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RECENT TENDENCIES IN DISTRIBUTION OF EPIPHYTIC BRYOPHYTES IN URBAN AREAS: A WROCŁAW CASE STUDY (SOUTH-WEST POLAND)

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Abstract. The lists of moss and liverwort species found on tree-trunks in the Wrocław parks obtained in three recent surveys (in the years 2000, 2006 and 2011) were compared and changes in species composition and abundance of records were discussed to define apparent recent trends in the bryo-epiphyte occurrence within the city. General ecological requirements of the species colonizing tree-trunks in relation to substratum reaction were analyzed. In the last decade there has been greater bryophyte colonization of tree-trunks in the city. This effort is realized by an influx of additional species from outside, mainly obligate epiphytes (both acidophilic and subneutrophilic), by expansion of urban epiphytes tolerant of city conditions - such as the acidophilic *Dicranoweisia cirrata* (Hedw.) Lindb. and eurybiontic *Hypnum cupressiforme* Hedw. and *Amblystegium serpens* (Hedw.) Schimp., as well as by species occurring in urban areas on other substrata (often on walls) but which are able also to colonize the bark of trees. Details of the epiphytes occurring in the Wrocław parks are here provided for the first time.

Key words: urban bryophytes, bryophyte dynamics, acidophilic epiphytes, *Orthodicranum tauricum*, Wrocław, Poland

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INTRODUCTION

The second half of the 20th century is generally regarded as a period of retreat and extinction of epiphytes due to increase in air pollution and high exposure of SO_2, NO_x and dust (for example, Barkmann 1958; Gilbert 1968, 1970, 1971; Rao 1982).

At the end of the 20th century Greven (1992) reported a new phenomenon, observed by him in the forests of Holland, where there was an abundant occurrence of epiphytic bryophyte species that had not been previously documented in the 1950s. They all showed a preference for acid substrata. Greven (1992) named them 'acidophilic epiphytes' and their influx and range expansion resulted from acidification due to acid rain which altered the nature of the tree bark and thus increased the number of habitats available for these epiphytes to colonize. Surveys undertaken by Bates *et al.* (1997) across southern Britain showed an increase in the number of records of 13 obligate epiphytes in comparison with their distributions mapped over the preceding 30 years. Only two of them were acidophilic. Among 24 obligate epiphytes recorded in the years 1992–1995 nine were not reported before the year 1950 (Bates *et al.* 1997).

During the 20th century many epiphytic mosses and liverworts almost completely disappeared from city centers and they remained in cities only in parks, with species richness and frequency rather low (Seaward 1979; Wittig 1991; During 1992; Fudali 1994). In many cases only *Hypnum cupressiforme* Hedw. and *Dicranoweisia cirrata* (Hedw.) Lindb. appeared to be sustainable in city conditions, although other epiphytic bryophytes were noted sporadically within urban areas (Nordhorn-Richter & Düll 1982; Ron *et al*. 1987; Müller 1993; Fudali 1996, 2005; Vanderpoorten 1997; Solga 1998; Hohenwalner 2000; Fojcik & Stebel 2001; Humer-Hochuimmer & Zechmeister 2001).

Müller (1993) analyzed the distribution of mosses and liverworts within the town of Halle in the 1990s and suggested the possibility of

bryo-epiphyte vegetation recovery in this town. This was subsequently confirmed by Richter *et al.* (2009) in a survey carried out in the years 2005–2006. Recently, Stapper and Kricke (2004) reported a visible increase in the number of epiphytic bryophytes found in the area of Dusseldorf town between 1979 and 2003.

Considering the reports from German towns and the fact that an expansion of acidophilic epiphytes has been recently confirmed from many regions of Poland (Stebel 2006; Stebel *et al.* 2008; Fojcik 2011; Fudali *et al*. 2010) the author formulated the following questions: have acidophilic epiphytes came to Wrocław town and established? Are there any preferences in distribution? Have other bryophytes shown epiphytic tendencies in the city in the last decade and what are their ecological requirements in relation to substratum reaction and type?

Preliminary results of studies on the bryophyte dynamics in five large parks of Wrocław (Fudali 2007) revealed an increase in the number of species colonizing tree-trunks between 2000 and 2006 and a further influx of new epiphytes in 2011 (Fudali 2011). In the present paper a list of moss and liverwort species found on tree-trunks in 15 Wrocław parks in the years 2000, 2006 and 2011 with details of their occurrence, abundance and tree host preferences (published for the first time) is presented and changes in the species composition, records frequency and distribution are discussed in relation to recent trends in the bryo-epiphytes occurrence within the city. General ecological requirements in relation to substratum reaction of the species colonizing tree-trunks were analyzed to determine the number of the acidophilic epiphytes.

Wrocław is one of the biggest towns in Poland and occupies an area of 290 km^2 with a population of almost 700 000 inhabitants. It was established at the end of the 12th century and was in the past an administrative, political and industrial center in the region of Lower Silesia. Through the town, from SE to NW, flows the river Odra with its four tributaries.

The annual rainfall is highly variable and ranges between 318 to 892 mm annually (average annual precipitation in the 20th century was 583 mm), and quite frequent are series of wet years with an annual rainfall higher than 600 mm. In the years 1997 and 1998, 2009 and 2010 summer floods appeared. The average annual temperature is 9°C; annual amplitude of temperature 19.2°C. Winters are short (65 days) and mild, with frequent periods of warming in February up to 10–15°C. The most frequent winds are from the west (25% of days in a year) and south (23.1%). Within the center of Wrocław an urban island of warming was detected (Dubicka & Szymanowski 2000).

The vegetation of the region is deciduous mesophilous forests with a prevalence of oaks and hornbeams (Matuszkiewicz *et al.* 1995) but the surrounding area for many centuries has been used for agriculture. In the last decade there has been a strong increase of building investment within the town.

Parks chosen for study differ in their area (from 2.52 ha to 1000 ha), history, architecture of greenery and location in relation to the city center (Fudali 2001) but the all are historical sites and were established in the 19th century or at the beginning of the 20th century. Four of them are situated within old historical center, others are situated outside but still within built up areas (Fig. 1).

Material and methods

Field studies entailed the making of a precise bryofloristic inventory within 15 parks situated in the area of Wrocław town and the collection of herbarium specimens for taxonomic identification. In each park every tree was examined. For each occurrence of a bryophyte species the tree host was identified and height of a bryophyte patch situated on the tree-trunk (up to 50 cm or higher) recorded. The studies were regularly repeated at 5–6 years intervals since 2000. Since 2006 some additional observations have been made along main streets and within 10 selected housing estates with green afforested areas.

In total 1680 records were made and 136 herbarium specimens were collected. The latter are deposited in the herbarium [KRAM-B]. Nomenclature of mosses follows Ochyra *et al.* (2003) with the exception of *Rosulabryum moravicum* (Podp.) Ochyra & Stebel. General ecological requirements of the species analyzed in relation to substrate reaction were extracted from Dierssen's (2001)

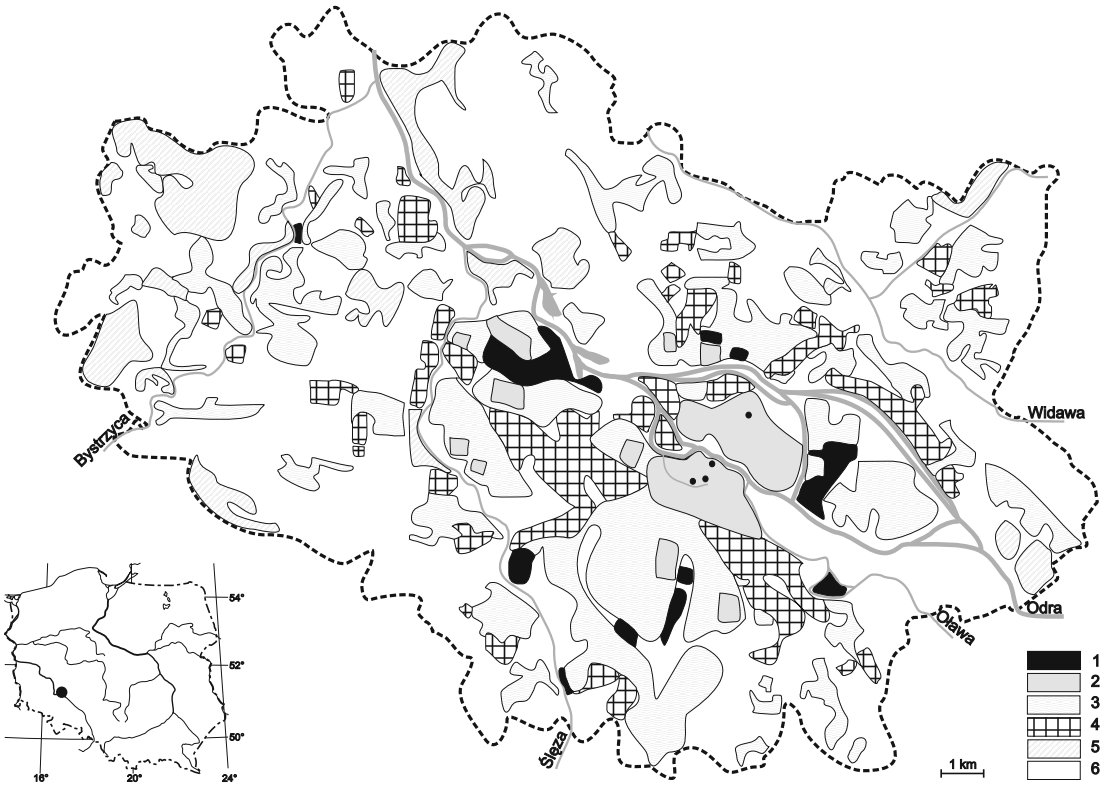

Fig. 1. Situation of the parks studied on the background of the Wrocław town land use (according to Dubicka & Szymanowski 2000, modified). 1 – parks studied, 2 – densely built up area, 3 – industrial buildings, 4 – housing settlements, 5 – municipal forests, 6 – open area, rural or neglected; C – historical center of the town.

characterization of the European bryophytes ecological amplitudes.

Results

Species diversity of colonizing bryophytes

Altogether 36 species were recorded from tree trunks in urban parks, along major streets, and within housing estates, including two liverworts (*Lophocolea heterophylla* (Schrad.) Dumort. and *Ptilidium pulcherrimum* (Weber) Vain.) and 34 mosses (Table 1). In the parks, most often the species colonized the lower parts of tree trunks. Only *Dicranoweisia cirrata* and *Hypnum cupressiforme* occurred also quite abundantly on tree trunks higher than 50 cm above the ground. Bryophytes were also recorded on a few trees occurring within some of housing estates – in total four moss species were recorded (Table 1), often growing at a height of 0.5 to 3.0 m above the ground. Among them only *Orthotrichum diaphanum* Schrad. *ex* Brid., and *Ceratodon purpureus* (Hedw.) Brid., were frequently recorded and abundant.

The bryophyte species were collected from 26 tree species, but the most frequently colonized tree host species were: *Quercus robur* L. (24 species), *Fraxinus excelsior* L. (18), *Acer platanoides* L. (17), cultivars of *Populus* L. (17) and *Betula pendula* Roth. (16).

Trunks of trees growing individually along main streets were devoid of bryophytes.

Increase species richness and fluctuations in species composition

Since the year 2000 the number of species colonizing tree trunks in Wrocław's parks has increased

Table 1. List of species colonizing tree-trunks in the Wrocław's parks in the period of 2000–2011 ordered according to their maintenance and the year of their record with brief characteristics of their station's abundance and range. A – tree trunk at height more than 50 cm above the ground level, B – tree trunk up to 50 cm above the ground level, N – total number of records, O – total number of parks, in which species was noted, PC – parks situated in the city center, PP – parks out of the center; [1] – in Wrocław *Dicranum scoparium* occurred exclusively on trees (Fudali 2001, 2007, 2011), * – species noted also on few trees within housing estates studied, ● – specialized epiphytic species, • – epiphytic-epilithic species; abbreviations for tree species: Ac – *Acer platanoides* L., Ae – *Aesculus hippocastanum* L., Al – *Alnus glutinosa* (L.) Gaertn., An – *Acer negundo* L., Ap – *Acer pseudoplatanus* L., Be – *Betula pendula* Roth., Ca – *Carpinus betulus* L., Co – *Cornus mas* L., Cr – *Crategus* L. *sp.*, Cs – *Cerasus avium* (L.) Moenck, Fr – *Fraxinus excelsior* L., Pa – *Picea abies* (L.) H. Karnst, Pi – *Pyrus communis* L., Pl – *Platanus* × *acerifolia* (Aiton) Willd., Pr – *Prunus* L. sp., Ps – *Pinus sylvestris* L., Px – cultivars of *Populus* L. sp., Qu – *Quercus robur* L., Qr – *Quercus rubra* L., Ro – *Robinia pseudoacacia* L., Sa – *Salix alba* L., Th – *Thuja occidentalis* L., Ti – *Tilia cordata* Mill., Ul – *Ulmus laevis* Pall., Tulip – *Liriodendron tulipifera* L.

Species		2000			2006			2011			
		PP	N	O	PP	NN	O	PC	PP	N	O
SPECIES PERSISTENT IN THE YEARS 2000-2011											
**Amblystegium serpens* (Hedw.) Schimp.	A	1-*Ac*	1	1	2-*Ac*,*Fr*; 1-*Ti*,*Px*,*Qu*	7	5	1-*Px*	10-*Ac*; 4-*Cs*; 3-*Fr*; 2-*Ro*; 1-*Qu*,*Sa*	22	8
	B	5-*Ac*,*Fr*; 3-*Qu*; 1-*Fa*,*Ro*,*Ti*	16	6	11-*Fr*; 9-*Ac*; 4-*Qr*; 2-*Ro*,*Qu*	28	6	1-*Ac*	45-*Ac*; 26-*Qu*; 20-*Fa*; 18-*Fr*; 13-*Qr*; 9-*Ca*,*Px*; 8-*Al*,*Ro*,*Sa*; 7-*Ti*; 4-*Be*,*Pa*; 3-*Ul*; 1-*Ae*,*Ap*,*Pl*,*Pr*;	188	9
Brachytheciastrum velutinum (Hedw.) Ignatov & Huttunen	A		0	0	2-*Be*; 1-*Ac*	3	2		2-*Fr*;1-*Px*	3	3
	B	1-Ac,*Qu*	1	2	4-*Qr*; 2-*Fr*,*Qu*; 1-*Ac*,*Be*,*Ro*,*Ti*	12	4		18-*Ac*; 9-*Be*; 5-*Fr*; 4-*Al*,*Qr*,*Qu*,*Ro*; 2-*Ca*,*Cr*,*Ti*,*Ul*; 1-*Ap*,*Sa*,*Th*,*Pl*	60	7
**Brachythecium rutabulum* (Hedw.) Schimp.	A		0			0			1-*Be*,*Sa*	2	2
	B	1-*Cs*	1	1	2-*Ro*,*Ti*	4	1		17-*Qu*; 14-*Ac*; 7-*Be*; 4-*Fr*; 3-*Al*,*Cr*,*Qr*,*Ro*,*Fa*; 2-*Ca*; 1-*Ae*,*Ap*,*Pa*,*Px*,*Th*,*Ti*	65	6
**Ceratodon purpureus* Hedw.	A	2-*Be*	2	1	3-*Qu*; 1-*Ro*,*Ti*	4	3	1-*Ac*,*Ae*,*Ro*	3-*Ac*; 1-*Be*,*Fr*,*Qu*,*Px*,*Ro*,*Sa*	12	7
	B	2-*Fr*; 1-*Ac*	3	2	2-*Al*,*Fr*,*Ro*; 1-*Ac*,*Be*,*Qr*	9	4	1-*Px*	12-*Ac*; 6-*Qu*; 5-*Fr*,*Qr*,*Ro*; 3-*Fa*; 2-*Be*; 1-*Ca*,*Th*,*Ul*	42	9
Dicranoweisia cirrata (Hedw.) Lindb.●	A	3-*Qu*	3	2	5-*Qu*; 2-*Ac*,*Be*; 1-*Fr*	10	3		18-*Ac*; 16-*Be*; 10-*Qu*; 5-*Px*; 3-*Al*,*Cs*,*Ro*; 2-*Ac*,*Qr*; 1-*Ca*,*Cr*,*Fa*,*Fr*	64	5
	B	2-*Ac*,*Qu*; 1-*Be*,*Pa*	6	4	4-*Be*,*Qu*; 1-*Fr*,*Ro*	10	4		48-*Qu*; 18-*Be*; 13-*Al*; 8-*Ac*; 7-*Ti*; 5-*Px*; 4-*Qr*; 3-*Pa*; 2-*Ae*,*Fr*; 1-*Fa*,*Ro*,*Pi*	113	5
[1]*Dicranum scoparium* Hedw.●	A	1-*Qu*	1	1	2-*Px*; 1-*Be*,*Qu*	4	1		1-*Px*,*Qx*	2	2
	B		**0**			0			2-*Qu*; 1-*Be*,*Fr*	4	2
Hypnum cupressiforme Hedw.	A	4-*Px*; 2-*Qu*,*Ro*; 1-*Ca*	9	4	9-*Be*,*Qu*; 5-*Px*; 4-*Ac*,*Fr*; 1-*Ro*,*Ti*	32	6	1-*Ac*,*Px*	19-*Qu*; 15-*Ac*; 7-*Px*; 6-*Fr*; 5-*Be*,*Cs*,*Sa*; 4-*Al*,*Ro*; 3-*Qr*; 1-*Cr*,*Ti*,*Ul*	78	10
	B	31-*Qu*; 5-*Ac*; 4-*Px*; 3-*Fr*; 2-*Be*; 1-*Ro*	44	6	31-*Qu*; 13-*Ac*; 5-*Be*,*Fr*; 3-*Ti*; 2-*Cr*,*Px*,*Ro*; 1-*Ca*	64	7	1-*Ac*	167-*Qu*; 58-*Ac*; 36-*Be*;32-*Al*; 26-*Fr*; 24-*Qr*; 17-*Px*,*Ti*; 8-*Ca*; 7-*Fa*,*Ro*; 6-*Sa*; 5-*Pa*; 3-*Ae*,*Ul*; 1-*Ae*,*Ap*,*Pi*,*Tulip*	420	9
Lophocolea heterophylla (Schrad.) Dumort.	A	1-*Qu*	1	1	1-*Be*	1	1			0	0
	B	4-*Qu*;1-*Pa*	5	2	1-*Qu*	1	1		7-*Qu*; 1-*Be*,*Pl*,*Ti*	10	2

Orthodicranum montanum (Hedw.) Loeske●	A	1-*Qu*,*Ro*	2	1		0	0			0	0
	B		**0**	**0**	1-*Qu*	1	1		1-*Qr*	1	1
Plagiothecium curvifolium Schlieph. *ex* Limpr.	B	1-*Pa*,*Qu*	2	1	3-*Qu*; 1-*Be*,*Ti*	5	2		2-*Qu*; 1-*Be*	3	2
Plagiothecium denticulatum (Hedw.) Schimp.	B	1-*Pa*	1	1	1-*Ro*	1	1		1-*Qu*	1	1
Plagiothecium laetum Schimp.●	B	1-*Qu*,*Ti*	2	1	4-*Qu*	4	2		3-*Qu*	3	2
Pohlia nutans (Hedw.) Lindb.	B	2-*Qu*	2	1	1-*Be*,*Qu*,*Pa*	3	3		9-*Be*; 3-*Qu*; 2-*Al*; 1-*Fa*,*Fr*,*Px*	17	2
Pylaisia polyantha (Hedw.) Schimp.•	A	1-*Px*	1	1	1-*Fr*,*Px*	2	2		1-*An*,*Cs*,*Px*	3	3
	B	1-*Qu*	1	1	1-*Fr*	1	1		1-*Sa*	1	1
Rosulabryum moravicum (Podp.) Ochyra & Stebel•	A		0	0	2-*Qu*	2	1		2-*Ac*,*Px*; 1-*Ro*	5	3
	B	3-*Qu*; 1-*Ac*,*Ro*	5	2	1-*Px*,*Qu*,*Ro*	3	1		10-*Fr*; 5-*Ac*; 3-*Px*; 2-*Qr*; 1-*Ae*,*Be*,*Qu*,*Ro*,*Sa*	24	5
SPECIES REPORTED FOR THE FIRST TIME IN 2006 AND STILL OCCURRING IN 2011											
Mnium hornum Hedw.	B		**0**	**0**	1-*Qu*	1	1		2-*Qu*	2	1
Orthotrichum affine Schrad. *ex* Brid.●	A		**0**	**0**	1-*Px*	1	1		3-*Cs*,*Px*,*Sa*	5	3
	B		**0**	**0**		0	0		2-*Ac*,*Qu*; 1-*Cs*,*Th*	6	3
Orthotrichum pallens Bruch *ex* Brid.•	A		**0**	**0**		0	0	1-*Ac*,*Px*	7-Ac; 4-*Cs*; 2-*Fr*; 1-*Ap*,*Cr*,*Qu*	18	6
	B		**0**	**0**	1-*Cs*,*Fr*,*Qu*	3	2	1-*Px*	13-*Ac*; 5-*Qu*; 3-*Px*; 2-*Fr*; 1-*Al*,*Be*	26	6
Platygyrium repens (Brid.) Schimp.●	A		0	0		0	0	1-*Ac*	5-*Ac*; 4-*Qu*; 2-*Fr*; 1-*Al*,*Ap*,*Be*,*Cs*,*Ti*	17	8
	B		**0**	**0**	2-*Qu*; 1-*Fr*	3	3	1-*Be*	22-*Qu*; 6-*Ac*; 2-*Be*,*Px*; 1-*Al*,*Fr*,*Pl*,*Sa*,*Ul*	38	6
SPECIES REPORTED FOR THE FIRST TIME IN 2011											
Bryum argenteum Hedw.	B		**0**	**0**		0	0	1-*Ac*	1-*Ac*	1	1
Dicranella heteromalla (Hedw.) Schimp.	B		**0**	**0**		0	0		2-*Ac*	2	1
Herzogiella seligeri (Brid.) Z. Iwats.	B		**0**	**0**		0	0		1-*Qu*	1	1
Hypnum pallescens (Hedw.) P. Beauv.●	A		0	0		0	0		1-*Qu*	1	1
	B		**0**	**0**		0	0		4-*Qu*; 1-*Be*,*Fr*	6	2
Leptodictyum riparium (Hedw.) Warnst.	B		**0**	**0**		0	0		1-*Sa*	1	1
Orthodicranum tauricum (Sapjegin) Smirnova●	A		**0**	**0**		0	0		1-Ac,*Qu*	2	2
	B		**0**	**0**		0	0		1-*Qu*	1	1
Orthotrichum anomalum Hedw.	A		**0**	0		0	0		2-*Ac*; 1-*Cs*	3	2
	B		**0**	**0**		0	0	3-*Ac*,*Fr*	1-*Qu*,*Px*,*Sa*	9	5
**Orthotrichum diaphanum* Schrad. *ex* Brid.•	A		**0**	**0**		0	0	2-*Px*; 1-*Ac*	7-*Px*; 3-*Ac*,*Fr*; 1-*Ap*,*Cr*,*Fr*	19	5
	B		**0**	0		0	0	6-*Fr*; 1-*Qu*	5-*Ac*; 3-*Fr*,*Px*; 2-*Ro*; 1-*Sa*	21	7

Table 1. *Continued.*

Species		2000			2006			2011			
		PP	N	O	PP	NN	O	PC	PP	N	O
Orthotrichum pumilum Sw. *ex* anon. •	A		**0**	**0**		0	0		*Ac*	1	1
Orthotrichum speciosum Nees●	A		**0**	**0**		0	0	1-*Px*	2-*Px*; 1-*Ac*,*Fr*,*Sa*,*Ti*	7	5
	B		0	0		0	0		2-*Ac*,*Fr*,*Qu*; 1-*Ti*	7	3
Plagiomnium cuspidatum (Hedw.) T. Kop.	B		**0**	**0**		0	0		1-*Be*,*Ro*	2	1
Sanionia uncinata (Hedw.) Loeske•	A		0	0		0	0		1-*Px*	1	1
	B		**0**	**0**		0	0		1-*Ac*	1	1
Sciuro-hypnum populeum (Hedw.) Ignatov & Huttunen	A		0	0		0	0	1-*Ac*		1	1
	B		**0**	**0**		0	0		1-*Ac*,*Be*	2	1
Syntrichia virescens (De Not.) Ochyra•	A		0	0		0	0	1-*Px*		1	1
SPECIES REPORTED IN 2000 AND 2006 AND NOT REFOUND IN 2011											
Leskea polycarpa Hedw.●	A	1-*Qu*	1	1		0	0			0	0
	B		**0**	**0**	1-*Fr*	1	1			0	0
SPECIES REPORTED FOR THE FIRST TIME IN 2006 AND NOT REFOUND IN 2011											
Aulacomnium androgynum (Hedw.) Schwägr.	B		**0**	**0**	1-*Fr*	1	1			0	0
Ptilidium pulcherrimum (Weber) Vain.	A		**0**	**0**	1-*Qu*	1	1			0	0

Table 2. Number of species reported from tree trunks in the years of the bryofloristical surveys. A – tree-trunks at height more than 50 cm above the ground level, B – tree-trunks at height up to 50 cm above the ground level.

Category of parks	2000		2006		2011	
	A	B	A	B	A	B
	Number of species					
All the parks	**16**		**22**		**33**	
	10	13	11	20	21	32
Parks in the town center	**0**		**1**		**10**	
	0	0	0	1	9	7
Parks situated out of the center	**16**		**21**		**32**	
	10	13	11	19	21	30

markedly, especially in parks situated out of the historical center (Table 2). Comparison of the species lists obtained in the years of observation shows that among 36 species reported 15 (42 %) have maintained a presence within the town's parks during the 11 years and only one species, *Leskea polycarpa* Hedw., recorded in 2000 and 2006 has not been found subsequently (Table 1). In 2006, 7 species were recorded for the first time, but two of them, *Aulacomnium androgynum* (Hedw.) Schwägr., and *Ptilidium pulcherrimum*, were not refound in 2011. In 2011 an additional 14 species were collected from tree trunks for the first time.

ECOLOGICAL CHARACTER OF THE SPECIES RECORDED FROM TREE-TRUNKS

Analysis of the species' habitat reaction and substratum preferences shows that only 10 species are obligate epiphytes (Fig. 2). Among others the most frequent are 7 species occurring both on tree bark and walls (epilithic-epiphytic species) and 11 species colonizing more than two substratum types (multi-substrata species). The latter dominate among the persistent species while those noted for the first time in the years 2006 and 2011 show ecological differentiation and more than half of them (11 species or 52%) were obligate epiphytes or epiphytic-epilithic species.

Analysis of the species requirements towards substratum reaction revealed a high percentage incidence of both highly to moderate acidophilic species – 33% and eurybiontic species occurring in habitats of wide amplitude of reaction from

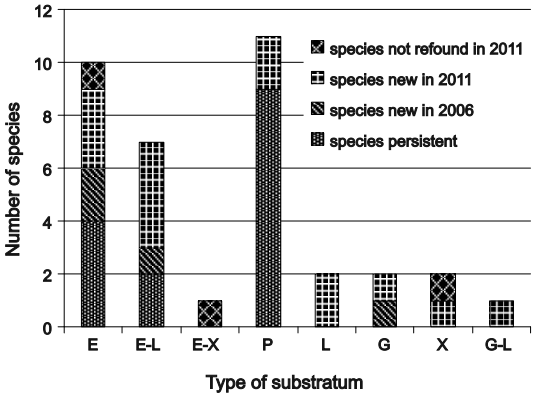

Fig. 2. Substratum preferences of species recorded from tree trunks in the parks with regards to the date of their records. Species occurring on: G – soil (exclusively), E – trees bark (exclusively), L – walls (exclusively), X – decayed wood (exclusively), P – more than two substratum types.

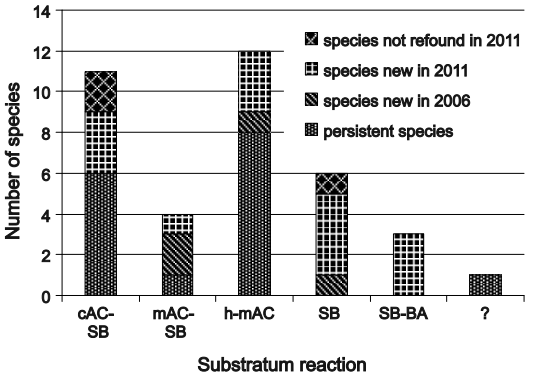

Fig. 3. General ecological requirements in relation to the substratum reaction of the species recorded from tree trunks in the parks with regards to the date of their records. Reaction of substratum: AC – acid, BA – basic, c – considerably, h – highly, m – moderately, SB – subneutral.

considerably acid to subneutral – 31%. The percentage incidence of subneutral and subneutral to basophilic species is also high – 25% (Fig. 3). Most of the latter species have appeared recently (reported for the first time in the year 2011).

CHANGES IN SPECIES ABUNDANCE AND DISTRIBUTION

The 7 (47%) 'persistent' species have shown constant and multiple increase of the number of records and parks in which they were observed

(Table 1). These are: multi-substratum species of wide amplitude in relation to the substratum reaction (from considerably acid to subneutral) as *Amblystegium serpens*, *Brachytheciastrum velutinum* (Hedw.) Ignatov & Huttunen, *Brachythecium rutabulum* (Hedw.) Schimp., *Ceratodon purpureus* and *Hypnum cupressiforme*, acidophilic epiphyte *Dicranoweisia cirrata* and epiphytic-epilithic species of undetermined reaction preferences (Dierssen 2001) *Rosulabryum moravicum* (Podp.) Ochyra & Stebel. The remaining 'persistent' species have not shown such spectacular changes in their abundance and distribution.

Three of the species reported for the first time in the year 2006 also have shown constant tendency to establishment (Table 1). These are two obligate epiphytes of quite wide ecological amplitude in relation to the substratum reaction (from moderately acid to subneutral) *Orthotrichum pallens* Bruch *ex* Brid., and *Platygyrium repens* (Brid.) Schimp., as well as the epiphytic-epilithic species *Orthotrichum pallens* preferring habitats of subneutral reaction.

Most of the species recorded for the first time in the year 2011 occurred sporadically with the exception of subneutrophilic species: the epiphyte *Orthotrichum speciosum* Nees and epiphytic-epilithic species *O. diaphanum* as well as epilithic *O. anomalum* Hedw., colonizing moderately acid to subneutral habitats, which were noted several times.

Table 3. Ecological character of the species recorded in 2011 on tree-trunks in the parks situated in the city center. Explanations as for Figs 2 and 3.

Name of species	Substratum reaction	Substratum preferences
Amblystegium serpens	c AC-SB	P
Bryum argenteum	SB	G-L
Ceratodon purpureus	m AC-SB	P
Hypnum cupressiforme	h AC-SB	P
Orthotrichum diaphanum	SB-BA	E-L
Orthotrichum pallens	SB	E-L
Orthotrichum pumilum	SB-BA	E-L
Orthotrichum speciosum	SB	E
Platygyrium repens	m AC-SB	E
Syntrichia virescens	SB-BA	E-L

The changes described above in species abundance and distribution refer to parks situated out of the historical town center. Trees situated in parks within the city center have been sporadically colonized by mosses (Table 1). However the bryo-floristic inventory done in the year 2011 revealed a striking increase in the number of species colonizing tree-trunks in the period between 2006 and 2011 (10 new species). They show high ecological similarity (Table 3).

Discussion and conclusions

During the last 11 years the number of species colonizing tree trunks in the Wrocław municipal parks doubled from 16 to 33, including 5 new obligate epiphytic species not previously noted in the city (Fudali 2001): *Orthodicranum tauricum* (Sapjegin) Smirnova, *Hypnum pallescens*, *Orthotrichum affine*, *O. pumilum* Sw., *O. speciosum*. Only one eiphytic species, *Leskea polycarpa*, was not refound in 2011.

These new epiphytes differ in their requirements towards substratum reaction: three of them prefer subneutral to basic habitats (species of the genus *Orthotrichum*) and two are acidophytes (*Orthodicranum tauricum*, *Hypnum pallescens*). The surveys demonstrate that some acidophilic epiphytes sensu Greven (1992) have reached Wrocław town recently and are establishing. They were reported from the largest parks situated out of the city center and their sites were in every case situated on the parks' borders in the vicinity of a street. *Quercus robur* trunks seem to be a favoured substrate.

Orthodicranum tauricum is considered to be a species significantly expanding its range in Europe in the second half of the 20th century (Söderstrom 1992). In Poland, until 1986 the species was known only from eight localities but since the late 1980's the number of its new stations increased remarkably to about 70 (Stebel *et al*. 2008). Some of these stations are situated within administrative borders of Polish cities and towns (Katowice, Kraków, Łódź, Poznań, Rybnik, Zgierz) but always in municipal forests or nature reserves. In Wrocław the species was

recorded in three distant sites within two large historical parks (Zachodni, Szczytnicki) established in the past within natural forests but presently surrounded by buildings. *Orthodicranum tauricum* was also reported from the German city Düsseldorf (Stapper & Kricke 2004) as very rare, but without details of its habitat. The reasons for the spread of *Orthodicranum tauricum* are still unclear; some authors suggested that it may be associated with acidification of habitats (Greven 1992; Söderstrom 1992) or climatic changes (Stebel *et al.* 2008).

Considering the problem of the supposed expansion of acidophilic epiphytes in urban areas it is worth stressing that *Dicranoweisia cirrata*, classified by Greven (1992) in this ecological group, showed a remarkable increase in a number of stations in the Wrocław parks. Similar changes in this species distribution and frequency were reported from two German towns: Düsseldorf (Stapper & Kricke 2004) and Halle (Richter *et al.* 2009). The species is known to be tolerant of acid precipitation (Dierssen 2001).

The studies carried out in Wrocław parks revealed also a remarkable increase in the species richness of bryophytes preferring substrata of subneutral or basic reaction, mainly rocks (or walls in towns) and tree bark, including 4 species of *Orthotrichum* genus. These species showed a tendency to colonize tree bark even in parks situated in the city center and those trees growing within housing estates. The *Orthotrichum* species were collected mainly from the trunks of *Fraxinus excelsior*, hybrids of *Populus* sp., *Salix alba* L. and *Acer platanoides* having bark that is known to be slightly acid (Barkmann 1958).

The most spectacular increase occurred with *Orthotrichum diaphanum*, commonly occurring in Wrocław on walls and concrete (Fudali 2001). It seems probable that a strong intensification of building investment within the town in the last decade has promoted the expansion of subneutral epilithic-epiphytic species and their settlement on tree bark covered with building dust containing concrete. On tree trunks *Orthotrichum diaphanum* was noted with high frequency also in Düsseldorf (Stapper & Kricke 2004) and Halle (Richter *et al*. 2009).

A number of other normally epilithic species are occurring with remarkable frequency as epiphytes on tree trunks (Fudali 2005): *Dryptodon pulvinatus* (Hedw.) Brid., and *Bryum argenteum* Hedw., in Düsseldorf (Stapper & Kricke 2004), *Orthotrichum pumilum* in Halle (Richter *et al*. 2009) and *Orthotrichum pallens* in Wrocław. The appearance of epiphytic tendencies in species overgrowing rocks was reported already by Barkmann (1958).

The recent increase in the number of species colonizing tree trunks in towns has been earlier reported from Germany. Surveys undertaken by Stapper & Kricke (2004) in the Düsseldorf town reported significant increase in corticolous bryophyte species diversity between 1979 and 2003. On the trunks of 1015 trees they found 23 bryophyte species of which 11 are also reported in Wrocław. They identified three species of *Orthotrichum*, of which *O. affine* and *O. diaphanum* occurred with high frequency.

Richter *et al.* (2009) encountered 40 bryophyte species colonizing tree trunks within Halle town in the years 2005–2006, while in the same area Müller (1993) collected from trees 21 species, including 10 obligate epiphytes. Unfortunately these authors did not provide a full list of recently recorded species but they listed two new epiphytes: *Orthotrichum affine* and *Ulota bruchii* Hornsch. Except for *Pylaisia polyantha* all species noted by Müller (1993) still occurred. They also noticed that some obligate epiphytic species, especially *Orthotrichum*, showed a strong increase in the number of sites and population abundance but only within that part of Halle town situated on the floodplain of the Saara river. The 18 species reported from tree trunks in Halle (Müller 1993) occurred also on trees in the Wrocław parks.

The species of bryo-epiphytes reported recently from tree trunks within the cited German towns seem to be heterogenic with regard to substrate specialization. The list contains not only obligate but facultative epiphytes as well, such as epiphytic-epilithic species, epixylic species, typical epiliths, species colonizing mainly humus

and multi-substratum species. This is also observed in the parks of Wrocław.

In all towns compared some species showed a clear increase in frequency and colony spread. These are: *Dicranoweisia cirrata*, as well as the eurybiontic multi-substratum species *Hypnum cupressiforme* and the subneutral epilithic-epiphytic species *Orthotrichum diaphanum*. A similar tendency, but only in Halle and Wrocław, was shown also for the subneutral epilithic-epiphytic species *Orthotrichum pumilum*, the acidophilic *Dicranum scoparium* Hedw., which in these cities occurred exclusively on trees, and the obligate epiphyte *Platygyrium repens* of wide amplitude of sites reaction.

As every survey referred to here has utilized different methods in relation to the area studied and the trees investigated, the results are not strictly comparable. However, in general they confirm Müller's (1993) suggestion of bryophyte recovery within towns and allow the conclusion that in the last two decades bryophytes have started to recolonize trees in towns. This has occurred through the influx of new species from outside, mainly obligate epiphytes (both acidophilic and subneutrophilic), by expansion of existing urban epiphytes such as the acidophilic *Dicranoweisia cirrata* and eurybiontic *Hypnum cupressiforme* and *Amblystegium serpens*, that appear to be sustainable in city conditions as well as by the species occurring in towns on other substrata (often on walls).

In general, a share of acidophilic epiphytes is less significant than the participation of eurybiontic species tolerating habitats of wide substrate reaction amplitude from considerably or moderately acid to subneutral, and an incidence of species preferring habitats of subneutral or basic reaction. The latter are mainly epilithic-epiphytic species, with a remarkable representation of the genus *Orthotrichum*.

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