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Original Research

Effects of Acid Rain Stemflow of Beech Tree (*Fagus sylvatica* L.) on Macro-Pedofauna Species Composition at the Trunk Base

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Abstract

Forest soil together with the mulch covering it, its chemical composition, oxygen conditions, pH, moisture, and food resources determine the specific species composition of edaphon. The aim of this study was to evaluate the effects of acidic runoff off the bark of a tree on the faunistic list of macro-pedofauna at different distances from the base of the trunk. The study was conducted in the central part of the Świętokrzyskie Mountains located in southeastern Poland. Stemflow of beech (*Fagus silvatica* L.) were collected using bands fitted around five trunks at a height of DBH. The composition of pedofauna was determined using the Morris frameworks mounted at three different distances from the trunks: 10 cm, 50 cm, and 100 cm. At the same points, the pH and the moisture content of the soil were measured. In the soil samples, we also determined heavy metals (Pb, Cd, Cr, Co, Cu, and Zn). The data allowed us to analyze the determinants of distribution of pedofauna, depending on the distance from the trunk of the surveyed trees. The data shows that the main factors affecting the change in the number of pedofauna are soil pH, heavy metals, and resistance of organisms against contamination. Least resistant to high pH and heavy metal content in the soil are *Diplopoda*, *Collembola*, and *Araneae*.

Keywords: air pollution, biomonitoring, geoecosystem, pedofauna

Introduction

Physico-chemical properties and chemistry of precipitation under the influence of air pollution is one of the key elements affecting the modern degradation of the natural environment. It is known that water, beside being a physical reaction partner, also is a carrier of anthropogenic transformation of the natural environment. In foreign literature [1-6] a lot of space is devoted to the problem of acid rain and its negative impact on forest ecosystems. In the more temperate regions of fragile ecosystems, anthropogenically accelerated flow of sulphur caused dramatic changes in the chemical composition of soil solutions and is partly responsible for the spread of forest, especially mountain forest, dieback [7-9]. One of the consequences of the increasing acidification of the soil also is an increase in mobility and availability of heavy metals [10]. Starting in 1994, research in the central part of the Świętokrzyskie Mountains has shown that excessive deposition of acidifying components can result in, among other things, deterioration of forest health as well as the significant acidification of soils [8, 11, 12].

Physico-chemical and biological properties of the soil are significantly altered by pH. The increase in acidity causes deterioration of the structure and permeability of the soil, and increases the solubility of compounds containing heavy metals, which in turn causes an increase in their concentra-

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tion in the biotope [13]. The effects of the varying pH levels of the soil in a forest environment is mainly reflected in the composition and life activity of the edaphon, e.g. worms, nematodes, myriapoda, rotifers, and microorganisms such as bacteria and fungi [14]. Acidification is closely connected with the presence of certain species of organisms from geobiont and geophilic groups, the process of their ontogenetic cycles, and sizes of populations of identified species. The importance of soil meso-and macrofauna results from its effect on the granulometry of the soil, the quantity and size of the pores in the structure of the substrate, which in turn affects the activity of the absorption process, the maintenance and storage of water by the soil, and thus the increase of the availability of micro-organisms [15]. In terrestrial ecosystems there are about 150 earthworms (*Lumbricidae*) on 1 m^2, while the density of the remaining macrofauna of larvae of beetles (*Coleoptera*), imago ants (*Formicidae*), and spiders (*Aranea*) can be up to several hundred per m^2 [16]. Mesofauna density, i.e. springtails (*Collembola*), mites (*Acarina*), and the larvae of Diptera (*Diptera*), comes to the tens of thousands [17]. These invertebrates are numerous in many types of soil, and the assessment of the size of the populations is quite accurate because of the possibility of determining the boundaries of distribution. This allows for the use of pedofauna in bioindication research and estimation of the size of the population, and the analysis of species composition may indicate the impact of pollution on the ecological condition of the soil [18, 19].

The aim of this study was to assess the impact of acid rain stemflow of beech trees on the species composition of macro-pedofauna at the base of tree trunks in the forest ecosystem in the central part of the Świętokrzyskie Mountains.

Research Site Characteristics

The study was conducted at Świętokrzyski National Park on experimental plots located in the Base Station of the Integrated Environmental Monitoring (BS IEM) Święty Krzyż in the central part of the Świętokrzyskie Mountains (Fig. 1).

The station includes the geologically oldest and most raised part of the region (altitude 510-520 m a.s.l.) and has the character of the lower subalpine forest with prevailing fir-beech stand. Boulder fields are a characteristic phenomenon in this area (fields of quartzite boulders). The two-zone, subalpine character of the vegetation distinguishes this area from adjacent areas, which also is reflected in the composition of the forest entomofauna with numerous mountain and boreal-mountain species [20]. The area includes the lower part of the periglacial terrace and is located in a forest ecosystem, having a scanty version of a *Dentario glandulosae Fagetum*. Due to the elevation of about 400 m above the surrounding land, the area is under the influence of both local and remote immisions, with dominant western and north- and southwestern winds [21]. Pollution brought over the area comes from the Ostrava-Karviná Industrial Basin in the Czech Republic, the Upper Silesian Industrial Region, Kraków municipal region, and Sendzimir Steelworks, local heating plants, and households. The soils of the study area are acidic, cold, and damp. These are brown hypostatic and glial soils of varying thickness. Aeolian deposits cover 80-100 cm lying on a layer of dust-solifluction clays. There also is a cover of weathered rock, with podsolic luvisol soils and lithosols [8].

Materials and Methods

The research was conducted in 2010-11 in the forest ecosystem in the central part of the Świętokrzyskie Mountains at an altitude of 513 m above sea level. We measured pH of: precipitation, stemflow of beech tree, and soil solutions obtained at a depth of 15 cm. The research was conducted on a weekly basis and the pH measurements were performed directly in the field. Five beech trees were selected for measuring the pH of water flowing down the trunks. On randomly selected specimens with different trunk circumference we mounted bands in order to collect

Fig. 1. Research area location.

the run-off water at the diameter at breast height (DBH). The water was caught in containers with a capacity of 120 l. The proposed amount of five trees, in accordance with the data provided in the literature [22], provides a representative sample. Among the 436 monitored areas included in the Monitoring of Forests in Europe Level II, this method was used in 81% of experimental areas [23].

The tree species was chosen for several reasons. It is the dominant species in the central part of the Świętokrzyskie Mountains, the shape of the crown facilitates the movement of water from the branch to the trunk of the tree, and thus a large amount of water enters the soil. The flow also is easier because of the horizontally striped, thin, smooth bark. Water penetration into the soil is facilitated by the highly developed heart root system, dense with strong lateral roots up to 6-10 m from the trunk with prevalent sprout roots, ingraining vertically to a depth of 12-14 dm [24, 25].

In order to determine the degree of acidity of the soil at the test plot, three lysimeters were fitted at a depth of 15 cm.

Soil samples for physico-chemical analysis were collected from the top mineral (0-10 cm) at a distance of 10, 50, and 100 cm from the trunk of the tree, according to the methodology developed in Germany [26] and modified by Kowalkowski et al. [27]. The pH of the samples was determined in a suspension of H_2O and KCl. In order to determine the content of heavy metals (Pb, Cd, Cr, Co, Cu, Zn), the samples were mineralized in an Anton Paar Multiwave 3000 Microwave Sample Preparation Platform System in a mixture of hydrochloric and nitric acids (65% Suprapur), and determined using a GBC ICP-MS/TOF spectrometer.

Research areas to measure pedofauna were established at the foot of the adjacent beech trees. To obtain the pedofauna, we used Morris frameworks with the dimensions of 25 cm width, 25 cm length, and 10 cm depth. Due to the inclination of the land and the possibility of water runoff, the framework was mounted on the north side of trees (according to the inclination) at a distance of 10 cm, 50 cm, and 100 cm from the trunks of trees. Due to the life cycle of pedofauna, the research was conducted in two-month cycles, in April, June, August, and October. Each time, soil pH was measured and 3 samples were collected near each tree, macroscopically selecting the pedofauna. The series of research each time consisted of 6 samples with a total area of 0.375 m^2.

After determination of taxa, we found the rate of attendance, dominance, stability, and taxonomic diversity of invertebrates.

To determine the dominance of taxa found, the following formula was used:

$$D=Sa/S \times 100\%$$

...where:

Sa – the number of individuals of a species

S – number of individuals of all other species

A distinction of classes was adopted after Kasprzak and Niedbała [28] regarding the following classification:

D_5 – eudominants – more than 10.0% of the total compared taxonomic group

D_4 – dominant players 5.1-10.0%

D_3 – subdominants 2.1-5.0%

D_2 – recedents 1:1-2.0%

D_1 – subrecedents below 1.0%

In order to determine the prevalence of taxon-attendance proving its commonness or rarity, calculations were made on the basis of the following formula:

$$Fi= s/S \times 100\%$$

...where:

Fi – the *i*-th species

s – number of positions within the *i*-th species

S – total number of posts

In research on the stability of taxon, the model proposed by Szujecki [20] was used:

$$C= q/Q \times 100\%$$

...where:

C – stability

q – the number of samples in which the analyzed species appeared

Q – the total number of samples

Pedofauna was divided into: euconstants (> 75.00%), constants (50.01-75.00%), subconstants (30.01-50.00%), accessory species (15.00-30.00%), and accidentals (<15.00%).

The marked taxa were photographed and archived in electronic form using the NIS-Elements BR software using a Nikon SMZ 1500 microscope.

In order to determine the level of statistical significance between the parameters being determined, the collected data was statistically processed using Statistica version 7.0 software.

Results

The presence of pollution of local or remote origin in the air determines the presence of acid rains in the central part of the Świętokrzyskie Mountains [6, 29-31]. During the study period (April-October), the pH of precipitation in 2010 ranged from 3.54 in October to 7.11 in April, with an average of seven months of 5.07 (Fig. 2). In 2011 these values were lower (Fig. 3). The average pH of precipitation

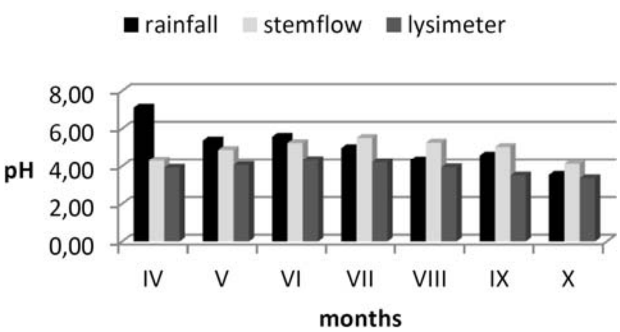

Fig. 2. pH of precipitation, water stemflow of beech, and soil solution at a depth of 15 cm during April to October 2010.

Table 1. Change of pH in relation to the distance from the trunk.

Distance from beech trunk	Soil pH depending on distance from the trunk	
	pH_{KCl}	pH_{H_2O}
10 cm	2.67 (2.44-2.97)	3.36 (3.12-3.64)
50 cm	2.81 (2.70-2.97)	3.49 (3.26-3.63)
100 cm	2.85 (2.50-3.14)	3.51 (3.16-3.74)

was 4.78, while at the same time the difference between the lowest values (pH 4.20 in September) and the highest (pH 5.55 in October) was smaller. The pH in the stemflow of beech were shaped conversely. In 2010 it was lower (average for 7 months was pH 4.91) compared to 2011, where the average pH was 5.26. Bulk precipitation and the stemflow water had an impact on the pH of the soil solution measured at a depth of 15cm. In 2010 the average pH for the period of the studied 7 months was 3.91, with a maximum pH of 4.33 recorded in June and a minimum of 3.36 in October (Fig. 2). In 2011 the average pH at a depth of 15 cm was higher by pH 0.48 and was 4.39.

Acidification and spatial distribution of pH in the topsoil at a depth of 0-10 cm indicates the dependency of pH increase on distance from the tree trunks (Table 1).

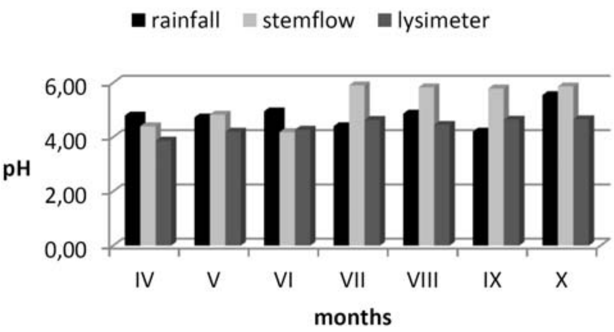

Fig. 3. pH of precipitation, water stemflow of beech, and soil solution at a depth of 15 cm during April to October 2011.

Statistical analysis of testing conducted using the U Mann-Whitney Test showed statistically significant differences in pH values depending on the distance from the trunk (Table 2).

It was found that acidic solutions running down the trunks of trees most intensely affect the pH of the soil at a distance of 50 cm. At over 50 cm, the amplitude of fluctuations is drastically reduced, which results, on the one hand, in a weaker interaction of the solutions flowing down the trunks, and on the other hand from the supply of alkaline ions from washing the surfaces of plants.

Under these edaphic conditions, we found a total of 369 imago forms that belonged to 9 taxa, i.e. *Acarina*, *Araneae*, *Chilopoda*, *Coleoptera*, *Collembola*, *Diplopoda*, *Isopoda*, *Pseudoscorpionidea,* and *Staphylinidae* (Table 3), and 147 larval forms belonging to two taxa – *Diptera* and *Coleoptera* (Table 4).

The calculated attendance rate indicates that the most commonly occurring taxa were represented by the *Chilopoda* and *Staphylinidae* and in the order *Acarina*, *Collembola*. Consistent attendance rate (10%) was reported for *Isopoda*, *Diplopoda*, and *Araneae* (Fig. 4).

Studies of the dominance ratio show that the highest share (29%) was held by *Chilopoda* and *Staphylinidae*, *Acarina*, and *Collembola*, which form a group of eudominants (Fig. 5).

Study of the dependancy of the amount pedofauna on the date of measurement indicates that most individuals were found in June (33.1% of all identified individuals) and August (27.4%), and the least individuals in April (15.7%) and October (23, 8%). The most numerous taxa were *Chilopoda* (28.7%), showing a steady increase in the size of the population in each successive period of research, and *Staphylinidae* (22.8%), which appeared particularly abundant in June, and then *Acarina* (20.1%). In the case of this taxa, an increase in the number was recorded mainly in the months of April, June, and August. Other taxa were characterized by increased numbers in June, with the exception of the *Diplopoda*, for which growth was in April and October (Fig. 6).

Adopting the 5-step scale of Kasprzak and Niedbała [28], the pedofauna stability coefficients were determined.

Table 2. The statistical results of the U Mann-Whitney Test.

Distances tested	Sum of rang group 1	Sum of rang group 1	U	Z	P	N group 1	N group 2
Measurment pH – values in KCl solution							
10 cm:50 cm	**1044.5**	**1881.5**	**341.5**	**-3.95**	**0.00**	**37**	**39**
10 cm:100 cm	**988.5**	**2171.5**	**285.5**	**-4.83**	**0.00**	**37**	**42**
50 cm:100 cm	1483.5	1837.5	703.5	-1.09	0.27	39	42
Measurment pH – values in H_2O solution							
10 cm:50 cm	**1111.5**	**1814.5**	**408.5**	**-3.25**	**0.00**	**37**	**39**
10 cm:100 cm	**1048.5**	**2111.5**	**345.5**	**-4.24**	**0.00**	**37**	**42**
50 cm:100 cm	1511.0	1810.0	731.0	-0.83	0.41	39	42

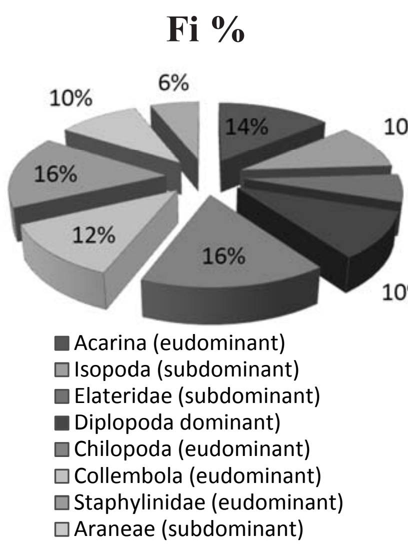

Fig. 4. Frequency ratio (*Fi*) for each taxa.

We found a lack of euconstants (D_5) and constants (D_4), which is the result of unfavourable chemical changes in biotope and large habitat requirements of the studied taxa. To relatively constant (D_3 subconstants), with the participation of 43.7%, 47.9%, and 43.7%, we included *Staphylinidae*, *Chilopoda*, and *Acarina*, to the accessory taxa (D_2): Isopoda (20.8%), *Diplopoda* (20.8%), and *Collembola* (25.0%); and to accidentals (D_1): *Elateridae* (8.3%), *Araneae* (12.5%), and *Pseudoscorpionidea* (8.3%).

This study also shows the diversity of species of organisms depending on the content of heavy metals in the soil. The study of chemical composition showed that the highest concentrations of metals (Pb, Cd, Co, Cr, and Zn) were right at the trunk of a tree (10 cm) and decreased with distance (Fig. 7).

The same process was found in the size of Isopoda, Coleoptera, Pseudoscorpionidea, and larvae of beetles. The greatest number of these organisms has been shown at the trunk of a tree, where we recorded the highest concentrations of heavy metals and the highest soil acidification.

Table 3. Diversity of pedofauna in relations to distance from beech trunk.

Name of taxon	Distance			Sum
	10 cm	50 cm	100 cm	
Acarina	23	30	21	74
Isopoda	7	6	3	16
Coleoptera (*Elateridae*)	8	2	0	10
Diplopoda, Helminthomorpha	4	5	11	20
Chilopoda (*Lithobiomorpha*)	33	46	27	106
Collembola	10	13	23	46
Staphylinidae	24	40	20	84
Araneae	1	2	5	8
Pseudoscorpionidea	3	1	1	5
Sum	113	145	111	369

Table 4. Number of larva forms in relation to distance from beech trunk.

Name of taxon	Distance			Sum
	10 cm	50 cm	100 cm	
Diptera	12	23	30	65
Coleoptera	38	24	20	82

This indicates their high tolerance to harsh edaphic conditions (Fig. 8).

Dipteran larvae, *Diplopoda*, *Helminthomorpha*, *Collembola*, and *Araneae* show an inverse relationship. Their number increases as we move away from the trunks of trees, reflecting their sensitivity to the presence of heavy metals and low soil pH (Fig. 9).

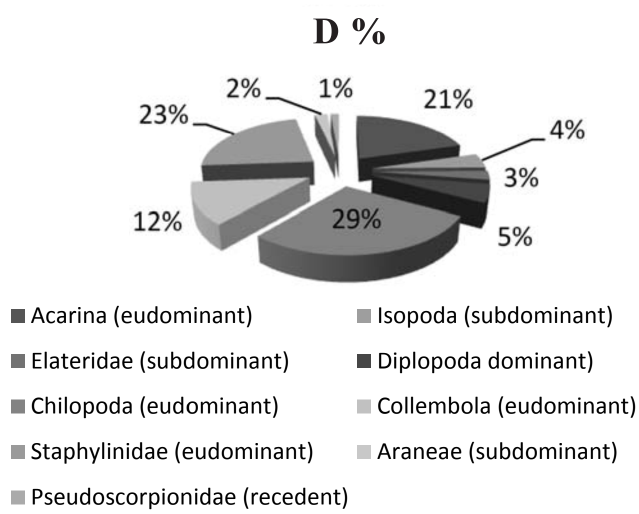

Fig. 5. Dominance ratio (D) for each taxa.

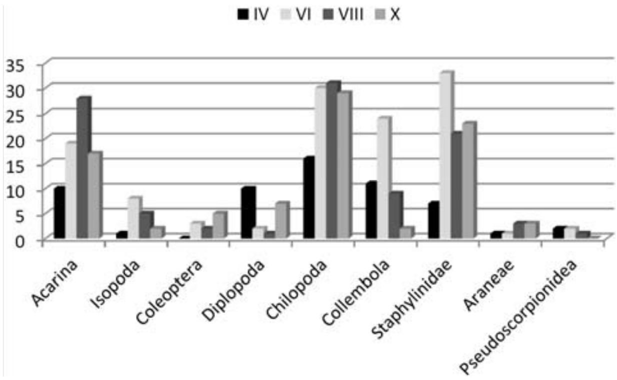

Fig. 6. Number of individuals of pedofauna caught during the study period.

Discussion

The observed poor health of forests, especially in the central part of the Świętokrzyskie Mountains, as well as the publications reporting on destabilization of environmental equilibrium caused by strong acidification resulting from air contaminated by emissions, and the threat and extinction of many species of flora and fauna in this region, support this thesis [32, 33]. The dying of the old growth of fir trees, ongoing for the last 30 years, considered to be degenerative forms of fertile acidic beech woods, hornbeam forests and mixed forests, has a causal relationship with this phenomena [34, 35]. For several years, a beech trees disease has been developing [36, 37]. The sum of these actions poses a

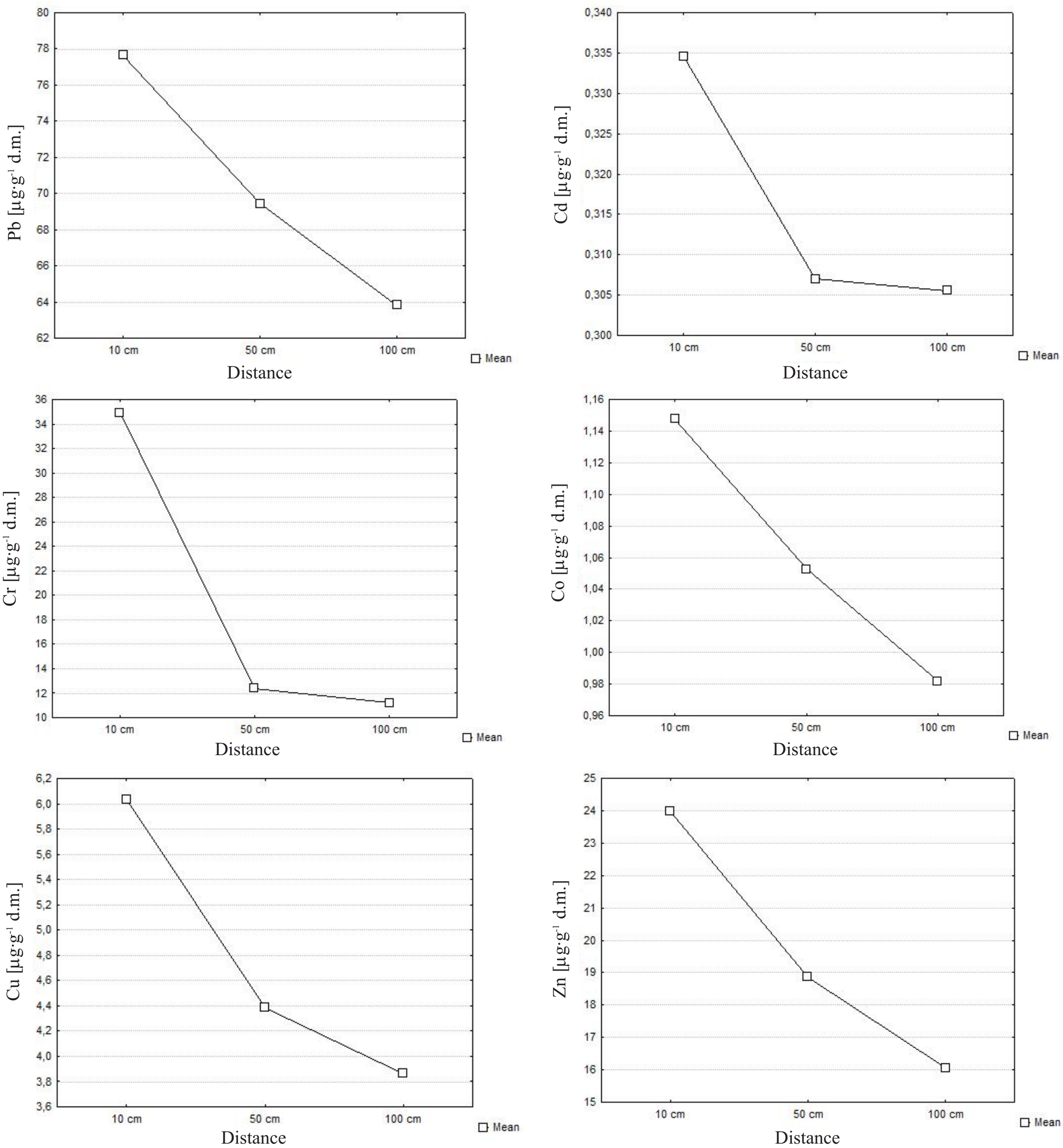

Fig. 7. Change of content of select heavy metals in the soil, depending on distance from tree trunks.

serious threat to the continued functioning of and preservation of natural resources of animate and inanimate natures. Emissions of various gases linked to economic activity and living conditions of humans causes the creation of gas mixtures, and the dust suspended in the air is converted to aerosols, mainly of a highly acidic nature. The effects these mixtures have on soil and vegetation may be: additive in time, synergistic or antagonistic, which leads to selective death of the old stands, the concentration of the forest floor vegetation cover, soil acidity changes, changes in the course of growth and nutritional status of plants, and changes in the circulation of water and substances.

Toxic nitrogen compounds that enter the air have a long-term deforming effect on the soil environment [8, 11, 38]. The concentrations of this component are generally lower than S-SO_2, but have a significant impact on the further development of the properties of soils occurring here. In acidic forest soils, due to a slowed-down ammonification, we can observe reduced mineralization of organic matter, combined with a significant nitrification that takes place even at a pH of about 3.5.

The conducted study, aimed at determining the effect of acid rain stemflow of beech on the biodiversity of pedofauna, indicated that the primary restrictor is the pH of soil and habitat requirements of taxa.

The presence of the identified taxa is associated with persistent high humidity around the trunks and the biological characteristics of, in particular, *Chilopoda* and *Staphylinidae*. The permeability of the cuticle is not a sufficient protection from drying out and forces a specific (for them) type of habitat. The identified *Staphylinidae* and their environmental requirements are not well understood. There are species here with no covers protecting the abdomen (osmoregulative sensitivity) and therefore, they occupy the ecotone habitats of water edges [39], and in the examined biotope in the central part of the Świętokrzyskie Mountains they occupy the very moist soil around the tree trunks. Numerous studies provide a variety of habitats for *Staphylinidae*: forest litter, moist peat soil, vicinity of trunks of old trees, hollow rot [40-44].

Their moist body surfaces favour the penetration of pollutants dissolved in the soil solution into the tissues. While washing the deposits accumulated in tree crowns by precipitation modifies the physico-chemical and chemical properties of precipitation reaching the soil [45], the variation in pH, depending on the distance from the base of the trunk (10-100 cm), varies only by 0.15 pH_{H_2O}. Mobility and the penetration of toxins into the body of soil organisms in these conditions is very high. Low soil pH increases the absorption of heavy metals (especially Pb and Cd) by soil

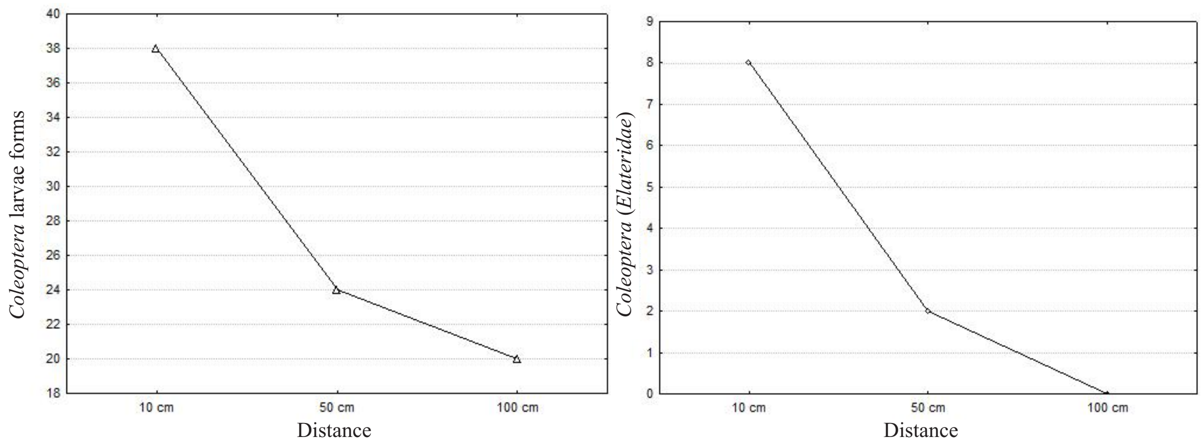

Fig. 8. Change of size depending on distance from tree trunks.

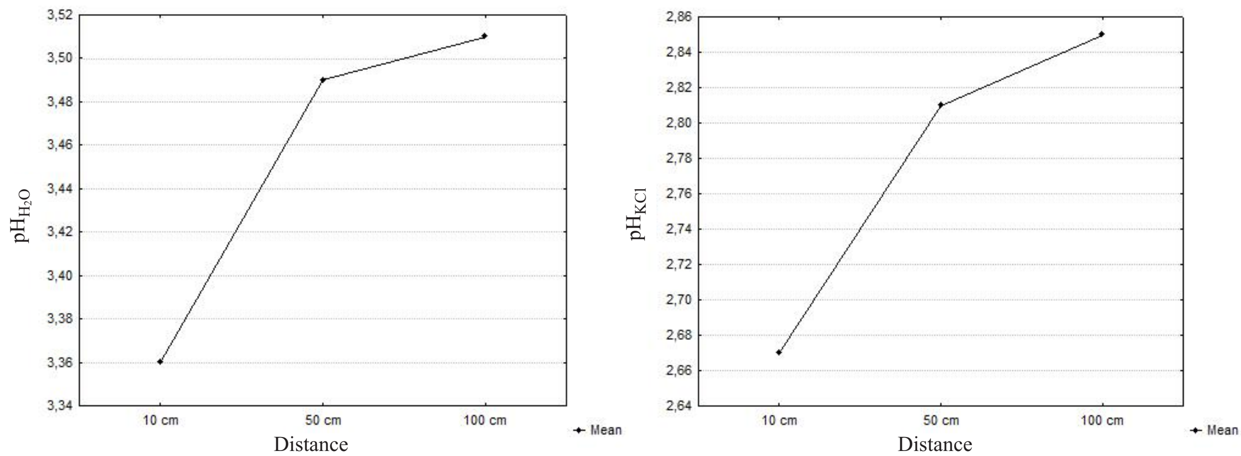

Fig. 9. Changes in size depending on distance from tree trunks.

organisms [46, 47]. Studies carried out by many authors on the impact of chemical pollution of soils on pedofauna indicate a significant decrease in the number and diversity of species as a result of the use of pesticides and heavy metals contamination [18, 48, 49]. Analyses conducted by Marko-Worłowska and Chrzan [15] in the area of the natural landscape park Kraków Zakrzówek show a much greater variety of species, density, and size of the studied populations than that seen in the central part of the Świętokrzyskie Mountains. However, the pH of the soil there was significantly higher (7.56-7.74, 7.36-7.78) while in the studied area, it had a range of 2.44-3.74. On this basis, it can be assumed that the main restrictor of the size and biodiversity of pedofauna is soil pH.

Conclusions

- The conducted study, aimed at determining the effect of acid rain stemflow of beech on the biodiversity of pedofauna, indicated that the primary restrictor is the pH of soil and habitat requirements of taxa.
- The research found a statistically significant relationship between soil pH and distance from tree trunks.
- The study showed a decrease in the content of heavy metals in soils with distance from the tree trunks.
- High sensitivity to the high content of heavy metals and low pH is shown by *Diptera* larvae, *Diplopoda*, *Helminthomorpha*, *Collembola*, and *Araneae*. Their number increases as the distance from tree trunks grows.
- The study showed that the highest (29%, determined by the dominance factor), share is held by millipedes (*Diplopoda*), which may result from a developed chitin cuticle reinforced with calcium carbonate. The armor built in such a way protects against drying and provides effective protection against the effects of environmental toxins.
- Volume share determined by the dominance factor for a given taxon on the selected study surface and the knowledge of the habitat requirements allows for the assessment of this organism as a biomarker.

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