DOI https://doi.org/10.32782/geotech2022.35.05
UDC 574:630*18(477.42)

O. Orlov

Orlov O.O., PhD (Biol.), Senior Researcher, State Institution "The Institute of Environmental Geochemistry of National Academy of Sciences of Ukraine", ORCID 0000-0003-2923-5324, orlov.botany@gmail.com

EVALUATION OF MOSSES AND LICHENS AS TEST-OBJECTS OF MONITORING OF ^{137}CS CONTAMINATION OF PINE FOREST BIOGEOCENOSES IN UKRAINIAN POLISSIA

Abstract. *The goal of this study was to give comparative evaluation of applicability of different species of mosses and lichens for radiation monitoring of ^{137}Cs contamination of pine forest biogeocenoses in Ukrainian Polissia in different forest-ecological conditions (FEC). Objects of research were: species composition of mosses and lichens on stationary experimental plots (SEP), their occurrence in FEC–B_3 and FEC–A_1, sufficiency for multiyear monitoring, values of ^{137}Cs specific activity in investigated indicator species, and concentration ratio (CR) in the system «indicator biomass – substratum». Research was carried out in 2020 in Ukrainian Polissia, Zhytomyr Region, on 4 stationary experimental plots: SEP-1 – in forest-ecological conditions FEC–B_3, SEP-2, 3, 4 – in FEC–A_1. For these forest-ecological conditions occurrence of indicator species of mosses and lichens as well as their sufficiency for sampling at multiyear monitoring was studied by route method on 20 forest sites. On each SEP, samples of moss and lichen species were collected in sets of 3-5 repetitions. The substratum was sampled directly below them: for epigeous species – soil at the depth of 20 cm, for epiphytic ones – pine bark. ^{137}Cs specific activity was measured on spectrum analyser SEG-001 «AKP-S»-150 with scintillation detector BDEG-20-R1. Relative error of measurement – < 15 %. A concentration ratio (CR) was chosen as an index of intensity of ^{137}Cs accumulation by biota. The occurrence of the following species-indicators of radioactive contamination of a pine forest were shown to prevail in FEC–B_3: Dicranum polysetum, Pleurozium schreberi, Hypogymnia physodes; in FEC–A_1: Cladonia mitis, Cladonia rangiferina, Hypogymnia physodes, Dicranum polysetum. It was found that in FEC–B_3, the average values of CR in Dicranum polysetum (2.31±0.127) significantly exceeded the corresponding values in Pleurozium schreberi (1.64±0.06). The difference of the average CR values was essential at a confidence level of 95 %. In FEC–B_3, epiphytic lichen Hypogymnia physodes was characterized by the highest average CR value (8.45±0.33), i.e. the difference with mosses was statistically reliable. In FEC–A_1, epigeous mosses accumulated ^{137}Cs more intensively than epigeous lichens of genus Cladonia, the average CR values were 4.78±0.28 and 2.51±0.15, respectively, the difference was essential. In FEC–A_1, the group of epiphytic lichens was characterized by the maximum CR, with average value 6.84±0.36, which was essentially and reliably different from the corresponding values of the group of epigeous lichens and the group of epigeous mosses. It was found that among the indicator species of mosses and lichens, Hypogymnia physodes was characterized by the highest values of radiocontamination in investigated forest ecological conditions.*

Key words: *Ukrainian Polissia, forest biogeocenoses, ^{137}Cs specific activity, radiation monitoring, test-objects, mosses, lichens, Hypogymnia physodes, concentration ratio.*

Introduction

From the time of global «bomb» radionuclide fallouts in 1950s-1960s mosses and lichens have been used as test-objects of radioactive contamination of different terrestrial biogeocenoses [3, 7, 9, 11]. This is explained by significant sorption capacity of the mentioned groups of biota with respect to ^{137}Cs [7, 9]. Mosses and lichens don't have roots, they absorb mineral substances and radionuclides by the whole surface exposed to aerial dry and wet fallouts [1, 3]. After Chornobyl catastrophe radioecologists again drew attention to mosses and lichens, in particular for conducting of multiyear monitoring of radioactive contamination of forest biogeocenoses [5, 8]. In the last 10 years in Ukraine publications concerning application of mosses and lichens in radiation monitoring are fragmentary, but at the same time a lot of scattered data were published concerning ^{137}Cs content in their species in forest and bog biogeocenoses of Ukrainian Polissia. In this regard, comparative evaluation of suitability of different species of mosses and lichens and their ecological and morphological groups as test-objects for multiyear radiation monitoring of ^{137}Cs contamination of biogeocenoses of pine forest dominant in the region seems interesting.

Analysis of the recent research and publications

Results of corresponding research mainly in Ukrainian Polissia during the last 10 years are briefly analysed in this chapter. In particular, O.V. Fedotiuk, T.V. Kurbet [4] admitted that *Dicranum polysetum* in dry bors (A_1) of Zhytomyr Polissia was characterized by higher ability to accumulate ^{137}Cs than *Cladonia rangiferina*, respective values of the concentration ratio (CR) were 3.2 and 0.7, the difference was statistically reliable. Researchers [2] investigated specific activity of ^{134}Cs and ^{137}Cs in epiphytic parmelioid lichens *Flavoparmelia caperata*, *Parmotrema clavuliferum* 2 years after the accident

at the Fukushima NPP. It was shown that both species are accumulators of radiocaesium, wherein *Flavoparmelia caperata* accumulates ^{137}Cs approximately 2 times weaker than *Parmotrema clavuliferum.* A close connection was calculated (r=0.90-0.92; $p < 0.01$) between specific activity of ^{134}Cs and ^{137}Cs in thaloms of these lichens and levels of radiocontamination of the territory by radionuclides, which allows to use these species as bioindicators of radioactive contamination of the territory on a quantitative level. V.V. Melnyk, T.V. Kurbet [10] showed that in wet subors (B_3) of Zhytomyr Polissia *Dicranum polysetum* accumulates ^{137}Cs statistically reliably more intensely than *Pleurozium schreberi,* which was also confirmed by A.A. Pavlenko, O.O. Orlov [12]. For both mentioned species of moss, a close (r=0.83-0.85), reliable ($p<0.000$) connection was detected between the ^{137}Cs content in phytomass and the density of ground deposition of the radionuclide [10]. It was shown [6] that in Western Polissia of Ukraine on forest sphagnum bogs maximum values of ^{137}Cs specific activity were observed in species of flooded hollows – *Sphagnum fallax, Aulacomnium palustre* (CR=2.5), and minimum – in hummock species – *Sphagnum magellanicum, Polytrichum strictum* (CR=1.3-2.0). It was also shown that epigeous lichens (*Cladonia digitata*, *C. gracilis*) accumulated less ^{137}Cs (CR=1.1-1.7) in comparison with epiphytic species (*Hypogymnia physodes*, *Pseudevernia furfuracea*) (CR=3.1-11.1). O.O. Orlov [14] in Ukrainian Polissia studied specific activity of ^{137}Cs in mosses and lichens on geochemical barriers of marginal zone of a mezotrophic bog. It was detected that at density of contamination of the territory by ^{137}Cs near 37 kBq·m^{-2}, ^{137}Cs specific activity was maximum in *Sphagnum fallax* – 2810±280 Bq·kg^{-1}, and significantly lower in brie (green) mosses – from 1500±148 Bq·kg^{-1} in *Dicranum polysetum* to 1064±100 Bq·kg^{-1} in *Pleurozium schreberi.* In epiphytic lichens maximum ^{137}Cs content was measured in thalloms of *Hypogymnia physodes* – 4292±450 Bq·kg^{-1}, and minimum – in *Pseudevernia furfuracea* – 3657±370 Bq·kg^{-1}.

Goal of the study

The goal of this study was to give comparative evaluation of suitability of different species of mosses and lichens for radiation monitoring of ^{137}Cs contamination of biogeocenoses of pine forests of Ukrainian Polissia depending on the ecological, in particular, forest-ecological conditions, and also to select the most convenient species of these groups of biota as test-objects for multiyear monitoring of radioactive contamination of forest territories of the studied region.

Objects and methodology of research

Objects of research were: species composition of mosses and lichens on stationary experimental plots (SEP), occurrence of indicator species in types of forest-ecological conditions (FEC) – B_3 and A_1, sufficiency for multiyear monitoring, values of ^{137}Cs specific activity in investigated species as well as the concentration ratio (CR) in the system «biomass – substratum».

The research was conducted in February 2020 in Ukrainian Polissia, Zhytomyr region, State Enterprise "Luhyny Forestry", on 4 stationary experimental plots (SEP), 1 ha each. SEP-1: Povchanske forestry unit, square 50, unit 16, 70-years old pine forest of association *Pinetum myrtilloso-hylocomiosum*, FEC – wet subir (B_3). On SEP-1, projective cover of mosses varied in range of 75-95 %, *Pleurozium schreberi* and *Dicranum polysetum* were equally present, *Sphagnum capillifolium* was found in depressions; epiphytic foliose lichen *Hypogynnia physodes* prevailed on pine trunks. SEP-2: Povchanske forestry unit, square 11, unit 10, 30-years old pine forest of association *Pinetum hylocomioso-cladinosum* on sand dune, FEC – dry bir (A_1). Projective cover of epigeous mosses varied in the range of 15-20 %, *Pleurozium schreberi* and *Dicranum polysetum* were equally present, *Ceratodon purpureus* grew near pine trunks. Projective cover of epigeous lichens was 65-70 %, the base of this layer was created by *Cladonia mitis* and *Cladonia rangiferina*, *Hypogynnia physodes* dominated on pine trunks. SEP-3: Lypnyky forestry unit, square 26, unit 15, 40-years old pine forest of association *Pinetum cladinosum* on sand dune, FEC – dry bir (A_1). SEP-4: Lypnyky forestry unit, square 22, unit 30, 38-years old pine forest of association *Pinetum cladinosum* on sand dune, FEC – dry bir (A_1). On FEC-3 and FEC-4, epigeous lichens created a solid layer – *Cladonia mitis* and *Cladonia rangiferina*; *Cladonia uncialis, Cladonia rangiformis* and some other lichen species were found as an admixture. Epiphytic lichens were common on trunks of *Pinus sylvistris* – mainly *Hypogymnia physodes* with some admixture of *Pseudevernia furfuracea* and *Usnea hirta*. Epigeous mosses were found from the northern side of pine trees, *Pleurozium schreberi* and *Dicranum polysetum* – in projections of the tree crowns (each with projective cover of about 10-15%), and *Ceratodon purpureus* (about 1%) – near trunk bases.

For forest-ecological conditions of wet subir (B_3) and dry bir (A_1), occurrence of the indicator species of mosses and lichens was studied by route method. Each species as well as its sufficiency for sampling for multiyear radiation monitoring was studied at 20 forest sites. On each SEP, samples of moss and lichen species were collected in sets of 3-5 repetitions, the substratum was sampled directly below them: for epigeous species – soil at the depth of 20 cm [13], for epiphytic species – bark of *Pinus sylvestris*. All samples were dried at temperature 80ºC during 72 h and homogenized into powder. ^{137}Cs specific activity was measured using spectrum analyzer SEG-001 «AKP-S»-150 with scintillation detector BDEG-20-R1. Relative error of measurement of ^{137}Cs specific activity in all samples didn't exceed 15 %. For all species of mosses and lichens values of the concentration ratio (CR) were calculated – as a ratio of ^{137}Cs specific activity in biomass of moss or lichen (Bq·kg^{-1}) to ^{137}Cs specific activity in growth substrate (Bq·kg^{-1}). The results were statistically processed.

Results and discussions

As the result of the route investigation of typical sites of pine forests in different types of forest-ecological conditions it was found that according to their occurrence, species-indicators in the FEC – wet subir (B_3) created the following row: *Dicranum polysetum* (occurred on 97.6%

of sites) > *Pleurozium schreberi* (95.4%) > *Hypogymnia physodes* (94.3%) > *Dicranum scoparium* (17.8%) > *Sphagnum capillifolium* (14.9%). The first three species were characterized by the highest occurrence in FEC-B_3, as well as by phytomass per square unit, sufficient to carry out of multiyear radiation monitoring. In the FEC dry bir (A_1), the row of indicator species was as follows: *Cladonia mitis* (85.2% sites) > *Hypogymnia physodes* (82.6%) > *Cladonia rangiferina* (68.7%) > *Dicranum polysetum* (65.4%) > *Pleurozium schreberi* (60.8%) > *Cladonia uncialis* (35.2%) > *Pseudevernia furfuracea* (34.9%) > *Ceratodon purpureus* (15.3%) > *Usnea hirta* (10.1%). Thus, for pine forests in FEC–A_1, the first four species can be recommended as indicators of contamination of forest biogeocenoses by ^{137}Cs. But it should be noted that collection of samples of epigeous moss and lichens is technically much easier and less time-consuming in comparison with sampling of epiphytic lichens when significant amount of time and efforts should be wasted for separation of lichen thalli from growth substrate (bark of pine). In this study, average values of density of ^{137}Cs ground deposition (As) and of ^{137}Cs specific activity (Am) in biomass of each indicator species were calculated. The calculations showed that on SEP-1 (FEC–B_3) the average value of As was 123.9±11.04 kBq·m^{-2}, and the average values of Am in the indicator species were: *Pleurozium schreberi* – 3678±236.0 Bq·kg^{-1}, *Dicranum polysetum* – 6531±283.1 Bq·kg^{-1}, *Dicranum scoparium* – 7605±312.4 Bq·kg^{-1}, *Sphagnum capillifolium* – 3540±258.7 Bq·kg^{-1}, *Hypogymnia physodes* – 14679±1028.8 Bq·kg^{-1}; on SEP-2 (FEC-A_1), the average value of As was 23.2±1.47 kBq·m^{-2}, and the average values of Am: *Pleurozium schreberi* – 636±27.2 Bq·kg^{-1}, *Dicranum polysetum* – 876±43.9 Bq·kg^{-1}, *Ceratodon purpureus* – 907±45.1 Bq·kg^{-1}, *Cladonia mitis* – 547±27.0 Bq·kg^{-1}, *Cladonia rangiferina* – 532±68.2 Bq·kg^{-1}, *Hypogymnia physodes* – 1612±95.5 Bq·kg^{-1}. On SEP-3 (FEC-A_1), the average value of As was 17.1±0.68 kBq·m^{-2}, and the average values of Am: *Cladonia mitis* – 434±48.0 Bq·kg^{-1}, *Cladonia rangiferina* – 554±32.4 Bq·kg^{-1}, *Cladonia uncialis* – 299±22.3 Bq·kg^{-1}, *Pleurozium schreberi* – 461±34.5 Bq·kg^{-1}, *Dicranum polysetum* – 655±37.9 Bq·kg^{-1}, *Ceratodon purpureus* – 814±13.3 Bq·kg^{-1}, *Hypogymnia physodes* – 954±89.7 Bq·kg^{-1}, *Usnea hirta* – 707±26.4 Bq·kg^{-1}, *Pseudevernia furfuracea* – 593±71.2 Bq·kg^{-1}; on SEP-4 (FEC-A_1), the average value of As was 17.6±1.05 kBq·m^{-2}, and the average values of Am: *Cladonia mitis* – 267±55.7 Bq·kg^{-1}, *Cladonia rangiferina* – 345±38.1 Bq·kg^{-1}, *Cladonia uncialis* – 494±65.9 Bq·kg^{-1}, *Cladonia rangiformis* – 451±60.9 Bq·kg^{-1}, *Pleurozium schreberi* – 422±21.9 Bq·kg^{-1}, *Dicranum polysetum* – 693±27.4 Bq·kg^{-1}, *Ceratodon purpureus* – 827±57.2 Bq·kg^{-1}, *Hypogymnia physodes* – 1144±45.1 Bq·kg^{-1}, *Usnea hirta* – 778±54.7 Bq·kg^{-1}, *Pseudevernia furfuracea* – 665±50.3 Bq·kg^{-1}.

On each experimental plot, the average values of CR ^{137}Cs were calculated for all investigated indicator species of mosses and lichens. On SEP-1, significantly higher average CR values were found for *Dicranum polysetum* (2.31±0.127) than for *Pleurozium schreberi* (1.64±0.06). The difference of CR average values was essential at a 95 % confidence level ($F_{fact.} = 22.89 >> F_{0,95} = 7.71$; $p = 0.01$), that correlated well with the results of other researches [10, 12]. The difference of CR average values for *Pleurozium schreberi*, *Dicranum polysetum* and *Sphagnum capillifolium* (CR = 1.18±0.08) was essential and reliable as well ($F_{fact.} = 22.15\text{-}56.94 >> F_{0,95} = 7.71$; $p = 0.001\text{-}0.01$). The average CR values of all moss species on all experimental plots essentially differed from the analogous index for epiphytic foliose lichen *Hypogymnia physodes* (CR = 8.45±0.33) ($F_{fact.} = 188.87\text{-}272.41 >> F_{0,95} = 5.99$; $p < 0{,}000$). Since SEP-2, SEP-3 and SEP-4 were established at the same type of forest-ecological condition – dry bir (A_1) appropriate to calculate the average values of CR for each indicator species of mosses and lichens generally for this type, and also in the limits of ecological species groups (epigeous, epiphytic) in the whole massif of the mentioned above experimental plots. The obtained results justified that as in FEC–B_3, in FEC–A_1, the average CR values for *Dicranum polysetum* (5.46±0.47) significantly exceeded the analogous indexes for *Pleurozium schreberi* (3.32±0.26). The difference of average values of CR was essential at a 95% confidence level ($F_{fact.} = 15.78 >> F_{0,95} = 4.49$; $p < 0.000$). The difference of average values of CR for *Pleurozium schreberi* and *Ceratodon purpureus* was essential and reliable ($F_{fact.} = 30.72 >> F_{0,95} = 4.49$; $p < 0.000$). But between the average CR values for *Dicranum polysetum* and *Ceratodon purpureus* statistically reliable difference was absent. In dry pine forests (FEC–A_1), the layer of epigeous lichens plays the determining role in undergrowth vegetation, with the following average CR values for its species: *Cladonia mitis* – 2.57±0.263; *Cladonia rangiferina* – 2.55±0.186; *Cladonia uncialis* – 2.42±0.418; *Cladonia rangiformis* – 2.47±0.329. Statistically reliable differences were absent among the mentioned above lichen species ($F_{fact.} = 0.05 << F_{0,95} = 2.98$). Absence of statistically reliable differences in ^{137}Cs accumulation by different species of epigeous lichens allows to make a preliminary conclusion about possibility of collection of samples of epigeous lichen cover without of its division into species. However, we think that this conclusion requires additional, detailed, further research. As it was shown previously, in FEC-A_1, foliose lichen *Hypogymnia physodes* was found most frequently from the group of indicator epiphytic species (CR = 8.26±0.39), foliose lichen *Pseudevernia furfuracea* (CR = 5.07±0.41) and fruticulus lichen *Usnea hirta* (CR = 6.47±0.21) occurred much rarer. The results of ANOVA justified that average values of CR for *Hypogymnia physodes* and *Pseudevernia furfuracea* and *Usnea hirta* differed essentially and reliably ($F_{fact.} = 12.49\text{-}30.48 >> F_{0,95} = 4.67$; $p = 0.0000\text{-}0.004$), as well as those for *Pseudevernia furfuracea* and *Usnea hirta* ($F_{fact.} = 9.37 > F_{0,95} = 4.96$; $p = 0.01$).

Analysis of accumulative ability of different species of mosses and lichens with respect to ^{137}Cs as well as of their ecological groups is of significant theoretical and practical interest (Fig. 1-2).

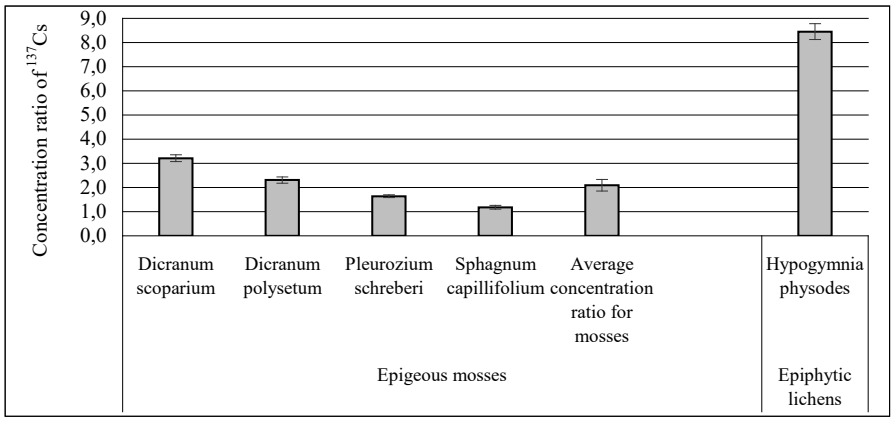


Fig. 1. Average values of ^{137}Cs concentration ratio for indicator species of mosses and lichens in wet subir (B_3)

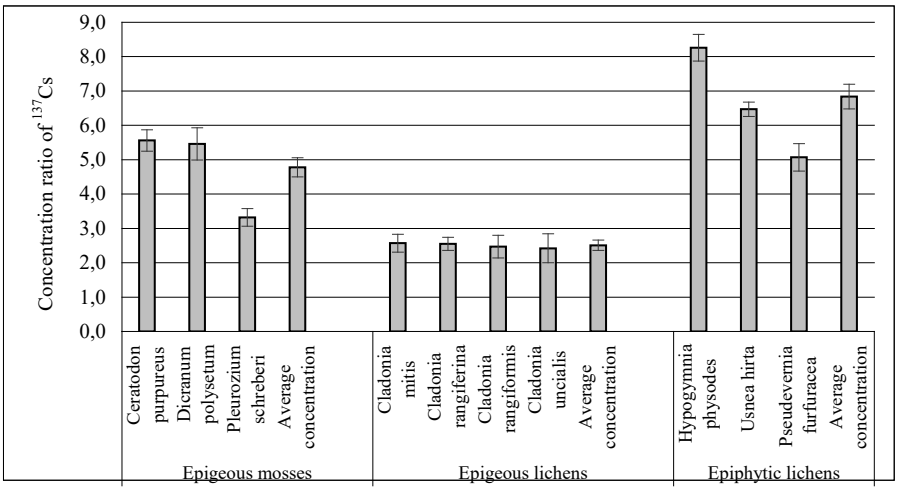


Fig. 2. Average values of ^{137}Cs concentration ratio for indicator species of mosses and lichens in dry bir (A_1)

Thus, the mentioned above data allow to give a complex quantitative evaluation of applicability of the investigated species of mosses and lichens as bioindicators of radioactive contamination of pine forests by ^{137}Cs. In this case, four parameters of indicator species were taken into account which are important for conducting of multiyear monitoring of radioactive contamination: occurrence in corresponding biogeocenoses, phytomass per unit of area, intensity of ^{137}Cs accumulation by biomass, relative easiness of sampling. It was found that the most convenient test-objects for multiyear radiation monitoring in FEC–B_3 are: *Dicranum polysetum*, *Pleurozium schreberi, Hypogymnia physodes,* and in FEC–A_1 – *Cladonia mitis*, *Cladonia rangiferina, Hypogymnia physodes, Dicranum polysetum.*

Conclusions

1. Based on complex assessment, the following species-indicators of contamination of pine forests by ^{137}Cs can be distinguished in wet subir (B_3): *Dicranum polysetum, Pleurozium schreberi, Hypogymnia physodes*, and in FEC–A_1 – *Cladonia mitis*, *Cladonia rangiferina, Hypogymnia physodes, Dicranum polysetum.*

2. In FEC–B_3, the average values of CR for *Dicranum polysetum* (2.31±0.127) exceeded the analogous index in for *Pleurozium schreberi* (1.64±0.06). The difference of the average values of CR was essential at a 95 % confidence level. Epiphytic foliose lichen *Hypogymnia physodes* was characterized by the highest average value of CR (8.45±0.33) in these forest-ecological conditions. In this species, the difference of CR value with epigeous mosses was statistically reliable at a 95 % confidence level.

3. In FEC–A_1, epigeous mosses accumulated ^{137}Cs more intensely than epiphytic lichens of the genus *Cladonia*. The average values of CR were 4.78±0.28 and 2.51±0.15, respectively, difference was reliable. Maximum values of CR in FEC–A_1 were observed in the group of epiphytic lichens with average value 6.84±0.36, which differed statistically essentially and reliably from the corresponding values in groups of epigeous lichens and epigeous mosses.

Prospects for further research

This research covered only FEC–B_3 and FEC–A_1, but similar research is actual also for other forest-ecological conditions of Ukrainian Polissia (A_2, A_3, A_4, A_5, B_1, B_2, B_4, B_5, C_2 etc.) and not only for Scots pine forests but also for the forests of other tree species composition – oak, pine-oak, birch etc.

References

1. Cornelssen, J.H.C., Lang, S.I., Soudzilovskaia, N.A., During, H.J. (2007), Comparative Cryptogam Ecology: A Review of Bryophyte and Lichen Traits that Drive Biogeochemistry. *Annals of Botany,* **99**: 987–1001.

2. Dohi T., Ohmura Y., Kashiwadani H., Fujiwara K., Sakamoto Y., Iijima K. (2015), Radiocaesium activity concentrations in parmelioid lichens within a 60 km radius of the Fukushima Dai-ichi Nuclear Power Plant. *J. Environ. Radioactivity*, **146**: 125-133.

3. Eckl, P., Turk, R., Hofmann, W. (1984), Natural and man-made radionuclide concentrations in lichens at several locations in Austria. *Nord-J.-Bot. Copenhagen, Denmark: Council for Nordic Publications in Botany*, **4(4)**: 521–524.

4. Fedotiuk, O.V., Kurbet, T.V. (2017), Distribution of caesium-137 specific activity in components of moss-lichen cover. *Abstracts of XIII Ukr. Scien. on-line Conf. "Modern Problems of Ecology"*. Zhytomyr, ZhDTU. URI: http://eztuir.ztu.edu.ua/123456789/6391.

5. Giovani, C., Nimis, P.L., Bolognini, G., Padovani, R., Usco, A. (1994), Bryophytes as indicators of radiocesium deposition in norteastern Italy. *Sci. Total Environ.* **157(1-3)**: 35-43. DOI: 10.1016/0048-9697(94)90563-0.

6. Golovko, O.V. (2021), *Migration and redistribution of ^{137}Cs in bog ecosystems of Western Polissia of Ukraine* (PhD Thesis). National University of Water and Environmental Engineering, Rivne, 26 p.

7. Guilitte, O., Brobant, B., Garsia, M.S. (1990), Use of mosses and lichens for the evaluation of radioactive fallout, deposits and flows under forest cover. *Mem. Soc. Royal Bot. Belg*. **12**: 89-95.

8. Hofmann, W., Attarpour, N., Letter, H., Turk, R. (1993), ^{137}Cs concentrations in lichens before and after the Chernobyl accident. *Health Phys*., **64(1)**: 70-73.

9. Mattsson, L.J.S. (1975), ^{137}Cs in the reindeer lichen *Cladonia alpestris*: deposition, retention and internal distribution, 1961-1970. *Health Physics*, **28(3)**: 233-248.

10. Melnyk, V.V., Kurbet, T.V. (2018), Peculiarities of accumulation of caesium-137 in moss cover of forests of Ukrainian Polissia. *Scientific Horizons*, **2(65)**: 51-57.

11. Miettinen, J.K. (1969), The present situation and recent developments in the accumulation of Cs-137, Sr-90 and Fe-55 in Arctic foodchains. *Environ. Contamin. Radioact. Mater*. Vienna: 145-150.

12. Pavlenko, A.P., Orlov, O.O. (2020), Mosses and lichens as test-objects of monitoring of radioactive contamination of pine forests of Ukrainian Polissia by ^{137}Cs. *XXVII Annual Scientific Conference of the Institute of Nuclear Research of NAS of Ukraine*: annotation to reports. Kyiv, Institute of nuclear research of NAS of Ukraine: 319-320.

13. Quality of Soil. Methodology of soil sampling for radiation control. *SOU 74.14-37-425:2006*. Kyiv, Ministry of Agrarian Policy of Ukraine, 2006. 15 p.

14. Orlov, O.O. (2021), Regularities of ^{137}Cs migration on geochemical barriers of marginal zone of mesotrophic bog in Ukrainian Polissia. *Geochemistry of Technogenesis*, **6(34)**: 58-70.

ОЦІНКА МОХІВ ТА ЛИШАЙНИКІВ ЯК ТЕСТ-ОБ'ЄКТІВ МОНІТОРИНГУ ЗАБРУДНЕННЯ ^{137}CS БІОГЕОЦЕНОЗІВ СОСНОВИХ ЛІСІВ УКРАЇНСЬКОГО ПОЛІССЯ

Орлов О.О.

Орлов О.О., кандидат біологічних наук, старший науковий співробітник, Державна установа «Інститут геохімії навколишнього середовища Національної академії наук України», ORCID 0000-0003-2923-5324, orlov.botany@gmail.com

Анотація. *Метою даного дослідження була порівняльна оцінка придатності різних видів мохів та лишайників для радіаційного моніторингу забруднення ^{137}Cs біогеоценозів соснових лісів Українського Полісся у різних лісорослинних умовах. Об'єктами дослідження були: видовий склад мохів і лишайників на постійних пробних площах (ППП), їх зустрічність у ТЛУ – B_3 та A_1, достатність для багаторічного моніторингу, величина питомої активності ^{137}Cs у досліджених видах та коефіцієнт накопичення (КН) у системі «біомаса – субстрат». Дослідження проведено 2020 р. в Українському Поліссі, у Житомирській обл., на чотирьох постійних пробних площах: ППП-1 – у типі лісорослинних умов (ТЛУ)–B_3, ППП-2, 3, 4 – у ТЛУ–A_1. Маршрутним методом для цих типів лісу вивчено розповсюдженість індикаторних видів мохів та лишайників на 20-и ділянках та їхня достатність для відбору зразків при багаторічному моніторингу. На кожній ППП зразки видів мохів та лишайників відбирали у 3-5-кратній повторності, безпосередньо під ними відбирали субстрат: для епігейних видів – ґрунт на глибину 20 см, для епіфітних – кору сосни. Питому активність ^{137}Cs вимірювали на спектроаналізаторі СЕГ-001 «АКП-С»-150 з сцинтиляційним детектором БДЕГ-20-Р1. Показником інтенсивності акумуляції ^{137}Cs біотою був коефіцієнт накопичення (КН). Показано, що у ТЛУ–B_3 за зустрічністю переважають такі види-індикатори забруднення соснових лісів ^{137}Cs: Dicranum polysetum, Pleurozium schreberi, Hypogymnia physodes, а у ТЛУ–A_1: Cladonia mitis, C. rangiferina, Hypogymnia physodes, Dicranum polysetum. Виявлено, що у ТЛУ–B_3 середні значення КН у Dicranum polysetum (2,31±0,127) значно перевищували такі у Pleurozium schreberi (1,64±0,06), різниця середніх значень КН була суттєвою на 95% довірчому рівні. Найбільшим середнім КН у ТЛУ–B_3 характеризувався епіфітний лишайник Hypogymnia physodes (КН = 8,45±0,33), у якого різниця з мохами була статистично достовірною. У ТЛУ–A_1 епігейні мохи накопичували ^{137}Cs інтенсивніше ніж епігейні лишайники роду Cladonia, середні значення КН дорівнювали відповідно 4,78±0,28 та 2,51±0,15, різниця була суттєвою. Максимальним КН у ТЛУ–A_1 відзначалася група епіфітних лишайників з середнім значенням КН = 6,84±0,36, яке відрізнялося суттєво та достовірно від відповідних значень у групи як епігейних лишайників, так і епігейних мохів. Виявлено, що серед індикаторних видів мохів та лишайників Hypogymnia physodes характеризувалася найвищими значеннями радіоактивного забруднення у досліджених типах лісорослинних умов.*

Ключові слова: *Українське Полісся, соснові біогеоценози, питома активність ^{137}Cs, радіаційний моніторинг, тест-об'єкти, мохи, лишайники, Hypogymnia physodes, коефіцієнт накопичення.*