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Determinants of occurrence of epiphytic mosses in the urban environment; a case study from Katowice city (S Poland)

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Abstract: Katowice is the largest city within the Upper Silesian Industrial District (S Poland). The investtigation conducted in this town earlier (1998-2000) showed limited number of epiphytic species. Recent study showed significant increase in number of localities of obligate epiphytes (mainly from the genera *Orthotrichum* and *Ulota*). They colonize mainly the edges of strongly urbanized areas bordering forest complexes and larger parks. This paper is an attempt to answer the question as currently in Katowice shape the main factors determining the occurrence of epiphytes. Crucial factors which govern epiphytes colonization processes in urban areas have been confirmed: bark chemistry (taking into account natural attributes and the influence of pollution) and air humidity. The preference of epiphytes towards inhabited phorophytes was confirmed as well. The most commonly and abundantly inhabited species were poplar and willow trees (which have a higher pH of bark).

Key words: epiphytes, mosses, urban areas, air pollution, Katowice city, Poland

Introduction

The effect of human activity is a set of harmful dynamic tendencies observed in local floras. They include vanishing of epiphytes (bryoflora and lichen biota) in urban and industrialized areas (Gilbert 1968; LeBlanc, De Sloover 1970; Adams, Preston 1992; Hallingbäck 1992; Govindapyari *et al*. 2010). This phenomenon has been associated with the air pollution (especially by sulphur oxide). Among mosses epiphytes are a strongly specialised group. First of all, they depend on precipitation from which they also obtain nutrients (Smith 1982). In urbanised areas precipitation contains a lot of pollutants which are for epiphytes, together with periodical lack of water, a main stress factors.

Especially interesting is observed in the last decades change in the dynamics of some bryophyte local ranges. As a result of diminishing of pollution and improvement of air quality, they spread on areas, which have not been observed for a long time (both lichens and mosses) (e.g. Gunn *et al*. 1995; Vanderpoorten 1997; Stapper *et al*. 2000; Bates *et al*. 2001; Vanderpoorten, Engels 2002). In the urbanized areas, for example, appearance or significant increase in number of localities of obligate epiphytes from the genera *Orthotrichum* or *Ulota* are recorded. Similar phenomenon is also observed in Katowice. The investigation conducted here earlier showed limited number of epiphytic species (Fojcik, Stebel 2001). Only on single localities of such species as *Orthotrichum diaphanum* or *O. pumilum* were noted, whereas *Ulota* species were absent. After ten years, field investigation demonstrate much more localities of epiphytes, including a lot of new for this area, for example *Leskea polycarpa, Orthotrichum rogeri, O. patens, O. stramineum, O. striatum, Ulota bruchii* and *U. crispa* (Stebel 2010; Fojcik, Stebel unpublished materials). The analysis of their current distribution shows, that they colonize mainly edges of strongly urbanized areas bordering forest complexes and larger parks (Fig. 1).

This paper is an attempt to answer the question as currently in Katowice shape the main factors determining the occurrence of epiphytes. The purposes of the investigation were:

- determination of differences in level contamination and humidity between localities with and without epiphytes,
- analysis of colonization degree of various tree species (phorophytes).

Three hypotheses were formulated:
- despite significant decrease of air contamination level, it is still one of the factors inhibiting the growth of epiphytes in Katowice,
- humidity is a one of the crucial factors conditioning success of epiphytes in the colonization of urban areas,
- degree of phoprophytes colonization depends also on the type of the phorophyte and its size.

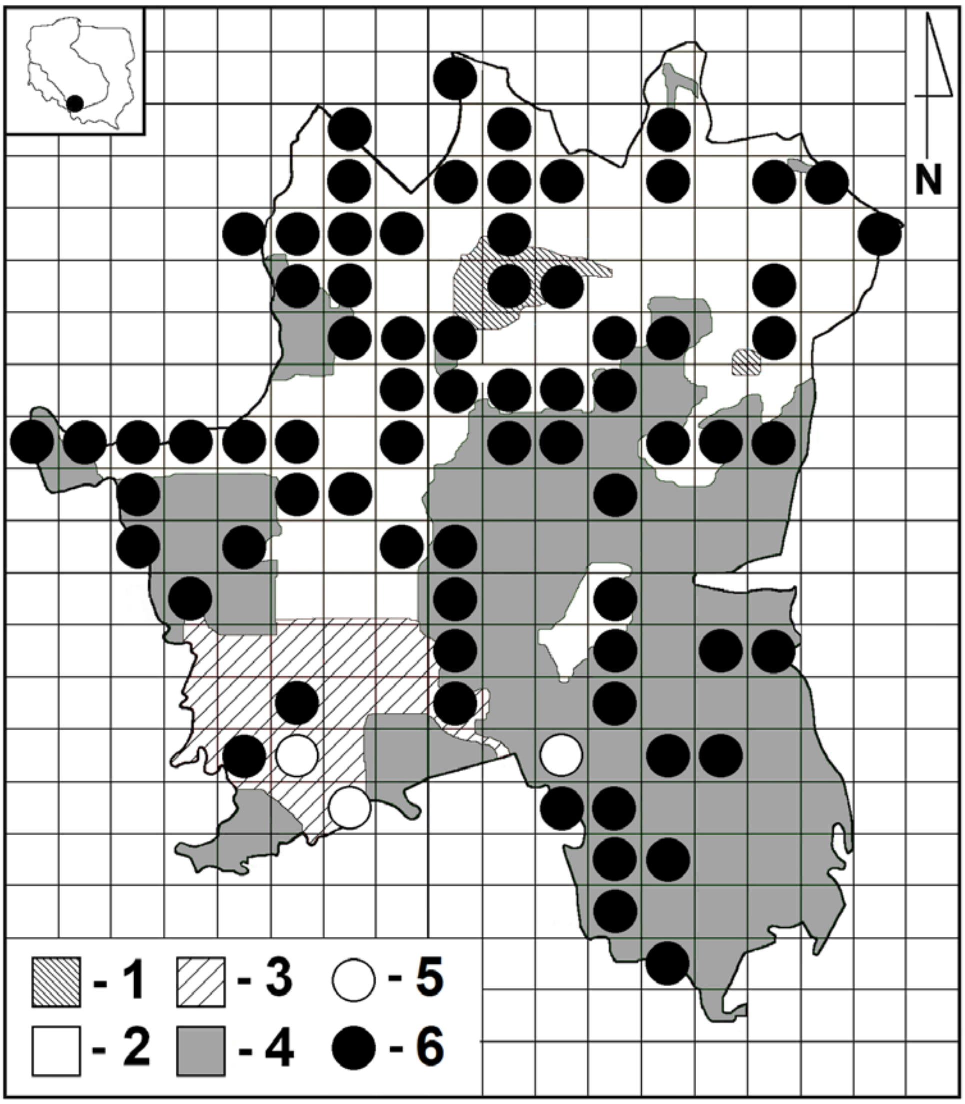

Fig 1: Distribution of *Orthotrichum pumilum* in the city of Katowice against the background of the main types of land-use complexes: 1 – down-town; 2 – suburbs; 3 – agricultural area; 4 – forest; 5 – localities before 2000; 6 – localities in 2015.

Materials and methods

The investigation was carried out in the area of Katowice city. This town is located in southern Poland, covers near 165 km^2 and has almost 300 000 inhabitants. Katowice is a capital of the Upper Silesian Industrial District and one of the biggest industry centres in Poland. Short time ago on this area there were 9 coal mines and 4 steel or non-steelworks. Some of them do not exist anymore, others have been significantly modernized. In the recent decades clear improvement of the condition of environment is observed. For example, emission of SO_2 has decreased from 6 363 tones in 1998 to 2 908 in 2010 (according to statistical yearbooks for Silesian province).

The investigation was carried out on 5 stations:
- park at the margin of forest in Ligota ('Ligota') – locality with epiphytes,
- park at the margin of forest in Muchowiec ('Muchowiec') – locality with epiphytes,
- park at the margin of forest in Janów ('Janów') – locality with epiphytes,
- wayside of busy road in Brynów ('Brynów') – locality without epiphytes,
- wayside of busy road in Witosa Estate ('Witosa') – locality without epiphytes.

For investigation of bark contamination the poplar *Populus* x *canadensis* was chosen (due to its wide range in Katowice and the frequent presence of epiphytes). Its worthy of notice, that in Ligota and Janów epiphytes grow on different kinds of phorophytes (also on investigated poplars), but in Muchowiec epiphytes were absent on investigated old poplars but grow on other, usually younger trees (especially willows). In each locality bark was sampled from five trees with circumferecne at least 150 cm (mixed samples of about 25 g weights). Heavy metals (Fe, Cd, Cu, Pb, Zn) and sulphur content was analyzed using Vario Max CNS microanalyser. Bark acidity was measured with a pH-meter (in distilled water).

Humidity was measured in four plots: two with epiphytes (Ligota, Muchowiec) and two without (Brynów and Downtown), using manual thermohygrometer AZ 8703.

The evaluation of the degree of colonization of various phorophytes was made on the base of the analysis of abundance of bryoflora on bark of 192 randomly selected trees growing in particular plots (approximately 60 trees from from Ligota, Muchowiec and Janów stations). For all trees the following parameters were established: species, circumference on height about 1.2 m and degree of epiphyte colonization. Degree of colonization was determined using the four degree scale:
0 – lack of epiphytes,
1 – occurrence of epiphytes only on base of tree trunks (up to 30 cm high),
2 – occurrence of epiphytes on trunk over 30 cm, but not abundantly,
3 – occurrence of epiphytes on trunk higher, more abundantly .

The data were analysed using Microsoft Office Excel (version 2003) and Statistica (version 10). In all statistic analyses statistical significance $p<0.05$ was accepted. Determination of correlation between variables was made using the Spearman's rank correlation coefficient.

Results

The average content of heavy metals in bark of poplar, taking into account the annual measurements, varied among the examined sites (Tab. 1). Higher levels of the analyzed heavy metals were found close to the roads in Brynów and Witosa. The presence of epiphytes in the following sites: Janów, Ligota and Muchowiec indicated them as being contaminated with pollutants such as heavy metals significantly less than Brynów and Witosa. In case of Ligota, the indication was proved to be true, whereas in case of Janów, where the quantity of zinc and cadmium exceeded significantly the values registered in any other area. Without doubt, Janów is heavily influenced by the close presence of metalworks 'Huta Metali Nieżelaznych Szopienice S.A'. At the beginning of the 20c., it used to be the largest producer of metals without iron content in Silesia, and one of the largest producers of cadmium worldwide.

Tab 1: Mean yearly content of heavy metals in poplar bark in different sampling sites (mg kg^{-1} d.w.; SD – in brackets).

	Pb	Zn	Cd	Cu	Fe
Janów	70,51 (±16,68)	321,86 (±60,95)	10,65 (±1,45)	13,51 (±2,98)	989,68 (±272,98)
Ligota	58,65 (±14,80)	184,16 (±20,29)	3,44 (±0,93)	21,32 (±3,33)	432,28 (±125,76)
Muchowiec	258,74 (±40,23)	238,98 (±20,56)	3,98 (±1,18)	39,26 (±3,89)	2959,37 (±102,40)
Witosa	138,36 (±10,38)	305,80 (±34,13)	6,59 (±0,88)	24,01 (±8,41)	2108,83 (±459,63)
Brynów	173,17 (±13,37)	206,18 (±24,24)	5,84 (±1,15)	28,50 (±9,81)	2096, ±43 (644,86)

The average content of some metals in Muchowiec was found to be relatively significant, despite the area being initially classified as less polluted. The data collected in Muchowiec indicate a close source of pollution emission. The elevated level of cadmium and copper can be explained by the nearby presence of the sports airport and the influence of the fumes emitted from the planes as the high levels of the specified metals can occur as a result of fuel combustion (Kabata-Pendias and Pendias, 1999). The high level of heavy metals, e.g. iron (annually about 2800-3080 mg kg^{-1}) is possibly a result of metalworks 'Huta Żelaza Ferrum' and 'Huta Metali Nieżelaznych Szopienice S.A.' being situated nearby. It is worthy of notice, that considerable standard deviation (Tab.1) is connect with fluctuations of heavy metals contamination, which over the period of examination were observed.

The highest sulphur content in poplar bark was registered in Muchowiec (Fig. 2). It is possibly a result of the sports airport located nearby, as well as the close presence of metalworks. Sulphur content has an effect on bark pH value. The average pH value, excluding Muchowiec, equals to about 5-5.5 (Fig. 3). In case of Muchowiec, the pH values are significantly lower. It is worth noticing that similar seasonal fluctuations were observed on all examined surfaces (Fig. 4). The pH of bark dropped at the turn of spring and summer, with its minimum in April and May. The highest pH values were registered in winter months.

The spectra of air humidity in selected areas differ (Fig. 5). Higher values were registered in Ligota and Muchowiec which are located in the close proximity of forests and water basins.

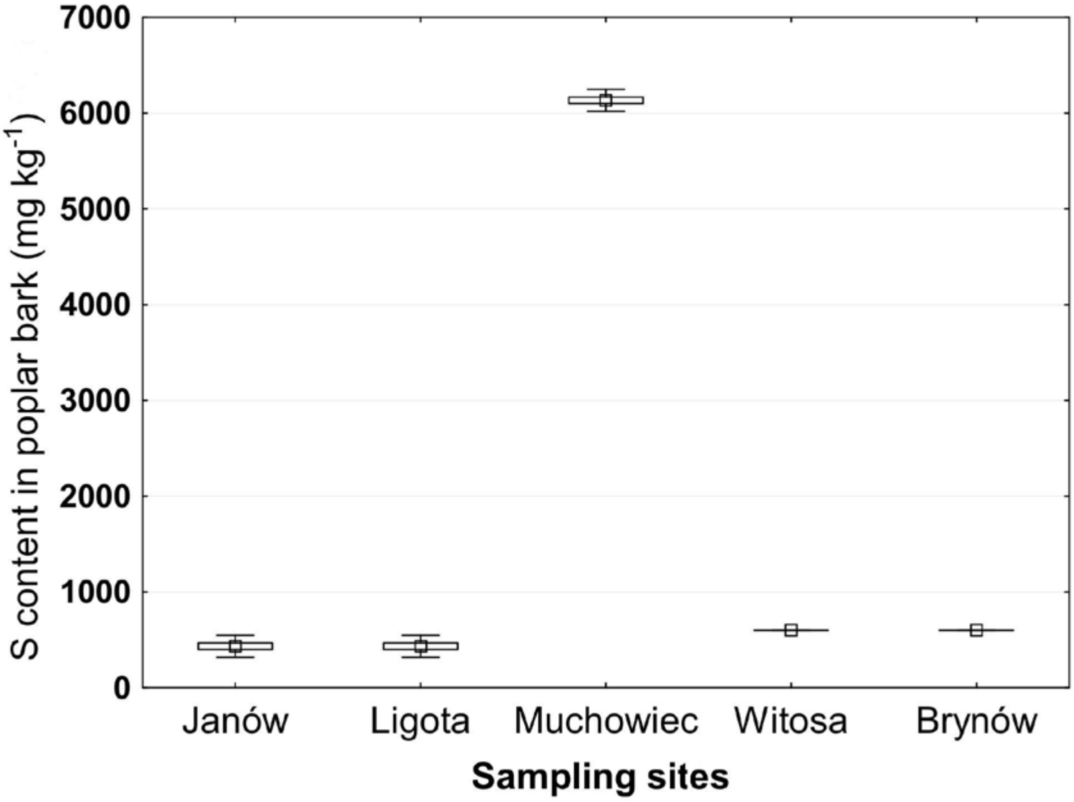

Fig 2: The content of sulphur in poplar bark.

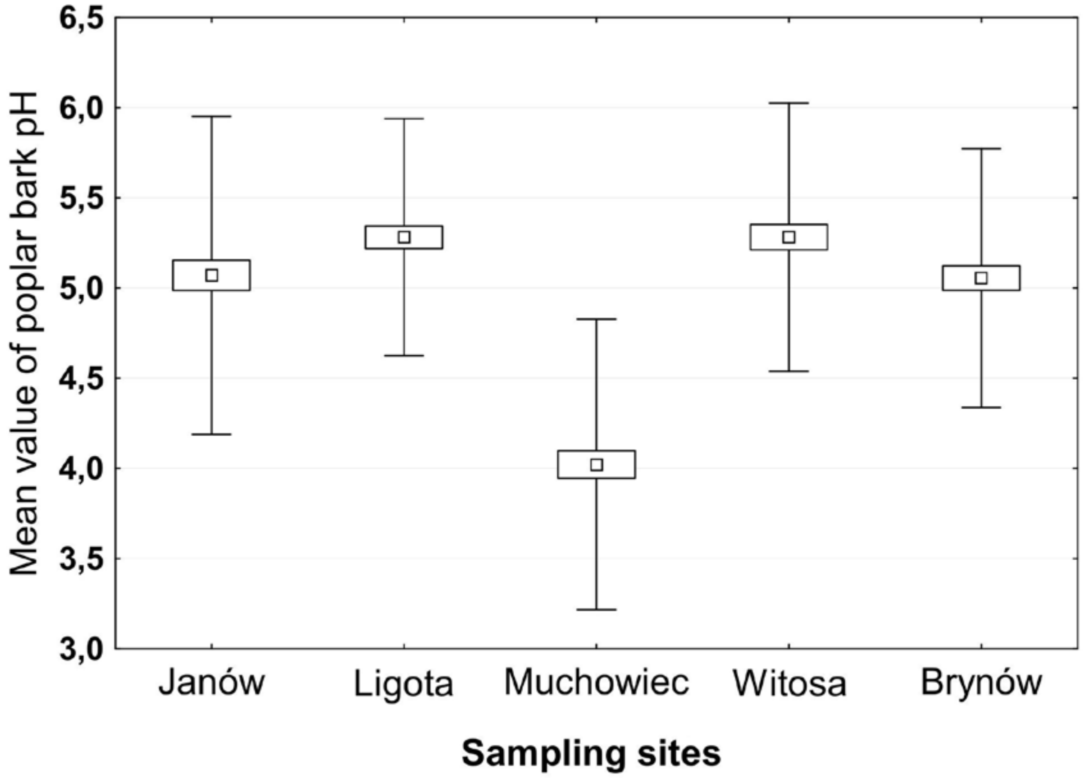

Fig 3: The average pH values of poplar bark.

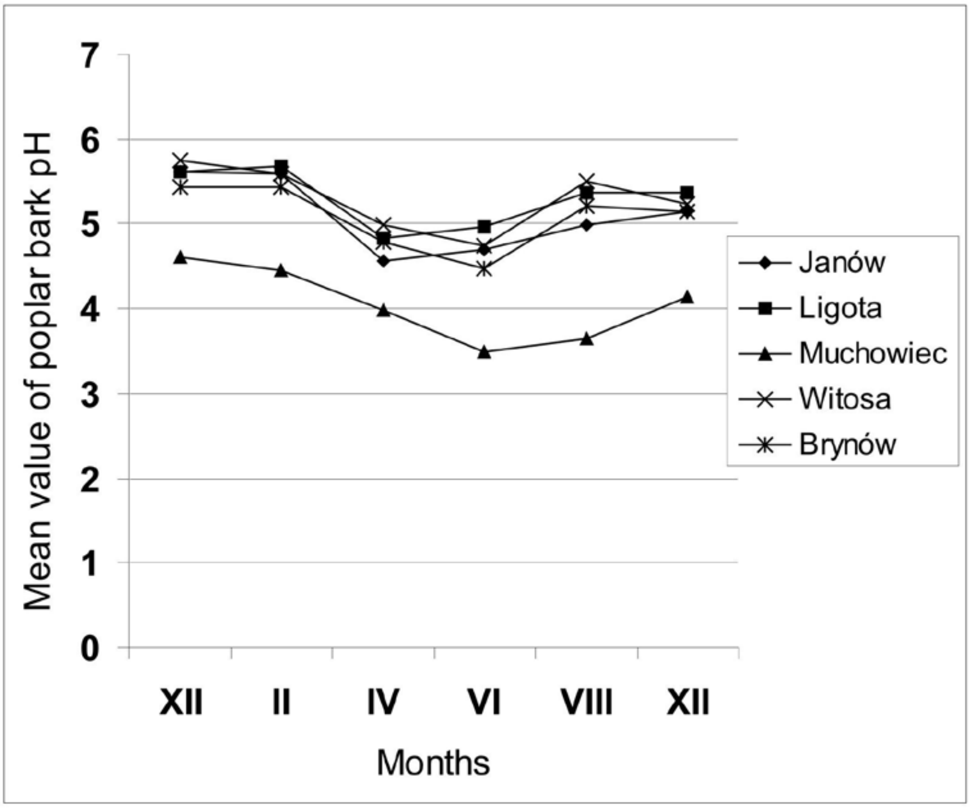

Fig 4: Seasonal fluctuations pH values of poplar bark.

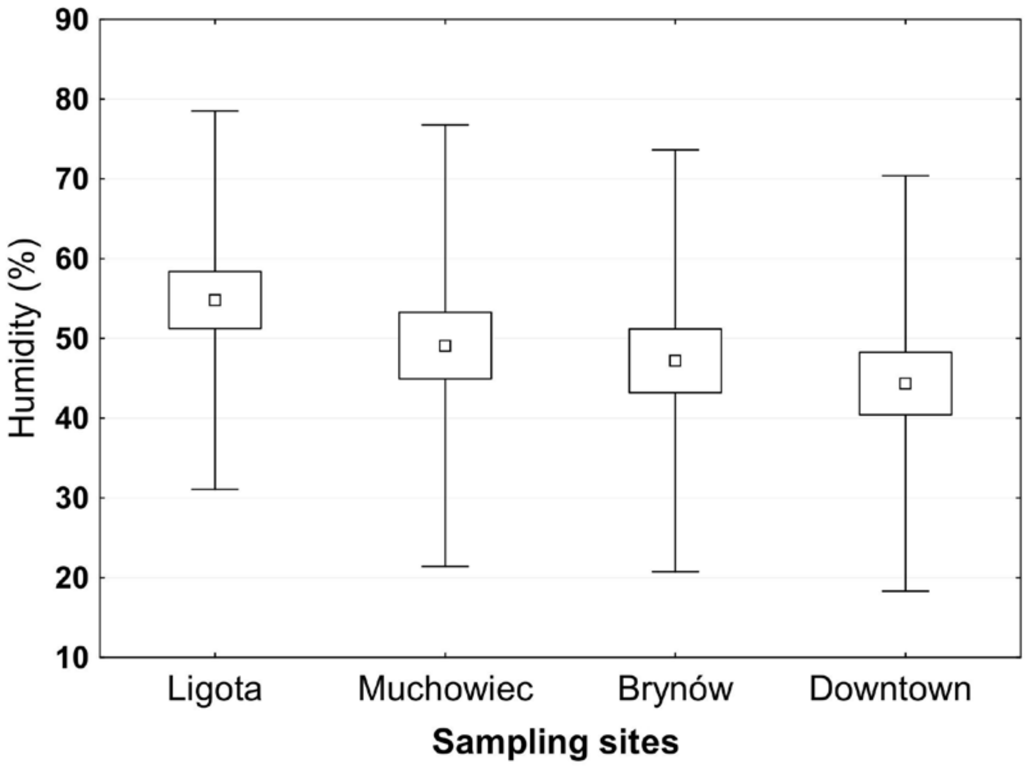

Fig 5: Values of humidity in selected plots.

Degree of colonization was examined for 192 trees represent 28 species (including 23 deciduous trees and 5 conifers) (Tab. 2). Poplar trees constituted the largest group (7 species). The largest number of specimen was reperesented by *Populus canadensis*. Other numerous species were: *Betula pendula*, *Quercus robur*, and *Salix fragilis*. Among conifers, *Larix decidua* was the most common species. In terms of size (the perimeter of trunk), poplar trees were observed to be the largest: *Populus nigra* (average perimeter 237.9 cm), *P. Canadensis* (232.4 cm) and P. ×*berolinensis* (198.1 cm). *Quercus robur* and *Salix fragilis* achieved large sizes as well. The average colonization degree was calculated for each species. The highest values were registered for willow tree (from 2.5 to 3) and poplar (up to 2.5). Among the species of foreign origin, the highest values were registered for: *Acer negundo* – one representative, *Fraxinus pennsylvanica* – one representative, and *Robinia pseudoacacia*. No epiphytes were found on Pinophyta species. It was also checked whether there exists a relationship between the perimeter of a phorophyte and the degree of colonization. Such statistically significant relationship was found (r = 0.322317).

Discussion

The local distribution of epiphytes is the result of mutual relationships between various habitat factors. In urban areas, the major factors which are responsible for epiphyte distribution are: air pollution, municipal climate (especially limited humidity) and the presence and variety of phorophytes (trees on which epiphytes grow) (Seaward 1979; Zechmeister, Hohenwallner 2006; Dymytrova 2009). Air pollution is mentioned as one of the major factors limiting the occurrence of epiphytes (Rao 1982; During 1992; Bates *et al*. 2004; Zechmeister, Hohenwallner 2006). Toxic substances, like water and nutrients, are absorbed by moss and lichen growing on trees with their entire body surface, to the lesser extent from the ground (Brown 1982; Bates 2008). They influence negatively the essential physiological processes. Heavy metals (lead, zinc, copper) and sulphur compounds may disturb the development of spores and the growth of protonema, which makes the colonization of habitats in polluted areas more difficult (Gilbert 1968; Krupińska 1976; Shaw *et al*. 1987; Krzesłowska *et al*. 1994; Basile *et al*. 1995).

Tab 2: The differentiation of mosses colonization degree of various phorophytes.

Tree species	Number of specimen	Average trunk perimeter (cm)	Average colonization degree
Acer negundo	2	93	2.5
Acer platanoides	11	170	0.45
Acer pseudoplatanus	6	133.5	1
Aesculus hippocastanum	4	117.5	0.4
Alnus glutinosa	1	98	1
Betula pendula	17	123.82	0.53
Cerasus avium	3	102.33	0.33
Fraxinus excelsior	8	112.63	0.86
Fraxinus pennsylvanica	1	182	2
Larix decidua	7	110.86	0
Picea abies	5	89.2	0
Picea pungens	2	20.8	0
Pinus nigra	3	104	0
Pinus sylvestris	5	112.6	0
Populus* x*berolinensis	8	198.13	2.5
***Populus canadensis* 'robusta'**	24	232.38	2.08
Populus candicans	3	120	2.33
***Populus* 'NE 42'**	8	69.36	1.13
Populus nigra	7	237.86	1.86
Populus simonii	1	96	3
Populus tremula	3	132	0.33
Quercus robur	17	179.24	0.76
Quercus rubra	3	105.33	0
Robinia pseudoacacia	7	158	1.71
***Salix alba* 'Tristis'**	11	146.45	3
Salix caprea	4	127.5	2.5
Salix fragilis	13	180.77	2.85
Tilia cordata	8	119.38	0.38

The research conducted in Katowice partially confirmed that epiphytes still avoid locations where air pollution exceeds some specified limits. At the same time, the results show that the analyzed habitat relationships are more complex than initially suspected. As was expected, the average content of lead, copper and iron in poplar bark were lower in Janów and Ligota (sites with epiphytes) in comparison with Witosa and Brynów (sites without epiphytes). Results from Muchowiec turned out to be amazing. The area was initially classified as clean, but the levels of lead, copper, iron, and sulphur in the investigated poplar bark proved to be the highest. This can be partially explained by the fact that Muchowiec was classified as clean due to the abundance of epiphytes growing on willow trees. The sampled poplar trees were deprived of epiphytes, which was initially unclear as they are one of the most readily colonized tree species (which can be seen in the analysis of colonization degree of various species). Lack of epiphytes on poplar trees in Muchowiec is probably not related with elevated content of selected heavy metals, but with elevated sulphur content and the co-rrelated lower pH value (the effect of acid rain), in comparison with other areas.

The pH of the bark is a result of a few factors – the species properties and the age of a tree (which is related with the possibility of buffering the acidification), the impact of acidic rainfall, and the chemical composition of water flowing on the trunk (containing substances flushed out of treetop and branches) (Barkman 1958; Bates *et al*. 2004; Poikolainen 2004). Acid rain causes drastic changes of chemical properties, both of bark as the ground layer and of epiphytes, by reducing the pH of water flowing on the trunk, the decrease in capacity of the buffering bark, the decrease in epiphyte internal pH, and loss of chlorophyll by epiphytes (Robitaille *et al*. 1977). Moreover, they cause the increase in the concentration of metals by increasing the solubility of their salts and the increase in their intake by mosses (Rao 1982). The average annual poplar bark pH measurement in most examined areas (apart from Muchowiec) is quite similar, about 5-5.5. Sulphur content does not exceed 1000 mg kg^{-1}. In Muchowiec, the elevated level of sulphur and heavy metals, as well as low bark pH, indicate the loss of buffering properties of poplar bark. As a result, there are no epiphytes. It may be connected with the advanced age of the trees – these from Muchowiec were the oldest among the examined specimen (the perimeter being from 3.20 to 4.20 m). Acidic air pollutants may cause an irreversible loss of poplar buffering abilities, hence epiphytes do not resume growing even after a significant reduction of acid rain (Farmer *et al*. 1991). The nearby willow trees on which epiphytes grew were relatively young (with the perimeter of approximately 120 cm). What's more, solubility and bioavailability of many metals is connected with acidity of solutions in which they are present. Basing on the examples on soil solutions Bergkvist *et al*. (1989) correlated the dependence between pH and the concentration of selected metals. A ra-pid increase in solubility and bioavailability of metals below the critical pH value of aqueous solutions (4-4.5 in the examined soiled samples). Despite that, it is well known that the pH of precipitates may drop below 4, e.g. the 9th of December 2009 in Katowice the pH value of a daily sample equaled to 3.52 (Degórska *et al*. 2011).

Buffering properties of a habitat play a significant role in areas with high air pollution levels. High pH allows sensitive species to survive even in the city centre by altering sulphur ions into a less toxic form (Gilbert 1968, 1969). Hence, in polluted areas (including Katowice), some typical epiphytes move to replacement habitats of higher pH levels, e.g. concrete walls (Adams, Preston 1992; Fojcik, Stebel 2001; Fudali 2012).

Chemistry of bark as a habitat is variable not only in space, but also in time. During the research, seasonal changes in metal and sulphur content in bark were observed, along with bark pH level. It is difficult to specify the patterns of heavy metals content changes. However, the same patterns for pH level changes were observed in all areas. Acidity increased significantly at the turn of spring and summer. Such phenomenon can be connected with relatively high precipitation levels observed during this period. During the dry season, it is alkali industrial dust that influences bark chemistry more. They are not flushed out by acid rain. Other authors have highlighted seasonal chemistry changes as well, interpreting them as a result of weather factors and the levels of emission (Poikolainen 2004).

One of the crucial factors which govern colonization processes and limit the occurrence of epiphytes is air humidity (Bergkvist *et al*. 1989). A city is an example of anthropogenic environment in which humans influence climate indirectly (Dudek *et al*. 2008). Relative humidity is usually lower than in neighbouring areas (Brys *et al*. 2003). Although epiphytes are generally resistant to drought, germination is the crucial stage which requires water (Proctor, Tuba 2002). Low humidity prolongs germination and limits its effectiveness (Wiklund, Rydin 2004). Moreover, protonema is the most vulnerable to drying (Glime 2007). The presented differences in humidity levels in areas with and without epiphytes reached up to 10%, which is in agreement with other research results concerning urban and suburban areas (Kratzer 1937; Rydzak 1958). These differences confirm the habitat preferences of spreading epiphytes. Their largest abundance is observed in the neighbourhood of forests and large park areas, commonly situated next to large water reservoirs. Epiphytes prefer locations characterized by larger air humidity, which confirms the significance of this factor for the colonization stage. Moreover, humidity may compensate for other foul circumstances, e.g. low pH of bark (Wiklund, Rydin 2004; Phillips 1951).

The preference of epiphytes towards inhabited phorophytes was confirmed as well. The most commonly and abundantly inhabited species were poplar trees and willow trees of higher pH of bark. Similar preferences in urban areas were observed by Adams (1990) in London, Dymytrova (2009) in Kiev or Fudali (2011) in Wrocław. Higher pH of bark may buffer the influence of foul habitat factors, which enhances the probability of colonization success of epiphytes. Many authors emphasize the meaning of phorophyte size – the larger the tree, the richer epiphyte flora (Hazell *et al*. 1998; Zotz, Vollrath 2003). 192 trees of 28 species were analyzed. The analysis showed a correlation between phorophyte perimeter and epiphyte abundance. The correlation is not very strong, which apparently results from the presence of many non-colonized, young phorophytes of small perimeter. The second reason is the presence of many large poplar trees not yet inhabited by epiphytes (in Muchowiec). The advantage of older trees is, for instance, larger diversity of microhabitats and longer period of their colonization (Barkman 1958; Rose 1992).

It is needed to notice that in urban areas the stand composition is a result of economical actions – both in woodlands and other areas. This limits the access to one type of phorophytes, at the same time enhancing the access to others. The abundance of poplar and willow trees in Katowice increases the probability of encountering non-forest epiphytes. This does not refer to conifers, poorly colonized by epiphytes, which is shown by the analysis of colonization degree of various phorophytes. Phorophytes of foreign origin play an important role as well. *Fraxinus pennsylvanica* is a good example of the most commonly colonized ones, which is observed not only in the area of Katowice (Fojcik, Stebel, 2001; Fojcik 2011).

Colonization processes, if conducted under appropriate conditions, occur relatively quickly. This is observed also beyond the area of Katowice (for instance *Orthotrichum pumilum* – Fig. 1). It is because epiphytes belong to the most mobile mosses (Adams, Preston 1992) and they exhibit various ways of reproduction (they form propagules quite often), which enables relatively fast recolonization of habitats (Longton 1997). Although air pollution inhibits amphigony of mosses, it is compensated by vegetative propagation which facilitates growth of some species in more areas (Rao 1982; Giordano *et al*. 2004).

Conclusions

The distribution of epiphytes in an urban area is largely conditioned by the effectiveness of colonization success. It depends on various factors, including: presence of an appropriate phorophyte, appropriate bark chemistry (taking into account natural factors and the influence of pollution), appropriate air humidity and the level of environmental disturbances which can be buffered by other factors.

The research shows that the factor which slows down the growth of epiphytes in Katowice might be the differences in air pollution and air humidity – both of which influence colonization success. Spreading of non-forest epiphytes is also enhanced by the presence of appropriate phorophytes, especially *Populus* and *Salix*. Their sizes are not a decisive factor in terms of colonization success; however, large phorophytes facilitate the growth of epiphytes.

It was essential to show the dynamics of bark as a habitat, which may also influence the colonization process. A phorophyte and altering air humidity, pH and pollution level are a variable configuration which buffers itself up to some extent. An epiphyte has to fit in in order to colonize successfully.

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