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FIRST DATA ON BRYOINDICATION MAPPING OF SMALL TOWNS OF UKRAINE

Yu. V. Gapon[1], S. Y. Kondratyuk[2] and S. V. Gapon[3]

[1]*Poltava Higher Interregional School State Educational Institution*
M. Biryuzova str. 64a, 36007 Poltava, Ukraine
[2]*M. H. Kholodny Institute of BotanyTereshchenkivska str. 2, 01004 Kyiv-4, Ukraine*
E-mail: ksya_net@ukr.net; corresponding author
[3]*Poltava V. G. Korolenko National Pedagogical University*
2, Ostrogradski Street, 36000 Poltava, Ukraine

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Results of bryoindication mapping based on calculation of an index of atmospheric purity (IAP) of towns of the Left Bank Ukraine, i.e. the smallest Romny (Sumy oblast) and Myrhorod (Poltava oblast) towns, small Pryluky (Chernihiv oblast) and Lubny (Poltava oblast) towns as well as medium size Poltava town (Poltava oblast), are provided. It is found that isotoxic bryoindication zones of moderately polluted air are predominate and often forming entire areas in the centre / industrial / densely built-up areas of Poltava, Lubny and Pryluky towns while isotoxic zones with slightly polluted or unpolluted air are predominant or more widely distributed in smaller towns Romny and Myrhorod. Correlation of data on species diversity, community composition of bryophytes as well as data of the IAP zoning of the territory of all towns mentioned as well as natural conditions of their territory and anthropogenic pressure is discussed.

Key words: bryophyte, communities, index of atmospheric purity, Left Bank of Dnipro River, species richness, zoning

INTRODUCTION

Various approaches and models for environmental assessment, particularly air quality assessment, such as sampling of bulk, dry, or wet deposition, and the measurement of living organisms including insects, birds, cryptogams (bryophytes and lichens), angiospermous leaves and barks, or gymnospermous needles, have been applied (Ćujić *et al.* 2016, Jiang *et al.* 2020, Stankovic *et al.* 2014). Bryophytes are popular indicator/monitor plants because they cause fewer technical and analytical problems than lichens or tree bark (Jiang *et al.* 2020, Pesch and Schroeder 2006, Szczepaniak and Biziuk 2003, Xu *et al.* 2018). The investigation of naturally growing bryophytes in specific regions is appropriate for extensive monitoring studies (Gao and Cao 1992, Gilbert 1968, Greven 1992, Jiang *et al.* 2020, Maxhuni *et al.* 2016, Qarri *et al.* 2019, Taoda 1973) and for understanding the responses of bryophytes to atmospheric environmental heterogeneity (Jiang *et al.* 2020, Wang *et al.* 2015, Zechmeister *et al.* 2003). When using naturally growing bryophytes as biomonitors, either the composition and structure of bryophyte communities (species richness, coverage, and life forms) and the development of certain bryophytes is considered (Jiang *et al.* 2020, Oishi and Hiura 2017, Zechmeister *et al.* 2003). The IAP method was used in a large number of investigation all over the world (e.g. Inui and Yamaguchi 1996, Palmieri *et al.* 1997, Sergio 1987, Zechmeister *et al.* 2002*a*, 2003).

In recent decades, naturally growing mosses have been used successfully as biomonitors of atmospheric deposition of heavy metals and nitrogen (Gombert *et al.* 2002, 2003, 2004, Harmens *et al.* 2015, Holy *et al.* 2010, Komisar and Boiko 2013, Maevskaya *et al.* 2001, Schröder *et al.* 2010, Stanković *et al.* 2018).

Epiphytic lichens and bryophytes are well known as indicators of air pollution and widely used to assess air quality (Giordani 2007, Nimis *et al.* 2002, Türk and Wirth 1975). 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), Chernihiv (Zelenko 1999), Kremenchuk (Nekrasenko and Bairak 2002), Poltava and Kyiv (Dymytrova 2008, 2009). To evaluate air quality in these cities an index of atmospheric purity (IAP) (LeBlanc and 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 within those studies. It should be stressed that small towns of Ukraine have been included in lichen indication exploring only during the last decade (Klymenko 2015, 2016, Litovynska 2016, Shershova 2016).

Bryophyte mapping based on IAP was carried out only in Lviv city and in the built-up area of Kyiv city (Dymytrova 2009, Mamchur 2005), while bryophyte indication mapping in smaller towns of Ukraine were so far not carried out.

The first results of special study of species diversity of bryophytes and moss community composition of investigated towns of Left Bank Forest-Steppe Ukraine were presented in earlier papers (Gapon 2016, 2017*a*, Gapon and Gapon 2020*a*).

The aim of this study was to present results of bryoindication zoning of small towns of Left Bank Ukraine based on calculations of IAP.

During special study of species diversity of bryophytes and moss communities of towns mentioned data on frequency and coverage of separate taxa were accumulated. They were used for the bryoindication purposes, i.e.: for calculation of the IAP.

MATERIALS AND METHODS

Study area

All towns are situated in Romny-Poltava geobotanic county of the Left Bank Dnipro Forest-Steppe of Ukraine (Andrienko *et al.* 1977, Didukh and Shelyag-Sosonko 2003). Among them three towns, i.e. Lubny, Myrhorod and Poltava are situated in Poltava oblast, Romny town – in Sumy oblast and Pryluky town – in Chernihiv oblast (Fig. 1). The smallest Romny and Myrhorod towns (less than 50,000 inhabitants) have area of 29 and 19 km^2 consequently (i.e. less than 30 km^2). Area of small Pryluky and Lubny towns (about 50,000 inhabitants) is 42 and 45.6 km^2 consequently while area of medium size Poltava town (about 296,000 inhabitants) is the largest, i.e. 112.5 km^2.

The location is characterised by a moderately continental climate with relatively mild winters and hot summers. The mean annual temperature is 7.6 °C, mean monthly temperatures varied from –6 °C in January to 20.1 °C in July. The annual rainfall is 495–570 mm. Western and north-western winds are predominant. All towns studied are positioned on banks of rivers, i.e. Romny town – on banks of Sula and Romen Rivers, Myrhorod town – on both banks of Khorol River, Pryluky town – on bank of Udaj River, Lubny town – on the right bank of Sula River, and Poltava town – on both banks of Vorskla River (Matsa 1998).

Area of parks and other green plantations within territory of towns studied varies from 2.5% in Romny town to almost 60% in Lubny town. Ognivshchyna' park and 'Pyvnyj Lis' (= Beer Forest) park are the largest in Romny town. 'Berezovy Haj' (= Birch Wood) Park is the largest in Myrhorod town. Pryluky dendropark (11.9 ha) is the largest park in Pryluky town. 'Moroziv dacha' (= Moroziv summer house) and 'Zhovtneva dacha' (= October summer house) nature monuments are on northern and southern vicinities of Lubny town. The biggest number of green plantations, i.e. totally 30 protected territories are present in Poltava town, where Poltava town park is the largest (124.5 ha).

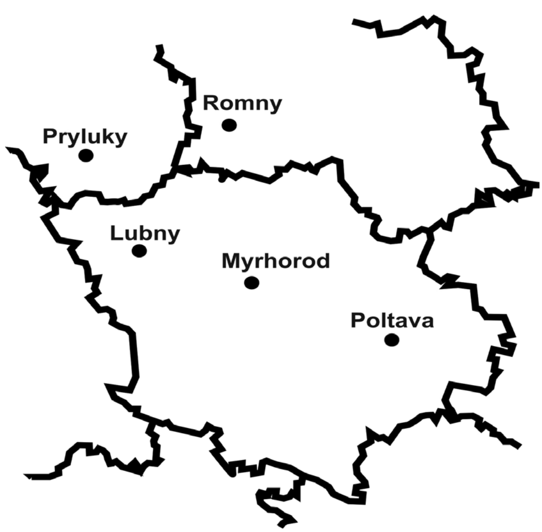

Fig. 1. Position of Lubny, Myrhorod and Poltava in Poltava oblast, Romny town – in Sumy oblast and Pryluky town – in Chernihiv oblast

Railway connection is in all towns, while Poltava has two railway stations and larger railway connection within town area. Number of industrial objects varies from 10 to 15 in small towns, while there are more than thousands of industrial objects in Poltava. Among studied towns the most intense pressure of exhaust fumes of vehicles is in Poltava as well as in Lubny, bordering on the international highway.

Field work

Field work was carried out over the period 2014–2018. Bryophyte vegetation was investigated on isolated trees with a diameter >30 cm. In each sampling plot at least five trees were monitored. Sampling plots in the territory of town Lubny are shown in Figure 5, while in the other towns they were used for the calculation of the IAP but now shown in the separate illustrations. The most common tree species in the study area are *Tilia cordata* Mill. and *Acer platanoides* L., which were chosen as phorophytes to reduce the influence of bark related variables. To assess bryophyte diversity in town investigated, 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.

Table 1
Ecological indices of bryophyte species in towns of Left Bank Ukraine (see LeBlanc and de Sloover 1970). Pr = Pryluky, Ro = Romny, Lu = Lubny, My = Myrhorod, Po = Poltava

Bryophyte species	Pr	Ro	Lu	My	Po	Average
Amblystegium serpens (Hedw.) Schimp.	2.76	1.71	0.70	0.6	1.44	1.44
Amblystegium juratzkanum Schimp.	0.5	0.67	0.43	0.44	0.66	0.51
Anomodon longifolius (Schleich. ex Brid.) Hartm.	0.33	0.33			0.33	0.33
Anomodon viticulosus (Hedw.) Hook. et Taylor	0.33		0.5		0.4	0.42
Atrichum undulatum (Hedw.) P. Beauv.	0.33			3	1.4	1.67
Barbula unguiculata Hedw.	0.43	1.17	0.38	1.67	1.59	1.05
Brachytheciastrum velutinum (Hedw.) Ignatov et Huttunen	0.43	1.17	0.38	1.67	1.59	1.05
Brachythecium albicans (Hedw.) Schimp.	0.33	1.3			1.7	1.11
Brachythecium rivulare Schimp.				0.33	0.33	0.33
Brachythecium salebrosum (Hoffm. ex F. Weber et D. Mohr) Schimp.	2	1.25	0.37	0.95	1.25	1.16
Bryum argenteum Hedw.	1	0.38	0.33	0.47	0.52	0.67
Bryum ruderale Crundw. et Nyholm	0.5				0.59	0.5
Ceratodon purpureus (Hedw.) Brid.	1	0.67	0.78	0.86	0.86	0.83
Funaria hygrometrica Hedw.	0.33	1				0.67

Table 1 (continued)

Bryophyte species	Pr	Ro	Lu	My	Po	Average
Dicranella heteromalla (Hedw.) Schimp.		0.33		2	1.9	1.41
Dicranum montanum Hedw.		0.2		1.2	0.8	0.73
Dicranum polysetum Sw. ex anon.				3	1.4	2.2
Dicranum scoparium Hedw.				0.6	1.2	0.9
Dicranum tauricum Sapjegin			2.2	2.5	3	2.56
Hypnum cupressiforme Hedw.	0.5	0.6	0.46	0.92	0.92	0.68
Hypnum cupressiforme var. *filiforme* Brid.	0.6	0.5	0.4	0.9	0.9	0.7
Jochenia pallescens (Hedw.) Hedenäs, Schlesak et D. Quandt	0.67	0.5	0.46	0.92	0.92	0.69
Leskea polycarpa Hedw.	1.6	1.54	0.54	0.48	1.3	1.09
Leucodon sciuroides (Hedw.) Schwägr.			1		1	1
Lewinskya affinis (Schrad. ex Brid.) F. Lara, Garilleti et Goffinet	1	0.33	0.2		0.4	0.48
Lewinskya speciosa (Nees) F. Lara, Garilleti et Goffinet	1.41	1	0.53	0.78	0.98	0.94
Nyholmiella obtusifolia (Brid.) Holmen et E. Warncke	1	0.63	0.43	1	1	0.81
Orthotrichum diaphanum Brid.	0.67		0.47	3	2	1.38
Orthotrichum pumilum Sw. ex anon.	1	0.4	0.44	2	1	0.76
Orthotrichum pallens Bruch ex Brid.	1.5	1.17	0.38	1.71	1.26	1.20
Oxyrrhynchium hians (Hedw.) Loeske	0.4	0.33	2	1		0.88
Plagiomnium cuspidatum (Hedw.) T. J. Kop.		1.33		3	0.92	0.84
Plagiothecium laetum Schimp.	0.5	0.67	0.4	1	1	0.71
Platygyrium repens (Brid.) Schimp.	0.5	0.67	0.4	1	1	0.71
Pleurozium schreberi (Willd. ex Brid.) Mitt.		0.3			0.1	0.2
Pohlia nutans (Hedw.) Lindb.		0.33	5	3	2.27	2.65
Polytrichum longisetum Sw. ex Brid.	0.2		0.1		0.22	0.17
Pseudoleskeella nervosa (Brid.) Nyholm	0.4		0.47		0.54	0.47
Ptychostomum capillare (Hedw.) Holyoak et N. Pedersen		0.25	0.25	2.25	1.25	1
Ptychostomum imbricatulum (Müll. Hal.) Holyoak et N. Pedersen			0.33	0.33	033	0.33
Ptychostomum moravicum (Podp.) Ros et Mazimpaka		0.33	1.33	1.33	1.33	1.2
Pylaisia polyantha (Hedw.) Schimp.	1.38	1.56	0.5	0.5	1.56	1.10
Radula complanata (L.) Dumort.			2	6	3	3.6
Sciuro-hypnum curtum (Lindb.) Ignatov	0.6			2.5	1.25	1.45
Tortula muralis Hedw. subsp. *muralis* var. *aestiva* Hedw.	1		0.08	1.67	1	0.94
Tortula muralis Hedw. subsp. *muralis* var. *muralis*			1	0.87		0.93
Total number of species	31	30	33	36	43	

According to the different human use, five zones were mostly distinguished in towns studied: industrial area, residential area, roads (trees along the streets), inner and outer parks belonging to suburban forests of towns. Bryophyte species are listed in Table 1 with their author's names, therefore the authors are not mostly mentioned in the text. Nomenclature of bryophytes follows Hodgetts with colleagues (Hodgetts *et al.* 2020) with one exception where it follows Boiko (2014).

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 frequency of each species were assessed using a five-point scale of LeBlanc and de Sloover (1970) combining both these parameters.

Data analysis

The IAP based on bryophyte species richness, cover, and frequency is an important approach for assessing atmospheric environments and is measured using the following equation:

$$\mathrm{IAP} = \sum s_i = 1(Q_i \times f_i),$$

where 's' is the species richness at each sampling site; 'Q' is an ecological index, which refers to the mean species richness of all sampled sites; and 'f' is a comprehensive value of the cover and frequency of each bryophyte species, which was determined according to LeBlanc and de Sloover (1970, Zechmeister *et al.* 2003).

RESULTS

Species richness and communities

A total of 108 bryophyte species belonging to 54 genera in 31 families, 14 orders, 5 classes of two divisions Marchantiophyta and Bryophyta are found in towns investigated. Species richness of bryophyta of the latter towns is the following: Romny – 53 species, Myrhorod – 52 species, Pryluky – 54 species, Lubny – 58 species, and Poltava – 92 species (Gapon 2016, 2017*a*, Gapon and Gapon 2020*a*).

Syntaxonomy of bryophyte communities of five towns investigated, which was provided for the first time within this study too includes 18 rankless communities, 8 subassociations and 25 associations belonging to 15 unions, 12 orders and 9 classes (Gapon 2017*b*, Gapon and Gapon 2018, 2019, 2020*b*). Epiphyte bryophyte communities found to be the most diverse in towns investigated and include 5 rankless communities, one subassociation and 13 associations of three classes (Cladonio digitatae-Lepidozietea reptantis Lez. et Vondr. 1962, Neckeretea complanatae Marst. 1986, and Frullanio dilatatae-Leucodontetea sciuroidis Mohan 1978 em. Marst. 1985) (Gapon and Gapon 2020*b*).

Isotoxic zones

Five isotoxic zones were delineated on the basis of results of IAP calculation, where the first zone (zone I, IAP = 0–0.9), or the most polluted zone, is characterised by the presence of only a few toxitolerant bryophyte species, i.e.: *Leskea polycarpa, Pylaisia polyantha* and *Orthotrichum pumilum*. This zone is found only in small areas in Myrhorod and Romny towns, while in the other towns and especially in the medium size Poltava town areas of this zone were registered the largest. Only associations *Pylaisietum polyantae* Filf. 1941 and *Orthotrichetum fallacis* Krus. 1945 of the class Frullanio dilatatae-Leucodontetea sciuroidis were observed among bryophyte communities.

The second zone (zone II, IAP = 1–2.9) or zone of moderate pollution, as usual is registered close to main roads with the most intensive flow of vehicles. Species richness of bryophytes is rather low as in previous zone. The following taxa *Amblystegium serpens*, *A. juratzkanum*, *Ceratodon purpureus*, *Oxyrrhynchium hians* are usually recorded here. Moss associations mentioned above as well as *Leskeetum polycarpae* Horvat ex Pec. 1965, and *Orthothrichetum speciosi* Barkm. 1958 of the same class are only present in the zone II.

The next zone (zone III, IAP = 3–4.9), or zone of medium polluted air, is characterised by higher species diversity of bryophytes. Species of the genus *Orthotrichum* are more common in areas of this zone. The following taxa *Amblystegium serpens*, *A. juratzkanum*, *Brachytheciastrum velutinum*, *Brachythecium albicans*, *B. salebrosum* and *Ceratodon purpureus* are rather widely distributed in this zone. Additionally to mentioned above moss communities the following associations *Orthotrichetum pallentis* Ochsn. 1928, *Orthotrichetum obtusifolii* Horvat ex Pec. 1965 of the same class or also *Brachythecio salebrosi-Amblystegietum juratzkani* (Sjog. ex Marst. 1987) Marst. 1989 and rankless community *Ceratodon purpureus* – comm. are registered in zone III.

Zone IV (IAP = 5–9.9), or slightly polluted zone, is usually registered close to green plantations or parks within towns mentioned. Additionally to bryophyte communities listed above the following rankless communities *Platygyrium repens* – comm., *Jochenia pallescens* – comm., and *Hypnum cupressiforme* – comm. are usual here.

Areas of zone V (IAP ≥ 10), or unpolluted zone, are rather common for large parks or woodlands of town vicinities, nature monuments or other protected territories. Bryophytes *Dicranum tauricum*, *Homalia trichomanoides* (Hedw.) Brid., *Anomodon longifolius*, *A. viticulosus*, *Hypnum cupressiforme* var. *filiforme*, *Leucodon sciuroides*, which are common in woodlands are rather common here. Species diversity may reach to 43 species per plot. Among communities the most common are the following: *Dicrano scoparii-Hypnetum filiformis* Barkm. 1949, *Orthodicrano montani-Hypnetum reptile* Gapon 2010, of the class *Tetraphido pellucidae-Orthodicranetum stricti* Heb. 1973, as well as *Anomodonte-*

tum attenuati (Gams 1927) Barkm. 1958, *Anomodontetum longifolii* Waldh. 1944, and rankless communities *Homalia trichomanoides* – comm. and *Radula complanata-Pseudoleskeella nervosa* – comm., while some of them are rather rare.

Ecological index Q_i of each taxon is shown in Table 1. As it is seen from Table 1 ecological indices of bryophyte species in individual towns vary from 0.08 (in *Tortula muralis* Hedw. subsp. *muralis* var. *aestiva*) to 5 (in *Pohlia nutans*) in Lubny and 6 (in *Radula complanata*) in Myrhorod. At the same time the lowest average ecological index (0.33) found to be present in three species, i.e.: *Anomodon longifolius, Brachythecium rivulare*, and *Ptychostomum imbricatulum,* while the highest average ecological index (2.65) was calculated for *Pohlia nutans.*

As it is seen from Table 1 among total 46 bryophyte species used for calculation of IAP only 3 species, i.e.: *Funaria hygrometrica, Oxyrrhynchium hians* and *Tortula muralis* subsp. *muralis* var. *muralis* were not found in the town Poltava. Thus the highest number of species i.e. 43 species were used for calculation of IAP in Poltava town, while in the other towns total number of bryophyte species varies between 30 and 36 species only.

These bryophyte species (for author names see Table 1) were registered in the following isotoxic zones (Table 2).

Table 2
Bryophyte species in different isotoxic zones of towns of Left Bank Ukraine (the range of IAP values are in brackets)

Bryophyte species	Zone I (0–0.9)	Zone II (1–2.9)	Zone III (3–4.9)	Zone IV (5–9.9)	Zone V (10 ≥)
Amblystegium serpens		+	+	+	+
Amblystegium juratzkanum		+		+	+
Anomodon longifolius				+	+
Anomodon viticulosus				+	+
Atrichum undulatum				+	+
Barbula unguiculata				+	+
Brachytheciastrum velutinum		+	+	+	
Brachythecium albicans		+	+	+	+
Brachythecium rivulare			+	+	+
Brachythecium salebrosum		+	+	+	+
Bryum argenteum		+	+	+	+
Bryum ruderale			+	+	
Ceratodon purpureus		+	+	+	+
Dicranella heteromalla					+

Table 2 (continued)

Bryophyte species	Zone I (0–0.9)	Zone II (1–2.9)	Zone III (3–4.9)	Zone IV (5–9.9)	Zone V (10 ≥)
Dicranum montanum			+	+	+
Dicranum polysetum			+	+	+
Dicranum scoparium			+	+	+
Dicranum tauricum				+	+
Hypnum cupressiforme		+	+	+	+
Hypnum cupressiforme var. *filiforme*				+	+
Jochenia pallescens			+	+	+
Leskea polycarpa	+	+	+	+	+
Leucodon sciuroides		+		+	+
Lewinskya affinis				+	+
Lewinskya speciosa				+	+
Nyholmiella obtusifolia			+	+	+
Orthotrichum diaphanum				+	+
Orthotrichum pallens		+	+	+	+
Orthotrichum pumilum	+	+	+	+	+
Oxyrrhynchium hians	+	+	+	+	+
Plagiomnium cuspidatum					+
Plagiothecium laetum				+	+
Platygyrium repens		+	+	+	+
Pleurozium schreberi		+	+	+	+
Pohlia nutans					+
Polytrichum longisetum		+	+	+	
Pseudoleskeella nervosa		+	+	+	
Ptychostomum capillare		+	+	+	+
Ptychostomum imbricatulum		+	+		
Ptychostomum moravicum				+	+
Pylaisia polyantha	+	+	+	+	+
Radula complanata			+	+	+
Sciuro-hypnum curtum				+	+
Tortula muralis Hedw. subsp. *muralis* var. *aestiva*		+	+	+	
Tortula muralis Hedw. subsp. *muralis* var. *muralis*			+		

All four small towns (Romny, Myrhorod, Pryluky and Lubny, less than 50,000 of inhabitants in each) investigated and Poltava, the biggest town (about 300,000 of inhabitants and 103 km² territory), found to have similar number of bryoindication zones, while characters and territory of these zones are quite different.

The town Romny

Among couple of the smallest towns (i.e. the towns Romny and Myrhorod with 40,000 of inhabitants and more than 19–27 km²) the situation based on IAP zones is the following. The largest area of the slightly polluted zone, i.e. zone IV were found in the territory of the town Romny, while areas of unpolluted zone (or zone V) distinctly correlate with valley of Sula and Romen Rivers as well as with position of protected woodlands, i.e. 'Ognivshchyna' and 'Pyvny Lis' parks (Fig. 2). The highest species richness of bryophytes is

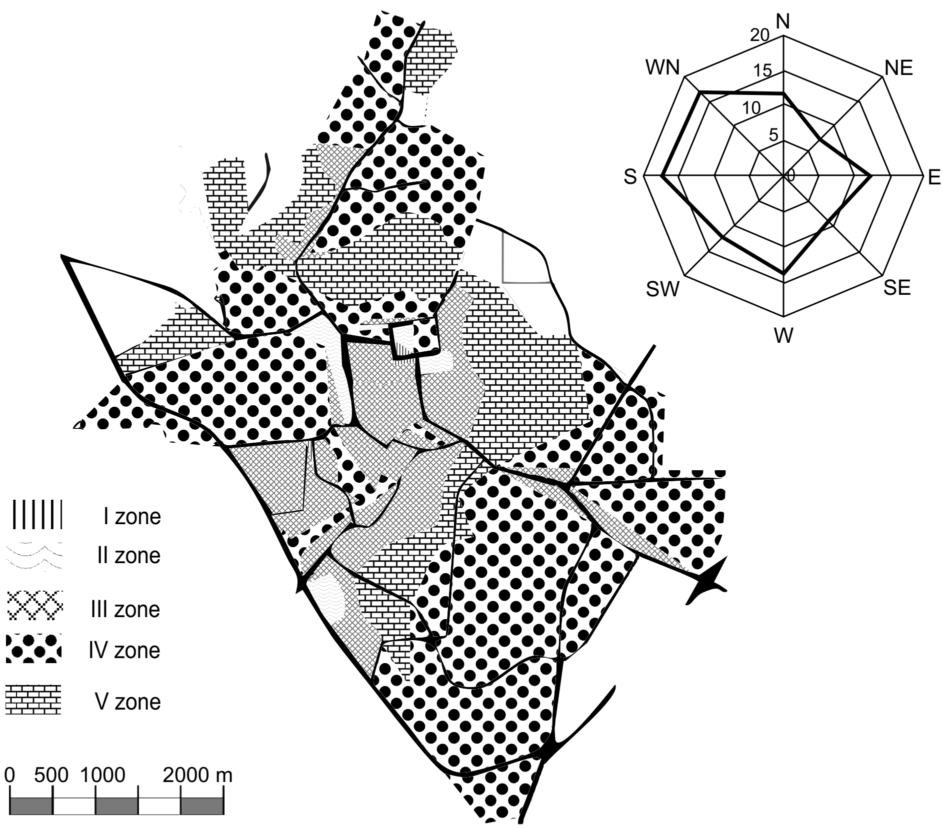

Fig. 2. Isotoxic zones in the territory of the town Romny on the basis of the calculation of the IAP as well as prevailing W and WN wind direction of this area

found in these areas of zone V. *Anomodon longifolius, Dicranella heteromalla, Lewinskya speciosa, Plagiomnium cuspidatum, P. medium* (Bruch et Schimp.) T. J. Kop., *Pohlia nutans* etc., were found here. Furthermore *Amblystegium serpens, A. juratzkanum, Atrichum undulatum, Barbula unguiculata, Brachytheciastrum velutinum, Brachythecium albicans, B. rivulare, B. salebrosum*, and *Bryum argenteum* were registered in Zone IV of the town Romny. Three isolated areas of zone I and II were found only along Gorjkoho street and Shevchenko boulevard, as well along the streets Ovsyannikova and Admiral Lozovsky.

The town Myrhorod

The town Myrhorod is characterised by the largest area of the IV isotoxic zone (or 'slightly polluted' zone, IAP = 5–9.8), while moderately polluted zone is located in smaller industrial area, between the streets Voskresinska, Zaliznychna, Kyivska, Khorolska, Shyshatska, Shlyakhovykiv and Kotlyarevskogo (Fig. 3), as well as the second in smaller area near Guramishvili, Spartakivs-

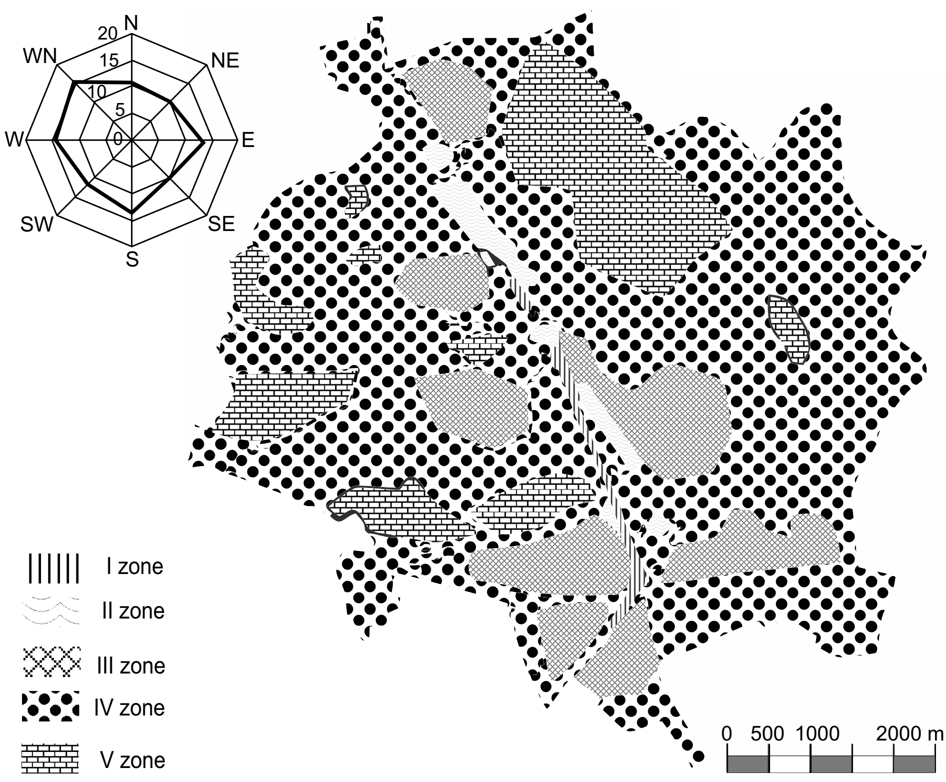

Fig. 3. Isotoxic zones in the territory of the town Myrhorod on the basis of the calculation of the IAP as well as prevailing W and WN as well as S wind direction of this area

ka, Komyshnyanskoyi streets and Vokzalny alley as well as in Donchenko park. Typical species for forest areas, *Atrichum undulatum* and *Plagiothecium laetum* were found in areas of IV isotoxic zone of the town Myrhorod. Such ecological situation is connected with well air conditioning owing to numerous lakes and water reservoirs in the territory of the town as well as prevailing W and WN as well as S wind direction (Fig. 3). The cleanest zone, i.e. V isotoxic zone (IAP = 10–11) is found in park zone of sanatorium complex Myrhorod as well as scattered small woodlands which are far of main roads. *Atrichum undulatum*, *Dicranum tauricum*, *Homalia trichomanoides*, *Plagiomnium cuspidatum* are found in this zone in town Myrhorod.

The town Pryluky

Isotoxic zone I in the town Pryluky is registered only in small areas at junction of Kyiv and Yu. Koptyev streets, in the market square area, along the street First of May (near the streets Andreyevska and Kozacha) (Fig. 4). It is

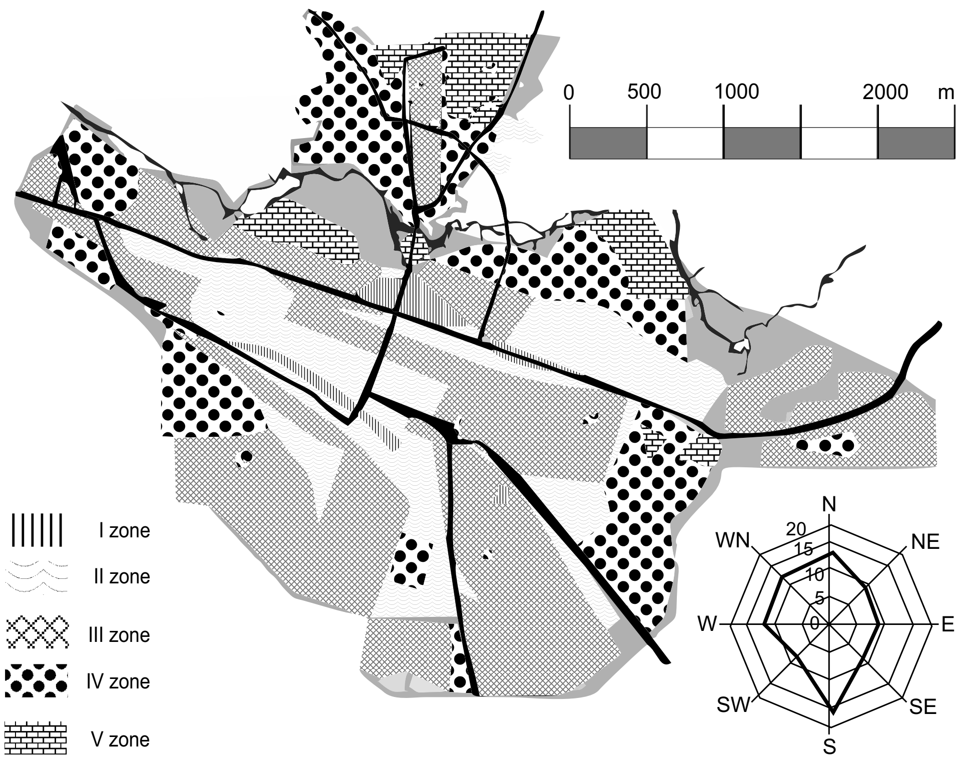

Fig. 4. Isotoxic zones in the territory of the town Pryluky on the basis of the calculation of the IAP as well as prevailing S, N and NW wind direction of this area

interesting that bryophyte species in the isotoxic zone I of the town Pryluky are different from those in Lubny town, i.e. *Ceratodon purpureus, Nyholmiella obtusifolia, Orthotrichum pallens* in zone I and *Amblystegium serpens* in zone II. The areas of the cleanest isotoxic zone V were shown only along Uday River where the highest species richness of bryophytes was found. *Anomodon longifolius, A. viticulosus, Dicranum montanum, D. polysetum, D. scoparium, Plagiomnium cuspidatum, P. medium, Platygyrium repens, Pleurozium schreberi, Pohlia nutans* were recorded in this zone of the town Pryluky. In contrast to the town Lubny, the second isotoxic zone occupied the larger area of the town Pryluky. The latter is probably connected with prevailing S wind direction in town Pryluky (Fig. 4).

Thus among these two moderately polluted towns the town Pryluky has the largest areas with isotoxic zones II and III.

The town Lubny

Among a couple of medium size small towns Lubny and Pryluky (approx. 50,000 of inhabitants and more than 40 km^2 territory) small areas of isotoxic zone I is present along the streets Shevchenko, Vyshnevetskykh, Olexandrivska and avenue Volodymyr of the town Lubny (Figs 5–6). Additionally to the areas of the first zone slightly larger areas of the isotoxic zone II in the same roads are correlating with the highest level of exhaust fumes of vehicles of the town Lubny, and additionally along the street P. Slynjka and in the park on ‘Slavy’ square (= Honour). Among the species only 1–2 species of bryophytes (i.e.: *Leskea polycarpa, Pylaisia polyantha* and *Orthotrichum pumilum*) were found in zone I, and additionally to the above mentioned *Orthotrichum pallens* and *Lewinskya speciosa* in zone II. Thalli (gametophytes) of bryophytes in this zone are often damaged and becoming colourless. Bryophyte species characteristic to natural woodlands (3–4.9) that can be connected with influence of the M03 international highway Kyiv-Kharkiv-Rostov as well as in prevailing winds from international highway in the direction of the town Lubny.

This zone is registered in all districts of the town as well as in the Central park and Donchenko part of this town [which are situated in the centre of the town]. Additionally of bryophyte species registered in the zones I and II the following taxa are found to be present here: species of the genus *Orthotrichum*, *Hypnum cupressiforme*, *Brachytheciastrum velutinum*, *Brachythecium salebrosum*, *Ptychostomum capillare*, etc.) (see Table 2).

Unfortunately the cleanest isotoxic zones (zone V based on IAP values) are recorded only in the isolated small areas corresponding to ‘Moroziv dacha’ (= Moroziv summer house) and ‘Zhovtneva dacha’ (= October summer house), botanical reserves, dendropark and wooden plantations along the bank of Sula River.

Thus among the five towns investigated, a couple of medium size small towns, i.e. Pryluky and Lubny towns, are characterised by the largest territory of moderately polluted isotoxic zones, that may be connected with influence to the M03 international highway Kyiv-Kharkiv-Rostov as well as orographic / landscape peculiarities favouring zones, due to air pollution from highway to town in the latter case (Lubny town) and with presence of small industrial objects and densely built areas as well as prevailing S wind direction in the first one (the town Pryluky).

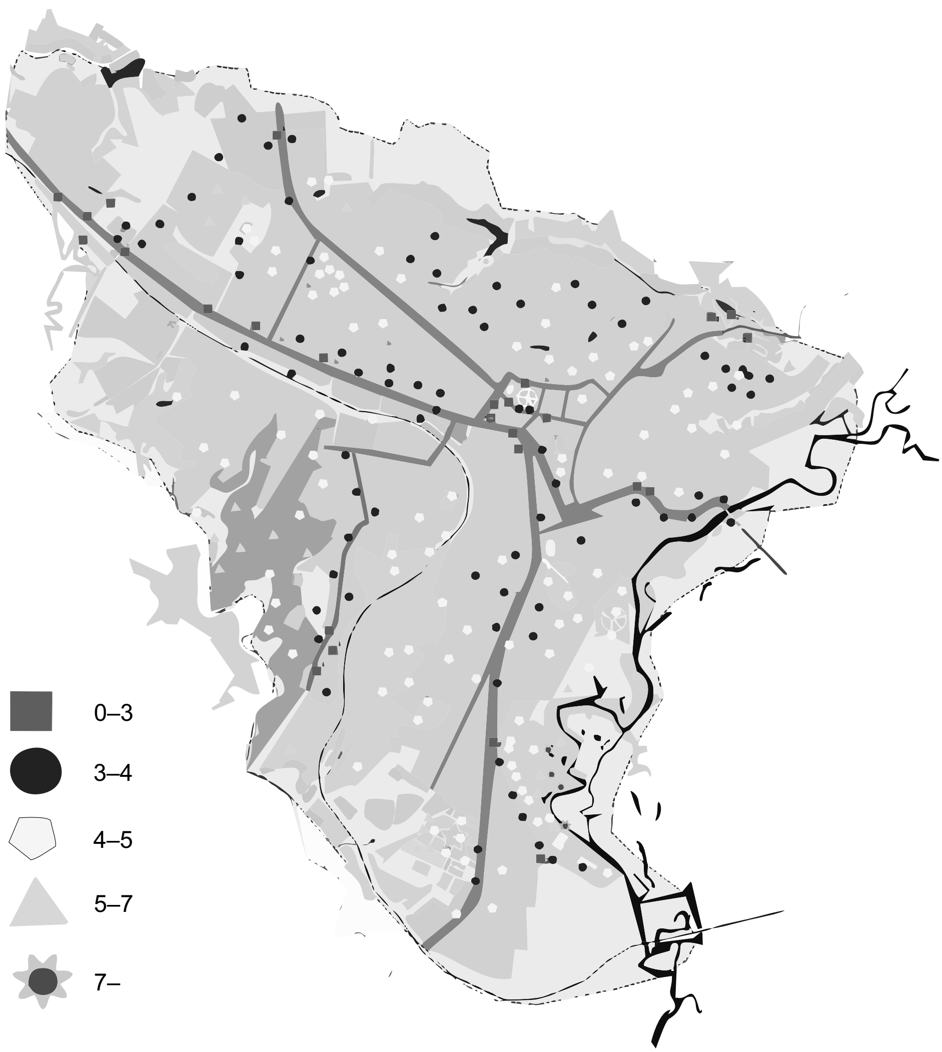

Fig. 5. Sampling plot in the territory of the town Lubny and total number of bryophyte species per sampling plot

The town Poltava

Similarly to the small towns Pryluky and Lubny a so called 'city effect', i.e. especially polluted areas are found in the central parts and southern part of the largest Poltava town among the investigated towns (Fig. 7).

The areas of slightly polluted and unpolluted izotoxic zones in the town Poltava town after bryoindication mapping are registered only in northern and north-eastern vicinities of the town. In contrast to our data, areas of unpolluted zones have been found regularly in all directions from the centre in the town Poltava town based on lichen indication mapping (Dymytrova 2008, Dymytrova, in Kondratyuk 2008). Thus in general based on bryoindication mapping the southern half of the town Poltava is more polluted than lichen indication zones which have been established about 15 years ago. It would be interesting to confirm regular zoning of the town Poltava on the basis of repeated lichen indication mapping in future, as far this difference in results of lichen- and bryoindication mapping can be connected with different sensitivity of these two groups of indicator organisms too.

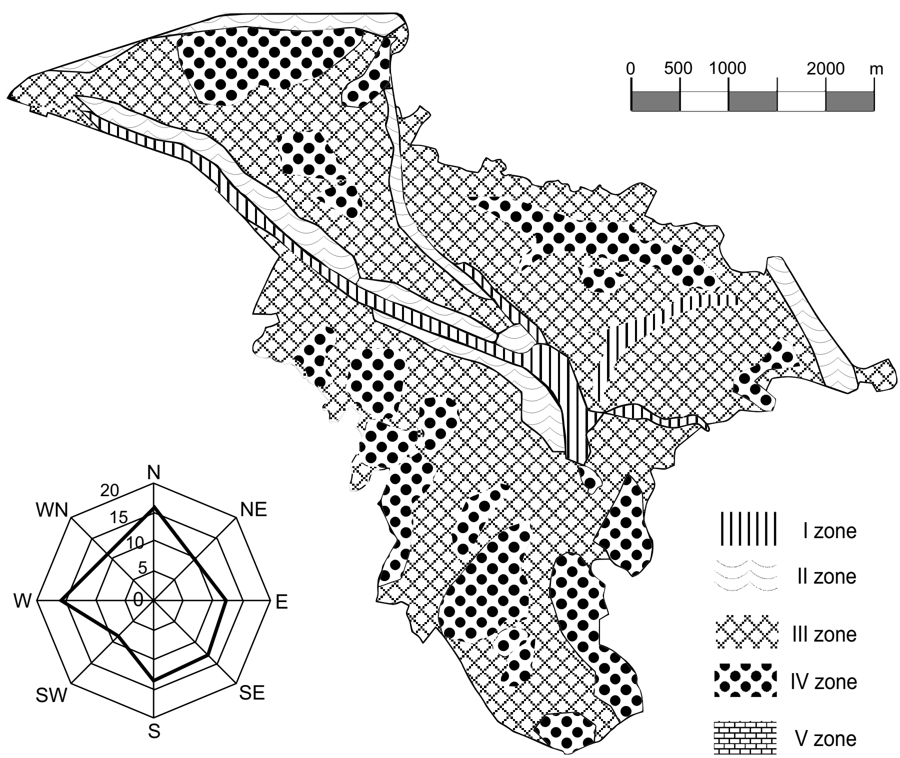

Fig. 6. Isotoxic zones in the territory of the town Lubny on the basis of the calculation of the IAP as well as prevailing N and W wind direction of this area

DISCUSSION

Species and community diversity

From our data it is seen that species diversity of bryophytes in small towns of Left Bank Ukraine is much higher than data on bryophyte species diversity in Kyiv city. For comparison, 20 bryophyte species were found in the built-up area of the city of Kyiv (Dymytrova 2009).

In comparison with other Ukrainian cities where studies on lichen indication have been carried out (Dymytrova 2008, Khodosovtsev 1995, Kondratyuk *et al.* 1991, 1993, Nekrasenko and Bairak 2002, Zelenko 1999), the highest species richness of epiphytic lichens (i.e. 65 species) was recorded in Kyiv. For example, the poorest epiphytic lichen flora (35 species) was determined in Kremenchuk (Nekrasenko and Bairak 2002) where many heavy industrial 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 Chernihiv (Zelenko 1999).

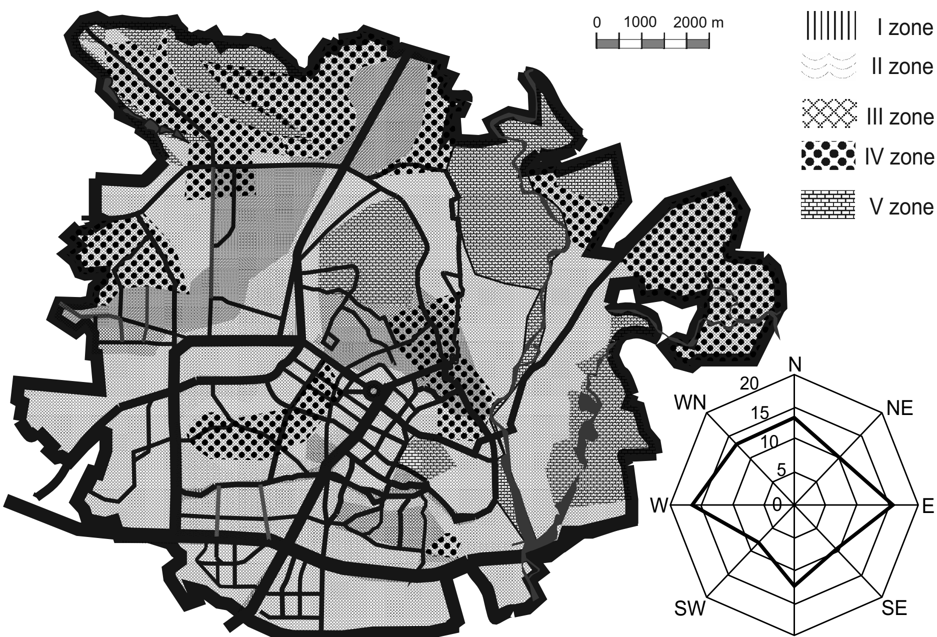

Fig. 7. Isotoxic zones in the territory of the town Poltava on the basis of the calculation of the IAP as well as prevailing W and E wind direction of this area

The results of our research were compared with similar studies in Europe, in particular with the studies of G. Zechmeister with colleagues (Zechmeister *et al.* 2002*a*) conducted in Linz (Upper Austria). It was found that the bryoflora of Ukrainian urban ecosystems studied (108 species, 12.7% of the total number of species in Ukraine) is much poorer than the bryoflora of Linz (319 species, 31.3% of the total number of species in Austria). In Ukrainian urban ecosystems, the usual, urban-tolerant species, resistant to anthropogenic factors, predominate, while the bryoflora of Linz includes 63 rare and endangered species. The epiphytic bryoflora of Linz has a number of species that are not observed in Ukrainian studied urban ecosystems (*Dicranoweisia cirrata* (Hedw.) Lindb., *Orthotrichum stramineum* Hornsch. ex Brid., *Pulvigera lyellii* (Hook. et Taylor) Plášek, Sawicki et Ochyra, *Syntrichia papillosa* (Wilson) Jur., *S. virescens* (De Not.) Ochyra, *Ulota crispa* (Hedw.) Brid.).

Data on community diversity so far cannot be compared with other towns as these data were obtained for the first time in Ukraine within this study.

Ecological index Q_i

The values of ecological index Q_i of various bryophyte species obtained within this study (between 0.33 and 2.65) seem to be very low, in comparison with data for lichen species in Ukrainian cities / towns (see for example between 0.33 and 16 (in Kondratyuk *et al.* 1991), and between 8.0 and 23.0 (in Klymenko 2015). It illustrates that the further comparative study should be carried out with aim to have comparable results of bryo- and lichen-indication mapping in the same town / place.

Comparison of bryoindication results in Ukraine and Austria (after Zechmeister *et al.* 2002*a*) based on calculation of IAP shows significant differences too. For our urban ecosystems, ecological index Q_i is much lower and ranges from 0.2 (for *Pleurozium schreberi*) to 2.65 for *Pohlia nutans*. For the urban ecosystem of Linz, it varies from 2.7 for *Platygyrium repens* to 5.6 for *Syntrichia virescens*.

Bryoindication zoning

The zones of different air pollution level in Kyiv based on IAPm-B have been distinguished (Dymytrova 2009). Only two zones were separated based on the data of bryophytes. 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 River where trees are absent or are very young (*ca* 5–10 years old). Bryophytes which are tolerant of the urbanised environment, e.g. *Bryum argenteum*, *Ceratodon purpureus, Leskea polycarpa*, *Orthotrichum pumilum* and *Py-*

laisia 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 urbanised environment. The number of bryophytes per sampling plot in this unpolluted zone varied from 5 to 7 species.

It should be mentioned that for lichen indication mapping in Ukraine the modified IAP (i.e. IAP_m sensu Dymytrova 2009) was proposed in 1994 (Kondratyuk 1994). It was used in consequence of lichen indication mapping studies in the city Kyiv, the town Poltava town and other towns (Kondratyuk 2008, Dymytrova 2008, 2009). Furthermore the modified IAP for conditions of Ukraine was confirmed as the most informative in case of special comparative analysis (Dymytrova 2009). In this case the original IAP was used for the bryoindication purpose. So may be in future some kind of modification of the IAP for bryophyte communities can be proposed, too.

In general data used for the IAP, bryophyte communities are much lower than similar data based on the results of lichen indication mapping (zone I, IAP = 0–0.9 in bryoindication in this paper there are no data on lichen indication, based on Dymytrova 2009), zone II, IAP = 1–2.9 in bryoindication and IAP = 1.6–6.0 in lichen indication, zone III, IAP = 3–4.9 in bryoindication and IAP = 6.1–15.6 in lichen indication, zone IV IAP = 5–9.9 in bryoindication and IAP = 15.7–25.2 in lichen indication, and zone V, IAP = 10 and more in bryoindication and IAP = 25.3–82.0 in lichen indication (Dymytrova 2009).

Dymytrova (2009) has recognised only four zones, i.e. highly, moderately, slightly polluted and unpolluted ones, which correspond to our zones II–V. Furthermore only two zones: polluted (IAP = 0.1–0.3) and unpolluted (IAP = 0.4–3.6) were recognised based on bryological data themselves in built-up areas of the city of Kyiv.

So may be in future zones I and II can be considered as one single zone, and zones IV and V zones united as another single zone of bryoindication mapping too. In this case data on the IAP indices will be almost the same as those of lichen indication.

Based on a special comparable indication study in the city of Kyiv, Ukraine it was concluded that mapping by bryoindication was less informative than mapping based on lichen indication, and it was also correlating less with air pollution (Dymytrova 2009). However it should be emphasised that this conclusion was connected with the following: the bryophytes were present only in 145 of total 272 sampling plots and only the built-up areas of the city of Kyiv had been investigated.

The distribution of epiphytes in small towns of Left Bank Ukraine as it has been pointed out also in several other studies (Dymytrova 2009, Marmor and Randlane 2007, Mežaka *et al.* 2008), depends on the species of phorophytes. The most common tree species in towns studied, namely *Tilia cordata, Acer platanoides* and *Populus* spp. are characterised by the highest numbers of epiphytic species. Epiphyte richness was lower on phorophytes which mainly occur in inner parks of towns: *Quercus robur* and *Betula pendula*. However, the number of these trees in our study was rather low.

The bryophytes growing on trees along the streets and the roads with heavy traffic may indicate that tree bark was heavily polluted by dust (Davies *et al.* 2007, Fudali 2006, Liška and Herben 2008). It explains the occurrence of some bryophytes typically present on soil, e.g. *Bryum argenteum*, *Ptychostomum capillare* and *Ceratodon purpureus,* which grew on trunks affected by dust. The conclusion is that the tree bark, as well as the urban air/atmosphere in the towns investigated are evidently strongly polluted by dust because of the increasing number of vehicles.

Our results confirm previous data that epiphytic bryophyte richness and the distribution of bryophytes in towns were determined by local environmental features, mainly present on old trees and in parks without considerable disturbance, since according to previous studies (Fudali 2006, Mamchur 2005, Mežaka *et al.* 2008), the main factor determining the epiphytic bryophyte richness was the age of the tree.

On the other hand, the qualitative composition of mosses found during bryoindication studies Ukraine and Austria (after Zechmeister *et al.* 2002*a*) also differs: first of all, in our studies there are not only typical epiphytes among bryophytes on trees, but also polysubstrate species that settle in the root zone of trees. These are *Ceratodon purpureus*, *Bryum imbricatulum*, *Plagiomnium cuspidatum*, *Pleurozium schreberi* and others. This difference can be explained, in our opinion, by different climatic conditions (degree of humidity, temperature, continental climate), as well as different degrees of anthropogenic transformation in urban ecosystems of Ukraine.

CONCLUSIONS

Based on results of calculation of IAP, five zones with different air pollution were distinguished in small towns Romny, Myrhorod, Pryluky, and Lubny, as well as medium size Poltava town. Isotoxic bryoindication zones with slightly polluted or unpolluted air are predominant or more widely distributed in smaller towns Romny and Myrhorod, while isotoxic zones of moderately polluted air found to be predominate and often forming entire areas in the centre / industrial / densely built-up areas of towns Pryluky and

Lubny, as well as in the town Poltava. Indicator bryophyte species of these zones were proposed and these data, as well as zoning proposed can be used as a basis for the further monitoring of the towns investigated. It seems to be promising to compare indicative values of bryophytes and lichens in the towns mentioned in future too.

*

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