Ann. Bot. Fennici 44: 170–180 ISSN 0003-3847
Helsinki 20 June 2007

Polish urban flora: conclusions drawn from *Distribution Atlas of Vascular Plants in Poland*

Ireneusz R. Moraczewski[1] & Barbara Sudnik-Wójcikowska[2]

[1)] *Department of Plant Systematics and Geography, Warsaw University, Al. Ujazdowskie 4, PL-00-478 Warsaw, Poland (e-mail: moraczew@biol.uw.edu.pl)*
[2)] *Department of Environmental Botany, Warsaw University, Al. Ujazdowskie 4, PL-00-478 Warsaw, Poland (e-mail: barbara.sudnik@uw.edu.pl)*

Received 29 May 2006, revised version received 27 Sep. 2006, accepted 18 Oct. 2006

Moraczewski, I. R. & Sudnik-Wójcikowska, B. 2007: Polish urban flora: conclusions drawn from *Distribution Atlas of Vascular Plants in Poland*. — *Ann. Bot. Fennici* 44: 170–180.

The aim of the paper was to determine a group of plant species whose distribution is highly correlated with the urbanization pattern in Poland. For this purpose the atlas of species distribution in Poland providing about 2300 cartograms was used. The population density was taken as an urbanization marker. By means of χ^2-test and the linear correlation coefficient species whose distribution was highly correlated with population density were selected. The raw list of species was consequently narrowed down to alien taxa, which did not reach the limits of their distribution in Poland. Species proposed as urban indicators have a continental character as well as high light and temperature requirements. Distributions of nine such species were mapped. Some synthetic variables showing cumulative distribution (referred to as mean and sum) proved to be even better urban indicators. The urbanophiles determined for Warsaw and cities from the western part of central Europe shared about 50% of the species.

Key words: bioindicators, flora of Poland, plant distribution maps, urban flora, urbanophiles

Introduction

In 2001, after twenty years of floristic data gathering and compilation, the much-anticipated *Distribution atlas of vascular plants in Poland* (ATPOL, Zając & Zając 2001a) was published. About 4.5 million floristic records were accumulated in the atlas. As many as 89% of the records were collected after 1945. The editors, therefore, assumed that most of the data entered in ATPOL are "up-to-date within a half-century time scale".

The atlas contains a collection of over 2300 species distribution maps. For various reasons, data pertaining to about 200 other species were not considered. A synoptic approach to the floristic data of each grid cell reveals an uneven level of flora recognition in particular regions of the country. Usually, in far-flung studies a homogeneous covering of the investigated area is very difficult to achieve. The ATPOL undertaking is not an exception in this respect. The simplest indicator of the data completeness in a square is the number of species found in it. These figures may, of course, vary depending on the geographical location of the squares, their habitat variability and form of land use. However, floristic lists ascribed to squares dramatically differ in length. Especially striking are 28 (out of 3276) almost "empty" squares (of 100 km^2 area) that are located inside the territory and have even fewer than 30 species. This suggests that one of the main factors influencing the final shape of the cartograms is the uneven coverage of various regions of Poland by the studies. Still, the atlas is of particular importance to researchers. It was successfully used in search for regularities of plant distribution in Poland (Zając & Zając 2000, 2001b, 2005, Kucharczyk 2003, Tokarska-Guzik 2003). On the one hand ATPOL provides material for syntheses, on the other it shows the blanks and gives an impulse and directions for further research. Atlases or flora distribution databases issued in adjacent countries have played a similar role, e.g., in Germany (Haeupler & Schönefelder 1989, Benkert *et al*. 1996, Deutschewitz *et al*. 2003, *see* also works based on them: Korsch 1999, Kühn *et al*. 2003, Kühn *et al*. 2004, Korsch & Westhus 2004).

The present study is aimed at analyzing the flora of cities and towns, which in the light of the collected data belong to the best investigated areas in Poland. In particular, the authors intend to determine a group of urban indicators (species associated strongly with urban areas) for the whole country.

Since the authors have been conducting their long-term floristic studies in selected cities of Poland (especially in Warsaw), they were able to postulate that there is a group of vascular plants in Poland, whose joint occurrence indicates strong anthropogenic transformations of the ecosystems. In other words, urban areas could be recognized on maps by examining the distribution patterns of some species as well as some synthetic distributions created by simple logical arithmetical or logical operations on the original maps.

Interesting results are obtained when the above group of species is compared with that of "extreme urbanophiles from the western part of central Europe", distinguished by some authors who investigated the urban flora of this region.

Material and methods

A total of 2304 original cartograms were digitized. Each cartogram consists of 3276 basic 10 × 10-km squares. In the process of database creation, non-existing stands, as well as erroneous or doubtful ones were omitted. Each species variable in the database is a binary (0/1) vector, as in the ATPOL only qualitative data were gathered. The database can provide material for simple visualizations (e.g., showing the number of species in particular grid squares) and more complex computations.

Population density, expressed as the number of people per km^2, was taken as an objective and plausible measure of urbanization advancement. A map provided by Environmental Information Center in Warsaw (Fig. 1) was digitized and generalized so that each grid square was assigned a mean population density value.

Measuring association between spatial distribution of a species and an abiotic variable within a grid is not a straightforward matter. This is due to the fact that particular observations (values in grid cells) can hardly be treated as independent (Manly 2001). Sophisticated methods for assessing correlation between spatial variables have recently been proposed. These techniques (e.g. Perry 1995, 1998) involve construction of a specialized statistics based on permutations of the input data set and therefore are computationally too costly to be applied to a database with over 3000 records and 2000 variables. It seems doubtful whether this computational strategy applied to a small subset of data (extracted to make the computation possible) would yield reliable results, since even the whole database is far from being complete. For these reasons the authors deliberately decided to proceed according to a simplified algorithm.

First, χ^2-test for 2 × 2 contingency tables was applied to eliminate spurious and too weak relationships. For each species distribution pattern the continuous population density variable was converted into a binary variable (with two classes: low and high population densities) so as to get the highest Cramer's V value between the resulting Boolean variable and the species variable. The V value is defined as follows:

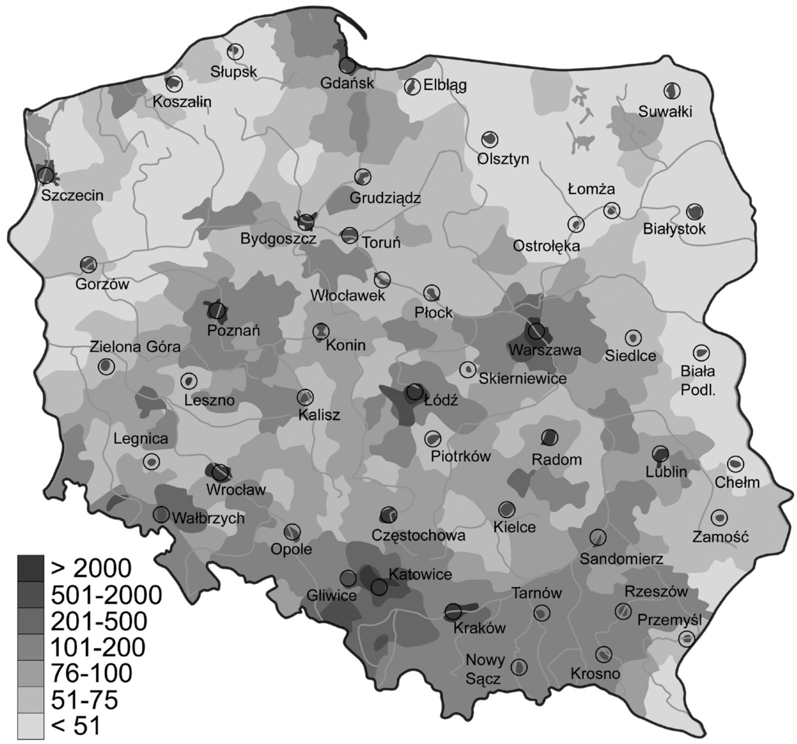

Fig. 1. Population density per km^2 in Poland (based on a map provided by UNEP/GRID-Warsaw, modified).

$$V = (\chi^2/N)^{½} \quad (1)$$

where N stands for the number of observations (squares). The threshold value dividing the population density into two classes was reported for each species variable. Contingency tables having one or more fields with counts < 5 or statistically insignificant ($P > 0.01$) were rejected.

Second, the linear correlation coefficient r was calculated for the remaining species variables and the population density (in its original continuous version). Its values can be treated as a rough approximation of correlation strength between population density and each species. Each case of particularly high correlation must be then subject to thorough informal, expert examination.

In order to determine a group of urban indicators for Poland, we analyzed the list of species obtained and subsequently made a further selection of species. Species that meet the following two criteria were finally accepted:

1. Plants of alien origin; native species were rejected. Although many of them are frequently encountered on anthropogenic sites, their natural stands are usually present outside the city, where they often occur abundantly. Therefore their indicator value would be restricted.
2. Plants that are expected to occur in the whole territory of Poland (i.e., do not show geographic preferences) and do not reach their distribution limits in Poland; however, *Oenothera* species were not considered in the study as they are difficult to identify, their origin is often unclear and the recognition of these species in the whole territory of Poland is uneven (most of the localities are in Silesia).

We constructed two synthetic variables for a group of species (presented in Table 1) with relatively high values of linear correlation coefficient and pointing to the population density values of over 500 people per km^2. The first one, referred to as *mean*, takes the value of 1 for squares where at least a half of all the selected species are present. The second variable (*sum*) is the logical sum of all the selected maps. Both are charted and compared with the location of cities and towns in Poland.

The species list obtained by us was compared with analogous "lists of urbanophiles" proposed by other researchers on the basis of long-term studies of urban flora, e.g. Wittig *et al.* (1985), whose concept was further developed by other authors (Sudnik-Wójcikowska 1986, Wittig 1991, Sudnik-Wójcikowska & Moraczewski 1997, Wittig 2002). Urbanophiles are defined here as species that are encountered more frequently in the city center than in the peripheries. The inner city is understood as an area highly altered by man and usually also most densely populated.

Special attention was paid to the origin and ecological requirements of the selected groups of species. Ellenberg's indicator values of vascular plants in central Europe were used (Lindacher 1995).

Table 1. List of species whose distribution in Poland is strongly correlated with population density. The synthetic variables *sum* and *mean* are obtained for species set in boldface (*see* Material and methods).

Species	Mean population density (people per km^2) in squares where the species was found	Correlation coefficient (*r*)	Cramer's *V*	Threshold value
Potentilla intermedia	**772.6646**	0.4159	0.309697	299.2653
Lepidium virginicum	**624.8266**	0.3934	0.331177	370.4082
Bassia scoparia (*Kochia scoparia*)	444.0872	0.3301	0.311197	368.3673
Atriplex tatarica	**536.9049**	0.3295	0.284625	370.4082
Chenopodium strictum	**745.1429**	0.3293	0.220008	169.4286
Atriplex oblongifolia	**618.6171**	0.3231	0.256595	169.4286
Iva xanthiifolia	**509.7778**	0.3087	0.268674	381.5918
Centaurea diffusa	**601.9865**	0.2924	0.252709	276.7551
Parthenocissus inserta	363.7049	0.2909	0.283288	260.2041
Clematis vitalba	419.7186	0.2824	0.263954	423.4694
Bunias orientalis	289.2864	0.2692	0.274484	150
Atriplex sagittata (*A. nitens*)	315.4168	0.2667	0.245435	371.1633
Lepidium campestre	275.3525	0.2614	0.319564	150
Ambrosia artemisiifolia	**654.2144**	0.2609	0.140335	148.7143
Euphorbia virgultosa	436.828	0.2531	0.255298	370.4082
Fallopia sachalinensis (*Reynoutria sachalinensis*)	353.2439	0.2529	0.238823	288.7755
Amaranthus albus	315.8097	0.2504	0.247147	370.4082
Sisymbrium altissimum	244.4038	0.2465	0.256292	368.3673
Sisymbrium volgense	**723.4197**	0.2414	0.138786	150
Hordeum murinum	268.2728	0.2411	0.249476	169.4286
Diplotaxis tenuifolia	356.5804	0.2375	0.21929	370.4082
Artemisia austriaca	368.2324	0.2365	0.202819	569.3469
Amaranthus blitoides	414.0839	0.2352	0.233951	382.7959
Sisymbrium loeselii	225.5547	0.2329	0.268726	66.85714
Chenopodium suecicum	485.4769	0.2329	0.163051	325.5102
Salsola kali ssp. *iberica* (*S. kali* ssp. *ruthenica*)	283.7856	0.2325	0.232268	370.4082
Artemisia annua	412.0167	0.2303	0.182835	378.5714
Epilobium ciliatum (*E. adenocaulon)*	276.9762	0.2273	0.278212	180.6122
Chenopodium album	288.6254	0.2256	0.205338	276.7551
Bidens frondosa	216.0052	0.2252	0.278172	171.2889
Tanacetum parthenium	243.1807	0.2251	0.253269	150
Ornithogalum umbellatum	286.3141	0.2236	0.199046	66
Digitaria sanguinalis	236.3329	0.2227	0.252554	169.4286
Geranium pyrenaicum	289.4096	0.2211	0.20428	205.6122
Bromus carinatus	286.6734	0.2192	0.260598	150
Fallopia japonica (*Reynoutria japonica*)	208.563	0.2183	0.308716	150
Synthetic variables: *Mean*	1442.197	0.5534	0.196755	150
Sum	318.3919	0.2929	0.285961	404.4082

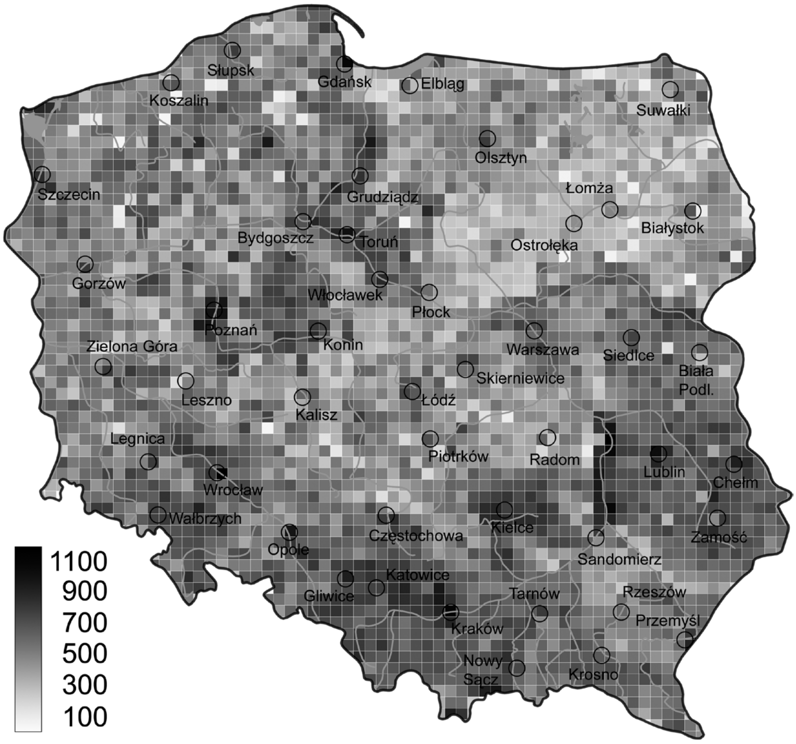

Fig. 2. The number of species recorded in the ATPOL grid squares (data from Zając & Zając 2001a).

All calculations were performed with programs written by the senior author.

Nomenclature of species follows that of Rothmaler (2002).

Results

Can cities be seen on ATPOL pages?

The population density varies within Poland (Fig. 1): the southern and central parts of the country are the most densely populated areas, whereas the north-west and north-east are much less populous. However the principal cities are distributed fairly evenly throughout Poland.

Nearly all cities with academic institutions (Bydgoszcz, Gdańsk, Katowice, Kraków, Lublin, Poznań, Szczecin, Toruń, Wrocław, etc.) can be easily distinguished on the cartograms showing the number of species in each square (Fig. 2).

The number of species recorded in the above areas is higher than the mean. One of the grid squares covering Wrocław has the highest (over 1100) number of species among all grid squares overlaying Poland. A few other squares covering cities contain more than 1000 taxa. For comparison: over 900 species were noted in one of the richest-in-species squares covering the Tatra Mountain region.

Floristic reflection of urban areas by the mere number of species is, of course, imperfect. For instance, non-urban areas with a high heterogeneity of habitats or rich in species for other reasons, as well as intensively studied regions such as the Wolin Island, Lublin region, some mountain ranges (the Tatras), big and medium-sized river valleys (e.g. the lower Vistula valley, the valley of the Bug river) are also very rich in species. The fact that cities can be more or less easily distinguished on maps is ascribed not only to real floristic enrichment in introduced species (sometimes only temporarily established), but also to the better coverage of the area by floristic studies as compared with suburban areas.

Making a thorough study of the possible correlation between population density and the spatial distribution of particular species and species groups is a more reliable method than the analysis of the floristic richness itself. It is less affected by the investigation time and complex methodics of floristic data compilation.

Correlation between plant species distribution and population density

A list of species whose distribution is most strongly correlated with the variable "population density" is compiled in Table 1. The species were arranged according to the decreasing values of linear correlation coefficient (r). Before the list was compiled, a preliminary selection of the species was made, as pointed out in "Material and methods". The names of the nine leading urban indicators (i.e., those pointing to population density of over 500 people per km^2) are set in boldface. The synthetic variables *sum* and *mean* obtained for these selected species, as described in the previous section, are also included.

The species list (Table 1) includes mostly epoecophytes, some archeophytes and single species cultivated mainly in parks, green areas and allotments, which escaped locally from cultivation and seem to be permanently established in their new habitats (e.g. *Ornithogalum umbellatum, Kochia scoparia*).

Distribution maps of nine urban indicators with relatively high values of linear correlation coefficient and pointing to the population density values of over 500 people per km^2 are presented in Fig. 3. The distribution patterns of particular species reflect the distribution of some large cities in Poland. However, the synthetic variables *sum* and *mean* are much better urban indicators (Fig. 4):

— the variable *sum* presented in form of a map clearly corresponds with the location of medium-size and large cities of Poland;
— the variable *mean* is more restrictive and takes the value of 1 for squares which share at least five species of the nine selected; it shows quite accurately where the largest cities are located.

Urban indicators *versus* urbanophiles

Table 2 lists 20 species that are most strongly associated with high population density in Poland. We compared the above group of plants with a group of 20 urbanophiles from the western part of central Europe (Wittig 1991, 2002), and with a group of 14 urbanophiles selected for Warsaw (Sudnik-Wójcikowska 1998a, 1998b). In the case of alien species their origin was indicated. It should be noted that the above-mentioned authors considered also a few native taxa (apophytes).

Contrary to the expectations, the three lists had only few elements in common (marked with an asterisk). Wittig's (1991, 2002) list included alien species as well as four species regarded by the author as indigenous plants (*Cardaminopsis arenosa, Lactuca serriola, Silene vulgaris, Vulpia myuros*). The 20-element sublist (Table 2) and Wittig's list have four species in common. The number of shared species could increase when the list in Table 2 is extended through the inclusion of another ten species. The list of urbanophiles for Warsaw contains mostly alien species (including five taxa shared with the list proposed in this article: *Atriplex tatarica, Bunias orientalis, Hordeum murinum, Iva xanthiifolia, Potentilla intermedia*). However, the Warsaw list also contains some indigenous species, i.e. *Astragalus cicer, Euphorbia peplus*, and *Potentilla supina*.

The analysis of the main centers of distribution of urbanophiles selected for Poland revealed the dominating role of continental species which originated in southeastern Europe and western or central Asia from steppes, forest-steppes and semideserts. The proportion of species of American origin did not exceed 25% in this species group; among them were *Iva xanthiifolia* and *Ambrosia artemisiifolia*, which are associated mostly with the steppe zone. As could be expected, most of the Eurasian "continental" species, such as *Atriplex tatarica*, *A. oblongifolia*, *Bunias orientalis*, and *Kochia scoparia* were not included in Wittig's list (although the list contains some species with similar origin, e.g. *Sisymbrium altissimum* and *Salsola kali* subsp. *iberica*).

Ellenberg's indicator values were used to determine the light and temperature requirements for species included in the three lists. In agreement with previous works (e.g. Landolt

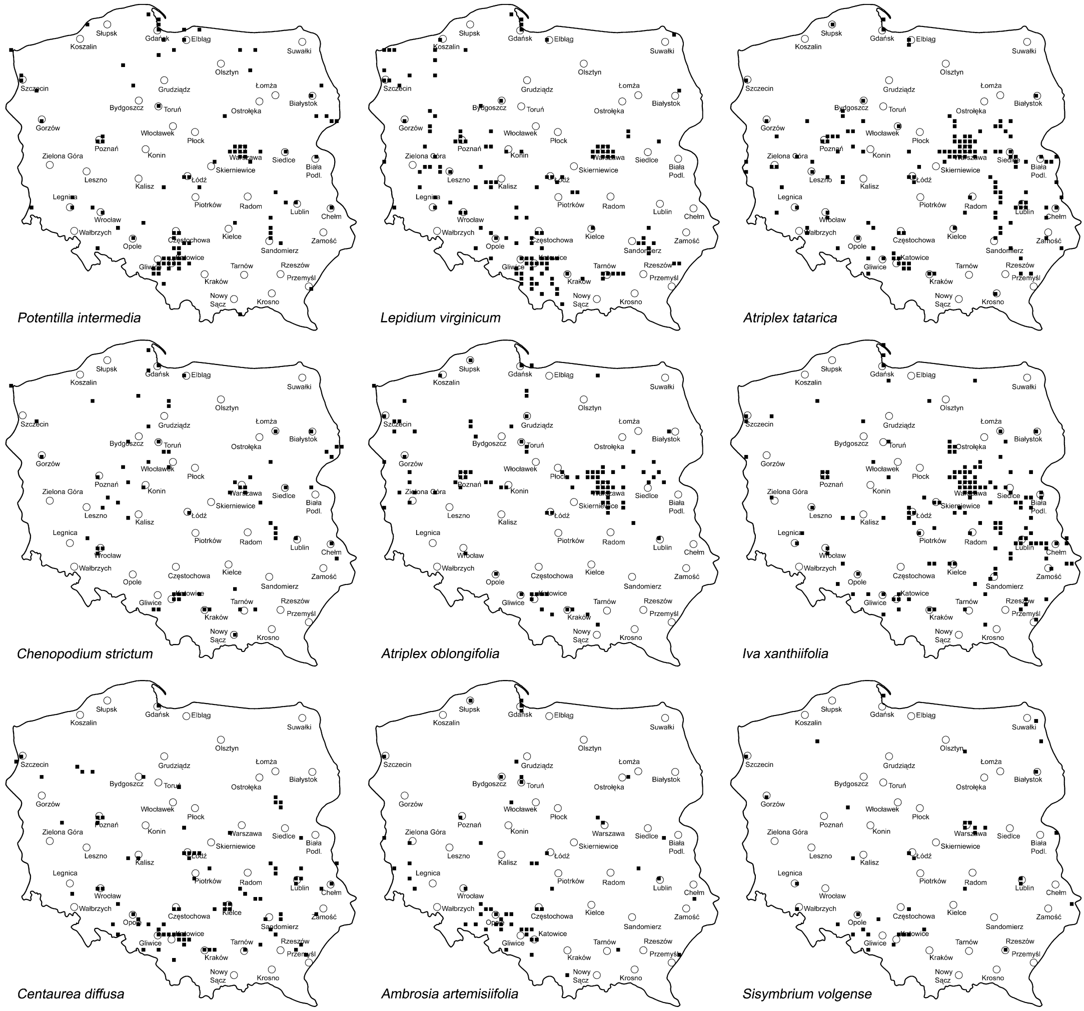

Fig. 3. Distribution of the nine leading urbanophiles in Poland (based on the ATPOL data, Zając & Zając 2001a).

1991a, 1991b, Celesti Grapow 1995, Sudnik-Wójcikowska 1998a, 1998b, 2000, Wittig 2002), species with high light and temperature requirements dominated in all three cases. The mean values for temperature exceeded 6.6 (6.64–6.71), and for light oscillated around 8 (7.9–8.3).

Discussion

Distribution of the largest cities in Poland and indicator species

An analysis of the population density map of Poland (Fig. 1) showed an uneven distribution of population within the country. The southern territories are more densely populated, which is due to the long history of intensive settlement of this area (Małopolska) and the presence of natural resources, as well as the development of mining industry and concentration of big industrial centers in the region. By contrast, the north-west and north-east regions of Poland are less populated which is mainly associated with the migration of people after World War II.

It should be emphasized, however, that the more or less regular distribution of small areas with a maximum number (> 500) of people per km^2 within the country corresponding to medium-size and large cities (Fig. 1) suggests

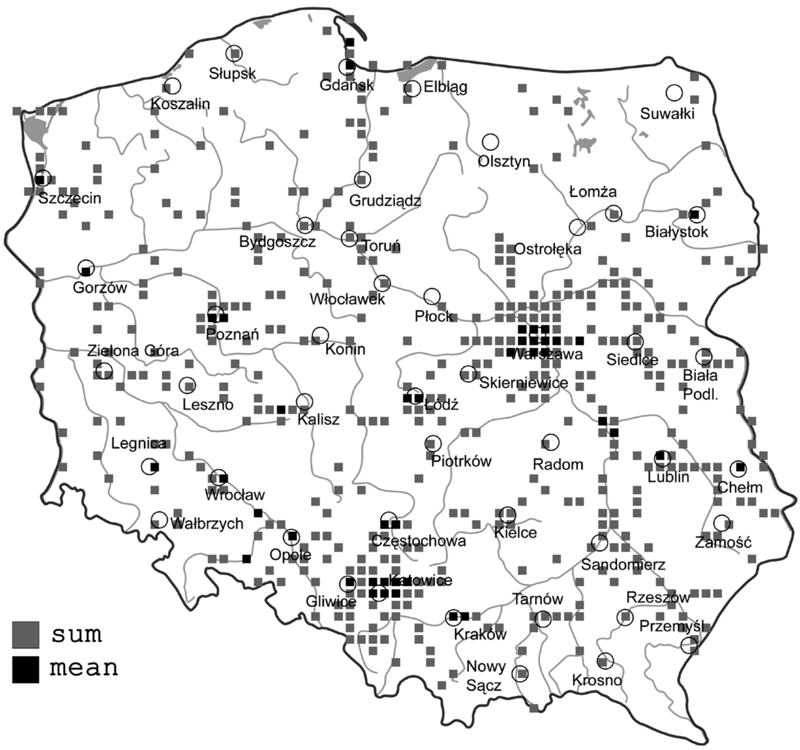

Fig. 4. A synthetic map created for a group of nine urbanophiles. The variables *mean* and *sum* are marked black and gray, respectively (*see* Material and methods).

that transition species, with no distribution limits in Poland, should be the best urban indicators. Particularly misleading in this respect would be species with northern limit of distribution in Poland (i.e. occurring mostly in southern Poland). The distribution of the above species would appear to correlate with higher population density, whereas the main factor determining their distribution was the climate. Therefore species with a wider distribution in Europe, even cosmopolitan plants, are much better urban indicators.

The problem of the universal character of urban indicators

We compared the above-mentioned lists containing 14 urbanophiles selected for Warsaw and 20 urbanophiles for cities in the western part of central Europe with the obtained list of urban indicators. It should be noted that the methods used for selecting the urbanophiles and urban indicators were not identical:

— urbanophiles both for Warsaw and other central European cities were selected with regard to the contrast between the city center and periphery;
— urban indicators were determined only for the Polish cities; their distribution was correlated with population density; the basic unit of the area investigated was a 10 km^2 square.

The present study allowed us only to draw conclusions about species associated with eastern part of central Europe. The analysis of species groups "associated" with large cities in different parts of central Europe revealed that they shared a few species. Some unification of urban flora within this region is brought about by, among others, the presence of a heat island in central European cities. It was found that most plants that are regarded as useful urban indicators had high light and temperature demands. It seems, however, that the role of the urban heat island, which is particularly marked in the zone of proper temperate climate prevailing in central Europe, changes in southern Europe (warm tem-

Table 2. Species currently regarded as bioindicators of Polish cities and species treated by various authors as urbanophiles in central Europe. The list is supplemented with data regarding the species origin as well as their temperature and light requirements (boldface, *see* Table 1; asterisk, species listed in at least two publications).

	Bioindicators proposed for Polish cities	T	L	Origin	Urbanophiles of Warsaw (Sudnik–Wójcikowska 1998a)	T	L	Origin	Urbanophiles of central Europe	T	L	Origin
1	*Amaranthus albus	8	8	Am N	Amaranthus lividus	7	8	Eur S, Afr N	*Amaranthus albus	8	8	Am N
2	**Ambrosia artemisiifolia**	7	9	Am N	Astragalus cicer	6	7	–	Berteroa incana	6	9	–
3	Atriplex sagittata = A. nitens	7	9	Eur SE, Asia W	*Atriplex tatarica	7	9	Asia C	Bromus tectorum	6	8	Eur S, Asia SW
4	**Atriplex oblongifolia**	7	9	Eur E, Asia W	*Bunias orientalis	6	7	Eur SE, Asia W	Cardaminopsis arenosa	0	9	–
5	***Atriplex tatarica**	7	9	Asia C	Diplotaxis muralis	8	8	Eur S,W	Cardaria draba	7	8	Eur SE, Asia SW
6	Bassia scoparia = Kochia scoparia	–	–	Eur E, Asia W	Eragrostis minor	7	8	Eur SE	Carduus acanthoides	5	9	Eur S
7	*Bunias orientalis	6	7	Eur SE, Asia W	Euphorbia peplus	6	6	Eur S	Chenopodium botrys	7	8	Asia C
8	**Centaurea diffusa**	7	9	Eur E, Asia SW	*Hordeum murinum	7	8	Eur ES, Asia SW	Diplotaxis tenuifolia	7	8	Eur S,W
9	**Chenopodium strictum**	7	9	Asia C	*Iva xanthiifolia	7	9	Am N	Eragrostis minor	7	8	Eur SE
10	Clematis vitalba	6	7	Eur C, SW	Lepidium ruderale	6	9	Asia SW	*Hordeum murinum	7	8	Eur ES, Asia SW
11	Euphorbia virgultosa	6	9	Eur SW	Malva neglecta	6	8	Asia SW	Lactuca serriola	7	9	Eur S, Asia SW
12.	Fallopia sachalinensis	7	7	Asia E	Onopordum acanthium	7	9	Eur S, Asia SW	*Lepidium virginicum	7	8	Am N
13.	*Hordeum murinum	7	8	Eur ES, Asia SW	*Potentilla intermedia	6	8	Eur NE, Asia N	Oenothera biennis	7	9	–
14.	***Iva xanthiifolia**	7	9	Am. N.	Potentilla supina	7	7	–	Poa compressa	0	9	–
15.	Lepidium campestre	6	7	Eur S					Reseda lutea	6	7	–
16.	***Lepidium virginicum**	7	8	Am N					Reseda luteola	7	8	Eur S, Asia W
17.	Parthenocissus inserta	–	–	Am N					S. kali ssp. iberica	7	9	Eur SE, Asia C
18.	***Potentilla intermedia**	6	8	Eur NE, Asia N					Silene vulgaris	0	8	–
19.	*Sisymbrium altissimum	6	8	Eur SE, Asia C					*Sisymbrium altissimum	6	8	Eur SE, Asia C
20.	**Sisymbrium volgense**	6	8	Eur SE					Vulpia myuros	7	8	–

perate climate) along the north–south axis.

The apparent differences between the three species groups compared may result from the changing climate conditions along the east–west gradient (smaller contrasts between climate, especially humidity, increasing toward the west) and, to some extent, the application of slightly different methodology. Poland is situated in a zone of transition from the oceanic climate in the west and the continental climate in the east. Our study confirms that species with continental distribution play a leading role as urban indicators in this part of central Europe.

Acknowledgements

Population density map (for computations and the presentation) was prepared based on an original map provided by Environmental Information Center in Warsaw (UNEP/GRID, Warsaw).

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