type and phytosociological affiliation. Greater species diversity was observed in communities that developed on mineral soils, are used as pastures, and belong to the class *Molinio-Arrhenetheretea*. The biodiversity of grassland communities on the Popielno Peninsula is affected by habitat conditions. The relationship between vegetation biodiversity and habitat quality is difficult to grasp due to its multidimensional character. The methods of multivariate statistics may prove useful in this respect.

RÓŻNORODNOŚĆ GATUNKOWA ZBIOROWISK ŁĄKOWO-PASTWISKOWYCH W RÓŻNYCH WARUNKACH SIEDLISKOWYCH

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Słowa kluczowe: użytki zielone, zbiorowiska roślinne, różnorodność gatunkowa, ekologiczne liczby wskaźnikowe.

Abstrakt

Na łąkach i pastwiskach rolniczej części Półwyspu Popielniańskiego zidentyfikowano 200 gatunków roślin naczyniowych. Różnorodność gatunkową zbiorowisk roślinnych, mierzoną wskaźnikiem Shannona-Wienera, różnicował rodzaj gleby, sposób użytkowania oraz przynależność do klasy fitosocjologicznej. Większą różnorodność osiągały ugrupowania formujące się na glebach mineralnych, użytkowanie pastwiskowo oraz przynależące do klasy *Molinio-Arrhenetheretea*. Bioróżnorodność zbiorowisk użytków zielonych Półwyspu Popielniańskie-

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go wykazywała związek z warunkami siedliska. Pełne uchwycenie tej zależności jest trudne z uwagi na jej wielowymiarowość. Pomocne w tym względzie mogą być metody statystyki wielozmiennej.

Introduction

The Convention on Biological Diversity was adopted in Rio de Janeiro in 1992. Since that time the issues dealt with under the Convention have received wide recognition (RICOTTA 2003, WAMELINK et al. 2003). Apart from research aimed at exploring and documenting various aspects of biodiversity (e.g. *World Atlas of Biodiversity, World Biodiversity Database*, *Różnorodność biologiczna...* 2003, WILSON 1990), studies are also undertaken to determine the effect of biodiversity on ecosystem functioning (BALVANERA et al. 2006, DUFFY et al. 2007, HOOPER et al. 2005). From the standpoint of energy and production, a key role is played by plant communities which constitute the basis of all ecological systems (HOOPER et al. 2005). Attempts are continuously made to confirm a positive correlation between plant community diversity, productivity and response to environmental stress factors (SHLAPFER, SCHMID 1999, HOOPER et al. 2005, BULLOCK et al. 2001, DUFFY et al. 2007).

Numerous authors point to the direct and strong link between biodiversity and ecological conditions (SPANOS, FEEST 2007). The global-scale geographic patterns of species diversity and richness have been already established (MAY 1993, STEVENS 1989, 1992), whereas the problem of biodiversity response to changing microhabitat conditions has not been fully elucidated, particularly when biodiversity is considered from a functional perspective, taking into account not only the number of taxa in the investigated communities, but also their quantitative proportions (RICOTTA 2003).

The objective of this study was to analyze plant community biodiversity in permanent grasslands on the Popielno Peninsula, with the use of biological indices, and to determine the relationship between biodiversity and habitat conditions. The study is a continuation of the earlier work of JASTRZĘBSKA et al. (2007) in which the investigated habitats were assessed by a phytoindication method.

Materials and Methods

A total of 194 phytosociological relevés were carried out by the Braun-Blanquet technique in permanent grasslands in the northern part of the Popielno Peninsula. The environmental and geographic characteristics of the research area can be found in a paper by JASTRZĘBSKA et al. (2007). The phytosociological relevés provided a basis for computing the values of biological indices. For each species in a single relevé, the degrees of cover/abundance were replaced by values determined by the midpoints of the cover ranges (%), corresponding to particular degrees: 5–87.5%, 4–62.5, 3–37.5, 2–17.5, 1–5.0, + –0.1%. The average cover of a given species was a measure of its abundance in a plant community, while total cover was a measure of abundance of the entire community. The Shannon-Wiener diversity index, the Shannon-Wiener evenness index (SHANNON 1948, WIENER 1948; see also WEINER 2003) and the Simpson's domination index (SIMPSON 1949) were computed for all communities represented by phytosociological relevés.

The biological indices were calculated as follows:
– the Shannon-Wiener diversity index (H'): $H' = -\sum (p_i \cdot \ln p_i)$,
– the Shannon-Wiener evenness index (J'): $J' = H' \cdot (\ln S)^{-1}$,
– the Simpson's domination index (λ): $\lambda = \sum p_i^2$,
where:
p_i – the proportion of individuals of the *i*-th species to the total number of individuals in the community,
S – species richness (the number of species in the community).

The values of indices determined for particular relevés were tabulated, summarized and generalized. They were independently grouped four times, according to the criteria given in Table 1. Some relevés were disregarded while grouping since they could not be classified based on the adopted assumptions. Mean, range of variation, coefficient of variation, median, mode and mode count were calculated for the entire research area and for particular groups, in accordance with the established criteria. Within each criterion, mean values for groups were compared by the t-test for independent samples. Coefficients of simple correlation were used to present relationships between the indices of diversity, evenness and domination and the synthetic indices of habitat conditions (*L* – light, *T* – temperature, *W* – soil moisture content, *Tr* – trophic state of soil/waters, *R* – soil reaction, *D* – soil particle size distribution, *H* – soil organic matter content). The latter were computed referring to the ecological

Table 1

Criteria for the division of the experimental material into groups

Criteria	Group	Number of relevés in a group
Location	Popielno	178
	Wierzba	16
Soil type	organic	80
	mineral	114
Land use type	pasture	129
	meadow	51
Plant community (phytosociological class)	*Molinio-Arrhenetheretea* (Mol-Arr)	157
	Phragmitetea (Phragm)	37

indicator values (Zarzycki et al. 2002) and were presented in the earlier work of Jastrzębska et al. (2007). Based on the Shannon-Wiener index and the synthetic indices of habitat conditions, phytosociological relevés representing particular phytocenoses were grouped into clusters by the Ward method (Filipiak, Wilkos 1998).

Results

A total of 200 species of vascular plants were identified in the analyzed area, including 196 in the grasslands of Popielno and 80 in the grasslands of Wierzba, 124 on organic soils and 147 on mineral soils, 179 in pastures and 95 in meadows, 187 in communities of the class *Molinio-Arrhenetheretea* and 92 in communities of the class *Phragmitetea*. Significant differences in the number of taxa in groups result primarily from considerable asymmetries in the phytosociological material (the majority of relevés were carried out within communities of the class *Molinio-Arrhenetheretea* which developed in pastures in Popielno – Figure 1),

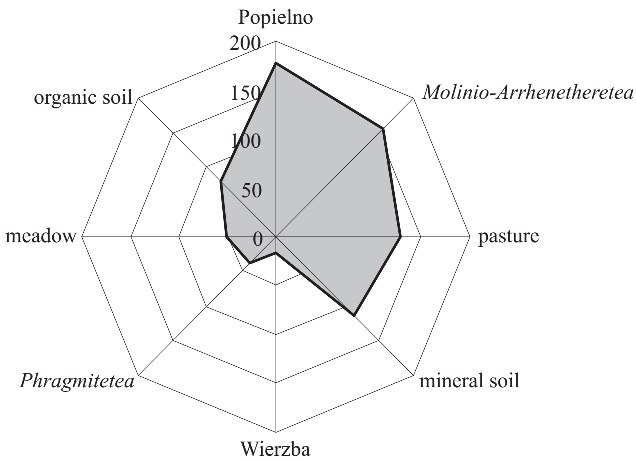

Fig. 1. Distribution of relevés in groups

which in turn are due to the study area characteristics. It is a well-known fact that – within certain limits – an increase in land area (i.e. a greater number of relevés) is followed by an increase in the number of accessory species. For the above reasons, the analysis involved a comparison of information on the existing plant communities which developed under specific conditions. As a result, variation in the number of species actually detected within phytocenoses was narrowed down to a range of 2–31 (on average 16.4 species, coefficient of variation – 32%; Table 2). Species richness is the simplest indicator of diversity, however it gives equal weight to abundant species and to taxa represented by single individuals

Table 2

Biological indices determined for plant communities in the investigated area – statistical characteristics

Basic descriptive statistics	Total cover	Species richness	Index		
			H'	*J'*	*λ*
Mean	142.2	16.4	1.566	0.561	0.317
Median	136.9	16	1.685	0.592	0.252
Mode	multimodal	multimodal	0.259	0.125	0.886
Mode count	4	19	3	3	3
Minimum	73.3	2	0.009	0.013	0.102
Maximum	243.7	31	2.587	0.850	0.998
Coefficient of variation, %	24.4	32.0	33.7	28.9	60.0

in the phytocenosis. The Shannon-Wiener index (also known as the Shannon index) is commonly used in studies on functional biodiversity in communities of living organisms. The value of this index increases along with a rise in the number of species in the community. Maximum evenness also maximizes the Shannon-Wiener index, therefore the index of evenness and the index of domination are usually calculated simultaneously. In general, the index of domination constitutes the reverse of the index of biodiversity. Basic statistical measures for the entire study area (i.e. for all analyzed relevés) can be found in Table 2. They are documentary in character. More interesting material for analysis is contained in Tables 3–7, where the characteristics of plant communities are compared according to the established criteria. It should be noted that grassland phytocenoses located in Popielno and Wierzba do not differ in terms of the investigated features. However, a different situation was observed with respect to the three criteria adopted in the study, i.e. soil type, land use type

Table 3

Statistical characteristics of total cover in plant communities

Specification		Mean	Range of variation	Coefficient of variation, %
Location	– Popielno	142.3^{a}	73.3–293.1	24.6
	– Wierzba	141.6^{a}	93.1–186.0	22.2
Soil type	– organic	134.7^{a}	73.3–198.5	21.0
	– mineral	147.5^{b}	86.2–243.7	31.0
Land use type	– pasture	147.8^{A}	73.3–243.7	25.4
	– meadow	131.0^{B}	88.1–198.5	19.8
Plant community	– Mol-Arr	145.8^{A}	86.2–243.7	23.6
	– Phragm	127.2^{B}	73.3–198.5	25.6

AB, ab – significance of differences between means: values in particular categories with identical superscript letters are not significantly different at p = 0.05 (small letters) and at p = 0.01 (capital letters)

Table 4

Statistical characteristics of species richness in plant communities

Specification		Mean	Range of variation	Coefficient of variation, %
Location	– Popielno	16.4^{a}	2–31	32.3
	– Wierzba	16.1^{a}	8–25	28.8
Soil type	– organic	16.6^{a}	2–30	32.9
	– mineral	16.3^{a}	2–31	31.4
Land use type	– pasture	17.0^{a}	2–31	32.1
	– meadow	15.9^{a}	7–25	29.5
Plant community	– Mol-Arr	16.9^{A}	2–31	29.7
	– Phragm	14.1^{B}	2–29	39.6

* Explanatory notes as in Table 3

Table 5

Statistical characteristics of the diversity index (H') in plant communities

Specification		Mean	Range of variation	Coefficient of variation, %
Location	– Popielno	1.57^{a}	0.009–2.587	33.0
	– Wierzba	1.48^{a}	0.259–2.382	42.2
Soil type	– organic	1.41^{A}	0.053–2.382	43.3
	– mineral	1.68^{B}	0.009–2.587	25.6
Land use type	– pasture	1.67^{A}	0.009–2.587	28.5
	– meadow	1.35^{B}	0.053–2.382	44.6
Plant community	– Mol-Arr	1.70^{A}	0.009–2.587	25.0
	– Phragm	0.99^{B}	0.053–2.150	54.1

* Explanatory notes as in Table 3

Table 6

Statistical characteristics of the evenness index (J') in plant communities

Specification		Mean	Range of variation	Coefficient of variation, %
Location	– Popielno	0.56^{a}	0.013–0.850	28.1
	– Wierzba	0.53^{a}	0.120–0.782	37.4
Soil type	– organic	0.50^{A}	0.027–0.787	37.0
	– mineral	0.65^{B}	0.013–0.850	21.1
Land use type	– pasture	0.60^{A}	0.013–0.850	24.1
	– meadow	0.48^{B}	0.027–0.782	39.1
Plant community	– Mol-Arr	0.61^{A}	0.013–0.850	20.7
	– Phragm	0.38^{B}	0.027–0.641	45.4

* Explanatory notes as in Table 3

Table 7

Statistical characteristics of the domination index (λ) in plant communities

Specification		Mean	Range of variation	Coefficient of variation, %
Location	– Popielno	0.31^{a}	0.102–0.998	60.6
	– Wierzba	0.37^{a}	0.125–0.886	62.7
Soil type	– organic	0.38^{A}	0.113–0.986	62.3
	– mineral	0.27^{B}	0.102–0.009	51.7
Land use type	– pasture	0.28^{A}	0.102–0.998	60.3
	– meadow	0.41^{B}	0.125–0.986	57.6
Plant community	– Mol-Arr	0.26^{A}	0.102–0.998	51.4
	– Phragm	0.54^{B}	0.171–0.986	43.5

*Explanatory notes as in Table 3

and phytosociological affiliation. Communities that developed on organic soils, compared with those occupying mineral soils, are characterized by significantly lower values of total cover, highly significantly lower values of diversity and evenness, and higher values of species domination (measured with the relevant indices). Species richness in communities on both soil types is identical in statistical terms. Land use type exerted no considerable influence on the number of species in phytocenoses, but had a highly significant effect on the other investigated parameters: pasture communities are marked by higher total cover, higher average indices of species diversity and evenness, and lower species domination. The most natural division of plant communities, based on phytosociological classes, was found to be significant for all analyzed features, including for species richness. Higher total cover, greater biodiversity (measured as the number of species and the Shannon-Wiener index), higher evenness and lower domination values were reported for communities of the class *Molinio-Arrhenetheretea*, in comparison with communities of the class *Phragmitetea*. The variation ranges of features within groups are relatively

Table 8

Correlation between the diversity index (H') and other characteristics of plant communities

Specification		Total cover	Species richness	J'
Location	– Popielno	0.56***	0.70***	0.94***
	– Wierzba	0.65***	0.83***	0.98***
Soil type	– organic	0.64***	0.76***	0.97***
	– mineral	0.53***	0.76***	0.90***
Land use type	– pasture	0.55***	0.67***	0.92***
	– meadow	0.57***	0.83***	0.99***
Plant community	– Mol-Arr	0.47***	0.71***	0.91***
	– Phragm	0.85***	0.74***	0.95***

* Significant at $p = 0.05$, ** significant at $p = 0.01$, *** significant at $p = 0.001$

wide, but the coefficients of variation are not particularly high, which is indicative of the concentration of values from single relevés around the mean; the highest variation was noted for the index of species domination (43.5–62.7%). The Shannon-Wiener diversity index increased along with a rise in the evenness of the distribution of individuals among species, and in species richness (Table 8). Both correlations are strong and highly significant. A strong positive relationship was also observed between the diversity index and total cover.

The analyzed features of grassland communities on the Popielno Peninsula were also related to habitat conditions expressed in the form of synthetic indices based on the ecological indicator values proposed by ZARZYCKI et al. (2002). It should be stressed that habitat conditions, except for soil moisture content, varied within a relatively narrow range, which is presented in a synthetic form in Table 9. The continentality index was disregarded in the assessment, because in our previous study (JASTRZĘBSKA et al. 2007) it was found to be nearly constant in all communities; therefore, no significant correlations were expected between this index and the characteristics of phytocenoses.

Table 9

Synthetic indices of habitat conditions, determined for the investigated area, and their statistical characteristics

Indicator values for habitats	Scale	Mean	Range of variation	Coefficient of variation, %
Light value (L)	1–5	4.07	3.47–4.65	3.6
Temperature value (T)	1–5	3.56	3.48–3.99	3.2
Soil moisture value (W)	1–6	3.62	2.83–5.89	18.1
Soil (water) trophy value (Tr)	1–5	3.89	3.32–4.20	3.4
Soil (water) acidity value (R)	1–5	4.16	3.56–4.79	3.8
Soil granulometric value (D)	1–5	4.18	3.13–5.00	5.6
Organic matter content value (H)	1–3	2.18	1.90–2.95	10.9

An analysis of the entire experimental material (with no division into groups) revealed that species diversity, evenness and total cover in communities increased with an improvement in light conditions, and decreased with a rise in the indices of temperature, soil moisture content, soil trophic state, soil particle size distribution and soil organic matter content. The domination index always follows the opposite trends to the diversity index (Table 10). It is noteworthy that the diversity index H' usually showed greater strength (and in some cases also greater significance) of correlation with habitat conditions than species richness. No relationships were found between community features and soil reaction (R) across the research area.

Table 10

Coefficients of simple correlation between habitat indices and the characteristics of plant communities in the entire research area

Characteristics of plant communities		Indicator values for habitats						
		L	*T*	*W*	*Tr*	*R*	*D*	*H*
Species richness		0.16*	–0.18*	–0.18*	–0.09	–0.12	–0.27***	–0.23**
Total cover		0.17*	–0.18*	–0.30***	–0.06	–0.12	–0.29***	–0.30***
Indices	H’	0.27***	–0.36***	–0.50***	–0.22**	–0.10	–0.51***	–0.52***
	J’	0.27***	–0.39***	–0.54***	–0.25***	–0.04	–0.54***	–0.56***
	λ	–0.32***	0.37***	0.54***	0.23***	0.04	0.55***	0.56***

* Significant at $p = 0.05$, ** significant at $p = 0.01$, *** significant at $p = 0.001$

Interesting data are provided by an analysis of the above dependencies within particular groups (Tables 11–14). Table 11 shows that the relationships between the investigated characteristics of phytocenoses and the synthetic indices of habitat conditions *L*, *T*, *W*, *Tr*, *R*, *D* and *H* in Popielno and Wierzba are almost identical, and that they do not differ considerably from those determined for all relevés. The absence of significant correlations in communities located in Wierzba, despite relatively high coefficients of correlation (compared to those determined in Popielno), most probably results from a small number of relevés in this group.

Table 11

Coefficients of simple correlation between habitat indices and the characteristics of plant communities in Popielno and Wierzba

Characteristics of plant communities		Indicator values for habitats						
		L	*T*	*W*	*Tr*	*R*	*D*	*H*
Popielno								
Species richness		0.13	–0.16*	–0.16*	–0.08	–0.14	–0.25***	–0.19*
Total cover		0.14	–0.17*	–0,32***	–0.06	–0.14	–0.29***	–0.31***
Indices	*H’*	0.21**	–0.31***	–0.48***	–0.20**	–0.12	–0.48***	–0.50***
	J’	0.20**	–0.33***	–0.53***	–0.23**	–0.06	–0.50***	–0.54***
	λ	–0.25***	0.32***	0.53***	0.21**	0.06	0.51***	0.53***
Wierzba								
Species richness		0.55*	–0.42	–0.53*	–0.27	0.22	–0.49	–0.68**
Total cover		0.50*	–0.28	–0.21	–0.07	0.23	–0.37	–0.43
Indices	*H’*	0.66**	–0.67**	–0.64**	–0.49	0.16	–0.73***	–0.79***
	J’	0.66**	–0.71**	–0.63**	–0.52*	0.17	–0.77***	–0.77***
	λ	–0.69**	0.66**	0.60*	0.46	–0.23	0.75***	0.75***

* Significant at $p = 0.05$, ** significant at $p = 0.01$, *** significant at $p = 0.001$

The division of relevés into groups based on soil type (Table 12) revealed differences in the response of plant communities that developed on organic and mineral soils to changing habitat conditions, even if the changes were slight. The relationships noted in the group of communities on organic soils were similar to those observed across the entire study area. The only exception was a slight (though statistically significant) increase in species evenness (accompanied by a decrease in domination) reported for neutral and alkaline soils. In communities on mineral soils none of the examined features depended on the values of *L*, *W*, *Tr*, *D* and *H* (except for a correlation between *H* and total cover). However, in contrast to organic soils, there was a strong and significant correlation ($p = 0.001$) between the characteristics of communities on mineral soils and soil reaction. The response to higher pH levels included an increase in species domination and a decrease in the values of the other features.

Table 12

Coefficients of simple correlation between habitat indices and the characteristics of plant communities on organic and mineral soils

Characteristics of plant communities		Indicator values for habitats						
		L	*T*	*W*	*Tr*	*R*	*D*	*H*
Organic soil								
Species richness		0.26*	–0.12	–0.61***	–0.23*	0.17	–0.47***	–0.43***
Total cover		0.30**	–0.04	–0.52***	–0.34**	0.15	–0.52***	–0.37***
Indices	*H'*	0.31**	–0.28**	–0.76***	–0.43***	0.21	–0.64***	–0.61***
	J'	0.31**	–0.29**	–0.73***	–0.46***	0.25*	–0.66***	–0.63***
	λ	–0.36***	0.27**	0.75***	0.45***	–0.27*	0.65***	0.61***
Mineral soil								
Species richness		0.09	–0.24**	0.02	–0.03	–0.49***	–0.12	–0.12
Total cover		0.01	–0.26**	–0.08	0.05	–0.36***	0.04	–0.22*
Indices	*H'*	0.09	–0.46***	–0.05	–0.10	–0.59***	–0.07	–0.18
	J'	0.07	–0.51***	–0.05	–0.13	–0.50***	–0.00	–0.14
	λ	–0.12	0.53***	0.02	0.10	0.59***	0.02	0.15

* Significant at $p = 0.05$, ** significant at $p = 0.01$, *** significant at $p = 0.001$

A different and interesting response of plant communities to soil reaction was noted when the experimental material was divided subject to land use type (Table 13). In pastures, situated primarily on mineral soils, the relationships between variables were the same as in all grassland communities on this type of soil. In meadows, species domination decreased along with an increase in soil acidity or, more precisely, with a shift in the index gradient towards moderate acidity. In pastures, like in communities on mineral soils, no directed relationships were noted between the characteristics of communities and the trophic state of soils.

Table 13

Coefficients of simple correlation between habitat indices and the characteristics of plant communities in pastures and meadows

Characteristics of plant communities		Indicator values for habitats						
		L	*T*	*W*	*Tr*	*R*	*D*	*H*
Pasture								
Species richness		0.14	–0.04	–0.09	–0.03	–0.34***	–0.07	–0.06
Total cover		0.15	–0.17*	–0.24**	–0.02	–0.38***	–0.15	–0.23**
Indices	*H'*	0.23**	–0.22*	–0.41***	–0.17	–0.52***	–0.23**	–0.34***
	J'	0.21**	–0.31***	–0.45***	–0.21*	–0.49***	–0.23**	–0.38***
	λ	–0.26**	0.31***	0.45***	0.17	0.54***	0.21*	0.34***
Meadow								
Species richness		0.28*	–0.25	–0.72***	–0.36**	0.38**	–0.65***	–0.65***
Total cover		0.20	–0.04	–0.30*	–0.31*	0.36**	–0.48***	–0.33*
Indices	*H'*	0.25	–0.35*	–0.76***	–0.46***	0.46***	–0.78***	–0.72***
	J'	0.24	–0.34*	–0.72***	–0.46***	0.49***	–0.79***	–0.71***
	λ	–0.30*	0.31*	0.74***	0.47***	–0.53***	0.81***	0.72***

* Significant at p = 0.05, ** significant at p = 0.01, *** significant at p = 0.001

Within the ranges of the synthetic indices of habitat conditions in the investigated area, the features of plant communities belonging to the class *Molinio-Arrhenetheretea* were not dependent on changes in light, moisture (except for *J'*) and trophic conditions (Table 14). The measures of species diversity and evenness decreased with an increase in the mean values of *T*, *R*, *D* and *H* (species domination showed the opposite trend).

Table 14

Coefficients of simple correlation between habitat indices and the characteristics of plant communities of the classes *Molinio-Arrhenetheretea* and *Phragmitetea*

Characteristics of plant communities		Indicator values for habitats						
		L	*T*	*W*	*Tr*	*R*	*D*	*H*
Molinio-Arrhenetheretea								
Species richness		0.10	–0.22**	0.03	–0.01	–0.36***	–0.09	–0.09
Total cover		0.07	–0.23**	–0.15	0.04	–0.28***	–0.08	–0.19*
Indices	*H'*	0.07	–0.38***	–0.12	–0.11	–0.43***	–0.19*	–0.21**
	J'	0.04	–0.41***	–0.18*	–0.15	–0.38***	–0.19*	–0.22**
	λ	–0.12	0.45***	0.15	0.11	0.43***	0.16*	0.24**
Phragmitetea								
Species richness		0.15	0.08	–0.45**	–0.37*	0.20	–0.37*	–0.19
Total cover		0.25	0.16	–0.61***	–0.48**	0.11	–0.54***	–0.34*
Indices	*H'*	0.33*	–0.01	–0.67***	–0.58***	0.25	–0.54***	–0.43**
	J'	0.37*	–0.04	–0.65***	–0.56***	0.31	–0.56***	–0.51***
	λ	–0.35*	–0.01	0.65***	0.57***	–0.29	0.54***	0.41*

* Significant at p = 0.05, ** significant at p = 0.01, *** significant at p = 0.001

Species diversity, evenness and domination in communities of the class *Phragmitetea* on the Popielno Peninsula were not related to the values of *T* and *R*, and increased with a rise in L and a decline in the mean values of *W*, *Tr*, *D* and *H*.

The relationship between the species diversity of plant communities and particular habitat features is easy to interpret since it has the form of a linear correlation. It should be noted that such an analysis is a simplification, because habitat quality is a multidimensional property. In three-dimensional space, biodiversity can be illustrated graphically only in the gradient of two habitat features as independent variables. An example may be a graph showing the dispersion of points representing the diversity indices *H*' for particular communities (relevés), compared with the habitat indices of soil moisture content (*W*) and soil particle size distribution (*D*), which had the greatest ranges of variation within the research area (Figure 2). A cluster analysis may be employed to grasp

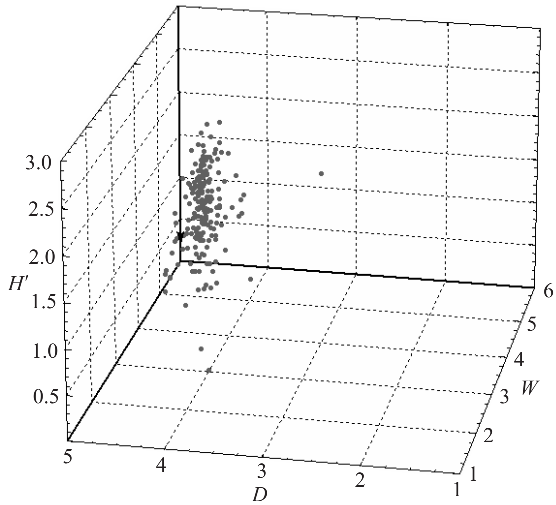

Fig. 2. Species diversity (*H*') in plant communities on the Popielno Peninsula as dependent on soil moisture content (*W*) and soil particle size distribution (*D*) – point dispersion

the multidimensional character of habitats. Table 15 presents the division of the experimental material into six groups, arranged according to increasing diversity (*H*'). There was almost no difference between clusters with regard to the mean values of climate indices (*L* and *T*). Table 15 shows than in the analyzed area biodiversity is affected to the greatest extent by soil moisture content. Similar mean values of the habitat indices in clusters 4 and 5, and considerably different mean values of diversity indices (*H*') are indicative of a differentiating effect of other habitat variables not included in the analysis.

Table 15

Values of variables in particular groups of relevés (clusters)

Variables	Clusters (number of relevés)					
	1 (17)	2 (15)	3 (29)	4 (41)	5 (45)	6 (47)
H'	0.52	0.94	1.21	1.56	1.91	2.04
L	3.92	4.03	4.03	4.08	4.10	4.11
T	3.57	3.69	3.62	3.54	3.51	3.54
W	4.99	3.00	4.33	3.14	3.82	3.11
Tr	3.97	3.94	3.91	3.89	3.86	3.88
R	4.08	4.34	4.21	4.15	4.19	4.09
D	4.63	4.06	4.31	4.05	4.17	4.07
H	2.66	2.08	2.37	2.09	2.15	2.03

Discussion

According to literature data (BULLOCK et al. 2001, MINNS et al. 2001, SZOSZKIEWICZ, SZOSZKIEWICZ 1999, GRYNIA et al. 1998), the last fifty years have seen agricultural intensification and the improvement of grassland productivity accompanied by a decrease in diversity. The negative impact of the above processes on ecosystems is less noticeable in Poland than in Western Europe. Today, when organic farming is becoming increasingly popular, low fertilization levels contribute to higher species diversity in permanent grasslands, which is not always accompanied by better productivity and quality (FISHER, RAHMAN 1997, GRYNIA et al. 1998) because natural succession proceeds towards the domination of ruderal weeds (BENNIE et al. 2006, GRABOWSKI et al. 1996, SZOSZKIEWICZ, SZOSZKIEWICZ 1998). The biodiversity of permanent grasslands has been the subject of long-term studies conducted at international research centers (SZOSZKIEWICZ, SZOSZKIEWICZ 1998). In Poland a vast body of literature is floristic documentation (GRYNIA, KRYSZAK 1998, TRĄBA et al. 2004, WYŁUPEK 2002) which provides scant information on a comparison of plant communities from the perspective of their functional biodiversity (SZOSZKIEWICZ, SZOSZKIEWICZ 1998). According to SZOSZKIEWICZ and SZOSZKIEWICZ (1998, 1999), the species diversity of grassland phytocenoses can be assessed and compared not only on the basis of the number of species in a community, but also with the use of the Shannon-Wiener diversity index, the Shannon-Wiener evenness index, the Simpson's diversity index, the species rarity index and the Rényi diversity profiles. In the present study, the Shannon-Wiener diversity index was considered most suitable for an analysis of the gathered material. The value of this index increases with a rise in the number of species and in species evenness in the community. The Shannon-Wiener evenness index and the Simpson's domination index provide complementary information. The Simpson's diversity index, proposed by SZOSZKIEWICZ and SZOSZKIEWICZ (1998), is a derivative of the domination index – diversity is determined as the reverse of domination or by subtraction from unity. The application of the quotient form is limited by the fact that this measure increases to the value referred to as the maximum diversity, equal to the number of species forming a community; thus, this index is suitable for comparing phytocenoses characterized by the same species richness (WANIC et al. 2005). According to Rényi (TÓTHMÉRÉSZ 1995), biodiversity is a multidimensional concept, and one community is more diverse than another if its diversity profile is above that of another over the whole range of the examined parameter. Diversity profiles may be used to compare actual phytocenoses as well as abstract clusters (groups), provided that the homogeneity of the experimental material and procedures is preserved. In the present study biodiversity was not assessed in the Rényi system due to considerable differences in the number of relevés in the compared groups, and the resulting heterogeneity of the material.

In this study biodiversity indices were computed based on phytosociological relevés, replacing the degrees on the Braun-Blanquet cover/abundance scale by the mean values of percentage cover. ŚWIERKOSZ (2003) proposed to use this measure of species abundance while calculating the Shannon-Wiener diversity index in plant communities for the purpose of agricultural and environmental programs. CIEŚLAK (1993) demonstrated that biodiversity indices may be based on different quantitative parameters of taxa and communities, such as the number of individuals, number of pairs, biomass or the percentage share in the community. The information about plant communities acquired with the use of the Braun-Blanquet system is not precise (in contrast to frame methods employed e.g. in agricultural research), but this technique enables a rapid evaluation of vegetation cover within a relatively large area. In the course of analysis, the classical notation is often transformed into numeric form with the use of comprehensive database management systems, e.g. JUICE (TICHÝ 2002) or TURBOVEG (HENNEKENS, SCHAMONEE 2001). Multivariate statistical methods are commonly applied in ecological surveys. The possibilities they offer, with particular emphasis on the analysis of phytosociological relevés, have been discussed in detail by DZWONKO (2007). In this study the relationship between biodiversity and habitat conditions was determined using simple correlation and cluster analysis. KNOLLOVÁ et al. (2005) pointed out that the choice between traditional and modern methods is dependent on the ultimate goal which is to be achieved.

Works on the dependence of plant diversity (mostly species richness) on ecological factors sometimes refer to Ellenberg's indicator values (ELLENBERG 1974, ELLENBERG et al. 1991) which are calibrated so as to adjust them to local conditions (ERSTEN et al. 1998). An analysis of changes in biodiversity along ecological (environmental) gradients is extremely difficult due to the multidimensionality of the natural environment. As indicated in professional literature on the subject, environmental heterogeneity exerts a non-monotonic effect on diversity due to changes (shifts) in the abundance of constant or accidental species (SCHWILK, ACKERLY 2005). In most cases the analysis is performed in mono- or two-dimensional systems (CHYTRÝ et al. 2003, CORNWELL, GRUBB 2003, GODEFROID, KOEDAM 2000). It would be difficult to confront the above works with the present results, due to both the incomparability of study sites and procedural differences. An analysis of the cited sources suggests that soil moisture content is one of the factors exerting the most profound effect on species diversity across habitats (beta-diversity) (CHYTRÝ et al. 2003, CORNWELL, GRUBB 2003, HAVLOVÁ et al. 2004). HAVLOVÁ et al. (2004) demonstrated that a rise in the soil moisture content of grasslands in the Czech Republic was followed by an increase in beta-diversity. CORNWELL and GRUBB 2003 reported that in Central Europe species diversity reached a peak on nutrient-deficient soils in grasslands and swamps, while on nutrient-rich soils in forests, and that Ellenberg indicator values for moisture in the herbaceous and dwarf shrub layer were low (1–4). CHYTRÝ et al. (2003) observed no simple correlation between species diversity and soil acidity, following the Central-European approach to vegetation classification. GODEFROID and KOEDAM (2000) noted a positive correlation between species richness and Ellenberg indicator values for light in forests surrounding Brussels. The present paper describes preliminary findings that may represent a valuable contribution to a broader discussion. Such research projects should be undertaken not only for purely scientific purposes, but also for practical reasons, since environmental quality improvement is a prerequisite for biodiversity preservation (WAMELINK et al. 2003).

Conclusions

1. The Shannon-Wiener diversity index, accompanied by the Shannon--Wiener evenness index and the Simpson's domination index, are good measures of species diversity in plant communities.
2. Greater species diversity was observed in communities that developed on mineral soils, are used as pastures, and belong to the class *Molinio-Arrhenetheretea,* compared with communities that developed on organic soils, are used as meadows, and belong to the class *Phragmitetea.*
3. The biodiversity of grassland communities on the Popielno Peninsula is affected by habitat conditions, as reflected in the synthetic indices computed based on the ecological indicator values.
4. The relationship between vegetation biodiversity and habitat quality is difficult to grasp due to its multidimensional character. The methods of multivariate statistics may prove useful in this respect.

Translated by Aleksandra Poprawska Accepted for print 21.11.2008

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