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RESEARCH ARTICLE

The bioaccumulation of lead in the organs of roe deer (*Capreolus capreolus* L.), red deer (*Cervus elaphus* L.), and wild boar (*Sus scrofa* L.) from Poland

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Abstract The aim of this study was to evaluate the level of lead (Pb) in the livers and kidneys of free-living animals from Poland, with regard to the differences in tissue Pb content between the species. The research material consisted of liver and kidney samples collected from roe deer (*Capreolus capreolus*), red deer (*Cervus elaphus*), and wild boar (*Sus scrofa*) that had been hunted in 16 voivodeships of Poland. The concentration of lead had been measured using inductively coupled plasma optical emission spectrometry (ICP-OES) method. The results show that differences in lead concentration in the organs depended on the geographic location. In roe deer and red deer, the highest mean lead concentrations in the livers and kidneys, observed in the central region of Poland, were twice as high as the lowest concentration of Pb in these animals from the northeastern region of the country. In wild boar, the highest mean concentration of Pb was noted in the livers of animals from the central region of Poland and in the kidneys of animals from the northwestern region, while the lowest lead concentrations in both organs were typical for wild boar from the southeast part of the country. Our results show that areas located in the center and in the north of Poland carry most of the burden of lead bioaccumulation.

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Introduction

Lead is a dangerous element in the environment and, if introduced to the environment in larger concentrations, may contribute to disorganizing the balance between the functions of other metals such as Cu or Zn, which are crucial for maintaining correct body functions.

According to the EU report about air pollution, Poland is a leading country for heavy metal emission (European Environment Agency 2012). By 2010, in the countries of the EU and in Poland, the decrease in total Pb emissions had reached 89 and 62 %, respectively, compared to 1990. However, from 2009 increase in the content of this element in the air has been noted in Europe, mainly as a result of the emissions in Poland. In most European countries, the increase in Pb emissions was 9.1 %, while in Poland it was 14.3 % (European Environment Agency 2012).

In an evaluation of animal exposure to heavy metals, it is important to study the location they live, and for this reason, the environment in which the free-living animals remain strongly influences the content of heavy metals in their tissues. The territory of Poland includes some regions commonly considered as unpolluted, as well as areas in which concentrated industry strongly affects the environment.

The presence of Pb applies to water, air, soil, plants, and animal tissues, making monitoring of its level relevant for every form of life. The accumulation of toxic heavy metals in soils and plants increases the risk of transferring them to animals (Falandysz et al. 2005). Although animals can uptake heavy metals directly through the respiratory system, the digestion tract is the main route. It is said that the share of the

digestion tract in the total intake of heavy metals in animals reaches about 80 % (Borowiec et al. 2009; Cizmecioglu and Muezzinoglu 2008; Silva et al. 2005; Popiołek-Pyrz et al. 2003).

Bioaccumulation of heavy metals in the tissues is one of the many consequences of environment pollution, and in the evaluation of this, bioindicator methods are used (Gworek et al. 2008). Game animals are considered good indicators of environment contamination, as they remain in natural habitats all life long, and accordingly, it influences their health status (Skibniewski et al. 2015; Wieczorek-Dąbrowska et al. 2013; Bilandžic et al. 2012; Garcia et al. 2011; Rudy 2010; Bilandžic et al. 2010; Kalisińska et al. 2003; Kucharczak et al. 2003; Szkoda and Żmudzki 2001; Pokorny 2000; Żarski et al. 1994; Michalska and Żmudzki 1992).

Many authors indicate the viability of using the game animals as indicators of environment pollution (Długaszek and Kopczyński 2013; Amici et al. 2012; Tomza-Marciniak et al. 2010; Falandysz et al. 2005). Moreover, the livers and kidneys from such game animals are used in venison products for human consumption (Amici et al. 2012; Kucharczak et al. 2003; Dobrowolska and Melosik 2002), and for this reason, the presence of dangerous substances in these organs is one of the most important criteria to evaluate in food safety and quality (Duma 2012).

The aim of this study therefore was to evaluate the level of lead (Pb) in the livers and kidneys of free-living animals (roe deer, red deer, and wild boar) in selected regions of Poland, with regard to the differences in tissue Pb content between species.

Material and methods

Study area

To maintain clarity in the experiment, we divided Poland into five geographic regions:

- The northwestern region, which included zachodniopomorskie and pomorskie voivodeships
- The northeastern region, which included warmińsko-mazurskie and podlaskie voivodeships
- The central region, which included wielkopolskie, kujawsko-pomorskie, mazowieckie, and łódzkie voivodeships
- The south-western region, which included lubuskie, dolnośląskie, opolskie, and śląskie voivodeships
- The south-eastern region, which included lubelskie, podkarpackie, świętokrzyskie, and małopolskie voivodeships (Fig. 1).

Between those, some regions in Poland are heavily industrialized and the main heavy metals emitters are located there.

The northwestern region (pomorskie) contains factories that produce phosphate fertilizers; a refinery that produces fuels, oils, and lubricants; as well as a few power plants and shipyards.

The central region (kujawsko-pomorskie, łódzkie, and mazowieckie) contains a chemical plant that produces lime fertilizers, as well as a power plant, a paints and varnishes factory, and several nitrogen-processing plants. Various branches of industry such as mining, coal power plants, machinery and electrical engineering, metallurgy, printing and polygraphy, electronics, automotive, and transportation are also well-developed in this region.

The south-western region (mostly dolnośląskie, opolskie, and śląskie) abounds in numerous mines, steel mills, and copper ore plants. The machinery, fuel and energy, and chemical and automotive industries are highly expanded there.

The south-eastern region (świętokrzyskie and małopolskie) contains industry branches including mining, crude oil processing, iron and steel processing, electrical engineering, metallurgy, ceramics, foundries, and energy production.

The north-eastern region (podlaskie, warmińsko-mazurskie), due to the low number in industrial plants, is considered to be an uncontaminated region with expansive rural and forest areas. The use of pesticides and nitrogen fertilizers in the agriculture and forestry sectors of the industry have however contributed to soil acidification, which in turn increases the mobility of heavy metals.

Samples

The research material was collected from 27 points located in the above-mentioned 16 voivodeships of Poland.

Samples of livers and kidneys were collected from three game animal species: the roe deer (*Capreolus capreolus*), red deer (*Cervus elaphus*), and wild boar (*Sus scrofa*) were examined. In total, samples from 235 animals were collected (80 red deer, 75 roe deer, and 80 wild boar) that had been shot during the hunting season from 15 August 2009 to 15 January 2010 by the huntsmen, within officially determined hunting limits. Animals from the particular voivodeships were of a similar age and had similar body weight. The age of the roe deer was assessed by the huntsmen at 3–4 years old and the body weight at 14–16 kg, the red deer at 4–6 years old and 60–80 kg, and the wild boars at 2–4 years old and 35–65 kg (Przybylski et al. 2010; Morow 2003).

The research materials, fragments of livers and kidneys not damaged by gunshots, were stored at −20 °C until the laboratory analyses.

Chemical analyses

The samples of livers and kidneys (cortical and medullar parts) were homogenized and mineralized in

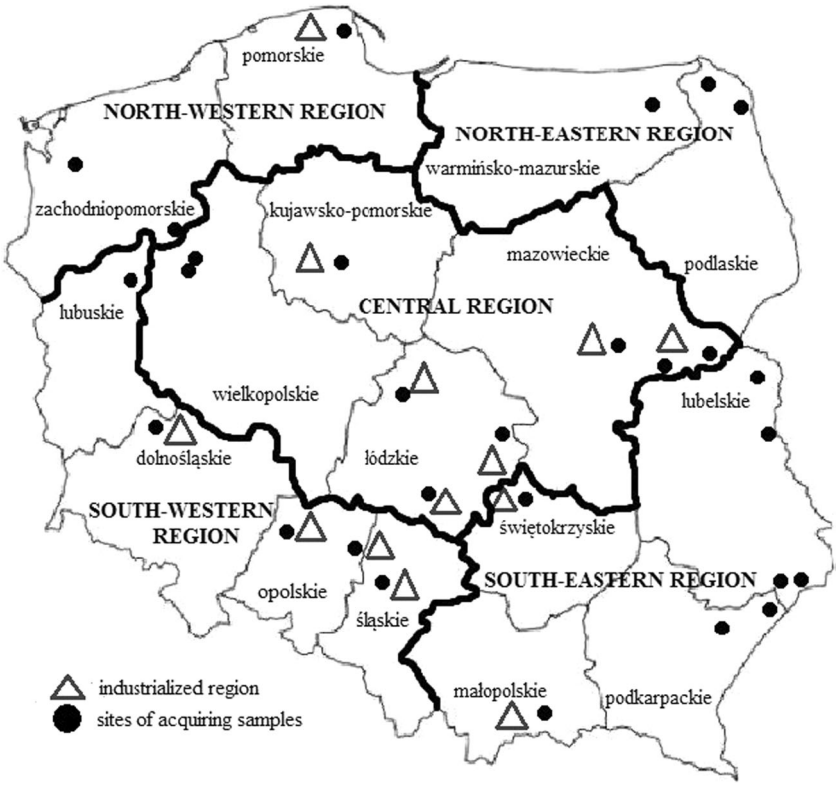

Fig. 1 Locations of sample collection, with accordance to the geographic regions

4.5 ml of 65 % nitric acid (Suprapur, Darmstadt, Germany) and 0.5 ml of 30 % hydrogen peroxide (Suprapur, Merck, Darmstadt, Germany) in an Anton Paar Multiwave microwave oven (Anton Paar Ltd., Hereford, UK). The schedule of the oven included the following steps: 0–5 min—linear growth of generator power from 100 to 600 W; 5–10 min—constant power, 600 W; 10 min—power increase to 1000 W, kept unchanged until the 20th minute (with the temperature and pressure not reaching the threshold values: 75 MPa and 300 °C, respectively); and 20–35 min—system cool down.

The concentrations of lead in the research material were evaluated using inductively coupled plasma optical emission spectrometry (ICP-OES) with a Perkin-Elmer OPTIMA 2000 DV unit. The detections were made along the axial optical pattern (along the plasma). The concentrations of Pb were calculated using the calibration curves estimated for the standards (Merck, Darmstadt. Germany). The detection limit of the unit was 0.002 μg/ml (Pb).

The correctness of the analytical procedure was checked by evaluating the concentration of examined elements in reference material NCS ZC 71001 (beef liver) (China National Analysis Center for Iron and Steel, Beijing, China) (Table 1).

Alternately with the series of samples, we analyzed the reference material samples ($n = 15$) and reagent samples (blank sample) ($n = 15$).

Statistical analysis

The results were analyzed statistically with STATISTICA 9.0 PL software. Shapiro-Wilk test was used to evaluate the normal distribution of the variables. In the case of a nonnormal distribution, we calculated logarithm values of the variables and used them for further statistical analyses. One-way ANOVA was performed and the significance of differences between the mean concentrations of Pb for samples from the different regions of Poland calculated using the parametric Duncan's test.

Results

The study we performed has in general shown a highest mean concentration of lead in the organs of the wild boar and the lowest in the organs of the roe deer. The mean concentrations

Table 1 The concentration of lead in the NCS ZC 71001 reference material (bovine liver, μg/g dry matter)

Element	Reference material NCS ZC 71001		Recovery (%)
	Certified concentration (μg/g dry matter)	Obtained concentration (μg/g dry matter)	
Pb	0.54	0.53 ± 0.03	**99.1 %**

of lead in the liver of the roe deer, red deer, and wild boar from Poland were 0.445, 0.484, and 0.502 μg/g wet weigh (w.w.), respectively, and in the kidney 0.460, 0.493, and 0.533 μg/g w.w., respectively (Table 2).

The results obtained in this study indicate a diverse lead content in the organs of the animals in the particular regions of Poland. The highest concentrations of Pb were found in the organs of studied animals originating from the central and north-western regions of Poland, and in case of the wild boar, also from the north-eastern region.

In the roe deer, the highest mean Pb concentrations were observed in the livers and kidneys from the central region (0.567 and 0.584 μg/g w.w., respectively) as well as from the north-western region (0.524 and 0.527 μg/g w.w.), and these values differed significantly ($P \leq 0.01$) from the mean lead concentrations in the livers and kidneys of roe deer from the north-eastern (0.296 and 0.284 μg/g w.w.), south-eastern (0.391 and 0.413 μg/g w.w.), and south-western (0.393 and 0.421 μg/g w.w.) regions of Poland. Additionally, in the north-eastern region, the lowest mean concentration of Pb in the kidneys of the roe deer was significantly ($P \leq 0.01$) lower than the mean concentration of lead in the kidney samples from all the other regions of Poland (Table 2)

In the red deer the situation was similar. The highest mean concentrations of Pb were observed in the livers and kidneys collected in the central region (0.596 and 0.590 μg/g w.w., respectively) and north-western region (0.556 and 0.577 μg/g w.w.) of Poland. These values were significantly ($P \leq 0.01$) higher than the lowest mean concentration of Pb in the red deer livers and kidneys from the north-eastern (0.338 and 0.343 μg/g w.w.) and south-eastern (0.416 and 0.417 μg/g w.w.) regions of Poland. The mean Pb concentration in red deer livers from the south-western region (0.487 μg/g w.w.) was significantly ($P \leq 0.05$) higher than the lowest mean Pb concentration in red deer livers from the north-eastern region and significantly ($P \leq 0.05$) lower than the highest mean Pb concentration in red deer livers from the central region. Furthermore, the mean concentration of Pb in red deer kidneys in this region (0.503 μg/g w.w.) also differed significantly ($P \leq 0.05$) from the mean lead concentration in red deer kidneys obtained in the north-western region (Table 2).

In wild boar, the highest mean Pb concentrations were found in livers from the central (0.596 μg/g w.w.) and north-western (0.595 μg/g w.w.) regions, and these values were significantly ($P \leq 0.05$) higher than the mean Pb concentration in wild boar livers from the south-western region (0.467 μg/g w.w.). The lowest mean Pb concentration was detected in wild boar livers from the south-eastern region (0.373 μg/g w.w.) and was significantly ($P \leq 0.01$) lower than the mean concentrations of Pb in wild boar livers from the north-western, north-eastern, and central regions.

In the kidneys of the wild boar, high mean concentrations of Pb were found in the animals from the north-western (0.649 μg/g w.w.), north-eastern (0.615 μg/g w.w.), and central (0.597 μg/g w.w.) regions, with these levels significantly ($P \leq 0.01$) higher than the lowest mean concentration of Pb in

Table 2 The mean concentration of lead in the livers and kidneys studied animals in accordance to geographic location

Region	Pb content (μg/g w.w.)											
	Roe deer				Red deer				Wild boar			
	N	*Mean*	SEM	Range	N	*Mean*	SEM	Range	N	*Mean*	SEM	Range
Liver												
north-western	10	0.524^{DEF}	0.043	0.269-0.671	10	0.556^{CD}	0.024	0.482-0.699	10	0.595^{Bb}	0.024	0.475-0.756
north-eastern	10	0.296^{CFa}	0.017	0.233-0.400	10	0.338^{BDb}	0.016	0.279-0.418	10	0.550^{C}	0.066	0.324-0.771
central	20	0.567^{ABC}	0.018	0.431-0.717	20	0.596^{ABa}	0.032	0.322-0.816	20	0.596^{Aa}	0.023	0.430-0.831
south-eastern	20	0.391^{ADa}	0.031	0.244-0.634	20	0.416^{AC}	0.035	0.250-0.702	20	0.373^{ABC}	0.028	0.252-0.621
south-western	15	0.393^{BE}	0.046	0.215-0.641	20	0.487^{ab}	0.047	0.223-0.913	20	0.467^{ab}	0.035	0.241-0.705
Total	75	0.445	0.018	0.215-0.717	80	0.484	0.020	0.223-0.913	80	0.502	0.018	0.241-0.831
Kidneys												
north-western	10	0.527^{Dab}	0.041	0.294-0.713	10	0.577^{CDc}	0.023	0.479-0.680	10	0.649^{Ba}	0.020	0.546-0.740
north-eastern	10	0.284^{CDEF}	0.013	0.244-0.357	10	0.343^{BDb}	0.015	0.287-0.422	10	0.615^{C}	0.091	0.321-0.932
central	20	0.584^{ABC}	0.018	0.470-0.760	20	0.590^{ABa}	0.022	0.425-0.814	20	0.597^{A}	0.018	0.467-0.744
south-eastern	20	0.413^{AFb}	0.030	0.255-0.692	20	0.417^{AC}	0.033	0.267-0.671	20	0.391^{ABC}	0.033	0.227-0.625
south-western	15	0.421^{BEa}	0.036	0.226-0.607	20	0.503^{abc}	0.055	0.229-0.933	20	0.495^{a}	0.047	0.204-0.929
Total	75	0.460	0.017	0.226-0.760	80	0.493	0.020	0.229-0.933	80	0.533	0.021	0.204-0.932

A, B, C… - the same characters indicate the significant differences in particular organs at $P \leq 0.01$;

a, b - the same characters indicate the significant differences in particular organs at $P \leq 0.05$

the wild boar kidneys from the south-eastern region (0.391 μg/g w.w.). The mean concentration of lead in the kidneys of wild boar from the south-western region (0.495 μg/g w.w.) was significantly ($P \leq 0.05$) lower than the highest mean concentration of Pb in the wild boar kidneys from the north-western region (Table 2).

The content of Pb in the organs of the examined species from the same regions of Poland seem to be comparable, with an exception in the north-eastern region. The highest mean concentrations of Pb in the livers and kidneys of the roe deer, red deer, and wild boar were found in the central (0.586 and 0.590 μg/g w.w.) and north-western (0.559 and 0.584 μg/g w.w.) regions of Poland, with the lowest in the south-eastern region of Poland (0.393 and 0.407 μg/g w.w., respectively).

In the north-eastern region, the lowest mean concentrations of Pb in the livers and kidneys of roe deer and red deer were significantly ($P \leq 0.01$) lower than in wild boar, and they were twice as low as the highest mean concentration of this element in roe deer and red deer from the central region. In the wild boar, the highest mean lead concentration in the kidneys from the north-western region was significantly ($P \leq 0.05$) higher than the mean concentration of Pb in roe deer kidneys from the same region (Table 3).

Discussion

The environment in which the free-living animals remain has a considerable effect on the heavy metal content in their tissues.

Regarding the geological composition of Poland, two geochemical regions may be seen: the northern (lowlands) and the southern (highlands), which differ due to the geochemical background of elemental composition, including Pb (Lis et al. 2012).

In Poland, soil contamination is commonly observed, mostly on a local scale in industrialized regions from ore mining and processing, in the neighborhood of steel mills and metallurgic plants, and close to urban areas with landfills for municipal and industrial waste. A strongly pronounced geochemical background is characteristic for the southern regions of Poland, resulting from the fact that the soils developed on the basis of igneous and metamorphic rocks, as well as from the industries located in these regions. In turn, despite the low geochemical background in the lowlands, we can observe local lead enrichment, in the surroundings of urban areas, following human activities such as industrial plants, factories, and public transport. In the central, north-eastern, and eastern regions of Poland, the concentration of Pb in the soil reaches

Table 3 The mean concentration of lead in the livers of examined animals in accordance to the geographic region

Animal	Region	N	Pb content (μg/g w.w.)					
			liver			kidneys		
			Mean	SEM	Range	*Mean*	SEM	Range
Roe deer	North-western	10	0.524	0.043	0.269–0.671	0.527a	0.041	0.294–0.713
Red deer		10	0.556	0.024	0.482–0.699	0.577	0.023	0.479–0.680
Wild boar		10	0.595	0.024	0.475–0.756	0.649a	0.020	0.546–0.740
Total		30	0.559	0.018	0.269–0.756	0.584	0.019	0.294–0.740
Roe deer	North-eastern	10	0.296A	0.017	0.233–0.400	0.284A	0.013	0.244–0.357
Red deer		10	0.338B	0.016	0.279–0.418	0.343B	0.015	0.287–0.422
Wild boar		10	0.550AB	0.066	0.324–0.771	0.615AB	0.091	0.321–0.932
Total		30	0.395	0.032	0.233–0.771	0.417	0.041	0.244–0.932
Roe deer	Central	20	0.567	0.018	0.431–0.717	0.584	0.018	0.470–0.760
Red deer		20	0.596	0.032	0.322–0.816	0.590	0.022	0.425–0.814
Wild boar		20	0.596	0.023	0.430–0.831	0.597	0.018	0.467–0.744
Total		60	0.586	0.014	0.322–0.831	0.590	0.011	0.425–0.814
Roe deer	South-eastern	20	0.391	0.031	0.244–0.634	0.413	0.030	0.255–0.692
Red deer		20	0.416	0.035	0.250–0.702	0.417	0.033	0.267–0.671
Wild boar		20	0.373	0.028	0.252–0.621	0.391	0.033	0.227–0.625
Total		60	0.393	0.018	0.244–0.702	0.407	0.018	0.227–0.692
Roe deer	South-western	15	0.393	0.046	0.215–0.641	0.421	0.036	0.226–0.607
Red deer		20	0.487	0.047	0.223–0.913	0.503	0.055	0.229–0.933
Wild boar		20	0.467	0.035	0.241–0.705	0.495	0.047	0.204–0.929
Total		55	0.457	0.025	0.215-0.913	0.480	0.029	0.204–0.933

Values with uppercase letters indicate the significant differences in particular organs at $P \leq 0.01$; values with lowercase letter a indicate the significant differences in particular organs at $P \leq 0{,}05$

13 mg/kg, and in the north-west and west of the country is about 25 mg/kg, while in the region of Sudety and Świętokrzyskie Mountains it rises to 50 mg/kg and even reaches 100 mg/kg in the śląsko-krakowski region. The highest lead concentrations (200 mg/kg) were noted in areas of ore mining and processing and in the neighborhood of metallurgic plants (Lis et al. 2012).

In Poland, the content of lead in the organs of the studied animals was diverse between the particular regions of the country. The concentration of this element in the liver of cervids from the central region was almost twice as high as the liver concentration of Pb in animals from the north-eastern region, an area not heavily industrialized and with only a few plants or factories, which reflects in the low lead content in the examined organs of the animals. In this work, we decided to include the mazowieckie, łódzkie, wielkopolskie, and kujawsko-pomorskie voivodeships into the area of the central region of Poland. In these voivodeships, except the wielkopolskie, numerous plants and factories are located (e.g., chemical, mining, energetic, or metallurgic), which largely contribute to the pollution of the environment. In comparison to the results obtained in roe deer from the central region, Długaszek and Kopczyński (2011) in the same part of the country (łódzkie and mazowieckie) have demonstrated slightly lower content of Pb in the livers of this species. In the case of wild boar, our study showed over two times higher lead content than in the work of the cited authors. In comparison to our experiment, lower lead concentrations in the livers and kidneys of roe deer and red deer were found in Wielkopolska by Michalska and Żmudzki (1992) (Table 4).

High concentrations of Pb were also found in the north-western region in our study. In the livers of roe deer and red deer, the results were about twice as high as those obtained by Wieczorek-Dąbrowska et al. (2013). Additionally, the content of Pb in the cervid kidneys was even five times higher than in the work of the cited authors. This large content of lead in the animals from the north-western region may be explained by the impact of anthropogenic factor (local Pb emitter). In this study, the north-western region includes the zachodniopomorskie and pomorskie voivodeships. In case of zachodniopomorskie, the samples were collected in the rural areas, in which the organic and mineral fertilizers as well as pesticides are an additional source of metals in soil. In turn, in pomorskie the samples were obtained in the areas where shipyard industry is well developed. Also not meaningless is the presence of a refinery and a factory that produce phosphate fertilizers which contain different metals, including lead (Table 4).

The lowest content of lead was found in roe deer and red deer from the north-eastern region. The results were only slightly higher than presented by Falandysz et al. (2005) in red deer livers and kidneys from Warmia and Mazury. In comparison to the results we obtained, Drozd and Karpiński (1997) observed an almost two times higher Pb content in red deer livers. The concentrations of lead in the organs of roe deer and wild boar from this region in our work were much higher than the concentrations of Pb in the organs of roe deer and wild boar from the Mazury Lakes area noted by Durkalec et al. (2015). In wild boar from the north-eastern region, the mean concentration of Pb in the livers and kidneys was 1.5 times higher than in the organs of roe deer and red deer from that area. This situation may be the effect of the different nutrition habits of these species. Roe deer and red deer, as ruminants, consume mostly aboveground parts of plants, which are exposed to the deposition of dust pollutants. The diet of roe deer includes grass, herbs, tree and shrub buds and leaves, blackberry shoots and leaves, raspberry leaves, mushrooms, and food crops (Obidziński et al. 2013). All these plants develop new tissues annually and, for this reason, are considered good indicators of current atmospheric pollutions. In turn, the wild boar diet includes the underground parts of plants, which would indicate the load of lead in the soils in that area.

Contrary to the roe deer or red deer, wild boar are the omnivorous animals and collect food mostly from the ground (acorns, beech, nuts, herbs, grass, roots, rhizomes, or earthworms) which maintains 80–90 % of its diet, while the remaining part includes insects, frogs, eggs, chicks, rodents, and carrion (2–11 %) (Baubet et al. 2004; Schley and Roper 2003; Genov 1981). Earthworms are an important component of the wild boar diet as they can cumulate considerable amounts of lead as well as other heavy metals in their tissues (Latif et al. 2013). As noted by Dobrzański et al. (2009), the transfer of heavy metals to animal tissues proceeds mainly through the digestive tract as a result of either consumption of fodder that contains heavy metals or that is contaminated with soil. Additionally, drawing the soil clods while grazing (in wild boar called rooting) may also play an important role in this process. Due to the factors such as uncontrolled heavy metal emission by industrial plants, the increasing number of cars, and motoring and agricultural plant treatments, the metals diffuse into the soil, water, and air. Pb is characterized by a low level of migration within the soil; however, this parameter increases in acidic soils. As reported by IUNG Puławy, in the warmińsko-mazurskie voivodeship, 41–60 % of soils are classified as acid, while in podlaskie this proportion reaches even 61–80 % (Jadczyszyn et al. 2010). In this region, organisms are exposed to greater amounts of mobile metal forms. Probably this is a result of the intensified agriculture in this region (artificial fertilizers are commonly in use, mostly nitrogenic) (Jadczyszyn et al. 2010; Hołubowicz-Kliza 2006) (Table 4).

In the south-western region, the concentrations of lead found in the livers of roe deer and wild boar were comparable to the results obtained in dolnośląskie voivodeship (Grębocice, terrain of LGOM) by Kucharczak et al. (2003).

Table 4 The concentration of lead in the livers and kidneys of roe deer, red deer, and wild boar from the selected regions of Europe

Species	Location	Organ		Reference
		Liver μg/g w.w.	Kidneys μg/g w.w.	
Roe deer	Mazury (Poland)	0.058	0.102	Durkalec et al. (2015)
	Górny Śląsk (Poland)	0.303	0.906	
	Pomorze Zachodnie (Poland)	0.271	0.134	Wieczorek-Dąbrowska et al. (2013)
	Central Poland	0.43	–	Długaszek and Kopczyński (2011)
	Dolnośląskie voivodeship, Bogatynia (Poland)	0.351	1.179	Kucharczak et al. (2006)
	Dolnośląskie voivodeship (Poland)	0.35	0.87	Kucharczak et al. (2003)
	Kraków (Poland)	0.57	0.51	Lech and Gubała (1998)
	Wielkopolskie voivodeship (Poland)	0.13	0.23	Michalska and Żmudzki (1992)
	Slovenia	0.71	–	Pokorny and Ribarič-Lasnik (2000)
	Slovenia	0.11 to 0.71	–	Pokorny 2000
	Slovakia	0.12	0.25	Kottferová and Koréneková (1998)
Red deer	Pomorze Zachodnie (Poland)	0.209	0.157	Wieczorek-Dąbrowska et al. (2013)
	Warmia and Mazury (Poland)	0.26	0.31	Falandysz et al. (2005)
	Warmia and Mazury (Poland)	0.70	–	Drozd and Karpiński (1997)
	wielkopolskie voivodeship (Poland)	0.11	0.14	Michalska and Żmudzki (1992)
	Croatia	–	2.28	Lazarus et al. (2005)
	Slovakia	1.904	0.561	Kramarova et al. (2005)
	Slovakia	0.73	0.31	Kottferová and Koréneková (1998)
	Spain	0.57	0.33	Santiago et al. (1998)
Wild boar	Górny Śląsk (Poland)	0.904	1.190	Durkalec et al. (2015)
	Mazury (Polska)	0.083	0.088	
	Central Poland	0.25	–	Długaszek and Kopczyński (2011)
	South-easretn Poland	0.145	–	Rudy (2010)
	dolnośląskie voivodeship (Poland)	0.44	0.52	Kucharczak et al. (2003)
	Italy	0.329	–	Danieli et al. (2012)
	Croatia	–	From 0.036 to 0.441	Bilandžic et al. (2010)
	Croatia	from 0.061 to 0.202	From 0.056 to 0.434	Bilandžic et al. (2009)
	Slovakia	0.24	0.39	Piskorová et al. (2003)
	Slovakia	0.67	0.25	Kottferová i Koréneková (1998)

Still, in comparison to our results, the cited authors have shown almost two times higher concentrations of Pb in the kidneys of roe deer and a slightly higher concentration in the kidneys of wild boars. In the other studies, Kucharczyk et al. (2006) have also noted a comparable concentration of lead in the livers and a concentration twice as high in the kidneys of roe deer from areas located in close proximity to the Bogatynia mine and power plant. However, the concentrations of lead in the organs of wild boars from this region were much smaller than those observed by Durkalec et al. (2015) in the livers and kidneys of wild boars from Górny Śląsk. In the case of the roe deer, the concentration of Pb was comparable in the livers, but much smaller in the kidneys than the concentrations we noted in the organs of roe deer from Górny Śląsk (Durkalec et al. 2015) (Table 4).

In the south-eastern voivodeships, the lowest concentration of lead between all the examined species was found in wild boar. An almost 1.5 times lower Pb content in the livers of wild boar was found by Rudy (2010) in that region of Poland (lubelskie and podkarpackie voivodeships). However, this author observed an increase of lead content in the described area from 2002 to 2006. Still, in roe deer from that region, the concentrations of lead found in our study were smaller than those observed by Lech and Gubała (1998) in Kraków (Table 4).

Regarding the fact that the maximal acceptable level of lead in livers and kidneys in Poland is established at 0.5 μg/g w.w. (Commission Regulation (EC) No 1881/2006), in each of the animal species we examined, the levels of Pb exceeded the cited norm, with the exception of the roe deer and red deer from the north-eastern voivodeships. The highest number of

samples that exceeded the acceptable level of lead was found in the north-western and central regions. On the other hand, the lowest percent of samples that exceeded the acceptable level of Pb was found in the organs of animals from the south-eastern region. Table 5 shows detailed information about the number of animals and the percentage of samples that exceeded the acceptable concentration of lead.

In European countries, the situation of the lead content in game animal (roe deer, red deer, and wild boar) organs is diverse. A higher (1.5×) lead content in the livers of roe deer, compared to our results, was observed by Pokorny (2000) and Pokorny and Ribarič-Lasnik (2000) in different regions of Slovenia. Oppositely, a lower (3.5×) Pb concentration in the roe deer livers was noted by Kottferová and Koréneková (1998) in Slovakia, while in the case of the kidneys, the difference was much less (over 1.5×) (Table 4).

A four times higher lead content in the liver of red deer, in comparison to our observations, was found in Slovakia by Kramárová et al. (2005) and two times higher by Kottferová and Koréneková (1998). A higher Pb concentration in red deer livers was found in Southern Spain by Santiago et al. (1998). Also in the kidneys, in comparison to our results, a higher lead level in red deer was detected by Kramárová et al. (2005) in Slovakia and by Lazarus et al. (2005) in low-industrialized regions of Croatia (four times). Lazarus et al. (2005) explain this high Pb content as pollution from public transport, contamination caused by gunshots, and consequences of the then-recent war in Croatia. On the other hand, lower Pb concentrations in the kidneys of red deer in comparison to our results were found by Kottferová and Koréneková (1998) in Slovakia and Santiago et al. (1998) in Southern Spain (Table 4).

In relation to the results in wild boar, a lower lead content in the liver was found by Piskorová et al. (2003) in Slovakia, Bilandžic et al. (2009) in north-eastern Croatia, and Danieli et al. (2012) in Italy. Similarly in the kidneys, lower Pb levels in Slovakia were found by Piskorová et al. (2003) and Kottferová and Koréneková (1998), as well as in north-eastern Croatia by Bilandžic et al. (2009) and Bilandžic et al. (2010), while earlier studies in Slovakia by Kottferová and Koréneková (1998) found lower Pb concentration in wild boar livers in comparison to our studies (Table 4).

Summary

In this study, we have demonstrated the differences between the lead concentrations in the organs of free-living animals in relation to the geographic region. The results show that the central and northern regions of Poland are the most burdened with Pb. The highest mean concentration of Pb was found in the organs of wild boars and the lowest in roe deer. The maximal acceptable concentrations of lead in the organs were exceeded in all the examined animals except in the roe deer and red deer from the north-eastern region. The highest percent of liver and kidney samples that exceeded the acceptable levels of Pb were obtained in central and north-western Poland, while the lowest percent exceeding the acceptable levels were found in organs obtained in the south-eastern region.

Table 5 The number of animals and the percentage of samples with the exceeded maximal lead concentration in livers and kidneys

Region	Roe deer (*N*)		Red deer (*N*)		Wild boar (*N*)	
	Liver (%)	Kidneys	Liver (%)	Kidneys	Liver (%)	Kidneys
North-western	8 (80)	7 (70)	7 (70)	9 (90)	9 (90)	10 (100)
North-eastern	nf	nf	nf	nf	5 (-5-0)	5 (50)
Central	16 (80)	18 (90)	13 (65)	15 (75)	17 (85)	18 (90)
South-eastern	5 (25)	5 (25)	6 (30)	7 (35)	6 (30)	6 (30)
South-western	5 (33)	5 (33)	10 (50)	10 (50)	10 (50)	10 (50)
The maximal Pb concentration in the animal organs for human consumption in Poland	0.5 μg/g w.w. (Comission Regulation (EC) No 1881/2006)					

nf not found

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