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Accumulation of microelements by different invertebrate trophic groups on wasted lands

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The problem of transformation of natural landscapes resulted from the negative technogenic impact is highlighted. It is shown that mining enterprises are powerful anthropo-technical sources of organic and inorganic toxicants entering the environment. Their wastes pollute all components of the ecosystems and negatively influence human health by increasing a risk of disease. The nature of the accumulation of trace elements (Fe, Cu, Zn, Ni, Cd, and Pb) by invertebrate animals of various functional groups under conditions of anthropo-technogenic pressure was studied. The sample plots were located on self-overgrowing sites with ruderal vegetation located in the immediate vicinity of the Mangan ore-dressing and processing enterprise (Dnipropetrovsk region). It is quite naturally that among the studied biogenic microelements (Fe, Cu, Zn and Ni), the phyto-, zoo-, and saprophages in the investigated zone of technogenic pollution most actively accumulate Fe: 22758, 17516 and 18884 mg/kg dry weight on average, respectively. There are significant differences ($p \le 0.05$) in the content of studied microelements between saprophages and phytophages. The saprophages accumulate such trace metals as Mn, Cu, Zn and Cd in high quantities, but Ni and Pb – in smaller ones. The saprophagous functional group of invertebrates is an active agent of detritogenesis, in the conditions of modern nature management it acts as a powerful element of ecosystem engineering (habitat transformation), the main ecological role of which is to modify the habitat of other soil biota. In addition, the saprophages fulfil their concentrating geochemical function. They actively participate in the most important soil biochemical process: the formation of humus, the migration of microelements along trophic chains, the biological cycle in general, and provide such supporting ecosystem services as increasing soil fertility and nutrient cycling.
Key words: technogenesis; ecosystem engineering; functional groups of invertebrates; microelement accumulation; trophic chains; ecosystem services; geochemical role of saprophages

Introduction

In recent decades, by its importance and scale the technogenic impact has become the leading environmental factor affecting the ecological and economic condition of natural landscapes. Intensive industrial and agricultural use of natural resources caused significant changes in the biogeochemical cycles of most chemical elements. This primarily applies to heavy metals, the accumulation of which in high concentrations in the natural environment is due to anthropo-technogenic activity (Dixit et al., 2015; Farid et al., 2015; Gall et al., 2015; Luo et al., 2015). A significant amount of polluting the environment heavy metals (Mn, Cr, F, Cd, Ni, Pb, Zn, Cu, As, Co, Hg, and other elements) is released to the soil, which is the most important protective barrier (Blum, 2005; Zverkovskyi et al., 2017) and the main life-supporting sphere (Trap et al., 2016; Usman et al., 2016). The soil is most negatively affected by accumulation of technogenesis products (Rodríguez-Seijo et al., 2016).
Large industrialized centers produce a significant range and amount of pollutants that are transformed and introduced into the environment in industrial regions (Benbrahim et al., 2004; Faly et al., 2017; Kovach, Lysychenko, 2017). One of the powerful anthropo-technogenic sources of toxic substances entering the environment is the wastes from mining enterprises. The situation is aggravated by a simultaneous reduction in vegetation of natural areas (devegetation), biodiversity loss, invasive processes, an incessant decrease in soil humus (dehumification), the expansion of erosion processes, and other negative phenomena associated with soil degradation (Chakravarty, 2012; Chibrik et al., 2016). These processes are accompanied by the climate change (Stott, Moebius-Clune, 2017) towards drought and temperature rise (Klymenko et al., 2017) and lead to the imbalance in the content of chemical elements, not only in the chain of soil – plant – animal – human, but also in the entire terrestrial ecosystem. In addition, heavy metal contamination of the atmosphere, soil and water in the cultural and agricultural

landscapes is also worrying because it inevitably worsens the living conditions of human beings. It negatively affects the hygienic quality of the human environment and safety of agricultural products, which ultimately upsets the human health potential (Singh et al., 2011; Francová et al., 2016; Lykholat et al., 2016; Ogundele et al., 2017).

Vertebrate and invertebrate animals take an active part in the cycle of matter in terrestrial ecosystems. Among all the trophic groups of invertebrates – phytophages, zoophages and saprophages – it is the soil saprophages that involved in the processes of phytodetritus transformation link soil to plants functionally (Chornobai, 2000) and act as "ecosystem engineers". Therefore, they are an important functional group that, on the one hand, modulate the resources availability to other species by changing the physical state of abiotic and biotic matter, modifying, supporting and / or creating habitats (Wright, Jones, 2006; Lavelle et al., 2016), and on the other – provides, in so doing, a cycle of substances in the terrestrial ecosystem and such supporting ecosystem services such as increasing soil fertility and nutrient cycling (Cunha et al., 2016). As a result of the active destruction of a dead organic plant residues, saprophages accelerate the release of chemical elements into the soil. They participate in the secondary redistribution of chemical elements in terrestrial ecosystems, affecting, to some extent, their biogenic migration and the stable functioning of the ecosystem as a whole (Bulakhov, Pakhomov, 2011). Such saprophagous functions of environment transformation contribute to the restoration of terrestrial ecosystems in technogenic areas. Moreover, it is an active factor in the process of managed environmental rehabilitation of disturbed lands (Lavelle et al., 1997).

As is known, the content of most chemical elements in living organisms differs significantly from their average content in the earth's crust, since they, being involved in the biological cycle, can selectively absorb by organisms. The geochemical functions of living matter are diverse. One of these functions is concentration, which manifests itself through the capture of chemical elements and their selective accumulation by the organisms from the environment (Dmytruk, Berbec', 2009). In studying the biological cycle in a terrestrial ecosystem, as a rule, the soil – plant – soil system is considered, and little attention is paid to the biogeochemical role of animal trophic groups.

There is no doubt that all three functional links of invertebrate heterotrophs (phyto-, zoo- and saprophages) in terrestrial ecosystems are of crucial importance for their functioning, treating them as drivers of ecosystem processes (Yang, Gratton, 2014). Since in trophic chains, which are rows in which each previous link serves as a food source for the following, for example, soil – plant – animal, then chemical contamination results in emerging previously missing chemical elements in the chain or increasing their concentration (Cyraniak, Draszawka-Bołzan, 2014). Thus, the accumulation of elements in the animal biomass and the migration of elements along trophic chains, entailed by animal trophism, are the links in a single process – a biogenic cycle of matter. Accumulating chemical elements in various quantities, animals can determine the nature of their further movement (migration) along food chains.

The purpose of this work is to study the nature of the accumulation of trace elements by invertebrates of various trophic groups under the conditions of anthropo-technogenic press in areas of ruderal vegetation self-growth located in the immediate vicinity of the Mangan ore-dressing and processing enterprise (Dnipropetrovska oblast).

Material and methods

The field material is collected on sites of self-growth with a dominance of ruderal vegetation located in the immediate vicinity of the Mangan ore-dressing and processing enterprise (city of Marganets, Dnipropetrovska oblast, 47°38'53"N 34°37'00"E). The Mangan Ore-Dressing and Processing Plant is one of the world's largest enterprises for the extraction and processing of the manganese ore. The ore is mined by opencast and underground working. That ore-dressing and processing enterprise produces the manganese sulphate, which then used in agriculture, chemical and oil industries. The manganese concentrate produced there is the most valuable raw material for the production of high-grade alloyed steels.

Our study of the heavy metal accumulation (Mn, Fe, Ni, Cu, Zn, Cd, and Pb) by phyto-, zoo- and saprophagous invertebrates is caused by various reasons. First, they cover almost all groups of the periodic system of chemical elements. Their atomic mass varies from 54.94 (Mn) to 65.39 (Zn) and from 112.4 (Cd) to 207.2 (Pb).

Secondly, these microelements are from different geochemical groups – lithophilic (Mn), chalcophilic (Cu, Zn, Cd, and Pb), and siderophilic (Fe, Ni). A special collective group of biophilic elements includes such elements as Mn, Fe, and Cu. Thirdly; all these microelements are priority pollutants of the environment in the Steppe Dnieper area (Tsvetkova, 2016).

In Ukraine, these elements are divided into three classes by their degree of toxicity (hazard): Zn, Cd and Pb are classified as I class hazard (highly hazardous); Cu, Ni – II hazard class (moderately hazardous), and Mn – III hazard class (slightly hazardous).

The content of microelements in invertebrates was determined with the use of atomic absorption spectrophotometer AAS-30 (Karl Zeiss, Jena, Germany). The samples to be analyzed was dried to constant weight at a temperature of 105 °C and subsequently incinerated. Then, the content of elements such as iron, zinc, manganese, copper, cadmium, nickel and lead was investigated in an ash sample (Khavesov, Tsalev, 1983).

Results and discussion

Soil-litter invertebrates, for which the soil and its upper horizons are not only the habitat, but also nutrition, are able to accumulate trace elements in fairly large quantities. Our studies conducted in the territory exposed to the emissions of the Mangan ore-dressing and processing enterprise (city of Marganets) have established the features of the accumulation of microelements by soil invertebrates of various trophic groups (Table 1).

Table 1. Accumulation of heavy metals by soil invertebrates of various trophic groups under conditions of environmental contamination by emissions from the Mangan ore-dressing and processing enterprise (average and standard error)

Trophic group	Content of microelements, mg/kg, oven dry weight			
	Fe	Mn	Cu	Zn
Saprophages	18884±631.5	11648±467.1	571±20.40	2104±65.21
Phytophages	22758±700.3	6654±362.1	492±18.70	1816±71.79
Zoophages	17516±786.9	15370±1329.9	523±25.78	2058±71,47
	Ni	Pb	Cd	
Saprophages	560±23.24	89.5±3.12	9.1±0.10	
Phytophages	3366±132.7	147.3±4.42	6.5±0.35	
Zoophages	2085±61.60	165.8±9.15	1.7±0.07	

We detected statistical differences in the content of microelements for invertebrates of various trophic groups in the territory contaminated by the emissions of the Mangan ore-dressing and processing enterprise (Table 2). Among the microelements considered, it is common trait to have a significant difference in their content between saprophages and phytophages. For all compared pairs of trophic invertebrate groups, statistically significant differences were found between the average content of such trace elements as Pb and Ni.

Table 2. Statistical estimation of the difference of arithmetical mean of microelements in invertebrates of different trophic groups under conditions of environmental contamination by emissions from the Mangan ore-dressing and processing enterprise

Microelement	Compared trophic groups	The level of significance of the differences
Fe	Saprophages – Phytophages	0.02[a]
	Saprophages – Zoophages	0.25
	Phytophages – Zoophages	0.008[c]
Mn	Saprophages – Phytophages	0.0011[b]
	Saprophages – Zoophages	0.06
	Phytophages – Zoophages	0.003[b]
Cu	Saprophages – Phytophages	0.046[a]
	Saprophages – Zoophages	0.22
	Phytophages – Zoophages	0.39
Zn	Saprophages – Phytophages	0.04[a]
	Saprophages – Zoophages	0.66
	Phytophages – Zoophages	0.08
Ni	Saprophages – Phytophages	0.00003[c]
	Saprophages – Zoophages	0.00002[c]
	Phytophages – Zoophages	0.0009[c]
Pb	Saprophages – Phytophages	0.0004 [c]
	Saprophages – Zoophages	0.0014[b]
	Phytophages – Zoophages	0.14
Cd	Saprophages – Phytophages	0.002[b]
	Saprophages – Zoophages	0.000001[c]
	Phytophages – Zoophages	0.0002[c]

Note. *a* – significant difference with probability 95–99%; *b* – significant difference with probability 99–99.9%; *c* – significant difference with probability 99.9%.

Based on data on statistical differences, we note that among biogenic microelements, phytophages accumulate, on average, manganese 1.8–2.3 times less than in zoophages and saprophages. The content of nickel in the saprophages 3.7 and 6 times lower than in zoophagous and phytophagous invertebrates, respectively. Among the toxic microelements, saprophages accumulate lead 1.6–1.8 times on average less in comparison with phyto- and zoophages, respectively, while cadmium is accumulated 1.4 and 5.4 times more by saprophages than by phyto- and the zoophages, respectively.

Conclusions

Thus, our studies confirm that invertebrate animals of all functional groups are accumulators of lithophilic (Mn), chalcophilic (Cu, Zn, Cd, and Pb), siderophilic (Fe, Ni) and biophilic microelements in the territory contaminated by the emissions from the Mangan ore-dressing and processing enterprise. Among the studied biogenic microelements, invertebrates of all trophic groups accumulate Fe most actively in the investigated zone of technogenic pollution. There are significant differences in the microelement (Fe, Cu, Zn, Ni, Cd, and Pb) levels between saprophages and phytophages: saprophagous invertebrates accumulate such trace elements as Mn, Cu, Zn, and Cd in large quantities, but Ni and Pb – in smaller ones. Saprophages, being active agents of detritogenesis, under the conditions of technogenic press act as powerful transformers of the media: they prove their concentrating geochemical function, actively participate in the migration of trace elements along trophic chains and in the biological cycle as a whole.

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