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THE BIOINDICATIVE ROLE OF GAME ANIMALS IN MONITORING THE CONDITION OF FOREST HABITATS IN VINNYTSIA REGION

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Today, under conditions of increasing technogenic pressure on the environment, the issue of heavy metal accumulation in the trophic chains of forest ecosystems is becoming increasingly important. Game animals, as an essential component of biocenoses, are sensitive to environmental pollution levels and can serve as reliable bioindicators of ecological conditions. The aim of the study was to assess the accumulation levels of lead (Pb), cadmium (Cd), zinc (Zn), and copper (Cu) in the organisms of wild ungulates – wild boar (Sus scrofa L.) and roe deer (Capreolus capreolus L.) harvested in the hunting grounds of the Haisyn Forest Enterprise, a branch of the State Forest Resources Agency of Ukraine (Vinnytsia region).

The material for the study consisted of biological samples that reflect the characteristics of toxic element accumulation in game animals as components of forest ecosystems. The content of heavy metals was determined using atomic absorption spectrophotometry. To provide an integrated assessment of toxic load, the hazard coefficient (Hc) was applied, allowing comparison of heavy metal accumulation levels with established regulatory standards.

It was found that the level of toxic element content largely depends on the animal species, which is likely determined by their bioecological characteristics and feeding behavior. The highest concentrations of Pb and Zn were detected in roe deer, while Cd showed a tendency to accumulate predominantly in wild boar. Overall, the intensity of heavy metal accumulation was moderate, with some values approaching the maximum permissible limits. The obtained results confirm the feasibility of using game animals as natural bioindicators for environmental monitoring of forest ecosystems. This study contributes to a deeper understanding of the ecological state of forest habitats and is relevant to both game management and broader environmental assessment.

Key words: *forest ecosystems, biocenosis, Pb, Cd, Zn, Cu, hazard coefficient.*
Table 2. Fig. 2. Lit. 24.

Problem setting. At present, the state of the natural environment in Ukraine is characterized by a high level of anthropogenic pressure, which manifests itself in the continuous influx of various pollutants into the components of the biosphere. One of the most critical consequences of this process is the accumulation of heavy metals in food chains, particularly through wild animals that form an integral part of forest ecosystems. Considering that game meat is consumed by humans, it is essential to examine its quality in light of potential environmental contamination. At the same time, analyzing the content of toxic elements in the tissues of game animals makes it

possible to consider them as bioindicators of the ecological condition of the areas in which they reside. The study of heavy metals (Cd, Pb, Hg, As, etc.) and essential trace elements (Zn, Cu, Fe, Se) in the organisms of wild game animals makes it possible not only to assess the quality of biological resources but also to identify potential environmental threats associated with the transformation of forest ecosystems. In Vinnytsia region, where agriculture, industry, and transportation infrastructure are actively developing, the issue of technogenic pressure on forest habitats is particularly acute.

The relevance of this topic is driven by growing interest in the quality and safety of animal-derived food products, particularly the meat of wild animals, which is often perceived as a natural and environmentally friendly alternative to conventional agricultural products. At the same time, the level of toxic substances present in game meat and adipose tissue is directly linked to the state of the environment, which underscores the need for a scientifically grounded assessment of such risks.

Analysis of research and publications. Wild game meat has long been valued for its superior taste and considerable nutritional properties. In contemporary settings, interest in this product continues to grow, particularly as a source of high-quality protein, vitamins, and minerals – such as Ca, Fe, and P – especially among advocates of healthy and diet-conscious eating. Game meat is typically characterized by a high protein content and relatively low fat levels [1–3]. For instance, wild boar meat contains approximately 18.6% protein and 17.5% fat, contributing to its high energy value. In contrast, roe deer and moose meat exhibit higher protein levels (21.3% and 21.4%, respectively) along with a lower fat content (13.7% in roe deer and only 1.7% in moose), making these types of meat particularly suitable for dietary nutrition [4].

According to Peshuk L.V., wild boar meat contains more moisture and protein, lower caloric value, and a more favorable lipid profile compared to pork. In particular, the proportion of monounsaturated fatty acids reaches 46.2%, which exceeds that found in domestic pork (43.3%). Additionally, higher levels of tryptophan (1.37 g/100 g) and hydroxyproline (0.75 g/100 g) were recorded, indicating good digestibility and high nutritional value of this type of meat [5]. Furthermore, atomic absorption spectrophotometry revealed that, under the influence of lactic and phosphoric acids, iron and zinc can leach from the meat into the marinade. This phenomenon should be considered when evaluating the mineral composition of game meat after culinary processing [5].

The findings of other studies indicate that roe deer meat contains twice as little fat as beef and four times less than pork. At the same time, its protein value is higher, with 2.8% more protein than beef and 5.2% more than pork. The mineral composition of male roe deer meat confirms its high nutritional quality, with notable levels of potassium (302.4 mg/100 g), phosphorus (193.8 mg/100 g), and iron (2.7 mg/100 g). Moose meat stands out with the highest moisture content among all species studied (75.6%), along with the highest protein level (21.2%) and the lowest fat content (1.9%) [6].

Research findings indicate that wild game meat possesses not only high nutritional value but also additional functional properties. When properly prepared, it can serve as a source of biologically active compounds. For example, Takeda S. et al. (2020) demonstrated that peptides isolated from game meat can inhibit the activity of angiotensin I-converting enzyme, which plays a role in blood pressure regulation. In addition, the high bioavailability of wild meat is attributed to its optimal content of purine compounds, creatine, and other metabolites that support the functioning of the nervous system [7].

Given its high nutritional properties, wild game meat is widely used in culinary practice as a premium raw material for preparing a variety of dishes. Its firm texture, rich flavor, and distinctive aroma set it apart from other types of meat, imparting a refined character to prepared meals [8]. In Central and Southeastern European countries such as the Czech Republic, Slovakia, Croatia, and Bulgaria, game meat is an important element of culinary tradition.

In many European countries, there is a growing consumer interest in game meat as a source of healthy and environmentally friendly nutrition. According to recent studies, wild meat is considered a more nutritious and safer alternative to conventional livestock products due to its lower fat and cholesterol content, high level of complete protein, balanced fatty acid profile, and absence of antibiotic and hormone residues [9–10]. However, the level of game meat consumption varies significantly between countries. For example, in Poland it amounts to only 0.08 kg per person per year, whereas in the Czech Republic it is 1.1 kg, in Slovakia 0.56 kg, and in Croatia 0.55 kg [11].

Despite the exceptional nutritional value and potential health benefits of wild game meat, concerns about its environmental safety have been increasing in recent years, particularly in the context of intensified anthropogenic pressure on natural ecosystems [12–13]. Forests that serve as habitats for game animals may be exposed to heavy metal contamination as a result of industrial emissions, vehicular traffic, and the agrochemical burden placed on soils and water bodies [14].

Particular attention should be paid to the impact of military actions on the environmental conditions of wildlife habitats. According to research by Pysarenko P.V. et al. (2022), military activity in Ukraine contributes to technogenic pollution of agricultural lands, primarily by heavy metals (Pb, Zn, Cd) and petroleum products. It has been established that under increased technogenic pressure, the assimilation of heavy metals by plants rises significantly, increasing the risk of these contaminants entering food chains [15]. This has a direct impact on wild animals that feed on vegetation. As a result, toxic elements such as lead, cadmium, mercury, arsenic, and others may accumulate in the muscle and adipose tissues of game animals, which not only diminishes the biological value of the meat as a food product but also poses potential health risks to consumers [14].

The highest concentrations of heavy metals in game animals are typically found in organs such as the liver and kidneys; however, substantial levels may also be

present in muscle and adipose tissues. For example, the study by Bilandžić (2009) revealed that cadmium concentrations in the kidneys of wild boars were significantly higher than those in red deer, and considerable levels of lead were detected in the muscle tissue of both species [16]. Similar results were reported in the study by Bąkowska et al. (2024), which found that cadmium concentrations in the liver and kidneys of wild boars and roe deer varied significantly depending on the level of industrial impact on the environment. The highest Cd levels were recorded in southern regions of Poland, characterized by a high density of industrial facilities, particularly metallurgical and mining enterprises. At the same time, elevated cadmium concentrations were also observed in animals harvested from the northeastern regions with lower anthropogenic pressure, which the authors attribute to the natural geochemistry of the soils and localized sources of pollution [17].

Thus, the identified patterns of toxic element accumulation in the bodies of game animals once again highlight the relevance of this line of research. The integration of knowledge from wildlife management, forestry, ecology, and environmental protection enables a comprehensive assessment of anthropogenic pressure on forest ecosystems and supports the development of evidence-based approaches to the sustainable use of wildlife resources and the effective management of forest habitats.

In view of the above, the **aim of our study** is to monitor the contamination of muscle and adipose tissues of wild animals by heavy metals and trace elements.

Research material and methods. The study assessed the content of heavy metals in the tissues of game animals: wild boar (*Sus scrofa* L.) and roe deer (*Capreolus capreolus* L.), harvested in 2018 (four individuals of each species) in the hunting grounds of Vinnytsia region (Haisyn Forestry Branch, State Enterprise “Forests of Ukraine”). The analyzed samples included muscle tissue (femoral part) and adipose tissue (abdominal area of the carcass).

The collected samples were labeled, packed in sterile containers, cooled, and transported to the laboratory for further analysis. Quantitative determination of Pb, Cd, Zn, and Cu was performed using atomic absorption spectrophotometry. Prior to analysis, the samples were mineralized by dry ashing. The results are expressed in mg/kg.

Statistical analysis of the experimental data was performed using Microsoft Excel and the STATISTICA 10.0 software package. The significance of differences between mean values was evaluated using Student’s *t*-test at a confidence level of $p < 0.05$. To obtain a deeper understanding of the results, a hazard coefficient (HC) was calculated, reflecting the degree of toxic burden caused by the investigated metals in animal tissues. The coefficient was determined using the following formula:

$$HC = C / MRL,$$

where: C is the actual concentration of the element in the tissue (mg/kg); MRL is the maximum residue level permitted for that element in food products, according to the sanitary regulation “Regulation of Maximum Levels of Certain Contaminants

in Food Products" [18]. Interpretation of the hazard coefficient (HC) values allows for the assessment of how closely the element concentrations approach established regulatory limits. Specifically, an HC value greater than 1 indicates an exceedance of the permissible level, while HC ≤ 1 reflects compliance with the standard. However, values approaching 1 require attention due to the potential for bioaccumulation with regular consumption of wild game meat. The hazard coefficient enables not only a quantitative assessment of metal accumulation but also conclusions regarding the degree of compliance with current food safety regulations.

The study also included an analysis of trace elements such as Zn and Cu, which play an important role in determining the nutritional value of meat. Their assessment was carried out based on reference guideline values [19].

Research results and their discussion. To evaluate the level of contamination in the tissues of wild animals, the concentrations of Pb and Cd were measured in the muscle and adipose tissues of wild boar and roe deer. A summary of the results is presented in table 1.

Table 1

Intensity of heavy metal accumulation in bioindicator material, mg/kg (n = 4; M ± m)

Indicator	Species			
	Wild boar		Roe deer	
	Muscle tissue	Fat tissue	Muscle tissue	Fat tissue
Pb content	0,23 ± 0,042	0,04 ± 0,0032	0,68 ± 0,037	0,09 ± 0,0024
Pb hazard coefficient	2,3	0,4	6,8	0,9
Cd content	0,04 ± 0,00031	0,05 ± 0,0024	0,008 ± 0,0005	0,002 ± 0,0043
Cd hazard coefficient	0,8	1,0	0,16	0,04

Source: formed on the basis of own research

It was established that the Pb content in the tissues of roe deer was significantly higher than the corresponding values in wild boar. In particular, the concentration of Pb in the muscle tissue of roe deer was 0.68 ± 0.037 mg/kg, which is 2.96 times higher than in wild boar (0.23 ± 0.042 mg/kg). In adipose tissue, the Pb level in roe deer was 0.09 ± 0.0024 mg/kg, which is 2.25 times higher than that in wild boar (0.04 ± 0.0032 mg/kg). Given the maximum permissible level of Pb (0.1 mg/kg), the hazard coefficient (HC) for roe deer muscle was 6.8, indicating a significant exceedance of the regulatory threshold. In wild boar, this coefficient was lower (HC = 2.3) but still above the acceptable level. In adipose tissue of both species, the coefficients were lower (0.9 in roe deer and 0.4 in wild boar), although the value for roe deer was close to the permissible limit.

Regarding Cd, which is considered one of the most toxic elements, its concentration in muscle tissue of both wild boar and roe deer was 0.05 mg/kg (HC = 1.0), corresponding to the maximum permissible level. In adipose tissue of both species, the concentration of Cd was identical (0.008 mg/kg; HC = 0.16). Notably,

the Cd content in muscle tissue was 6.25 times higher than in adipose tissue (for both species), indicating a pronounced organ-specific distribution of this element. This reflects minimal toxicological burden in adipose tissue, in contrast to muscle tissue, where Cd levels reach the critical threshold.

Thus, the results demonstrate a clear organ-specific accumulation of toxic elements: Pb is predominantly retained in muscle tissue, while Cd is present in lower amounts but also with a preference for muscle over fat. A distinct species-related contrast is also observed: roe deer exhibited higher Pb levels in both muscle and fat – 2 to 3 times higher than in wild boar. This may be associated with differences in trophic behavior, access to contaminated food sources, or environmental conditions of their habitats. Information on the content of Zn and Cu in the muscle and adipose tissues of the studied wild species is summarized in table 2.

Table 2

Accumulation of microelements in bioindicator material, mg/kg (n = 4; M ± m)

Indicator	Species			
	Wild boar		Roe deer	
	Muscle tissue	Fat tissue	Muscle tissue	Fat tissue
Zn content	70 ± 1,2	11,3 ± 0,7	170 ± 3,8	17,2 ± 1,4
Zn hazard coefficient	1,0	0,16	2,43	0,25
Cu content	5,0 ± 0,4	0,02 ± 0,003	2,04 ± 0,7	0,07 ± 0,003
Cu hazard coefficient	1,0	0,004	0,408	0,014

Source: formed on the basis of own research

It was found that the Zn content in the tissues of roe deer was significantly higher than in wild boar. In particular, the concentration of Zn in roe deer muscle tissue was 170 ± 3.8 mg/kg, which is 2.43 times higher than the corresponding value in wild boar (70 ± 1.2 mg/kg). In adipose tissue, the Zn level in roe deer was also higher – 17.2 ± 1.4 mg/kg, which is 1.52 times greater than in wild boar (11.3 ± 0.7 mg/kg). Considering the approximate safe level of Zn (70 mg/kg), the hazard coefficient (HC) for roe deer muscle was 2.43, indicating a potential excess relative to physiological requirements. In wild boar, this coefficient was 1.0, which corresponds to the acceptable limit. In adipose tissue of both species, the Zn HC values were low (0.25 for roe deer and 0.16 for wild boar), posing no toxicological concern.

The highest Cu content was recorded in the muscle tissue of wild boar (5.0 ± 0.4 mg/kg), which is 2.45 times higher than in roe deer (2.04 ± 0.7 mg/kg). In adipose tissue, the Cu level in wild boar was 0.02 ± 0.003 mg/kg, while in roe deer it was 0.07 ± 0.003 mg/kg – 3.5 times higher. However, due to the overall low Cu levels in adipose tissue (dozens of times lower than in muscle), these values have limited toxicological significance. Accordingly, the hazard coefficients for Cu in adipose tissue were minimal: 0.004 in wild boar and 0.014 in roe deer. In muscle tissue, the

HC values were 1.0 for wild boar and 0.408 for roe deer.

Thus, a clear organ-specific pattern of microelement accumulation was observed: Zn predominantly accumulates in muscle tissue, especially in roe deer, whereas Cu is more concentrated in the muscles of wild boar. In the adipose tissue of both species, both Zn and Cu were present in significantly lower concentrations. These findings reflect differences in mineral metabolism between the species, which may be attributed to both physiological characteristics and environmental conditions of their habitats.

Figure 1 presents a comparative analysis of Pb and Cd concentrations in the muscle and adipose tissues of two game animal species – wild boar and roe deer. The highest Pb content was recorded in the muscle tissue of roe deer (0.68 mg/kg), which is 6.8 times higher than the maximum permissible level (0.1 mg/kg). In wild boar muscle, the Pb level was 0.23 mg/kg. In adipose tissue, Pb concentrations were lower: 0.09 mg/kg in roe deer and 0.04 mg/kg in wild boar.

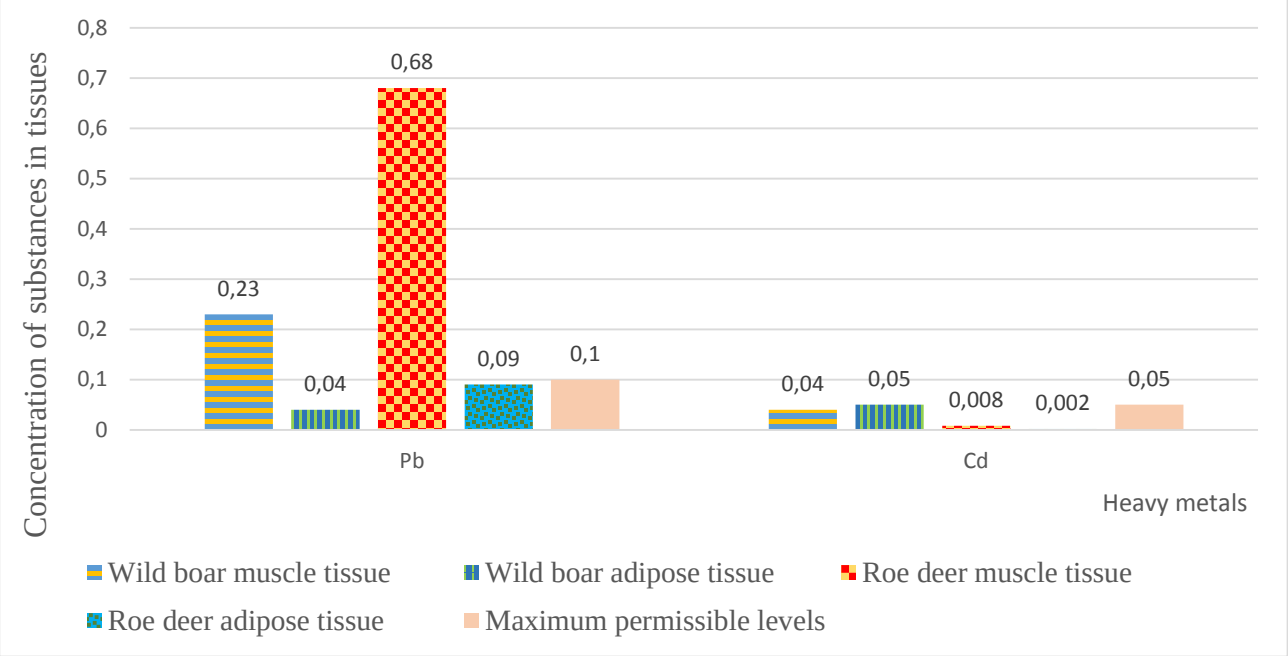

Fig. 1. Content of Pb and Cd in bioindicator material compared to maximum permissible levels (MPL)

Source: formed on the basis of own research

Regarding Cd, its concentration in the muscle tissue of wild boar was 0.04 mg/kg, which is slightly below the maximum permissible level (0.05 mg/kg), while in roe deer it was only 0.008 mg/kg. In adipose tissue, Cd accumulated to a greater extent in wild boar (0.05 mg/kg), whereas in roe deer it was the lowest among all samples.

Figure 2 shows the accumulation levels of Zn and Cu in the tissues of two game animal species. The highest Zn content was recorded in the muscle tissue of roe deer (170 mg/kg), which is 2.43 times higher than the permissible level (70 mg/kg) and significantly exceeds the corresponding value in wild boar muscle (70 mg/kg). In adipose tissue, Zn accumulated at much lower levels: 17.2 mg/kg in roe deer and

11.3 mg/kg in wild boar, accounting for 24.6% and 16.1% of the permissible level, respectively.

The Cu content in wild boar muscle reached the normative level (5.0 mg/kg), while in roe deer it was lower – 2.04 mg/kg (41% of the permissible level). In adipose tissue, Cu concentrations were minimal: 0.02 mg/kg in wild boar and 0.07 mg/kg in roe deer.

Overall, the figure illustrates a clear organ-specific distribution: Zn and Cu predominantly accumulate in muscle tissue, with Zn showing much higher concentrations in roe deer and Cu in wild boar. In the adipose tissue of both species, microelement levels were several times lower, indicating their limited accumulation in fat.

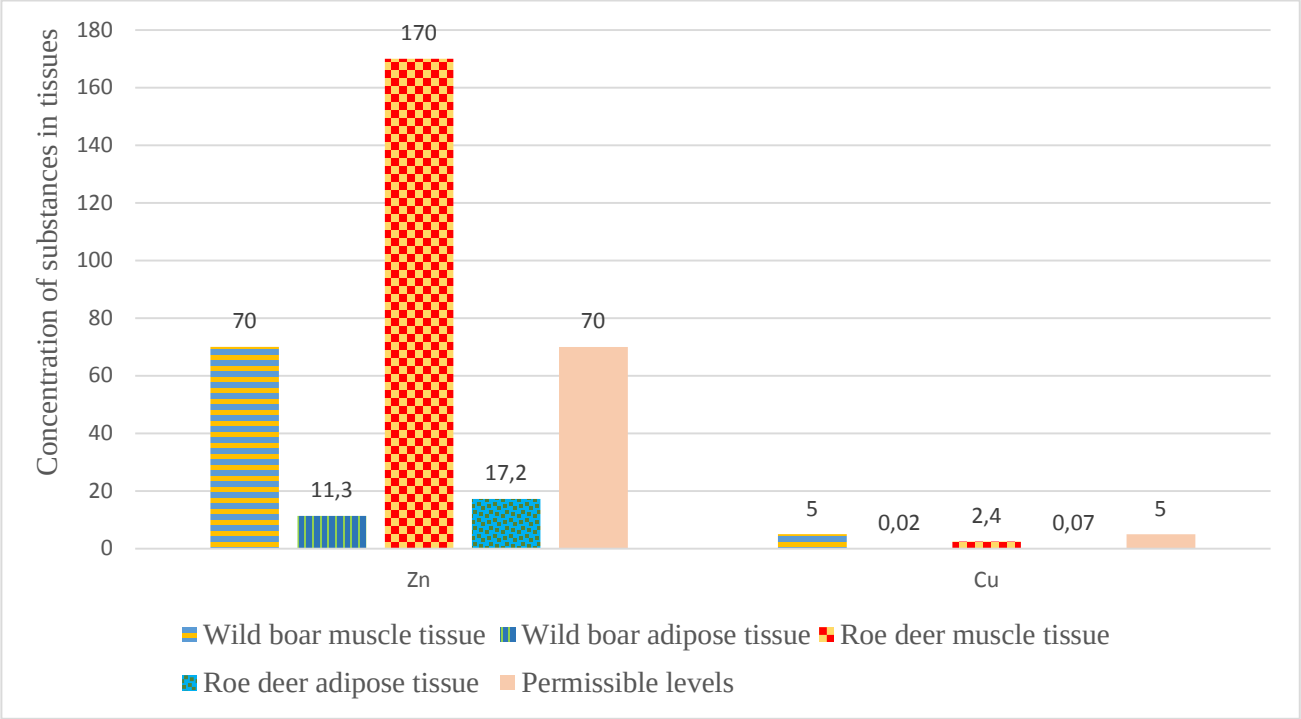

Fig. 2. Comparative assessment of Zn and Cu content in bioindicator material against provisional permissible levels

Source: formed on the basis of own research

The study revealed that the content of heavy metals in the tissues of wild game animals, particularly roe deer and wild boar, depends on several factors, including the species, tissue type, and habitat conditions. Similar patterns are confirmed in a number of scientific sources, which report age- and sex-related differences in the concentrations of Cd, Pb, Zn, and Cu in the tissues of wild ungulates [20-21].

According to the results of our study, the highest concentrations of Pb, Zn, and Cd were found in muscle tissue, indicating a predominant accumulation of these elements in muscles. In adipose tissue, the levels were significantly lower, particularly in the case of Cd and Cu. These differences in metal distribution between tissues are related to metabolic characteristics and the specific functions of the

respective organs. Particular attention should be paid to the study by Jota Baptista et al. (2024), which revealed elevated Cd levels in the kidneys of wild boars, potentially indicating local environmental contamination [22]. Another study from Hungary reported elevated levels of lead in the muscles of certain individuals, as well as differences in manganese concentrations between males and females [23]. Such observations confirm the importance of considering sex, age, and individual characteristics of animals when analyzing contamination indicators.

Additionally, a study conducted in Sweden examined the levels of Cd, Pb, Zn, Cu, and other elements in the kidneys of female wild boars. In nearly all samples, Cd concentrations exceeded the recommended limits for food products, and levels increased with the animals' age. At the same time, Pb concentrations remained relatively low. The authors also noted that local environmental features, such as proximity to roads and other factors, may influence toxic element levels [24].

Summarizing the results, it can be concluded that wild game animals are appropriate and sensitive bioindicators of environmental quality. They help detect levels of heavy metal contamination in forest ecosystems and provide an objective understanding of the ecological situation.

Conclusions. It was established that the tissues of wild game animals (wild boar and roe deer) hunted in the forest areas of Vinnytsia Region exhibit differentiated accumulation of heavy metals. Specifically, species- and tissue-specific differences in the accumulation of heavy metals (Pb, Cd) and microelements (Zn, Cu) were observed in the muscle and adipose tissues of wild boar (*Sus scrofa L.*) and roe deer (*Capreolus capreolus L.*). The highest concentrations of Pb, Zn, and Cd were recorded in muscle tissue, indicating its greater tendency to accumulate metals compared to adipose tissue. The Pb content in roe deer muscle exceeded the permissible limits by more than 2.5 times, highlighting the need for further monitoring. Cd was also detected at levels approaching the regulatory threshold in the muscle tissue of both species, supporting the relevance of continued research with broader geographic coverage and inclusion of additional tissue types.

In adipose tissue, metal concentrations were significantly lower, especially for Cd and Cu, with hazard coefficients not exceeding 0.2 in most cases. This indicates a relatively low toxicological burden in this tissue. The identified organ-specific and species-related differences in metal accumulation are determined by a range of biological and environmental factors, including feeding behavior, metabolic characteristics, and habitat conditions of the animals.

The obtained results confirm the appropriateness of using wild ungulates as sensitive bioindicators of the condition of forest ecosystems. Further research should focus on expanding the sample size, including other tissue types (such as liver and kidneys), and studying seasonal variations as well as the impact of anthropogenic factors, particularly sources of technogenic pollution. These findings are important for game management, quality control of wild game meat, and environmental protection, as they help identify areas with elevated levels of contamination.

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АНОТАЦІЯ
БІОІНДИКАЦІЙНА РОЛЬ МИСЛИВСЬКИХ ТВАРИН У МОНІТОРИНГУ СТАНУ ЛІСОВИХ УГІДЬ ВІННИЦЬКОЇ ОБЛАСТІ

Сьогодні в умовах зростання техногенного навантаження на довкілля, особливого значення набуває проблема накопичення важких металів у трофічних ланцюгах лісових екосистем. Мисливські тварини, які є важливою складовою біоценозів, здатні чутливо реагувати на рівень забруднення середовища і можуть слугувати надійними біоіндикаторами його екологічного стану. Метою дослідження було оцінити рівень акумуляції свинцю (Pb), кадмію (Cd), цинку (Zn) та міді (Cu) в організмах диких копитних тварин – дикого кабана (Sus scrofa L.) та козулі європейської (Capreolus capreolus L.), добутих у мисливських угіддях філії «Гайсинське лісове господарство» ДП «Ліси України» (Вінницька область).

Матеріалом дослідження слугували біологічні зразки, що відображають особливості акумуляції токсичних елементів у мисливських тварин як компонентів лісових екосистем. Вміст важких металів визначали методом атомно-абсорбційної спектрофотометрії. Для інтегральної оцінки токсичного навантаження застосовано показник коефіцієнта небезпеки (Кн), який дозволяє зіставляти рівні накопичення важких металів з встановленими нормативами.

Установлено, що рівень вмісту токсичних елементів значною мірою залежить від виду тварини, що, ймовірно, обумовлено їхніми біоекологічними особливостями та характером

живлення. Найвищі концентрації Pb і Zn виявлено у козулі, тоді як Cd мав тенденцію до накопичення переважно у дикого кабана. Загалом, інтенсивність накопичення металів була помірною, а за деякими показниками наближалась до гранично допустимих значень. Отримані результати підтверджують доцільність використання мисливських тварин як природних біоіндикаторів для екологічного моніторингу стану лісових угідь. Дослідження сприяє глибшому розумінню екологічного стану лісових угідь та має значення для мисливського господарства й моніторингу навколишнього природного середовища.

Ключові слова: *лісові екосистеми, біоценоз, Pb, Cd, Zn, Cu, коефіцієнт небезпеки.*

Табл. 2. Рис. 2. Літ. 24.

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