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Epiphytic lichens and bryophytes as indicators of air pollution in Kyiv city (Ukraine)

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Abstract: The distribution of epiphytic lichens and bryophytes was studied in the built-up area of Kyiv (Ukraine). 65 epiphytic lichen and 20 bryophyte species were found in 272 sampling plots. Three indices (the total number of species, the index of atmospheric purity and the modified index of atmospheric purity) were calculated separately for lichens and bryophytes, and for all epiphytic species. A total of nine indices were quantified. Based on these indices, four zones with different air pollution were distinguished in Kyiv. Indicator species of these zones were proposed and can be used for further monitoring. Indicative value of lichens and bryophytes was compared.

Kokkuvõte: Epifüütsed samblikud ja samblad kui õhu saastatuse indikaatorid Kiievis (Ukraina).

Uuriti epifüütsete samblike ja sammalde levikut Kiievi tiheasustusaladel. 272 analüüsialal leiti 65 epifüütse sambliku ja 20 sambla liiki. Arvutati kolme indeksi (liikide üldarv, õhu puhtuse indeks ja õhu puhtuse modifitseeritud indeks) väärtused eraldi samblike ja sammalde kohta, aga ka kõikide epifüütide kohta kokku. Nende indeksite põhjal eristati Kiievis neli õhu saastatuse tsooni. Määratleti nende tsoonide indikaatorliigid, mida on võimalik edaspidises seires kasutada. Võrreldi samblike ja sammalde indikatsioonilist väärtust.

INTRODUCTION

The impact of air pollution on lichen and bryophyte distribution in Kyiv city has not hitherto been investigated. Only four lichen and eight bryophyte species were previously recorded in the built-up area of this city. The most investigated area is the suburban forests of Kyiv where 141 lichens and 241 bryophytes have been found (Kondratyuk et al., 2006).

Epiphytic lichens and bryophytes are well known as indicators of air pollution and widely used to assess air quality (Nimis et al., 2002; Giordani, 2007). In Ukraine lichen mapping studies have been carried out in many cities, for example Lviv (Kondratyuk et al., 1991), Ivano-Frankivsk, Lutsk, Rivne, Ternopil (Kondratyuk et al., 1993), Kherson (Khodosovtsev, 1995), Chernigiv (Zelenko, 1999), Kremenchuk (Nekrasenko & Bairak, 2002) and Poltava (Dymytrova, 2008). To evaluate air quality in these cities an index of atmospheric purity (IAP) (Leblanc & De Sloover, 1970) and a modified index of atmospheric purity (IAPm) (Kondratyuk, 1994) based on a quantitative assessment of abundance and species coverage were used. Bryophyte mapping based on IAP was carried out only in Lviv (Mamchur, 2005).

According to previous investigations the coverage and the frequency of species are very important variables, and indices based on these parameters are highly correlated with air pollution levels (Leblanc & De Sloover, 1970; Pirinitos et al., 1993; Biazrov, 2002; Nimis et al., 2002). However, it has been suggested that the total number of species per sampling plot is sufficiently informative and, consequently, quantitative assessment of the coverage and of the frequency of species is unnecessary (Herben & Liska, 1986; Geebelen & Hoffman, 2001). Another study established that indices based only on corticolous lichens gave a higher correlation with air pollution than all epiphytes, especially with concentrations of SO_2 (Geebelen & Hoffman, 2001).

The aim of the current study was 1) to investigate epiphytic lichen and bryophyte diversity in the built-up area of Kyiv; 2) to assess air quality in Kyiv using epiphytic lichens and bryophytes and 3) to compare the value of lichens and bryophytes as indicators of air pollution.

MATERIALS AND METHODS

Study area

Kyiv city is the capital of Ukraine and the biggest industrial and transport centre. It is about 839 km^2 with a population of 2.7 million people (Ecological passport of Kyiv, 2007). According to informal data the population of Kyiv includes up to 5 million people (www.stolitsa.glavred.info). The river Dnipro divides Kyiv into high steep right-bank and flat left-bank parts. The city is situated at the intersection of broad leaved forest and forest-steppe zones of Ukraine. Forest and other green plantations comprise 41% of the total Kyiv area (Ecological passport of Kyiv, 2007). The location is characterized by a moderately continental climate with relatively soft winters and hot summers. The mean annual temperature is 7°C, mean monthly temperatures varied from -6 °C in January to 19.6 °C in July. The annual rainfall is 495–610 mm. Western and north-western winds are predominant (Sakali, 1980).

Emissions from industry and from vehicles influence air quality in Kyiv. Vehicles represent the principal source of air pollution in Kyiv with the annual emission in 2007 corresponding to more than 83% of the total amount of emissions. The second biggest pollution source is factories (there are 418 factories in Kyiv emissions of which are considered polluting), especially in the power industry. Annual emission of power industry in 2007 comprised about 19 500 tonnes (Ecological passport of Kyiv, 2007). One power plant is situated in the south of right-bank part of Kyiv near Dnipro; the others are situated in different parts of left-bank area. The principal pollutant of power plants is SO_2 whose emissions increased from 1000 tonnes in 2005 to 1400 tonnes in 2007. Over the last five years NO_2 emissions increased in line with the increase of vehicles (Ecological passport of Kyiv, 2007).

Field work

Field work was carried out over the period 2006–2008. Epiphytic vegetation was investigated on isolated trees with a diameter >30 cm. In each sampling plot at least five trees were monitored. The most common tree species in the study area are *Tilia cordata* Mill. and *Acer platanoides* L. (Ecological passport of Kyiv, 2007) which were chosen as phorophytes to reduce the influence of bark related variables. To assess lichen and bryophyte diversity in the built-up area of Kyiv, other trees species were investigated as well, e.g. *Populus* spp., *Acer saccharinum* L., *Quercus robur* L., *Q. rubra* L., *Aesculus hippocastanum* L., *Fraxinus excelsior* L., *Betula pendula* Roth., *Pinus sylvestris* L. and *Ulmus* spp., however, these trees were excluded from the calculation of IAP and IAPm (see below). A total of 1730 trees were selected and 272 sampling plots were investigated in different parts of Kyiv (Fig. 1). According to the different human use four zones were distinguished in Kyiv: industrial area, residential area, roads (trees along the streets) and inner parks. Outer parks belonging to suburban forests of city were omitted from this study. Nomenclature of lichens follows Kondratyuk et al. (1998, 2003) and of bryophytes Boiko (2008).

All species were recorded on the trunk of each tree from the base up to 1.5 m above ground level in every sampling plot. The coverage and the abundance of each species were assessed using two approaches. The first approach was based on a five-point scale of Leblanc and De Sloover (1970) combining both these parameters. The second approach evaluated the coverage (a_{ij}) of each species according to a four-point scale: 1 – coverage does not exceed 1%, 2 – 1–20%, 3 – 21–50% and 4 – 51–100%. The species abundance (b_{ij}) was recorded as the occurrence for each coverage class (Kondratyuk, 1994).

Data analysis

The relationship between the epiphytic community composition and environmental variables was assessed using correspondence analysis. We applied the matrix species × sampling plots excluding from the analysis the species with the frequency <1%. Pearson's correlation coefficient was used to evaluate the correlation between different indices and between these indices and a gradient of air pollution. Clustering analysis by group average as a hierarchical classification method was applied to establish the relation between all indices. From the analysis of a difference between epiphytic species richness and tree species, four tree species (*Pinus sylvestris, Quercus rubra, Fraxinus excelsior* and *Ulmus* spp.) which were represented by less than ten tree individuals were excluded. All obtained data were analyzed using Statistica version 6, (StatSoft, Inc. 2001).

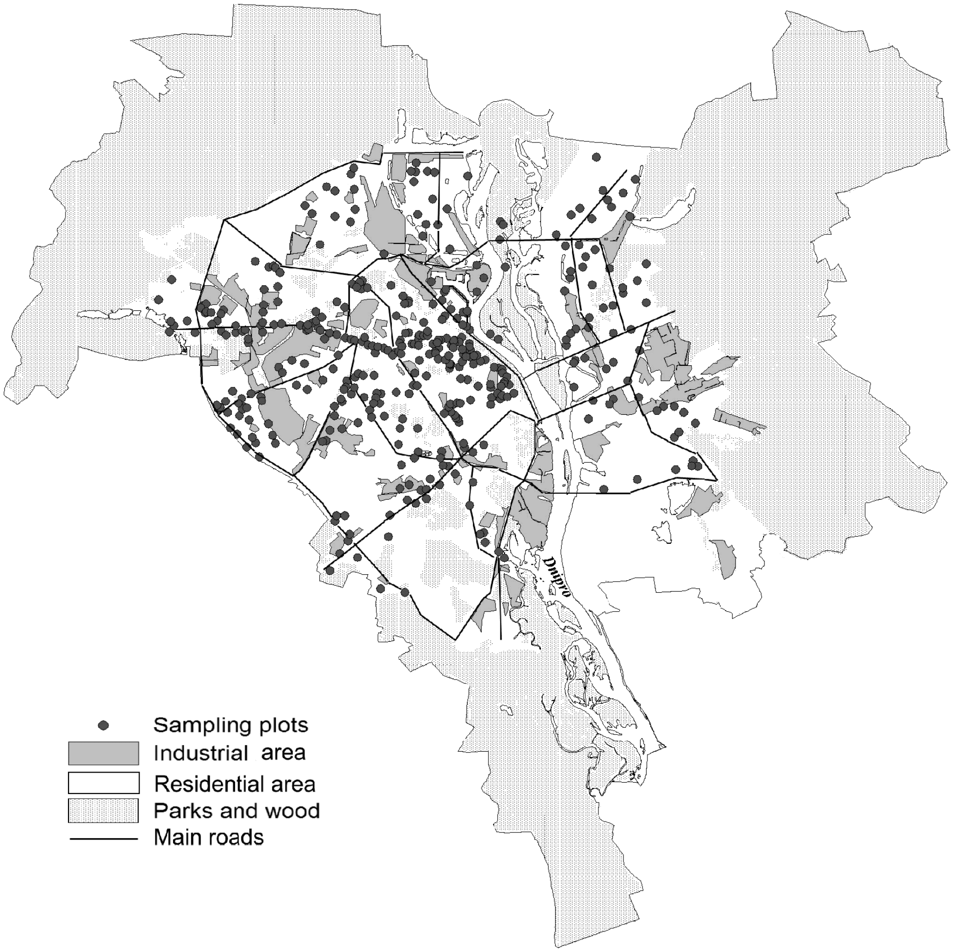

Fig. 1. Location of 272 sampling plots in the built–up area of Kyiv.

To assess air pollution in Kyiv three indices, the total number of species (N), the index of atmospheric purity (IAP) (Leblanc & De Sloover, 1970) and the modified index of atmospheric purity (IAPm) (Kondratyuk, 1994) were used:

$$N = \sum_{i}^{n} n,$$

$$IAP = \frac{1}{10}\sum_{i}^{n} Q_i \times f_i,$$

$$IAPm = \sum_{i}^{n} \frac{Q_i}{10} \sum_{j}^{m} \frac{a_{ij} \times b_{ij}}{m},$$

where n is the total number of species per the sampling plot, Q_i is the ecological index (average number of accompanying species), f_i is the combined index of the coverage and the frequency, a_{ij} indicates the coverage class of «i» species, b_{ij} is the occurrence of species with the coverage of «j» class and m is number of the coverage classes of «i» species.

These indices were calculated separately for lichens (L) and bryophytes (B), and for all epiphytic species (E), thus altogether nine indices were calculated. Results are demonstrated on the maps where the zones of different air pollution are distinguished. Based on lichen and epiphyte indices four zones of different pollution level were distinguished: highly, moderately, slightly polluted and unpolluted. Based on bryophyte data only two zones were identified: polluted and unpolluted. Maps were generated using the package MapInfo Professional 7.0 SCP.

RESULTS

A total of 65 lichen and 20 bryophyte species were found in the built-up area of Kyiv (Table 1).

The most common lichen species (>193 records) were *Phaeophyscia orbicularis*, *P. nigricans*, *Physcia adscendens*, *P. tenella*, *Xanthoria parietina* and *X. polycarpa,* and bryophyte species

Table 1. Frequency of recorded epiphytic lichen and bryophyte species in different areas of Kyiv

	Industrial area	Residential area	Trees along the streets	Inner parks	Total frequency (%)
Number of sampling plots	18	33	123	97	
Total number species	32	41	54	85	
Number of lichen species	25	30	43	65	
Number of bryophyte species	7	11	11	20	
Lichen species					
Amandinea punctata (Hoffm.) Coppins & Scheid.	3	11	37	15	34.3
Caloplaca cerina (Ehrh. ex Hedwig) Th. Fr.		2	3	3	3.0
C. decipiens (Arnold) Blomb. & Forssell	1		3	1	1.8
C. pyracea (Ach.) Th. Fr.	4	2	7	14	10.0
Candelaria concolor (Dicks.) Stein			2	0	0.7
C. vitellina (Hoffm.) Müll. Arg.	9	7	43	8	34.7
C. xanthostigma (Ach.) Lettau	3	5	25	7	21.4
Cladonia coniocraea (Flörke) Spreng.	1			5	2.2
C. fimbriata (L.) Fr.				3	1.1
Evernia prunastri (L.) Ach.		5	15	32	19.2
Flavoparmelia caperata (L.) Hale				1	0.4
Hypocenomyce scalaris (Ach. ex Lilj.) M. Choisy			2	7	3.3
Hypogymnia physodes (L.) Nyl.		6	12	36	20.3
H. tubulosa (Schaer.) Hav.				3	1.1
Lecania cyrtella (Ach.) Th. Fr.				3	1.1
L. koerberiana Lahm			1	0	0.4
L. naegeli (Hepp) Diederich & P. Boom				4	1.5
Lecanora carpinea (L.) Vainio	1	4	5	10	7.4
L. chlarotera Nyl.			1	3	1.5
L. conizeaiodes Nyl. ex Cromb.			5	2	2.6
L. expallens Ach.				1	0.4
L. hagenii (Ach.) Ach.	3	1	15	6	12.5
L. pulicaris (Pers.) Ach.			1	4	1.8
L. saligna (Schrad.) Zahlbr.	3	5	1	19	13.7
L. sambuci (Pers.) Nyl.				1	0.4
L. symmicta (Ach.) Ach.	1	2	1	6	3.7
L. varia (Hoffm.) Ach.				1	0.4
Lecidella elaeochroma (Ach.) M. Choisy				1	0.4
Lepraria incana (L.) Ach.				1	0.4
Melanelia exasperata (De Not.) Essl.		1	1	2	1.5
M. exasperatula (Nyl.) Essl.	2	9	26	14	25.5
M. fuliginosa (Fr. ex Duby) Essl.			2	9	4.1
M. subaurifera (Nyl.) Essl.	2	1	7	21	11.4
Oxneria fallax (Hepp) S. Kondr. & Kärnefelt			1	2	1.1
Parmelia sulcata Taylor	7	21	73	71	63.5
Parmelina tiliacea (Hoffm.) Hale		2	4	11	6.3
Phaeophyscia nigricans (Flörke) Moberg	15	23	93	50	73.4
P. orbicularis (Neck.) Moberg	19	33	122	95	99.3

Table 1(continued)

	Industrial area	Residential area	Trees along the streets	Inner parks	Total frequency (%)
Physcia adscendens (Fr.) H. Olivier	16	28	98	85	83.8
P. aipolia (Ehrh. ex Humb.) Furnr.				2	1.1
P. caesia (Hoffm.) Furnr.			1	1	0.7
P. dubia (Hoffm.) Lettau	2	1	3	10	5.9
P. stellaris (L.) Nyl.	9	22	64	54	55.0
P. tenella (Scop.) DC	1	24	78	82	71.6
Physconia detersa (Nyl.) Poelt		1		1	0.7
P. enteroxantha (Nyl.) Poelt		3	7	17	10.0
P. grisea (Lam.) Poelt	1		5	11	6.3
Pleurosticta acetabulum (Neck.) Elix & Lumbsch.	1	2	2	7	4.4
Pseudevernia furfuracea (L.) Zopf.				4	1.5
Punctelia subrudecta (Nyl.) Krog				1	0.4
Ramalina farinacea (L.) Ach.				1	0.4
R. pollinaria (Westr.) Ach.				1	0.4
Rinodina pyrina (Ach.) Arnold	2	2	9	5	5.2
R. sophodes (Ach.) A. Massal.				1	0.4
Scoliciosporum chlorococcum (Stenh.) Vězda	1	2	9	7	7.0
Strangospora moriformis (Ach.) Stein				1	0.4
S. pinicola (A. Massal.) Körb.			2	3	1.8
Tuckermannopsis chlorophylla (Willd.) Hale				2	0.7
T. sepincola (Ehrh.) Hale				2	0.7
Usnea hirta (L.) Weber ex F. H. Wigg.				7	2.6
Vulpicida pinastri (Scop.) J.–E. Mattson & M.–J. Lai				2	0.4
Xanthoria candelaria (L.) Th. Fr.			1	3	1.5
X. parietina (L.) Th. Fr.	16	28	14	71	80.8
X. polycarpa (Hoffm.) Rieber	15	24	8	74	71.2
X. ucrainica S. Kondr.		1	4	3	3.0
Bryophyte species					
Amblystegium serpens **(Hedw.) Schimp.**	1	2	2	5	3.7
Brachytheciastrum velutinum **(Hedw.) Ignatov & Huttenen**		1	1		0.4
Brachythecium salebrosum (Hoffm. ex F. Weber & Mohr) Schimp.			1		0.7
Bryum argenteum Hedw.	2	1	8	5	5.9
B. capillare Hedw.	1		1	2	1.5
B. ***pallens*** Sw.				1	0.4
Ceratodon purpureus (Hedw.) Brid.	3	1	8	15	10.0
Dicranum scoparium Hedw.				1	0.4
Grimmia pulvinata (Hedw.) Sm.			1		0.4
Hygroamblystegium varium (Hedw.) Mönk.		1			0.4
Hypnum cupressiforme Hedw.				4	1.5
Leskea polycarpa Hedw.	4	9	26	14	17.7
Leucodon sciuroides (Hedw.) Schwaegr.				1	0.4
Orthotrichum diaphanum Schrad. ex Brid.		1			0.4
O. pumilum Sw.	12	15	53	55	49.8
O. ***speciosum*** Nees		1	5	14	7.4
Pohlia nutans (Hedw.) Lindb.				1	0.4
Pylaisia polyantha (Hedw.) Schimp.	5	9	24	42	29.5
Radula complanata (L.) Dumort.		1	1		0.7
Syntrichia ruralis (Hedw.) F. Weber & Mohr				1	0.4

were *Orthotrichum pumilum* (135 records) and *Pylaisia polyantha* (80 records). 64.4% of the total number of epiphytes were species with a low frequency (< 5%). Some of them were found only in one sampling plot.

The coverage of epiphytes on different tree species and in different sampling plots varied significantly. However, species with high frequency had also high coverage. For example, the most frequent lichen *Phaeophyscia orbicularis* had the coverage over 20% in 145 sampling plots while the coverage of rare epiphytes (with the frequency about 1%) did not exceed 1%. The high coverage (51–100%) of crustose lichens *Candelariella vitellina*, *Lecanora hagenii* and bryophytes *Bryum argenteum*, *Ceratodon purpureus* was recorded on trees along the streets.

The highest richness of epiphytic species (mean 14.2 and mean 11.6) as well as the highest richness of lichen species (mean 11.7 and 10.6) was found on *Quercus robur* and on *Betula pendula,* accordingly. On the other hand, the highest richness of bryophyte species was observed on *Quercus robur* (mean 2.5) and *Populus* spp. (mean 2.3) (Fig. 2). The highest number of lichens was recorded on the bark of *Tilia cordata* (50 species) and bryophytes on *Populus* spp. (16). On bark of trees along the streets and the roads with heavy traffic or near factories typically epilithic lichens *Caloplaca decipiens, Physcia caesia* and bryophyte *Grimmia pulvinata* were found. Several bryophytes, usually common on soil, were recorded in Kyiv on tree trunks: *Bryum argenteum* (16 records), *B. capillare* (4 records) and *Ceratodon purpureus* (27 records).

As expected, the highest epiphytic richness was recorded in the inner parks (85 species) while in the industrial area only 32 epiphytic species were found. The total number of lichen species in the residential area (30) was less than on trees along the streets (43) but the total number of bryophyte species was equal in both areas (11 species).

Results of the correspondence analysis of the epiphytic species composition on trees are presented on Fig. 3. The first axis explains 33.0% and the second axis includes 7.3% of the total variation in community composition. High values on the first axis are occupied by lichen species which are tolerant to air pollution, such as *Candelariella vitellina, Phaeophyscia*

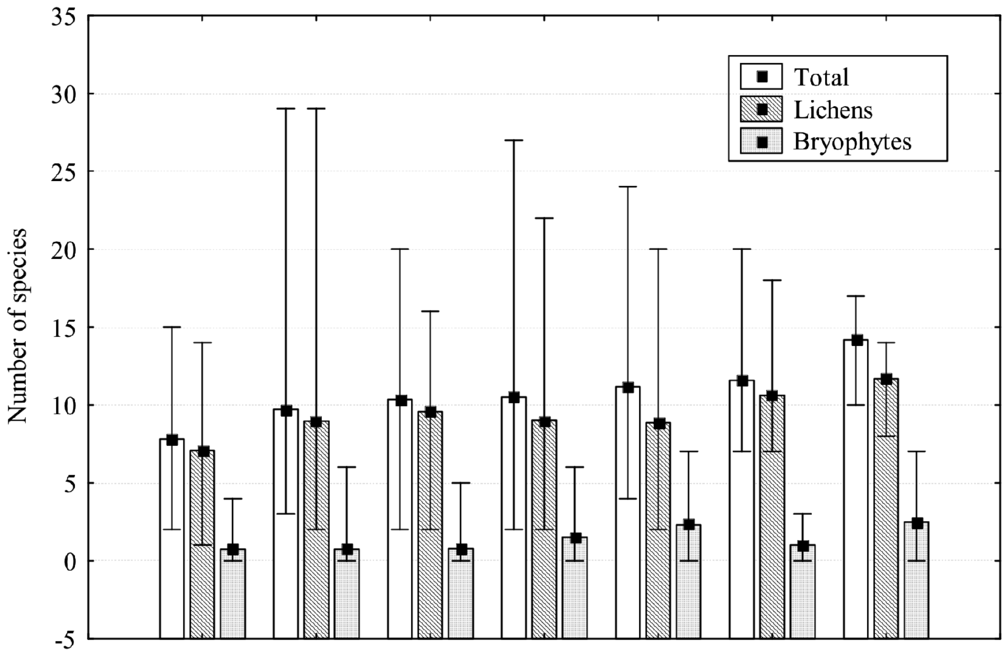

Fig. 2. Species richness of epiphytic lichens and bryophytes on different tree species (box: standard error; spot: mean species number; whisker: minimum and maximum values).

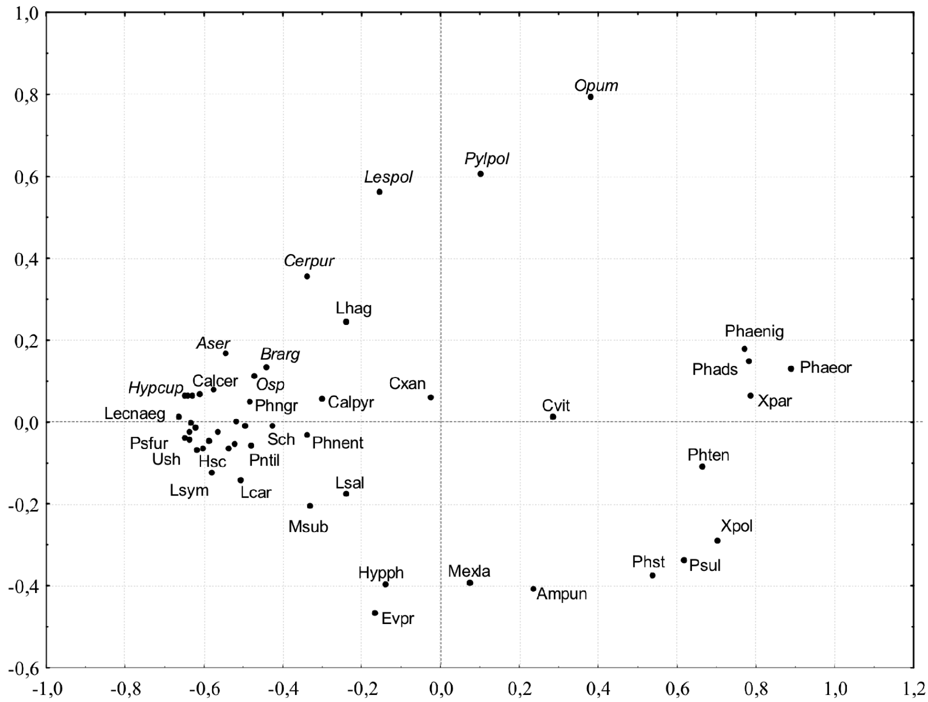

Fig. 3. Epiphytic species ordination using correspondence analysis. The first axis explains 33.0% and the second axis 7.3% of the total variation in community composition. Only species with the frequency > 1% are shown. Bryophyte species are italicized. Species abbreviations: Ampun – *Amandinea punctata. Aser – Amblystegium serpens. Brarg – Bryum argenteum.* Calcer – *Caloplaca cerina.* Calpyr – *C. pyracea.* Cvit – *Candelariella vitellina.* Cxan – *C. xanthostigma. Cerpur – Ceratodon purpureus.* Evpr – *Evernia prunastri.* Hsc – *Hypocenomyce scalaris. Hypcup – Hypnum cupressiforme.* Hypph – *Hypogymnia physodes.* Lecnaeg – *Lecania naegeli.* Lcar – *Lecanora carpinea.* Lhag – *L. hagenii.* Lsal – *L. saligna.* Lsym – *L. symmicta. Lespol – Leskea polycarpa.* Mexla – *Melanelia exasperatula.* Msub – *M. subaurifera. Opum – Orthotrichum pumilum. Osp – O. speciosum.* Psul – *Parmelia sulcata.* Pntil – *Parmelina tiliacea.* Phaenig – *Phaeophyscia nigricans.* Phaeor – *Ph. orbicularis.* Phads – *Physcia adscendens.* Phst – *Ph. stellaris.* Phten – *Ph. tenella.* Phnent – *Physconia enteroxantha.* Phngr – *Ph. grisea.* Psfur – *Pseudevernia furfuracea. Pylpol – Pylaisia polyantha.* Sch – *Scoliciosporum chlorococcum.* Ush – *Usnea hirta.* Xpar – *Xanthoria parietina.* Xpol – *X. polycarpa.*

orbicularis, *P. nigricans*, *Physcia adscendens* and *Xanthoria parietina.* They mainly grew on trees with eutrophicated bark. Lichen species which are relatively sensitive to air pollution, e.g. *Evernia prunastri, Hypogymnia physodes, Melanelia exasperatula, M. subaurifera, Pseudevernia furfuracea* and *Usnea hirta,* were characterized by low values. Bryophytes such as *Bryum argenteum, Ceratodon purpureus, Leskea polycarpa, Orthotrichum pumilum* and *Pylaisia polyantha* are located at the positive extreme of the second axis. These species were common in the investigated area especially on eutrophicated bark of *Populus* spp. which grew along the streets and the roads. Thus, the first axis reflects a gradient from sampling plots with polluted air (positive values) to sampling plots with pure air (negative values) (Nimis, 1989; Pirintsos et al., 1993). The second axis separates the trees with neutral bark on which nitrophilous species e.g. *Phaeophyscia orbicularis, P. nigricans, Physcia adscendens* and *Xanthoria parietina* (Davies et al., 2007) were often found from the trees with acid bark where such acidophytic species as *Hypocenomyce scalaris, Pseudevernia furfuracea* and *Usnea hirta* (Davies et al., 2007) were recorded.

Three clusters of indices were identified by correlation coefficient (Fig. 4). Cluster 1 includes indices which were calculated using only bryophyte species. Cluster 2A includes indices which used the total number of lichens (or epiphytes) or the combined index f_i of lichens (or epiphytes). In cluster 2B indices IAPm-L and IAPm-E based on a quantitative evaluation of the species coverage and the abundance gave the highest correlation with the location of polluting factories.

The zones of different air pollution level in Kyiv based on IAPm-L have been distinguished

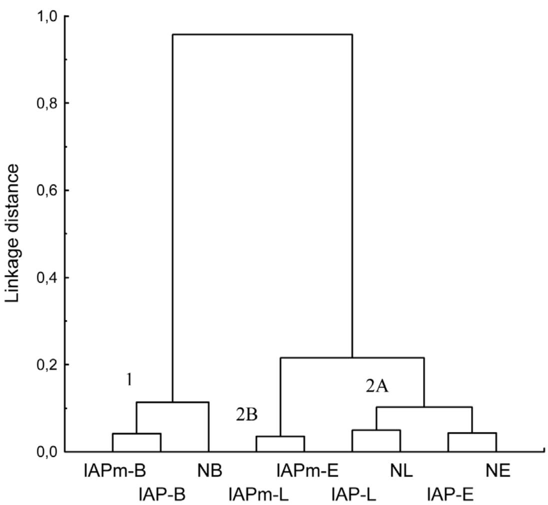

Fig. 4. Similarity of indices by Pearson's correlation coefficient.

(Table 2, Fig. 5). In the highly polluted zone situated in the centre of city and near large industrial plants less than four lichen species per sampling plot were recorded. Only the most tolerant to air pollution and the most frequent in Kyiv lichens such as *Phaeophyscia orbicularis*, *P. nigricans*, *Physcia adscendens*, *P. tenella, Xanthoria parietina* and *X. polycarpa* were found there. Indicators of the moderately polluted zone are *Amandinea punctata*, *Candelariella vitellina*, *C. xanthostigma*, *Lecanora saligna*, *L. hagenii, Melanelia exasperatula*, *Parmelia sulcata* and *Physcia stellaris.* The total number of lichen species in a sampling plot of this zone varied from 5 to 8. The slightly polluted zone is characterized by the occurrence of *Evernia prunastri*, *Hypogymnia physodes*, *Melanelia subaurifera, Parmelina tiliacea* and *Pleurosticta acetabulum,* and by the increase of the number of lichen species to 12. Many rare and very sensitive to air pollution lichen species, e.g. *Hypogymnia tubulosa*, *Lecania cyrtella*, *L. naegeli, Melanelia exasperata*, *Pseudevernia furfuracea*, *Ramalina farinacea, Strangospora pinicola*, *Tuckermannopsis sepincola*, *Usnea hirta* and *Vulpicida pinastri* were found in sampling plots of this zone. The highest diversity of lichen species per sampling plot in the unpolluted zone was found on *Tilia cordata* in the park situated on Dnipro's island (29 species). The maximum number of lichens in a sampling plot in other inner parks was 22. The unpolluted zone mainly occurs in inner parks near suburban forests of Kyiv.

The zones of different air pollution level in Kyiv based on IAPm-B have also been distinguished (Table 2, Fig. 6). Based on the data of bryophytes only two zones were separated. The polluted zone includes areas with new buildings in the west and in the south of Kyiv, and in the north along banks of Dnipro where trees are absent or are very young (ca 5–10 years old). Bryophytes which are tolerant to the urbanized environment, e.g. *Bryum argenteum*, *Ceratodon purpureus, Leskea polycarpa*, *Orthotrichum pumilum* and *Pylaisia polyantha,* were listed there. In sampling plots of the polluted zone only 1 or 4 bryophyte species were recorded. Epiphytic bryophytes were totally absent in 127 sampling plots. In the unpolluted zone which occurs mainly in inner parks, Dnipro's islands and areas nearby suburban forests additional bryophyte species, e.g. *Dicranum scoparium, Leucodon sciuroides*, *Orthotrichum diaphanum, Pohlia nutans* and *Radula complanata,* were recorded. They can be considered sensitive to the urbanized environment. The number of bryophytes per sampling plot in this unpolluted zone varied from 5 to 7 species.

DISCUSSION

As expected, the diversity of epiphytic lichen and bryophyte species in the built-up area of Kyiv is not very high. However, the number of lichen species in the same sampling plots in different parts of the investigated area was considerably higher than the number of bryophyte species. In comparison with other Ukrainian cities where studies on lichen indication have been carried out (Kondratyuk et al., 1991; Kondratyuk et al., 1993; Khodosovtsev, 1995; Zelenko, 1999;

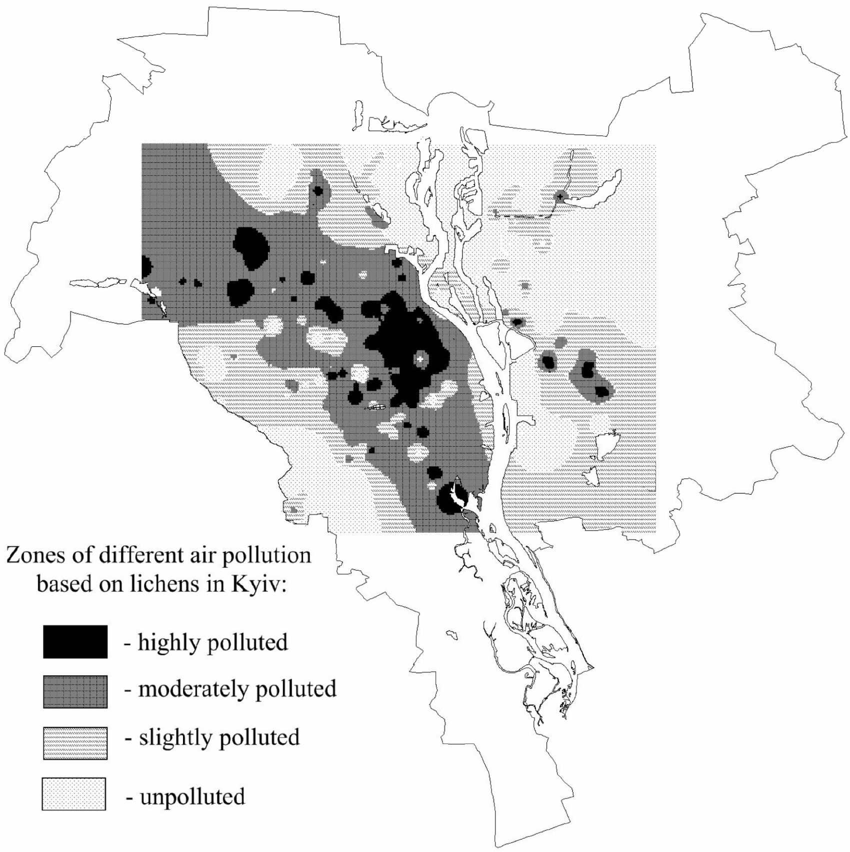

Fig. 5. Zones of different air pollution level based on lichens in Kyiv according to IAPm–L.

Table 2. Characteristics of zones of different air pollution level in Kyiv

Zones based on lichens	IAPm–L	IAP–L	NL	Mean number of lichen species
Highly polluted	0–8.6	1.6–6.0	1–4	3.6
Moderately polluted	8.7–25.5	6.1–15.6	5–8	7.3
Slightly polluted	25.6–42.5	15.7–25.2	9–12	10.9
Unpolluted	42.6–173.8	25.3–82.0	13–29	16.0
Zones based on epiphytes	IAPm–E	IAP–E	NE	Mean number of epiphytic species
Highly polluted	0–12.4	0–8.5	1–5	3.9
Moderately polluted	12.5–32.3	8.6–20.2	6–9	7.7
Slightly polluted	32.4–52.3	20.3–31.9	10–14	11.5
Unpolluted	52.3–189.3	32.0–88.8	15–29	19.3
Zones based on bryophytes	IAPm–B	IAP–B	NB	Mean number of bryophyte species
Polluted	0.1–2.2	0.1–0.3	1–4	2.1
Unpolluted	2.3–5.2	0.4–3.6	> 5	5.6

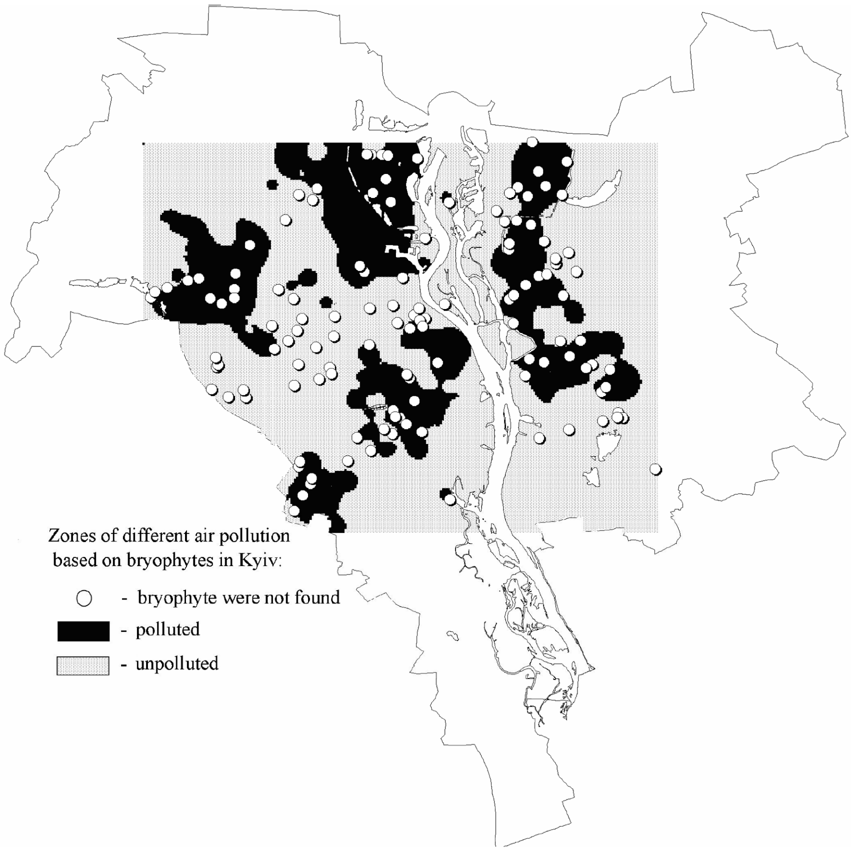

Fig. 6. Zones of different air pollution level based on bryophytes in Kyiv according to IAPm–B.

Nekrasenko & Bairak, 2002; Dymytrova, 2008), the highest diversity of epiphytic lichens was recorded in Kyiv. For example, the poorest epiphytic lichen flora (35 species) was determined in Kremenchuk (Nekrasenko & Bairak, 2002) where many heavy engineering plants and the petroleum refinery are located. In other Ukrainian cities where both suburban forests and the built-up area have been investigated and all available tree species have been monitored, only 35–60 epiphytic lichen species have been recorded, e.g. 38 species in Kherson (Khodosovtsev, 1995), 48 in Lviv (Kondratyuk et al., 1991) and 56 in Chernigiv (Zelenko, 1999). The richness of epiphytic lichen flora of Kyiv could be explained by a special location of this city at the intersection of broad leaved forests and the forest-steppe zone of Ukraine. Furthermore, Kyiv is the biggest city in Ukraine and the study area of the present project was bigger than in other similar studies.

The distribution of epiphytes in Kyiv as it has been pointed out also in several other studies (Marmor & Randlane, 2007; Mežaka et al., 2008), depends on the species of phorophytes. The most common tree species in the built-up area of Kyiv *Tilia cordata* (650 investigated trees), *Acer platanoides* (445) and *Populus* spp. (324) are characterized by the highest numbers of epiphytic species: 60, 53 and 59 species accordingly. Epiphytic diversity was lower on phorophytes which mainly occur in inner parks of Kyiv, *Quercus robur* (32 species) and *Betula pendula* (30). However, the number of these trees in our study was also low, i.e. 37 and 24 trees accordingly.

The lichens and bryophytes growing on trees along the streets and the roads with heavy traffic may indicate that tree bark was heavily polluted by dust (Fudali, 2006; Davies, 2007; Liška & Herben, 2008). It explains the occurrence of some epilithic lichens (*Caloplaca decipiens* and *Physcia caesia*) and a bryophyte (*Grimmia pulvinata*) on tree bark. Some bryophytes typically presented on soil, e.g. *Bryum argenteum, B. capillare* and *Ceratodon purpureus,* grew on trunks affected by dust. The conclusion is that tree bark and the atmospheric air in Kyiv are evidently strongly dusted because of the increasing number of vehicles.

Results of bioindication studies based on NL, IAP-L and IAPm-L showed that zones with the polluted air depend strongly on a location of factories and plants as well as on the position of main roads with heavy traffic. The unpolluted zone is situated mainly near suburban forests of Kyiv and includes the inner parks. However, it was established that the zones distinguished using bryophytes did not coincide with the location of industrial plants. As a result, these zones did not correlate with the zones distinguished using lichens. The polluted zone according to the bryophytes corresponds to the areas of new buildings with young trees while the unpolluted zone is situated in Dnipro's islands and in the inner parks nearby suburban forests. It appeared that epiphytic bryophyte richness and the distribution of bryophytes in Kyiv was determined by local environmental features, mainly presence of old trees and parks without considerable disturbance. According to previous studies (Mamchur, 2005; Fudali, 2006; Mežaka et al., 2008), the main factor determining the epiphytic bryophyte richness was the age of tree.

Zones of different pollution level based on epiphytes are similar to the ones defined using epiphytic lichens only. The minor difference between these zones is explained by the distribution of epiphytic bryophytes. Thus, the best indicators of the air pollution in Kyiv are epiphytic lichens. This is also confirmed by the comparison of indices (Fig. 4). The indices based on lichen data (r IAPm-L = -0.80; r IAP-L = -0.76 and r NL = -0.64, $p > 0.05$) as well as epiphytic indices (r IAPm-E = -0.74; r IAP-E = -0.66 and r NE = -0.56, $p > 0.05$) correlate strongly with the values of the first axis which presents the gradient of air pollution. The indices based on bryophyte data were not significant at 5%-level. When comparing the indices, the following ranking can be made according to higher correlation: IAPm > IAP > N

Therefore, the indices, based on a quantitative assessment of the coverage and the frequency of each epiphytic species correlate with the gradient of air pollution better than the number of epiphytic species. To assess the air pollution in Kyiv, we recommend using the modified index of atmospheric purity (IAPm).

Conclusions

To estimate the air pollution in Kyiv we recommend using only the corticolous lichens and the modified index of atmospheric purity (IAPm). Indicator species of epiphytic lichens for zones with different air quality were proposed and can be used for further monitoring. It was established that air pollution in Kyiv was influenced by factories (especially power and construction industries) and exhaust fumes of vehicles.

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