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MICROCLIMATIC AND TOPOCLIMATIC DIFFERENCES BETWEEN THE PHYTOCOENOSES IN THE VILJSKA PONIKVA SINKHOLE, MT. RISNJAK, CROATIA

Mikroklimatske i topoklimatske razlike između fotocenoze u Viljskoj ponikvi, Risnjak, Hrvatska

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Primljeno

Abstract: The microclimatic differences (based on field measurements) and topoclimatic differences (based on digital terrain model) between phytocoenoses in the sinkhole were tested and interpreted statistically. The results correspond to previous assumptions regarding climatic differences among phytocoenoses. The relation between the microclimate and the topoclimate was examined. Insolation quantity significantly correlates with air temperature (positively) and relative air moisture (negatively), only after weighting by the relative illumination in the forest phytocoenosis. The first principal component of the soil temperature daily dynamics at four soil depths is not correlated with the other variables, reflecting the particularity of the thermic processes in the soil. The impact of two important causes of thermic differences between phytocoenoses was distinguished. The daily air temperature dynamics is basically conditioned by insolation and the nightly temperature dynamics is conditioned by altitude in the sinkhole.

Key words: air temperature, average relative direct insolation, digital terrain model, karst vegetation, relative air moisture, relative illumination, soil temperature

Sažetak: Mikroklimatske razlike (na temelju terenskih mjerenja) i topoklimatske razlike (na temelju digitalnog modela reljefa) između fitocenoza u ponikvi testirane su i interpretirane statistički. Rezultati se slažu s ranijim pretpostavkama o klimatskim razlikama između fitocenoza. Razmatran je odnos mikroklime i topoklime. Količina insolacije značajno korelira s temperaturom zraka (pozitivno) i s relativnom vlažnošću zraka (negativno), tek nakon ponderiranja s relativnim osvjetljenjem u šumskim fitocenozama. Prva glavna komponenta dnevne dinamike temperature tla na četiri dubine tla ne korelira s drugim varijablama, odražavajući posebnost termičkih procesa u tlu. Razlučen je utjecaj dva važna uzroka termičkih razlika između fitocenoza. Dinamika dnevne temperature zraka prvenstveno je uzrokovana insolacijom, a dinamika noćnih temperatura visinom u ponikvi.

Ključne riječi: temperatura zraka, srednja relativna direktna insolacija, digitalni model reljefa, vegetacija krša, relativna vlaga u zraku, relativno osvjetljenje, temperatura tla

1. INTRODUCTION

The specific vegetation distribution in the karst sinkholes when compared to open slopes was recognized early (Kitaibel 1802 in Degen 1936), and also topoclimatically[1] explained on a general

1 the term „microclimate" frequently used in the sense of „macroclimate modified by relief" (terrain slope and aspect) and related derivatives are reserved in this paper for the „within plant community climate" (macroclimate modified by relief and crowns), and it has, consequently, been replaced with the recent term „topoclimate" (e.g. Dubayah 1994) and respective derivatives.

and descriptive level (Kerner 1876). Numerous vegetation surveys (detailed list in Horvat 1953) found similar spatial relations in the sinkhole vegetation types, the so–called inversions of vegetation zones. A qualitative description of the topoclimatic peculiarities (reduced duration of insolation, temperature inversion, wind absence) of the Dinaric sinkholes, with geobotanical and (syn)ecological consequences was given in the classic paper by Horvat (1953). His ingenious, but qualitative observations were followed by further attempts in field climatic research (Bertović 1975b, Hrašovec 1984). Those studies were limited to microclimate measurements in the target phytocoenoses (following Braun–Blanquet 1964), neglecting the influence of the tree canopy shading in the interpretation of results. The impact of two important causes of topoclimatic differences between phytocoenoses in the sinkhole (altitude and insolation differences) was recognized but not clearly distinguished. Moreover, the importance of insolation duration was emphasized, yet insolation quantification was neglected (Neidhardt & Tomašegović in Horvat 1953, Hrašovec et al. 1994). Finally, the conclusions were not supported by statistical testing.

Research presented in this paper comprises a re–interpretation of the existing microclimatic data (Hrašovec 1984), including topoclimatic estimators derived from the digital terrain model (hereafter DTM). The basic aim of this study was the statistical testing of climatic differences between phytocoenoses. A further aim was to distinguish microclimate and topoclimate and also the impact of altitude and insolation quantity in the interpretation of results. Finally, the field microclimatic measurements and topoclimatic estimators derived from DTM were correlated, as a support to the further development of the topoclimatical modelling procedures based on DTM and raster–GIS (Hetrick et al. 1993, Dubayah 1994, Dubayah & Rich 1995, Antonić 1996).

2. MATERIAL AND METHODS

Mt. Risnjak is situated in Western Croatia and it belongs to the Dinaric karst area (Figure 1a–b). The macroclimate there is perhumid: moderately cold, with a high amount of precipitation (over the 3500 mm annually), high air moisture, of high and lasting snow cover and frequent frost over the entire, relatively short growing season. Forestry and agriculture activities are forbidden on the whole area of Mt. Risnjak (3014 ha), as this area has been protected as a National Park since 1953. The vegetation complex of NP Risnjak belongs to the North Dinaric inland type (Antonić & Lovrić 1996).

The sinkhole „Viljska ponikva" (see Figure 1b–c, Figure 2 and Figure 3) is a typical karst sinkhole, with a depth varying between 100 m and 200 m. The sinkhole average diameter is cca 780 m and the total area between the ridges and peaks is over 45 ha. Compact Jurassic limestone and dolomite are the lithological substratum.

Microclimatic measurements were performed in the summer of 1984 (Hrašovec 1984), during three days (from July 28 to July 30). Six microclimatic stations were established in the following phytocoenoses (Figure 1c):

1. *Festucetum pungentis* Horv. 30 – sinkhole brink, altitude ca 1300 m, aspect W
2. *Homogyno alpinae – Fagetum* (Horv. 38) Borh. 63 – altitude ca 1250 m, aspect W
3. *Homogyno alpinae – Fagetum* (Horv. 38) Borh. 63 – altitude ca 1220 m, aspect SW
4. *Listero – Piceetum excelsae* (Horv. 38) Fuk. 69 – altitude ca 1220 m, aspect E
5. *Lonicero – Pinetum mughi* Horv. 38 – altitude cca 1220 m, aspect N
6. *Salicetum appendiculate* Horv. (62) 74 – sinkhole bottom, altitude 1184 m, flat

Floristic descriptions of the phytocoenoses are given in Horvat (1962). The boundaries between the phytocoenoses in the sinkhole are relatively sharp (see Figure 2) and all these six phytocoenoses are practically monodominant.

The measured microclimatic variables were air temperature (°C), relative air moisture (%), soil temperatures (°C) at four soil depths (5, 10, 30

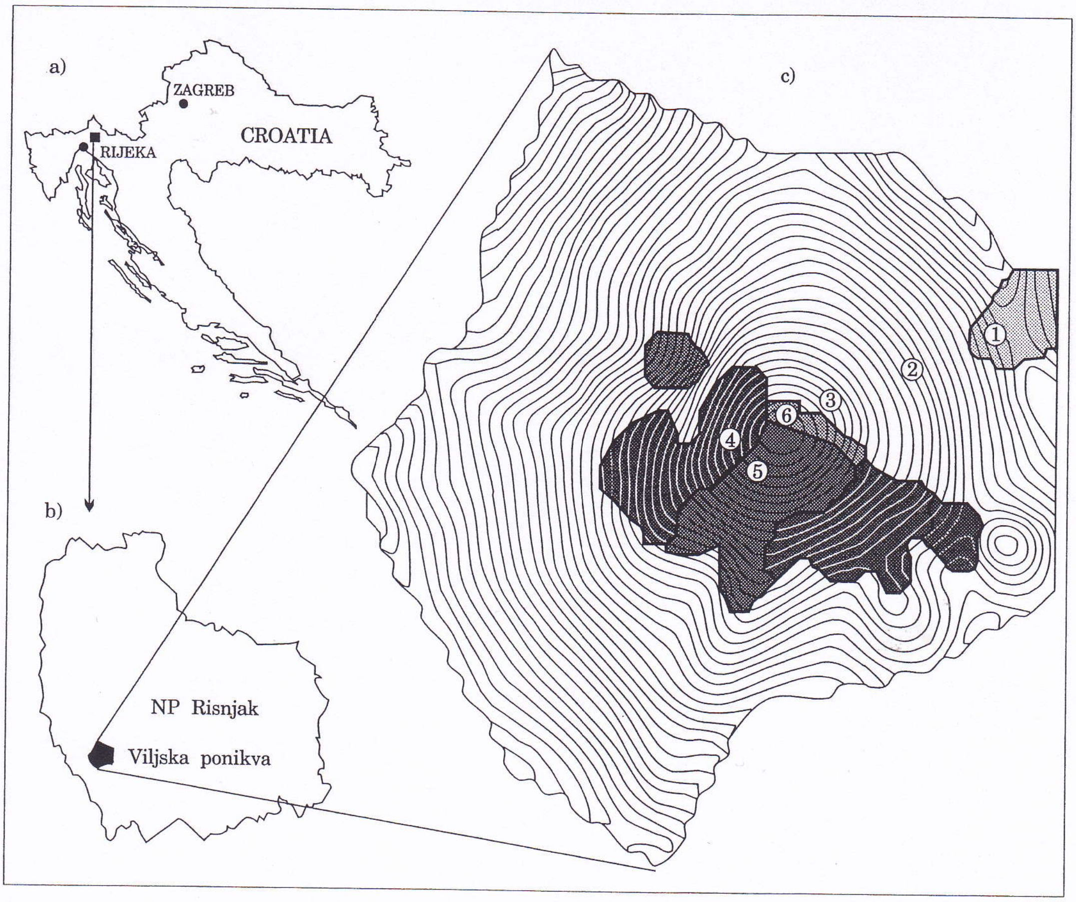

Figure 1 The geographic situation of the research area: a) the position of NP Risnjak in Croatia, b) the position of the „Viljska ponikva" sinkhole on NP Risnjak, c) sinkhole topography (bottom at 1184 m, equidistance of 5 m) with superimposed phytocoenoses areas and microclimatic stations (encircled numbers). White, including stations 2 and 3: *Homogyno alpinae–Fagetum*; very light grey, including station 1: *Festucetum pungentis*; light grey, including station 6: *Salicetum appendiculate*; grey, including station 5: *Lonicero–Pinetum mughi*; dark grey, including station 4: *Listero–Piceetum excelsae*). The dark grey polygon without a station also belongs to the *Listero–Piceetum*. The grey polygon without a station belongs to the phytocoenosis *Calamagrostio–Abietetum,* which is not examined in this study

Slika 1. Geografski položaj istraživanog područja: a) pozicija NP Risnjak u Hrvatskoj, b) pozicija Viljske ponikve u NP Risnjak, c) topografija ponikve (dno na 1184 m, ekvidistanca 5 m) s fitocenozama i mikroklimatskim postajama (zaokruženi brojevi). Bijelo, s postajama 2 i 3: *Homogyno alpinae–Fagetum*; vrlo svjetlo sivo, s postajom 1: *Festucetum pungentis*; svjetlo sivo, s postajom 6: *Salicetum appendiculate*; sivo, s postajom 5: *Lonicero–Pinetum mughi*; tamno sivo, s postajom 4: *Listero–Piceetum excelsae*). Tamno sivi poligon bez postaje pripada fitocenozi *Listero–Piceetum*. Sivi poligon bez postaje pripada fitocenozi *Calamagrostio–Abietetum* koja nije razmatrana u ovoj studiji

and 50 cm) and relative illumination (%). Two automated thermohygrographs, situated 1.5 m above the ground, were used for continuous measurements at the 1st and 6th station. Dry and wet thermometer (also situated 1.5 m above the ground) and also soil thermometers (only for the last two days) were read at 7, 10, 12, 14, 16 and 19 hours at the remaining stations. The minor difference between meridian (Mid–European) time and local time (2 min) was ignored. The relative illumination was repetitively measured (also at a height of 1.5 m) in the neighbourhood of the forest stations 2, 3 and 4, using two light meters simultaneously, inside and outside the forest. At the other stations, the relative illumination was 100% at a height of 1.5 m above the ground (grassland and shrub communities).

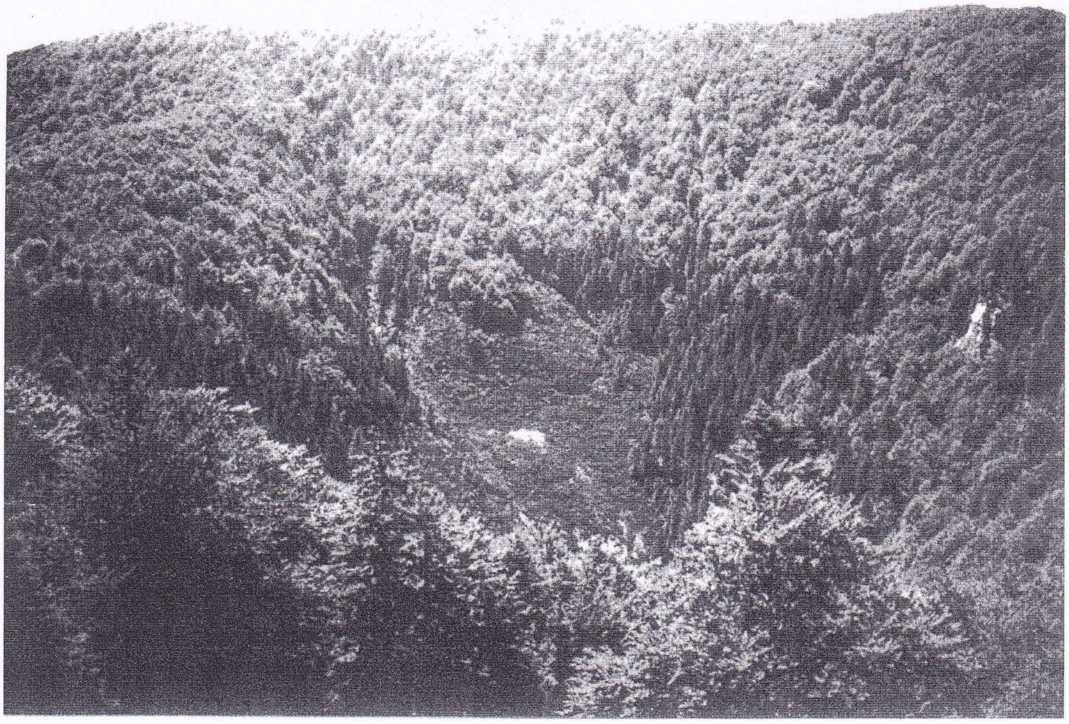

Figure 2 The southeast slopes of the Viljska ponikva sinkhole

Slika 2. Jugoistočne padine Viljske ponikve

Figure 3 Cloud stagnation in the Viljska ponikva sinkhole

Slika 3. Stagnacija oblaka u Viljskoj ponikvi

All the microclimatic variables were included in the testing of differences among phytocoenoses without transformation, except for soil temperatures. This system of basically four variables (temperatures at four soil depths) was reduced by principal component analysis. Components with an eigenvalue less than one were ignored (Mulaik 1972, Preisendorfer et al. 1981).

The topoclimatic variable was the phytocoenosis average relative direct insolation, modelled for July 29. Only this day, during microclimatic measurements, had a full clear sky during the whole day, and the impact of cloudiness could be ignored. The modelled values were obtained in the following way. First, a raster DTM of the sinkhole, based on a digitized map (scale 1:5000) and an interpolated grid (50 x 50 m), was established with superimposed phytocoenosis boundaries. This DTM had been visualized from the „sun perspective" (sun positions calculated with the help of ephemeris) for each hour with available microclimatic measurements and the areas of the phytocoenosis projections on the plane normally placed to the sun flux were calculated. The values of these projected areas were divided by the respective real sloped area of each phytocoenosis. The last result is the average relative direct insolation quantity of all points (imagined small areas with equal real sloped area) belonging to a certain phytocoenosis. This can be proven very simply. Let ***A*** be the real sloped area of the phytocoenosis, ***A'*** is the projected area of the phytocoenosis on the plane normally placed to the sun flux, ***a*** is the real sloped area of one point, ***a'*** is the projected area of this point on the normal plane and ***n*** is the number of points within the phytocoenosis. The ratio between ***a'*** and ***a*** is the relative direct insolation of the point at a certain moment. Finally, we can derive:

$$\frac{\sum_{i=1}^{n} \frac{a_i'}{a}}{n} = \frac{\sum_{i=1}^{n} a_i'}{n \cdot a} = \frac{A'}{A} \qquad (1)$$

The first ratio in equation (1) represents the average relative direct insolation of all points that belong to a certain phytocoenosis, and the last ratio represents the value of the described topoclimatic variable, both at a certain moment in time. This variable was used in statistical analyses in the form described above, abbreviated in the following text as PARDI (phytocoenosis average relative direct insolation), and also in the weighted form using multiplication by the relative average illumination values (WPARDI). The last was an attempt to distinguish topoclimate and microclimate in the forest phytocoenoses (other stations are not sheltered by canopies).

The differences between stations belong to different phytocoenoses depending on their air temperature, relative air moisture and scores of the first component of soil temperature were evaluated by the non–parametric Wilcoxon matched pairs test as well as the differences between the phytocoenoses according to PARDI and WPARDI. This testing was performed for the full daily time–series (three–day, two–day or one–day, respectively). The test results for particular pairs of stations (phytocoenoses) were interpreted in the way the stations were chained in the univariate sequences. For example, if values of hypothetic population A are significanly lower than values of populations B and C, if D is also significantly lower than B, and if other differences are unsignificant, then sequence A, D, C, B over the testing variable can be derived. The obtained sequences were compared to the qualitative assumptions by other authors.

The relative illumination differences between the forest phytocoenoses were tested by the t – test supported by an F – test and the Cochran–Cox approximation (Sokal & Rohlf 1981).

Linear regression was used in the examination of the correlations between microclimatic and topoclimatic variables. The variables were standardized to remove the differences in hourly averages. Only the data for June 29 were used for this analysis, and the values from the two stations in the *Homogyno–Fagetum* were replaced with their respective average.

The software used was *Arc–Info* for the digitization and rasterization, *Surfer* for the visualization of DTM, and *Statistica* for the data analyses.

3. RESULTS AND DISCUSSION

The assumptions about climatic differences among the phytocoenoses in the „Viljska ponikva" sinkhole, based on field experience and previous descriptive surveys (Horvat 1953, 1962, Horvat et al. 1974, Bertović 1975a, 1975b), could be described as follows:

1. the basic macroclimatic and/or topoclimatic sequence of the relevant phytocoenoses, based on temperature differences could be (starting with the „coldest"): *Salicetum appendiculate*, *Lonicero–Pinetum*, *Listero–Piceetum*, *Homogyno–Fagetum*;
2. an analogous sequence according to humidity differences could be supposed (starting with the „most humid");
3. *Festucetum pungentis* is the grassland in the *Homogyno–Fagetum* succession series and these two phytocoenoses are not topoclimatically, but microclimatically different (*Festucetum pungentis* is „warmer" and „drier").

These assumptions were used as a starting hypothesis in the interpretation of the statistical testing results.

Air temperature dynamics at the stations in the phytocoenoses *Festucetum pungentis* and *Salicetum appendiculate* (Figure 4) suggests that a daily and a nightly temperature dynamics in the sinkhole can be distinguished, because the relation of these two stations during the day is exactly opposite to their analogous relation over the night. The comparison of the air temperature daily dynamics among stations (from hour 7 to hour 19 during three days) by the Wilcoxon test gave the results summarized in Figure 9a. If the *Festucetum pungentis* station is „warmer" than the *Listero–Piceetum* and the *Homogyno–Fagetum* stations (the two *Homogyno–Fagetum* stations are not significantly different), if, also, the *Lonicero–Pinetum* station is significantly „warmer" than the *Listero–Piceetum* station, and if the *Salicetum appendiculate* station is not significantly different from any other station, then the following temperature sequence arises from the test results (starting with the „coldest"): *Listero–Piceetum* station, *Homogyno–Fagetum* (both stations), *Salicetum appendiculate* station, *Lonicero–Pinetum* station, *Festucetum pungentis* station. This sequence disagrees with the starting hypothesis. The relative illumination is significantly different in these phytocoenoses (Table 1) and we can expect the influence of the tree canopy shading to blur topoclimatical relations among the stations. Moreover, the interpretation of the test results, separately for forest and non–forest phytocoeno-

Table 1 Relative illumination (%) in the forest phytocoenoses (LIS–PIC: *Listero–Picetum*, HOM–FAG: *Homogyno–Fagetum*, 1st and 2nd station): a) obtained values (*std* — standard deviation, *n* — number of cases, non–forest phytocoenoses have a relative illumination of 100%); b) statistical testing by the *F*–test and *t*–test (the bold values represent significant difference at $p=0.05$, the value of $t_{\text{(Cochran-Cox)}}$ represents the approximative marginal value of *t*–statistics at $p=0.05$, when *F*–statistics is significant)

Tablica 1. Relativno osvjetljenje (%) u šumskim fitocenozama (LIS– PIC: *Listero–Picetum*, HOM–FAG: *Homogyno–Fagetum*, 1. i 2. postaja): a) dobivene vrijednosti (*mean* — aritmetička sredina, *std* — standardna devijacija, *n* — broj opažanja, nešumske fitocenoze imaju relativno osvjetljenje 100%); b) statističko testiranje pomoću *F*–testa i *t*–testa (masne vrijednosti predstavljaju značajnu razliku na $p=0.05$, vrijednost od $t_{\text{(Cochran-Cox)}}$ predstavlja približnu graničnu vrijednost *t*–statistike na $p=0.05$, kada je *F*–statistika značajna)

a)

	LIS–PIC	HOM–FAG2	HOM–FAG1
mean (%)	9.66	2.54	2.13
std (%)	3.17	1.03	1.34
n	62	44	62

b)

	F	*t*	*t* *(Cochran–Cox)*
LIS–PIC *vs.* HOM–FAG2	**10**	**17**	2
LIS–PIC *vs.* HOM–FAG1	**10**	**17**	2
HOM– FAG1 *vs.* HOM–FAG2	**2**	1.8	2

Table 2 Univariate correlations between climatic variables (PCA — principal component analysis, PARDI — phytocoenosis average relative direct insolation, WPARDI — phytocoenosis average relative direct insolation weighted by relative illumination, n — number of cases, R — correlation coefficient, p - probability, bold R values — significant correlation)

Tablica 2. Univarijatne korelacije između klimatskih varijabli (PCA — analiza glavnih komponeneti, PARDI — srednja relativna direktna insolacija u fitocenozi, WPARDI — srednja relativna direktna insolacija u fitocenozi ponderirana s relativnim osvjetljenjem, n — broj opažanja, R — koeficijent korelacije, p — vjerojatnost, masne R vrijednosti - značajna korelacija)

climatic variables correlated	n	R	p
air temperature *vs.* relative air moisture	30	**- 0.694**	0.000
air temperature *vs.* soil temperature (1st PCA–axis scores)	18	0.180	0.475
relative air moisture *vs.* soil temperature (1st PCA–axis scores)	18	0.094	0.712
air temperature *vs.* PARDI	30	0.322	0.083
air temperature *vs.*WPARDI	30	**0.535**	0.002
relative air moisture *vs.* PARDI	30	–0.168	0.376
relative air moisture *vs.*WPARDI	30	**–0.730**	0.000
soil temperature (1st PCA–axis scores) *vs.* PARDI	18	0.433	0.073
soil temperature (1st PCA–axis scores) *vs.*WPARDI	18	–0.157	0.535

ses, agrees with the starting hypothesis.

The differences in night air temperatures cannot be directly tested due to lack of data, but they can be tested indirectly by simple combinatorial examination. At each daily start (hour 7) and each end (hour 19) of measurements during the three days (see Figure 4), the same sequence is recognizable (starting with the „coldest"): *Salicetum appendiculate* station, *Lonicero–Pinetum* station, *Listero–Piceetum* station, *Homogyno–Fagetum* (2nd station), *Homogyno–Fagetum* (1st station), *Festucetum pungentis* station. This sequence is in complete agreement with the starting hypothesis and it is congruent with the altitudinal sequence of the stations. In case of a random event, the total number of possible events (sequences) would be 6! = 720, and the probability of this event is less than 0.0014. Moreover, the probability of this event randomly repeated six times consecutively is 0.0014^6, according to the law of probability multiplication. These results clearly suggest non–random event and the existence of hard positive correlation between night air temperatures and altitudes in the sinkhole over the whole night (altitudinal temperature gradient), due to the confluence of colder and weightier air into the sinkhole (temperature inversion in the strict meaning). Also, a positive correlation between the depths in the sinkhole and the night air temperature amplitude could be expected (see Figure 4) and explained by a (still hypothetic) amplification of the described confluence effect during the night. It is unclear why the *Lonicero–Pinetum*, *Listero–Piceetum* and *Homogyno–Fagetum* (2nd) stations are always arranged according to the starting hypothesis, although they have the same altitude. It is possible that the different altitudes of the sinkhole brinks influence the spatial variability of air confluence.

The relative air moisture dynamics (Figure 5) seems to be more complex and less interpretable than the air temperature dynamics, although these two variables are significantly negatively correlated (Table 2). The day and night relative air moisture dynamics are not distinguishable as clearly as the related components of air temperature dynamics. The daily relative air moisture sequence of the stations, arising from the Wilcoxon tests (Figure 9b) is (starting with the „most humid"): 2nd station of the *Homogyno–Fagetum*, *Listero–Piceetum* station, 1st station of the *Homogyno–Fagetum*, *Lonicero–Pinetum* station, *Salicetum appendiculate* station,

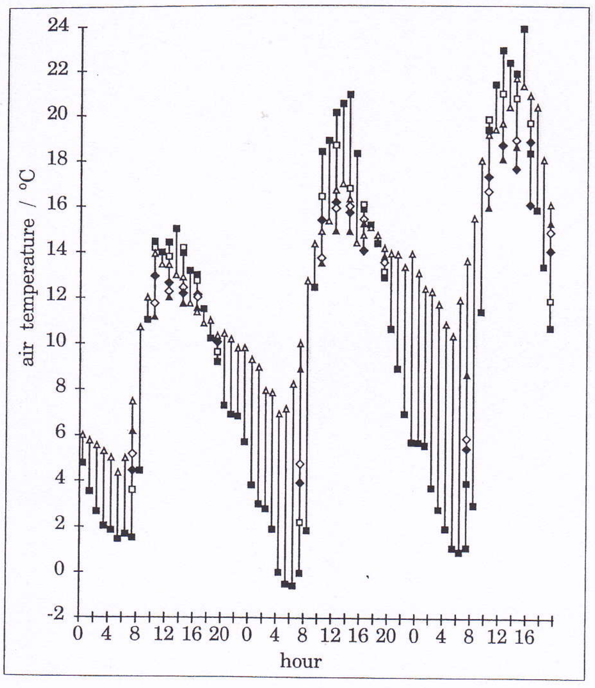

Figure 4 Air temperature (°C) dynamics in the phytocoenoses of the Viljska ponikva sinkhole (July 28–30). Black squares: *Salicetum appendiculate*, white squares: *Lonicero–Pinetum*, black rhombs: *Listero–Piceetum*, white rhombs: *Homogyno–Fagetum* (2nd station), black triangles: *Homogyno–Fagetum* (1st station), white triangles: *Festucetum pungentis*

Slika 4. Dinamika temperature zraka (°C) u fitocenozama Viljske ponikva (28–30. srpnja). Crni kvadrati: *Salicetum appendiculate*, bijeli kvadrati: *Lonicero–Pinetum*, crni rombovi: *Listero–Piceetum*, bijeli rombovi: *Homogyno–Fagetum* (2. postaja), crni trokuti: *Homogyno–Fagetum* (1. postaja), bijeli trokuti: *Festucetum pungentis*

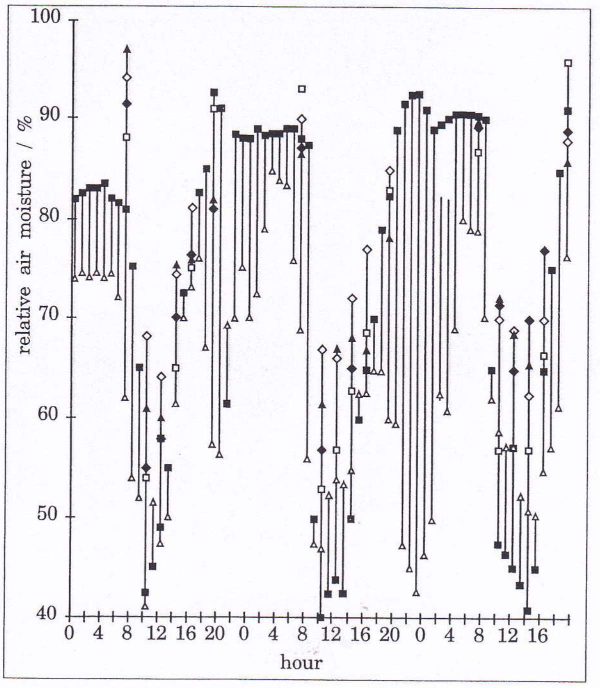

Figure 5 Relative air moisture (%) dynamics in the phytocoenoses of the Viljska ponikva sinkhole (July 28–30). Black squares: *Salicetum appendiculate*, white squares: *Lonicero–Pinetum*, black rhombs: *Listero–Piceetum*, white rhombs: *Homogyno–Fagetum* (2nd station), black triangles: *Homogyno–Fagetum* (1st station), white triangles: *Festucetum pungentis*

Slika 5. Dinamika relativne vlage zraka (%) u fitocenozama Viljske ponikva (28–30. srpnja). *Salicetum appendiculate*, bijeli kvadrati: *Lonicero–Pinetum*, crni rombovi: *Listero–Piceetum*, bijeli rombovi: *Homogyno–Fagetum* (2. postaja), crni trokuti: *Homogyno–Fagetum* (1. postaja), bijeli trokuti: *Festucetum pungentis*

Festucetum pungentis station. This disagrees with the starting hypothesis, although forest and non–forest phytocoenoses are separated again. An altitudinal sequence of night air moisture values might exist, but it is not provable in the way situation described, because, if it exists, it is established after the last and vanishes before the first daily measurement. Stagnation of clouds (see Figure 3) probably influences the diminution of the air moisture amplitude in the sinkhole during the night (Figure 5).

Figure 6 shows the daily dynamics of the first principal component of soil temperatures at four soil depths. The other principal components can be ignored (Table 3). Wilcoxon tests results (Figure 9c) suggest the following sequence (starting with the „coldest"): *Listero–Piceetum* station, *Lonicero– Pinetum* station, *Homogyno–Fagetum* (the two stations are not significantly different), which is not agreeable with the starting hypothesis. The first principal component of the soil temperature is not correlated with the other variables (Table 2), reflecting the particularity of thermic processes in soil. The lower amplitudes of soil temperature in the forest phytocoenoses (see Figure 6) could be explained by the impact of tree canopies.

Visualizations of the sinkhole from different „sun perspectives", with superimposed phytocoenosis boundaries are given in Figure 7. The

Table 3 Principal component analysis of soil temperatures at four soil depths: a) eigenanalysis results, b) first principal component statistics

Tablica 3. Analiza glavnih komponenti temprature tla na četiri dubine tla: a) rezultati analize svojstvenih vrijednosti, b) statistika prve glavne komponente

a)

factor	eigenvalue	eigenvalue (%)
1	3.14	78.53
2	0.82	20.46
3	0.04	0.88
4	0.01	0.13

b)

soil depth	loading	coefficient
5 cm	0.62	0.20
10 cm	0.98	0.31
20 cm	0.94	0.30
30 cm	0.95	0.30

daily dynamics of PARDI and WPARDI are shown in Figure 8. The sequence *Lonicero–Pinetum*, *Listero–Piceetum*, *Salicetum appendiculate*, *Homogyno–Fagetum*, *Festucetum pungentis* arises from the PARDI comparisons by the Wilcoxon test (Figure 9d). It agrees with the starting hypothesis, with the exception of the *Salicetum appendiculate* place in the sequence. This phytocoenosis occupies a very small area at the bottom of the sinkhole that is intensively insolated around noon (see Figure 1c, Figure 7 and Figure 8), but the plants there are probably primarily affected by low temperatures and/or high humidity during the night. Interpretation of the WPARDI comparison results yields the sequence (Figure 9e): *Homogyno–Fagetum*, *Listero–Piceetum*, *Salicetum appendiculate*, *Lonicero–Pinetum*, *Festucetum pungentis* that is almost the same as the sequence obtained by the air temperature comparison (the places of the forest phytocoenoses *Homogyno–Fagetum* and *Listero–Piceetum* are exchanged). The positive correlation between air temperature and average relative direct insolation and the negative correlation between relative air moisture and average relative direct insolation becomes signi-

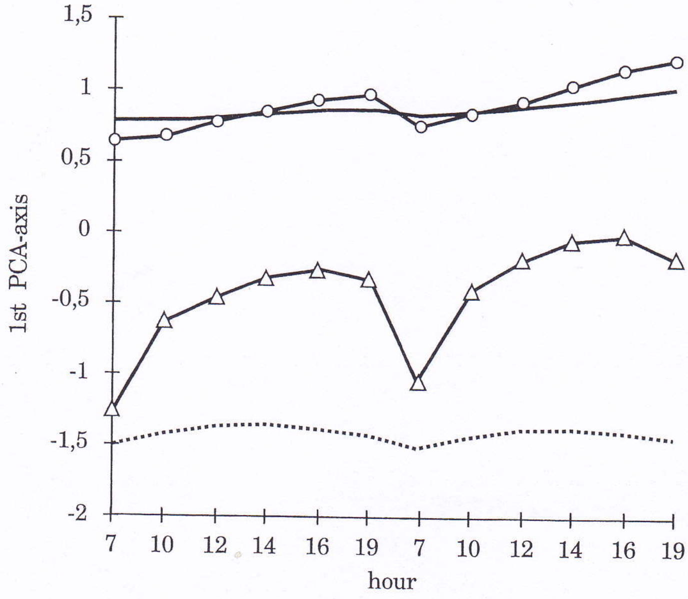

Figure 6 Dynamics of the first principal component of soil temperature at four soil depths (5 cm, 10 cm, 20 cm and 30 cm) in the phytocoenoses of the Viljska ponikva sinkhole (July 29–30). Solid line: *Homogyno–Fagetum* (1st station), line with circles: *Homogyno–Fagetum* (2nd station), dotted line: *Listero–Piceetum*, line with triangles: *Lonicero–Pinetum*

Slika 6. Dinamika prve glavne komponente temperatura tla na četiri dubine tla (5 cm, 10 cm, 20 cm i 30 cm) u fitocenozama Viljske ponikve (29–30). Puna linija: *Homogyno–Fagetum* (1. postaja), linija s krugovima: *Homogyno–Fagetum* (2. postaja), točkasta linija: *Listero–Piceetum*, linija s trokutima: *Lonicero–Pinetum*

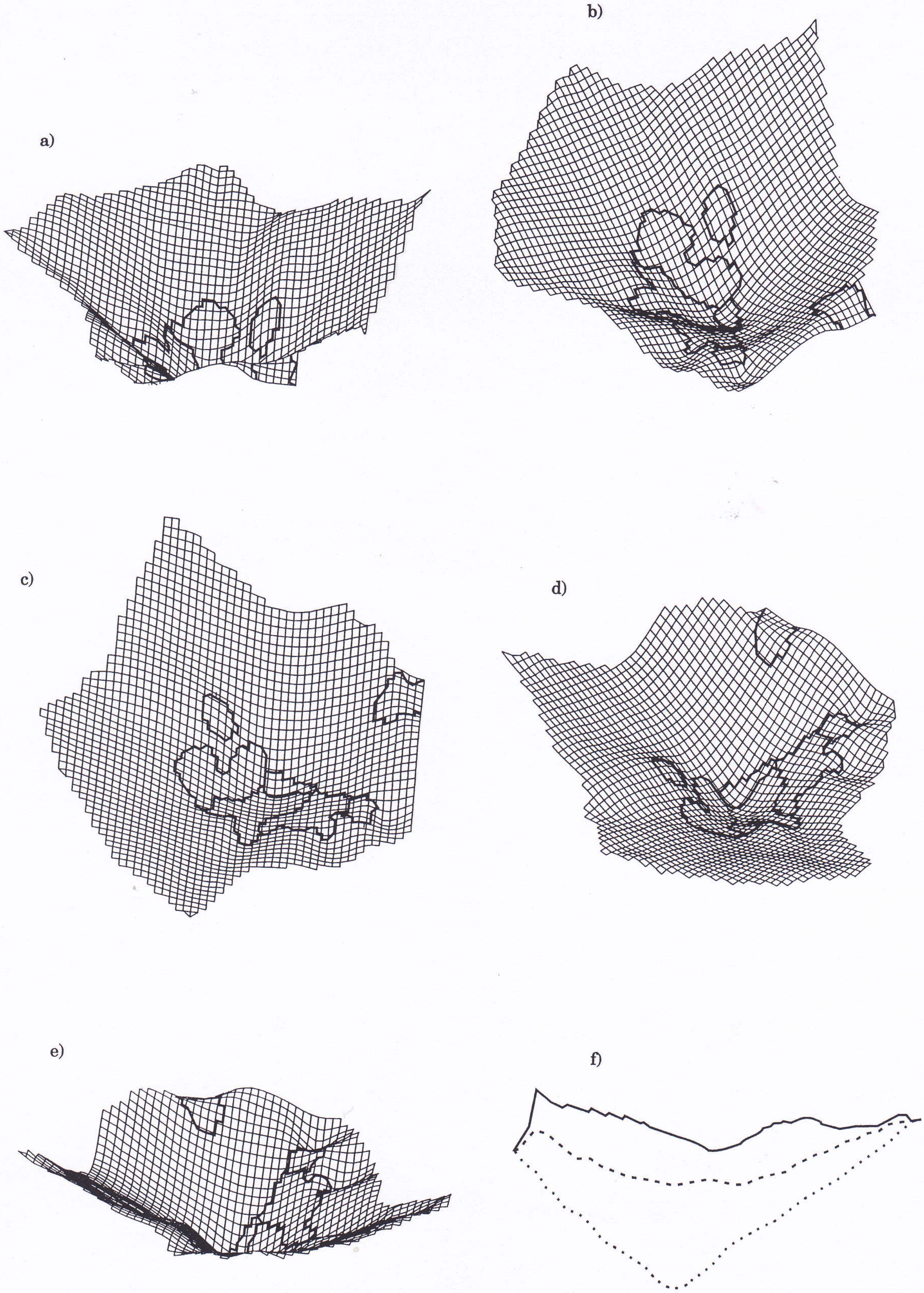

Figure 7 The Viljska ponikva sinkhole (digital terrain model) and the superimposed phytocoenoses areas from different Sun perspectives: a) at hour 7, b) at hour 10, c) at hour 12, d) at hour 14, e) at hour 16, f) at hour 19

Slika 7. Viljska ponikva (digitalni model reljefa) i površine fitocenoza iz različitih Sunčevih perspektiva: a) u 7 h, b) u 10 h, c) u 12 h, d) u 14 h, e) u 16 h, f) u 19 h

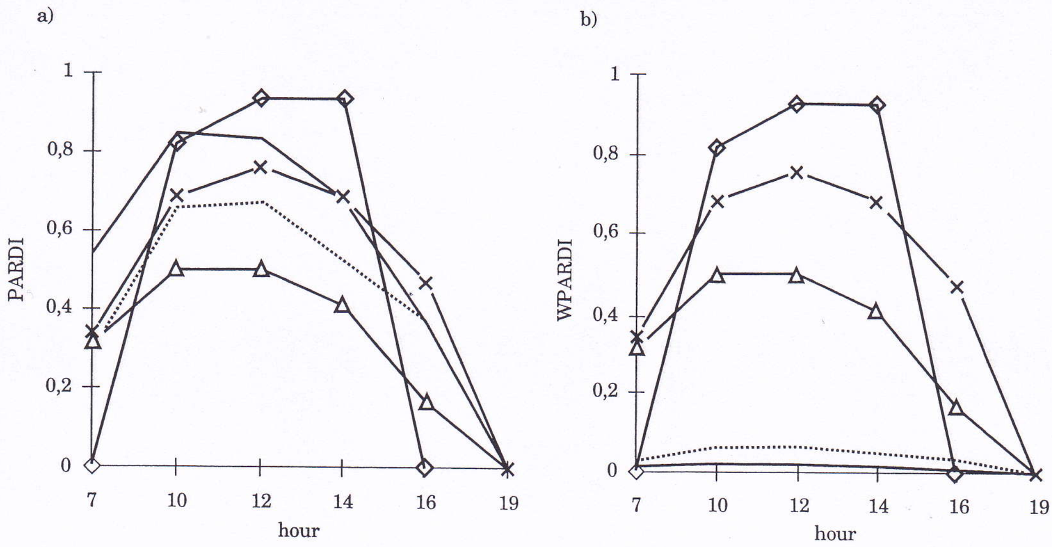

Figure 8 The phytocoenoses average relative direct insolation dynamics (July 29): a) unweighted, b) multiplied by relative illumination. Solid line: *Homogyno–Fagetum*, dotted line: *Listero–Piceetum*, line with rhombs: *Salicetum appendiculate*, line with triangles: *Lonicero–Pinetum*, line with crosses: *Festucetum pungentis*

Slika 8. Dinamika srednje relativne direktne insolacije u fitocenozama (29. srpnja): a) neponderirano, b) pomnoženo s relativnom osvijetljenošću. Puna linija: *Homogyno–Fagetum*, točkasta linja: *Listero–Piceetum*, linija s rombovima: *Salicetum appendiculate*, linija s trokutima: *Lonicero–Pinetum*, linija s križićima: *Festucetum pungentis*

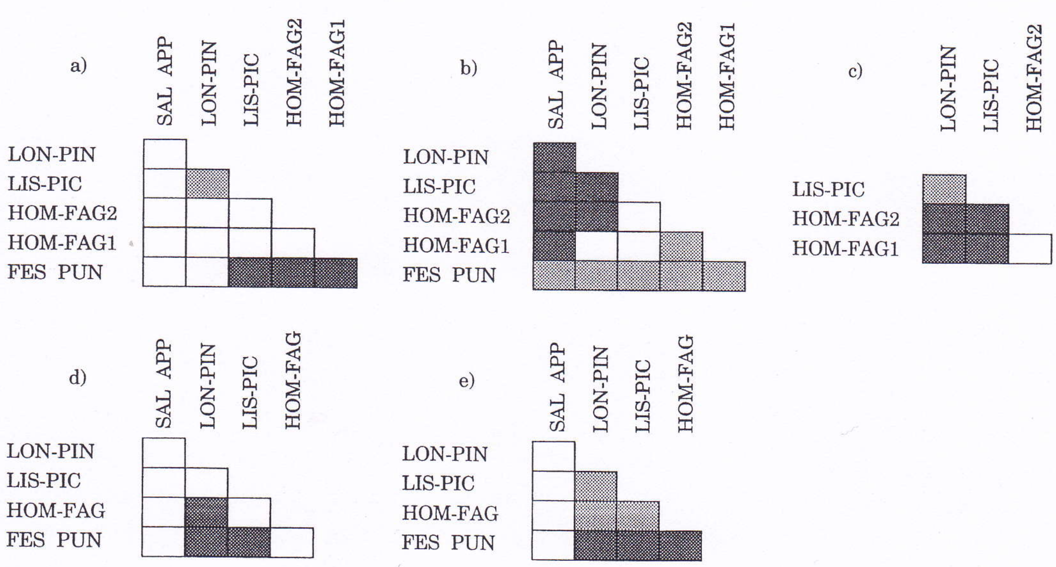

Figure 9 Statistical testing of the microclimatic and topoclimatic differences among the phytocoenoses (row *vs.* column) by Wilcoxon matched pairs test (light grey – significantly lower, grey – significantly higher, white – insignificant difference, SAL–APP: *Salicetum appendiculate*, LON–PIN: *Lonicero–Pinetum*, LIS–PIC: *Listero–Piceetum*, HOM–FAG: *Homogyno–Fagetum* (1st and 2nd station), FES–PUN: *Festucetum pungentis*): a) air temperature, b) relative air moisture, c) soil temperature – 1st principal component, d) phytocoenoses average relative direct insolation, e) phytocoenoses average relative direct insolation weighted by relative illumination

Slika 9. Statističko testiranje mikroklimatskih i topoklimatskih razlika između fitocenoza (red *vs.* stupac) s Wilcoxon- ovim testom združenih parova (svijetlo sivo — značajno manje, sivo — značajno veće, bijelo — bez značajne razlike, SAL–APP: *Salicetum appendiculate*, LON–PIN: *Lonicero-Pinetum*, LIS–PIC: *Listero–Piceetum*, HOM–FAG: *Homogyno–Fagetum* (1. i 2. postaja), FES–PUN: *Festucetum pungentis*): a) temperatura zraka, b) relativna vlaga zraka, c) temperatura tla – 1. glavna komponenta, d) srednja relativna direktna insolacija u fitocenozi, e) srednja relativna direktna insolacija u fitocenozi ponderirana s relativnom osvjetljenošću ficant (Table 2) only after the multiplication of PARDI values with the respective relative illumination values. All these results clearly confirm that the daily dynamics of air temperature and relative air moisture measured in the forest phytocoenoses relate to the microclimate. The spatial variability of microclimatic variables during the day is basically conditioned by the incoming insolation quantity that is differently reduced for each forest phytocoenosis due to its crown density. Removal of this reduction in the data analysis is possible and it provides the correlation of microclimate and topoclimate.

4. CONCLUSION

The recent re–interpretation of previously collected data, supported by simple topoclimatic estimators based on DTM, clearly distinguishes topoclimate and microclimate and provides statistical support to the explanation of climatic (especially thermic) differences among stations located in different phytocoenoses in the sinkhole. These differences correspond to the qualitative phytoecological assumptions of other authors. Some insignificant differences obtained cannot be interpreted strictly, because the spatial variability of climatic parameters within the phytocoenoses is unknown. Insolation quantity (during the day) and sinkhole altitude (during the night) are probably the main variables that influence the sinkhole topoclimate. The daily topoclimate is strongly affected by the tree canopy shading.

More exact conclusions could be probably reached by using spatially and temporally more intensive climatic measurements, especially with regard to research of boundaries between vegetation types. This approach is expensive, time–consuming and consequently inapplicable for research over a larger area. The results of this study suggest that topoclimatical modelling procedures based on DTM and raster–GIS (see also Hetrick et al. 1993, Dubayah 1994, Dubayah & Rich 1995, Antonić 1996) and their application to vegetation science (e.g. Brown 1994) could be used instead. As for the microclimate, these models could be improved by using photogrametric records of crowns or their topography. This approach is cheaper and it results in spatially explicit vegetation models with the high spatial resolution, i.e. for the calibration of analogous regional models (e.g. Brzeziecki et al. 1995). These local models could be generally more useful for the precise explanation of the vegetation spatial distribution, especially in the karst areas, than the stochastical models, which are often hardly applicable in the field.

The results of this study also suggest that the phytocoenosis (in sense of Braun–Blanquet 1964), as a unit of vegetation pattern, is probably not specific enough for this kind of analysis, especially for forests. It seems that future research in the correlation between forest vegetation and local climate should be oriented to separate synusia and/or to particular species (see for example a new approach proposed by Gillet & Gallandat 1996).

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