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Spatial diversity of thermal preferences of vascular plants in Łódź

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Abstract: Using temperature indicator values according to Ellenberg, spatial diversity of the vascular flora was determined with regard to thermal preferences of species growing in the area of Łódź (the city with the third largest population in Poland). Study results were compared to meteorological data indicating the presence of an urban heat island (UHI). Analysis of spatial diversity of thermal preferences of the flora was conducted with regard to 292 basic study fields – squares with sides 1 km long. Indicator values of thermal preferences of the flora were determined for the flora of each basic study field – the number and percentage share of thermophilous species (T>6) as well as the average of temperature indicator values. Thermal requirements of the vascular plant species occurring in basic fields within the area of compact tenement-style buildings, industrial and railway terrain are higher than in suburban area. Average temperature indicator values for the flora of basic study fields vary from 5.28 in the peripheries to 5.97 in city centre, while the number of thermophilous species – from 1 to 34, and percentage share of thermophilous species – from 0.6% to 17.5%.

Key words: urban flora, urban heat island, phytoindication, synanthropisation, Central Poland

1. Introduction

One of the most important effects of ongoing urban development pressure is the increase of air temperature in the atmosphere layer adjacent to the ground in relation to air temperature in neighbouring rural areas. This phenomenon is called the urban heat island (UHI). It is caused by the particular radiation balance of cities, increased heat capacity of building materials and emission of anthropogenic heat (Fortuniak 2003). The heat island is a phenomenon which is continuously changing in time and space. Due to its dynamic character, delimiting the borders of the heat island in details is impossible. It should, however, be emphasised that there exists a steep horizontal temperature gradient at the limits of compact urban built-up area (Oke 1995). Existence of UHI is one of significant factors which influence the spatial structure of the flora (Sukopp & Werner 1983; Stülpnagel *et al*. 1990; Wittig 1991, 2002; Jackowiak 1998; Sudnik-Wójcikowska 1998a; Sukopp & Wurzel 2003). The link between geographical distribution of some species and areas of increased temperature was indicated, i.a., by Gödde & Wittig (1983), Kowarik & Böcker (1984), Landolt (1991), Wittig (1991), Jackowiak (1998) and Sudnik-Wójcikowska (1998a, 1998b, 2000, 2002). The following plants are often listed among thermophilous species, the occurrence of which is linked to the warmest areas of cities in Central Europe: *Ailanthus altissima*, *Buddleja davidii*, *Bromus sterilis*, *Diplotaxis muralis*, *Eragrostis minor*, *Hordeum murinum*.

Differences in the spectrum of thermal preferences of species in the flora of central regions of German cities compared to their suburban zones were pointed out already by Wittig & Durwen (1981, 1982). The spatial aspect of relation between changes of thermal spectrum and optimum of species of the flora with regard to the urban functional structure and thermal diversity of individual city districts was studied directly in Münster (Gödde & Wittig 1983), while more recently this problem was investigated in Warsaw (Sudnik-Wójcikowska 1998a, 1998b, 2000, 2002). In these cities, diversity of thermal conditions was estimated on the basis of absolute number and relative share of groups of species having temperature indicator values within specific ranges (T>5, T>6 or T>7) as well as on the basis of average temperature indicator values in individual study fields.

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Łódź, due to its size (760 thousand inhabitants), structure of the built-up area and natural conditions, may serve as a model object for studies on urban heat island and its reflection in the spectrum of thermal preferences of species in the flora.

The emergence of a high intensity heat island in Łódź was facilitated by the following factors: size of the city, monocentric urban layout, compact building structure and very close layout of the built-up area in the city centre (more than 90% of the city centre is covered by artificial surfaces), small hipsometric diversity, lack of a major river which could modify the spatial temperature distribution.

Existence of UHI in Łódź is well documented by measurement results from two measuring sites located in the city centre and a weather station located at the suburban airport (Kłysik & Fortuniak 1998; Kłysik *et al.* 2002; Fortuniak 2003). These data allow the following conclusions:

- momentary temperature difference between the centre of Łódź and its peripheries is largest in summertime and equals on the average 3-4°C (Fig. 1); in favourable weather conditions the momentary temperature difference may exceed 6°C; the highest value of thermal contrast was recorded in winter when it reached 12°C;
- the average monthly temperature differences equal ca. 2°C;
- in the city centre due to ground surface shadowing at noontime the air adjacent to the ground may be cooler than outside of the city, while the layer of warmer air commences at the altitude of 15-30 m above ground.

Data on the spatial structure of air temperature distribution in the area of Łódź are not complete for the whole area of the city but refer to specific days and have been collected by the patrol method using sensors located on automobiles. The spatial image of thermal diversity in the city based on these measurements may thus only be of a draft character and of limited reference value. These studies have shown the emergence of heat island that is cellular or generalised in type – depending on meteorological conditions (Kłysik 1998). In both cases, the warmest area is located in the city centre.

The aim of the study was to obtain answers to the following questions:

- is the existence of UHI reflected in the spatial diversity of thermal requirements of vascular plants in Łódź?
- which phytoindicators of thermal conditions best denote the existence of UHI?

2. Material and methods

Analysis of spatial diversity of thermal preferences of vascular plants was conducted with regard to 292 basic study fields – squares with sides 1 km long. It is based on floristic data gathered between 1996-2003. Only indigenous species and permanently naturalised anthropophytes were taken into account. Thermal preferences of individual species were determined on the basis of ecological indicator values (Ellenberg *et al.* 1991).

The number and share of thermophilous species (T>6) as well as the average values of the temperature indicator were determined for the flora of each basic

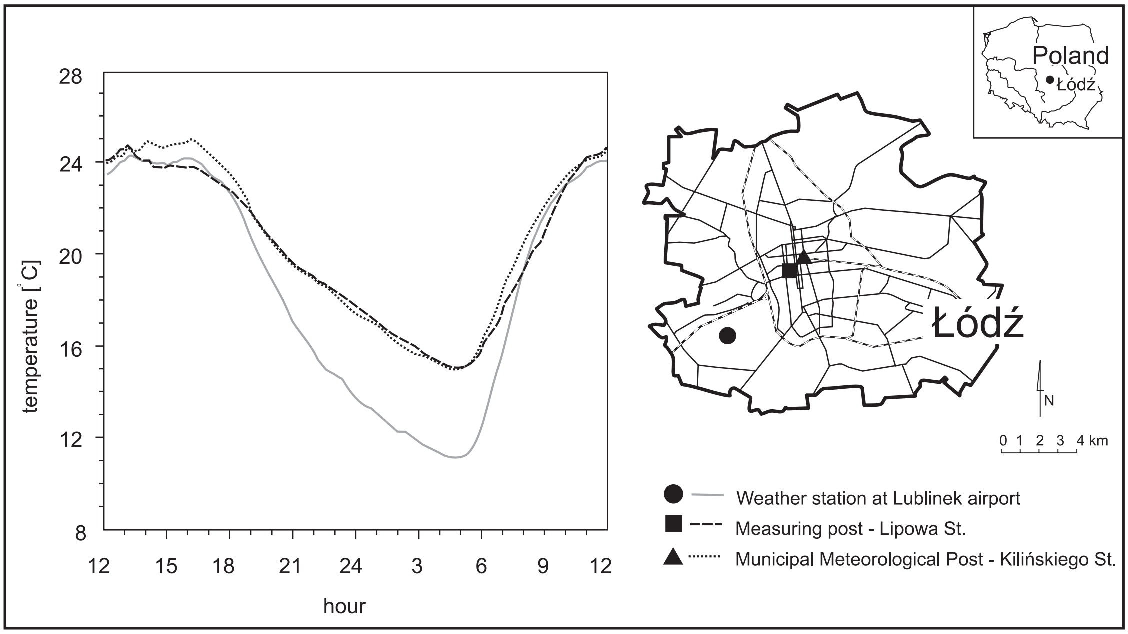


Fig. 1. Comparison of average 24-hour temperature change plots within the city and outside of it on sunny and windless days (average values for 14 days of August in the period 1997-1999 according to Kłysik *et al.* 2002)

field. Spatial diversity of variable values was illustrated using cartograms. In order to facilitate the interpretation of data on cartograms, the following variants of class interval calculation have been adopted (Figs. 2-4): A – proportional intervals, B – based on the analysis of frequency ogive discontinuity, C – based on typical classic variability interval (s-avg+s), and D – based on typical positional variability interval (Q-me+Q).

Diversity of thermal preferences for species in floras of basic study fields was confronted with the urban and functional layout of the city (Witosławski 2006). Statistical significance of differences between urban functional zones was estimated using the Kruskal-Wallis test.

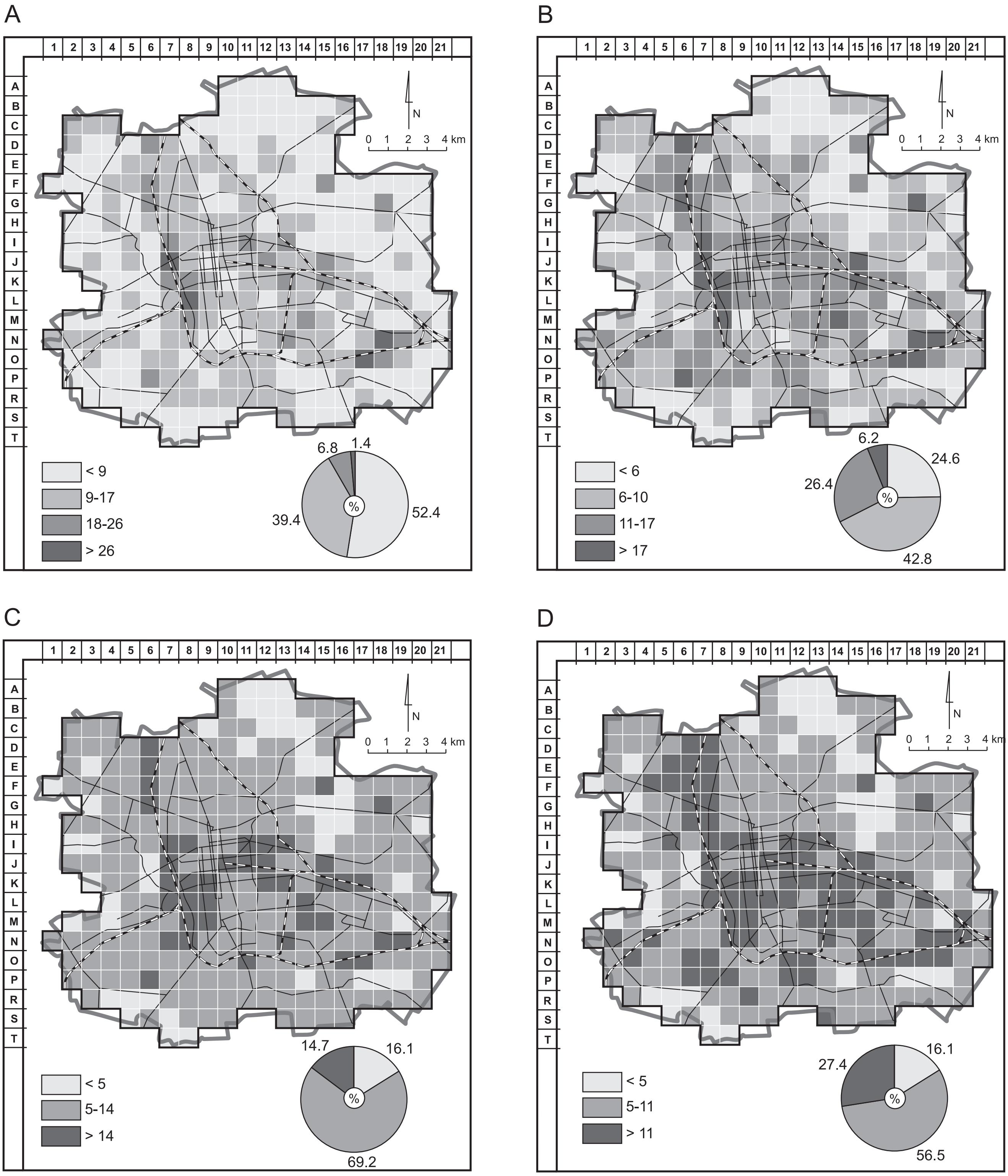


Fig. 2. Spatial diversity of density of localities for thermophilous species
Explanations: A, B, C, D – variants of class interval determination (circular plots show the frequency of described map units)

3. Results

The flora of Łódź includes 107 species with temperature indicator value T>6: 39 spontaneophytes, 18 archaeophytes and 50 kenophytes. The following species show highest frequency of occurrence within this group: among spontaneophytes – *Oenothera biennis*, *Centaurea stoebe*, *Coronilla varia*, *Populus alba*, *Veronica verna*; among archaeophytes – *Echinochloa crus-galli*, *Lactuca serriola*, *Setaria pumila*, *Hordeum murinum*, *Malva pusilla*; among kenophytes – *Amaranthus retroflexus*, *Diplotaxis muralis*, *Echinocystis lobata*, *Eragrostis minor*, *Lepidium densiflorum*.

The floras of individual study fields which coincide with the locations of meteorological measurement sites show significant diversity with regard to thermal preferences of species (Table 1).

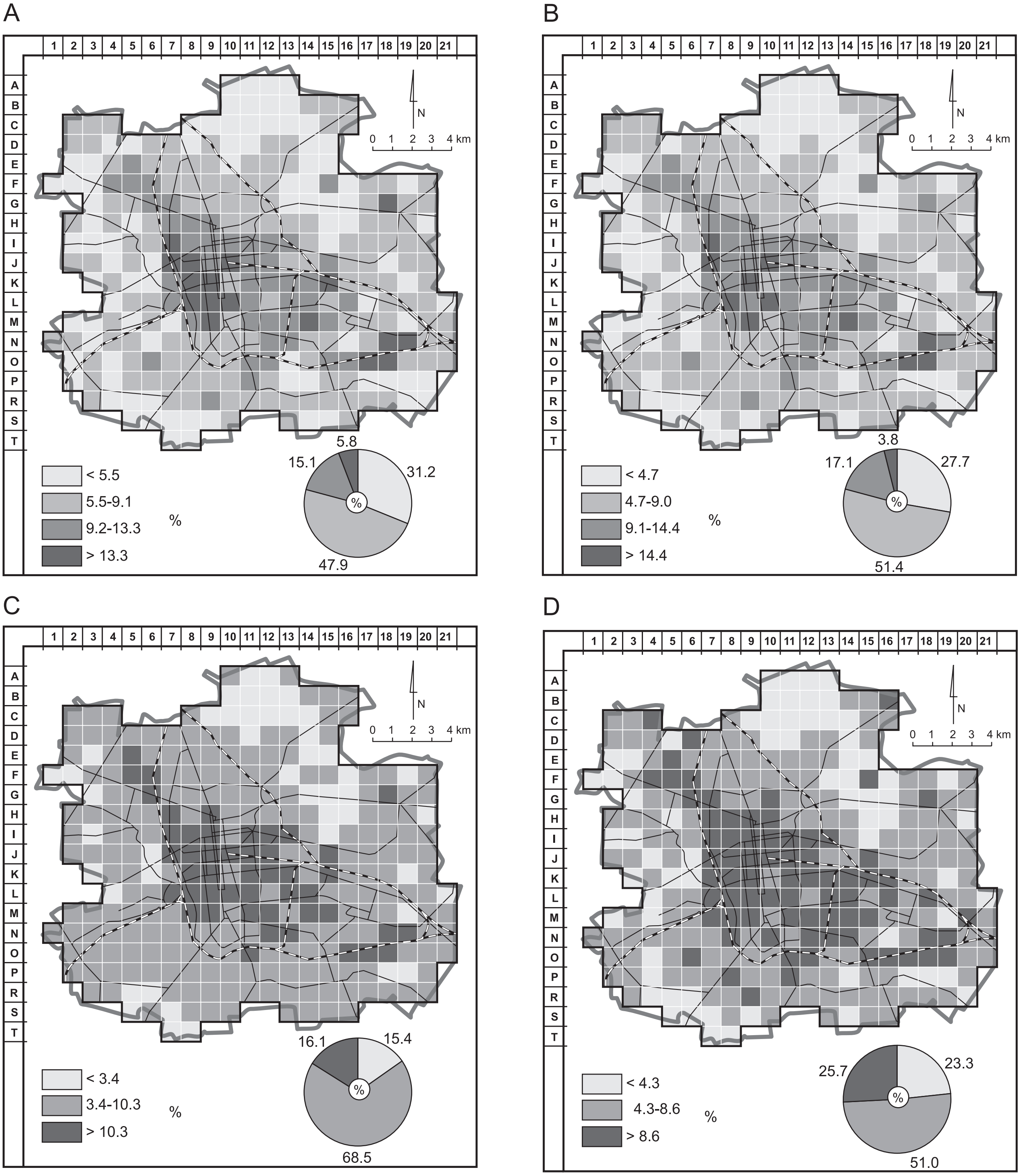


Fig. 3. Spatial diversity of percentage share of thermophilous species in the flora
Explanations: see Fig. 2

Table 1. Thermal preferences of species in the floras of basic study fields fitted with meteorological measurement sites

Indicators	Lublinek airport	Lipowa St.	Kilińskiego St.
Number of species with T>6	7	16	15
Percentage share of species with T>6 (%)	6.60	14.95	14.85
Average of indicator values T	5.74	5.94	5.97

In the entire city area, individual study fields may be found, where the number of species with T>6 ranges from 1 to 34. Their density increases progressively from rural areas towards the city centre (Figs. 2, 5). The highest values are recorded, however, outside the city centre, on railway and storage sites.

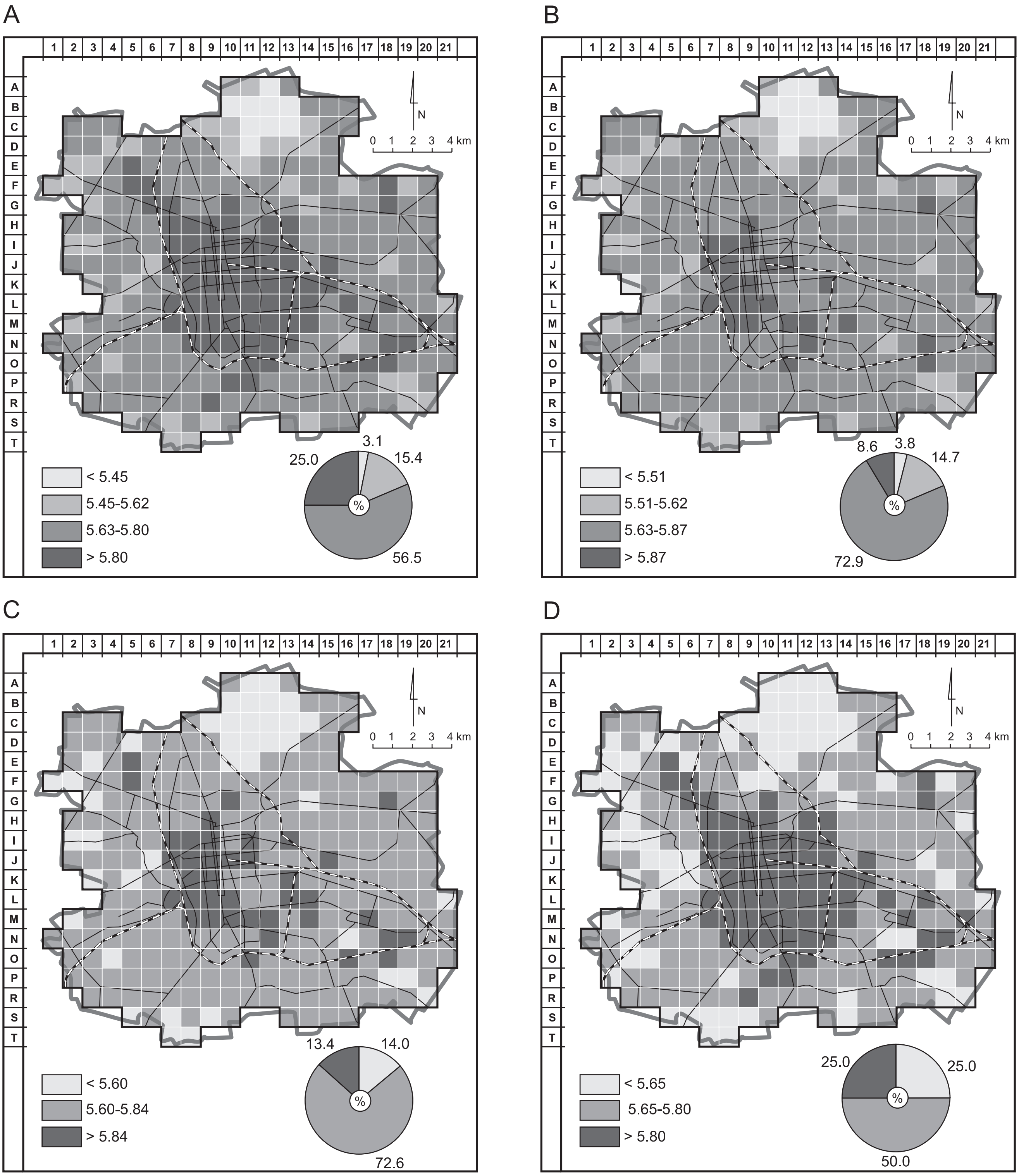
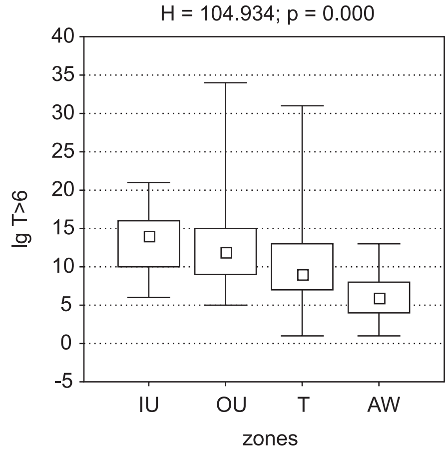


Fig. 4. Spatial diversity of average temperature indicator values
Explanations: see Fig. 2

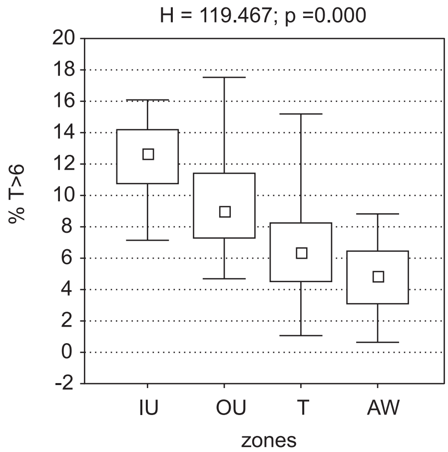
A

Statistical measure	lg T>6			
	IU	OU	T	AW
min	6	5	1	1
max	21	34	31	13
R	15	29	30	12
avg	13.2	12.7	10.2	5.8
s	3.8	5.0	5.8	2.6
V_s	28.7	39.6	56.5	45.2
Q_1	10.0	9.0	7.0	4.0
me	14.0	12.0	9.0	6.0
Q_3	16.0	15.0	13.0	8.0
R_Q	6.0	6.0	6.0	4.0
V_Q	21.4	25.0	33.3	33.3



B

Statistical measure	% T>6			
	IU	OU	T	AW
min	7.1	4.7	1.1	0.6
max	16.1	17.5	15.2	8.8
R	9.0	12.8	14.1	8.2
avg	12.5	9.4	6.6	4.6
s	2.4	2.8	3.0	2.1
V_s	19.5	29.2	46.0	45.3
Q_1	10.8	7.3	4.5	3.1
me	12.7	9.0	6.3	4.8
Q_3	14.2	11.4	8.2	6.5
R_Q	3.4	4.1	3.7	3.4
V_Q	13.5	22.9	29.5	34.8



C

Statistical measure	T_{avg}			
	IU	OU	T	AW
min	5.79	5.63	5.51	5.28
max	5.97	5.95	5.91	5.81
R	0.18	0.32	0.40	0.53
avg	5.89	5.81	5.71	5.64
s	0.05	0.07	0.09	0.11
V_s	0.88	1.17	1.54	1.93
Q_1	5.86	5.78	5.65	5.58
me	5.91	5.82	5.71	5.66
Q_3	5.93	5.85	5.77	5.72
R_Q	0.07	0.07	0.12	0.14
V_Q	0.56	0.58	1.05	1.21

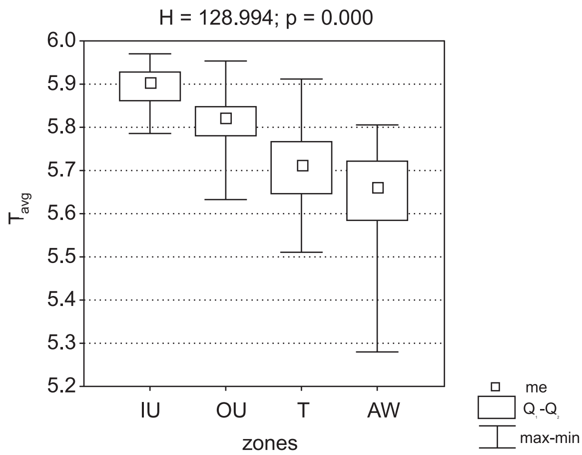


Fig. 5. Diversity of thermal preferences of species in the floras of basic study fields in urban functional zones
Explanations: A – number of thermophilous species, B – percentage share of thermophilous species, C – average of temperature indicator values; min – minimal value, max – maximal value, R – range, avg – average value, s – standard deviation, V_s – classical coefficient of variability, Q_1 – lower quartile, me – median value, Q_3 – upper quartile, R_Q – interquartile range, V_Q – positional coefficient of variability; zones: IU – inner urban (compact tenement-style buildings), OU – outer urban (areas built up by scattered block-style buildings and family houses), T – transitional, AW – agricultural and woodland

The percentage share of species with T>6 in individual study fields varies from 0.6% to 17.5%. Minimal values are recorded in the agricultural and forest zone, while maximal ones are reached in the centre and on railway and storage sites (Figs. 3, 5).

Average temperature indicator values in individual study fields within the city vary from 5.28 to 5.97. Lowest values are obtained for the floras of study fields located within the large forest complex in the northern part of the city (Łagiewniki Forest), while highest values are recorded for the floras of study fields located in the centre, on railway and storage sites as well as in a single study field that includes gravel pits in the north-eastern part of the city. Average temperature indicator values display a consistent tendency of progressive increase along the sequence from the agricultural and forest zone towards the inner urban zone (Figs. 4, 5).

Spatial diversity of values of individual measures of thermophilous character of the flora, which were considered in this study, was presented as variants for different class intervals (Figs. 2-5). Analysis of individual variants shows that the city area with the increased thermal requirements of the flora, which can be related to UHI and which corresponds to the range of zones with the urban character of buildings, in the conditions of Łódź is best delimited by values of thermophilous species share greater than 8.6% and average temperature indicator values greater than 5.80 (i.e. greater than the typical positional variability interval). Nearly all individual study fields with such parameters of the flora are located in the area of compact urban-type buildings (with the exception of study fields that include gravel pits and railway terrain).

4. Discussion and conclusions

The study has shown a spatial diversity of thermal preferences of the vascular plants of Łódź which is characteristic for major urban areas (e.g. Wittig 1991, 2002; Jackowiak 1998; Sudnik-Wójcikowska 1998a). Average temperature indicator values for the floras of individual study fields in the agricultural and forest zone and in the inner urban zone, recorded from Łódź, are close to the values reported by Wittig & Durwen (1981, 1982) for urban and rural floras in German cities.

The observed increase of thermal requirements of species in the flora is caused by forms of land use that:

- lead to the emergence of UHI and are reflected in an increasing gradient of thermal requirements of plants towards the city centre;
- are not linked to the emission of anthropogenic heat but contribute to transformations of topoclimatic conditions leading to an increase of temperature near the surface of the ground and are reflected in the occurrence of foci of thermophilous flora in areas located outside of the city centre (e.g. on railway terrain, storage areas or gravel pits).

The resulting image of diversity of thermal conditions in the city depends on the applied phytoindicator values and the method of cartographic result interpretation. Among the investigated thermal condition measures (based on the number of species with T>6, percentage share of species T>6 in the flora as well as average of temperature indicator values T_{avg}), the UHI area is reflected best by the diversity of thermophilous species percentage share (T>6) as well as diversity of average temperature indicator values. In the local conditions of Łódź, the area of the city which seems to be linked with the UHI is best delineated by the values of thermophilous species percentage share exceeding 8.6% and average temperature indicator values exceeding 5.80. Available sources lack relevant data to establish the extent to which the delimiting power of both values is only of local significance and to which they may be used to delineate UHI, also in other cities of Central Europe. Lower sensitivity with regard to UHI detection is ascribed to the indicator based on the number of thermophilous species (T>6). Due to the general decrease in species number towards the city centre this absolute number is not an objective measure of thermal requirements diversity in basic study fields.

The obtained results must be treated with due caution for at least two reasons. Firstly, due to its dynamic character, accurate borders of UHI are impossible to determine conclusively, although with some approximation it may be assumed that they overlap the boundary between urban and rural areas where a strong thermal gradient exists. Secondly, as indicated by Jackowiak (1998), pattern of occurrence of thermophilous species within the city may be related to other causes than the thermal gradient alone.

Investigations conducted in Łódź have confirmed the suitability of phytoindication for estimation of variability of thermal conditions in the city. An advantage of this method is the relatively small susceptibility of the results to fluctuations of intensity and spatial range characteristic for urban heat islands. However, no phytoindicative confirmation could be obtained for the periodic decrease of temperature of low-altitude air layers in the city centre caused by shading by densely distributed buildings when compared to suburban areas. Perhaps this could be changed by application of a different basic study field size.

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