Distribution of plant communities as a function of the relative insolation of the Czyżówki rocky ridge in the Ojców National Park

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Abstract

Highly significant dependences were found between the distribution of plant communities and the relative insolation on a small rocky ridge with relief and microclimatic conditions varying to a very great degree. The dependences are presented in graphical and numerical forms, and their significance is tested using non-parametric statistics.

Key words: ecological differentiation of plant communities, microclimate, relative insolation, non-parametric statistics, Ojców National Park

INTRODUCTION

The Ojców National Park covers an area of highly morphologically varied rocky valleys. It is characterized by a great variability of habitat conditions, particularly microclimatic ones (Klein 1974). The plant communities occurring there show very differentiated ecological characteristics (Szafer 1928). Their spatial distribution depends on microclimatic conditions. This dependence has been stressed by numerous authors (e.g. Szymkiewicz 1923, Medwec-ka-Kornaś and Kornaś 1963, Klein 1974, Michalik 1978, 1983). However, their remarks were rather descriptive in character.

The present paper is an attempt at determining this dependence quantitatively, using statistical methods. Relative insolation, which is a function of exposition and inclination (Struzka 1959), was accepted as an indicator of the microclimate. It shapes the pattern of temperature, humidity, saturation deficit, rate of snow cover disappearance etc., and very well characterized microclimatic conditions (Klein 1974, Michalik 1979, 1984).

AREA OF INVESTIGATIONS

The investigation on the dependence between the distribution of plant communities and the relative insolation was carried out on a permanent study plot, Czyżówki (Fig. 1). It lies on the eastern slope of the Prądnik stream valley in Ojców. Occupying a large, morphologically varied, rocky ridge mostly covered with forests and thickets. Grassland communities occur on non-shaded rocks only (Michalik 1991). A small side-valley covered by meadows, pastures, and farm building, lies on the north. The strongly varied relief on the study area accounts for the pronounced variation of relative insolation (Michalik 1983). On the assumption that the total annual insolation on a horizontal surface is 100%, the relative insolation in the discussed study area reaches values from several percentage points at the northern foot of the high rocky wall to 135% in the apical part of the ridge facing south (Fig. 2).

Fig. 1. Position of the study plot, Czyżówki on the background of its immediate vicinity.

1 — contour lines, 2 — streams, 3 — rocks, 4 — buildings

Fig. 2. Distribution of plant associations and differentiation of some chosen elements of the microclimate on the profile of the Czyżówki rocky ridge. A — relative insolation; B — delay in snow cover disappearance in relation to the place where the snow melted earliest; C — day-and-night maximum (1), minimum (2) temperature, and temperature amplitude (3) in the above-ground plant layer (5 cm) for a typical, clear summer day; D — saturation deficit in the above-ground plant layer (5 cm) at 1 p.m. for a typical, clear summer day. E — distribution of plant communities: 1 — montane sycamore forest *Phyllitido-Aceretum*, 2 — lime-hornbeam forest *Tilio-Carpinetum* (a — typical subassociation, b — humid subassociation *T.C. stachyetosum*, c — thermophilous subassociation *T.-C. melittetosum*), 3 — saxicolous beechwood *Carici-Fagetum convallarietosum*, 4 — xerothermal thickets *Peucedano cervariae-Coryletum*, 5 — xerothermal grassland *Origano-Brachypodietum*, 6 — saxicolous grassland *Festucetum pallentis neckeretosum*

METHODS

Analysis of distribution of communities against the background of the relative insolation was carried out on the basis of a detailed phytosociological map in a scale of 1:500 (Michalik 1991). A net of about 1000 sites in a systematic arrangement was plotted on the map. The type of the plant community and the value of the relative insolation obtained from the Struzka tables (1959, cf. also Michalik 1979) on the basis of exposition and inclination were determined for each site. Twelve classes of relative insolation were defined

The number of sites belonging to each class was determined. The percentage distribution of all sites in the twelve classes (cf. Fig.3) was accepted as a null hypothesis H_0). This distribution may be regarded as characteristic for a community of entirely random disposition, i.e., neutral to the differentiation of insolation. The significance of differences between the percentage distribution of sites for the particular plant communities and the null hypothesis was determined using non-parametric statistics: test χ^2 and the Kolmogorov and Smirnov test. The W coefficient determining the dependence of their distribution on the relative insolation was calculated for all communities. This calculation was based on the following formula (Michalik 1979):

$$W = (a_1 \times b_1) + (a_2 \times b_2) + \dots + (a_{12} \times b_{12}),$$

where: $a_1, \dots, a_{12}$ = percentage of sites in the insolation classes,
 $b_1, \dots, b_{12}$ = values (ranks) accepted for the particular insolation classes,
 corresponding to numbers of the successive classes.

Fig. 3. Distribution of different subassociations of *Tilio-Carpinetum* depending on the relative insolation. A — *T.C. typicum*, B — *T.C. stachyetosum*, C — *T.C. melittetosum*. H_0 — the distribution curve of sites for the null hypothesis

The difference between the W values for the given plant community and W_{H_0} makes it possible to evaluate the magnitude and direction of deviation from the null hypothesis in the distribution of sites of this community.

RESULTS

In the investigated area the distribution of plant communities shows distinct and strongly varied dependences on the relative insolation. These dependences are not only manifested between associations but also in the case of lower

syntaxonomic units. For example, within the lime-hornbeam forest *Tilio-Caprinetum* the identified subassociations significantly differ from each other. The typical subassociation occurs in all insolation classes and the distribution of its sites approximates to the greatest degree the null hypothesis (Fig. 3A, Table 1). The other two subassociations show a quite different behaviour. The humid *T-C. stachyetosum* subassociation distinctly prefers shaded habitats, since 53% of its sites occur in the first four classes of insolation and it does not appear in insolation areas above 110% (Fig. 3B). *Tilio-Carpinetum melittetosum* covers better insulated places, usually above 100% relative insolation, completely avoiding habitats with low values of this factor (Fig. 3C).

Table 1

Significance of differences between the null hypothesis and the actual distribution of sites in the classes of the relative insolation for the particular plant communities and the value of the W coefficient

Plant community	Sites		χ^2	Kolmogorov, Smirnov test	Value of W coefficient	$W - W_{H_0}$ ($W_{H_0}=650$)
	Number	%				
<i>Tilio-Carpinetum typicum</i>	269	27.3	S ²	S ²	660	+10
<i>Tilio-Carpinetum stachyetosum</i>	103	10.4	S ²	S ²	430	-220
<i>Tilio-Carpinetum melittetosum</i>	76	7.7	S ²	S ²	813	+163
<i>Phyllitido-Aceretum</i>	25	2.5	S ²	S ²	148	-502
<i>Carici-Fagetum convallarietosum</i>	7	0.7	—	NS	957	+307
<i>Pino-Quercetum</i>	7	0.7	—	NS	786	+136
<i>Alno-Padion</i>	26	2.6	S ²	S ¹	538	-112
<i>Peucedano cervariae-Coryletum</i>	21	2.1	S ²	S ²	1086	+436
<i>Festucetum pallentis sempervivetosum</i>	15	1.5	S ²	S ²	973	+323
<i>Festucetum pallentis neckeretosum</i>	12	1.2	S ²	S ²	150	-500
<i>Origano-Brachypodietum</i>	30	3.0	S ²	S ²	960	+310
<i>Arrhenatheretum medioeuropaeum typicum</i>	129	13.2	S ²	S ²	559	-91
<i>Arrhenatheretum medioeuropaeum salvietosum</i>	46	4.7	S ²	S ²	943	+293
<i>Lolio-Cynosuretum typical variant</i>	81	8.2	S ²	S ²	711	+61
<i>Lolio-Cynosuretum Chaerophyllum variant</i>	28	2.8	S ²	S ²	396	-254
<i>Lolio-Plantaginetum, Leonuro-Arctietum</i>	32	3.2	NS	NS	650	0
Buildings, roads, fields	81	8.2	—	—	—	—

S — significant difference (¹ — $\alpha=0.05$, ² — $\alpha=0.01$), NS — non significant difference.

The magnitude of the internal variability of plant associations with regard to their microclimatic requirements is precisely determined by differences in the value of the W coefficient between the particular subassociations and variants, while the range and direction of the deviation from the null hypothesis are ascertained by their differences in relation to W_{H_0} (Table 1).

Three subassociations of the lime-hornbeam forest *Tilio-Carpinetum* have different optimum values of relative insolation but their distribution ranges

overlap and together they cover the entire variability scale of this factor. The following differences were found in these values between the particular subassociations:

	<i>T.-C. typicum</i>	<i>stachyetosum</i>	<i>melittetosum</i>
<i>T.-C. typicum</i>	—	230	135
<i>stachyetosum</i>	—	—	393

The most shade-loving forest community is the montane sycamore stand *Phyllitido-Aceretum* which almost exclusively (96% of sites) grows in habitats belonging to the two lowest classes of insolation (Fig. 4A). The *W* values reaching 148 approximate the lower limit of the theoretically possible range of this coefficient (100-1200) and reach the greatest difference in the relation to W_{H_0} found in the investigated area (Table 1).

Fig. 4. Distribution of different forest communities depending on the relative insolation. A — *Phyllitido-Aceretum*, B — *Carici-Fagetum convallarietosum*, C — *Pino-Quercetum*, D — *Alno-Padion* (fragments). H_0 — cf Fig. 3

Saxicolous beechwood *Carici-Fagetum* is a distinctly thermophilous association and occurs in habitats with high values of relative insolation (Fig 4B). The remaining forest communities, mixed acidophilous forest *Pino-Quercetum* (Fig. 4C) and particularly fragments of riverside forests (Fig. 4D), exhibit mesophilous traits to a greater degree.

In the group of non-forest communities, xerothermal thickets *Peucedano cervariae-Coryletum* show the highest positive dependence on insolation (Fig. 5A). For this association the value of the W coefficient is 1086 and approximates the upper limit of its theoretically possible variation. The xerothermal grassland *Origano-Brachypodietum* is characterized by a slightly greater tolerance (Fig. 5D). In the study area it usually covers places of high values of relative insolation but is also sporadically encountered within the mean range of variability of this factor.

Saxicolous grassland *Festucetum pallentis* is separated in two subassociations greatly differing from each other with regard to microclimatic requirements. The subassociation *F. P. sempervivetosum* ($W = 973$) solely occurs on strongly insulated rocks (Fig. 5B), while *F. p. neckeretosum* ($W = 150$) grows only on rocky walls with northern exposition, included in the 3 lowest classes of

Fig. 5. Distribution of thickets and grassland communities depending on relative insolation. A — *Peucedano cervariae-Coryletum*, B-C — *Festucetum pallentis* (B — *F.P. sempervivetosum*, C — *F.P. neckeretosum*), D — *Origano-Brachypodietum*. H_0 — cf Fig 3.

insolation (Fig. 5C). The difference between these subassociations reaches 820. The ranges of their distribution are distinctly limited and do not overlap in the mean variability range of relative insolation.

The rich meadow *Arrhenatheretum medioeuropaeum* and the rich pasture *Lolio-Cynosuretum* are most frequently found in areas of the average values of relative insolation. However, they are fairly numerous in habitats of stronger or poorer insolation, where they develop in separate subassociations or variants (Fig. 6). The difference in the value of W coefficients between the typical (Fig. 6A) and thermophilous (Fig. 6B) subassociation of *Arrhenatheretum medioeuropaeum* amounts to 348. *Lolio-Cynosuretum* is characterized by a slightly smaller difference, amounting to 315, between the typical variant (Fig. 6C) and that with *Chareophyllum hirsutum* (Fig. 6D). The above subassociations and variants show different distribution optima. However, their ranges overlap to a fairly great degree.

Fig. 6. Distribution of meadow, pasture, and ruderal communities depending on the relative insolation. A-B — *Arrhenatheretum medioeuropaeum* (A — *m. typicum*, B — *A. m. salviolosum*), C-D — *Lolio-Cynosuretum* (C — the typical variant, D — the shade-loving variant with *Chaerophyllum*), E — ruderal communities *Lolio-Plantaginietum*, and *Leonuro-Arcietum tomentosii*, H_0 — cf Fig. 3.

DISCUSSION

The results of the investigation are in agreement with earlier opinion concerning the ecological differentiation of plant communities in Ojców National Park (Szafer 1928, Medwecka-Kornaś and Kornaś 1963, Michalik 1978, 1983, and many other authors). Thanks to the application of objective statistical methods, this problems could be presented quantitatively for the first time.

Analysis of dependences between the occurrence of associations and other units and the relative insolation, and particularly the calculated values of the W coefficient made it possible to arrange all of the plant communities occurring in the investigated area in an ecological series (Fig. 7.). It was also possible to determine the magnitude of differences between the actual spatial distribution of communities and the accepted null hypothesis (Table 1). The most shade-loving nature is manifested by *Phyllitido-Aceretum* and *Festucetum pallentis neckeretosum*. The values of W for these associations appear in the lowest variation range of coefficient (100-200).

Fig. 7. Ecological series of plant communities arranged according to the value of W coefficient from communities of the most shady habitats to those in the best insolated sites

The moderately shade-loving (*Lolio-Cynosuretum* variant with *Chaerophyllum*, and *Tilio-Carpinetum stachyetosum*), mesophilous (*Alno-Padion*, *Arrhenatheretum medioeuropaeum typicum*, *Tilio-Carpinetum typicum* a typical variant *Lolio-Cynosuretum*, and *Pino-Quercetum*), and thermophilous (*Tilio-Carpinetum melittetosum*) communities form a fairly large group. The values of W typical

for the above group occur in the central variability range of this coefficient (400–800).

The communities of distinctly light-loving, thermophilous or xerothermal character ($W > 900$) are represented by *Arrhenatheretum medioeuropaeum salvi-etosum*, *Carici-Fagetum*, *Origano-Brachypodietum*, *Festucetum pallentis sem-pervivetosum*, and *Peucedano cervariae-Coryletum*. The latter association shows the strongest positive dependence on relative insolation in the investigated area.

The method applied in evaluating the ecological character and classification of plant communities is based on microclimatic criteria. It allows the requirements of plant communities with regard to such elements of the microclimate as light, air temperature, the amplitude of temperatures, and saturation deficit to be estimated.

The investigations carried out so far on the dependence between the distribution of plant species and communities, and the intensity of relative insolation (Michalik 1979, 1983, 1984, 1985, 1986–1987) suggest the usefulness of the method presented above. It is particularly useful in areas of a strongly differentiated relief, where the microclimatic conditions vary to a great degree and significantly affect the plant cover. Absolute values of the W coefficient are important for the given area, while the relations between particular communities and the position of these communities in the ecological series to a greater degree illustrate general regularities. The difference between the values of coefficients W and W_{Ho} makes it possible to estimate the (zonal or azonal) character of the spatial distribution of plant communities in the different areas of their geographical ranges.

REFERENCES

- Klein J., 1974. Mezo- i mikroklimat Ojcowskiego Parku Narodowego. Meso- and microclimate of the Ojców National Park. *Studia Naturae*, A, 8: 1-105.
- Medwecka-Kornaś A., Kornaś J., 1963. Mapa zbiorowisk roślinnych Ojcowskiego Parku Narodowego. Vegetation map of the Ojców National Park. *Ochr. Przyr.* 29: 17-87.
- Michalik S., 1978. Spatial distribution of plant cover in the Ojców National Park according to habitat conditions. Wydawn. UAM w Poznaniu, Ser. Biol. 11: 324-326.
- Michalik S., 1979. Charakterystyka ekologiczna kserotermicznej i górskiej flory naczyniowej Ojcowskiego Parku Narodowego. Ecological characterization of xerothermal and montane vascular flora of the Ojców National Park. *Studia Naturae*, A, 18: 1-95.
- Michalik S., 1983. Rozmieszczenie roślin kserotermicznych i górskich w Ojcowskim Parku Narodowym w zależności od warunków mikroklimatu. Distribution of xerothermal and montane plants in the Ojców National Park depending on microclimatic conditions. *Studia Naturae*, A, 24: 1-74.
- Michalik S., 1984. The occurrence of carpathian beechwood and the relative insolation in Southern Poland. *Bull. Pol. Acad., Biol.* 32: 321-327.
- Michalik S., 1985. La repartition des hêtres suivant le relief du terrain sur les pentes du nord de Stara Planina dans la Réserve Boatin. *Colloques Phytosociologiques* 13: 867-874.
- Michalik S., 1986-1987. Zależność między występowaniem zespołu *Dentario glandulosae-Fagetum* i gatunku *Dentaria glandulosa*, a nasłonecznieniem względnym w Polsce poł-

- dniovej. Distribution of the *Dentario glandulosae-Fagetum* association and *Dentaria glandulosa* species according to relative insolation in Southern Poland. *Fragm. Flor. Geobot.* 31, 1-2: 233-245.
- Michalik S., 1991. Mapa zbiorowisk roślinnych powierzchni badawczej Czyżówki w Ojcowskim Parku Narodowym. Map of the plant communities of the Czyżówki study plot in the Ojców National Park. *Ochr. Przyr.* 49, cz. II: 37-43.
- Struzka V., 1959. Metody badań bioklimatycznych (Metody bioklimatických průzkumu). *Przegl. Zagr. Lit. Geogr., Zagadnienia klimatologii* 3: 170-195.
- Szafer W., 1928. Guide for the excursion to the Valley of the River Prądnik (Biały Kościół-Ojców-Pieskowa Skała-Olkusz). V I.P.E. 1928. Guide des Excursion en Pologne 10: 1-25.
- Szymkiewicz D., 1923. Etudes climatologiques. III. Sur le climat local de la vallée d'Ojców. *Acta Soc. Bot. Pol.* 1: 253-262.

Zależność między występowaniem zbiorowisk roślinnych a nasłonecznieniem względnym w masywie skalnym Czyżówki w Ojcowskim Parku Narodowym

Streszczenie

Badania prowadzono na stałej powierzchni obejmującej masyw skalny położony na wschodnim zboczu doliny potoku Prądnik w Ojcowskim Parku Narodowym (ryc. 1, 2). W celu wykazania zależności rozmieszczenia zbiorowisk roślinnych od mikroklimatu wykorzystano zróżnicowanie nasłonecznienia względnego. Jest ono najbardziej reprezentatywnym wykładnikiem mikroklimatu (Klein 1974, Michalik 1979, 1983). Na bardzo szczegółowej mapie zbiorowisk roślinnych w skali 1:500 (Michalik 1991) wyznaczono około 1000 punktów, dla których odczytano typ zbiorowiska roślinnego oraz wyliczono nasłonecznienie względne na podstawie ekspozycji i nachylenia (por. Struzka 1959). Procentowy rozkład wszystkich punktów w wyróżnionych dwunastu klasach nasłonecznienia przyjęto jako hipotezę zerową (H_0). Rozkład taki jest charakterystyczny dla zbiorowiska roślinnego o rozmieszczeniu losowym, całkowicie obojętnego na zróżnicowanie nasłonecznienia względnego. Istotność różnic między procentowym rozkładem stanowisk dla poszczególnych zbiorowisk roślinnych a hipotezą zerową obliczono przy użyciu statystyki χ^2 i Kolmogorowa-Smirnowa. Dla wszystkich zbiorowisk obliczono współczynnik W określający zależność ich występowania od nasłonecznienia względnego:

$$W = (a_1 \times b_1) + \dots + (a_{12} \times b_{12}),$$

gdzie $a_1, \dots, a_{12}$ = % stanowisk w klasach nasłonecznienia, $b_1, \dots, b_{12}$ = wartości (rangi) przyjęte dla poszczególnych klas nasłonecznienia równe numerom kolejnym klas. Różnica między wartością W dla konkretnego zbiorowiska roślinnego a W_{H_0} umożliwia ocenę wielkości i kierunku odchylenia rozkładu stanowisk tego zbiorowiska od hipotezy zerowej.

Analizowane zbiorowiska wykazują bardzo różne zależności od nasłonecznienia względnego (ryc. 3, 4, 5, 6). Ich rzeczywiste rozmieszczenie na badanym terenie różni się wyraźnie od przyjętej hipotezy zerowej (tab. 1). Najbardziej cieniobulbny charakter wykazują *Phyllitido-Aceretum* i *Festucetum pallentis neckeretosum*, występujące głównie na siedliskach o najmniejszym nasłonecznieniu. Miejsca najbardziej nasłonecznione zajmują: *Origano-Brachypodietum*, *Festucetum pallentis semper-viventosum* i *Peucedano cervariae-Coryletum*.

Na podstawie wartości współczynnika W można uporządkować wszystkie zbiorowiska roślinne występujące na badanym terenie w ekologiczny szereg w zależności od ich wymagań w stosunku do cech mikroklimatu warunkowanych przez nasłonecznienie (ryc. 7), jak np: niedosyt wilgotności, temperatura powietrza, dobową amplitudę temperatury, czas zalegania pokrywy śnieżnej.