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TOXICOLOGICAL STUDY OF MOSS COVER OF PINE FORESTS IN BIOGEOCHEMICAL LANDSCAPE OF BACKGROUND AREA OF UKRAINIAN POLISSIA. PART 1. HEAVY METALS

Tasks of this study – to investigate levels of contamination of soils of background forest area of Ukrainian Polissia by heavy metals (Cu, Cd, Pb, Zn); to evaluate of concentrations of these heavy metals in fractions of mosses; to calculate values of coefficient of biological absorption of heavy metals by fractions of moss species. Study was conducted in July 2021 at 3 experimental plots in Zhytomyr Region, Povchanske forest division of branch «Lugyny Forestry». Vegetation was presented by association Molinio-Pinetum Matuszkiewicz (1973) 1981, and by moist fairly infertile pine site type (B_3). Moss were sampled by fractions: Pleurozium schreberi and Dicranum polysetum – increment of 1-2 years, increment of earlier period; Polytrichum commune – increment of the first year, increment of the second year, increment of earlier period; Leucobryum glaucum, Sphagnum capillifolium and S. palustre – increment of the first year, increment of the second year, peat litter (semi-decomposed). Measurement of heavy metals content was conducted on atomic-absorption spectrophotometer C-115-M1. Coefficient of biological absorption was used as an index of intensity accumulation of heavy metals by mosses in the chain «soil – moss». Concentrations of heavy metals in 10-cm soil layer changed in such range: Pb > Zn > Cu > Cd; in absolute values ($mg \cdot kg^{-1}$) – 3,75±0,06; 3,56±0,10; 1,10±0,05; 0,002±0,00. Specific distribution in fractions of all studied moss species – terrestrial and paludal – was found for concentrations of Cu – maximal concentration was in the increment of the first year with decrease to the increment of the second year and lower – to the old moss fraction. Opposite distribution in moss fractions was observed for Zn and Pb in all studied moss species. More complicated distribution in moss fractions was observed for concentrations of Cd. For terrestrial mosses, such as Pleurozium schreberi, Dicranum polysetum and Polytrichum commune this distribution was similar – decrease Cd concentrations from increment of the first year to increment of the second year and to the lower part of mosses, but for Sphagnum spp. was differ. An important conclusion can be made that ranged row of heavy metals accumulated in the upper moss part (increment of the first year) looks like this: Cd > Cu > Zn > Pb; in the increment of the second year – Cd > Zn > Cu > Pb; in the lower part of moss cover – Cd > Zn > Pb > Cu. Also general conclusion can be made that intake of each heavy metal is species-dependent as well as distribution of its concentration among moss fractions.

Key words: *Ukrainian Polissia, forest biogeocenoses, soils, moss cover, fractions of mosses, heavy metals, concentration, intake, coefficient of biological absorption.*

Introduction. Mosses were first proposed for the study of atmospheric deposition of heavy metals in [25]. Researchers underlined that mosses receive its supply of macro- and trace elements mainly from the atmosphere and that there is no significant uptake from the substrate because the majority of mosses lack a root system (ectohydrite species). As a rule they haven't rhizoids, cuticle on leaves surface and water-conducting system. These species effectively absorb water and another atmospheric fallouts (wet and dry) by whole surface [6, 26] and are the main test-objects of pollution bryomonitoring, for example such species as *Hylocomium splendens*, *Pleurozium schreberi, Dicranum polysetum, Sphagnum* spp. etc. But for some moss species (endohydrite) uptake of trace elements, at least from the soil, does not turn on [4]. They are characterized by the presence of branched rhizoids in the soil, their leaves are covered by epidermis and cuticle, water-conducting system is well developed [16]. Examples – *Polytrichum commune, P. formosum, P. piliferum*. To evaluate differences in intake of heavy metals by different moss species of these groups is actual problem.

Purpose of study. Purpose was investigation of contamination of geochemical landscape in background forest area by heavy metals on the basis of bryoindication of it by the common forest mosses of Ukrainian Polissia.

Tasks of study. Tasks of study were: investigation of contamination of background forest area by heavy metals; to evaluate of concentrations of heavy metals in fractions of moss species-bioindicators; to calculate values of coefficient of biological absorption by different fractions of moss species in the chain «soil-moss».

Literature review. Researchers [28, 30] have analyzed sources and ways of heavy metals intake to mosses. In particular, it was concluded that additionally to the main – atmospheric way of heavy metals intake to mosses also such ways are important: cycling of elements from the soil (study insufficiently, and is debatable until now), leaching substances from higher plants of upper layers of forest vegetation (trees, shrubs, grasses, etc.), in some cases – due to direct uptake from the substrate [19], direct contact with the soil surface and intake due to capillary forces or differences in concentrations of trace elements in mosses and upper soil layers [28].

Contamination by local mineral particles and their accumulation in the dense carpets and pillows of mosses also can be observed, for example via passage of large animals – moose, roe deer or burrowing activities of wild boar, small rodents, etc. For some trace elements resuspension is very important – contamination of moss surface by windblown dust containing trace elements and radionuclides [10, 11]. Also quality of precipitation plays an important role in absorption of heavy metals by mosses, in particular at pH=4 absorption is less than at pH = 5 [12].

Occurrence of moss species-bioindicators of airborne pollution in different forest ecological conditions of Ukrainian Polissia was analyzed by [20]. In particular, it was shown that 2 species of terrestrial mosses such as *Dicranum polysetum* and *Pleurozium schreberi* were present respectively on 97,6% and 95,4% of studied sites of moist fairly infertile pine site type (B_3) which allows to use these species for bioindication and monitoring purposes.

Median concentrations of heavy metals (Cd, Cu, Pb, Zn) ($mg \cdot kg^{-1}$) in mosses – bioindicators of airborne pollution – in Europe were reported by [14, 15]: in Czech Republic – 0,23; 5,23; 4,94; 33,3; Slovakia – 0,50; 14,9; 12,3; 48,9; Poland – 0,25; 6,58; 5,09; 34,1; Ukraine (Volyn' and Sumy Regions) – 0,32; 7,20; 7,65; 36,2 respectively.

Results of bryogeochemical indication of atmospheric fallouts of heavy metals in forests of Zhytomyr and Kyiv Regions were reported by [31]. For this purpose common terrestrial green moss *Pleurozium schreberi* was used. Heavy metals content in phytomass of *Pleurozium schreberi* (n = 67 sites) was ($mg \cdot kg^{-1}$): Cd – 0,32; Zn – 34,3; Cu – 12,9; Pb – 4,3; Ti – 21,0; Ni – 3,4; Cr – 3,1; Co – 0,45; Sb – 0,21. Geochemical associations of heavy metals were given for Ukrainian Polissia [31]: Ca/Mg/Fe/Na/Ti/Cr/Cu, connected with the local technogenesis or with long-range atmospheric transport of pollutants; and for Forest-Steppe Zone – Mg/Al/Ni/Cd/Sb/Pb, mainly connected with dry dust-aerosol fallouts of pollutants and their resuspension.

It was concluded that by accumulation level and retention by mosses heavy metals can be placed in such range: Cu > Pb > Ni > Co > Cd > Zn > Mn [24].

Pleurozium schreberi and *Hylocomium splendens* were used as heavy metals bioindicator in many studies: in Poland – for multiyear monitoring of atmospheric fallouts of Cd, Cr, Cu, Fe, Pb, Zn on forest biogeocenoses [29]; in Finland – for multiyear monitoring of atmospheric fallouts of Cd, Cr, Cu, Fe, Ni, Pb, Zn, V, As, Hg on forest biogeocenoses [21]; in Czech Republic – for monitoring of atmospheric fallouts of As, Cd, Cr, Cu, Fe, Hg, Pb, V, Zn on forest biogeocenoses [17]; in Slovakia – for mapping of heavy metal fallouts on forest ecosystems [9]; in Norway and Finland – for monitoring of transboundary transfer of Cd, Cr, Cu, Fe, Ni, Zn and their fallouts on forests [27].

Concentrations of heavy metals in separate segments of mosses as well as in parts with different pigmentation were analyzed in Norway spruce forests [18]. It was found that in annual segments concentrations of K and Pb showed negative correlation with segment dry weight (as a reflection of their young age). Concentrations of Ca, Mg and Cu were lower in ramify segments in comparison with terminating ones. Reduced competition in pair Mg–Pb for exchange sites determines higher Pb concentrations in ramifying parts. Segments of mosses with lower chlorophyll content and pale color showed reduced K and Mg concentration.

It was reported [12] that the peat moss *Sphagnum fuscum* absorbed Zn, Cu, Cd and Pb slightly more efficient than the green moss *Hylocomium splendens*. Also it was made a conclusion that as a rule the metal uptake after equilibrium in moss cover decreases in the following order: Pb>Cd>Cu>Zn.

It was shown [23] that for the regional mapping of heavy metals moss samples can be combined without interspecies calibration. But these researchers concluded that inside all experimental sampling plots variation of heavy metal content in moss cover was large, thus big moss samples consisting of a lot of small samples should be sampled and analyzed. Interspecies variability in accumulation of heavy metals between *Pleurozium schreberi* and *Hylocomium splendens* were generalized by [13]. It was concluded that mentioned above variability is high, despite the calibration carried out. Researcher explained this phenomenon by differences in sampling, analytical methods, geochemical conditions of heavy metals deposition, absence of systematical network of moss sampling over large geographical region.

Leaching of trace elements from the tree canopy influences to a certain extent on input of elements, especially K, Cd and Mg, by mosses [32, 33]. Concentrations of Pb, Cd and Cu were significantly negatively correlated with vascular plant cover, indicating that uptake of elements from leaching from vascular plant foliage is almost negligible. The concentration of Cu in *Hylocomium splendens* was weakly positively correlated with closeness of tree canopy.

Some conclusions can be made from this literary review: data on the concentration of heavy metals in the moss cover of forests in Ukrainian Polissia are fragmented; interspecies differences in heavy metals accumulation in different moss species insufficiently studied; the contribution of various sources other than atmospheric in heavy metals concentration in mosses has not been quantified.

Objects and methodology. Toxicological study of moss cover was conducted in July 2021 at 3 experimental plots (each – 1,0 ha) in Zhytomyr Region, Korosten district, Povchanske forest division of branch «Lugyny Forestry» of State Enterprise «Forests of Ukraine» (table 1).

Vegetation was presented by association *Molinio-Pinetum* Matuszkiewicz (1973) 1981. Tree canopy consisted of *Pinus sylvestris* L. with separate trees of *Betula pendula* Roth, undergrowth with density about 20% included mainly *Frangula alnus* Mill. (17–19%) and *Sorbus aucuparia* L.

(1–3%). Grass-dwarf-shrub layer was dense, with projective cover 60–80%, consisted of *Vaccinium myrtillus* L. (40–60%), *V. vitis-idaea* L. (5–10%), *V. uliginosum* L. (1–3%), *Molinia caerulea* (L.) Moench (1–3%), *Pteridium aquilinum* (L.) Kuhn (3–5%), *Dryopteris carthusiana* (Vill.) H.P.Fuchs (1%), *Equisetum sylvaticum* L. (1%), etc. Moss layer was continuous, with projective cover 75-95%. It mainly consisted of two green moss species – *Pleurozium schreberi* (Willd. ex Brid.) Mitt. (30–45%) and *Dicranum polysetum* Sw. ex Anon. (30–45%). Less participation took part such moss species as *Polytrichum commune* Hedw. (3–5%), *Leucobryum glaucum* (Hedw.) Ångstr. (1–3%), and in depressions – paludal sphagnous mosses – *Sphagnum capillifolium* (Ehrh.) Hedw. (1–3%) and *S. palustre* L. (1–3%). Forest site condition typical for the region of Ukrainian Polissia has formed – moist fairly infertile pine site type (B_3).

On each experimental plot 20 soil samples were systematically taken – by cylindrical drill, with diameter 5 cm, to the depth 10 cm. They were combined into one sample. Uniting sample was desiccated and mixed, 4 aliquots were taken from it for characterization of heavy metal content in the soil.

Moss were sampled in triplicate by fractions: *Pleurozium schreberi* and *Dicranum polysetum* – increment of 1–2 years, increment of earlier period; *Polytrichum commune* – increment of the first year, increment of the second year, increment of earlier period; *Leucobryum glaucum, Sphagnum capillifolium* and *S. palustre* – increment of the first year, increment of the second year, peat litter (semi-decomposed).

After drying during 72 h at temperature 80 ºC moss samples were ashed on white ash in muffle furnace, and soil samples also were ashed. Subsequent sample's preparation for analysis was carried out by standard methods. Measurement of heavy metals content was conducted on atomic-absorption spectrophotometer C-115-M1 («Academprylad» Ltd., Symy, Ukraine). Minimal detectable concentration of heavy metals were (mg·kg^{-1}): Cu – 0,005; Zn – 0,0008; Pb – 0,100; Cd – 0,002. Recalculation from heavy metal concentration in white ash of mosses into its dry weight was done.

Coefficient of biological absorption was used as an index of intensity accumulation of heavy metals by mosses in the chain «soil – moss». It was calculated as a ratio of concentration of certain heavy metal in moss to its concentration in the soil:

$$CBA = \frac{C_{moss}}{C_{soil}},$$

CBA – coefficient of biological absorption;
C_{moss} – concentration of heavy metal in moss, mg·kg^{-1};
C_{soil} – concentration of heavy metal in the soil, mg·kg^{-1}.

Statistical processing of obtained results was conducted by accepted methods [2] in package Excel. Names of vascular plant species was given by POWO [22], and mosses – according with [1]. Forest site types were identified by [5], and associations of forest vegetation – by methodology of floristic classification [7, 8]; names of vegetation syntaxons were given by [3].

Results. Measurement of heavy metals concentrations in mosses and soil allowed to evaluate values of pollution of pine forests in background area (Table 2).

Data of Table 2 show that concentrations of heavy metals in 10-cm soil layer change in such range: Pb > Zn > Cu > Cd; in absolute values (mg·kg^{-1}) – 3,75±0,06; 3,56±0,10; 1,10±0,05; 0,002±0,00, respectively. It should be noted that values for Cd was on the minimal limit of measurement. Such concentrations are typical for forest areas of Ukrainian Polissia without intensive industrial activity, and where the main way of intake of heavy metal to the environment is atmospheric, mainly by gravitational sedimentation of dry aerosols and by precipitation washing of atmosphere, thus our studied forest area can be evaluated as a background.

It is important that despite significant number of soil samples (n = 60) values of coefficient of variation of heavy metals in the soil were low: Zn – 4,99%; Pb – 2,82%; Cu – 7,77%; Cd – 0%.

Results of measurement found that concentrations of all heavy metals in fractions of all studied moss species exceeded corresponding values in the soil. For terrestrial moss species, such as *Pleurozium schreberi*, *Dicranum polysetum* and *Polytrichum commune* maximal concentrations of Pb were observed in the lower fraction of moss carpets – in fractions below of increment of the second year (mg·kg^{-1}) – from 12,07±0,12 in *Dicranum polysetum* to 11,38±0,25 in *Polytrichum commune*. In the semi-paludal moss *Leucobryum glaucum* concentration of Pb was also highest in the lower part of moss pillows – in peat litter (semi-decomposed moss residuals) – 18,30±0,41 as well as in paludal mosses – *Sphagnum capillifolium* – 11,70±0,40 and *Sphagnum*

Table 1. A brief description of forest experimental plots
Таблиця 1. Короткий опис лісових дослідних ділянок

Forest division, quarter/ elementary ferest stand	Geographical coordinates	Composition of tree canopy, stand origin	Age, years	Height, m	Diameter, cm	Stand density	Stand quality class
Povchanske, 50/20	51°08'13.29"N, 28°35'32.72"E	Pine – 100%, natural	66	23	28	0,70	I
Povchanske, 50/21	51°08'13.12"N, 28°35'42.41"E	Pine – 100%, forest cultures	51	16	16	0,80	II
Povchanske, 50/22	51°08'13.58"N, 28°35'48.87"E	Pine – 100%, forest cultures	51	18	22	0,80	I

Table 2. Concentration of heavy metals in fractions of moss cover (d.w.) and in the soil, mg·kg^{-1}
Таблиця 2. Концентрація важких металів у фракціях мохового покриву (на суху вагу) та у ґрунті, мг·кг$^{-1}$

Moss species	**Fraction of moss cover**	**M**	**m**	**Std**	**V%**	**P%**	**max.**	**min.**
1	2	3	4	5	6	7	8	9
		Pb						
Pleurozium schreberi	Increment of 1–2 years	4,75	0,13	0,23	4,82	2,79	4,95	4,50
	Increment of earlier period	11,67	0,17	0,30	2,55	1,48	12,00	11,42
Polytrichum commune	Increment of the first year	7,00	0,18	0,31	4,40	2,54	7,26	6,66
	Increment of the second year	8,25	0,34	0,59	7,10	4,10	8,76	7,61
	Increment of earlier period	11,38	0,25	0,43	3,81	2,20	11,84	10,98
Leucobryum glaucum	Increment of the first year	8,00	0,23	0,39	4,88	2,82	8,45	7,75
	Increment of the second year	5,00	0,15	0,26	5,20	3,00	5,15	4,70
	Peat litter (semidecomposed)	18,30	0,41	0,71	3,90	2,25	18,84	17,49
Sphagnum capillifolium	Increment of the first year	7,50	0,10	0,17	2,31	1,33	7,70	7,40
	Increment of the second year	5,00	0,12	0,20	4,08	2,36	5,16	4,77
	Peat litter (semidecomposed)	11,70	0,40	0,70	5,98	3,45	12,50	11,20
Sphagnum palustre	Increment of the first year	8,33	0,22	0,38	4,59	2,65	8,63	7,90
	Increment of the second year	6,12	0,09	0,16	2,61	1,51	6,28	5,96
	Peat litter (semidecomposed)	10,88	0,41	0,71	6,53	3,77	11,57	10,15
Dicranum polysetum	Increment of 1–2 years	9,14	0,31	0,54	5,91	3,41	9,67	8,59
	Increment of earlier period	12,07	0,12	0,21	1,75	1,01	12,29	11,87
Soil (layer 0–10 cm)		3,75	0,06	0,11	2,82	1,63	3,83	3,63
		Cd						
Pleurozium schreberi	Increment of 1–2 years	0,48	0,02	0,03	5,51	3,18	0,51	0,46
	Increment of earlier period	0,17	0,01	0,01	5,88	3,40	0,18	0,16
Polytrichum commune	Increment of the first year	0,73	0,03	0,05	6,28	3,62	0,77	0,68
	Increment of the second year	0,60	0,02	0,03	4,41	2,55	0,63	0,58
	Increment of earlier period	0,42	0,02	0,03	6,30	3,64	0,45	0,40
Leucobryum glaucum	Increment of the first year	1,75	0,04	0,07	3,75	2,16	1,82	1,69
	Increment of the second year	1,05	0,05	0,09	8,73	5,04	1,13	0,95
	Peat litter (semidecomposed)	0,78	0,03	0,04	5,59	3,23	0,83	0,75
Sphagnum capillifolium	Increment of the first year	0,30	0,02	0,03	8,82	5,09	0,32	0,27
	Increment of the second year	0,90	0,03	0,05	5,09	2,94	0,94	0,85
	Peat litter (semidecomposed)	0,22	0,01	0,02	7,87	4,55	0,24	0,21
Sphagnum palustre	Increment of the first year	0,34	0,02	0,03	7,78	4,49	0,36	0,31
	Increment of the second year	0,86	0,04	0,07	8,14	4,70	0,93	0,79
	Peat litter (semidecomposed)	0,28	0,01	0,02	6,19	3,57	0,30	0,27
Dicranum polysetum	Increment of 1–2 years	0,82	0,03	0,04	5,32	3,07	0,85	0,77
	Increment of earlier period	0,51	0,02	0,03	5,19	3,00	0,54	0,49
Soil (layer 0-10 cm)	–	0,002	–	–	–	–	–	–
		Cu						
Pleurozium schreberi	Increment of 1–2 years	8,13	0,17	0,29	3,58	2,07	8,35	7,80
	Increment of earlier period	3,50	0,14	0,24	6,80	3,93	3,68	3,23
Polytrichum commune	Increment of the first year	9,20	0,17	0,29	3,17	1,83	9,52	8,95
	Increment of the second year	7,34	0,22	0,38	5,14	2,97	7,65	6,92
	Increment of earlier period	5,25	0,10	0,17	3,24	1,87	5,42	5,08
Leucobryum glaucum	Increment of the first year	4,10	0,10	0,18	4,34	2,50	4,30	3,96
	Increment of the second year	3,05	0,09	0,16	5,15	2,98	3,19	2,88
	Peat litter (semidecomposed)	2,01	0,06	0,10	5,19	3,00	2,08	1,89
Sphagnum capillifolium	Increment of the first year	4,30	0,11	0,19	4,42	2,55	4,46	4,09
	Increment of the second year	3,40	0,09	0,15	4,53	2,61	3,57	3,27
	Peat litter (semidecomposed)	2,83	0,05	0,08	2,76	1,59	2,88	2,74
Sphagnum palustre	Increment of the first year	4,58	0,07	0,12	2,57	1,49	4,71	4,48
	Increment of the second year	3,22	0,08	0,14	4,40	2,54	3,38	3,11
	Peat litter (semidecomposed)	2,11	0,05	0,09	4,05	2,34	2,20	2,03

Continuation of table 2

Moss species	Fraction of moss cover	M	m	Std	V%	P%	max.	min.
Dicranum polysetum	Increment of 1–2 years	5,06	0,11	0,19	3,81	2,20	5,20	4,84
	Increment of earlier period	3,27	0,12	0,21	6,54	3,77	3,51	3,10
Soil (layer 0–10 cm)	–	1,10	0,05	0,09	7,77	4,48	1,19	1,02
		Zn						
Pleurozium schreberi	Increment of 1–2 years	20,00	0,50	0,87	4,34	2,51	20,82	19,09
	Increment of earlier period	26,70	0,75	1,30	4,88	2,82	28,11	25,54
Polytrichum commune	Increment of the first year	18,30	0,75	1,29	7,06	4,08	19,33	16,85
	Increment of the second year	24,27	0,69	1,20	4,95	2,86	25,62	23,32
	Increment of earlier period	27,35	1,04	1,79	6,56	3,79	29,42	26,23
Leucobryum glaucum	Increment of the first year	10,08	0,18	0,31	3,05	1,76	10,41	9,80
	Increment of the second year	16,53	0,17	0,29	1,78	1,03	16,85	16,27
	Peat litter (semidecomposed)	25,16	0,59	1,02	4,04	2,33	26,25	24,24
Sphagnum capillifolium	Increment of the first year	15,00	0,34	0,59	3,95	2,28	15,56	14,38
	Increment of the second year	23,30	0,50	0,87	3,74	2,16	24,08	22,36
	Increment of earlier period	30,70	0,80	1,39	4,52	2,61	32,30	29,81
Sphagnum palustre	Increment of the first year	14,83	0,30	0,52	3,52	2,03	15,18	14,23
	Increment of the second year	25,33	0,37	0,64	2,52	1,46	26,05	24,83
	Peat litter (semidecomposed)	28,78	0,88	1,53	5,32	3,07	30,38	27,33
Dicranum polysetum	Increment of 1–2 years	14,23	0,41	0,70	4,95	2,86	14,86	13,47
	Increment of earlier period	22,16	0,47	0,81	3,67	2,12	22,63	21,22
Soil (layer 0–10 cm)	–	3,56	0,10	0,18	4,99	2,88	3,70	3,36

Note: M – arithmetic mean; m – error of arithmetic mean; V % – coefficient of variation; p – relative error of arithmetic mean; min. – minimum value; max. – maximum value

palustre – 10,88±0,41. Minimal Pb concentrations were obtained for the upper, younger fraction of mosses – increment of the first year. For terrestrial mosses this index varied (mg·kg^{-1}) from 4,75±0,13 in *Pleurozium schreberi* to 8,25±0,34 in *Polytrichum commune*; in paludal species, in particular *Sphagnum* spp., its values changed in the range 7,50±0,10 – 8,33±0,22. Mentioned above distribution of Pb in different moss fractions probably can be explained by vertical migration of this metal downward in moss carpets and also by increase of levels of moss phytomass decomposition, which causes decrease of mass and respectively increase of metal concentration per mass init.

Specific distribution in fractions of all studied moss species – terrestrial and paludal – was found for concentrations of Cu – maximal concentration was in upper moss fraction – increment of the first year with decrease to the increment of the second year and lower – to the old moss fractions. For example, concentration of Cu in *Polytrichum commune* was (mg·kg^{-1}): in increment of the first year – 9,20±0,17; increment of the second year – 7,34±0,22; lower parts – 5,25±0,10; in *Sphagnum palustre* corresponding values were (mg·kg^{-1}): 4,58±0,07; 3,22±0,08 and 2,11±0,05.

Opposite distribution in moss fractions was observed for Zn in all studied moss species – terrestrial and paludal – maximal concentrations of this metal were found in the lower, older fractions – parts below of increment of the second year and peat litter, with decrease of this parameter to increment of the second year and further decrease to the increment of the first year. In particular, in terrestrial moss *Polytrichum commune* concentration of Zn in fractions was (mg·kg^{-1}): in lower parts – 27,35±1,04; increment of the second year – 24,27±0,69; increment of the first year – 18,30±0,75; and in paludal *Sphagnum capillifolium* – 30,70±0,80; 23,30±0,50; 15,00±0,34 respectively.

More complicated distribution in moss fractions was observed for concentrations of Cd. For terrestrial mosses, such as *Pleurozium schreberi*, *Dicranum polysetum* and *Polytrichum commune* this distribution was similar – decrease Cd concentrations from increment of the first year to increment of the second year and further – to the lower part of mosses. For example, in *Polytrichum commune* values of Cd concentrations were (mg·kg^{-1}): 0,73±0,03; 0,60±0,02 and 0,42±0,02 respectively. In paludal sphagnous mosses distribution of Cd concentrations in moss fractions was differ. For both *Sphagnum* species minimal Cd content was observed in the increment of the first year, with significant increase of this index in increment of the second year and further – with significant decrease in the lower part of moss cover – peat litter.

Discussion. Measurement of concentrations of heavy metals in the soil and mosses allowed to calculate values of coefficient of it biological absorption (Fig. 1–4).

It should be noted that in the analyzed dataset heavy metals intake was differ for various moss species and metals. Data of Fig. 1–4 show that heavy metals accumulate in the increment of the first year of mosses in such range of values of CBA: Cu – from 8,38±0,22 (*Polytrichum commune*) to 4,17±0,13 (*Sphagnum palustre*); Cd – from 875±18,93 (*Leucobryum glaucum*) to 150±7,64 (*Sphagnum*

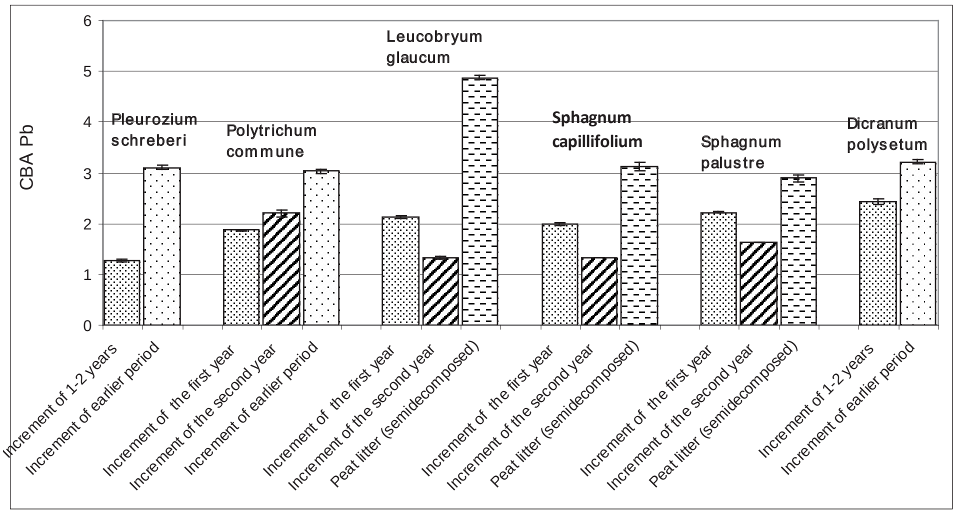

Fig. 1. Mean values (M±m) of coefficient of biological absorption of Pb in fractions of different moss species

Рис. 1. Середні значення (M±m) коефіцієнта біологічного поглинання Pb у фракціях різних видів мохів

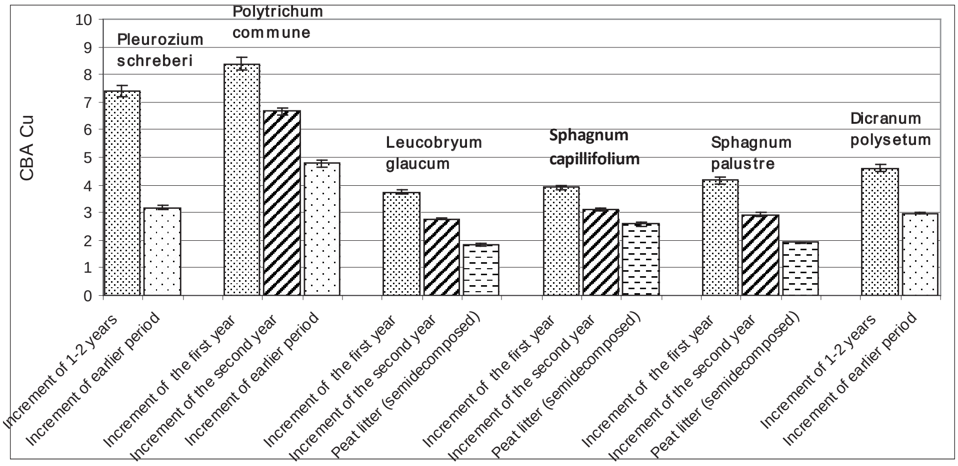

Fig. 2. Mean values (M±m) of coefficient of biological absorption of Cu in fractions of different moss species

Рис. 2. Середні значення (M±m) коефіцієнта біологічного поглинання Cu у фракціях різних видів мохів

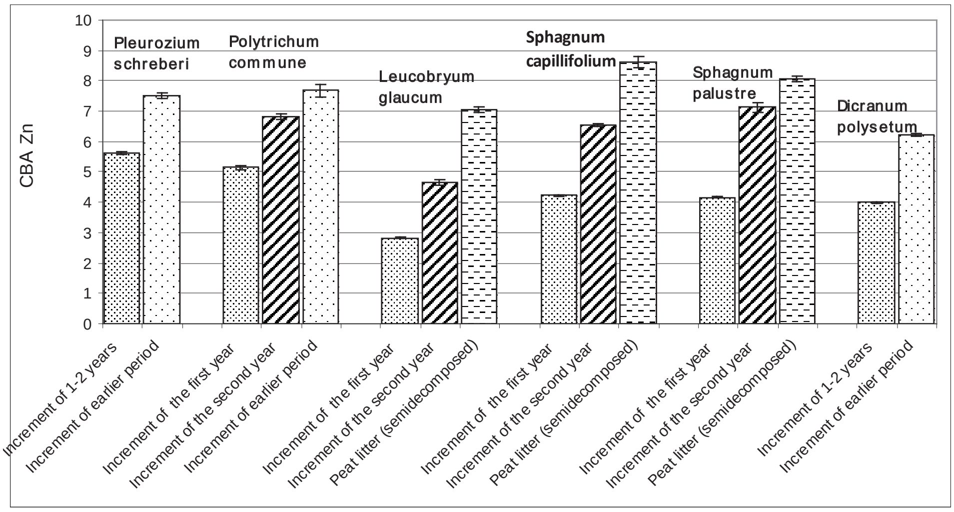

Fig. 3. Mean values (M±m) of coefficient of biological absorption of Zn in fractions of different moss species

Рис. 3. Середні значення (M±m) коефіцієнта біологічного поглинання Zn у фракціях різних видів мохів

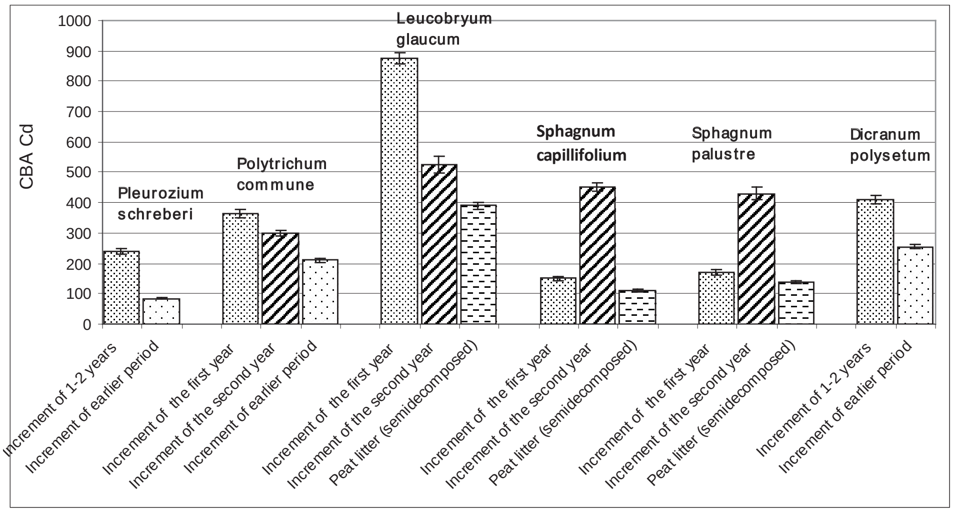

Fig. 4. Mean values (M±m) of coefficient of biological absorption of Cd in fractions of different moss species

Рис. 4. Середні значення (M±m) коефіцієнта біологічного поглинання Cd у фракціях різних видів мохів

Table 3. Results of statistical analysis of differences of mean values of CBA of heavy metals in moss fractions

Таблиця 3. Результати статистичного аналізу різниці середніх значень КБП важких металів у фракціях мохів

Moss species	Values of $F_{fact.}$ for differences of mean values of CBA of heavy metals in moss fractions				$F_{0,95}$
	Cu	Cd	Pb	Zn	
Pleurozium schreberi	421,61	360,38	3462,53	322,75	7,71
Polytrichum commune	119,04	62,31	251,73	88,87	5,14
Leucobryum glaucum	263,19	154,50	3279,32	698,87	5,14
Sphagnum capillifolium	78,77	401,03	377,37	412,63	5,14
Sphagnum palustre	180,56	155,19	246,53	438,90	5,14
Dicranum polysetum	171,73	110,88	212,07	1349,67	7,71

Note: p < 0,000

capillifolium); Pb – from 2,22±0,02 (*Sphagnum palustre*) to 1,27±0,02 (*Pleurozium schreberi*); Zn – from 5,62±0,04 (*Pleurozium schreberi*) to 2,83±0,04 (*Leucobryum glaucum*).

Results of statistical analysis clearly showed that concentrations of studied heavy metals essentially differ among fractions in all moss species on 95% confidence level (table 3).

The maximal differences of CBA heavy metals in moss fractions were observed: for Cu – in *Pleurozium schreberi* ($F_{fact.}$ = 421,61 >> $F_{0,95}$ = 7,71) and *Leucobryum glaucum* ($F_{fact.}$ = 263,19 >> $F_{0,95}$ = 5,14); for Cd – in *Sphagnum capillifolium* ($F_{fact.}$ = 401,03 >> $F_{0,95}$ = 5,14) and *Pleurozium schreberi* ($F_{fact.}$ = 360,38 >> $F_{0,95}$ = 7,71); for Pb – in *Pleurozium schreberi* ($F_{fact.}$ = 3462,53 >> $F_{0,95}$ = 7,71) and *Leucobryum glaucum* ($F_{fact.}$ = 3279,32 >> $F_{0,95}$ = 5,14); for Zn – in *Dicranum polysetum* ($F_{fact.}$ = 1349,67 >> $F_{0,95}$ = 7,71) and *Leucobryum glaucum* ($F_{fact.}$ = 698,87 >> $F_{0,95}$ = 5,14).

Interspecies differences of CBA heavy metals in fractions of different moss species also were evaluated. It was found that differences in Cu accumulation in the increment of the first year differed essentially between *Pleurozium schreberi* and *Polytrichum commune* ($F_{fact.}$ = 10,71 > $F_{0,95}$ = 7,71; p = 0,031) as well as between *Polytrichum commune* and *Leucobryum glaucum* ($F_{fact.}$ = 384,52 >> $F_{0,95}$ = 7,71; p = 0,000). But in pairs *Leucobryum glaucum – Sphagnum capillifolium, Sphagnum capillifolium – Sphagnum palustre* and *Sphagnum palustre – Dicranum polysetum* there were no statistically significant differences of mentioned above index. For Cd interspecies differences of CBA heavy metals in fractions of different moss species were more essential than for Cu. In particular, essential and reliable differences in Cd accumulation by the increment of the first year were observed in pairs: *Pleurozium schreberi – Polytrichum commune, Polytrichum commune – Leucobryum glaucum, Leucobryum glaucum – Sphagnum capillifolium, Sphagnum palustre – Dicranum polysetum* ($F_{fact.}$ = 66,96–1261,50 >> $F_{0,95}$ = 7,71; p = 0,000). Between *Sphagnum capillifolium* and *Sphagnum palustre* statistically reliable differences of CBA were absent ($F_{fact.}$ < $F_{0,95}$). For Pb differences of CBA heavy metals in fractions of different moss species were essential and reliable on 95% confidence level in all pair of mosses ($F_{fact.}$ = 7,72–664,64 >> $F_{0,95}$ = 7,71; p = 0,000–0,05). Mean values of CBA heavy metals in the increment of the first year differed essentially among majority of moss species, including pairs *Pleurozium schreberi – Polytrichum commune, Polytrichum commune – Leucobryum glaucum, Leucobryum glaucum – Sphagnum capillifolium, Sphagnum palustre – Dicranum polysetum* ($F_{fact.}$ = 17,12–918,41 >> $F_{0,95}$ = 7,71; p = 0,000–0,014). In pair *Sphagnum capillifolium – Sphagnum palustre* there were no statistically significant differences of mentioned above index.

Generalizing mentioned above results an important conclusion can be made that ranged row of heavy metals accumulated in the upper moss part (increment of the first year) looks like this: Cd > Cu > Zn > Pb; in the increment of the second year – Cd > Zn > Cu > Pb; in the lower part of moss cover – Cd > Zn > Pb > Cu. Thus, general conclusion can be made that intake of each heavy metal is species-dependent as well as distribution of its concentration among moss fractions.

Conclusions. Concentrations of heavy metals in 10-cm soil layer change in such range: Pb > Zn > Cu > Cd; in absolute values ($mg \cdot kg^{-1}$) – 3,75±0,06; 3,56±0,10; 1,10±0,05; 0,002±0,00, respectively.

Ranged row of heavy metals accumulated in the increment of the first year looks like this: Cd > Cu > Zn > Pb; in the increment of the second year – Cd > Zn > Cu > Pb; in the lower part of moss cover – Cd > Zn > Pb > Cu.

Intake of each heavy metal is species-dependent as well as distribution of its concentration among moss fractions.

Studied moss species can be used as bioindicators of pollution of forest ecosystems by heavy metals.

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ТОКСИКОЛОГІЧНЕ ДОСЛІДЖЕННЯ МОХОВОГО ПОКРИВУ СОСНОВИХ ЛІСІВ У БІОГЕОХІМІЧНОМУ ЛАНДШАФТІ ФОНОВОГО РАЙОНУ УКРАЇНСЬКОГО ПОЛІССЯ. ЧАСТИНА 1. ВАЖКІ МЕТАЛИ

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Завданнями цього дослідження було вивчення рівнів забруднення важкими металами (Cu, Cd, Pb, Zn) ґрунтів фонового лісового району Українського Полісся; оцінка концентрацій цих важких металів у фракціях мохів; розрахунок величин коефіцієнта біологічного поглинання важких металів фракціями різних видів мохів. Дослідження проведене в липні 2021 р. на трьох пробних площах у Житомирській області, Повчанському лісництві ДП «Лугинське лісове господарство». Рослинність була представлена асоціацією Molinio-Pinetum Matuszkiewicz (1973) 1981 і типом лісорослинних умов вологий субір (B_3). Зразки мохів відбирали за фракціями: Pleurozium schreberi та Dicranum polysetum – приріст 1–2-го років, приріст більш раннього періоду; Polytrichum commune – приріст 1-го року, приріст 2-го року, приріст більш раннього періоду; Leucobryum glaucum, Sphagnum capillifolium та S. Palustre – приріст 1-го року, приріст 2-го року, очіс (напіврозкладений). Вимірювання вмісту важких металів проводилося на атомно-абсорбційному спектрофотометрі С-115-М1. Як показник інтенсивності акумуляції важких металів мохами в ланці «ґрунт – мох» використано коефіцієнт біологічного поглинання. Виявлено, що концентрації важких металів у 10-см шарі ґрунту змінювалися в такому порядку: Pb > Zn > Cu > Cd; в абсолютних величинах (мг·кг$^{-1}$) – 3,75±0,06; 3,56±0,10; 1,10±0,05; 0,002±0,00. Особливий розподіл у фракціях всіх досліджених видів мохів – суходільних і болотних – виявлено для концентрацій Cu – максимальна концентрація зафіксована у прирості 1-го року, зі зменшенням у прирості 2-го року та далі – у нижній, старій фракції мохів. Протилежний розподіл у фракціях мохів спостерігався у Zn та Pb у всіх досліджених видах мохів. Більш складний розподіл у фракціях мохів спостерігався у Cd. Для суходільних мохів, таких як Pleurozium schreberi, Dicranum polysetum і Polytrichum commune згаданий розподіл був подібним – зменшення концентрацій Cd у прирості 1-го року, зі зменшенням у прирості 2-го року та далі – у нижній фракції мохів, однак у сфагнів він відрізнявся від цього. Зроблено важливий висновок, що рангований ряд важких металів, акумульованих у прирості 1-го року, є таким: Cd > Cu > Zn > Pb; у прирості 2-го року – Cd > Zn > Cu > Pb; у нижній фракції мохового покриву – Cd > Zn > Pb > Cu. Також може бути зроблено узагальнений висновок, що поглинання кожного важкого металу мохами є видоспецифічним, як і розподіл їх концентрацій між фракціями мохів.

Ключові слова: *Українське Полісся, лісові біогеоценози, ґрунти, моховий покрив, фракції мохів, важкі метали, концентрація, надходження, коефіцієнт біологічного поглинання.*