

Richness of vascular flora in Lublin city, east Poland, under different urban pressure

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Abstract Cities are commonly described as mosaics of habitats with increasing degrees of human impact along a gradient from the outskirts to the centers, which may lead to both an increase and a decline in species richness and diversity. Data on species richness in the city of Lublin had been collected in a model transect containing 20 1-km² study squares. We used ordination methods correspondence analysis (CA) and redundancy analysis (RDA), Spearman's rank correlation, forward selection, and the Monte Carlo permutation test to determine which factors have the greatest effect on species richness in various types of city habitats. There were 795 vascular plant species in squares, with predominance of native (540) rather than alien (255) species. The greatest richness was reported in the city center, where residential areas border railway infrastructure and extensively cultivated agricultural areas. The lowest number of species was found in peripheral areas overgrown by seminatural vegetation. The main factor determining species richness and flora quality in the city is human impact. Species richness of native and alien plants is influenced by the landscape structure created by land-use and land-cover variability, hemeroby level, and the period under urban pressure.

Keywords Urban flora · Native plants · Alien plants · Anthropopressure indicators · Land-use · Land-cover

Introduction

Urban ecosystems differ from natural or rural ones in many obvious ways. Human activities, such as building, traffic, and industrial production affect air, water, and soil quality, which affects ecosystems in many ways (Starfinger and Sukopp 1994). Plants can be destroyed or their production reduced. Typically, cities show a mosaic of habitats with increasing degrees of human impact along a gradient from the outskirts to city centers. Organisms and communities in these habitats react to human influences (synanthropization) in various ways and are consequently different for each structural unit of the city (Sukopp 2004).

According to Faliński (1972): Synanthropization of vegetation is a part of directional changes occurring on Earth under the impact of human activities, manifesting themselves as replacement of specific, i.e. endemic components, with nonspecific, i.e. cosmopolitan elements, replacement of native (autochthonic) components with newcomers (allochthonic elements), and replacement of stenotopic components with eurytopic ones. In consequence, this means replacement of primary systems conditioned by the joint effect of endogenic and exogenic factors with secondary systems conditioned mainly by exogenic factors.

Classification of synanthropic floras and its terminology adopted in Central Europe was elaborated by Thellung (1918–1919, after Tokarska-Guzik 2005), applied in Poland, and modified by Kornaś (1981), who adopted the following basic criteria: origin, time of arrival, and degree to which a particular species is established. Based on this idea, flora of urban areas consist of two main groups of species: The first group is native—spontaneophytes, non-synanthropic species occurring exclusively on natural and seminatural habitats; and apophytes, occurring in human

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habitats. The second group is alien—anthropophytes, plant taxa whose presence is due to intentional or accidental introduction as a result of human activity. The second group is permanently or temporarily established in anthropogenic habitats and sometimes penetrate into seminatural or natural communities. Among anthropophytes, three categories have been distinguished: archaeophytes (older newcomers), introduced before 1500; and kenophytes (newer newcomers), introduced after 1500 when Christopher Columbus arrived in the New World and the Columbian Exchange began. To the latter group belong diaphytes, i.e., species with temporary occurrence in human habitats only (noninvasive).

Human interference with the natural environment in terms of species richness (SR) and diversity has a bidirectional character, which may lead to an increase and a decline in both these values. This is related to changes in the landscape structure and an influx of species colonizing new habitats. Initially, anthropopressure greatly contributed to the increase in SR; it is estimated that the highest values of plant species diversity in Europe were recorded in the period preceding the Industrial Revolution (Kornaś 1981). The subsequent period was characterized by gradual disappearance of taxa: first of native stenotopic species and next of older newcomers associated with extensive agriculture and early settlement (Zajac et al. 2009). Alien species (AS) appearing in an ecosystem or plant community exert an impact on biodiversity, depending on the level of their expansiveness. In the case of invasive species, this is mainly associated with a decrease in diversity indicators (Parker et al. 1999; Hejda et al. 2009).

The aim of this work was to assess the impact of various factors on species diversity and the quality of spontaneous flora in the city of Lublin, Poland, observed within a model transect comprising representative habitats in the city area. The objectives formulated by the authors also include estimation of the significance of the factors in question for qualitative and quantitative traits of flora and its transformations. It was assumed prior to the investigations that the floristic richness of the study area depends on urban factors, e.g., form of land use, habitat heterogeneity (HH), period under urban pressure (PU), and hemeroby level (HL), as well as on natural conditions, i.e., soil cover and proportion of AS in flora and vegetation cover.

Methods

Study area

Lublin is the principle city of southeastern Poland and capital of the province. In its present administrative

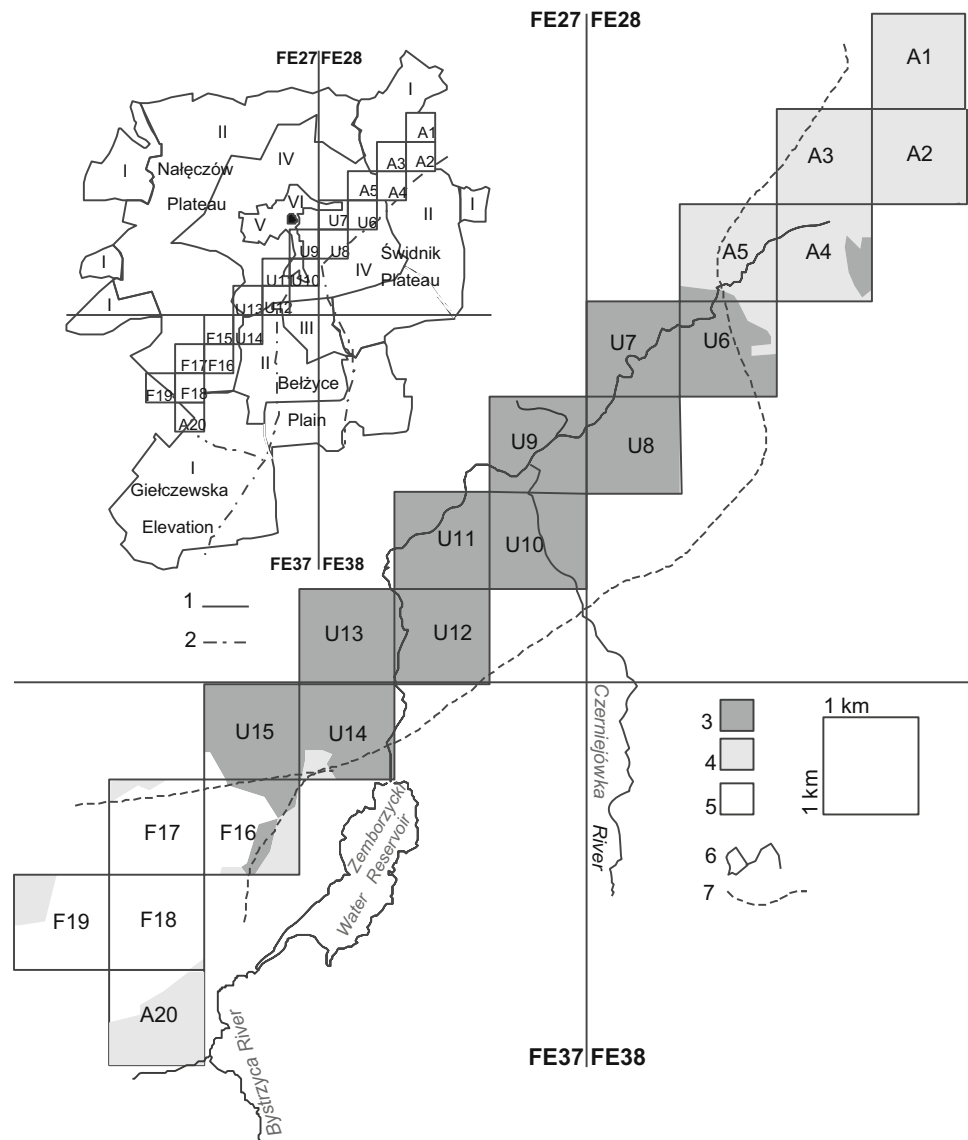
boundaries, it covers the area of 148 km² situated between 51°08′–51°18′N and 22°27′–22°41′E and has a population of 300,000 permanent residents. The city is located in the central-northern part of the macroregion of the Lublin Upland on the border of four subregions (Fig. 1): Nałęczów Plateau, Bełżyce Plain, Świdnik Plateau, and Giełczewska Elevation (Kondracki 2009). The city of Lublin is characterized by fairly specific climatic properties. The average growing season lasts 209 days (Kaszewski 2008). The basic Quaternary substratum is composed of loess predominating in the western part and loess-like and clay covers predominating in the southern part (Chałubińska and Wilgat 1954). Most often, these are urban and industrial soils with different degrees of pollution and contamination (Kukier 1985; Turski et al. 2008). The oldest records concerning the origins of Lublin date back to the ninth century. The city began as a settlement on the three Old Town's Hills (Rozwałka 1997). At the beginning of the twentieth century, the growing population numbered 50,000 (Sochacka 1997).

Research data was collected along a transect consisting of 20 1-km² study squares. The established squares correspond to the arrangement of the squares used in the ATPOL grid system (Zajac 1978). The transect crosses the area of Lublin from NE to SW and passes through diverse types of habitats that are representative for the city area (Fig. 1). Each study square was assigned a number of traits classified into two categories—flora and urban indicators—described in Tables 1 and 2.

Data collection

Habitat analyses were performed taking into account selected urban indicators (Table 1). PU was determined based on historical data (Rozwałka 1997). This period in the study squares distinguishes between study areas that have been used for >600 years and those that were included in the city limits in the 1980s (Fig. 1; Table 1). The landscape structure (caused by land-use and land-cover variability), communication network, and HH was assessed on the basis of Landsat digital data available at the European Environmental Agency (EEA). Those urban areas are defined from classes of land cover contributing to the urban tissue and function and laying less than 200 m apart. Land-use and land-cover data contain three main data sets—from general in label 1 to details in label 3. In this study, three land-cover and land-use classes from label 1 were taken into account: agricultural areas (A), artificial surfaces in work-named urban areas (U), and forests and seminatural (F) areas distinguished on the basis of the dominant major form of land use and land cover in the study square (Fig. 1). Differentiation of particular land-use and land-cover labels are given in Table 1 (labels 1 and 3) and their

Fig. 1 Study area on the background of the *Atlas of Distribution of Vascular Plants in Poland* (ATPOL) grid and development of the city. Period under urban pressure from the longest to the shortest: VI foundation territory, V ~600 years, VI ~100 years (before 1916), III 1916–1931 (~90–80 years), II 1954–1959 (~60–50 years), I 1975–1989 (~40–25 years); land use and land cover levels of study squares (I–20): 1 squares of ATPOL grid 10 km × 10 km, 2 boundaries of physicogeographical subregions of the Lublin Upland by Kondracki (2009), 3 urban areas, 4 agricultural areas, 5 forests and seminatural areas, 6 rivers and water bodies, 7 railway tracks



proportions in Table 3 and “Appendix”. We mapped the distribution of land use and land cover and calculated their proportion using a geographic information system (ESRI 2003) for each transect square. The length of roads (Ro) and railways (Ra) were calculated in the same way. The communication network included paved roads and railway tracks (“Appendix”). Landscape or HH is a complex phenomenon involving size, shape, and composition of different landscape areas and the spatial relations between them. Land-use and land-cover units have been used to compare differences in heterogeneity of study patches within city landscapes (Cale and Hobbs 1994). On the basis of number of land-use and land-cover types in a study square, for the purposes of this paper, HH indicator was evaluated. If in a study square only one form of land use and land cover exists (label 1), $HH = 1$, regardless of the variation (label 3); for example, the proportion of A in

square A1 is 100% and $HH = 1$; in square F16, $HH = 3$, which is caused by three types of land-use and land-cover units (Table 3).

A slightly modified 4-grade scale developed by Sukopp (1972) was used to assess HL given in Table 1. Levels of species hemeroby were estimated during the field research ascribed in accordance with the increasing intensity of anthropopression. Our data set was taken from the BiolFlor database, according to which hemeroby is a measure of departure from naturalness. Habitats and vegetation types are classified along the hemeroby scale from ahemerob (natural) to polyhemerobic (non-natural). Sites without plant life are metahemerobic. BiolFlor indicates the amplitudes of hemeroby so that all levels of hemeroby are indicated in which a plant species can occur. Particular species may vary in scope of HL. There are strongly transformed habitats appearing

Table 1 List of urban indicators used to describe habitat in study squares

Variable	Description
Period under urban pressure (PU)	VI: foundation territory, V: ~600 years, IV: ~100 years (before 1916), III: 1916–1931 (~90–80 years), II: 1954–1959 (~60–50 years), I: 1975–1989 (~40–20 years)
Land-use and land-cover levels	F: forests and seminatural areas: broad-leaved (blf), coniferous (cf); A: agricultural areas: complex cultivation patterns (ccp), nonirrigated arable land (al), pastures (p), land principally occupied by agriculture with significant areas of natural vegetation (nv); U: urban areas: continuous urban fabric (cuf), discontinuous urban fabric (duf), green urban areas (gua), construction sites (cs), sport and leisure facilities (sandl)
Communication network	Ro: roads ($\text{km} \times 1 \text{ km}^{-2}$); Ra: railway areas ($\text{km} \times 1 \text{ km}^{-2}$)
Habitat heterogeneity (HH)	Amount of land-use and land-cover habitats
Hemeroby level (HL)	1: oligohemerobic—little anthropogenic influence, actual vegetation corresponds with natural vegetation, e.g., best preserved patches of forest, xerothermic grasslands; 2: mesohemerobic—anthropogenic factors in a low to moderate degree, e.g., meadows, pastures, bushes; 3: euhemerobic—anthropogenic factors act constantly to a high degree; ruderal, segetal, and transformed seminatural communities, e.g., field and garden habitats, fallow grounds, waste lands; 4: polyhemerobic—influence of anthropogenic factors is constant and very strong, e.g., roadsides, railway areas

simultaneously in natural and seminatural environs. The HL was calculated by assigning a value to each hemeroby degree (Table 1). The HL for species is the sum of hemeroby degrees divided by their number, e.g., *Adoxa moschatelina*: $1 + 2 = 3/2$ and $HL = 1.5$. HL for the square is the sum of the average degree of species hemeroby divided by the number of species in a square (Table 3).

Floristic data had been collected during field studies, i.e., by mapping the Lublin vascular flora in 2002–2008 (Rysiak 2009), which was repeated in vegetation seasons 2010–2011 in all habitats along a study transect. Distribution of species was noted in the grid composed of squares $1 \times 1 \text{ km}$. Occurrence of a species in a square was regarded as its locality (binary variables, presence or absence of species in square). Analysis of flora was performed at two levels: general flora in the entire transect, and flora of each study square. The description of each taxon comprises affiliation to geographical-historical (geohistorical) elements on the basis of papers by Zajac (1979) and Tokarska-Guzik (2005), syntaxonomic (synecological) affiliation of species after Matuszkiewicz (2008) and endangered species, both according to the Regional (Kucharczyk 2003) and National (Mirek et al. 2006) Red Lists, and legally protected species listed in the Regulation of the Minister of Environment (2012). Based on the number of native and AS, synanthropization indicators were calculated for each plot (Kornaś 1977; Jackowiak 1990). This data was defined as flora indicators. Latin names of species are based on nomenclature proposed by Mirek et al. (2002).

Statistical analyses

To analyze the relationship between flora and urban indicators in Lublin, we calculated Spearman's rank coefficient. Species responses to experimental treatments were evaluated with multivariate methods in Canoco version 4.5 (ter Braak and Šmilauer 2002), with flora indicators in squares as response variables and values of urban indicators as explanatory variables, i.e., predictors (Tables 1, 2). According to gradient length from a preliminary detrended correspondence analysis (DCA), a linear method, redundancy analysis (RDA) was used for flora and urban indicators. Relationships between flora and urban indicators were analyzed by three series of RDA: SR/urban indicators, geohistorical elements/urban indicators, and synecological groups of species/urban indicators. The first RDA analysis was based on SR as compositional data matrix and urban indicators as explanatory variables. In the second and third RDA analyses, based on SR, number of geohistorical elements and synecological groups of species in each study square were calculated. RDA models are free from problems caused by multicollinearity of variables. Variance of the inflation factor (VIF) of each explanatory variable was measured in the extent of multiple correlation with other predictors. If VIF variables are large (>20), they are almost perfectly correlated with each other. High VIFs indicate multicollinearity among explanatory variables. If an explanatory variable is completely multicollinear, its VIF is set to 0 (–0.000) and its regression coefficient to 0. Normally, VIFs are usually >1.0 . (ter Braak and Šmilauer 2002). During the fitting of explanatory variables, collinearity of U, $VIF_U = 27.13$ and multicollinearity

Table 2 Flora indicators used to describe study squares

Flora indicator	Description
Species richness (SR)	Numbers of species in basic squares or entire transect
Endangered species (ES)	Species from Regional and National Red Lists and legally protected
<i>Geographical-historicalelements</i>	
Sponthaneophytes (N_{SP})	Indigenous species, occupying natural and seminatural habitats
Apophytes (N_{AP})	Indigenous species, permanently occupying anthropogenic habitats
Native species (N_{NS})	Amount of apophytes and sponthaneophytes
Archeophytes (N_{AR})	Species of foreign origin, introduced before the end of fifteenth century, permanently naturalized
Kenophytes (N_{KN})	Species of foreign origin introduced after fifteenth century, permanently naturalized
Diaphytes (N_{DIA})	Species of foreign origin, occurring sporadically, introduced by human activity or growing wild from arable lands
Alien species (N_{AS})	Amount of archeo-, keno-, and diaphytes
<i>Synecological groups</i>	
Forest species (N_F)	Species from syntaxa: <i>Rhamno-Prunetea</i> , <i>Salicetea purpureae</i> , <i>Alnetea glutinosae</i> , <i>Erico-Pinetea</i> , <i>Vaccinio-Piceetea</i> , <i>Quercetea robori-petraeae</i> , <i>Querco-Fagetea</i>
Cut-over and moorland species (N_{CM})	Species from syntaxa: <i>Nardo-Callunetea</i> , <i>Epilobion angustifolii</i>
Meadow species (N_M)	Species from syntaxa: <i>Molinio-Arrhenatheretea</i>
Xerothermic species (N_X)	Species from syntaxa: <i>Festuco-Brometea</i> , <i>Trifolio-Geranietea sanguinei</i>
Water and waterside species (N_W)	Species from syntaxa: <i>Lemneteae</i> , <i>Potametea</i> , <i>Utricularietea intermedio-minoris</i> , <i>Montio-Cardaminetea</i> , <i>Scheuchzerio-Caricetea fuscae</i> , <i>Bidentetea tripartiti</i> , <i>Isoëto-Nanojuncetea</i> , <i>Phragmitetea</i>
Segetal species (N_S)	Species from syntaxa: <i>Polygono-Chenopodietalia</i> , <i>Stellarietea mediae</i>
Ruderal species (N_R)	Species from syntaxa: <i>Eragrostietalia</i> , <i>Sisymbrietalia</i> , <i>Artemisietea vulgaris</i> , <i>Agropyreteae intermedio-repentis</i>
Undefined species (N_{UN})	Species with undefined phytosociological affiliation
<i>Synanthropization indicators</i>	
Anthrophytization indicator (I_{AN})	$I_{AN} = (N_{AR} + N_{KN}) \times 100/SR$
Archaeophytization indicator (I_{AR})	$I_{AR} = N_{AR} \times 100/SR$
Kenophytization indicator (I_{KN})	$I_{KN} = N_{KNz} \times 100/SR$
Modernization indicator (I_M)	$I_M = N_{KN} \times 100/(N_{KN} + N_{AR} + N_{DIA})$

among forests (F) $VIF_F = -0.000$, variables were detected; in all RDA analyses, these factors were removed.

RDA analysis was combined with Monte Carlo permutation tests (499 permutations). The test has the ability to evaluate the significance of constrained ordination models and relate to the general null hypothesis, stating the independence of the primary (species) data on values of explanatory variables. Consequently, values of environmental variables are randomly assigned to individual samples of species composition, ordination analysis is done with this permuted (shuffled) data set, and the value of the test statistic is calculated. In this way, both response variable distributions and explanatory variable correlation structures remain the same in the real data and in the null-hypothesis simulated data. Stepwise selection of the model testing the usefulness of each potential predictor (environmental) variable for extending the subset of explanatory variables was used in the ordination model. The

relationship is characterized by the F value of the analysis of variance (ANOVA) of the regression model. Unconstrained correspondence analysis (CA) was run to quantify the unique contribution of each of the 20 groups of plants in transect squares. In this way, data set homogeneity was tested (ter Braak and Šmilauer 2002; Lepš and Šmilauer 2002).

Results

Value of habitat indicators

The study transect contained three major types of habitats (Fig. 1): Agricultural (A1–A5 and A20), urban (U6–U14), and forest (F16–F19) areas differ in terms of particular land-use and land-cover, proportion of communication network, and urban indicators. A and F areas are less

Table 3 Proportion of particular land-use and land-cover areas and value of urban indicators in study squares

Square	Land-use and land-cover										
	Agricultural areas (%)					Urban areas (%)					
	ccp	al	p	nv	Sum	cuf	duf	gua	cs	sandl	Sum
A1	2	89	0	9	100	0	0	0	0	0	0
A2	4	62	0	34	100	0	0	0	0	0	0
A3	18	62	8	2	100	0	0	0	0	0	0
A4	30	4	36	0	72	0	14	0	0	15	28
A5	67	25	0	0	92	0	8	0	0	0	8
A20	2	54	0	0	57	0	0	0	0	0	0
F16	5	3	0	0	8	0	0	0	7	0	7
F17	0	14	0	0	14	0	0	0	0	0	0
F18	4	0	0	0	4	0	0	0	0	0	0
F19	20	0	0	0	20	0	0	0	0	0	0
U6	10	10	0	0	20	2	60	18	0	0	80
U7	0	0	0	0	0	0	32	29	0	39	100
U8	0	0	0	0	0	1	47	0	0	52	100
U9	0	0	0	0	0	36	35	28	1	100	100
U10	0	0	0	0	0	0	73	26	0	0	100
U11	0	0	0	0	0	34	20	46	0	0	100
U12	0	0	0	0	0	0	53	46	1	0	100
U13	0	0	0	0	0	43	13	44	0	0	100
U14	0	0	0	0	0	0	70	21	1	0	93
U15	0	0	0	0	0	0	17	0	15	62	79

Square	Land-use and land-cover									
	Forests (%)			Communication network in km, 1 km ⁻²				Urban indicators		
	blf	cf	Sum	Ro	Ra	PU	HH	HL		
A1	0	0	0	4.17	0	1	1	3.12		
A2	0	0	0	4.76	0	1	1	2.85		
A3	0	0	0	5.83	0	1	1	2.86		
A4	0	0	0	12.42	2.11	1.5	2	2.93		
A5	0	0	0	8.16	0	2	2	2.78		
A20	43	0	43	4.73	0	1.5	2	3.1		
F16	85	0	85	4.31	5.36	2	3	2.7		
F17	53	33	86	0	2.06	2	2	2.8		
F18	79	17	96	0	0	2	2	2.84		
F19	80	0	80	0	0	2	2	2.78		
U6	0	0	0	5.36	1.75	3	2	3.08		
U7	0	0	0	28.86	0	3	1	2.98		
U8	0	0	0	16.43	0	3.5	1	3.09		
U9	0	0	0	18.62	0	4.5	1	2.96		
U10	0	0	0	18.33	0.26	3.5	1	3.16		
U11	0	0	0	18.35	0	3.5	1	3.01		
U12	0	0	0	5.47	2.0	3	1	3.09		
U13	0	0	0	17.98	0	2.5	1	2.97		
U14	7	0	7	12.48	2.43	2.5	2	3.10		
U15	6	0	21	17.07	0.24	2	2	2.85		

For abbreviations see Table 1 and Fig. 1

diverse in terms of habitat types than are U areas (Fig. 1; Table 3). HL increases significantly in areas that have been under urban pressure over a longer period, particularly when it is associated with compact development and a dense communication network. The highest Ro density is in square F16, located along an F complex (Table 3). Soils naturally occurring in the study transect are fairly varied; however, since they are covered with artificial forms and highly transformed, they do not have a significant impact on SR and flora quality.

The RDA of SR and main urban factors shows grouping of the environmental variables (Fig. 2). Three of the seven urban indicators are statistically significant (Table 4). HH is positively correlated with the two axes of the ordination diagram. A areas are negatively correlated with the first axis and strong positively with the second. Road (Ro) density is negatively correlated with both axes and weaker with the second. Statistically significant urban factors (HH, A, and Ro) are correlated with other factors, and HL is positively correlated with Ro and PU. The proportion of A is negatively correlated with the other groups of variables. HH and Ra density are positively correlated with the first axis and each other. HH is positively correlated with the second axis, in contrast to the proportion of Ro density. HH is not correlated with the PU or with HL but depends on the form of land use (A, Ra) (Fig. 2). HH is a statistically significant factor in relation to flora of the entire transect

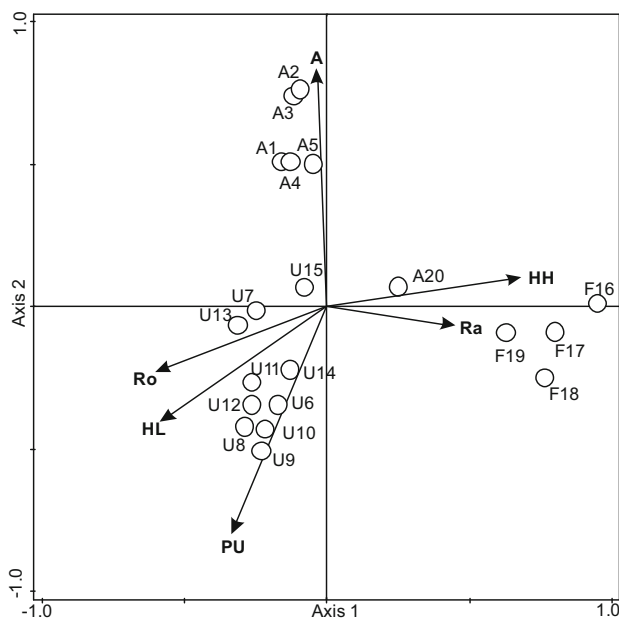


Fig. 2 Ordination diagram showing redundancy analysis (RDA) for species richness (SR) and urban indicators. Test of significance of all canonical axes: trace = 0.435, $F = 1.32$, $P = 0.002$. Variance of the inflation factor (VIF) for explanatory variables used in the analysis: $VIF_A = 3.71$, $VIF_{HH} = 3.48$, $VIF_{HL} = 1.87$, $VIF_{PU} = 3.82$, $VIF_{Ra} = 2.18$, $VIF_{Ro} = 2.52$. For abbreviations in subscript, see Table 1

Table 4 Forward selection of urban indicators for species richness and Monte Carlo permutation test

Variable	Explains (%)	Contribution (%)	F value	P value
HH	8.2	21.9	1.6	0.002
A	6.9	18.5	1.4	0.004
Ro	5.9	15.9	1.2	0.054
PU	5.6	15.0	1.1	0.208
Ra	5.4	12.1	1.1	0.254
HL	5.4	14.3	1.1	0.286

Abbreviations are shown in Table 1

but is, however, important for each species group. It is positively correlated with the number of spontaneophytes (N_{SP}) and negatively correlated with anthropophytization (I_{AN}) and kenophytization (I_{KN}) indicators (Table 5).

The communication network is an important factor in flora quality. Ro and Ra density is varied in the study area. Ro density has a significant impact on AS distribution (N_{AS}) and is positively correlated with the number of archeophytes (N_{AR}), which is reflected in the high proportion of segetal (N_S) and ruderal (N_R) vegetation on these sites (Table 5). There are no roads in three squares (F17–F19), whereas square U7 has the highest road density. There are railway tracks in all major habitat types, which are related to the presence of the Ra network.

The PU is a not statistically significant factor (Table 4) but is strongly negatively correlated with the first and second axis of the ordination diagram (Fig. 2). It is positively correlated with the squares located in the city center, which was longest under urban pressure.

Value of flora indicators

In total, 795 vascular plant species occurred in the study squares. The greatest SR was in U, where 698 species were recorded which represents $\sim 88\%$ of the total number of species in the transect, while in A, 474 species were observed ($\sim 60\%$) and 388 were found in F ($\sim 49\%$). The greatest number of species, both native and alien, was recorded in squares U13 and U15. The lowest level of SR was displayed by the two most peripheral squares: A1 and A20. The number of species therein reached ~ 100 , while the number of AS did not exceed 50. Squares A2, A4, U14, U15, and F17 were the richest in endangered/protected taxa (Table 6).

The quantitative ratio of native (N_{NS}) and alien (N_{AS}) species is similar in A and F areas. In U, the mean number of AS increases, whereas the mean number of native species remains unchanged in comparison with the other habitat types. This exerts a positive effect on SR in these squares (Table 6).

Table 5 Spearman rank correlations between flora and urban indicators

Variable	PU	HH	HL	A	U	F	Ro	Ra
SR	0.26	0.11	0.40	−0.28	0.47*	−0.39	0.40	−0.22
N_{Ap}	0.18	0.16	0.32	−0.20	0.43	−0.39	0.37	−0.16
N_{Sp}	−0.30	0.55*	−0.28	0.27	−0.27	0.30	−0.04	−0.03
N_{NS}	0.08	0.31	0.19	−0.11	0.27	−0.18	0.30	−0.09
N_{Ar}	0.70**	−0.29	0.66**	−0.68*	0.79**	−0.45*	0.54*	−0.32
N_{KN}	0.28	−0.10	0.12	−0.34	0.32	−0.04	0.24	−0.56**
N_{Dia}	0.17	−0.04	0.46*	−0.16	0.30	−0.39	0.22	0.33
N_{AS}	0.67**	−0.29	0.73**	−0.67**	0.80**	−0.54*	0.57**	−0.27
N_F	0.10	0.04	−0.06	−0.12	0.04	0.15	0.04	−0.35
N_{CM}	−0.11	0.17	−0.28	0.04	−0.04	0.09	−0.11	−0.10
N_M	0.35	0.33	0.41	−0.46*	0.55*	−0.19	0.32	0.07
N_X	0.31	0.41	0.42	−0.37	0.46*	−0.23	0.30	0.05
N_W	0.28	0.09	0.37	−0.42	0.52*	−0.26	0.30	0.06
N_R	0.70**	−0.04	0.63**	−0.80**	0.75**	−0.12	0.59*	0.03
N_S	0.72***	0.01	0.73***	−0.78***	0.81***	−0.33	0.59**	0.08
N_{UN}	0.52*	−0.18	0.38	−0.64**	0.55*	−0.06	0.46*	−0.26
I_{AN}	0.72**	−0.47*	0.78***	−0.67**	0.77**	−0.58**	0.48*	−0.18
I_{AR}	0.33	−0.28	0.48*	−0.26	0.38	0.46*	−0.35	−0.53*
I_{KN}	0.83***	−0.50*	0.80***	−0.12	0.54*	0.82***	−0.83***	−0.39
I_M	0.19	−0.24	0.00	−0.51*	0.06	0.14	−0.23	0.11

Abbreviations are shown in Table 1

P values: * <0.05; ** <0.01; *** <0.001

In terms of geohistorical elements, the study area is dominated by native (540) rather than alien (255) species. Among anthropophytes, kenophytes (127) predominate over archaeophytes (81) and diaphytes (47). Vegetation of the study area is classified into eight synecological groups (Table 2). All these groups, with various abundance, are represented in transect squares. The highest proportion was recorded for ruderal (N_R), forest (N_F), meadow (N_M), xerothermic (N_X), and segetal (N_S) species, which considerably contribute to SR in the squares and the established transect (Table 6).

Indicators of anthropogenic flora transformation for individual study squares are highly diverse (Table 6). High anthropophytization indicator values (I_{AN}) were recorded in the city center—squares U6, U8, U10, and U12—whereas the lowest were in F16 and F17 and grassland areas at the city limits (A3). The kenophytization indicator value (I_{KN}) shows that the particularly distinguished city-center habitats are characterized by compact development, dense transport networks, and industrial areas with a high HL—from ~20% (U10 and U12) to 22% (U8). Spatial distribution of the archaeophytization indicator (I_{AR}) is not as concentrated. A relatively high proportion of archaeophytes can be observed in areas that are distant from the center and that have retained their agricultural character (A1). The flora modernization indicator (I_M) exhibits the highest values in densely developed residential and Ra

infrastructure areas: U8, U13, U15, and F16. Its minimum values have been recorded in areas dominated by arable land (A1), forest (F18), and urban areas (U14) in close vicinity of the forest. The highest mean values of most flora indicators were noted in squares U6–U15 (Table 6), while the lowest were characteristic of squares A1–A5. Notably, the mean number of native species and spontaneophytes—with its highest values recorded in squares dominated by forest and seminatural areas—is an exception.

Four peripherally located squares are atypical (Fig. 3). Square U12 on the right, localized in a housing development district, is characterized by moderate SR, with a substantial proportion of alien elements compared with native elements. This is accompanied by high HL values (Table 3). Opposite is square F16, comprising a seminatural habitat, which exhibits different characteristics: small number of species, dominance of native elements, and low HL. The upper peripheral part of the diagram shows square A2 situated in a suburban area with an agricultural character and a high proportion of forest vegetation, namely, midfield woodlots. There, flora is characterized by remarkable richness, with a mixture of natural, seminatural, segetal, and ruderal vegetation (Table 6). The counterweight for this plot is square U8 in the city center, where SR declines considerably and the proportion of AS increases. HH for both squares is the same, but those areas differ in terms of spatial management, PU, and HL (cf.

Table 6 Flora indicators in study squares

Flora indicator	Type of square									
	Agricultural areas						Urban areas			
	A1	A2	A3	A4	A5	A20	U6	U7	U8	U9
SR	152	268	158	276	284	137	226	301	200	313
ES	4	10	7	10	7	1	6	2	8	4
N_{SP}	9	29	17	21	36	4	15	20	17	23
N_{AP}	95	162	103	171	179	87	126	175	97	173
N_{NS}	104	191	120	192	215	91	141	195	114	196
N_{AR}	14	30	20	35	40	29	36	54	40	52
N_{KN}	1	4	17	4	28	17	7	45	44	13
N_{DIA}	33	43	1	45	1	0	42	7	2	52
N_{AS}	48	77	38	84	69	46	85	106	86	117
N_F	24	82	15	15	33	22	29	30	32	48
N_{CM}	6	7	4	3	11	4	6	10	3	4
N_M	31	35	39	32	62	27	55	58	32	50
N_X	16	23	35	21	54	13	59	43	23	51
N_W	5	6	5	8	21	1	10	19	8	1
N_S	21	22	21	30	32	24	39	41	25	42
N_R	41	38	34	38	57	41	55	79	63	77
N_{UN}	7	7	5	5	14	5	12	21	14	26
I_{AN}	31.6	28.7	24.1	30.4	24.3	33.6	37.6	35.2	43.0	37.4
I_{AR}	21.7	16	13	16.3	14	21	18.6	18	20	16.6
I_{KN}	9.2	11.2	11	12.7	10	12	15.9	15	22	16.6
I_M	2.1	5.2	44.7	4.8	40.6	37.0	8.2	42.5	51.2	11.1

Flora indicator	Type of square									
	Urban areas						Forests and seminatural areas			
	U10	U11	U12	U13	U14	U15	F16	F17	F18	F19
SR	219	240	257	369	150	321	219	220	222	171
ES	5	2	7	2	11	10	4	10	7	6
N_{SP}	5	16	9	29	12	33	56	27	46	33
N_{AP}	127	136	146	211	92	187	117	139	114	97
N_{NS}	132	152	155	240	104	220	173	166	160	130
N_{AR}	43	49	51	60	20	48	33	28	20	23
N_{KN}	5	38	7	60	1	45	1	24	26	20
N_{DIA}	39	1	44	9	25	8	22	2	3	1
N_{AS}	87	88	102	129	46	101	54	62	46	41
N_F	30	36	30	47	31	49	26	47	64	51
N_{CM}	7	4	5	9	7	6	5	7	8	8
N_M	35	42	45	66	52	59	43	46	36	30
N_X	20	26	22	45	54	53	21	36	23	20
N_W	12	16	25	36	10	18	20	4	5	8
N_S	31	38	36	46	39	34	28	22	26	3
N_R	64	63	69	95	65	74	70	49	47	34
N_{UN}	19	17	23	27	17	28	13	9	13	30
I_{AN}	39.7	36.7	39.7	35.0	30.7	31.5	21.0	24.5	27.9	24.0
I_{AR}	17.8	20	17.1	35	16.7	15	10	13	15	11.7
I_{KN}	19.6	16	19.8	16	13.3	14	11	12	10.5	11.7

Table 6 continued

Flora indicator	Type of square									
	Urban areas					Forests and seminatural areas				
	U10	U11	U12	U13	U14	U15	F16	F17	F18	F19
I_M	5.7	43.2	6.9	46.5	2.2	44.6	48.8	44.4	2.2	41.9

For abbreviations, see Table 2

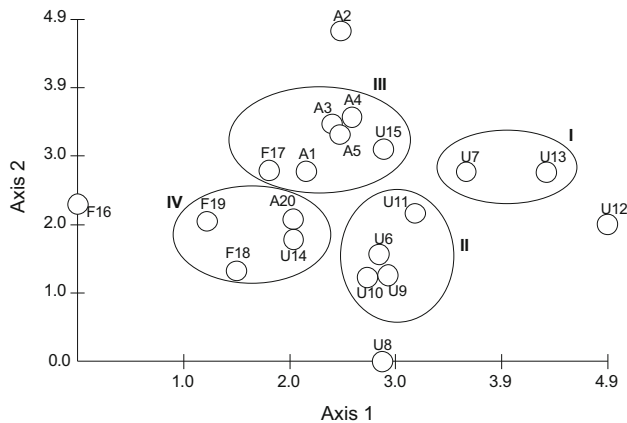


Fig. 3 Result of correspondence analysis (CA) for number of species collected in different habitats. Eigenvalues: *Axis 1* 0.263, *Axis 2* 0.157; cumulative percentage: *Axis 1* 11.907, *Axis 2* 19.030. For abbreviations see Table 1

Table 1; Fig. 1). Squares A1–A3 are a newly incorporated area, while U8 and U9 are in the Lublin settlement.

The diagram clearly shows four aggregations of the remaining squares, which display similar characteristics to those mentioned above (Fig. 3). The first cluster (I) comprises two study squares, which are the richest areas located in prefabricated concrete residential districts, similar to square U12. The second (II) cluster, composed of four squares, has similar characteristics to those of square U8 and is associated with the city center. The third (III) covers areas in the NE part of Lublin (A1, A3–A5), which exhibit similarity to square A2 and have a dual characteristic of seminatural associations of xerothermic vegetation and the area of a railway junction. Covering a fragment of Ra infrastructure, loess ravines, and plateaus, and with its less dense residential developments, the district located in square U15 appeared similar. The last cluster (IV) is clearly similar to square F16, as it comprises squares associated with the seminatural habitats and the neighboring residential district (U14). Spearman rank correlation coefficients (Table 7) show the gradient according to which study squares are ordered (Fig. 3). The first axis is strongly correlated with urban indicators, such as U proportion, HL, PU, and Ro density. The value of anthropopressure increases along this axis (Axis 1), which expresses those U indicators. The second axis is strongly

positively correlated with the proportion A areas, indicating their increasing proportion in the studied transect.

The greatest SR, >300 in each square, was reported in the city center where residential areas border railway infrastructure and extensively cultivated A. The lowest SR, <180 per square, was found in the peripheral transect squares. Those areas were overgrown by seminatural vegetation, i.e., forests and fragments of xerothermic grasslands (Table 6). Low habitat diversity and the low HL result in species composition stability and low susceptibility to disturbances.

Relation between flora and urban indicators

The proportion of U areas in the study transect was the only indicator that exhibited a significant correlation with SR (Table 5). The correlation between the number of native species (N_S) in study squares and U indicators was not statistically significant. Native species occur in all transect squares and predominate over AS. The number of AS (N_{AS}), both keno- and archaeophyte, is positively correlated with the typically urban features of the habitat (PU, HL, U, Ro). In this plant group, a negative correlation is found between the U and A areas. This is additionally confirmed by indicator values of anthropogenic flora changes. A similar correlation exists between individual ecological groups. Xerothermic, meadow, aquatic, segetal, and ruderal species prefer typically U habitats.

Analysis of statistical significance of the correlation between sample species composition and habitat indicators shows that HL, proportion of A areas, and Ro density are the most significant (Table 4). These indicators account for 21% of the total variability of occurrence of a given set of species. The other variables are not statistically significant at $P < 0.05$.

RDA analysis (Fig. 2) confirmed the great significance of HH for SR in transects. This indicator is positively correlated with Axis 1; likewise the proportion of U areas and Ro density. These two indicators are the most typical for U habitats and exhibit a strong correlation. Nearly all squares dominated by U habitats are concentrated around these indicators. The proportion of F and A are equally important for flora richness. The first indicator is positively

Table 7 Spearman rank correlations between Axes 1 and 2 in the correspondence analysis (CA) and urban indicators

	Variable							
	PU	HH	HL	U	A	F	Ro	Ra
Axis 1	0.58***	-0.33	0.77***	0.79***	-0.60**	-0.74***	0.58**	-0.36
Axis 2	-0.73**	0.43	-0.44	-0.46*	0.66**	-0.10	-0.15	-0.4

Abbreviations are shown in Table 1

P values: * <0.05; ** <0.01; *** <0.001

correlated with the first ordination axis and the other with the second axis. These indicators are linked to squares with an A and F characteristic, respectively. The center of the diagram is occupied by U squares U7, U13, and U15, which do not exhibit typical features of a U habitat. They border seminatural areas. F and A squares (F17, F19), characterized by the increasing gradient of Ra in the square, are noteworthy. The Ra network across F areas influenced flora features (U14, F16, F17). The number of AS increases, which is reflected by the higher values of the following coefficients: archaeophytization, kenophytization, and flora modernization (Table 6).

Stepwise selection of the variables of the impact of U indicators on the proportion of geohistorical elements of the study area (Table 8) demonstrates that the proportion of the communication network Ro and Ra is a significant factor, which accounts about 34% of the total SR variability in the transect.

RDA analysis (Fig. 4) shows that the most significant indicators for number and distribution of geohistorical elements include a proportion of U areas, HL, and Ro density; the latter in the case of archaeophytes (N_{AR}) and apophytes (N_{AP}). They are correlated with the first axis, which accounts for 33% of the total sample variability. The number of diaphytes (N_{DIA}) is negatively correlated with this axis. The second axis has a high positive correlation with the proportion of F areas in transect. HH, Ra network, and proportion of A has a lower significance.

Anthropophytes compete efficiently with native plant species in habitats with heavy urban pressure, which is evident in the central part of the transect and less visible in the peripheral fragments of the study area (Tables 3, 6). An interesting phenomenon can be observed in the case of archaeophytes: they are concentrated in the center of the transect, in compact residential and industrial areas, whereas their number is lower in A. The distribution of the proportion of kenophytes exhibits greater variability: the increase in their proportion (N_{KN}) is particularly visible in the industrial areas and along the transport network. AS occur spontaneously there and push out native plants. Nonpermanent flora elements (N_{DIA}) are concentrated in areas where the HL reaches the highest values, i.e., in various anthropogenic habitats with compact development and spontaneous ruderal vegetation and intensively

Table 8 Forward selection of urban indicators for number of geohistorical elements and Monte Carlo permutation test

Variable	Explains (%)	Contribution (%)	F value	P value
Ro	18.9	35.6	4.2	0.014
Ra	15.3	28.9	4.0	0.024
HL	10.3	19.5	3.0	0.052
A	5.0	9.5	1.5	0.252
HH	2.9	5.4	0.8	0.468
PU	0.6	1.1	0.2	0.902

Abbreviations are shown in Table 1

cultivated greenery—city squares and lawns. Ornamental and crop plants occur in these habitats ephemerally (Table 6).

Areas with high HH and HL values proved statistically significant for the distribution of synecological groups (Table 9). They account about 24% of variability at

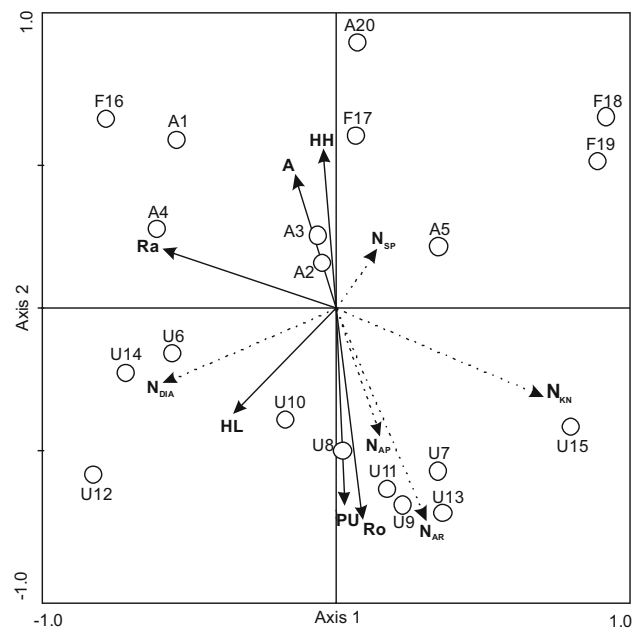


Fig. 4 Ordination diagram showing redundancy analysis (RDA) results for geohistorical and urban indicators. Test of significance of all canonical axes: trace = 0.53, $F = 2.4$, $P = 0.03$. Variance of the inflation factor (VIF) for explanatory variables used in the analysis: $VIF_A = 3.95$, $VIF_{HH} = 3.17$, $VIF_{HL} = 2.10$, $VIF_{PU} = 4.09$, $VIF_{Ra} = 2.11$, $VIF_{Ro} = 3.67$. For abbreviations, see Table 1

Table 9 Forward selection of urban indicators for number of synecological groups and Monte Carlo permutation test (499 permutations)

Variable	Explains (%)	Contribution (%)	F value	P value
HH	16.9	43.1	3.7	0.024
HL	6.8	17.4	1.5	0.043
Ra	6.0	15.4	1.4	0.244
A	4.0	10.2	0.9	0.490
PU	3.5	8.9	0.8	0.518
Ro	1.9	5.0	0.4	0.816

Abbreviations are shown in Table 1

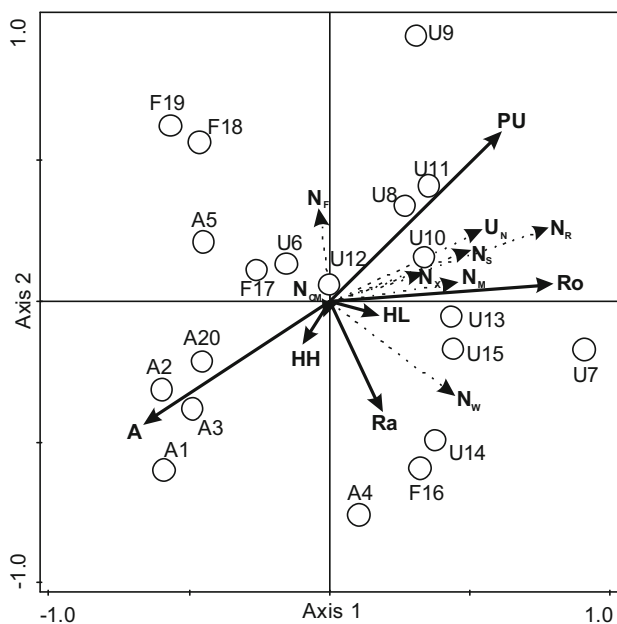


Fig. 5 Ordination diagram showing redundancy analysis (RDA) for synecological groups and urban (U) indicators. Test of significance of all canonical axes: trace = 0.39, $F = 1.39$, $P = 0.012$. Variance of the inflation factor (VIF) for explanatory variables used in the analysis: $VIF_A = 3.95$, $VIF_{HH} = 3.17$, $VIF_{HL} = 2.10$, $VIF_{PU} = 4.09$, $VIF_{Ra} = 2.11$, $VIF_{Ro} = 3.67$. For abbreviations see Table 1

$P < 0.05$. The other variables were not statistically significant. RDA analysis for synecological groups (Fig. 5) demonstrated a distinct correlation between the number of segetal (N_S), ruderal (N_R), and taxonomically unidentified species (N_{UN}) and the typically U habitat indicators (PU, Ro). HH has great significance for the other groups, including F species (N_F). All these indicators are positively correlated with the first axis, which accounts for 41% of total variability of the sample. The proportion of A areas exhibits a negative correlation with the two axes, but it is not correlated with any of the synecological species group.

Ruderal (N_R) and segetal (N_S) vegetation is concentrated in the highly transformed habitats of the central part of the transect; its lowest proportion was observed in peripheral

areas. The distribution of segetal vegetation (N_S) partly corresponds to that of archaeophytes (N_{AR}) (Table 6). The proportion of segetal taxa, which is lower than that of ruderal taxa, is associated with changes in A management and subsequent transformation into residential areas. The occurrence of ruderal (N_R) and segetal (N_S) vegetation exhibits a high positive correlation with the typically U habitat indicators (PU, HL, U) and Ro (Table 5), in contrast to A habitats. The number of F species (N_F) clearly declines toward the NE. This synecological group is the most abundant in the southern peripheral areas, which comprise F squares. In more transformed parts of the city, F species colonize replacement habitats, e.g., parks, cemeteries, tree buffer strips. Meadow vegetation (N_M) exhibits a mosaic distribution. The number of meadow species is homogenous in all types of habitats (Table 6). They prefer fresh and wet habitats and occur alternately with xerothermic grass species, which predominate on loess plateaus. The number of meadow species (N_M) exhibits a significant positive correlation with the proportion of U habitats and a negative correlation with the proportion of the A habitats (Table 5). Additionally, xerothermic species (N_X) occur on high Ra and Ro embankments and along roadsides. This is promoted by loess substrate, southern or western exposition, and artificial enrichment of the substrate with calcium carbonate. The increasing proportion of U habitats clearly contributes to the occurrence of xerothermic species (Table 5).

Discussion

The study confirms the statement that the main factor determining flora quality and condition in cities is human impact (Maurer et al. 2000; McKinney 2002). Urban areas are heterogeneous, consisting of a variety of settlement structures, land use and land cover, and small-scale habitats. This creates many specific and even unusual ecological conditions (Sukopp 2004). The transect across the city consisting of three habitat types representative of the Lublin area demonstrates diversity of SR in relation to various urbanity indicators. The highest number of species per square kilometer is in the transitional zone between the center and rural areas, where the mosaic of land-use types is most heterogeneous. Kunick (1974) divided the city of Berlin (west) into four zones characterized by floristic attributes. There was an increase in neophytes and therophytes and a decrease in rare species from suburbs to center. Concentric zonation was reported with the decrease in human impact—from the center to the suburbs—in both Berlin and Potsdam (Maurer et al. 2000).

Flora quantitative analysis demonstrated that urbanized habitats exhibit higher SR than do A and seminatural F

habitats. Most studies revealed that ecosystems with anthropogenic disturbances, such as cities or densely populated areas, contain high numbers of AS, whereas natural or seminatural ecosystems (like forests or bogs) display certain ecological resistance against introduction of AS (Kornaś 1990; Faliński 1998; Pyšek et al. 1998; McKinney 2008). In particular, densely built areas offer a more favorable environment to AS. The urban flora richness increases with increasing levels of urbanization (Ricotta et al. 2010). Land use, in particular, building densification in already built-up areas, is the main driver of plant species composition in Brussels: there is a strong positive relationship between density of built-up areas and the presence of AS (Godefroid and Koedam 2007). A similar phenomenon was observed in Lublin, where squares located in city center (U7–U13) were characterized by a large proportion of AS (87–129). Thus, the proportion of AS can be used as an indicator for the intensity of disturbances caused by human activities, as proposed by Ricotta et al. (2010).

Our studies showed that this higher number of species is not only related to higher numbers of AS but also to higher numbers of native species. In this sense, urban ecosystems provide much better living conditions for native plants and AS compared with surrounding large, monotonous, and intensively used A or F areas with low light availability. Species poorness in F areas is increased by the dominance of monospecific stands of coniferous trees growing in nutrient-poor, sandy soils (Deutschewitz et al. 2003). In the study we report here, the lowest floristic indicators were for squares dominated by areas of A and F, where HH was the lowest. This confirms the results presented in numerous papers that claim that the “rich get richer” (Stohlgren et al. 2003; Espinosa-García et al. 2004; Ricotta et al. 2010). Elton (1958) was the first to hypothesize that exotic species might more easily invade species-poor areas than species-rich areas. This hypothesis states that species-rich communities resist biotic invasion better than species-poor ones and is based on the idea that species-rich areas should use limiting resources more completely, leaving fewer open niches for invaders. It predicts that native and alien SR is negatively correlated. On the other hand, at coarser scales, the observed correlation between native and exotic SR is usually positive (e.g., Stohlgren et al. 2003; Deutschewitz et al. 2003; Ricotta et al. 2010). This effect, usually known as the “rich-get-richer” model, is often presented as evidence that, while at finer scales native richness can repel invasion via niche partitioning and competitive exclusion, at scales larger than local neighborhoods, variation in resource availability are important drivers of exogenous immigration (Stohlgren et al. 2003; Espinosa-García et al. 2004; Ricotta et al. 2010). Environmental heterogeneity would then allow higher SR. For weeds, HH also increases with human activities and in turn interacts with the natural

environmental variability, i.e., different types of crops, roads, and animal husbandry (Deutschewitz et al. 2003).

The average numbers of both native and AS were higher in the urban landscape of Lublin city. The number of native apophytes and sponthaneophytes was slightly higher only in F and seminatural areas compared with the U landscape section. In contrast, neophytes shared remarkably high proportions in the U landscape. Thus, it seems that the percentage of neophytes is most important for creating the difference between both landscapes in terms of species composition (Stadler et al. 2000; Deutschewitz et al. 2003; Kühn et al. 2004). Investigations in those studies were conducted on a regional and landscape-complex scale, whereas our study confirms the richness of native and AS co-occurrence on a scale of a representative transect.

Habitat diversity has an impact on flora quality, expressed in terms of the proportion of native and AS and various ecological groups. The number of native species in the study area is comparable in all habitat types. Despite high percentages of AS, widespread generalist native species remain the most common component of urban floras of central Europe, similar to cities in Britain (Roy et al. 1999) and northern Europe (Melander et al. 2009). The number of AS increases in highly transformed areas and is maintained at the same level in A and F areas. With increasing settlement size, trade, and traffic in and out of the city increases, the proportion of nonnative flora species increases. This increase due to immigration is chiefly caused either directly by human activity, as in the case of ornamental plants; or indirectly, e.g., when impurities get into transported materials or seeds (Sukopp 2004). The percentage proportion of archaeophytes in the study area is lower than that of kenophytes, which are concentrated in the central part of the study transect. Archaeophytes have been exposed to frequent disturbances since the Neolithic, when they migrated to new areas with the first farmers and became established in regularly disturbed habitats, such as arable land (Pyšek and Jarošík 2005). In contrast, the majority of archaeophytes became naturalized in central Europe long ago; their distribution, like that of native species, is much more limited by habitat differences than by climate (Pyšek et al. 2003).

In this work, we demonstrated that in addition to habitat diversity, the PU affects flora SR. Historically, species introduced into an area through human activity have begun their dispersal into U areas and therefore there occur most frequently with increasing settlement size, trade, and traffic in and out of the city (Sukopp 2004). The SR in relation to the PU and HL has been hypothesized to be highest at intermediate levels of disturbance (Connell 1979). The highest numbers of natives are found in areas where vegetation is less influenced by humans (hemeroby degree 2–3). Maximal species diversity in AS (both in archaeophytes and kenophytes), however, exists in vegetation areas that are obviously more greatly changed by human impact (hemeroby degree 4–5).

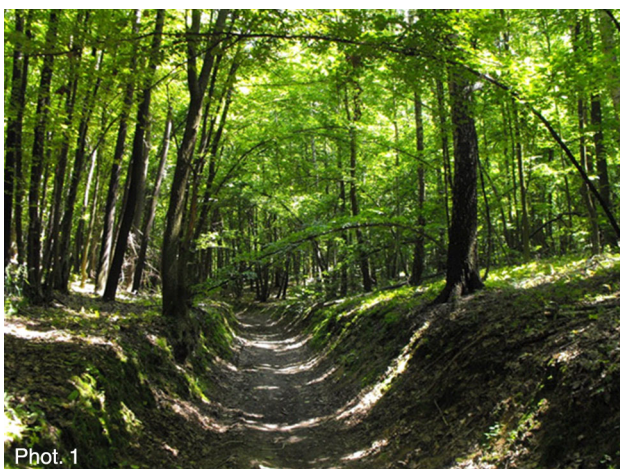
According to Kühn et al. (2004) and Gregor et al. (2012), the higher biodiversity of U areas compared with surrounding areas is independent of human land use and land cover. Areas with comparatively high diversity of habitat types favor the development of a city. Contrary to Kühn et al. (2004)—who argued that city areas are species rich not because of but in spite of urbanization—we regard the high and constantly rising number of neophytes as evidence that biodiversity in cities is generally augmented by human influence.

Analysis of the urbanization effect on qualitative and quantitative traits of flora shows significant correlation with the forms of urban use. Wania et al. (2006)—who argue that if we look at the distribution of plant species with regard to different types of land use and land cover, cities undoubtedly play an important role. SR of native and alien plants is influenced by the landscape structure determined by land-use and land-cover variability. We found this to be the most important factor for both alien and native plants. Our results support the assumption that habitat variability might be decisive for SR in cities (Kühn et al. 2004; Wania et al. 2006).

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Appendix

Examples of different forms of land-use and land-cover in Lublin city. *Photo 1*: forest, square F18; *photo 2*: agriculture area, square A2; *photo 3* urban area, square U13; *photo 4* railway, square U6



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