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EPIPHYTIC HABITATS IN AN URBAN ENVIRONMENT; CONTAMINATION BY HEAVY METALS AND SULPHUR IN THE BARKS OF DIFFERENT TREE SPECIES

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Key words: epiphytes, bark contamination, monitoring, urban ecology.

Abstract

Air pollution is mentioned as one of the major factors that limit the occurrence of epiphytes in urban areas. The purpose of the investigation was to analyze any dissimilarity in the amount of heavy metals and sulphur to the bark of different tree species that had been subjected to bark pollution (pH values were also analyzed). In order to estimate the differences in the amount of pollutants that had reached the bark, the "moss-bag" method was also used.

The present study confirms that the barks of tree species differ in the level of pollutants (such as heavy metals and sulphur). The higher pH values of the bark appears to be an important buffer for the adverse effects of air pollution and determines the recolonization processes of epiphytic species in urban areas.

SIEDLISKA EPIFITYCZNE W ŚRODOWISKU MIEJSKIM; ZANIECZYSZCZENIE KORY RÓŻNYCH GATUNKÓW DRZEW METALAMI CIĘŻKIMI I SIARKĄ

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Słowa kluczowe: epifity, zanieczyszczenie kory, monitoring, ekologia miasta.

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A b s t r a k t

Zanieczyszczenie powietrza jest jednym z głównych czynników ograniczających występowanie epifitów na obszarach zurbanizowanych. Celem badań było określenie zróżnicowania zawartości metali ciężkich i siarki w korze różnych gatunków drzew występujących na terenie zanieczyszczonym (analizowano także poziom pH). Różnice w ilości zanieczyszczeń docierających do kory porównano również za pomocą metody woreczkowej z wykorzystaniem mchu (metoda „moss-bag").

W prezentowanych badaniach potwierdzono, że kora różnych gatunków drzew różni się poziomem zanieczyszczenia (zarówno metalami ciężkimi, jak i siarką). Wyższy poziom pH kory wydaje się istotnym czynnikiem buforującym niekorzystne oddziaływanie zanieczyszczeń powietrza i warunkującym procesy rekolonizacji epifitów na terenach miejskich.

Introduction

Epiphytes are an ecological and physiological specialized group among the mosses. They depend on precipitation from which they also obtain nutrients (they are physiologically active only in a hydrated state) (VANDERPOORTEN and GOFFINET 2009). The local distribution of epiphytes is the result of mutual relationships between various habitat factors, like phorophyte species, the size of tree trunks and environmental conditions (SEAWARD 1979, ZECHMEISTER and HOHENWALLNER 2006, DYMYTROVA 2009). In urban areas one of the crucial element is also air pollution, because toxic substances negatively influence their essential physiological processes (RAO 1982, BATES et al. 2004, ZECHMEISTER and HOHENWALLNER 2006). Heavy metals (lead, zinc, copper) and sulphur compounds can disturb the development of spores and the growth of protonema, which makes the colonization of habitats in polluted areas more difficult (KRZESŁOWSKA et al. 1994, BASILE et al. 1995).

Bark and epiphytes are exposed to air pollutants either directly from the atmosphere or from stemflow (liquid that penetrates the canopy and flowing down the branches and stem of tree) (BERLIZOV et al. 2007, CATINON et al. 2012). Stored dust deposit formed on tree crown is washed out during rainfall, therefore concentrations of nutrients and metals in stemflow is higher compared with rainwater (PRYOR and BARTHELMIE 2005, XIAO and MCPHERSON 2011, CATINON et al. 2012). Percentages of rain water reaching the bole and epiphytes as stemflow is different in various tree species (from 0.8 to 22% of bulk precipitation) (PRYOR and BARTHELMIE 2005, XIAO and MCPHERSON 2011). Factors influencing stemflow are mainly: type of canopy, bark texture and leaf surface morphology (BARKMAN 1958, RASMUSSEN 1978, PRYOR and BARTHELMIE 2005).

The way in which the type of phorophyte (species of tree) influences the amount of pollutants that reach the bark, and inhabiting epiphytes, is interesting. The purpose of the investigation was to analyze any dissimilarities in the amount of heavy metals and sulphur as well as the pH values of different tree species that had been subjected to bark pollution. In order to estimate the amount of pollutants that had reached the bark and epiphytes (both from wet and dry deposition) the chemistry of bark were analyzed (amount of heavy metals and sulphur). The use of tree bark as indicatior in biomonitoring of air pollution in urban areas is still common (e.g. FUJIWARA et al. 2011, ŠKRBIĆ et al. 2012, BARBEŞ et al. 2014, DOGAN et al. 2014, MOREIRA et al. 2016). To estimate current levels of emission the "moss-bag" method were used in this study (with *Pleurozium schreberi* (WILLD. *ex* BRID.) MITT.). It is in general also standard method used in biomonitoring (SUN et al. 2009, TRACZEWSKA 2011).

Materials and Methods

The investigation was carried out in Bolina" park (about 4.7 ha) in the Janów district of Katowice town (GPS N: 50°13'55", E: 19°05'18"). The quantity of heavy metals, especially zinc and cadmium, in Janów is high, which is mainly the result of the close proximity of the metalworks "Huta Żelaza Ferrum" and "Huta Metali Nieżelaznych Szopienice S.A." (since 2008 in liquidation) – counted among the main sources of emission in Katowice (*Raport z realizacji*... 2014).

To estimate the amount of pollutants in the bark of different trees, bark from ten tree species was sampled (about 50 g), both deciduous and coniferous (*Acer platanoides* L., *Acer pseudoplatanus* L., *Betula pendula* Roth, *Fraxinus excelsior* L., *Picea pungens* Engelm., *Pinus sylvestris* L., *Populus tremula* L., *Quercus rubra* L., *Robinia pseudoacacia* L., *Tilia cordata* Mill.). The ages and sizes of the trees were approximate (were planted at the same time), only the specimen of *Picea pungens* was smaller. Bark samples, which were around 3 mm thick, were collected from a height of approximately 1.5 m in 30 August 2011.

To estimate the amount of pollutants, that had reached the epiphytes, modified "moss-bag" method were used (SUN et al. 2009, TRACZEWSKA 2011). *Pleurozium schreberi* samples were gathered in a large forest complex in the vicinity of the village of Panoszów (west of Częstochowa; GPS N: 50°48'13", E: 18°40'23"), an area far from the larger emission sources. In the laboratory *Pleurozium* samples were dried in room temperature. After cleaning they were divided into portions of 15 g. Each sample was packed into a polyethylene net bag (30 x 30 cm) with a 1 mm stitch (produced by the Tenax Company). Bags with *Pleurozium* were then hung on the bark of trees at a height of about 3 m. In order to expose the *Pleurozium* samples in a similar way as the epiphytes and to create similar water supply conditions, the bags were very closely adhered to the tree trunks. The exposure lasted for three months (from the end of May to the end of August 2011).

The samples of bark and moss (after exposition) were dried at 50°C for 24 hours and they were then crushed using a blender. In order to determine the pH, 1 g of each sample of powdered bark was taken and suffused in 5 ml of distilled water. After 48 hours, acidity was measured with a pH-meter. The pH analysis was repeated five times. For the chemical analysis of heavy metal content in bark and moss, 250 mg of each sample was mineralized. The material was digested in 5 ml of concentrated HNO_3 at a temperature up to 120°C for approximately one week (until a clear solution was obtained). The solution was filtered into measuring flasks and diluted with distilled water until the volume reached 10 ml. These solutions were analyzed for heavy metal content (Fe, Cd, Cu, Pb, Zn) using the Atomic Absorption Spectrometry method with a "Unicam 939 Solar" spectrometer. The analysis was repeated five times. The content of heavy metals in the initial examination moss material equaled (mg kg^{-1}): Pb – 66.3; Zn – 57.27; Cd – 2.76; Cu – 20.12; Fe – 316.82.

Sulphur content in *Pleurozium* samples were also studied. For this purpose 300 mg of a homogenous sample was put into a ceramic crucible into which 150 mg of tungsten trioxide was added. The content was analyzed using a Vario Max CNS microanalyzer (the analysis was repeated three times). The content of sulphur in the initial examination of the moss material equaled 630 mg kg^{-1}.

Values of Spearman rank correlation coefficient (with $p < 0.05$) were computed using STATISTICA software (version 10).

Results

The content of heavy metals in the bark and exposed moss varied among the tree species that were analyzed (Figures 1–5). Levels of contaminations in bark were varied more significantly (in moss samples the spread between the maximum and minimum values were lower).

In most of the samples the amount of lead was below 80 mg kg^{-1}. The highest content was detected in the bark of *Robinia pseudoacacia* (135.7 mg kg^{-1}) and *Tilia cordata* (102.18 mg kg^{-1}). A higher amount of Pb was registered in the material that was exposed on *Populus tremula* and *Quercus robur* (above 80 mg kg^{-1}), while the lowest level was found in the material from *Picea pungens* (55.02 mg kg^{-1}) and *Tilia cordata* (55.28 mg kg^{-1}).

The content of zinc in bark fluctuated a great deal and ranged from 16.31 mg kg^{-1} in *Quercus rubra* to more than 160 mg kg^{-1} in *Betula pendula*, *Picea pungens*, *Populus tremula* and *Robinia pseudoacacia*. In most cases of moss material the content of Zn fluctuated in the range of 50–71 mg kg^{-1}; significantly higher values were noted only in the material that was exposed on *Populus*

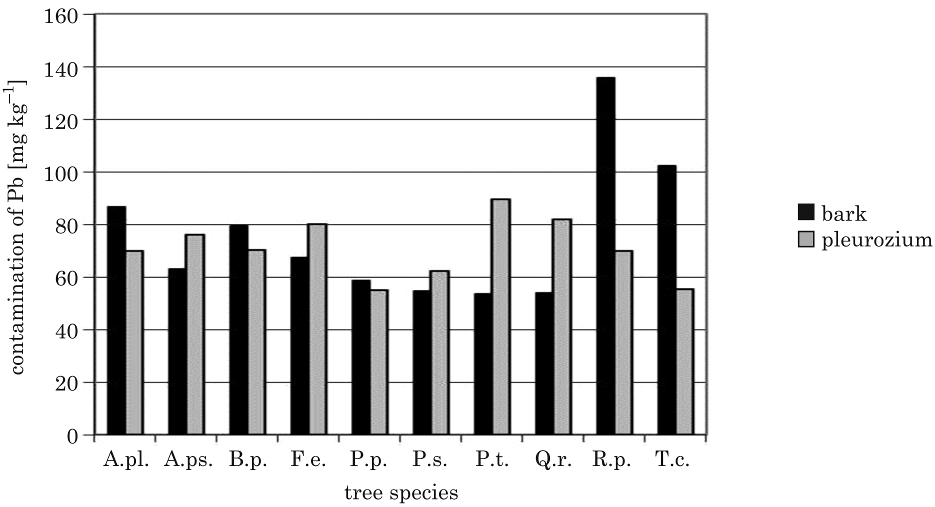

Fig. 1. The content of Pb [mg kg^{-1}] in bark of different tree species and *Pleurozium schreberi* exposed on their bark: A.pl. – *Acer platanoides*; A.ps – *Acer pseudoplatanus*; B.p. – *Betula pendula*; F.e. – *Fraxinus excelsior*; P.p. – *Picea pungens*; P.s. – *Pinus sylvestris*; P.t. – *Populus tremula*; Q.r. – *Quercus rubra*; R.p. – *Robinia pseudacacia*; T.c. – *Tilia cordata*

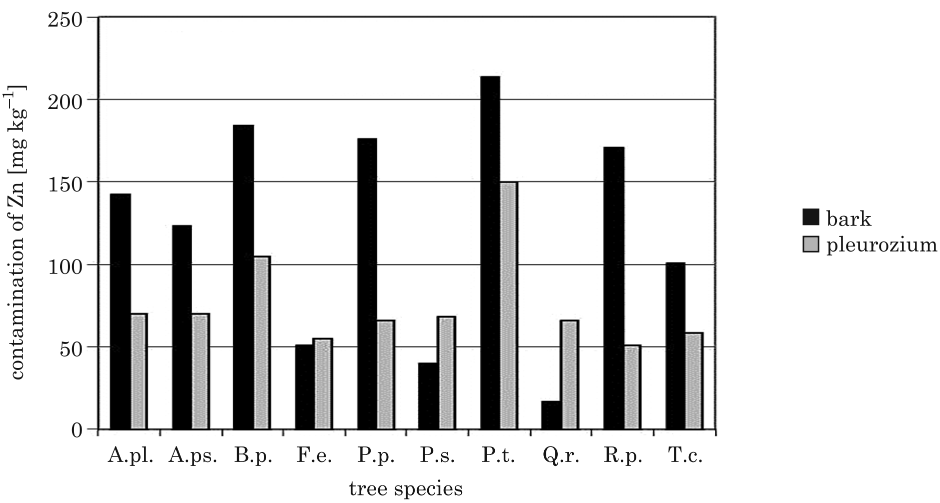

Fig. 2. The content of Zn [mg kg^{-1}] in bark of different tree species and *Pleurozium schreberi* exposed on their bark: A.pl. – *Acer platanoides*; A.ps – *Acer pseudoplatanus*; B.p. – *Betula pendula*; F.e. – *Fraxinus excelsior*; P.p. – *Picea pungens*; P.s. – *Pinus sylvestris*; P.t. – *Populus tremula*; Q.r. – *Quercus rubra*; R.p. – *Robinia pseudacacia*; T.c. – *Tilia cordata*

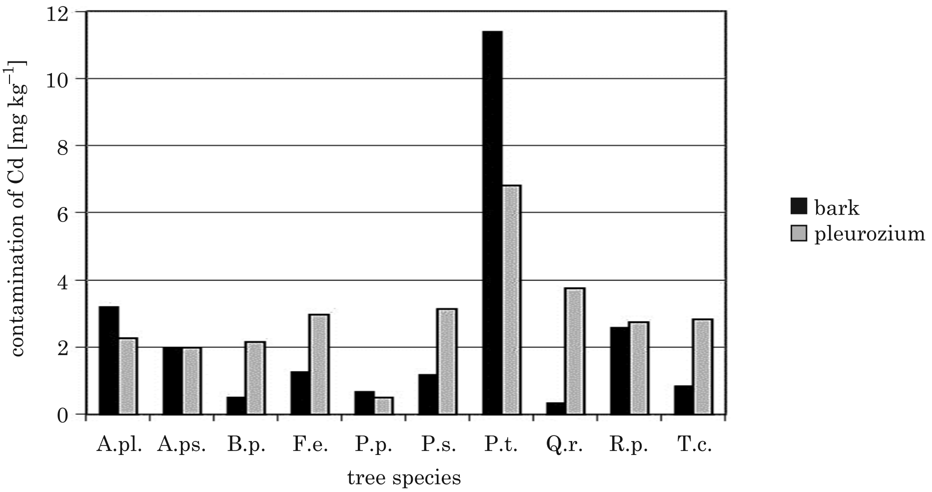

Fig. 3. The content of Cd [mg kg^{-1}] in bark of different tree species and *Pleurozium schreberi* exposed on their bark: A.pl. – *Acer platanoides*; A.ps – *Acer pseudoplatanus*; B.p. – *Betula pendula*; F.e. – *Fraxinus excelsior*; P.p. – *Picea pungens*; P.t. – *Populus tremula*; Q.r. – *Quercus rubra*; R.p. – *Robinia pseudacacia*; T.c. – *Tilia cordata*

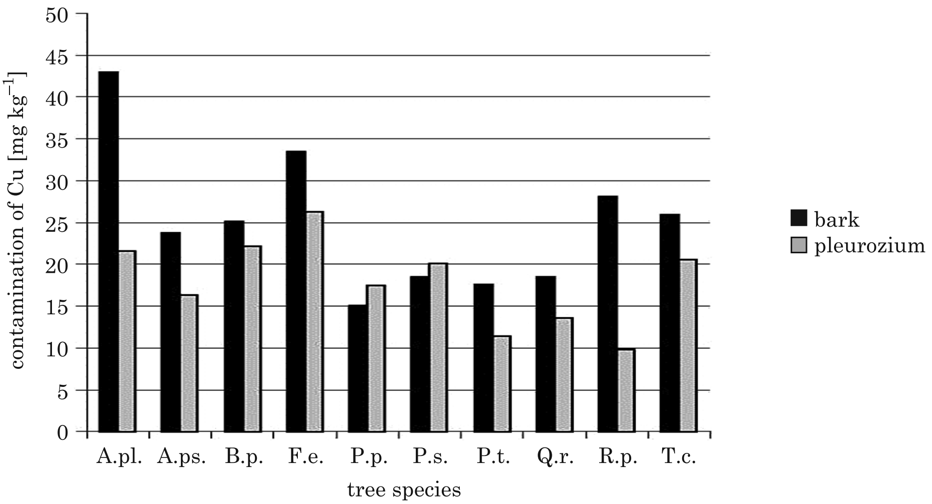

Fig. 4. The content of Cu [mg kg^{-1}] in bark of different tree species and *Pleurozium schreberi* exposed on their bark: A.pl. – *Acer platanoides*; A.ps – *Acer pseudoplatanus*; B.p. – *Betula pendula*; F.e. – *Fraxinus excelsior*; P.p. – *Picea pungens*; P.s. – *Pinus sylvestris*; P.t. – *Populus tremula*; Q.r. – *Quercus rubra*; R.p. – *Robinia pseudacacia*; T.c. – *Tilia cordata*

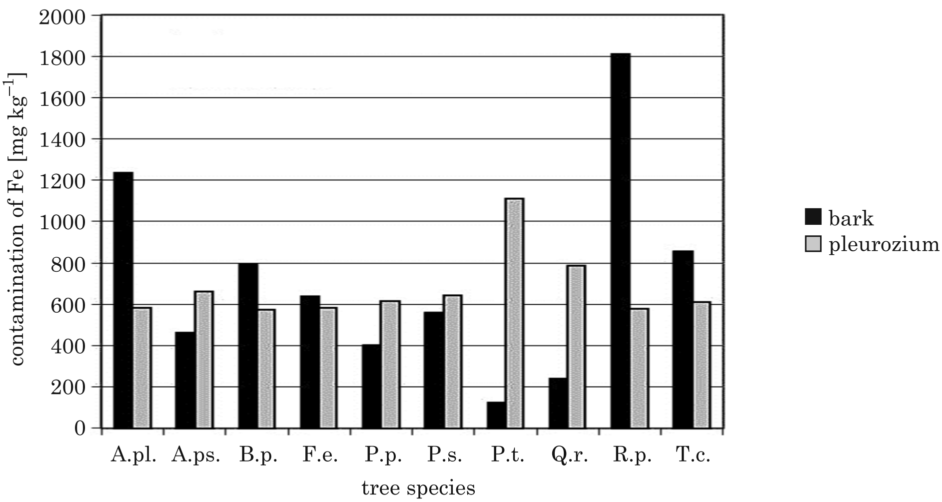

Fig. 5. The content of Fe [mg kg^{-1}] in bark of different tree species and *Pleurozium schreberi* exposed on their bark: A.pl. – *Acer platanoides*; A.ps – *Acer pseudoplatanus*; B.p. – *Betula pendula*; F.e. – *Fraxinus excelsior*; P.p. – *Picea pungens*; P.s. – *Pinus sylvestris*; P.t. – *Populus tremula*; Q.r. – *Quercus rubra*; R.p. – *Robinia pseudacacia*; T.c. – *Tilia cordata*

tremula (149.8 mg kg^{-1}) and *Betula pendula* (104.66 mg kg^{-1}). The tendency to significantly higher content of zinc in the bark vs. moss samples prevails.

The quantity of cadmium in the bark of most of the trees did not exceeded 4 mg kg^{-1} and only in the case of *Populus tremula* amount is much higher (11.39 mg kg^{-1}). The highest content of Cd was registered in the moss material that was exposed on *Populus tremula* (6.81 mg kg^{-1}), while the lowest level was found in the material that was exposed on *Picea pungens* (0.61 mg kg^{-1}). In the other moss samples the amount of cadmium fluctuated in the range of 1.97 (*Picea pungens*) to 3.74 mg kg^{-1} (*Quercus robur*).

The largest content of copper was registered in the bark of *Acer platanoides* (42.89 mg kg^{-1}), while the lowest levels of this metal were registered in bark of *Picea pungens* (15.02 mg kg^{-1}). The content of Cu in moss samples varied widely and ranged from 9.75 mg kg^{-1} (in material from *Robinia pseudoacacia*) and 11.37 mg kg^{-1} (material from *Populus tremula*) to 26.29 mg kg^{-1} (material from *Fraxinus excelsior*).

A higher content of iron was detected in the bark of *Robinia pseudoacacia* (1812.6 mg kg^{-1}), whereas the lowest content was found in the bark of *Populus tremula* (122.52 mg kg^{-1}). The amount of iron was similar and in most cases it had a level of 600 mg kg^{-1}; however, a significantly higher content was detected in the material that was exposed on *Populus tremula* (1109.36 mg kg^{-1}).

The results show that none of tree species that were analyzed had the highest levels of all of the heavy metals. According to the type of element, the

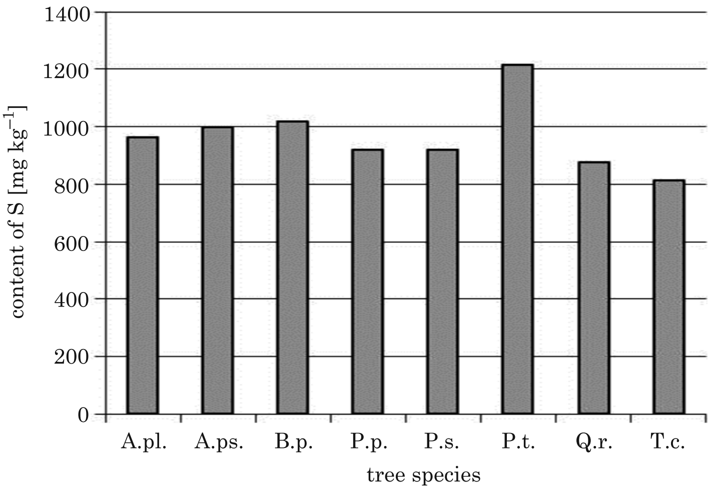

Fig. 6. The content of S [mg kg^{-1}] in *Pleurozium schreberi* exposed on different tree species: A.pl. – *Acer platanoides*; A.ps – *Acer pseudoplatanus*; B.p. – *Betula pendula*; F.e. – *Fraxinus excelsior*; P.p. – *Picea pungens*; P.s. – *Pinus sylvestris*; P.t. – *Populus tremula*; Q.r. – *Quercus rubra*; R.p. – *Robinia pseudacacia*; T.c. – *Tilia cordata*

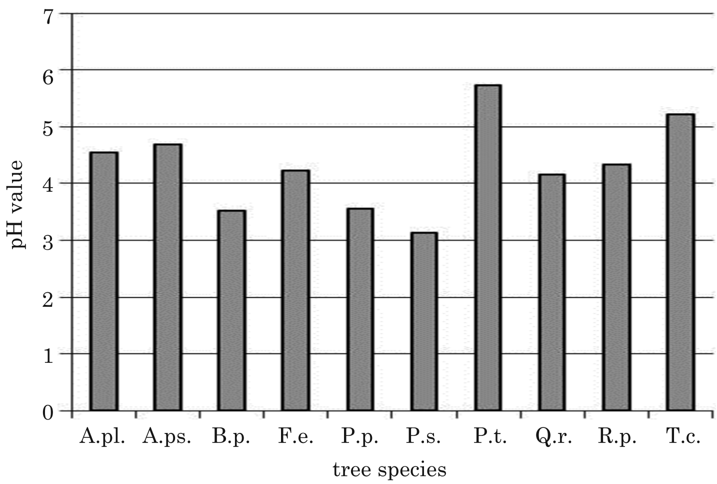

Fig. 7. The pH values of bark of different tree species: A.pl. – *Acer platanoides*; A.ps – *Acer pseudoplatanus*; B.p. – *Betula pendula*; F.e. – *Fraxinus excelsior*; P.p. – *Picea pungens*; P.s. – *Pinus sylvestris*; P.t. – *Populus tremula*; Q.r. – *Quercus rubra*; R.p. – *Robinia pseudacacia*; T.c. – *Tilia cordata*

most polluted bark occurred in *Robinia pseudoacacia* (Pb and Fe), *Populus tremula* (Cd and Zn) and *Acer platanoides* (Cu). The lowest levels of Pb, Zn and Cd and relatively low levels of Cu and Fe were noted for *Quercus rubra*. Comparing the level of contamination in the bark of different species of trees and in exposed moss samples – only for Zn and Cu clear tendency to higher values in the bark has been demonstrated.

There are only few highly significant correlation coefficients between the content of metals in the bark of trees and between the bark and the exposed moss samples. A positive relationships were demonstrated between Cu vs. Fe and Pb (r = 0.854545 and 0.793939, respectively), Fe vs. Pb (r = 0.951515) – in bark of trees, as well as between S in tree bark and Zn in bark (r = 0.79043) and exposed moss samples (r = 0.99403). A negative correlations were observed with respect to Fe in bark and moss samples (r = -0.851068), as well as between Fe in moss samples vs. Cu and Pb in bark of trees (r = -0.70517 and -0.832831, respectively).

The level of sulphur in exposed *Pleurozium* varied among the tree species and ranged from 813 (*Tilia cordata*) to 1214 mg kg^{-1} (*Populus tremula*) (Figure 6). Moreover, a significant differentiation in the bark pH values of different phorophytes was confirmed (Figure 7). The lowest pH was noted for coniferous trees – *Pinus sylvestris* (3.13) and *Picea pungens* (3.55). The pH of *Betula pendula* bark (3.52) was at a similar level. In other cases pH exceeded 4 and the bark of *Populus tremula* had the highest value (5.72).

Discussion

According to different authors normal value for Cu, Pb and Zn in bark and *Pleurozium schreberi* tissue is at a level of a few mg kg^{-1} (only in *Pleurozium* zinc reaches tens of mg kg^{-1}), for Cd – below 1 mg kg^{-1}, and relatively varied in the case of Fe – from a few to a few hundred mg kg^{-1} (SAMECKA-CYMERMAN et al. 2006, DOGAN et al. 2007, CELIK et al. 2010, SAWIDIS et al. 2011, OKLO and ASEMAVE 2012, MOREIRA et al. 2016). The level of contaminations in analyzed bark of trees and exposed moss samples is relatively high. This high content of heavy metals is possibly a result of metalworks "Huta Żelaza Ferrum" and "Huta Metali Nieżelaznych Szopienice S.A." being situated nearby.

The investigation confirms the essential differentiation of the chemistry of bark (epiphytic habitat) that result from contamination by heavy metals and sulphur. These differences are mainly affected by the bark quality, type of canopy and stemflow (SCHULZ et al. 1999, PRYOR and BARTHELMIE 2005). The bark and leaf surface morphology contributed to the trapping and retention of contaminations – the rougher the surface, the greater the accumulation of air dust particles. Also old leaves are more contaminated than the young (SAWIDIS et al. 1995). Stemflow washes away contaminations from the canopy (along a tree trunk) is one of the major sources of pollution that reaches epiphytes and may differ significantly in comparison with precipitated water (SKŘIVAN et al.

1995). According to Barkman (1958), the percentages of rain water reaching the bole in various trees is from 1% (*Picea*) to 22% (*Fagus*). For instance, spruce has a very dense crown and rainfall flows over its branches to the brink of the crown. Most tree species have a less dense crown and the majority of rainfall flows down the branches (Wittig 1986).

The level of heavy metals and sulphur in bark is modified not only by the inflow of elements during exposure, but also by the washing out of elements by rainfall. The influence of the quantity and form of precipitation is also important. Intensive rainfall is able to flush out significant amounts of elements, while mild rainfall results in water evaporation, which causes the substances to remain in the bark (Čeburnis and Valiulis 1999, Levia 2003). This refers to epiphytes as well – rainfall may wash out up to 20% of elements that are deposited on the surface of mosses (Čeburnis and Valiulis 1999).

No simple relations was found between the content of metals in the barks of trees and in the exposed moss. In many cases the level of heavy metals in moss is lower than in the barks of trees (especially it refers to *Acer platanoides*, *Betula pendula* and *Robinia pseudoacacia*) (Figures 1–5). It follows that the concentration of the elements that were examined in the bark is the result of many years of exposure to emissions and long-term accumulation of air pollution (Pacheco et al. 2002, Mandiwana et al. 2006). On the other hand content of contaminations in the moss that was exposed for a relatively short period of time seems to reflect the current levels of emission (also the effect of reducing emissions during the restructuration of the steelworks). Other authors have suggested that the concentration of the elements in moss is related more to the chemical composition of the last precipitates than to a long-term accumulation (Brown and Brumelis 1996, Reimann et al. 1999).

Moreover, a significant differentiation in the bark pH values of different phorophytes was confirmed (Figure 7). The pH of bark is the result of a few factors – the species properties and the age of a tree (which are related to the possibility of buffering acidification), the impact of acidic rainfall and the chemical composition of water flowing on the trunk (containing substances flushed out of the treetop and branches) (Bates et al. 2004, Poikolainen 2004). Acid rain causes drastic changes in the chemical properties of both the bark as the ground layer and epiphytes because it reduces the pH of water flowing on the trunk, which causes a decrease in the capacity of the bark to buffer, a decrease in the internal pH of epiphytes and a loss of chlorophyll by epiphytes (Robitaille et al. 1977). The buffering properties of a habitat play a significant role in areas that have high levels of air pollution. The described above results refer to *Populus tremula* seem to confirm this buffering properties (the highest pH of the bark in spite of the highest inflow of sulphur). High pH allows sensitive species to survive even in the city center by altering sulphur ions into a less toxic form (GILBERT 1968, 1969). Moreover the higher pH level reduce a mobility of metals ions occuring in bark (BATES and BROWN 1981) – it may diminish their bioavailability. It may be an explanation of attachment of epiphytes to phorophytes with more alkaline bark. The analysis of the preference of epiphytes in Katowice towards inhabited phorophytes reveals that the most commonly and abundantly inhabited species were poplar and willow trees, which show higher pH values of bark (STEBEL and FOJCIK 2016). Similar preferences in other urban areas were observed by ADAMS and PRESTON (1992) in London, DYMYTROVA (2009) in Kiev and FUDALI (2011) in Wrocław. Whereas in this study the highest content of Zn and Cd was detected just in the poplar bark, also high amount of Pb, Zn, Cd and Fe was detected in the material that was exposed on *Populus tremula*.

The distribution of epiphytes in an urban area is largely conditioned by the effectiveness of colonization success, which depends on various factors, including bark chemistry (taking into account natural factors and the influence of pollution). The present study confirms that the barks of tree species differ in the level of pollution (such as heavy metals and sulphur), which may be one of the crucial factors that governs the recolonization processes of epiphytic species in urban areas. Higher pH of bark may buffer the influence of foul habitat factors, which enhances the probability of colonization success of epiphytes (FOJCIK et al. 2015).

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References

ADAMS K.L., PRESTON C.D. 1992. *Evidence for the effects of atmospheric pollution on bryophytes from national and local recording*. In: *Biological recording of changes in British wildlife*. Ed. P.T. Harding, London, HMSO, pp. 31–43.

BARBEȘ L., BĂRBULESCU A., RĂDULESCU C., STIHI C., CHELARESCU E.D. 2014. *Determination of heavy metals in leaves and bark of Populus nigra L. by atomic absorption spectrometry*. Rom. Rep. Phys., 66(3): 877–886.

BARKMAN J.J. 1958. *Phytosociology and ecology of cryptogamic epiphytes*. Assen, The Netherlands, Van Gorcum-Hak & Prakke.

BASILE A., GIORDANO S., SPAGNUOLO V., ALFANO F., CASTALDO COBIANCHI R. 1995. *Effect of lead and colchicine on morphogenesis in protonema of the moss Funaria hygrometrica*. Ann. Bot., 76: 597–606.

BATES J.W., BROWN DH. 1981. *Epiphyte differentiation between Quercus petraea and Fraxinus excelsior trees in a maritime area of South West England.* Vegetatio, 48: 61–70.

BATES J.W., ROY D.B., PRESTON C.D. 2004. *Occurrence of epiphytic bryophytes in a "tetrad" transect across southern Britain. 2. Analysis and modelling of epiphyte-environmental relationships.* Journal of Bryology, 26: 181–197.

BERLIZOV A.N., BLUM O.B., FILBY R.H., MALYUK I.A., TRYSHYN V.V. 2007. *Testing applicability of black poplar (Populus nigra L.) bark to heavy metal air pollution monitoring in urban and industrial regions.* Sci. Total Environ., 372: 693–706.

BROWN D.H., BRUMELIS G. 1996. *A biomonitoring method using the celular distribution of metals in mosses.* Sci. Total Environ., 187: 153–161.

CATINON M., AYRAULT S., BOUDOUMA O., ASAT J., TISSUT M., RAVANEL P. 2012. *Atmospheric element deposit on tree barks: the opposite effects of rain and transpiration.* Ecol. Indic., 14: 170–177.

ČEBURNIS D., VALIULIS D. 1999. *Investigation of absolute metal uptake efficiency from precipitation in moss.* Sci. Total Environ., 226: 247–253.

CELIK S., YUCEL E., CELIK S., GUCEL S., OZTURK M. 2010. *Carolina poplar (Populus/canadensis Moench) as a biomonitor of trace elements in Black sea region of Turkey.* J. Environ. Biol., 31: 225–232.

DOGAN Y., DURKAN N., BASLAR S. 2007.*Trace element pollution biomonitoring using the bark of Pinus brutia (Turkish red pine) in the Western Anatolian part of Turkey.* Trace Elem. Electroly., 24(3): 146–150.

DOGAN Y., UNVER M.C., UGULU I., CALIS M., DURKAN N. 2014. *Heavy metal accumulation in the bark and leaves of Juglans regia planted in Artvin City, Turkey.* Biotechnol. Biotec. Eq., 28(4): 643–649.

DYMYTROVA L. 2009. *Epiphytic lichens and bryophytes as indicators of air pollution in Kyiv city (Ukraine).* Folia Cryptog. Estonica, 46: 33–44.

FOJCIK B., CHRUŚCIŃSKA M., NADGÓRSKA-SOCHA A., STEBEL A. 2015. *Determinants of occurrence of epiphytic mosses in the urban environment; a case study from Katowice city (S Poland).* Acta Mus. Siles. Sci. Natur., 64: 275–286.

FUDALI E. 2011. *Contemporary changes in urban bryophytes: a case study of Wrocław parks carried out in 2000, 2006 and 2011.* Acta Bot. Sil., 6: 81–95.

FUJIWARA F.G., GÓMEZ D.R., DAWIDOWSKI L., PERELMAN P., FAGGI A. 2011. *Metals associated with airborne particulate matter in road dust and tree bark collected in a megacity (Buenos Aires, Argentina).* Ecol. Indic., 11: 240–247.

GILBERT O.L. 1968. *Bryophytes as indicators of air pollution in the Tyne Valley.* New Phytol., 67: 15–30.

GILBERT O.L. 1969. *The effect of SO_2 on lichen and bryophytes around Newcastle upon Tyne. Air Pollution Proceedings of the first European Congress on the Influence of Air Pollution on Plants and Animals.* Wageningen, Pudoc, pp. 223–235.

KRZESŁOWSKA M., PUSTELNIK L., WOŹNY A. 1994. *Differentiated lead-induced inhibition of growth rate of Funaria hygrometrica Hedw. protonema.* Bull. Soc. Amis Sci. Lett., 30: 33–36.

LEVIA JR. D.F. 2003. *Winter stemflow leaching of nutrient-ions from deciduous canopy trees in relation to meteorological conditions.* Agric. For. Meteorol., 117: 39–51.

MANDIWANA K.L., RESANE T., PANICHEV N., NGOBENI P. 2006. *The application of tree bark as bio-indicator for the assessment of Cr(VI) in air pollution.* J. Haz. Mater. B, 137: 1241–1245.

MOREIRA T.C.L., DE OLIVEIRA R.C., AMATO L.F.L., KANG C.M., SALDIVA P.H.N., SAIKI M. 2016. *Intra-urban biomonitoring: source apportionment using tree barks to identify air pollution sources.* Environ. Int., 91: 271–275.

OKLO D.A., ASEMAVE K. 2012. *Heavy metal contents of tree barks as indicator of pollution in Makurdi Metropolis, Benue State – Nigeria.* Int. J. Toxicol. Appl. Pharmacol., 2(4): 45–48.

PACHECO A.M.G., BARROS L.I.C., FREITAS M.C., REIS M.A., HIPÓLITO C., OLIVEIRA O.R. 2002. *An evaluation of olive-tree bark for the biological monitoring of airborne trace-elements at ground level.* Environ. Pollut., 120: 79–86.

POIKOLAINEN J. 2004. *Mosses, epiphytic lichens and tree bark as biomonitors for air pollutants – specifically for heavy metals in regional surveys.* Oulu, Oulu University Press.

PRYOR S.C., BARTHELMIE R.J. 2005. *Liquid and chemicalfluxes in precipitation, throughfall and stemflow: observations from a deciduous forest and a red pine plantation in the midwestern U.S.A.* Water Air Soil Pollut., 163: 203–227.

RAO D.H. 1982. *Responses of bryophytes to air pollution*. In: *Bryophyte ecology*. Ed. A.J.E. Smith, London, Chapman & Hall, pp. 445–471.

Raport z realizacji programu ochrony środowiska dla miasta Katowice za lata 2012–2013. 2014. ATMOTERM S.A., Katowice.

RASMUSSEN L. 1978. *Element content of epiphytic Hypnum cupressiforme related to element content of the bark of different species of phorophytes*. Lindbergia, 4: 209–218.

REIMANN C., HALLERAKER J.H., KASHULINA G., BOGATYREV I. 1999. *Comparison of plant and precipitation chemistry in catchments with different levels of pollution on the Kola Peninsula, Russia*. Sci. Total Environ., 243/244: 169–191.

ROBITAILLE G., LEBLANC F., RAO D.N. 1977. *Acid rain: a factor contributing to the paucity of epiphytic cryptogams in the vicinity of a copper smelter*. Rev. Bryol. Lichenol., 43: 53–66.

SAMECKA-CYMERMAN A., KOSIOR G., KEMPERS A.J. 2006. *Comparison of the moss Pleurozium schreberi with needles and bark of Pinus sylvestris*. Ecotoxicol. Environ. Saf., 65: 108–117.

SAWIDIS T., BREUSTE J., MITROVIC M., PAVLOVIC P., TSIGARIDAS K. 2011. *Trees as bioindicator of heavy metal pollution in three European cities*. Environ. Pollut., 159: 3560–3570.

SCHULTZ H., POPP P., HUHN G., STÄRK H.J., SCHÜÜRMANN G. 1999. *Biomonitoring of airborne inorganic and organic pollutants by means of pine tree barks*. I. *Temporal and spatial variations*. Sci. Total Environ., 232: 49–58.

SEAWARD M.R.D. 1979. *Lower plants and the urban landscape*. Urban Ecology, 4: 217–225.

SKŘIVAN P., RUSEK J., FOTTOVÁ, BURIAN M., MINAŘÍK L. 1995. *Factors affecting the content of heavy metals in bulk atmospheric precipitation, throughfall and stemflow in central Bohemia, Czech Republic*. Water Air Soil Pollut., 85: 841–846.

STEBEL A., FOJCIK B. 2016. *Changes in the epiphytic bryophyte flora in Katowice city (Poland)*. Cryptogamie, Bryologie, 37(4): 399–414.

SUN S.Q., WANG D.Y., HE M., ZHANG C. 2009. *Monitoring of atmospheric heavy metal deposition in Chongqing, China – based on moss bag technique*. Environ. Monit. Assess., 148: 1–9.

ŠKRBIĆ B., MILOVAC S., MATAVULJ M. 2012. *Multielement profiles of soil, road dust, tree bark and wood-rotten fungi collected at various distances from high-frequency road in urban area*. Ecol. Indic., 13: 168–177.

TRACZEWSKA T.M. 2011. *Biologiczne metody oceny skażenia środowiska*. Wrocław, Oficyna Wydawnicza Politechniki Wrocławskiej.

VANDERPOORTEN A., GOFFINET B. 2009. *Introduction to bryophytes*. Cambridge, Cambridge University Press.

WITTIG R.1986. *Acidification phenomena in beech (Fagus sylvatica) forests of Europe*. Water Air Soil Pollut., 47: 321–333.

XIAO Q., MCPHERSON E.G. 2011. *Rainfall interception of three trees in Oakland,* California. Urban Ecosyst., 14: 755–769.

ZECHMEISTER H.G., HOHENWALLNER D. 2006. *A comparison of biomonitoring methods for the estimation of atmospheric pollutants in an industrial town in Austria*. Environ. Monit. Assess., 117: 245–259.