Biodiv. Res. Conserv. 38: 9-24, 2015

BRC
www.brc.amu.edu.pl

DOI 10.1515/biorc-2015-0013

Submitted 08.11.2014, Accepted 27.05.2015

Synanthropization of dendroflora near main roads in Białystok (NE Poland)

Grażyna Łaska

Department of Environmental Protection and Management, Białystok University of Technology, Wiejska 45a, 15-351 Białystok, Poland, e-mail: g.laska@pb.edu.pl

Abstract: The aim of the study was to analyze the species composition of the dendroflora near four main roads in the city of Białystok, taking into regard their geographical and historical origin. The wildlife inventory was conducted in the vegetation season of 2011. The inventory revealed presence of a total of 837 trees and bushes representing 36 species and 18 families. The most abundant trees were those from the family Aceraceae (63.8%), while the most abundant bushes were those representing Rosaceae (48.9%). The contribution of native species (65.7%) was found to be about twice as high as that of alien ones (34.3%). The dominant species among the native trees was *Acer platanoides* L., while the principal bush species was *Crataegus monogyna* Jacq. The alien tree species were most commonly represented by *Acer negundo* L., and bushes – by *Ligustrum vulgare* L. Spontaneously settled trees and bushes were clearly dominant (59.9%) over those originating from plantations (40.1%). Among the native species of local origin, the prevailing species were synanthropic spontaneophytes (52%), including *Acer platanoides* and *Tilia cordata* Mill. Anthropophytes were more abundantly represented by diaphytes (22.7%), followed by kenophytes (10.4%). The most abundant species among diaphytes was *Ligustrum vulgare*, and among kenophytes – *Acer negundo.*

Key words: urban infrastructure, four roads, inventory, dendroflora, synanthropic flora, valorization

1. Introduction

The dendroflora near roads undergoes continuous changes caused by road network modernization and the development of urban infrastructure (Haber 2001; Fortuna-Antoszkiewicz 2004). Another major problem concerns risks to the dendroflora growing along transport routes with high traffic volumes through the influence of air pollution (Treshew 2004; Juda-Rezler *et al.* 2011; Łaska & Jaros 2011). The system of public roads in the Podlaskie Province is 18,283 km long, comprising 976 km of national roads, 1,241 km – provincial roads, 7,889 km – district roads and 8,177 km of communal roads (Banas *et al.* 2002). The average daily traffic volume estimated for the roads in the Podlaskie Province in 2000 was 1,446 vehicles/day (the national average – 2,363 vehicles/day). The structure of the road transport in the Podlaskie Province is dominated by passenger car traffic which increased by 41% between 1995 and 2000. As of 31 December 2000, there were 73,873 cars registered in Białystok (Banas *et al.* 2002). The development of the traffic infrastructure in Białystok is one of the main aspects addressed in the Strategy for the Development of the City of Białystok in 2011-2020 (Augustyn *et al.* 2010).

The progressive urbanization and dynamic growth of transport in Poland's cities markedly reduce the total area of green space and affect the biodiversity of urban areas (Fortuna-Antoszkiewicz *et al.* 2007; Wysocki 2008). Under the influence of anthropogenic pressure, urban biotic communities constituting scattered "green islands" in the town landscape are exposed to the process of destruction of native dendroflora and the influx of numerous anthropophytes (Symonides & Solińska-Górnicka 1990). The processes often have their origin in the introduction of alien tree and bush species from other biogeographical areas to make up for natural deficits in species richness. Zimny (2005) states that large urban agglomerations harbour over 1,500 species of vascular plants, of which 30-70% are alien species. The urban

©Adam Mickiewicz University in Poznań (Poland), Department of Plant Taxonomy. All rights reserved.

flora is increasingly subject to depletion of native species stands, whereas more vulnerable species tend to become completely exterminated. Approximately 42 species (1.7% of the flora) have already been recognized as extinct in Poland (Kaźmierczakowa *et al.* 2014). The natural diversity of vegetation declines with growing anthropogenic modifications of the environment (Chmiel 2006), and the main feature of the observed progressive process of synanthropization of the flora is allochtonization, i.e. displacement of native species by alien species, combined with a growing heterogeneity of the flora in historical and geographical terms (Jackowiak & Żukowski 2000; Zając & Zając 2000, 2003; Tokarska-Guzik 2001, 2003, 2005; Jackowiak 2003). The situation clearly demonstrates the need for a sustainable management of urban space, depending on the availability of environmental resources and results of assessment of wildlife assets (Mahon & Miller 2003; Sukopp 2004; Brunetta & Voghera 2008; Szyszko *et al.* 2010; Wysocki & Sikorski 2010). It is also vital to ensure an appropriate composition and origin of the species of trees and bushes growing along transport routes, so that they can most effectively perform the function of an environmental barrier protecting the spread of air pollution and noise (Treshew 2004; Burden 2006; Łukasiewicz & Łukasiewicz 2006; Oleksiejuk 2005).

The present study seeks to explore the species composition of the dendroflora found along the main transport routes in Białystok, focusing on its abundance, dendrometric features, spatial distribution of dendroflora stands, and geographical and historical origin. The study also comprised an examination of in-

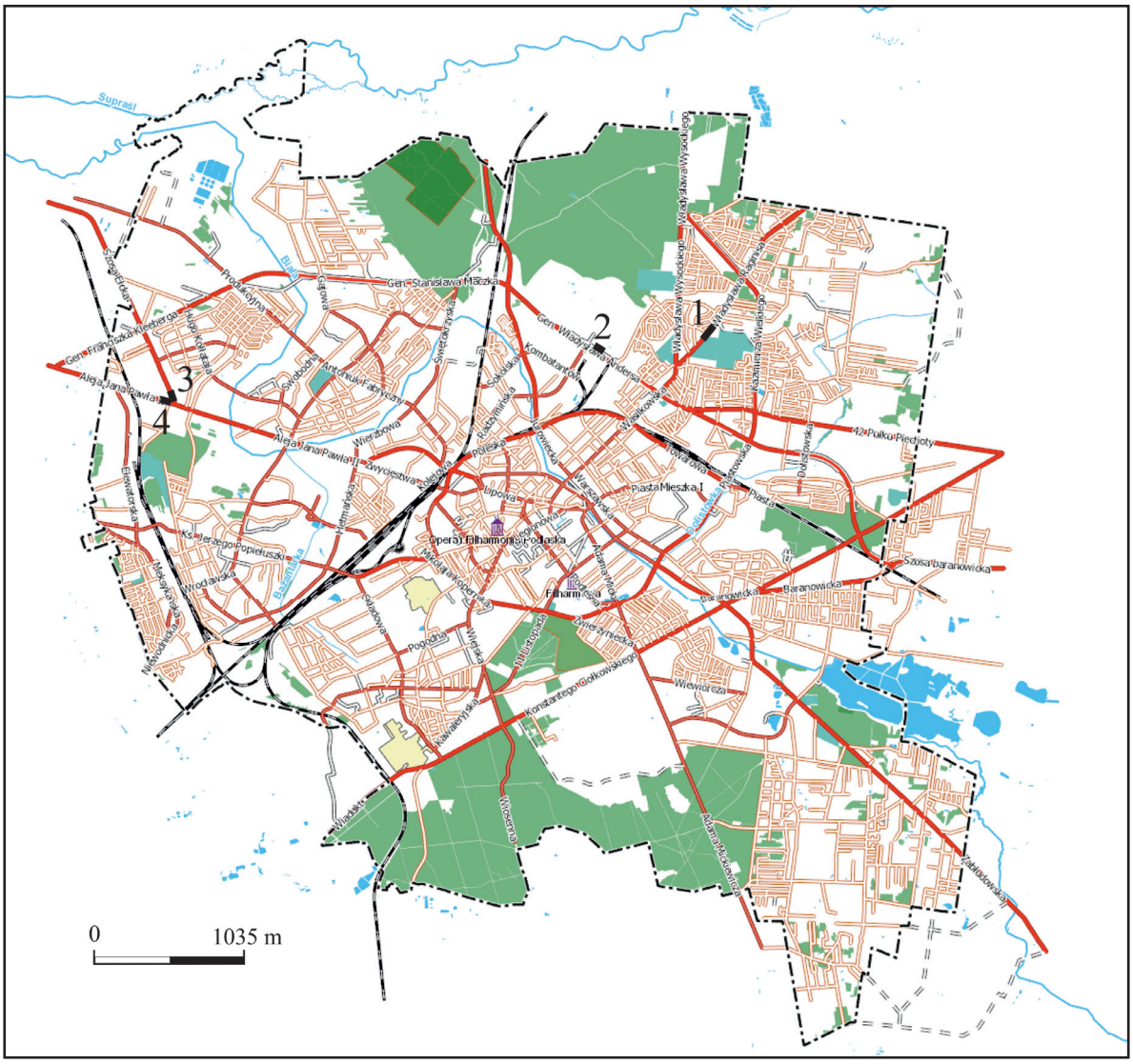

Fig. 1. The inventory of the species composition of dendroflora near the four main roads in Białystok (source: gis.bialystok.pl)

Explanations: Transect 1 – provincial road no. 676 between Białystok and Krynki, by Raginisa Street, N53°9'24.93", E23°11'47.97"; Transect 2 – national road no. 8 between Białystok and Suwałki, by Andersa Street, N:53°8'57.33", E23°10'25.44"; Transect 3 – provincial road no. 669 between Białystok and Ełk, by Narodowych Sił Zbrojnych Street, N53°8'36.62", E23°5'13.87"; Transect 4 – national road no. 8 between Bialystok and Warsaw, by Jana Pawła II Street, N53°8'36.1", E23°5'12.74"

dices of anthropogenic changes in the flora, identifying the city transport routes associated with a high lability of the flora, and determining the spatial distribution of the anthropophytization process affecting the city flora.

2. Material and methods

The study of the dendroflora near the main roads was conducted within the limits of the town of Białystok. The investigation was based on resource materials, site surveys and computer research methods. Source materials documenting the city areas included digital data in the form of Białystok orthophotomap sheets at a scale of 1:1000 (www.gisbialystok.pl) and a topographic map at a scale of 1:10000 (www.geoportal.gov.pl). These materials were used as a basis for drafting a general geographical map at a scale of 1:1000 for the purpose of conducting a wildlife inventory of tree and bush species in the field. The inventory was conducted in the vegetation season of 2011 along sections with a length of 100 m (exception: Raginisa Street – 200 m) and width of 30 m (referred to as transects) delimited along the four main roads in Białystok (Fig. 1). Geographical coordinates always indicate the beginning of the transect from which the inventory was started, that is, from the side of the city center.

The field works consisted of cartographic point studies of tree and bush stands performed using the topographic method along the transport routes. The studies were based on survey areas of 3000 m^2 (100 m x 30 m) (transects 2, 3, 4) and 6000 m^2 (200 m x 30 m) (transect 1), on each side of the street, divided into primary fields of 100 m^2 (10 m x 10 m). The species composition of the dendroflora, the number of trees and bushes, and their dendrometric features (height, circumference at a height of 120 cm above the ground), spatial structure including the density of trees and bushes in individual transects and spatial distribution of tree and bush species, tree rows and tree clusters were established. Dendrometric tree measurements were carried out for tree rows and individual tree specimens growing at a distance of not more than 10 m from the road and not occurring in clusters. Overall, dendrometric features were determined for 72 specimens representing 8 trees species in Andersa Street, 36 specimens representing 11 tree species in Raginisa Street, 18 specimens representing 6 species in Narodowych Sił Zbrojnych Street, and 45 specimens representing 9 tree species in Jana Pawła II Street.

The taxonomic names of species were based on the system proposed by Mirek *et al.* (2002). The study also determined geographical and historical origins according to the classification of synanthropic flora proposed by Chmiel (2006), and indices of anthropogenic changes in the species composition of the flora found in Białystok (Chmiel 2006).

All correlations were performed using Statistica 10.0 (StatSoft 2014). Correlations existing between the distance from the city centre and boundaries and the proportion of native and alien species, settled spontaneously and planted, and the proportion of non-synanthropic spontaneophytes, semi-synanthropic spontaneophytes, synanthropic spontaneophytes, kenophytes and diaphytes were calculated using a correlation matrix at a significance level of α=0.05. The dendroflora populating areas along the roads was also subjected to valorization by the method formulated by Lenart & Tyszecki (1998).

3. Results

3.1. Number of tree and bush species along investigated transport routes

The inventory conducted along the four main roads in the city of Białystok revealed the presence of 837 trees and bushes representing a total of 36 species including 25 tree species (69.4%) and 11 bush species (30.6%) (Table 1). Examining individual transport routes, the total number of tree and bush species ranged from 12 (33.3%) in Narodowych Sił Zbrojnych Street to 21 (58.3%) in Raginisa Street; the average number for the investigated routes – 17. Analyzing the number of tree species and bush species separately, similar correlations were identified (Fig. 2). The highest number of tree species was found in Raginisa Street (64%), and the lowest – in Narodowych Sił Zbrojnych Street (36%). The average number of tree species in the investigated transport routes was 12, and bush species – 5.

The investigated transport routes were dominated by deciduous trees and bushes. Out of the total of 25 tree species, 21 species were deciduous trees (84%), chiefly from the *Acer* L. and *Populus* L genera., and four species represented coniferous trees (16%), primarily from the *Picea* A. Dietr genus (Fig. 2). Out of the total of 11 bush species, 10 species were deciduous bushes (91%) dominated by the *Crataegus* L. genus, and only one species (*Juniperus communis* L.) represented conifers (9%). Along Andersa Street, only deciduous trees were identified (100%). The proportion of deciduous tree species was also high along the remaining transport routes: from 75% in Raginisa Street to 89% in Narodowych Sił Zbrojnych Street and 92% in Jana Pawła II Street (Fig. 2).

3.2. Number of tree and bush families along investigated transport routes

The inventory conducted along the four main roads in the city of Białystok demonstrated the presence of a

Table 1. Number of species and individuals of the synanthropic flora and other species (cultivars) along the four main roads in Białystok

Species	Transects along selected roads in Białystok				
	1 Raginisa st.	2 Andersa st.	3 Narodowych Sił Zbrojnych st.	4 Jana Pawła II st.	Total
Spontaneophytes (S)					
Spontaneophytes non-synanthropic (Sp)					
Juniperus communis L.	2	-	-	-	2
Spontaneophytes semi-synanthropic (Sp/Ap)					
Euonymus europaeus L.	-	10	-	7	17
Quercus robur L.	-	-	-	2	2
Sorbus aucuparia L.	-	8	-	-	8
Crataegus monogyna Jacq.	-	25	35	27	87
Populus nigra L.	-	-	-	5	5
Spontaneophytes synanthropic – apophytes (Ap)					
Betula pendula Roth	4	14	-	3	21
Tilia cordata Mill.	9	-	14	26	49
Acer platanoides L.	10	30	131	124	295
Salix fragilis L.	2	2	-	7	11
Fraxinus excelsior L.	-	6	1	1	8
Salix caprea L.	-	3	-	-	3
Pinus sylvestris L.	-	-	3	3	6
Malus sylvestris Mill.	9	2	2	1	14
Acer pseudoplatanus L.	-	-	10	10	20
Spontaneophytes (S) – total number of species	Spontaneophytes (S) – total number of individuals in the transects				
15	36	100	196	216	548
Anthropophytes (A)					
Kenophytes (Kn)					
Picea abies (L.) H. Karst.	2	-	-	-	2
Quercus rubra L.	1	2	2	-	5
Acer negundo L.	18	35	-	-	53
Robinia pseudoacacia L.	7	-	-	-	7
Sambucus racemosa L.	-	10	3	7	20
Picea pungens Engelm.	3	-	-	-	3
Liriodendron tulipifera L.	6	-	-	-	6
Magnolia acuminata L.	1	-	-	1	2
Populus balsamifera L.	-	5	-	-	5
Diaphytes (D)					
Prunus domestica L.	6	10	6	9	31
Physocarpus opulifolius 'Diabolo' L.	11	-	-	-	11
Rhus typhina L.	1	-	-	-	1
Acer tataricum L.	-	16	-	-	16
Thuja L.	30	-	-	-	30
Syringa vulgaris L.	3	-		2	5
Ligustrum vulgare L.	33	-	6	-	39
Cornus mas L.	4	-	-	-	4
Hippophaë rhamnoides L.	2	-	-	-	2
Morus nigra L.	-	-	3	-	3
Rosa multiflora Thunb.	-	-	-	9	9
Symphoricarpos albus (L.) S. F. Blake	-	-	-	35	35
Anthropophytes (A) – total number of species	Anthropophytes (A) – total number of individuals in the transects				
21	128	78	20	63	289
Total number of species of the synanthropic flora	Total number of individuals of the synanthropic flora in the transects				
36	164	178	216	279	837

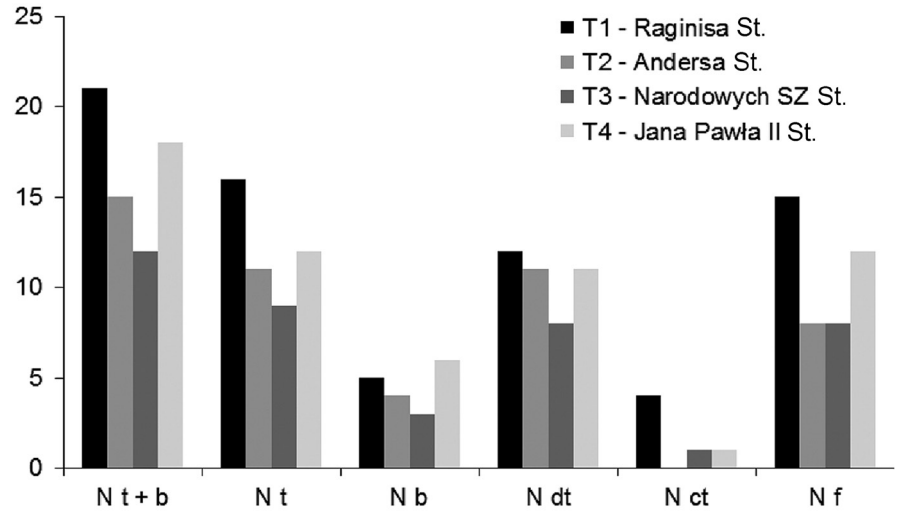

Fig. 2. Characterization of the total number of tree and bush species (N t +b), trees only (N t), bushes only (N b) and deciduous tree species (N dt), coniferous tree species (N ct) and all families (N f) in the transects

total of 837 specimens representing 18 families (Fig. 3). Overall, the highest proportion of tree and bush species represented the family of Aceraceae (45.9%). A lower proportion (19.1%) derived from the Rosaceae family, and the lowest – from the family of Anacardiaceae (0.1%). Examining tree species and bush species separately, the most abundant tree species were those from the Aceraceae family (63.8%), and the least abundant – Anacardiaceae (0.2%). Among the bush species, the most abundant were those representing Rosaceae (48.9%), and the least abundant – representatives of the Elaeagnaceae family (0.9%) (Fig. 3).

Taking into account the number of families, the greatest diversity of tree and bush flora among the investigated transport routes was noted in Raginisa Street (15 families) and Jana Pawła II Street (12 families). The lowest diversity was identified in Andersa Street (8 families) and Narodowych Sił Zbrojnych Street (8 families) (Fig. 2).

3.3. Characteristics of synanthropic species in investigated transects

The study found that the contribution of native species (65.7%) was about twice as high as that of alien ones (34.3%) (Fig. 4). The dominant among the native tree species was *Acer platanoides* L. (295 specimens), while the main bush species was *Crataegus monogyna* Jacq. (87 specimens). Alien tree species were the most abundantly represented by *Acer negundo* L. (53 specimens), while bushes by *Ligustrum vulgare* L. (39 specimens) (Table 1). Spontaneously settled trees and bushes constituted a majority (59.9%) over those from plantations set up and managed by municipal landscaping contractors (40.1%) (Fig. 4). Spontaneously settled species were dominated by *Acer platanoides* and *Tilia cordata* Mill., and planted species by *Acer negundo* and *Crataegus monogyna*.

Native species (spontaneophytes, S) and alien species (anthropophytes, A) occurred in all transects under study (Fig. 5). The proportion of native and alien species, both spontaneously settled and planted, in the investigated transects did not depend on the average daily volume of vehicle traffic on the roads, but on the distance of the transport routes under study from the city boundaries. Along the transport routes located at a closer distance to the city boundaries (Jana Pawła II Street, Narodowych Sił Zbrojnych Street), more trees and bushes represented native species (36-39%) and species of natural origin (i.e. settling spontaneously) (37-40%) than in the vicinity to the city centre (native species 7-18%, of natural origin 5-18%, respectively). In contrast, alien (27-44%) and planted species (26-41%) prevailed along the streets located near the centre of Białystok (Andersa Street, Raginisa Street) (Fig. 4).

Within the transects under study, the native species of local origin were dominated by synanthropic spontaneophytes (apophytes (Ap), 52%), including *Acer platanoides* (295 individuals) and *Tilia cordata* (49 specimens) (Table 1). Semi-synanthropic spontaneophytes (Sp/Ap, 14.7%) were the most numerously represented by *Crataegus monogyna* (87 specimens). The smallest proportion among the native species of local origin in the transects under study was determined for non-synanthropic spontaneophytes (Sp, 0.2%) with their sole representative *Juniperus communis* growing in Raginisa Street (Table 1, Fig. 5).

The proportion of apophytes tended to be greater in transects located closer to the city boundaries (63-75%) (along Jana Pawła II Street and Narodowych Sił Zbrojnych Street, respectively) than in transects in the

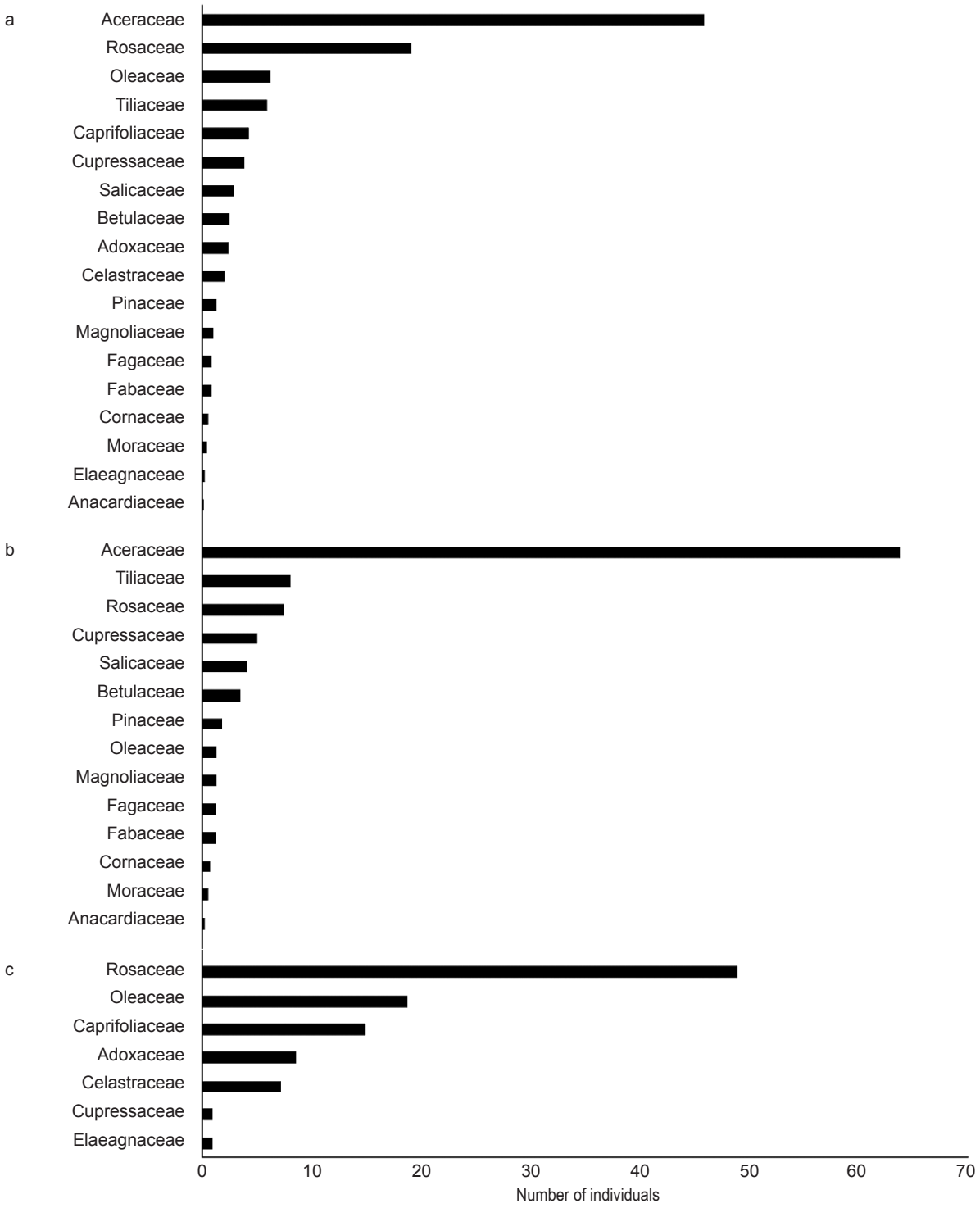

Fig. 3. Family contribution to tree and bush species together (a), tree species only (b) and bush species only (c) in the transects

vicinity of the city centre (22-33%) (along Raginisa Street and Andersa Street, respectively) (Fig. 5). Anthropophytes (A) were more abundantly represented by diaphytes (22.7%), followed by kenophytes (10.4%). The most abundant species among diaphytes was *Ligustrum vulgare* (39 specimens), and among kenophytes – *Acer negundo* (53 specimens) (Table 1, Fig. 5).

A greater number of permanently established species of alien origin (kenophytes) was found in transects located in the vicinity of the city centre (17-27%) (along Raginisa Street and Andersa Street, respectively) than in transects delimited close to the city boundaries (2-3%) (along Narodowych Sił Zbrojnych Street and Jana Pawła II Street, respectively). The proportion of alien species which occurred only occasionally without deliberate human intervention or planted species which transiently went wild (diaphytes) varied from 7-20% in transects located closer to the city boundaries (along

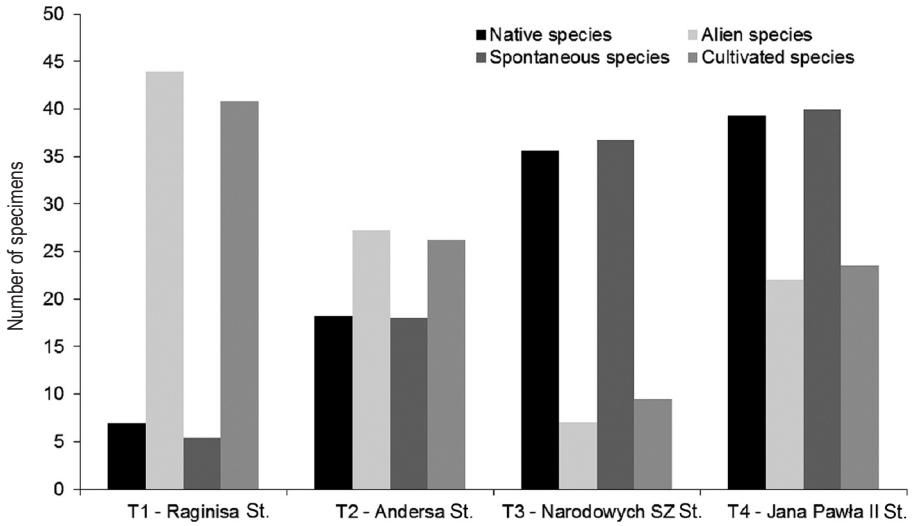

Fig. 4. Contribution of the tree and bush species with regard to their origin to the four transects (T)

Narodowych Sił Zbrojnych Street and Jana Pawła II Street, respectively) to 15-58% – in transects located near the city centre (along Andersa Street and Raginisa Street, respectively) (Fig. 5).

3.3.1. Statistical analysis

The correlation coefficient indicates that there was a very strong relationship (at a significance level of α=0.05) between the proportion of kenophytes in the dendroflora composition and the distance to the city centre and boundaries (Table 2). The proportion of kenophytes was found to grow towards the centre, i.e. with increasing distance from the city boundaries and decreasing distance to the city centre (Fig. 6). Another observation was that an increase in the proportion of native species was linked to an increase in the proportion of spontaneously settled species. The proportion of alien species increased with increasing proportion of planted species (Table 2).

3.3.2. Indices or anthropogenic changes in the species composition of the city flora

The study found that the dendroflora of the investigated transects exhibited a strong anthropogenic transformation. This is evidenced by the zero value of the index of dendroflora naturalness. The only exception

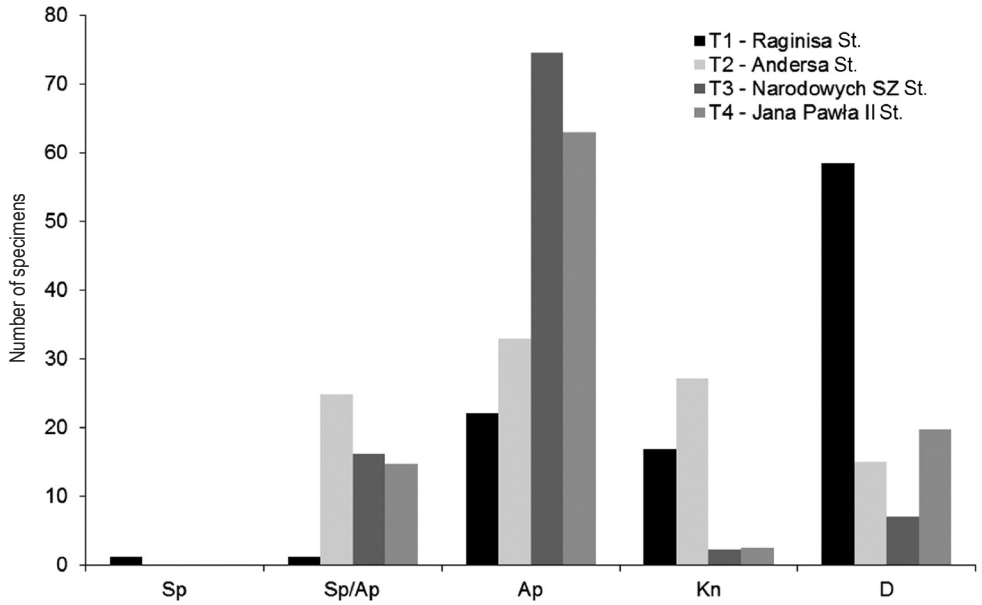

Fig. 5. Contribution of the tree and bush species to the transects with regard to their geographical and historical origin (abbreviations explained in Table 1)

Table 2. Values of the correlation coefficient between the distance to the city's centre and boundaries and the proportion of kenophytes, and the proportion of native and alien species – naturalized and planted

Pair of variables	*r*	*p*
Distance from the city's centre – proportion of kenophytes	-0.9956	0.0044
Distance from the city's boundaries – proportion of kenophytes	0.9770	0.0230
Proportion of native species – proportion of naturalized species	0.9956	0.0044
Proportion of alien species – proportion of planted species	0.9974	0.0026

Explanations: *r* – correlation coefficient, *p* – significance level

was Raginisa Street, where two specimens representing one species (*Juniperus communis*) from the group of non-synanthropic spontaneophytes were identified (Table 1). Another piece of evidence for the strong anthropogenic transformations of Białystok dendroflora was the specific synanthropization (Sw) index which defines the proportion of apophytes (Ap) and anthropophytes (A) in the total dendroflora. The values of the index in the investigated transects ranged between 75.1% and 85.3%. The only exception was Raginisa Street, where the specific synanthropization (Sw) index reached 97.4%.

In the group of synanthropic species, a considerable role can be attributed to native species occurring exclusively, or almost exclusively, in semi-natural and anthropogenic habitats (apophytes). The value of the specific apophytization index showed that the apophytic capabilities of native species in transects located closer to the city boundaries (63.0-74.5%) were over twice as high as those of the species growing along transport routes in the vicinity of the city centre (22.1-33.0%).

The calculated values of the anthropophytization (An) index also showed that geographically alien species played a larger role in the vegetation found in

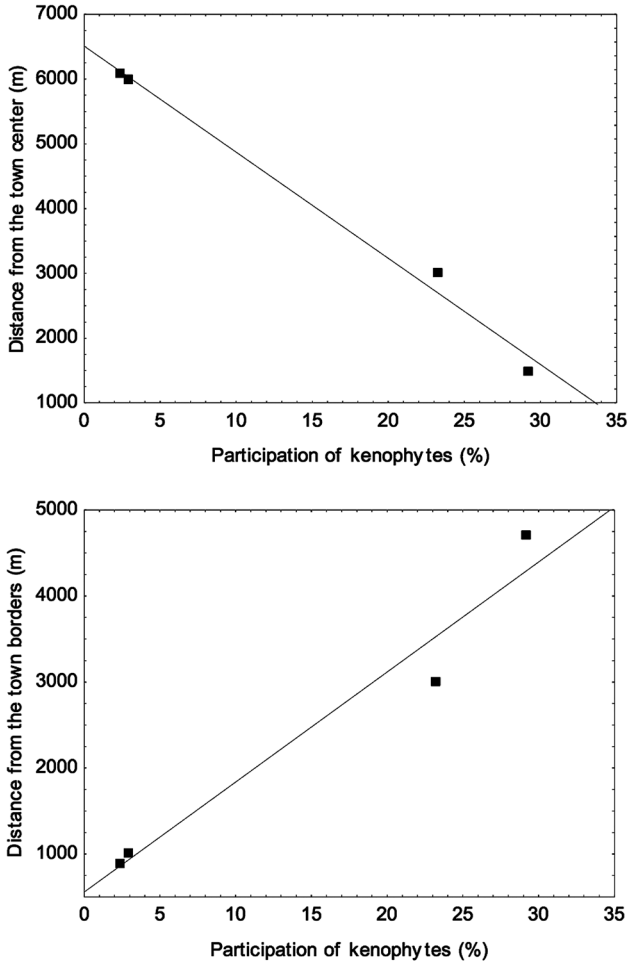

Fig. 6. Participation of kenophytes depending on the distance from the city center and the city borders

transects located in the city centre (42.2-75.3%) than the species occurring in transects closer to the city boundaries (9.3-22.3%). This was also demonstrated by the dendroflora kenophytization index which, in the investigated transects, ranged between 2.31-2.52% in Narodowych Sił Zbrojnych Street and Jana Pawła II Street (closer to the city boundaries), respectively, and 16.9-27.2% in Raginisa Street and Andersa Street (closer to the city centre), respectively (Table 1). The values of the dendroflora anthropophytization and kenophytization indices demonstrated that within the territory of the city of Białystok, characterised by a monocentric structure, the proportion of alien species exhibited a growing trend towards the city centre, whereas the spatial direction of the city anthropophytization increased away from the city centre, towards the city boundaries.

3.4. Spatial structure of tree species, tree rows and clusters

The distribution of tree species in the form of rows was observed to the greatest degree in the city centre, along Andersa Street (Fig. 7). Hence, as previously stated, along Andersa Street, near the centre of Białystok, there were more alien species (27%) than native species (18%), and more planted species (26%) than spontaneously settled species (18%) (Fig. 4). Tree

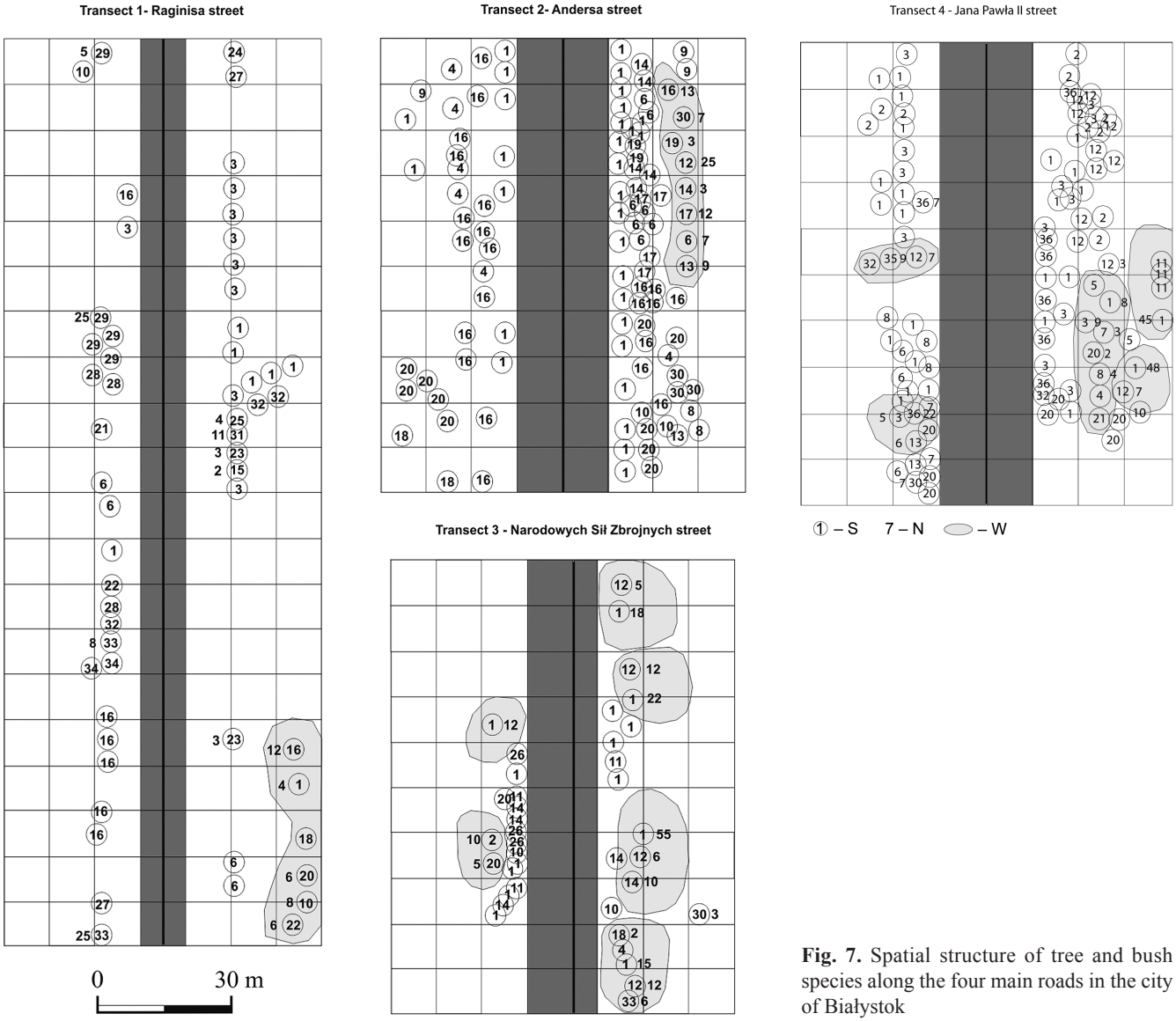

Fig. 7. Spatial structure of tree and bush species along the four main roads in the city of Białystok

Explanations: spontaneophytes (S), 1 – *Acer platanoides*, 2 – *Acer pseudoplatanus*, 3 – *Tilia cordata*, 4 – *Fraxinus excelsior*, 5 – *Quercus robur*, 6 – *Betula pendula,* 7 – *Populus nigra*, 8 – *Salix fragilis*, 9 – *Salix caprea*, 10 – *Malus sylvestris*, 11 – *Pinus sylvestris*, 12 – *Crataegus monogyna*, 13 – *Euonymus europaeus*, 14 – *Sorbus aucuparia*, 15 – *Juniperus communis*; antropophytes (A), 16 – *Acer negundo*, 17 – *Acer tataricum*, 18 – *Quercus rubra*, 19 – *Populus balsamifera*, 20 – *Prunus domestica*, 21 – *Magnolia acuminata*, 22 – *Robinia pseudoacacia,* 23 – *Lirodendron tulipifera*, 24 – *Rhus typhina*, 25 – *Cornus mas*, 26 – *Morus nigra*, 27 – *Picea abies*, 28 – *Picea pungens*, 29 – *Thuja* sp., 30 – *Sambucus racemosa*, 31 – *Physocarpus opulifolius* 'Diabolo', 32 – *Syringa vulgaris*, 33 – *Ligustrum vulgare*, 34 – *Hippophae rhamnoides*, 35 – *Rosa multiflora*, 36 – *Symphoricarpos albus*; S – sequence number of species, N – the number of individuals of a particular species, W – the spontaneous woodlots

rows were found there on both sides of the transport route. On one side, there were three tree rows with *Acer platanoides*, *A. negundo* and *Fraxinus excelsior* L., planted in a succession at a distance of 2 m, 10 m and 15 m from the road. On the other side of Andersa Street, there was a row of trees with *Acer platanoides* right next to the route. Spontaneous mid-field patches of trees grew here at a distance of 15 m from the road, occupying an area of 500 m^2. The tree density in the investigated transect was 3 specimens per 100 m^2 (Fig. 7).

In Raginisa Street, in the vicinity of the city centre, the majority of trees and bushes included in the inventory were growing on a private property, and were planted at a distance of 10 m from the road. Hence, as mentioned above, along Raginisa Street, near the centre of Białystok, there were more alien species (44%) than native species (7%), and more planted species (41%) than spontaneously settled species (5%) (Fig. 4). A single tree row with *Tilia cordata* was found there on one side of the road, whereas spontaneous mid-field patches of trees were growing at a distance of 30 m from the road, covering an area of 600 m^2. The tree density in the investigated transect was the lowest, amounting to 1.4 specimens per 100 m^2 (Fig. 7).

In transects located near the city boundaries (Narodowych Sił Zbrojnych Street and Jana Pawła II Street), the majority of trees formed spontaneous mid-field patches rather than growing in the form of anthropogenically shaped rows (Fig. 7). Along Narodowych Sił

Table 3. Contribution of trees in different height and thickness classes to the transects in Białystok

Height classes [m]	0-2.0	%	2.1-5.0	%	5.1-10.0	%	10.1-15.0	%	15.1-20.0	%	∑		
Transect 1 – Raginisa st.													
Number/ participation of individuals	8	22.2	11	30.6	2	5.6	6	16.7	9	25.0	36		
Transect 2 – Andersa st.													
Number/ participation of individuals	-	-	20	27.8	52	72.2	-	-	-	-	72		
Transect 3 – Narodowych Sił Zbrojnych st.													
Number/ participation of individuals	-	-	8	44.4	10	55.6	-	-	-	-	18		
Transect 4 – Jana Pawła II st.													
Number/ participation of individuals	-	-	17	37.8	28	62.2	-	-	-	-	45		
Total	8	4.7	56	32.7	92	53.8	6	3.5	9	5.3	171		
Thickness classes [cm]	0-50	%	51-100	%	101-150	%	151-200	%	201-250	%	251-300	%	∑
Transect 1 – Raginisa st.													
Number/ participation of individuals	15	41.7	9	25.0	7	19.4	4	11.1	-	-	1	2.8	36
Transect 2 – Andersa st.													
Number/ participation of individuals	16	22.2	56	77.8	-	-	-	-	-	-	-	-	72
Transect 3 – Narodowych Sił Zbrojnych st.													
Number/ participation of individuals	5	27.8	10	55.6	3	16.7	-	-	-	-	-	-	18
Transect 4 – Jana Pawła II st.													
Number/ participation of individuals	5	11.1	21	46.7	13	28.9	5	11.1	1	2.2	-	-	45
Total	41	24.0	96	56.1	23	13.5	9	5.3	1	0.6	1	0.6	171

Zbrojnych Street, mid-field patches of trees with *Acer platanoides* and *Crataegus monogyna* occupied a large area of approx. 1000 m^2, and the density of trees in the investigated transect was 3.6 specimens per 100 m^2. There were also several mid-field clusters of trees next to Jana Pawła II, at a distance of 18 m from the road, covering approx. 150 m^2, and ca. 30 m from the road, covering 450 m^2. They were dominated by *Acer pseudoplatanus* L. and *A. platanoides* trees. The tree density in the investigated transect was the highest, reaching 4.7 specimens per 100 m^2 (Fig. 7).

3.5. Characteristics of dendrometric features of tree species in investigated transects

The majority of trees in the investigated transects were found to represent the height classes from 5.1 to 10 m (53.8%) and from 2.1 to 5 m (32.7%) (Table 3). The two height classes were the most numerously represented by *Acer platanoides* specimens. Much lower proportions were determined for low trees, below 2 m in height (4.7%), and the highest trees, in the height classes of 10.1-15 m (3.5%) and 15.1-20 m (5.3%) (Table 3). The height class of up to 20 m was dominated by specimens of *Tilia cordata*.

The study found that the spontaneous mid-field patches of trees occurring more abundantly along streets closer to the city boundaries (Narodowych Sił Zbrojnych Street, Jana Pawła II Street) were mainly formed by young species, resulting from natural forest regeneration processes, lower in height and smaller in circumference than the species of anthropogenic origin which formed rows of trees near the city centre (Raginisa Street and Andersa Street). The greatest diversity in the height of trees representing all height classes, from 0-2 m to 15.1-20 m, was observed in Raginisa Street (Table 3). The most abundant tree height class there was the one from 2.1 to 5 m (31%), dominated by *Acer negundo*. The highest species, in the height class of 15.1-20 m (25%), were specimens of *Tilia cordata* and *Acer negundo* which reached 16-17 m in height. They were of anthropogenic origin and formed rows. Similar relationships were noted along Andersa Street, close to the city centre, where the highest specimens of *Acer negudo*, *A. platanoides* and *Fraxinus excelsior* (ca. 7 m high) were of anthropogenic origin and formed tree rows.

In the remaining transects, along streets closer to the city boundaries (Narodowych Sił Zbrojnych Street, Jana Pawła II Street), the variation in tree height was smaller and only two height classes were identified, from 2.1-5.0 m to 5.1-10 m, with *Acer platanoides* or *Tilia cordata* prevailing in both of them (Table 3).

With regard to tree girth classes, the majority of trees were found to reach the circumference of 51-100 cm (56.1%) (Table 3). Smaller proportions were observed for the thinnest trees, in the girth classes of up to 50 cm (24%), and the most massive trees, in the girth classes of 201-250 cm (0.6%) and 251-300 cm (0.6%) (Table 3). The specimen with the greatest circumference (270 cm) was *Acer negundo* growing in Raginisa Street.

The smallest variation in tree girth, limited only to two classes: 0-50 cm and 51-100 cm, was found in the transect located in Andersa Street, in the vicinity of the city centre, where one of the dominant tree species was the planted species of *Acer negundo*.

3.6. Natural value of vegetation growing along transport routes

An assessment of the natural value of vegetation populating areas along the transport routes under study showed that the value was more diverse (mean valorization index of 2-2.5) along the streets which were closer to the city boundaries (Jana Pawła II Street, Narodowych Sił Zbrojnych Street) than along the streets located in the city centre (Andersa Street, Raginisa Street), where the mean value of the valorisation index was low (1-1.5) (Table 4).

The vegetation found in the investigated transects varied in terms of their naturalness. A higher degree of consistency between the actual vegetation and the potential natural vegetation was determined along the streets which were nearer the city boundaries (Narodowych Sił Zbrojnych Street, index 2) than in the city centre (Andersa Street, index 0). The diversity of biotopes and the number of tree and bush species occurring in the investigated transects varied, too. Raginisa Street (21 tree and bush species) and Jana Pawła II Street (18 species) were found to be more diverse in terms of their flora than Andersa Street (15 species) and Narodowych Sił Zbrojnych Street (12 species). The complementarity index in the investigated transects was linked to the assessment of the entire ecological system which constituted an entity in terms of dynamic equilibrium. It was established that the natural ecological system in the heavily urbanized area in the centre of the city (Andersa Street, Raginisa Street) had been significantly destroyed by breaking up mutual interdependencies within spatial and functional natural units. This finding was corroborated by the number of spontaneously settled patches. This number was smaller along the streets in the city centre (one item, Andersa Street, Raginisa Street) than along the streets which were closer to the city boundaries (2-3 items, Jan Pawła II Street, Narodowych Sił Zbrojnych Street) (Table 4).

Since the vegetation inhabiting areas along the transport routes failed to include any plant communities that could be considered rare on the national or regional scale, or any protected natural objects according to the Act on Environmental Protection of 2004, the estimated valorisation index equalled zero (Table 4). The

Table 4. Evaluation of vegetation along the four main roads in the city of Białystok

Evaluation index	Number of points	The number of points allocated to vegetation in transects				
		Natural area	Raginisa	Andersa	Narodowych SZ	Jana Pawła II
Preservation of natural conditions	0	anthropopressure 75-100%	-	0	-	-
	1	anthropopressure 50-75%	1	-	-	1
	2	anthropopressure 25-50%	-	-	2	-
	3	anthropopressure 0-25%	-	-	-	-
Biodiversity – degree of biotope variety, number of plant taxa	0	0-2	-	-	-	-
	1	od 3 do 5	-	-	-	-
	2	od 6 do 8	-	2	2	-
	3	More than 9	3	-	-	3
Complementarity – evaluation of the ecological system	0	Non-wooded buffer strip	-	-	-	-
	1	Occurrence of one object in the form of wooded buffer strips	1	1	-	-
	2	Occurrence of two objects in the form of wooded buffer strips	-	-	-	2
	3	Occurrence of three objects in the form of wooded buffer strips	-	-	3	-
Uniqueness – objects where rare natural plant communities are preserved	0	No objects	0	0	0	0
	1		-	-	-	-
	2		-	-	-	-
	3		-	-	-	-
Conservation value	0	There are no protected objects	0	0	0	0
	1	There are some protected objects	-	-	-	-
	3	There are protected objects, the Natura 2000 objects and National Parks	-	-	-	-
Physiocenotic role	0	Low	-	-	-	-
	1	Medium	1	1		
	2	High	-	-	-	2
	3	Very high	-	-	3	
The total number of the indicators			6	4	10	8
Average			1	1.5	2.5	2
Nature value			low	low	medium	medium

assessment of the physiocenotic role was diversified due to environmental protection (climatic, water-protecting, soil-protecting) functions of the studied vegetation, assuming higher values of the valorization index for more abundant natural, spontaneously settled vegetation patches constituting biocenotic oases and green islands within the city. The heavily urbanized transects located closer to the city centre featured a greater number of anthropogenically organized tree rows (value: 1) than transects which were closer to the city boundaries. The vegetation found in transects near the city boundaries was more spontaneously settled in the form of mid-field tree clusters (values: 2-3) (Table 4).

4. Discussion

Studies of the dendroflora present in Białystok green areas conducted in 2004 demonstrated a total of 123 tree and bush species from 24 families and 59 genera (Kwiatkowski *et al.* 2004). The findings were influenced, to the greatest extent, by the richness of the dendroflora found in Białystok cemeteries accounting for a total of 88 tree and bush species representing 22 families and 53 genera. The dendroflora of developed areas and transport routes comprised 72 species belonging to 18 families (Kwiatkowski *et al.* 2004). The wildlife inventory conducted in 2011 for the purpose of the present

study along the four main transport routes in transects revealed a total of 837 trees and bushes representing 36 species and 18 families. These findings showed a similar diversity of the flora found along the transport routes over a period of seven years (2004-2011). Taking into account the number of trees and bushes determined in the present study in Andersa Street (178) and in Raginisa Street (164), it was similar to the results obtained by Kwiatkowski *et al.* in 2004 who recorded a total of 90-180 specimens. However, significant differences in the number of trees and bushes in the investigated transects were found along the streets closer to the city boundaries. In 2004, the number of tree and bush specimens along Narodowych Sił Zbrojnych Street and Jana Pawła II Street was estimated at 90-180. Currently, their number ranged from 216 (Narodowych Sił Zbrojnych Street) to 279 (Jana Pawła II Street). The difference can probably be attributed to the natural renewal of many species of young trees and bushes which appeared along these routes as spontaneous mid-field tree clusters.

Analyzing the biodiversity of urban ecosystems, Zimny (2005) indicated that the total number of vascular plants in urban agglomerations varies between 1010 and 1109 species. The author claims that the biodiversity of large urban agglomerations is both rich and wide-ranging. This is because the flora of vascular plants, in addition to native plants, also comprises an abundant group of anthropophytes. Zimny (2005) estimates that large urban agglomerations are populated by approx. 1500 species of plants, of which 30-70% are alien species, mainly elements of the dendroflora. In contrast, Olaczek (2000) argues that alien species have no impact on the increase in the diversity of the flora because their presence can trigger a recession of stenotopic species and obscure differences existing between regional floras. As shown by Chmiel (2006), the natural diversity of flora decreases with growing anthropogenic modifications of the environment. The thesis was also supported by the findings of the present study. A greater abundance of permanently settled species of alien origin (kenophytes) was recorded in transects near the city centre (17-27%) (in Raginisa Street and Andersa Street, respectively) under the strong pressure imposed by urbanization and modernization of transport infrastructure. A smaller proportion of kenophytes was found in transects near the city boundaries (2-3% in Narodowych Sił Zbrojnych Street and Jana Pawła II Street, respectively) which had not been modernized and enriched with any new municipal facilities for a long time.

In 2004, the most represented families in Białystok streets were: Salicaceae (13 species), Pinaceae (10), Rosaceae (9), Aceraceae (6), Betulaceae (5), Cupressaceae (5) and Fagaceae (5) (Kwiatkowski *et al.* 2004). The present study showed that the group of trees was most abundantly represented by species from the family of Aceraceae (63.8%), and the group of bushes – by species from the family of Rosaceae (48.9%). In 2004, species from the *Acer*, *Populus*, *Tilia*, *Fraxinus*, *Salix* and *Betula* genera were the prevalent ones along Białystok transport routes. In 2011, the most numerous tree species were found to be *Acer platanoides*, *A. negundo* and *Tilia cordata*, and bushes were dominated by *Crataegus monogyna* and *Ligustrum vulgare.* Investigations of the species composition of trees populating the town of Nowa Sól also determined that the most common tree species growing along transport routes were *Tilia cordata* and *Acer platanoides*, and bush species – *Ligustrum vulgare* (Klimko & Szczecińska 2004). Taking into account the establishment of green belts along transport routes in urban agglomerations, these species are recommended for planting along broad streets (Fortuna-Antoszkiewicz *et al.* 2007). Their preference is associated with high resistance to air pollution, since deciduous trees and bushes rank among less sensitive species (Haber 2001). Deciduous tree and bush species should constitute the main component of green belts planned along transport routes with high traffic volumes because of their key role as a biological barrier preventing the spread of air pollutants (Łaska & Jaros 2011). Deciduous tree leaves have a larger assimilation surface compared with the needles of coniferous trees, which is why they assimilate more carbon dioxide in the process of photosynthesis. They are also more resistant to car exhaust emissions than coniferous tree species. The effectiveness of green areas as biological barriers protecting against air pollution also depends to a great extent on the appropriate layered structure of vegetation due to the seasonal variability and the density of specimens per a unit of area (Łaska & Jaros 2011). In open areas, air pollution in the form of dust and gases spreads over considerable distances from the road, with areas directly adjacent to roads acting as their passive "accumulation zones". The phenomenon takes place differently in wooded areas, where trees serve as biological filters hindering the spread of harmful air emissions (Sukopp 2004; Treshew 2004; Burden 2006).

The progressing process of urbanization and development of transport infrastructure in urban agglomerations contributes to an increase in the synanthropization of the flora, since the establishment of green areas involves the supplementation or substitution of natural flora components with alien species. The present study demonstrated that the proportion of native species (65.7%) in the composition of the dendroflora along transport routes was approximately twice as high as the proportion of alien species (34.3%). Research into the origin of plant species conducted in Polish cities shows a range of correlations. For example, studies of alien and native species in Jarocin point to

the prevalence of anthropophytes (72.1%) over non-synanthropic spontaneophytes and apophytes (27.8%) (Klimko & Kaczmarek 2006). In turn, studies focusing on the species composition of the flora inhabiting the north-eastern part of Wielkopolska showed dominance of native species (70.7%), and among them prevalence of non-synanthropic spontaneophytes (32.6% of the flora) and apophytes (26.7% of the flora) (Chmiel 2006). In the group of alien species found in north-eastern Wielkopolska, diaphytes were classified more commonly (12.6% of the flora) than kenophytes (7.3% of the flora) (Chmiel 2006). Similar correlations were determined for the dendroflora studied in Białystok: in the group of anthropophytes, there were more diaphytes (22.7%) than kenophytes (10.4%).

The present study found that anthropogenic changes of the flora along transport routes demonstrated spatial diversity due to different degrees of the city urbanization. Transects located in the central part of the city exhibited a richer diversity of trees and bushes than along the main transport routes located in the vicinity of the city boundaries. The values of the dendroflora anthropophytization and kenophytization indices demonstrated that, within the territory of Białystok, which has a monocentric structure, the proportion of alien species showed a growing trend towards the city centre, whereas the spatial direction of the city anthropophytization increased away from the city centre, towards the city boundaries. Methodological studies investigating the spatial structure of the flora of major cities, including, in particular, the model solution which defines the city as a centre of crystallization in floristic-ecological space, were carried out by Jackowiak (1998a, 1998b). Based on his studies conducted in Poznań (Jackowiak 1990, 1998a) and in Vienna (Jackowiak 1998b), as well as research completed by other authors in Łódź (Olaczek *et al.* 1990) and in Warsaw (Sudnik-Wójcikowska 1994), he confirms the above tendencies identified in Białystok and asserts that the relative proportion of anthropophytes per a unit of area rises towards the centre, i.e. from the marginal zone towards the centre of the city. Data documenting the flora in Poznań and Vienna (Jackowiak 1998a, 1998b) also show that archaeophytes make up the greatest proportion in the flora of the internal marginal zone, where biotopes typical for small towns and villages are preserved. On the other hand, neophytes tend to dominate in the city centre, particularly in areas with a high concentration of industry and transport. This is also corroborated by the dendroflora kenophytization index in Białystok which was estimated at 2.31-2.52% in the investigated transects closer to the city boundaries and 16.9-27.2% – near the city centre. The tendencies identified by Jackowiak (1998a) regarding the spatial distribution of archaeophytes were not referred to the studies conducted in Białystok because the city dendroflora along the investigated transport routes was not found to contain any archaeophytes.

The progressive processed of synanthropization of the urban flora – and the diverse spatial direction of the anthropophytization of the flora – were also reflected in the results of assessment of the natural value of vegetation growing along the transport routes under study. Vegetation studied along the streets adjacent to the city boundaries exhibited a greater degree of naturalness and consistency between the actual vegetation and the potential natural vegetation. These areas also contained a greater number of spontaneously settled patches representing biocenotic oases and green islands than streets in the city centre. In contrast, natural ecological arrangements in the heavily urbanized space of the centre of the city, next to transport routes, tended to be destroyed. These areas had a greater number of anthropogenically established biotopes and established green spaces in the form of artificially planted tree rows.

Studies of alien plant species provide insights about anthropogenic changes in vegetation. However, it must be noted that earlier studies, conducted in 1960s, were devoted to the essence of the process of synanthropization affecting the vegetation cover (Faliński 1968, 1969a, 1969b, 1972), but in the course of time and advancement of the synanthropization process, various works were published describing the role of kenophytes in changes occurring in the natural environment (Tokarska-Guzik 2001; Zając & Zając 2001), confirming the indicative role of the flora with respect to thermal conditions in urban areas (Sudnik-Wójcikowska 2000), as well as studies focusing on the spatial structure of the flora of major cities (Jackowiak 1998a, 1998b; Sudnik-Wójcikowska 1998) or phytogeographical problems of synanthropic plants (Zając *et al.* 2003), processes of speciation in synanthropic floras (Zając & Zając 2000), rules of distribution of anthropophytes (Zając & Zając 2003) or mechanisms of anthropogenic changes of the plant cover (Jackowiak & Żukowski 2000). The steady growth of cities in already heavily urbanized areas can be a factor contributing to the continued interest of many researchers in exploring the structure and dynamics of vegetation found in urban agglomerations.

Acknowledgment. I wish to thank Agnieszka Sawicka for her help in conducting the wildlife inventory and performing dendrometric measurements of the dendroflora in transects which were investigated in Białystok.

References

Augustyn A. 2010. Strategia Rozwoju Miasta Białegostoku na lata 2011-2020 plus. 95 pp. Urząd Miejski w Białymstoku, Białystok.

Banas W., Ceborski J., Dziuban L., Porowska-Dorozik H., Skala-Pozniak A. & Zalewski D. 2002. Program zintegrowanego rozwoju drogownictwa w Województwie Podlaskim do 2005 r., z perspektywą do 2015 r. 130 pp. OBET P.P, Warszawa.

Brunetta G. & Voghera A. 2008. Evaluating Landscape for Shared Values: Tools, Principles, and Methods. Landscape Res. 33: 71-87.

Burden D. 2006. Benefits of Urban street trees. Glatting Jackson and Walkable Communities, Inc (http://www.ufei.org/files/pubs/22BenefitsofUrbanStreetTrees.pdf).

Chmiel J. 2006. Zróżnicowanie przestrzenne flory jako podstawa ochrony przyrody w krajobrazie rolniczym. Prace Zakładu Taksonomii Roślin UAM w Poznaniu 14: 1-250. Bogucki Wyd. Nauk., Poznań.

Faliński J. B. (ed.). 1968. Synantropizacja szaty roślinnej. I. Neofityzm i apofityzm w szacie roślinnej Polski. Mater. Zakł. Fitosoc. Stos. Uniw. Warsz. 25: 1-229.

Faliński J. B. 1969a. Zbiorowiska autogeniczne i antropogeniczne. Próba określenia i klasyfikacji. Dyskusje fitosocjologiczne 4. Ekol. Pol. 15: 173-182.

Faliński J. B. 1969b. Neofity i neofityzm. Dyskusje fitosocjologiczne 5. Ekol. Pol. 15: 337-355.

Faliński J. B. 1972. Synantropizacja szaty roślinnej – próba określenia istoty procesu i głównych kierunków badań. Phytocoenosis 1: 157-170.

Fortuna-Antoszkiewicz B. 2004. Struktura przestrzenna nasadzeń drzew przy ulicy miejskiej w świetle archiwaliów. In: A. Rylke (ed.). Przyroda i miasto, pp. 218-232. SGGW, Warszawa.

Fortuna-Antoszkiewicz B., Gadomska E. & Gadomski K. 2007. Urządzanie i pielęgnacja terenów zieleni. 33 pp. Wyd. Hortpress, Warszawa.

Haber Z. 2001. Kształtowanie terenów zieleni z elementami ekologii. 209 pp. Wyd. AR, Poznań.

http://gisbialystok.pl [dostęp: 23.10.2011]

http://geoportal.gov.pl [dostęp: 23.10.2011]

Jackowiak B. 1990. Antropogeniczne przemiany flory roślin naczyniowych Poznania. Wyd. Nauk. UAM, seria Biologia, 42, 232 pp. Poznań.

Jackowiak B. 1998a. The city as a centre for crystalization of the spatial-floristic system. In: J. B. Faliński, W. Adamowski & B. Jackowiak (eds.). Synanthropisation of plant cover in New Polish research. Phytocoenosis 10 (N.S.), Suppl. Cartogr. Geobot. 9: 55-67.

Jackowiak B. 1998b. The hemoroby concept in the evaluation of human influence on the urban flora of Vienna. In: J. B. Faliński, W. Adamowski & B. Jackowiak (eds.). Synanthropisation of plant cover in New Polish research. Phytocoenosis 10 (N.S.), Suppl. Cartogr. Geobot. 9: 79-96.

Jackowiak B. 2003. Spatial structure of urban flora and its dynamism. In: A. Zając, M. Zając & B. Zemanek (eds.). Phytogeographical problems of synanthropic plants, pp. 17-28. Institute of Botany, Jagiellonian University, Cracow.

Jackowiak B. & Żukowski W. (eds.). 2000. Mechanisms of anthropogenic changes of the plant cover. Publications of the Department of Plant Taxonomy of the Adam Mickiewicz University in Poznań 10: 1-303. Bogucki Wyd. Nauk. Poznań.

Juda-Rezler K., Reizer M. & Oudinet J. P. 2011. Determination and analysis of PM10 source apportionment during episodes of air pollution in Central Eastern European urban areas. The case of wintertime 2006. Atmos. Environ. 45: 6557-6566. Doi:10.1016/ j.atmosenv. 2011.08.020.

Kaźmierczakowa R., Zarzycki K. & Mirek Z. (eds.). 2014. Polska Czerwona Księga Roślin. Paprotniki i rośliny kwiatowe. Wyd. III uaktual. i rozszerz., 895 pp. PAN Instytut Ochrony Przyrody, Kraków.

Klimko M. & Kaczmarek G. 2006. Dendroflora of the town of Jarocin. Rocz. AR Poznań, Bot. 10: 121-136.

Klimko M. & Szczecińska A. 2004. Dendroflora parków i zadrzewień przyulicznych w Nowej Soli (województwo lubuskie). Rocz. AR Poznań, Bot. 7: 109-118.

Kwiatkowski W., Gajko K., Ksepko M., Miniuk P. & Stepaniuk M. 2004. Opracowanie ekofizjograficzne dla terenu miasta Białegostoku. 194 pp. Urząd Miejski w Białymstoku, Białystok.

Lenart W. & Tyszecki A. 1998. Poradnik przeprowadzania ocen oddziaływania na środowisko. 377 pp. Ekokonsult, Gdańsk.

Łaska G. & Jaros M. 2011. Planowanie terenów zieleni w obszarach zagrożeń w aspekcie zmienności aparatu fotosyntetyzującego i metali ciężkich. Wyd. Politechniki Krakowskiej, Czasop. Techn., Seria Architektura 17: 227-232.

Łukasiewicz A. & Łukasiewicz S. 2006. Rola i kształtowanie zieleni miejskiej. 128 pp. Wyd. Nauk. UAM, Poznań.

Mahon J. R. & Miller R. W. 2003. Identifying high-value greenspace prior to land development. J. Arboriculture 29 V(1): 25-33.

Mirek Z., Piękoś-Mirkowa H., Zając A. & Zając M. 2002. Flowering plants and pteridophytes of Poland. A checklist. In: Z. Mirek (ed.). Biodiversity of Poland, 1, 442 pp. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

Olaczek R. 2000. Antropogeniczne czynniki przekształcenia dolin rzecznych. Rzeki 9: 119-142.

Olaczek R., Ławrynowicz M., Witosławski P., Filipiak E. & Sieradzki J. 1990. Analiza przestrzenna flory obszaru zurbanizowanego na przykładzie Łodzi. W: H. Zimny (ed.). Funkcjonowanie układów ekologicznych w warunkach miasta, pp. 184-198. Wyd. SGGW-AR, Warszawa.

Oleksiejuk E. 2005. Rola i funkcje zieleni w mieście. In: E. Oleksiejuk & J. Piotrowicki (ed.). Zieleń miejska – zasady gospodarowania i ochrona, pp. 111-116. Zieleń miast i wsi, Toruń.

StatSoft 2014. Statistica ver. 10. StatSoft Polska, Kraków.

Sudnik-Wójcikowska B. 1994. Changes in the species composition of anthropophytes in Warsaw over the last 150 years. In: S. Mochnacký & A. Terpo (eds.). Proceeding of Intenational Conference: Anthropization and environment of rural settlements – flora and vegetation, pp. 154-158. Bot. Garden, P. J. Šafárik Univ. Košice.

Sudnik-Wójcikowska B. 1998. Czasowe i przestrzenne aspekty procesu synantropizacji flory na przykładzie wybranych miast Europy Środkowej. 167 pp. Wyd. Uniw. Warsz., Warszawa.

Sudnik-Wójcikowska B. 2000. The role of flora in bioindication of the temperature conditions in urban areas. In: B. Jackowiak & W. Żukowski (eds.). Mechanisms of anthropogenic changes of the plant cover, pp. 271-279. Bogucki Wyd. Nauk., Poznań.

Sukopp H. 2004. Human-caused impact on preserved vegetation. Landscape Urban Plan. 68: 347-355.

Symonides E. & Solińska-Górnicka B. 1990. Funkcjonowanie reliktów naturalnej roślinności leśnej w warunkach miejskich. In: H. Zimny (ed.). Funkcjonowanie układów ekologicznych w warunkach miasta, pp. 168-183. Wyd. SGGW-AR, Warszawa.

Szyszko J., Rylke J., Jeżewski P. & Dymitryszyn I. 2010. Ocena i wycena zasobów przyrodniczych. 411 pp. SGGW, Warszawa.

Tokarska-Guzik B. 2001. The history of studies of invasive alien plants in Poland. In: G. Brundu, J. H. Brock, L. Camarada, L. E. Child & P. M. Wade (eds.). Plant invasions: species ecology and ecosystem management, pp. 245-254. Backhuys Publishers, Leiden, The Netherlands.

Tokarska-Guzik B. 2003. The expansion of some alien plant species (neophytes) in Poland. In: L. E. Child, J. H. Brock, G. Brundu, K. Prach, P. Pyšek, P. M. Wade & M. Williamson (eds.). Plant invasions: ecological threats and management solution, pp. 147-167. Backhuys Publishers, Leiden, The Netherlands.

Tokarska-Guzik B. 2005. The Establishment and Spread of Alien Plant Species (Kenophytes) in the Flora of Poland. Prace naukowe Uniw. Śląskiego w Katowicach 2372: 1-192.

Treshew M. 2004. Zanieczyszczenie powietrza a życie roślin. 526 pp. WNT, Warszawa.

Wysocki Cz. 2008. Miasto jako specyficzne środowisko życia roślinności. Nauka Przyr. Technol. 2: 1-10.

Wysocki Cz. & Sikorski P. 2010. Ocena środowiska przyrodniczego na podstawie szaty roślinnej. In: J. Szyszko, J. Rylke, P. Jeżewski & I. Dymitryszyn (eds.). Ocena i wycena zasobów przyrodniczych, pp. 123-150. SGGW, Warszawa.

Zając A. & Zając M. 2000. Processes of Speciation in Synanthropic Floras. In: B. Jackowiak & W. Żukowski (eds.). Mechanisms of Anthropogenic Changes of the Plant Cover. Publications of the Department of Plant Taxonomy of the Adam Mickiewicz University in Poznań 10: 31-38. Bogucki Wyd. Nauk., Poznań.

Zając A., Zając M. & Zemanek B. (eds.). 2003. Phytogeographical problems of synanthropic plants. 353 pp. Institute of Botany, Jagiellonian University, Cracow.

Zając M. & Zając A. 2001. Success factors enabling the penetration of mountains areas by kenophytes: an example from the northern Polish Carpathians. In: G. Brundu, J. Brock, L. Camarada, L. E. Child & P. M. Wade (eds.). Plant invasions: species ecology and ecosystem management, pp. 271-280. Backhuys Publishers, Leiden, The Netherlands.

Zając M. & Zając A. 2003. Rules of local distribution of anthropophytes in the former Kraków voivodship. In: A. Zając, M. Zając & B. Zemanek (eds.). Phytogeographical problems of synanthropic plants, pp. 93-103. Institute of Botany, Jagiellonian University, Cracow.

Zimny H. 2005. Ekologia miasta. 233 pp. Agencja Reklamowo-Wydawnicza A. Grzegorczyk, Warszawa.