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Distribution of heavy metals in Warsaw soils as a factor affecting the soil biota

Abstract. An analysis was made of the influence of heavy metals on the soil fauna (*Lumbricidae*, *Collembola*) in the soils of Warsaw mown grasslands. No direct correlations were observed between the concentration of heavy metals in the soil and the numbers of animal groups, or between heavy metal concentrations and the degree to which animals are parasitised.

INTRODUCTION

The assessment of the influence of heavy metals on the soil environment, and on the micro-organisms and soil animals inhabiting it, is a very broad issue. In city soils in particular, the heavy metal content is one of the most significant factors influencing the functioning of the whole soil sub-system, and in consequence, the whole ecosystem. The influence of heavy metals on soil and the organisms living within it is connected with a whole series of changes brought about by other aspects of the pressures of urbanization influencing the degradation of the soils in cities to some extent. Examples are the pressures resulting in increased aridity, salinity and alkalinity of these soils. The degree of influence also depends on the type of chemical compound and the concentration at which the metal occurs in the soil.

In polluted soils heavy metals are fixed by organic, mineral and mineral-organic colloids by means of exchange absorbtion, and by humic and fulvic acid stabilization. This leads to a specific direction of change in organic matter, e.g. to the creation of calcified humates unavailable to the microflora. These groups of factors inhibit the process of humification, and therefore lead to disruption of the transformation of organic matter into humus substances and so dictate the basic properties of the soil. This leads to accumulation of organic carbon and immobilization of the elements assimilated by plants.

The influences of heavy metals may be investigated at various levels of organisation – from the molecular level, through the level of the individual, the organisation of the population and the community, to the level of the functioning of the soil sub-system (CHMIELEWSKI, RADWAN 1992).

At the molecular level, excess heavy metals become inhibitors of biochemical reactions, disrupting the ionic equilibrium, changing the spatial structure of macromolecules, and perhaps giving rise to mutations and the disruption of metabolic pathways.

It is also known that heavy metals have the capacity to accumulate in some tissues or organs, and that, above a certain concentration, they may cause disruption to tissue or organ functioning and may even lead to their degeneration. Concentration of heavy metals in an organism can therefore disturb its ionic balance, ability to conduct nerve impulses, secretory processes etc, has influence on the metabolic rate and in plants restricts photosynthesis.

At the level of organisation of populations and communities, heavy metals can give rise to changes in numbers, death rates, reproduction, life-span and biomass. They also cause changes in the species composition, dispersion and species diversity (HUNTER et al. 1987). The changes observed to community structure depend on changes in the dominant inter-relationships, competitive interactions and trophic structures. These are associated with the very varied capacity of different species to accumulate particular heavy metals, and the differences in resistance to damage.

Large doses of heavy metals have influence on the fertility of the soil, they disrupt the organisation and functioning of groups of micro-organisms (having an inhibitory or stimulatory influence on proteolytic, amylolytic and cellulolytic activities, as well as on ammonification and nitrification) and on the soil fauna. In consequence, they induce changes in nutrient cycling, primary production and decomposition (RAPPORT et al. 1985).

THE INFLUENCE OF HEAVY METALS ON ORGANISMS

Research into the contamination of urban soils in Warsaw by heavy metals was carried out in the years 1976–1980 by a group from the Department of Soil Science of the Academy of Agriculture (SGGW). Contamination of soils by lead, zinc, copper, chromium and manganese was studied. Only a small proportion of Warsaw soils (covering several per cent of the area) has moderate contamination by heavy metals exceeding the level of occurrence of these elements in natural soils, and this relates mainly to lead and copper. On the other hand, the maximum concentrations of the metals studied, recorded at certain points, exceed the average values many times and point to heavy spot-contamination (CZARNOWSKA et al. 1983).

The influence of heavy metals on micro-organisms is very variable. Studies on the influence of lead octane at concentrations of 50–5000 ppm have shown that it has a stimulatory effect on the development of actinomycetes, bacteria and fungi (STRZELEC 1978). As MALISZEWSKA and WIERZBICKA (1978) show, lead as the nitrate leads to increased abundance of nitrifying bacteria and cellulolytic actinomycetes. On the other hand it inhibits the development of cellulolytic fungi and *Nitrobacter*. In general, zinc inhibits microbiological processes, while, at concentrations known from urban areas, copper has a stimulatory influence on the development of fungi. Copper and zinc have an inhibitory effect on the process of nitrogen fixation, and lead nitrate has a stimulatory effect.

In the soils of mown grasslands beside roads in Warsaw, a decline in the numbers of micro-organisms and enzyme activity has been recorded (RUSSEL, PAWLIK 1983). This decline is not related directly to the heavy metal content of these soils. In the urban environment, a major role is played by both the aridity of these soils and their alkalization, which leads to the emergence of calcified humates unavailable to microflora, and chelates, and also to a reduced biomass of green plants and therefore also to less dead organic matter undergoing decomposition.

The possibility of increasing enzymatic activity through the application of mineral fertilizer (ZIMNY, ŻUKOWSKA-WIESZCZEK 1983) attests to the fact that heavy metals are not of great significance as inhibitors of these processes in the soils of urban mown grasslands.

Studies on the soil fauna were carried out in the Laboratory of Soil Fauna in the Institute of Zoology of the Polish Academy of Sciences between 1974 and 1983. Changes observed in the animal communities studied resulted from a number of disturbances to the functioning of the urban soil environment (PISARSKI, TROJAN 1976).

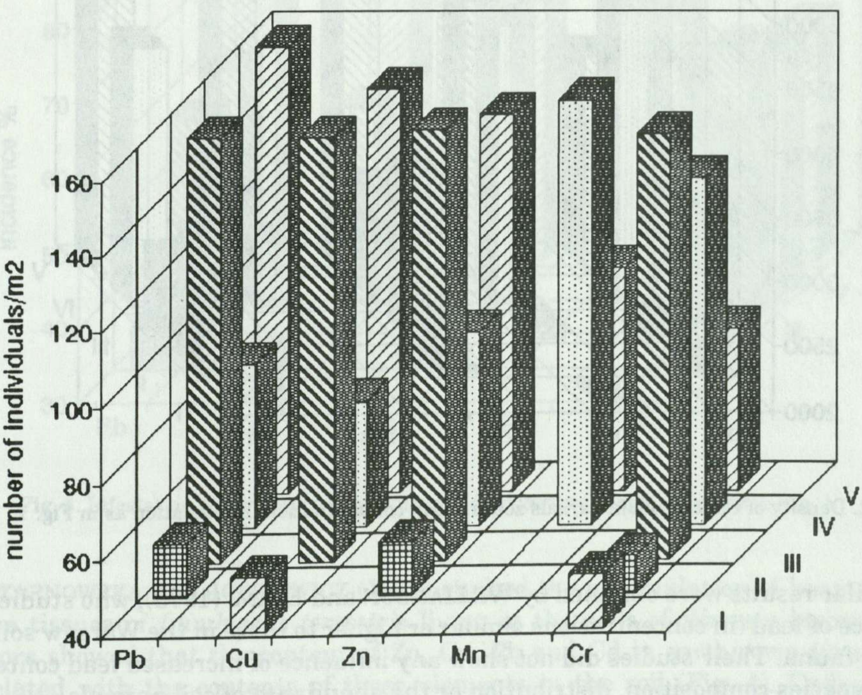

Fig. 1. Density of Lumbricidae in various zones of soil eontamination.
Pb – I < 20; II 20–50; III 50–100; IV 100–200; V >200 ppm
Cu – I < 10; II 10–20; III 20–30; IV 30–40; V >40 ppm
Zn – I < 20–50; II 50–100; III 100–200; IV 200–400; V >400 ppm
Mn – I < 60; II 60–120; III 120–240; IV 240–280; V >280 ppm
Cr – I < 10; II 10–20; III 20–30; IV 30–40; V >40 ppm

An evaluation of the effect of contamination of the soil with heavy metals on species composition and abundance has been carried out for two groups of soil-dwelling saprophages: springtails (*Collembola*) and earthworms (*Lumbricidae*). The abundance of these groups in zones of increasing soil contamination were compared. The concentration of heavy metals in the soil did not affect the abundance of *Lumbricidae* and *Collembola*. The highest densities of earthworms were noted both at the highest level of lead contamination (>200 ppm) as well as in soils in which the level of this element was 50–100 ppm. A relationship between the degree of contamination of the soil by Cu, Zn, Cr and Mn and the density of *Lumbricidae* (Fig. 1) was not reported either. *Collembola*, whose higher densities were observed in zones of higher soil contamination, showed similar variability (Fig. 2).

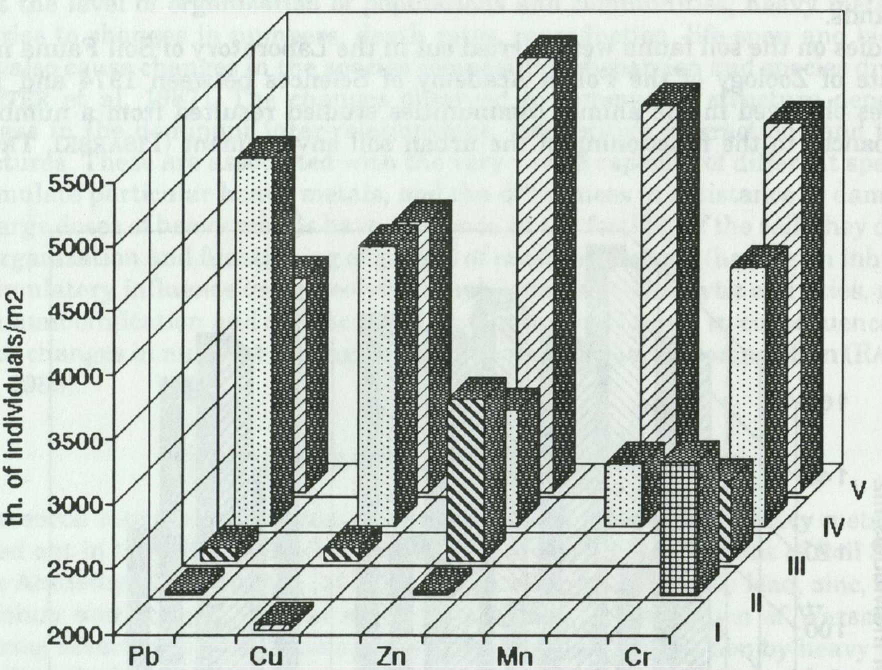

Fig. 2. Density of Collembola in various zones of soil contamination. Explanation as in Fig. 1.

Similar results were obtained by WILLIAMSON and EVANS (1973), who studied the influence of lead (in concentrations similar or higher to those in the Warsaw soils) on the soil fauna. Their studies did not show any influence of increased lead content in soil on species composition, distribution or the abundance of soil animals.

Results obtained from an evaluation of the relationship between the degree of infection of earthworms by parasitic Protozoa and the extent to which the soil is contaminated with heavy metals were indeterminate. Such studies were carried out by PIŽL and STERZYŃSKA [1991 (1993)] who compared the degree to which earthworms of the species *Lumbricus terrestris* were infested by gregarine parasites

(*Apicomplexa*, *Monocystidae*) (Fig. 3). A statistically significant correlation was obtained between the degree to which earthworms were infested and the general (total) pollution of the soils by heavy metals ($r = 0.79$, $p < 0.05$) and particularly with zinc ($r = 0.82$, $p < 0.05$). On the other hand, the correlations with copper, lead and cadmium were not statistically significant. A similar reaction, ie a decrease in the immunity of earthworms to parasites, results from other anthropogenic factors such as pesticide pollution, industrial contamination with SO_2 (PURRINI 1987) or herbicide use (PIŽL 1989). The evaluation of the degree to which earthworms are infested by *Protozoa* may therefore be an indirect indicator of the degree to which the immunity of animal populations inhabiting the soil environment has been lowered. However, it is not always unequivocal.

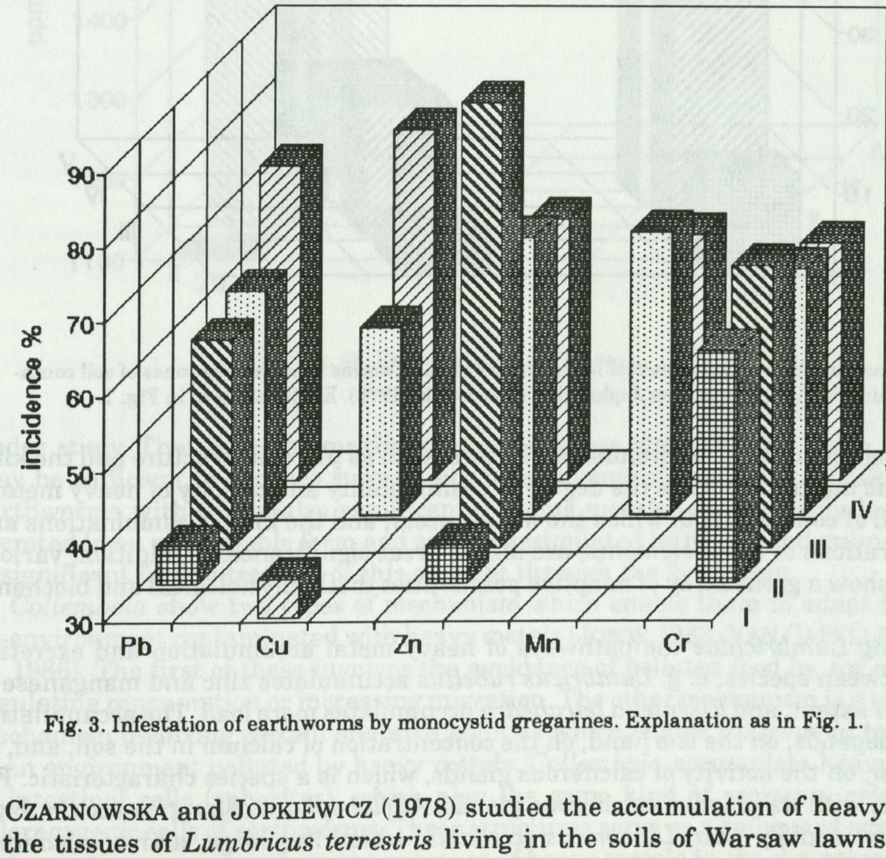

Fig. 3. Infestation of earthworms by monocystid gregarines. Explanation as in Fig. 1.

CZARNOWSKA and JOPKIEWICZ (1978) studied the accumulation of heavy metals in the tissues of *Lumbricus terrestris* living in the soils of Warsaw lawns. These authors showed that the content of Zn, Cu, Pb and Cd in earthworm tissues was correlated with the contents of these elements in the soil (Fig. 4). Cadmium, in particular, was accumulated in the bodies of earthworms in concentrations much higher than in the soil. The measures of the accumulation of heavy metals in tissues do not, however, allow for confident conclusions to be drawn regarding the disorders that they induce in soil functioning.

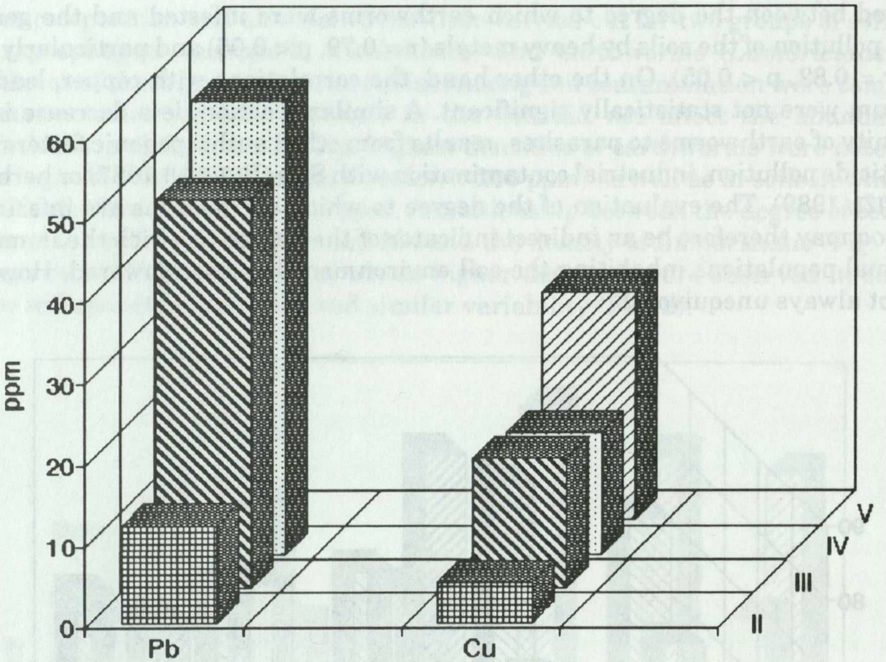

Fig. 4a. Accumulation of heavy metals in the tissues of earthworms from various zones of soil contamination (after data from Jopkiewicz, Czarnowska 1978). Explanation as in Fig. 1.

A whole complex of environmental factors, such as pH, soil structure and the kind of organic matter influence the degree of assimilability and toxicity of heavy metals. The kind of compounds in which the metals occur, and the kind of combinations and concentrations of these elements, are also of great significance. In addition, various species show a great array of adaptive possibilities (both physiological and biochemical).

Among *Lumbricidae* the pathways of heavy metal accumulation and excretion vary between species, e. g. *Lumbricus rubellus* accumulates zinc and manganese to a greater extent, and *Eiseniella tetrahedra* accumulates more lead. The accumulation of lead depends, on the one hand, on the concentration of calcium in the soil, and, on the other, on the activity of calciferous glands, which is a species characteristic. For example, with its inactive calciferous glands. *Allolobophora chlorotica* accumulates lead more rapidly than *Lumbricus terrestris*, which has large, active calciferous glands. Heavy metals may be excreted through the calciferous glands or the nephridial system, or may be immobilized in chloragogen cells, which play an analogous role to that of the liver (LEE 1985). The toxic effects of heavy metals on earthworms are manifested in a loss of body weight, increased mortality and a decline in the rate of production of cocoons. Development to sexual maturity is inhibited. The simultaneous action of several heavy metals intensifies the deleterious effects. However, this happens only at concentrations considerably higher than average in the urban soils

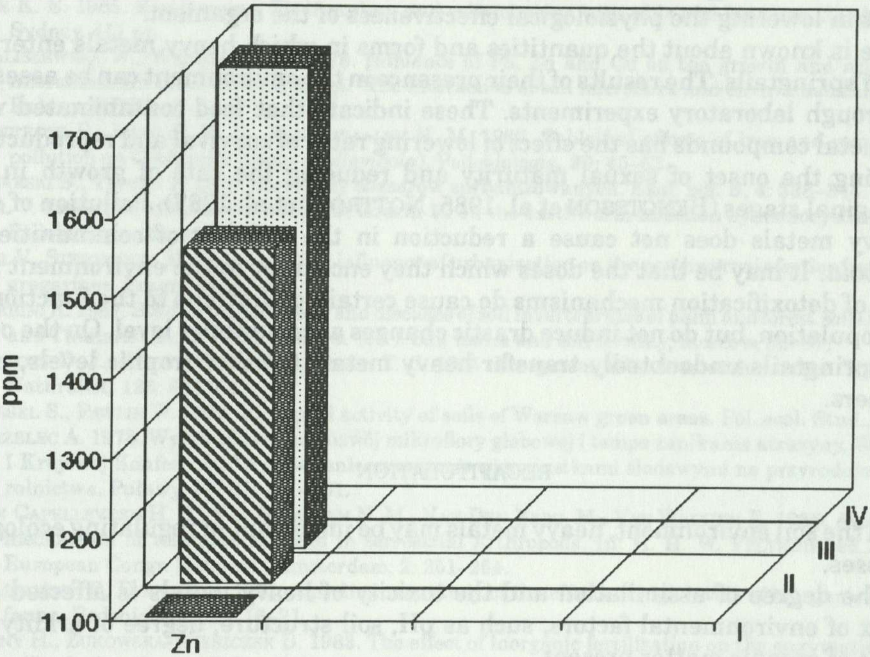

Fig. 4b. Explanation as in Fig. 4a.

under study. That said, the maximum doses of these elements that were recorded may be sufficient to produce such effects. The amount of heavy metals taken in by earthworms with soil is also significant as some metals – particularly lead – are excreted in an unavailable form and are not assimilated by plants and animals. This is significant for the transfer of this element through the food chain.

Collembola show two types of mechanism which enable them to adapt to life in an environment contaminated with heavy metals (JOSSE 1983, VAN CAPELLEVEEN et al. 1986). The first of these involves the avoidance of polluted food by, for example, regulating consumption or increasing migration. The other mechanism is a tolerance mechanism involving certain adaptive abilities which enable *Collembola* to remain in an environment polluted by heavy metals. *Collembola* accumulate heavy metals in intestinal cells (spherites), which play the same kind of secretory role as the chloragogenic cells of earthworms. These structures serve as a safeguard against the toxic reactions resulting from the presence of heavy metals in the digestive system. The contents of the gut epithelium are discharged regularly as gut pellets during consecutive moults. The utilization of this detoxification mechanism results in the loss of energy, which can have an unfavourable effect on the rate of growth and reproduction. On the other hand, the magnitude of the absorption of toxic substances is regulated by the gut epithelium. If the concentration of toxic elements in the food of *Collembola* is very high these will not be absorbed totally in the alimentary canal.

Some substances may therefore pass to the haemolymph, and this undoubtedly has an effect in lowering the physiological effectiveness of the organism.

Little is known about the quantities and forms in which heavy metals enter the bodies of springtails. The results of their presence in the environment can be assessed only through laboratory experiments. These indicate that food contaminated with heavy metal compounds has the effect of lowering rates of survival and reproduction; prolonging the onset of sexual maturity and reducing the rate of growth in the pre-imaginal stages (BENGTSSON et al. 1985, NOTTROTT et al. 1987). Pollution of soils by heavy metals does not cause a reduction in the number of communities of *Collembola*. It may be that the doses which they encounter in the environment plus the use of detoxification mechanisms do cause certain distortions to the functioning of the population, but do not induce drastic changes at community level. On the other hand, springtails undoubtedly transfer heavy metals to other trophic levels, eg to consumers.

RECAPITULATION

1. In the soil environment, heavy metals may be important in regulating ecological progresses.

2. The degree of assimilation and the toxicity of heavy metals is affected by a complex of environmental factors, such as pH, soil structure, degree of aridity and the type of organic matter present.

3. Soil saprophages (*Lumbricidae*, *Collembola*) use a whole group of adaptive physiological mechanisms leading to: the excretion, regulation of the degree of absorption, and immobilization (deactivation) of heavy metals.

4. High concentrations of heavy metals may lead to loss in body weight, a reduction of the growth rate, an increase in mortality and a lowering or inhibition of reproduction.

5. Different animal species have various mechanisms for detoxification.

6. At the concentrations observed in the city, the degree of influence of heavy metals on soil organisms cannot be estimated using simple dependent relationships such as: a correlation between the population levels in animal communities and the accumulation of these elements in the bodies of the animals or the degree to which infestation by parasites is affected by the heavy metal content of soils.

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