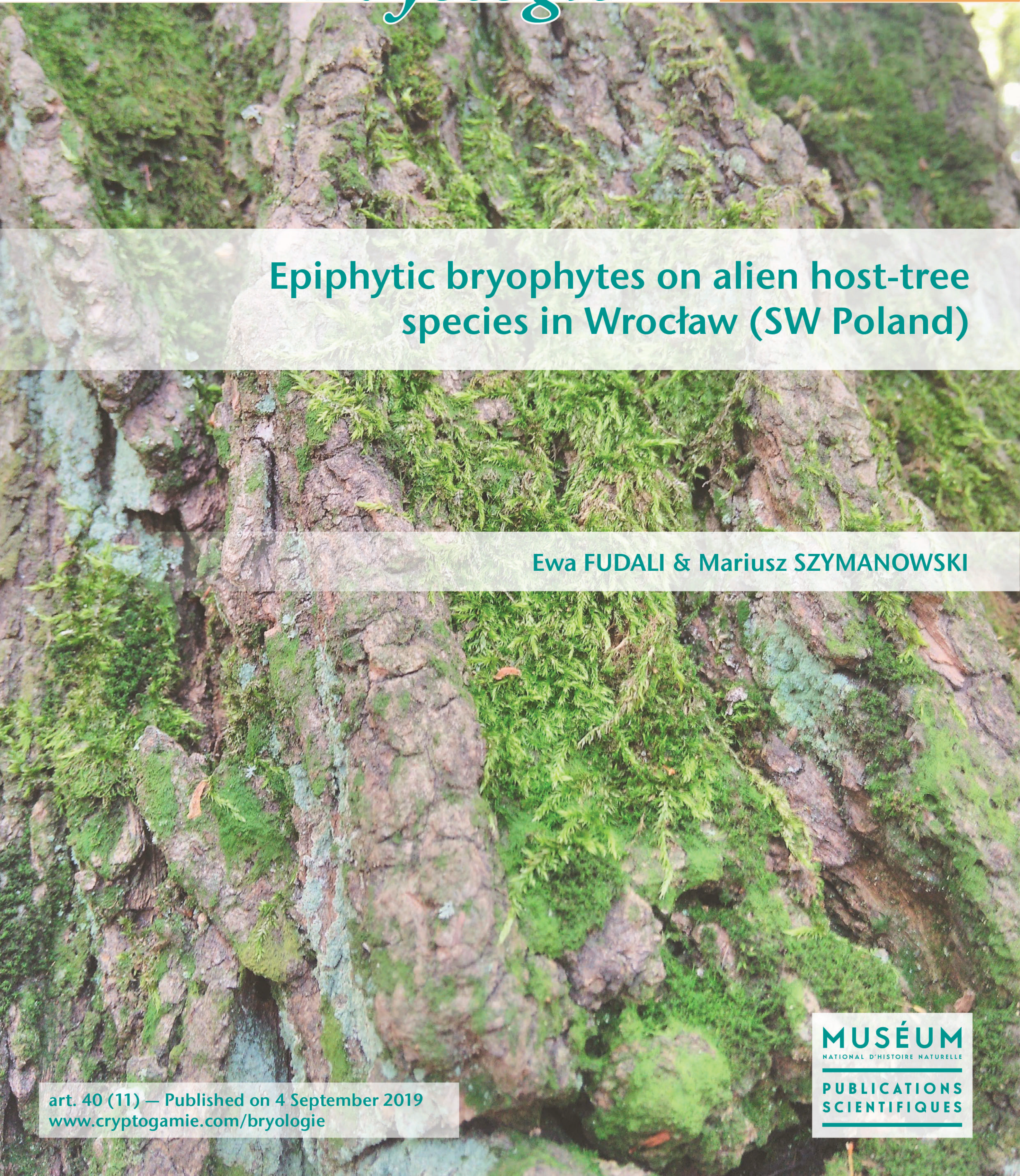
cryptogamie
Bryologie
2019 • 40 • 11



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art. 40 (11) — Published on 4 September 2019
www.cryptogamie.com/bryologie

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NATIONAL D'HISTOIRE NATURELLE
PUBLICATIONS SCIENTIFIQUES

Couverture / *Cover* :
Photographie de Ewa Fudali / Photo by Ewa Fudali

Cryptogamie, Bryologie est indexé dans / Cryptogamie, Bryologie *is indexed in:*
- Biological Abstracts
- Current Contents
- Science Citation Index
- Publications bibliographiques du CNRS (Pascal).

Cryptogamie, Bryologie est distribué en version électronique par / Cryptogamie, Bryologie *is distributed electronically by:*
- BioOne® (http://www.bioone.org)

Cryptogamie, Bryologie est une revue en flux continu publiée par les Publications scientifiques du Muséum, Paris
Cryptogamie, Bryologie *is a fast track journal published by the Museum Science Press, Paris*

Les Publications scientifiques du Muséum publient aussi / *The Museum Science Press also publish:*
Adansonia, ***Geodiversitas***, ***Zoosystema***, ***Anthropozoologica***, ***European Journal of Taxonomy***, ***Naturae***, **Cryptogamie sous-sections *Algologie*, *Mycologie*.**

Diffusion – Publications scientifiques Muséum national d'Histoire naturelle
CP 41 – 57 rue Cuvier F-75231 Paris cedex 05 (France)
Tél. : 33 (0)1 40 79 48 05 / Fax : 33 (0)1 40 79 38 40
diff.pub@mnhn.fr / http://sciencepress.mnhn.fr

ISSN (imprimé / *print*) : 1290-0796 / ISSN (électronique / *electronic*) : 1776-0992

Epiphytic bryophytes on alien host-tree species in Wrocław (SW Poland)

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Submitted on 14 June 2018 | Accepted on 21 November 2018 | Published on 4 September 2019

Fudali E. & Szymanowski M. 2019. — Epiphytic bryophytes on alien host-tree species in Wrocław (SW Poland). *Cryptogamie, Bryologie* 40 (11): 119-129. https://doi.org/10.5252/cryptogamie-bryologie2019v40a11. http://cryptogamie.com/bryologie/40/11

ABSTRACT
This paper presents the occurrence of 25 moss species on trunks of alien trees in Wrocław (without city forests), their species diversity, frequency, coverage in the plots, and preferences to the host-tree species. In general, 36% of the trees colonised by bryophytes in the city were of non-indigenous origin (11 taxa), and the most frequently occupied were *Populus xcanadensis* Moench., *Acer negundo* L. and *Robinia pseudoacacia* L. Research showed that alien trees hosted a large group of species rarely noted in the city, such as: *Syntrichia virescens* (De Not.) Ochyra, *Orthodicranum tauricum* (Sapjegin) Smirnova, *Leskea polycarpa* Hedw., *Hypnum pallescens* (Hedw.) P. Beauv. and *Orthotrichum affine* Schrad. ex Brid. But the most total coverage in the plots was occupied by two facultative epiphytes, *Orthotrichum diaphanum* Schrad. and *Hypnum cupressiforme* Hedw. Comparing the results of this study with data presenting bryoflora of *Robinia pseudoacacia* L. and *Quercus rubra* L. found in secondary woodlands, it appears that these phorophytes in the city are colonised by different bryophytes. Results of UPGMA classification of bryofloristic similarity of all phorophytes in the city are discussed in reference to the theory that alien species can facilitate the occurrence of native species, as formulated by Rodriguez (2006).

KEYWORDS
Mosses,
urban bryophytes diversity,
host tree preferences,
facilitation model,
Central Europe.

RÉSUMÉ
Bryophytes épiphytes de troncs d'arbres hôtes étrangers à Wrocław (Pologne SW).
Ce papier expose la présence de 25 espèces de mousses sur des troncs d'arbres étrangers à Wrocław (hors forêts urbaines), leurs diversités spécifiques, leurs fréquences, leurs couvertures, et leurs préférences vis-à-vis des hôtes. En général, 36 % des arbres colonisés par les bryophytes dans la ville sont d'origine non indigène (11 taxons), et les plus fréquemment occupés sont *Populus xcanadensis* Moench., *Acer negundo* L. et *Robinia pseudoacacia* L. Cette recherche montre que les troncs étrangers abritent un large groupe d'espèces rarement remarquées dans la ville, comme *Syntrichia virescens* (De Not.) Ochyra, *Orthodicranum tauricum* (Sapjegin) Smirnova, *Leskea polycarpa* Hedw., *Hypnum pallescens* (Hedw.) et *Orthotrichum affine* Schrad. ex Brid. Mais la couverture la plus grande dans les parcelles est le fait de deux épiphytes facultatifs, *Orthotrichum diaphanum* Schrad. et *Hypnum cupressiforme* Hedw. La comparaison de ces résultats avec des données sur la bryoflore de *Robinia pseudoacacia* L. et de *Quercus rubra* L. des forêts secondaires fait apparaître que ces phorophytes dans la ville sont colonisés par des bryophytes différents. Les résultats de la classification UPGMA de similutude des bryophytes de tous les phorophytes dans la ville sont discutés en référence à la théorie que les espèces étrangères peuvent faciliter la présence d'espèces natives, comme le formulait Rodriguez (2006).

MOTS CLÉS
Mousses,
bryophyte urbaine,
diversité,
préférence des arbres-hôtes,
modèle de facilitation,
Europe centrale.

INTRODUCTION

A high percentage of alien vascular plant species, including trees, is attributed to urban floras (Kowarik 1990; Pyšek 1998). Revision of rich data concerning the dendroflora of urban parks, domestic gardens, and tree plantings along city streets around the world revealed a high percentage of alien trees in every case, between 60 and 80% (Kowarik *et al.* 2013).

According to Barkman (1958), exotic trees have poor epiphytic bryoflora that is not exotic. He believed the trunks of alien trees are colonised by epiphytes passing from the trunks of the most common native tree species. For many years since Barkmann's book was published, this problem has not been studied carefully, and some studies on alien trees' effects on bryophytes in secondary woodlands have been reported only recently (Woziwoda *et al.* 2017; Jagodziński *et al.* 2018). They have documented that *Robinia pseudoacacia* L. and *Quercus rubra* L. are able to host a rich and differentiated epiphytic bryoflora. Woziwoda *et al.* (2017) found high bryofloristic similarity between *Quercus rubra* and native oak *Quercus robur* L. in post-agricultural forests, which they interpreted as the ability of alien oak to replace native oak as the 'host of bryophytes' according to the substitutive facilitation hypothesis formulated by Rodriguez (2006), which assumed that alien species can facilitate the occurrence of native species.

As for cities, influence of alien trees on epiphytic bryophyte species richness and frequency is hardly known; only a few observations that bryophytes occur on trunks of some alien trees species have been published so far (Stingl 1985; Richter *et al.* 2009; Fudali 2012, 2018; Müller 2014; Fojcik *et al.* 2015; Stebel & Fojcik 2016). Regarding the phenomenon of tree trunk recolonisation by epiphytic bryophytes reported recently from some European cities (i.e. Stapper & Kricke 2004; Richter *et al.* 2009; Fudali 2012; Sérgio *et al.* 2016; Stebel & Fojcik 2016), the question of what contribution alien trees make in the current state of epiphytic bryophyte distribution in the cities seems worthy of study.

The dendroflora of Wrocław contains nearly 100 woody alien species (Szopińska 2013) occurring with varying frequency, from the *Robinia pseudoacacia* and *Acer negundo* L. common in all urban habitats to the *Liliodendron* sp. sporadically found in parks. In recent decades, some alien species have shown visible expansion into the town area (Bąbelewski 2007; Dajdok 2013). That is why Wrocław might be a good case to study how the presence and spread of alien woody species in the city affects epiphytic bryophyte diversity and distribution. Obviously, the geographical origin of host tree is not recognized by bryophytes as a determinant of their settlement, but numerous researches in forests provide evidence that 'epiphytic diversity is closely related to tree species richness' (Ódor *et al.* 2014; and literature quoted therein).

In the years 2013-2016, we carried out the research on Wrocław to determine factors influencing the epiphytic bryophyte occurrence in the city. The study showed that a large group of alien tree species was colonised by bryophytes. As this aspect of epiphyte distribution in cities has hardly been discussed in the literature, we analysed our data concerning bryophyte occurrence on alien trees in order to answer the following questions: 1) how frequently do bryophyte species occupy trunks of alien tree species? 2) what is their species richness and substratum specialisation to corticolous habitats? 3) and do they show any tendencies to colonise only chosen alien host trees? The second goal was to find out which of the numerous alien tree species in the city harbored epiphytic bryophytes, the extent to which the availability of those trees ('habitat offer') was used by bryophytes, and how the location of alien trees in relation to the spatial structure of the city (densely built-up inner city versus outer city with disperse buildings; parks and other green spaces versus urban buildings and streets) affected the frequency of their colonisation by epiphytes. We also determined the bryofloristic similarity of all the tree species (both introduced and indigenous) more frequently occupied by bryophytes (10 or more tree individuals colonised) in the city to check the research hypothesis that at least some of the alien tree species facilitate the occurrence of native epiphytic bryophytes in the city. Results and conclusions are presented in this paper.

MATERIAL AND METHODS

Area characterization

Wrocław is one of the biggest and oldest towns in Poland, established at the end of the 12th century. It currently occupies an area of 293 km² and is inhabited by about 640 000 people. The city is located at altitudes of 95-125 m a.s.l. in a flat area formed by the Odra River and its five tributaries, which waters occupy about 3% of the city area. In these river valleys, the remnants of natural vegetation, wet meadows, and forests (mostly wet elm-ash forests and mesophilous oak-hornbeam forests) have been preserved; they cover approximately 7.6% of the city surface (Lewicki 2014). In the spatial structure of Wrocław, rural areas with sparsely arranged buildings and garden plots dominate (45% of the city area); they are partly fallowed and recently systematically built-up with residential estates. A compactly built-up centrum covers about 30% of the city area. It contains old downtown, factories and large housing estates with an extensive street network divided by urban greenery that harbours about 450 species of trees and shrubs (Szopińska 2013) and occupy about 1 472 ha (17% of the centrum surface). A large area of the city (9.7%) has been transformed for a communication network (Lewicki 2014). The climate is transitional, between oceanic and continental. Rainfall is highly variable, and the annual total rainfall ranges between 318 and 892 mm; the average annual precipitation in the 20th century was 583 mm. The average annual temperature is 9°C, and the annual temperature amplitude is 19.2°C. Winters are short (65 days) and mild, with frequent periods of warming in February of up to 10-15°C. Within the centre of Wrocław, an urban heat island (UHI) is detected, raising the annual mean temperature by 1°C, and in windless and cloudless nights even exceeding 9°C (Szymanowski & Kryza 2009). The most frequent winds are from a westerly direction (27.6% of days in a year; the highest speed of 4.4 m/s during winter and 3.4 m/s in summer) and from the south (23.1%); winds from the north and northeast are rare (7%) (Dubicki *et al.* 2002).

Sampling design

The study is based on the investigation of trees situated in 455 research plots distributed in Wrocław (without city forests). For the research, an initial network of 100 × 100-m plots (squares) was established over the whole area of Wrocław. Next, based on a 1-m surface digital terrain model (LiDAR-originated), determining the canopy of trees, we selected all the squares where trees existed. From that set, 500 research plots were randomly drawn. Finally, 45 plots located in the city forests were excluded, as alien trees occurred there incidentally (Fudali & Żołnierz 2019, Fig. 1).

Vegetation records were produced in 2013-2016; their methodology followed the principles of Richter *et al.* (2009), with some modifications. In every research plot (found in the field using a GPS device), all trees with a girth of more than 30 cm (minimal limitation taken from Mežaka *et al.* 2008) were studied at the height range of 0.8-1.2 m above ground level to find the presence of bryophytes. Bases of trees were excluded from the investigation, as they differ in ecological conditions from trunks and are often overgrown with competitive epigeic bryophytes (Barkman 1958). On trees with bryophytes at the height section studied, plots of 30 × 40 cm in size were established, and a list of the species and their % coverage in the plot was estimated (= bryosociological relevé). Also these tree species identity was recorded. Species that could not readily be identified in the field were sampled and subsequently determined in the laboratory. In total, bryophytes were recorded on 760 trees, of which 271 were alien. Additionally, for each research plot, the species diversity of dendroflora and number of individuals with a girth greater than 30 cm of each tree species were recorded. In total, 18 491 individual trees were registered, including 4 411 alien trees.

We arbitrarily determined the boundary between the inner and outer city based on the criteria of the density and continuity of buildings and their structural similarity; 156 research plots (with 135 individuals of alien tree species colonised by bryophytes) were situated in the densely built-up inner city, whereas 299 (136) were located in the outer city (Fig. 1). The location of alien trees colonised by bryophytes in relation to land use (built-up space with streets or urban greenery) was recognised in the field; 159 were situated within urban greenery and 112 within built-up space. This method of determining the affiliation of trees was more precise than using land-use/land-cover maps, which are, to some degree, generalised and can be inadequate in cases of plots with mixed land use. Differences in proportions between the number of bryophyte species records registered on alien trees located in both urban investment zones and urban-use complexes were tested using a Z-test with a null hypothesis H0: $p1=p2$ ($p1, p2 \neq 0$), where p1 and p2 were proportions of the bryophyte records in the inner or outer city, and in the urban greenery or in built-up space, respectively. All tests were performed using Statistica 13.1 software.

Classes of the bryophyte species' relative frequency were determined as follows: very frequent species, occurring on 100-75% of the alien trees colonised; quite frequent, 74-50%; rare, 49-25%; and very rare, less than 25%, including a subclass of extremely rare, which occurs on no more than 5% of the trees studied. Bryofloristic similarity of all the phorophytes was defined by applying the UPGMA classification and Euclidean distance measure using the MVSP v. 3.131 package.

The nomenclature of mosses follows Ochyra *et al.* (2003) with the exception of *Rosulabryum moravicum* (Podp.) Ochyra & Stebel. Specimens of bryophytes were deposited in [KRAM].

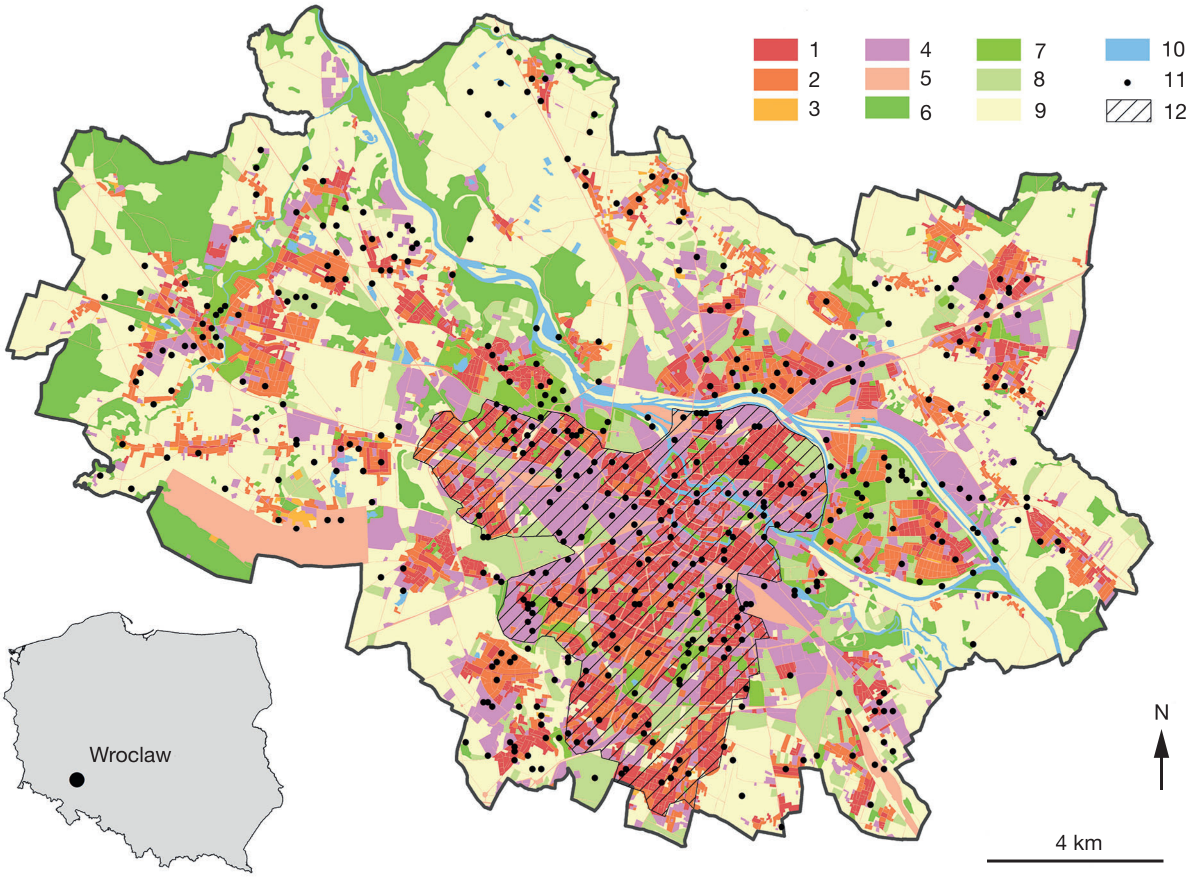

Fig. 1. — Location of the plots in relation to the spatial structure of Wrocław (based on Urban Atlas 2012, Copernicus Land Monitoring System). Legend: **1**, Continuous urban fabric (sealing level > 80%); **2**, Discontinuous dense urban fabric (S.L.: 50%-80%); **3**, Discontinuous medium and low urban fabric (S.L.: 10%-50%); **4**, Industrial and commercial areas; **5**, Transport and communication areas; **6**, Forests; **7**, Green urban areas; **8**, Sports and leisure facilities; **9**, Agricultural and semi-natural areas; **10**, Water bodies; **11**, Field measurements; **12**, City inner zone (description in text).

RESULTS

Alien trees as hosts for epiphytic bryophytes

About half (11) of the alien tree species registered (19) were colonised by bryophytes (Table 1). Some tree species, *Aesculus hippocastanum* L., *Pinus strobus* L., *Ailanthus altissima* (Mill.) Swingle, *Padus serotina* (Ehrh.) Borkh or *Prunus cerasifera* Ehrh., appeared not to be attractive phorophytes for bryophytes, although they occurred numerously. Epiphytic bryophytes were recorded on 271 individuals of alien trees what makes 36% of all tree trunks covered with epiphytes.

In general, the 'habitat offer' provided by aliens was used in 6.1% of cases, and this was higher than for native tree species, whose 'offer' was used in 3.6% of cases (Fudali 2016 unpublished data). *Populus xcanadensis* Moench., *Populus xberolinensis* (K. Koch) Dippel, and *Acer negundo* L. appeared at a rather high percentage of 'habitat offer' use (Table 1).

The number of specimens of the tree taxa colonised by bryophytes was strongly differentiated, from 1 to 88, and that number was greater than 10 for only five tree species. These tree species were: *Acer negundo, Robinia pseudoacacia, Populus xcanadensis, Populus nigra* var. *italica* and *Quercus rubra.*

Bryophyte species diversity and their substratum spectrum

In total, 25 moss species were registered and no liverwort species was found. Among the species recorded there are 18 epiphytes (7 obligatory and 11 facultative). Other species are, in general, poorly connected with the bark of trees as substratum and occur mostly on soil, rocks, and/or decayed wood (Table 2).

Relative frequency and total cover of bryophytes in plots on trunks of alien trees

Most of the species (84%) were classified as very rare, including 73% of the epiphytes and all of the species poorly connected with tree bark as substratum. Among the latter, most species were extremely rare. Only two species, both facultative epiphytes, occurred very frequently and quite frequently: *Orthotrichum diaphanum* Schrad. ex Brid. (noted on 76% of trees) and *Hypnum cupressiforme* Hedw. (50%) while two taxa were classified as rare, obligate epiphyte *Orthotrichum pumilum* Sw. (35%) and facultative *Amblystegium serpens* (Hedw.) Schimp. (34%).

The two most frequent species occupied 78% of the total area covered with bryophytes in the plots: *Ortotrichum diapha-*

num (58%) and *Hypnum cupressiforme* (20%) (Table 2). With regard to other species, the total surface covered in the plots was very small, with the exception of two obligatory epiphytes: *Dicranoweisia cirrata* (Hedw.) Lindb. (50.42 dcm² what makes 8% of the total area covered with bryophytes) and *Platygyrium repens* (Brid.) Schimp. (28.59 dcm²-5%). Thus, in the scale of the city, the bryoflora on trunks of aliens seems to be floristically monotonous and very poor in species.

Host-tree species preferences

Phorophytes differed in species number, which fluctuated between 1 and 22 (Table 1), and composition (Table 2). The richest in bryophytes and epiphytes was *Robinia pseudoacacia*; the poorest were *Platanus acerifolia* (Aiton) Willd., *Morus alba* L. and *Padus serotina.* Comparison of the bryophyte species compositions recorded for the individual phorophyte species showed that only one epiphyte, *Orthodicranum tauricum*, occurred exclusively on the trunks of only one phorophyte species, *Robinia pseudoacacia*. Other bryophyte species tended to colonise more phorophyte species, but only seven of them, were noted on all five phorophytes, with more than 10 individual trees occupied by bryophytes (Table 2).

Some of these bryophyte species showed differentiation in frequency, depending on the host-tree species. *Orthotrichum diaphanum* occurred on almost all of the specimens of *Populus xcanadensis* and *Acer negundo* and most of *Populus nigra var. italica*, whereas its frequency on other phorophytes was visibly lower. *Hypnum cupressiforme* was found on more than half of the specimens of *Quercus rubra* and *Robinia pseudoacacia*; *Syntrichia virescens* was found on more than half of the specimens of *Populus xcanadensis.* Among other bryophyte species, seven occurred with different frequencies on individual phorophytes and appeared visibly more often on trunks of only some host-tree species. These included *Dicranoweisia cirrata*, *Hypnum pallescens*, *Platygyrium repens* and *Rosulabryum moravicum* which tended to occupy trunks of *Robinia pseudoacacia*.; *Orthotrichum pumilum*, *Brachythecium rutabulum* and *Bryum argenteum* preferring trunks of *Populus xcanadensis*; and *Orthotrichum pumilum* and *Orthotrichum pallens*, which showed a tendency to occur on trunks of *Acer negundo* (Table 2).

Phorophytes differed also in the bryophyte total coverage in the plots in terms of both overall coverage, ranging between 17,17 and 215,31 dcm², and coverage by particular bryophyte species (Table 2). *Orthotrichum diaphanum* dominated in the plots on trunks of *Populus xcanadensis* (88% of the total cover of bryophytes registered on that host tree and 51% of the bryophyte total coverage on all phorophytes) and *Acer negundo* (86% and 40%, respectively). *Hypnum cupressiforme* had the highest coverage on trunks of *Robinia pseudoacacia* (65% and 72%, respectively), as well as *Dicranoweisia cirrata* (34% and 95%, respectively).

Distribution of bryophytes on alien trees in relation to spatial structure of the city

Twenty-four bryophyte species were recorded in parks and other elements of urban greenery; this number was higher than in the built-up area (18) (Fig. 2). Seven species (epiphytic, *Dicranoweisia cirrata*, *Hypnum pallescens*, *Orthodicranum tauricum* and *Pylaisia polyantha,* epixylic, *Plagiothecium denticulatum* and *Aulacomnium androgynum,* epigeic-epixylic, *Plagiomnium affine*) were noted only in green areas and one, epipetric *Dryptodon pulvinatus* (Hedw.) Brid., exclusively in built-up space. Among the 17 species occurring in both complexes, nine showed differentiation of frequencies. For eight species differences were statistically significant (p-value < 0.05; Fig. 2; Table 3 [test 1]). These were: *Amblystegium serpens, Brachythecium rutabulum, Brachytheciastrum velutinum* (Hedw.) Ignatov & Huttunen, *Ceratodon purpureus* (Hedw.) Brid.*, Hypnum cupressiforme, Platygyrium repens, Rosulabryum moravicum* and *Syntrichia virescens* that were noted more frequently in urban greenery than in built-up space. In cases when statistical testing was extended, we referred the number of alien trees settled by a given species to the number of all alien trees occupied by bryophytes in each complex respectively (Table 3 [test 2]). Then a statistical significance of preferences to occur more frequently within urban greenery was found only for two species: *Hypnum cupressiforme* and *Rosulabryum moravicum.* That test also showed statistical significance of occurrence within built-up space for *Orthotrichum diaphanum* (Table 3).

In the inner city, the number of bryophyte species recorded was lower than in the outer city: 20 (including 15 epiphytes) and 24 (17), respectively (Fig. 3). One moss, epipetric *Tortula muralis* Hedw., occurred exclusively on trunks of alien trees in the inner city. Exclusive occurrence in the outer city was

Table 1. — Use of the 'habitat offer' of all alien tree species recorded on the plots studied and number of bryophyte species recorded (species of alien trees arranged according to the number of available specimens).

Name of the host tree species	Trees available	Trees with bryophytes	%	∑ of bryophyte species
Robinia pseudoacacia L.	1981	74	3.7	22
Juglands regia L.	397	6	1.5	7
Acer negundo L.	345	67	19.4	14
Aesculus hippocastanum L.	305	0	0	0
Populus xcanadensis Moench.	199	88	44.2	14
Quercus rubra L.	177	12	6.8	17
Ailanthus altissima (Mill.) Swingle	157	0	0	0
Padus serotina (Ehrh.) Borkh	129	1	0.8	1
Populus nigra L. var. italica	118	14	11.9	9
Prunus cerasifera Ehrh.	111	0	0	0
Platanus acerifolia (Aiton) Willd.	97	1	1	1
Acer palmatum Thunb.	95	4	4.2	8
Pinus nigra Arn.	67	0	0	0
Pinus strobus L.	62	0	0	0
Catalpa bignonioides Walter	42	0	0	0
Pseudotsuga menziesii (Mirb) Franco	41	0	0	0
Morus alba L.	40	1	2.5	3
Magnolia L. sp.	36	0	0	0
Populus xberolinensis (K. Koch) Dippel	12	3	25	9
∑	4411	271	6.1	–

TABLE 2. — Number (N) of bryophyte records on trunks of alien trees and their total coverage (dcm²) in the plots (C) on individual tree species.

	∑ of the trees colonizied	Total coverage in the plots (dcm²)	Robinia pseudoacacia		Quercus rubra		Acer negundo		Populus xcanadensis		Populus nigra var Italica		Other aliens (number of tree species)		∑ of the tree species colonized
Only epiphytic in the studied area			N	C	N	C	N	C	N	C	N	C	N	C	
Orthotrichum pumilum	94	10.47	18	1.25	2	0.09	29	3.9	31	4.33	7	0.5	7 (3)	0.4	8
Dicranoweisia cirrata	36	50.42	28	48	7	2.3	–	–	–	–	–	–	1	0.12	3
Platygyrium repens	13	28.59	8	20.2	3	8.2	–	–	1	0.15	–	–	1	0.09	4
Orthotrichum affine	9	0.98	3	0.5	1	0.06	1	0.06	3	0.3	–	–	1	0.06	5
Hypnum pallescens	6	0.8	5	0.77	–	–	1	0.03	–	–	–	–	–	–	2
Orthodicranum tauricum	4	2.21	4	2.21	–	–	–	–	–	–	–	–	–	–	1
Leskea polycarpa	2	0.03	–	–	1	0.01	–	–	–	–	–	–	1	0.02	2
Epiphytic and on other substrata															
Orthotrichum diaphanum	206	367.91	33	13.8	3	0.4	63	146.6	84	189.2	10	9.6	13 (5)	8.31	10
Hypnum cupressiforme	138	125.36	55	90.5	9	5.2	25	7	36	6.85	7	13.95	6 (4)	1.86	9
Amblystegium serpens	92	19.66	26	8.01	2	0.1	24	4.8	27	5.1	6	0.8	7 (3)	0.7	8
Syntrichia virescens	19	2.32	3	0.03	1	0.03	3	1.3	9	0.4	1	0.06	2 (1)	0.5	6
Orthotrichum pallens	16	3.99	1	0.03	1	0.03	9	3	4	0.9	–	–	1	0.03	5
Rosulabryum moravicum	14	3.1	13	2.9	–	–	1	0.2	–	–	–	–	–	–	2
Pylasia polyantha	4	0.7	1	0.4	1	–	–	–	–	–	2	0.3	–	–	3
Dicranum scoparium	2	0.15	1	0.03	1	0.12	–	–	–	–	–	–	–	–	2
Brachythecium rutabulum	51	6.4	17	1.7	1	0.03	10	1	19	2.7	1	0.5	3 (3)	0.48	8
Ceratodon purpureus	57	9.7	17	2.6	1	0.4	8	0.2	20	5.1	5	0.6	6 (3)	0.8	8
Brachytheciastrum velutinum	11	0.88	5	0.42	1	0.12	4	0.32	1	0.06	–	–	–	–	4
Epipetric, epigeic or/and epixylic															
Bryum argenteum	14	0.3	1	0.01	–	–	3	0.1	8	0.16	1	0.02	1	0.01	5
Orthotrichum anomalum	7	0.14	2	0.06	–	–	1	0.03	4	0.05	–	–	–	–	3
Dryptodon pulvinatus	2	0.03	1	0.01	1	0.02	–	–	–	–	–	–	–	–	2
Tortula muralis	2	0.01	–	–	–	–	–	–	2	0.01	–	–	–	–	1
Plagiomnium affine	2	0.06	–	–	2	0.06	–	–	–	–	–	–	–	–	1
Aulacomnium androgynum	1	0.01	1	0.01	–	–	–	–	–	–	–	–	–	–	1
Plagiothecium denticulatum	1	0.02	1	0.02	–	–	–	–	–	–	–	–	–	–	1
∑ of bryophyte species	25	–	22		17		14		14		9		13		–
Total bryophyte coverage in the plots (dcm²)		634.22	193.5		17.17		168.54		215.31		26.33		13.38		–

recorded for five species, including two obligatory epiphytes, *Hypnum pallescens* and *Orthodicranum tauricum*, and three forest species, *Plagiomnium affine, Plagiothecium denticulatum* and *Aulacomnium androgynum,* connected with soil and/or decayed wood. Among the species noted in both zones of the urban areas, a statistical significance of more frequent occurrence on trees in the inner city was shown for five taxa: *Amblystegium serpens*, *Bryum argenteum*, *Ceratodon purpureus*, *Orthotrichum diaphanum* and *Syntrichia virescens* and of more frequent occurrence on trees in the outer city - for other five species: *Brachytheciastrum velutinum*, *Dicranoweisia cirrata*, *Hypnum cupressiforme*, *Platygyrium repens* and *Rosulabryum moravicum* (Fig. 3; Table 3 [test 1]). Extended testing showed statistical significance of more frequent occurrence in the inner city only for *Ceratodon purpureus* and *Orthotrichum diaphanum* and preferences to occur more frequently in the outer city for *Dicranoweisia cirrata*, *Hypnum cupressiforme*, *Platygyrium repens* and *Rosulabryum moravicum* (Table 3 [test 2]).

Bryofloristic similarity of alien and native host-tree species

Almost all the bryophyte species recorded on trunks of alien host-tree species (22) were also found on trunks of native trees (Fudali 2016 unpublished data). Three bryophyte species noted exclusively on trunks of aliens were not epiphytes, epipetric *Tortula muralis* and epigeic-epixylic *Plagiomnium affine* and *Plagiothecium denticulatum,* and they were recorded no more than two times.

The bryofloristic similarity classification (UPGMA) of all the phorophytes registered during studies (Fig. 4) clearly separated two alien tree species, *Acer negundo* and *Populus xcanadensis*, which formed the first group of floristic similarity (I). The other tree species formed one differentiated group (II), which was composed of four subgroups. The first subgroup (IIa) contained the alien *Robinia pseudoacacia* and native *Quercus robur* and was visibly distant from other tree species. Species forming the other subgroups appeared to have more similar bryoflora.

DISCUSSION

Our research evidenced that some alien tree species are not only important phorophytes for epiphytic mosses in Wrocław (the incidence percentage of aliens among trees occupied by bryophytes was 36%) but their presence contributes to an increased number of sites of rare epiphytic species in the city, such as: *Hypnum pallescens*, *Leskea polycarpa, Orthodicranum*

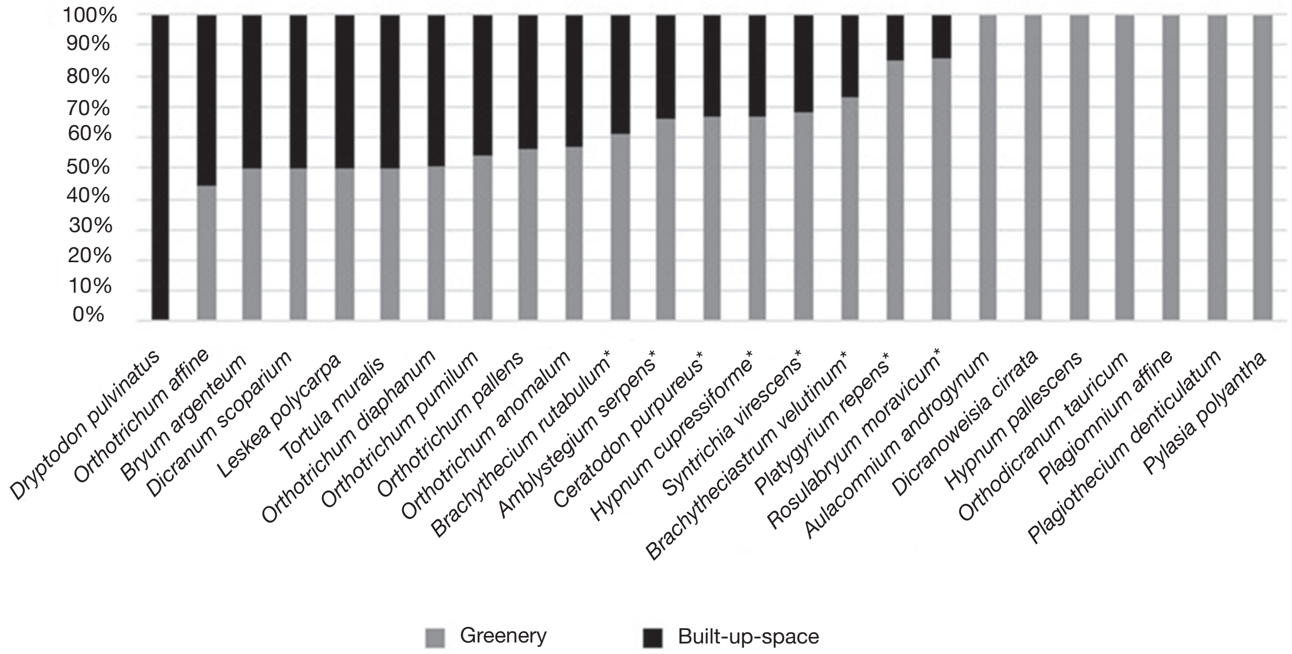

Fig. 2. — Comparison of the percentage of incidence of individual bryophyte species on trunks of alien host trees situated in complexes of urban greenery and urban buildings. Key: Species for which statistical significance (p<0.05) was found in preferences to occur more frequently in one of the land-use complexes are marked with an **asterisk**. Tests were not performed in cases in which one of the components (population in greenery or built-up space) was equal to zero.

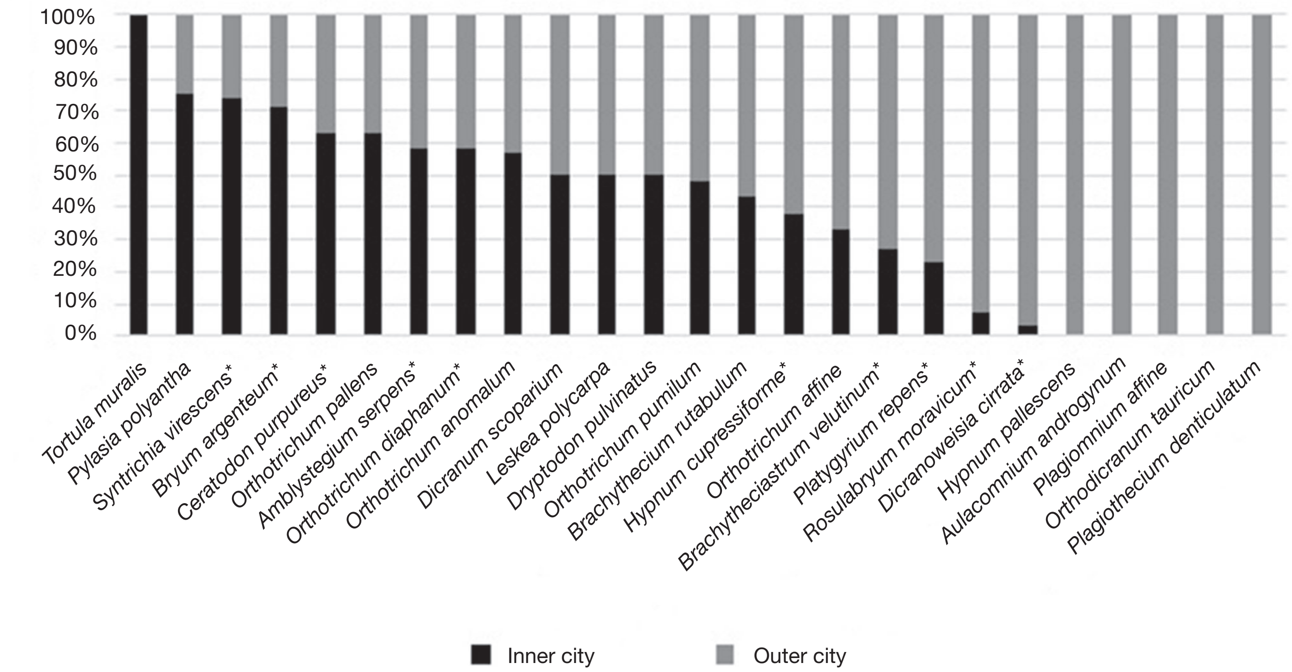

Fig. 3. — Comparison of the percentage of incidence of the individual bryophyte species on trunks of alien host trees situated in the inner vs. outer city. Key: symbols as in Fig. 2. Tests were not performed in cases in which one of the components (population in inner or outer city) was equal to zero.

tauricum, *Orthotrichum affine* and *Syntrichia virescens* (Fudali 2012), as well.

The research has shown that a general bryophyte species richness on alien host-tree species depends on the location of tree individuals in reference to the spatial and land-use structure of the city. More bryophyte species, especially epiphytes, occurred in the outer city than in the inner city, and within urban greenery than within built-up space. These results were expected and overlap with previous reports (i.a. Fudali 1996; Vanderpoorten 1997; Dymytrova 2009). But some bryophyte species has shown opposite tendencies; *Tortula muralis*, *Ceratodon purpureus* and *Orthotrichum diaphanum*

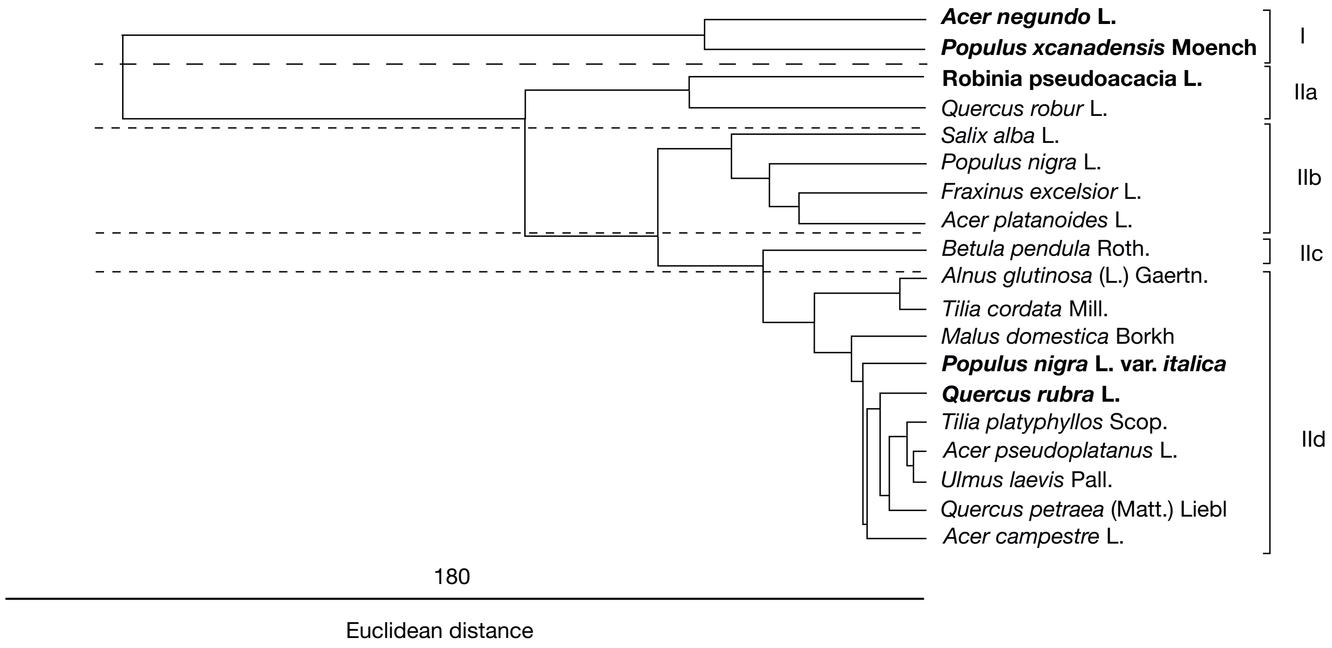

Fig. 4. — UPGMA phenogramme of the bryofloristic similarity of the phorophytes based on the species total coverage in the plots on the individual tree species. Key: I, II, IIa… groups and subgroups of the bryofloristic similarity; dashed lines show borders among the latter; alien tree species were marked in **bold**.

preferred to occur in the inner city, while *Dryptodon pulvinatus* and *Orthotrichum diaphanum* within built-up space. All the listed species are connected in the city with man-made habitats containing concrete (Fudali 2001). The phenomenon of epiphytic bryoflora ruderalisation in the city centres due to trunk colonisation by mosses passing from walls is also well documented in the literature and explained as a result of building dust deposition, which can change the chemical and physical properties of the trees' bark (i.e. Hohenwallner 2000; Fudali 2006; Fojcik *et al.* 2015; Sérgio *et al.* 2016). Indeed, in recent decades the centrum of Wrocław has been intensively built up.

In Wrocław, the most frequently colonised species were poplars, *Populus xcanadensis* and *Populus xberolinense* as well as the maple *Acer negundo* in the centrum. A large number of trunks occupied by bryophytes was noted for *Robinia pseudoacacia*, but the 'habitat offer' use of this phorophytes was much lower. These results coincide partly with data from other cities. In Katowice, epiphytes were recorded on several alien tree species (Stebel & Fojcik 2016), but poplars (including *Populus xcanadensis*, *Popolus xberolinense.* and *Populus balsaminera*) were the most frequently occupied by bryophytes (Fojcik *et al.* 2015). In Freiburg, among some alien phorophytes, the highest number of individuals colonised by bryophytes was noted for *Robinia pseudoacacia* and *Quercus rubra* (Stingl 1985).

Although in Wrocław the total number of bryophyte species recorded on trunks of alien trees was smaller than on trunks of natives, the richest epiphytic bryoflora was found on the alien *Robinia pseudoacacia* (22 species). For comparison, the most rich in bryophyte native tree species (*Acer platanoides*, *Fraxinus excelsior* and *Quercus robur*) harboured 19 bryophyte taxa each (Fudali 2016 unpublished data). Also, in the secondary woodlands on a reclaimed post-mining site, trunks of *Robinia pseudoacacia* hosted more epiphytic bryophytes (32) than other tree species (Jagodziński *et al.* 2018). In the same woodlands, an epiphytic bryoflora found on trunks of *Quercus rubra* contained 14 species. This is contrasting with the results of Woziwoda *et al.* (2017), which documented high bryophyte species richness (28) on trunks of the red oak in secondary forests on post-agricultural sites. In Wrocław, that tree species hosted quite numerous epiphytic bryoflora (17 species).

Our studies revealed that five bryophyte species had a tendency to colonise mostly trunks of *Robinia pseudoacacia*, four on *Populus xcanadensis*, and three on *Acer negundo*, while none for *Quercus rubra* and *Populus nigra* var. *italica.* Different results regarding red oak were presented by Woziwoda *et al.* (2017), who enumerated four epiphytic species occurring exclusively on that phorophyte in post-agricultural forests. Two of those species, *Orthotrichum affine* and *Orthotrichum diaphanum*, occurred in Wrocław on trunks of many tree species (Fudali 2012); just like in other cities (i.e. Stingl 1985; Richter *et al.* 2009; Dymytrova 2009; Stebel & Fojcik 2016). Exclusive occurrence of many bryophyte epiphytes was also revealed on trunks of *Robinia pseudoacacia* in woodlands on a reclaimed post-mining site (Jagodziński *et al.* 2018). But the species listed were different than in Wrocław, while in Freiburg a clear tendency was documented of *Dicranoweisia cirrata* to colonise trunks of black locust (Stingl 1985), coinciding with results from Wrocław. Based on these few data, it seems that the alien tree species host other epiphytic bryoflora in cities than in forests. This leads to the conclusion that epiphytic bryoflora on alien trees is formed from species passing from

Table 3. — Number of trees occupied by bryophytes and tests for proportional differences between populations observed in built-up (**B**) vs. greenery (**G**) and inner (**I**) vs. outer (**O**) zones. Test 1 refers to the number of alien trees occupied by a given bryophyte in a given zone to the sum of alien trees occupied by this bryophyte species in both zones; test 2 refers to the number of alien trees occupied by a given bryophyte in a given zone to the sum of alien trees occupied by all bryophytes in each zone (B,160; G,111; I, 135; O, 136), respectively.

	number of records		Test 1	Test 2	number of records		Test 1	Test 2
	G	B	p-value	p-value	I	O	p-value	p-value
Amblystegium serpens	61	31	0*	0.081	0	1	0.039*	0.066
Aulacomnium androgynum	1	0	–	–	22	29	–	–
Brachythecium rutabulum	31	20	0.029*	0.779	3	8	0.166	0.29
Brachytheciastrum velutinum	8	3	0.033*	0.346	10	4	0.033*	0.127
Bryum argenteum	7	7	1.	0.48	36	21	0.023*	0.097
Ceratodon purpureus	38	19	0*	0.188	1	35	0.005*	0.023*
Dicranoweisia cirrata	36	0	–	–	1	1	0*	0*
Dicranum scoparium	1	1	1.	0.794	1	1	1.	0.996
Dryptodon pulvinatus	0	2	–	–	53	85	1.	0.996
Hypnum cupressiforme	92	46	0*	0.009*	0	6	0*	0*
Hypnum pallescens	6	0	–	–	1	1	–	–
Leskea polycarpa	1	1	1.	0.794	0	4	1.	0.996
Orthodicranum tauricum	4	0	–	–	3	6	–	-
Orthotrichum affine	4	5	0.637	0.365	4	3	0.157	0.314
Orthotrichum anomalum	4	3	0.593	0.918	120	86	0.593	0.694
Orthotrichum diaphanum	104	102	0.844	0*	10	6	0.001*	0*
Orthotrichum pallens	9	7	0.48	0.815	45	49	0.157	0.296
Orthotrichum pumilum	51	43	0.243	0.243	0	2	0.56	0.641
Plagiomnium affine	2	0	–	–	0	1	–	–
Plagiothecium denticulatum	1	0	–	–	3	10	–	–
Platygyrium repens	11	2	0*	0.055	3	1	0.006*	0.048*
Pylasia polyantha	4	0	–	–	1	13	0.157	0.31
Rosulabryum moravicum	12	2	0*	0.037*	14	5	0*	0.001*
Syntrichia virescens	13	6	0.023*	0.388	2	0	0.004*	0.31
Tortula muralis	1	1	1.	0.794	–	–	–	–

the trunks of the native tree species in the nearest vicinity and is not specific. However, that thesis requires more data from both cities and forests.

Two alien phorophyte species, *Acer negundo* and *Populus xcanadensis*, appeared to be the most bryofloristically similar to each other; at the same, they differed strongly from other phorophytes, both aliens and natives, although no exclusive species was found on their trunks. Both host-tree species served as a main phorophyte for *Orthotrichum diaphanum* in Wrocław. That species was recorded on 17 tree taxa in the city (both native and alien), but 61% of its total coverage in the plots recorded on all the phorophytes was registered on trunks of these two alien tree species (Fudali 2016 unpublished data). Their geographical origin is obviously not a driver of the processes of moss colonisation. Numerous studies have evidenced that the epiphytic bryoflora species composition of the individual phorophyte species is determined by many factors, of which the most crucial are physical and chemical properties of bark (e.g. pH, water capacity, texture, content of pollutants, particles deposition and its longevity), as well as the air humidity and light availability in the site (Fojcik *et al.* 2015; Jagodziński *et al.* 2018; and the literature quoted therein). Preliminary studies on bark reaction of the chosen tree species in Wrocław (Pruchniewicz 2015 unpublished data) revealed a subneutral reaction of *Populus xcanadensis* (mean pH value of 6.5) and *Populus nigra var. ita*lica (6.25), moderately acidic bark of *Robinia pseudoacacia* (5.74), and acidic bark of *Quercus rubra* (4.94). As *Orthotrichum diaphanum* prefers subneutrophytic sites (Dierssen 2001), the species uses suitable bark of Canadian poplars with high efficiency. Thus, the presence of *Populus xcanadensis* in the city seems to facilitate the spread of *Orthotrichum diaphanum* by creating a more appropriate habitat than is made by other tree species. This approach to the concept of a 'novel facilitation model' formulated by Rodriguez (2006).

The UPGMA classification also visibly separated from others another group that consisted of the alien *Robinia pseudoacacia* and native *Quercus robur*. Among alien tree species, black locust was distinguished with the exclusive occurrence of *Orthodicranum tauricum* as well as the highest total coverage of three epiphyte species: *Dicranoweisia cirrata* (95% of that species coverage was noted on trunks of that tree species), *Hypnum pallescens* (96%), and *Platygyrium repens* (71%). The listed bryophyte species in the natural forests situated in Central Poland showed a trend to occur more frequently on trunks of *Quercus robur* than on other phorophytes (Fudali & Wolski 2015). This allows to assume that the presence of black locust in Wrocław could facilitate the spread of some epiphytic bryophytes naturally preferring pedunculate oak by replacing its functional role according to the 'model of substitutive facilitation' (Rodriguez 2006).

Summarising the discussion presented above, one can conclude that the abundant occurrence in the city of such alien tree species as *Populus xcanadensis*, *Acer negundo* and *Robinia pseudoacacia* has promoted wide spreading of some epiphytes, such *Dicranoweisia cirrata* and *Orthotrichum diaphanum.* Thus, the main research hypothesis formulated in the introduction cannot be rejected, and we claim that this is quite likely that some alien tree species could facilitate the occurrence of native epiphytic bryophytes in Wrocław. However the influence of alien trees on epiphytic bryophyte distribution in cities requires more data.

Urbanised areas create harsh conditions for epiphytic bryophytes, and only some species are able to survive and spread (i.e. Seward 1979; Fudali 1996; Davies *et al.* 2007; Larsen *et al.* 2007; Dymytrova 2009; Richter *et al.* 2009). The presence of epiphytic bryophytes on the urban areas is important not only from the point of view of the urban biodiversity conservation and preservation of ecological integrity in cities (Alvey 2006; McKinney 2006). These plants are useful indicators of UHI and the air quality (Stapper & Kricke 2004; Davies *et al.* 2007; Larsen *et al.* 2007; Sérgio *et al.* 2016).

The recent growing popularity of green walls or other installations with moss cultures designed to filter the air in cities (for example "CityTree" project) seems to open new perspectives for the use of epiphytic mosses in the urban aspect. Orthotropic epiphytic mosses, such as *Orthotrichum diaphanum* and *Dicranoweisia cirrata*, form dense turfs on trunks, and they can operate as an additional natural filter that stops dust pollution and works during the whole year. Our research has shown a potential value of some aliens for these mosses occurrence. Why not promote a development of additional toll-free green filters in cities by planting suitable tree species? That conception might be applied by designers of urban greenery and ecological engineering. But propagation of alien tree species in the cities could be controversial in respect to postulates of preserving native species diversity (Alvey 2006; McKinney 2006). On the other hand there are authors who find that traditional approach to urban biodiversity conservation as unrealistic in many urban landscapes and propose a new one. According to these authors 'it will have to be decided which species assemblages or which ecosystem functions are desired, and for what purposes they are desired' (Dearborn & Kark 2009).

Acknowledgements
The authors thank Dr Daniel Pruchniewicz, who provided unpublished data on the bark reaction of some tree species in Wrocław, and Professor Ludwik Żołnierz, who discussed the method of field research. We are also grateful to two anonymous reviewers for helpful advices.

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Submitted on 14 June 2018;
accepted on 21 November 2018;
published on 4 September 2019.