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CHANGES IN RADIOACTIVE CONTAMINATION OF LIVING GROUND COVER PLANTS IN BLACK ALDER STANDS SINCE THE CHORNOBYL ACCIDENT IN THE FORESTS OF ZHYTOMYR POLISSIA

The results of research conducted over the past 30 years in the forest ecosystems of Zhytomyr Polissia, in the areas affected by radioactive contamination as a result of the Chornobyl accident. In the course of the research carried out at the Poliskyi Branch of the Ukrainian Research Institute of Forestry and Forest Melioration named after G. M. Vysotsky, methods of forest radioecology, botany, and forestry were used, and the results were processed using statistical analysis. The peculiarities of radioactive contamination of the most common herbaceous and dwarf-shrub plants in the stands of black alder in damp fairly fertile site types were studied. As indicators characterizing these features, we used ^{137}Cs specific activity in the aboveground part of plants and the transfer factor of radionuclide to plant phytomass from the soil. It was found that the highest values of the transfer factor of ^{137}Cs from the soil to the aerial part of the plant phytomass in 1999 are characteristic of ferns: for *Dryopteris cristata* (L.) A. Gray (276.9 $m^2 \cdot kg^{-1} \cdot 10^{-3}$), *Dryopteris carthusiana* (Vill.) H. P. Fuchs (236.5 $m^2 \cdot kg^{-1} \cdot 10^{-3}$), *Thelypteris palustris* Schott (171.2 $m^2 \cdot kg^{-1} \cdot 10^{-3}$), and *Athyrium filix-femina* (L.) Roth (164.0 $m^2 \cdot kg^{-1} \cdot 10^{-3}$). It was found that among the higher plants, the highest values of this indicator are for the *Agrostis stolonifera* L. (263.5 $m^2 \cdot kg^{-1} \cdot 10^{-3}$), *Galium uliginosum* L. (155.8 $m^2 \cdot kg^{-1} \cdot 10^{-3}$) and *Maianthemum bifolium* (L.) F. W. Schmidt (155.4 $m^2 \cdot kg^{-1} \cdot 10^{-3}$). It was found out that the previously noted trends and interspecific differences in radionuclide accumulation persist after 22 years. It is shown, using the example of three plant species (*Lysimachia vulgaris* L., *Galium uliginosum*, and *Maianthemum bifolium*), that during the observation period (1991-2021) there is a gradual decrease in radioactive contamination of living ground cover plants and the intensity of ^{137}Cs intake into them. This is explained by the decay of the radioactive element, its entry into various perennial components of forest ecosystems, some fixation in the soil, and, possibly, its removal beyond their borders. The established decrease in ^{137}Cs specific activity in the aboveground part of plants is described by linear equations: for *Lysimachia vulgaris* – $A_m = -605.34a + 3745.6$; $R^2 = 0.98$; *Galium uliginosum* – $A_m = -5107.5a + 30698$; $R^2 = 0.99$; *Maianthemum bifolium* – $A_m = -4661.6\,a + 28280$; $R^2 = 0.98$. The identified peculiarities of radioactive contamination of various plant species, changes in ^{137}Cs specific activity in them, and transfer factors of the radionuclide from the soil in stands of black alder in damp fairly fertile site types can be used in scientific works to predict possible changes in its redistribution within the ecosystem, as well as in the practice of harvesting medicinal plants in areas contaminated with radionuclides.

Keywords: radionuclide; ^{137}Cs specific activity; transfer factor; type of forest ecological condition; *Alnus glutinosa* (L.) Gaertn.; herbaceous-dwarf-shrub layer; damp fairly fertile site type (C_4).

Introduction / Вступ

The radioactive elements released into the atmosphere during the Chornobyl accident were transported by air masses over significant distances and gradually settled on settlements, open areas, and forests. Surface radioactive contamination of all components of natural and anthropogenic landscapes occurred. After radionuclides entered the forest ecosystems, they were deposited on the surface of parts and organs of tree species, and subsequently, with annual precipitation as well as under the influence of wind, rain, and some natural processes, they moved to the surface of lower-level plants and soil. At the same time, surface radioactive contamination of herbaceous and dwarf-shrub plants of the living ground cover occurred, which in subsequent years was supplemented by root intake of radionuclides from the soil.

Since the Chornobyl accident, radionuclides have been redistributed among the components of forest ecosystems, and it is important for scientists to understand the directions

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of migration of radioactive elements within specific ecosystems, to quantify the processes existing at a certain time, and to develop methods for their prediction. Living ground cover plants often form dense coverings and have a significant phytomass; some species are perennials and can concentrate and retain a significant amount of radionuclides, which can significantly affect their redistribution. Some of them are used by humans for food (wild berries), as well as in folk and official medicine. These circumstances require studies on current levels of radioactive contamination of herbaceous and shrubby plants in plantations of different species compositions and in different types of forest ecological conditions.

Object of research – herbaceous and dwarf-shrub plants in forest stands of black alder in damp fairly fertile site type on radioactively contaminated lands of Zhytomyr Polissia.

Subject of research – methods and means of determining indicators characterising the degree of radioactive contamination of soil and plants growing in black alder stands in the study area.

The purpose of the work is to compare the levels of radioactive contamination of living ground cover plants over the past 30 years in black alder stands growing in damp fairly fertile site type.

To achieve this *purpose*, the following main *research objectives are identified*: to determine the values of ^{137}Cs specific activity in the aerial parts of herbaceous and dwarf-shrub plants; to compare the values of ^{137}Cs transfer factor to plants of living ground cover obtained in 1991-2021; to establish the dynamics of radioactive contamination of the most common herbaceous and dwarf-shrub species over the past 30 years.

Analysis of recent research and publications. The first studies on radioactive contamination of plants in Ukraine were conducted in the 60 s of the last century [2]. The researchers measured beta activity levels in soil and plants in different regions of the country. The results allowed the scientists to identify some anomalous areas (in Cherkasy, Vinnytsia, Kyiv, and Zaporizhzhia regions) in terms of beta activity levels, as well as determine these levels in lichens, mosses and many higher plants. The first two groups of plants were characterised by the highest levels of beta-activity, while the taller plants showed significant fluctuations in this indicator. The researchers were able to draw preliminary conclusions that a high accumulation of radionuclides is typical for plants of the families *Rosaceae*, *Primulaceae*, *Asteraceae*, and a low accumulation is typical for the families *Brassicaceae*, *Liliaceae*.

A small number of publications on radioactive contamination of various plant species in some natural and anthropogenic ecosystems appeared in the first years after the Chornobyl accident, but they were fragmentary, using different methodological approaches, and therefore the results presented were difficult to compare or generalise. A little later, a monograph was published in Ukraine, which also presents the results of the study of the radioactive contamination of various plants in different regions of the country [3]. The obtained data were presented without reference to the density of radioactive contamination of the soil at the sites of plant sampling and without a description of the ecological conditions of their growth, which did not allow comparison of the results obtained in different regions of Ukraine by other authors.

Over time, studies on radioactive contamination of herbaceous and shrubby plants of the living aboveground cover, in particular those related to medicinal and food plants, were conducted in the forest ecosystems of Ukraine's Polissia. The researchers ranked the plants according to the decrease in ^{137}Cs content in the aboveground part of the phytomass: *Vaccinium myrtillus* L. > *Thymus serpyllum* L. > *Convallaria majalis* L. > *Fragaria vesca* L. > *Helichrysum arenarium* (L.) Moench > *Hypericum perforatum* L. > *Origanum vulgare* L. [5]. Scientists analyzed the values of the transfer factor (TF) of different plant species that grew in optimal forest conditions and divided them into five groups: the first group of very weak ^{137}Cs accumulators with a transfer factor < 1, the second group of weak accumulators – 1 < TF < 10, the third group of medium accumulators – 10 < TF < 50, the fourth group of strong accumulators – 50 < TF < 100, and the fifth group of very strong accumulators – >100 [18].

Subsequently, researchers began to establish the peculiarities of radionuclide intake into components of forest ecosystems on a forest ecological type basis and found that the levels of radioactive contamination of one plant species in different types of forest ecological conditions and vegetation conditions within their ecological range are very different [17]. The scientists came to the generalised conclusion that these levels are higher in specimens that grow in more humid conditions.

A fairly small number of publications have been devoted to the study of the dynamics of radioactive contamination of some plant species since the Chornobyl accident. They are mainly devoted to those, as noted above, that are related to medicinal and food plants [8, 9]. The researchers found significant variability in the amount of radionuclides in plants over the years and a general decrease in this indicator since the Chornobyl disaster. The researchers explained the first trend by the peculiarities of weather conditions in each particular year of observation, and the second by the migration of the radionuclide to the components of forest ecosystems and its more rigid fixation in the soil.

Twenty-five years after the Chornobyl accident, several scientific publications have been published on ^{137}Cs migration in forest ecosystems in waterlogged areas and swamps in stands of different species compositions, including black alder [1, 15, 16]. The research was conducted in the Zhytomyr and Rivne regions. The scientists presented materials on ^{137}Cs migration in different soil types; distribution of the radionuclide in components of forest ecosystems in oligotrophic and mesotrophic bogs; peculiarities of radioactive contamination of the main tree species (*Pinus sylvestris* L., *Alnus glutinosa* (L.) Gaerth., *Betula pendula* Roth.); peculiarities of radionuclide accumulation by some species of herbaceous and dwarf-shrub plants in bogs of different types.

The analysis of publications concerning the peculiarities of radioactive contamination of herbaceous and dwarf-shrub plants in forest stands of different species compositions in Ukrainian Polissia. It allows us to conclude that this issue has been insufficiently studied and that there are no scientifically based proposals for the use of plants in stands of black alder in the type of forest ecological condition and vegetation conditions within its ecological range.

Materials and methods of research. The research was carried out on experimental plots in the Luhynske Forestry of the "Luhynske Forestry" branch of the State Enterprise "Forests of Ukraine" in pure stands of black alder (experi-

mental plots No. 71/38, 79/4 and 85/14) in damp fairly fertile site type (C_4). The taxonomic characteristics of the alder stands in the experimental plots were as follows: composition of tree canopy – alder 95-100 %, birch 0-5 %; stand origin – natural; stand quality class – I-I^a, stand density – 0.6-0.7. The age of the stands on the first two experimental plots is 45-48 years, and on the third – 74 years. The density of ^{137}Cs radioactive contamination of soil in 2021 was $48.0^{\pm 15.2}$; $70.0^{\pm 13.6}$ and $38.2^{\pm 1.03}$ kBk·m^{-2} respectively. The experimental plots have a well-defined microrelief, with trunk elevations and depressions between them. The understory consisted of *Rubus idaeus* L., with a closeness of 0.2-0.3. The projected coverage of the herbaceous-dwarf-shrub layer is 60-70 %. The herbaceous-dwarf-shrub layer on the experimental plots consisted of numerous species: *Carex acutiformis* Ehrh., *Carex brizoides* L., *Scirpus sylvaticus* L., *Agrostis stolonifera* L., *Calamagrostis canescens* (Web.) Roth, *Molinia caerulea* (L.) Moench, *Dryopteris carthusiana* (Vill.) H. P. Fuchs, *Athyrium filix-femina* (L.) Roth, *Filipendula ulmaria* (L.) Maxim., *Galium uliginosum* L., *Maianthemum bifolium* (L.) F. W. Schmidt, *Lysimachia vulgaris* L., *Geum rivale* L., *Lythrum salicaria* L., *Viola uliginosa* Bess, and other. The soils – soddy, highly podzolic, superficially peaty, gley on fluvioglacial sands.

The publication also used the radioecological reports of the Poliskyi Branch of URIFFM for 1991-2014 to study the dynamics of various plant species. The experimental plots were laid in 1991-1999. According to the 1999 report, the stand on the experimental plot had the following taxonomic indicators: tree canopy composition –v alder 100 %, age – 45 years, stand density – 0.6, stand quality class – I^a. The understory consisted of *Rubus idaeus* and *Rubus nessensis* W. Hall., with a closeness of 0.4. The projective cover of the herbaceous-dwarf-shrub layer consisted of 65 %. The list of plant species in the living ground cover is similar to the above descriptions of the experimental plots. The soil is swampy peat, gley. The average density of radioactive contamination of soil was 520 kBk·m^{-2} [16].

Improving ecological well-being performance (EWP) is important for the construction of ecological civilization and sustainable development [4]. The forest ecosystem provides multidimensional ecological well-being for humans, and forest ecological security (FES) has an important impact on the ability of human beings to obtain well-being from the ecosystem, providing multiple guarantees for EWP enhancement.

Within the experimental plot, 5 samples of soil and each plant species were collected evenly over the territory, from which mixed samples were prepared. The collected plant and soil samples were dried in desiccators and then ground. The ^{137}Cs specific activity (*Am*) in the samples was determined using multichannel analyzers "AFORA" LP-4900B and spectrum analyzers SEG-001 "AKP-C"-63 and SEG-001 "AKP-C"-150, using reference tanks. The average measurement error of radionuclide activity was ± 15 % (confidence level – 0.95). The research results were processed using the software package Microsoft Office Excel, Statgraphics, Statistica 6, and Statistica 10.

Research results and their discussion / Результати дослідження та їх обговорення

The results of the studies obtained in 1999 indicate that significant values of ^{137}Cs specific activity are recorded in the aboveground part of living ground cover plants, which is explained primarily by the high content of the radionuclide in the soil [16] (Table. 1). The highest values of radioactive contamination were found in all fern species: *Dryopteris cristata* (144000 Bq·kg^{-1}), *Dryopteris carthusiana* (123000 Bq·kg^{-1}), *Thelypteris palustris* (89000 Bq·kg^{-1}), *Athyrium filix-femina* (85300 Bq·kg^{-1}). However, plants that can be characterized as those with significant values of ^{137}Cs specific activity include *Agrostis stolonifera* (137000 Bq·kg^{-1}), *Galium uliginosum* (81000 Bq·kg^{-1}) and *Maianthemum bifolium* (80800 Bq·kg^{-1}). Some plant species have relatively low levels of radioactive contamination of the aboveground part of the phytomass, despite rather significant values of the density of radioactive contamination of the soil: *Scirpus sylvaticus* (6170 Bq·kg^{-1}), *Filipendula ulmaria* (14400 Bq·kg^{-1}), *Lythrum salicaria* (14500 Bq·kg^{-1}). The maximum value of ^{137}Cs specific activity in the aboveground part of *Dryopteris cristata* is 23.3 times higher than the minimum value of this indicator in *Scirpus sylvaticus.* Differences can be explained by the biological characteristics of each particular plant species, as well as the ecological characteristics of their growth within the ecosystem (degree of watering, peat thickness, elevation above the soil level, etc.).

The values of the transfer factor established for all plant species characterize the intensity of ^{137}Cs uptake. This indicator, to some extent, confirms the biological predisposition of the studied species to greater or lesser accumulation of radionuclide. The value of the transfer factor varies within a very significant range – from 11.9 for *Scirpus sylvaticus* to 276.9 m^2·kg^{-1}·10^{-3} for *Dryopteris cristata*.

The materials obtained in 2021, to some extent, confirm the patterns obtained in 1999 (Table. 2). The highest value of ^{137}Cs specific activity in the aboveground part of the phytomass was found for *Athyrium filix-femina* (6303 Bq·kg^{-1}), and the lowest for *Filipendula ulmaria* (192 Bq·kg^{-1}). The first value is 32.3 times higher than the second one. This confirms the significant interspecific differences in radionuclide accumulation obtained in 1999. Significant values of ^{137}Cs specific activity in the aboveground part of the phytomass, as in the previous year of observations, were also observed in *Galium uliginosum* (6274 Bq·kg^{-1}) and *Maianthemum bifolium* (6235 Bq·kg^{-1}). It should be noted that some plant species that were classified as intensive ^{137}Cs accumulators in 1991 had significantly lower levels of this radionuclide in 2021 (*Agrostis stolonifera*). This may be explained by some ecological differences in the conditions of growth of this species on the two plots.

Since our studies were conducted in different experimental plots (the stands of 1999 have already been cut down), the absolute values of ^{137}Cs specific activity in the aboveground part of the plants studied cannot indicate a change in this indicator over time, since the observations in 2021 were conducted in another area of the forest. To a certain extent, this can be illustrated by the values of the transfer factors of radioactive element from soil to aboveground phytomass of plants, which were studied twenty-two years after the first research. This indicator reflects the intensity of ^{137}Cs intake in plants. It was found that this indicator decreased. For example, in *Athyrium filix-femina*, which has the highest value, this indicator decreased from 164.0 to 131.3 m^2·kg^{-1}·10^{-3} (1.3 times), and in *Filipendula ulmaria*, which has the lowest value, from 27.7 to 2.7 m^2·kg^{-1}·10^{-3} (10.3 times).

Table. 1. Indicators of radioactive contamination and intensity of ^{137}Cs intake into the ground part of living ground cover plants in the stands of black alder in the damp fairly fertile site type (C_4) in 1999 / Показники радіоактивного забруднення та інтенсивності надходження ^{137}Cs у надземну частину рослин живого надґрунтового покриву у насаджені вільхи чорної сирого сугруду у 1999 р. [16]

Name of the plant species	^{137}Cs specific activity, Bk·kg^{-1}	Transfer factor, m^2·kg^{-1}·10^{-3}
Dryopteris cristata (L.) A. Gray	144000	276.9
Agrostis stolonifera L.	137000	263.5
Dryopteris carthusiana (Vill.) H. P. Fuchs	123000	236.5
Thelypteris palustris Schott	89000	171.2
Athyrium filix-femina (L.) Roth	85300	164.0
Galium uliginosum L.	81000	155.8
Maianthemum bifolium (L.) F. W. Schmidt	80800	155.4
Calamagrostis canescens (Weber.) Roth	76700	147.5
Peucedanum palustre (L.) Moench	75000	144.2
Molinia caerulea (L.) Moench	56200	108.1
Geum rivale L.	54900	105.6
Potentilla erecta L.	49400	95.0
Luzula pilosa (L.) Willd.	43800	84.2
Lysimachia vulgaris L.	42300	81.3
Viola uliginosa Bess.	30300	58.3
Carex acutiformis Ehrh.	18000	34.6
Caltha palustris L.	15600	30.0
Lythrum salicaria L.	14500	27.9
Filipendula ulmaria (L.) Maxim.	14400	27.7
Scirpus sylvaticus L.	6170	11.9

Table. 2. Indicators of radioactive contamination and intensity of ^{137}Cs intake into the ground part of living ground cover plants in the stands of black alder in the damp fairly fertile site type (C_4) in 2021 / Показники радіоактивного забруднення та інтенсивності надходження ^{137}Cs у надземну частину рослин живого надґрунтового покриву у насаджені вільхи чорної сирого сугруду у 2021 р.

Name of the plant species	^{137}Cs specific activity, Bk·kg^{-1}	Transfer factor, m^2·kg^{-1}·10^{-3}
Athyrium filix-femina (L.) Roth	6303	131.3
Galium uliginosum L.	6274	130.7
Maianthemum bifolium (L.) F. W. Schmidt	6235	129.9
Molinia caerulea (L.) Moench	1383	28.8
Viola uliginosa Bess.	1532	21.9
Lysimachia vulgaris L.	966	20.1
Luzula pilosa (L.) Willd.	1211	17.3
Calamagrostis canescens (Weber.) Roth	1023	14.6
Agrostis stolonifera L.	948	13.5
Carex acutiformis Ehrh.	888	12.7
Caltha palustris L.	623	8.9
Scirpus sylvaticus L.	503	7.2
Lythrum salicaria L.	462	6.6
Filipendula ulmaria (L.) Maxim.	192	2.7

Research on the dynamics of ^{137}Cs specific activity in the aboveground part of herbaceous plants in damp fairly fertile site type (black alder stands) over the years since the Chornobyl accident was conducted only for three plant species: *Lysimachia vulgaris*, *Galium uliginosum* and *Maianthemum bifolium* (Fig. 1). The obtained data indicate that a gradual decrease in the radionuclide content in the aboveground part of all studied species is observed. Over the entire period of research (30 years), the value of ^{137}Cs specific activity in the aboveground part of *Lysimachia vulgaris* decreased from $3279^{\pm121.2}$ to $868^{\pm18.2}$ Bq·kg^{-1} (3.8 times), *Galium uliginosum* from $26611^{\pm327.9}$ to $5633^{\pm118.0}$ Bq·kg^{-1} (4.7 times), and *Maianthemum bifolium* from $25016^{\pm328.8}$ to $5694^{\pm125.1}$ Bq·kg^{-1} (4.4 times). This is primarily due to a decrease in the density of radioactive contamination of the soil as a result of the physical decay of the radionuclide (Table. 3). During the same period, this indicator decreased by 2.1 times (from $79.3^{\pm1.7}$ to $38.2^{\pm1.0}$ kBq·m^{-2}).

It should also be noted that the above-mentioned general decrease in the value of ^{137}Cs specific activity in the aboveground part of plants over the years is almost identical in different species (observations in the stands were carried out at intervals of 7-9 years) (Table. 3). Thus, in *Maianthemum bifolium* vetch, this indicator decreased by 1.4 times from 1991 to 1998, by 1.3 times from 1998 to 2005, by 1.4 times from 2005 to 2014, and by 1.7 times from 2014 to 2021.

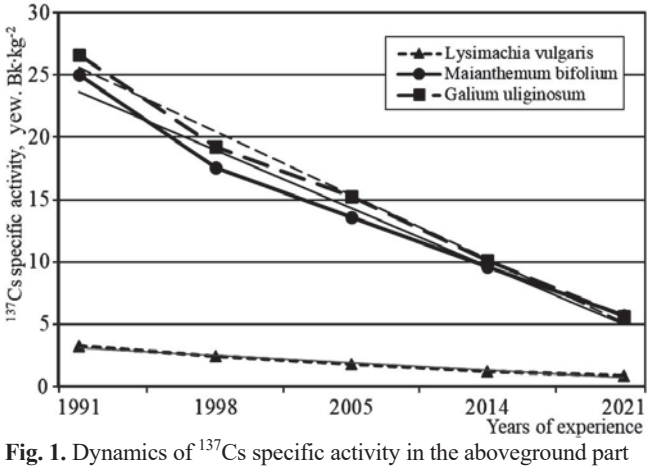

Fig. 1. Dynamics of ^{137}Cs specific activity in the aboveground part of *Lysimachia vulgaris*, *Galium uliginosum*, and *Maianthemum bifolium* / Динаміка питомої активності ^{137}Cs у надземній частині *Lysimachia vulgaris*, *Galium uliginosum* та *Maianthemum bifolium* по рокам

Table. 3. Dynamics of statistical indicators of soil radioactive contamination density /
Статистики динаміки щільності радіоактивного забруднення ґрунту за роками

Years (*a*) of experience	Statistical indicators					
	$M^{\pm m}$, kBk·m^{-2}	σ, kBk·m^{-2}	Max, kBk·m^{-2}	Min, kBk·m^{-2}	*V*, %	*P*, %
1991	$79.3^{\pm 1.7}$	3.9	84.3	74.6	5	2.2
1998	$68.9^{\pm 1.1}$	2.5	72.0	65.3	4	1.7
2005	$59.3^{\pm 0.9}$	2.0	61.7	57.1	3	1.5
2014	$51.7^{\pm 1.3}$	2.8	54.6	47.8	5	2.4
2021	$38.2^{\pm 1.0}$	2.3	40.8	35.3	6	2.7

In *Lysimachia vulgaris*, this decrease ranges from 1.3 to 1.5 times over the period of observation, and in *Galium uliginosum* – from 1.3 to 1.8 times. The overall decrease in specific activity of the radionuclide is explained by: its decay in all components of the ecosystem; its fixation in the soil; migration beyond the location of the root system of the plant under study; movement and concentration of part of ^{137}Cs activity in the aboveground part of forest plants, primarily woody plants. This decrease in the ^{137}Cs specific activity in the aboveground part of plants is described by linear equations: for *Lysimachia vulgaris* – $Am = -605.34a + 3745.6$; $R^2 = 0.98$; *Galium uliginosum* – $Am = -5107.5a + 30698$; $R^2 = 0.99$; *Maianthemum bifolium* – $Am = -4661.6a + 28280$; $R^2 = 0.98$.

Studies on the levels of radioactive contamination of living ground cover plants in the forest ecosystems of Polissia, the region most contaminated by the Chornobyl accident, were conducted on a very limited scale. Moreover, they were carried out mainly in the first 5-15 years after the Chornobyl accident. The researchers studied the peculiarities of radioactive contamination of tree species as the main components of forest ecosystems, as well as herbaceous and dwarf-shrub plants that had certain practical value (food, medicinal) [7]. The results of these studies became the basis for the development of regulatory documents that regulated forest use in conditions of radioactive contamination [6]. These studies were conducted mainly in areas with automorphic landscapes.

The materials analysed in this article, to a certain extent, expand the understanding of ^{137}Cs intake by herbaceous and dwarf-shrub plants growing in hydromorphic and semi-hydromorphic landscapes and allow for the identification of interspecies differences in radionuclide accumulation in these conditions. Waterlogged soils have specific ecological conditions that are determined by their water, air, and redox regimes. It was found that plants with intensive ^{137}Cs accumulation include ferns (*Dryopteris cristata*, *Dryopteris carthusiana*, *Thelypteris palustris*, *Athyrium filix-femina*), which have the highest values of specific activity and radionuclide transfer factor from soil. Some of the noted species create continuous coverings in alder stands in damp fairly fertile site types, which can significantly affect the redistribution of radionuclides among ecosystem components. Among herbaceous plants, *Maianthemum bifolium* is characterized by a significant radionuclide content and transfer factor. It is known that this perennial plant has a long creeping rhizome, which can accumulate ^{137}Cs and, at certain intervals of the vegetative period, enter the aboveground part, along with its intake from the soil. Information on these plant species is also important because they are widely used in folk medicine. Other plants that intensively accumulate ^{137}Cs include *Agrostis stolonifera*, *Galium uliginosum*, *Calamagrostis canescens,* and *Peucedanum palustre*.

It has been established that during the observation period (1991-2021), radioactive contamination of living aboveground plants and the intensity of ^{137}Cs intake into them have been decreasing. This is explained by the decay of the radioactive element, its entry into various perennial components of forest ecosystems, and, possibly, some fixation in the soil and its removal beyond its borders.

The established peculiarities of radioactive contamination of various plant species, changes in the specific activity of ^{137}Cs in them, and the transfer factors of the radionuclide from the soil in black alder stands in damp fairly fertile site type can be used in scientific works to predict possible changes in its redistribution within the ecosystem, as well as in the practice of harvesting medicinal plants in areas contaminated with radionuclides.

Discussion of research results. The scientists studied the dynamics of ^{137}Cs bioavailability in the aboveground phytomass of natural meadow vegetation on peat-bog soils [11]. They also found significant values of the transfer factors and accumulation of this radionuclide in *Festuca pratensis* Huds., *Poa pratensis* L., *Carex nigra* L., *Carex acuta* L. and *Carex cespitosa* L. [10]. Researchers studied the peculiarities of radioactive contamination of herbaceous plants in mesotrophic bogs [13], and compared the levels of radioactive contamination of plants in mesotrophic and oligotrophic bogs [1]. The study of plants in eutrophic bogs in 2005-2011 showed high radioactive contamination of *Dryopteris cristata* (5200 Bq·kg^{-1}), *Dryopteris carthusiana* (3238-4993 Bq·kg^{-1}), *Athyrium filix-femina* (1589-4661 Bq·kg^{-1}), *Thelypteris palustris* (3163-4600 Bq·kg^{-1}), and the lowest of *Maianthemum bifolium* (1367-2332 Bq·kg^{-1}), *Lysimachia vulgaris* (691-1743 Bq·kg^{-1}), *Lycopus europaeus* L. (492-1278 Bq·kg^{-1}) [12, 14].

So, based on the results of the work performed, it is possible to formulate the following scientific novelty and practical significance of the research results.

Scientific novelty of the obtained research results – the article presents and substantiates the data on the dynamics of radioactive contamination levels of living ground cover plants in forest stands of black alder in damp fairly fertile site type over the past 30 years.

Practical significance of the research results – the results obtained can be used in the practice of harvesting useful plants in areas contaminated with radionuclides in black alder stands in Volyn and Zhytomyr Polissia.

Conclusion / Висновки

A comparison of the levels of radioactive contamination of plants in the living ground cover over the past 30 years revealed their decrease during the observation period. This, in turn, indicates a decrease in the intensity of ^{137}Cs intake into plants over time. On the example of three plant species, it was found that during the observation period (1991-2021) there was a gradual decrease in the ^{137}Cs specific activity in their aboveground part, which is described by linear equations: for *Lysimachia vulgaris* – $Am = -605.34a + 3745.6$;

R^2 = 0.98; *Galium uliginosum* – *Am* = –5107.5*a* + 30698; R^2 = 0.99; *Maianthemum bifolium* – *Am* = –4661.6*a* + 28280; R^2 = 0.98. The results of the study (1999-2021) on the levels of radioactive contamination of living ground cover plants in black alder stands in damp fairly fertile site type allow us to classify the following plants as intensively accumulating ^{137}Cs: *Dryopteris cristata*, *Dryopteris carthusiana*, *Thelypteris palustris*, *Athyrium filix-femina*, *Agrostis stolonifera*, *Galium uliginosum,* and *Maianthemum bifolium*. It was found that the maximum value of the radionuclide transfer factor from soil to plants reaches 164.0 (in 1999) and 131.3 $m^2 \cdot kg^{-1} \cdot 10^{-3}$ (in 2021) for *Athyrium filix-femina*.

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ЗМІНА РАДІОАКТИВНОГО ЗАБРУДНЕННЯ РОСЛИН ЖИВОГО НАДҐРУНТОВОГО ПОКРИВУ У НАСАДЖЕННЯХ ВІЛЬХИ ЧОРНОЇ ВІД ЧАСУ АВАРІЇ НА ЧАЕС У ЛІСАХ ЖИТОМИРСЬКОГО ПОЛІССЯ

Наведено результати досліджень, що здійснювали впродовж останніх 30 років у лісових екосистемах Житомирського Полісся, на територіях, які зазнали радіоактивного забруднення внаслідок аварії на Чорнобильській АЕС. У процесі проведення досліджень, які виконані у Поліському філіалі Українського науково-дослідного інституту лісового господарства та агролісомеліорації ім. Г. М. Висоцького, використано методики з лісової радіоекології, ботаніки та лісівництва, обробляння результатів виконано з використанням статистичного аналізу. Досліджено особливості радіоактивного забруднення найпоширеніших трав'яних і чагарничкових рослин у деревостанах вільхи чорної у сирих сугрудах. Як показники, що характеризують ці особливості, використано питому активність ^{137}Cs у надземній частині рослин, а також коефіцієнт переходу радіонукліду до фітомаси рослин з ґрунту. Виявлено, що найбільші величини коефіцієнта переходу ^{137}Cs із ґрунту до надземної частини фітомаси рослин у 1999 р. властиві папоротям: для щитника гребенястого – 276,9 $м^2 \cdot кг^{-1} \cdot 10^{-3}$, щитника шартрського -236,5 $м^2 \cdot кг^{-1} \cdot 10^{-3}$, теліптеріса болотяного – 171,2 $м^2 \cdot кг^{-1} \cdot 10^{-3}$, безщитника жіночого – 164,0 $м^2 \cdot кг^{-1} \cdot 10^{-3}$. Встановлено, що із вищих рослин найбільші величини цього показника характерні для польовиці пагононосної – 263,5 $м^2 \cdot кг^{-1} \cdot 10^{-3}$, підмаренника багнового – 155,8 $м^2 \cdot кг^{-1} \cdot 10^{-3}$ і веснівки дволистої – 155,4 $м^2 \cdot кг^{-1} \cdot 10^{-3}$. З'ясовано, що відзначені раніше тенденції та міжви-

дові відмінності у нагромадженні радіонукліду зберігаються і через 22 роки. Показано, на прикладі трьох видів рослин (вербозілля звичайного, підмаренника багнового та веснівки дволистої), що впродовж періоду спостережень (1991-2021 рр.) відбувається поступове зменшення радіоактивного забруднення рослин живого надґрунтового покриву та інтенсивності надходження ^{137}Cs до них. Це можна пояснити розпадом радіоактивного елемента, його надходженням до різних багаторічних компонентів лісових екосистем, деяким закріпленням у ґрунті і, можливо, винесенням за їх межі. Встановлене зменшення питомої активності ^{137}Cs у надземній частині рослин описується лінійними рівняннями: для вербозілля звичайного – $A_m = -605{,}34a + 3745{,}6$; $R^2 = 0{,}98$; підмаренника багнового – $A_m = -5107{,}5a + 30698$; $R^2 = 0{,}99$; веснівки дволистої – $A_m = -4661{,}6a + 28280$; $R^2 = 0{,}98$. Виявлені особливості радіоактивного забруднення різних видів рослин, зміни величини питомої активності ^{137}Cs у них і коефіцієнтів переходу радіонукліду із ґрунту у деревостанах вільхи чорної у сирих сугрудах можна використовувати у наукових роботах для прогнозування можливих змін у його перерозподілі в межах біогеоценозу, а також у практиці заготівлі лікарських рослин на територіях, забруднених радіонуклідами.

Ключові слова: радіонуклід; питома активність ^{137}Cs; коефіцієнт переходу; *Alnus glutinosa* (L.) Gaertn.; трав'яно-чагарничковий ярус; тип лісорослинних умов; сирі сугруди (C_4).