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Levels of Toxic Elements and Functional Structure in Populations of Small Mammals under Conditions of Technogenic Pollution (with Reference to the Bank Vole)

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Abstract – The levels and the character of accumulation of heavy metals (Pb, Cd, Cu, Zn) in organs and tissues of bank voles, living under conditions of technogenic pollution (near a copper-smelting plant) and on the control territory, were studied. The fundamental distinctions in the character of accumulation of physiologically extraneous elements (lead and cadmium) and elements required for normal functioning (copper and zinc) were found. It was shown that the bank vole population responds to technogenic pollution of the environment depending on the ecological–functional features of the subpopulational groups that form this population.

Accumulation of toxic substances in natural populations of animals provokes theoretical and practical interest because the flows of the toxic substances, which are closed through these populations, are not only differentiated depending on their spatial–functional structure but, operating as an active toxic factor, also can modify this structure (Bezel', 1987; Bezel' and Olenev, 1989). The discovery of a regular relation between the functional (sex–age) structure of a population and the structure of levels of the toxic elements that are accumulated in this population promotes an understanding of the adaptation mechanism of natural populations to the technogenic environmental pollution.

From this point of view, the populations of small mammals are especially interesting, since their structure, mechanisms of functioning, and stability are well studied at present.

MATERIAL AND METHODS

We studied the influence of discharges of a copper-smelting plant (the Middle Urals) on the bank vole population. The choice of the bank vole as an object of our study was based on its dominating position in the region of exploration and also by sufficient knowledge of ecological features of this species (*The European Bank Vole*, 1981; *Ecology of the Bank Vole*, 1983). The bank vole is traditionally used as a standard model species on the territory of Russia.

Our study was performed from May - September, 1990 - 1994, in two zones of technogenic load: the impact zone (0 - 2.5 km from the source of emission) and the buffer zone (2.5 - 5 km). For the control we used the territory that is more than 20 km from the source of the influence. The trap-lines method was applied for catching small mammals. The traps were placed for four days in similar biotopes in lines, each with 25 - 100 traps. The traps were checked daily in the morning. According to the functional condition of the animals, which depends on specifics of their growth, development, and reproductive condition in the population, we marked out three functional-temporal groups of the animals: (1) overwintered individuals; (2) immature broods born in the current year; (3) mature individuals that were born and began reproducing in the same year.

Attaching particular importance to assessment of the role of direct toxic influence of pollutants on animal populations, we considered it necessary to estimate the levels of toxic substances that penetrate into the animal body. Due to the complex composition and plasticity of the food ration of bank voles, it is correct, in our opinion, to determine the levels of toxic elements in the stomach contents.

Among the wide range of heavy metals whose aerosols get into the atmosphere and pollute the environment, we chose as most significant under our conditions the elements copper, zinc, lead, and cadmium. The first two elements are physiologically indispensable, but lead and cadmium are typical toxicants whose negative influence on mammals is well known.

The choice of animal tissues for the analysis depended on the main deposit of toxicants in them: lead is accumulated in the skeleton, and cadmium is accumulated in the liver and kidneys (Ershov and Pletneva, 1989). We used the atomic-absorptive spectroscopy method for estimating lead, cadmium, copper, and zinc contents in the skeleton, liver, kidneys, and stomach contents of the caught animals. We analyzed 1161 samples, including 479 samples of skeletons, 350 of livers, 263 of kidneys, and 69 of stomach contents. The material was processed by standard mathematical methods.

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Table 1. The levels of accumulation of heavy metals (μg/g of dry matter) in the stomach contents of bank voles caught in different zones of technogenic load and the total toxic load (relative units)

Metal	Zone of technogenic load		
	control ($n = 16$)	buffer ($n = 33$)	impact ($n = 20$)
Cd	0.880 + 0.201	2.297 + 0.309	4.735 + 0.844
Pb	8.354 + 1.966	15.164 + 1.750	16.023 + 2.323
Cu	12.827 + 1.008	56.508 + 5.630	115.318 + 17.022
Zn	107.056 + 20.531	135.271 + 22.667	230.954 + 30.934
S_j	1	2.36	4.61

RESULTS AND DISCUSSION

For assessment of the magnitude of toxic load on mammals, most authors use data on the content of toxic elements in objects of the environment. However, spatial movement of small mammals over a territory and diversity in their vegetational ration make it impossible to correctly measure the levels of penetration of toxic elements into the vole body by their content in the vegetation. We accepted the concentration of toxicants in the stomach contents (toxic load) as an integral assessment of the level of environmental pollution, which causes the penetration of these toxicants into the animal body.

The natural rations of animals in the areas that are exposed to the intense technogenic influence have a higher concentration of heavy metals in comparison with the background level. Analysis of the contents of vole stomachs in the different areas shows (Table 1) that concentration increases in the buffer and impact zones, respectively, 1.2 and 1.9 times for lead, 1.2 and 2.2 times for zinc, 2.6 and 5.4 times for cadmium, and 4.4 and 9 times for copper.

The enumerated elements do not exhaust all the variety of toxicants entering with the food ration. Taking into account a possible combined effect of all pollutants, the chosen elements should be examined as indicators of the total toxic load on the animals, which is calculated for each zone as

$$S_j = \frac{1}{n}\sum\frac{C_{ij}}{C_{if}},$$

where summation is made by the n elements, C_{ij} is the concentration of i element in j zone, and C_{if} is the background concentration of i element in the contents of the gastrointestinal tract. In the direction of pollution growth, the total toxic load S_j on the animals increases by 2.36 and by 4.61 times in the buffer and impact zones, respectively (Table 1). A tendency towards increase in concentration of the pollutants with the growth of toxic load can be seen in the animals of all functional-temporal groups (Table 2).

While the concentration of copper and zinc in the liver does not depend on the place where the animals are caught, the levels of their accumulation in the skeleton of bank voles inhabiting the control area were lower than in the animals from the polluted areas. The highest concentration of cadmium was found in kidneys of voles inhabiting zones exposed to the technogenic influence. This concentration is reliably higher than the level of accumulation of this toxicant in kidneys of animals on the control territory (see Table 2). The same proportion was observed for cadmium deposited in a liver; however, its content in this organ is lower than that in the kidneys.

Lead that penetrates into an animal body is accumulated mainly in bone tissue (Ershov and Pletneva, 1989). We found the maximum concentration of this element in the skeleton of bank voles inhabiting the

Table 2. The levels of accumulation of heavy metals in the skeleton, liver, and kidneys of bank voles caught in different zones of technogenic load (μg/g of dry matter)

Age group	Zone of technogenic load		
	control	buffer	impact
	Lead in the skeleton		
SW	12.735 + 1.439 (37)	42.696 + 5.071 (39)	66.004 + 7.497 (20)
MB	20.270 + 3.108 (30)	48.031 + 4.019 (45)	57.931 + 5.473 (36)
JB	19.476 + 1.528 (146)	36.916 + 2.144 (99)	50.780 + 6.120 (27)
	Cadmium in the liver		
SW	1.683 + 0.188 (41)	6.247 + 1.129 (18)	9.635 + 2.221 (8)
MB	1.974 + 0.494 (26)	6.254 + 1.096 (39)	6.704 + 1.624 (15)
JB	1.252 + 0.121 (125)	7.641 + 0.487 (63)	6.089 + 0.964 (15)
	Cadmium in kidneys		
SW	10.884 + 0.899 (24)	35.973 + 3.284 (37)	55.690 + 9.517 (9)
MB	7.199 + 1.335 (10)	34.035 + 6.215 (9)	22.643 + 3.113 (11)
JB	3.062 + 0.274 (85)	22.865 + 2.172 (64)	24.340 + 3.541 (14)

Note: SW stands for the animals that survived winter; MB stands for mature broods of the current year; JB stands for juvenile broods of the current year. Sample size is in parentheses.

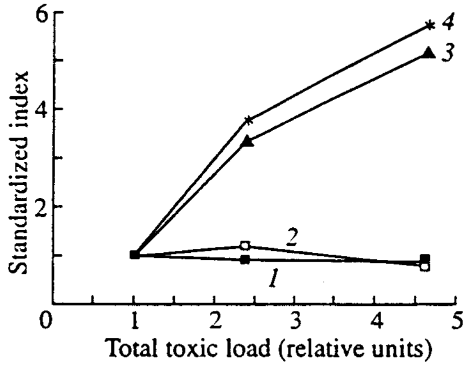

Fig. 1. The accumulation of heavy metals in bank voles that survived winter: (*1*) copper in the liver, (*2*) zinc in the liver, (*3*) lead in the skeleton and cadmium in kidneys, (*4*) cadmium in the liver.

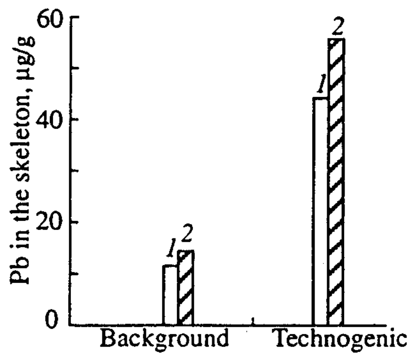

Fig. 2. The accumulation of lead in the skeleton of bank vole (*1*) males and (2) females along the gradient of the toxic pollution.

regions adjacent to the source of emission. It is reliably higher than the level of the toxicant accumulated in the skeleton of animals from the control area.

Accumulation of Physiologically Indispensable and Toxic Elements in Bodies of the Bank Vole

The fact of an increase in the level of toxic elements with a rise of pollution in the environment is obvious. We would like to note a distinction in the levels of the physiologically indispensable elements (zinc and copper) and the toxic ones (lead and cadmium). We shall examine this question with reference to the animals that survived winter (Fig. 1). An increase in the content of copper in the animal ration by 4.4 times in the buffer zone and by 9 times in the impact zone and for zinc by 1.2 and 2.2 times, respectively, virtually does not result in growth of the level of these elements in the animal tissues (the skeleton and liver). Here, we have an effect of the natural biological barrier at the level of the gastrointestinal tract that ensures internal homeostasis of physiologically indispensable zinc and copper. The content of these elements in the ration, which reaches on an average 135.3 - 230.9 μmg/g of dry matter for zinc and 56.5 - 115.3 μmg/g of dry matter for copper, probably is not sufficiently high to overcome the barrier and increase the levels of these elements in the tissue.

Toxic elements (lead and cadmium) act differently. The increase in the concentration of lead in the vole ration in the buffer zone by 1.2 times and in the impact zone by 1.9 times and, respectively, by 2.6 and 5.4 times for cadmium resulted in significant growth of their levels in the studied tissues (see Fig. 1). The absence of the physiological barrier for these elements makes possible their free penetration through the walls of the gastrointestinal tract and explains their heightened levels in the animal tissues.

Deposition of Toxicants in the Body of Bank Voles of Different Functional–Temporal Groups

Since the metabolic processes, especially energetic ones, in small mammals are provided by food ration, the amount of toxic elements penetrating into the animal body ought to correlate with the level of energetic expenditure. Hence, it follows that the heightened level of lead, which was found by us in the female skeleton in all age groups, apparently reflects the animals' increased energetic expenditure, which is related to their participation in reproduction. The findings on the accumulation of lead in the skeleton of overwintered individuals in the direction of an increase in technogenic load can be seen in Fig. 2. The lower level of the element in males can possibly be explained also by features of their spatial behavior. The males actively move over the territory, in contrast to the females characterized mainly by a settled way of life, especially during pregnancy and nursing. This means that our sample of individuals from the impact zone may include males migrating from the less polluted adjacent areas, which ought to decrease the average concentration of lead in the sample of males.

The information obtained from literature shows that under conditions of permanent influence the examined toxicants are able to be accumulated with age in large quantities in the organs (depots) (see, for example, Bezel', 1987). Therefore, we may expect that maximum levels of the studied heavy metals will be found in the organs and tissues of the overwintered animals (this especially concerns lead in the metabolically inert skeleton). We may also expect an increase in the concentration of toxicants in the body of mature individuals born in the current year, which are characterized by a higher level of energetic expenditure as compared to the immature individuals.

Our suppositions are confirmed by data on the content of the studied elements in organs and tissues of animals inhabiting the zone of maximum pollution. The voles in the first two groups had toxicant levels 1.1 - 2.3 times higher than immature individuals (see Table 2). The same proportion was observed for cadmium, which is concentrated in kidneys of the bank vole (the excess was 1.5 - 3.6 times).

Different values were found for the levels of accumulation of lead, in the skeleton, and cadmium, in the liver, in animals inhabiting the zone with low pollution and the control territory. Thus, in the control area the amount of lead in the skeleton of juvenile newborn individuals and individuals that survived winter was, respectively, 1.1 and 1.6 times less than in the adult animals (in the buffer zone – 1.04 and 1.3 times, respectively). The observed situation, apparently, can not be explained by the character of a toxic effect of pollutants with a low background level of pollution. We believe that the main toxic impact, which is the result of lead accumulation in the skeleton, is caused by the dynamics of its accumulation in the direction of an increase of technogenic load rather by than the difference in the levels of this element on the control territory. Thus, the lead content in the skeleton of the overwintered animals was 5 times higher in the impact zone, when compared with the control area; for the mature individuals born in the current year this was 2.9 times, and for the immature animals this was 2.6 times (Fig. 3a).

An analogous picture along the gradient of technogenic pollution was noticed for cadmium, which is accumulated in the liver (Fig. 3b). Similar concentrations of the element were found in the individuals born in the current year (mature and immature) inhabiting polluted areas. Their values were 3.2 - 3.3 times higher than in the mature animals born in the current year in the control area and 4.9 - 6.1 times higher in the immature individuals. The animals that survived winter had a sixfold increase in cadmium concentration with the growth of pollution.

We may expect that any toxic effect results in increasing variability of animal functional indicators in population samples, including variability of the levels of accumulated metals. If the toxicants in the animals inhabiting polluted areas cause a heightened level of mortality during winter, then the "sieve" effect, which results in the death of "the most poisoned" animals, has to decrease the variability in levels of toxic deposition in the body of the overwintered animals, in comparison with the samples of the animals entering a winter.

Proceeding from this assumption, we shall consider an accumulation of lead in the skeleton of voles inhabiting the area with maximal pollution. We found a decrease in the variation coefficient for the individuals that survived winter (51%) in comparison with mature broods born in the current year (57%) and the juvenile animals (63%), this being direct evidence of the discrimination in animals, which causes the death of the animals with maximum lead levels during winter.

We consider that this is one of the possible mechanisms of the influence of technogenic pollution on the demographic structure in a population. Due to the unfavorable influence of toxic factors, the mortality of animals in the zones of industrial pollution is significantly increased. Since there is a type of demographic vacuum on the polluted territory, this may cause an intensification of reproduction in the surviving part of the population of small mammals. Animal reproduction in the polluted areas increases owing to 2.5-fold shortening of the period of maturation of broods born in the current year. We did not reveal reliable differences in female fecundity along the gradient of the technogenic load. Thus, natural populations of small mammals respond to technogenic pollution of their habitats in accordance with ecological–functional features of subpopulational groups that form these populations. This can be seen first of all in the distinction of the levels of toxicants accumulated in the different animal groups. Selective elimination of the individuals having maximum levels of pollutants from the population is a consequence of that heterogeneity. This process, in its turn, results in changes in the demographic structure and in a number of important populational characteristics. The mentioned changes should be considered necessary adaptational restructuring of the population in response to extreme environmental conditions created by the technogenic pollution.

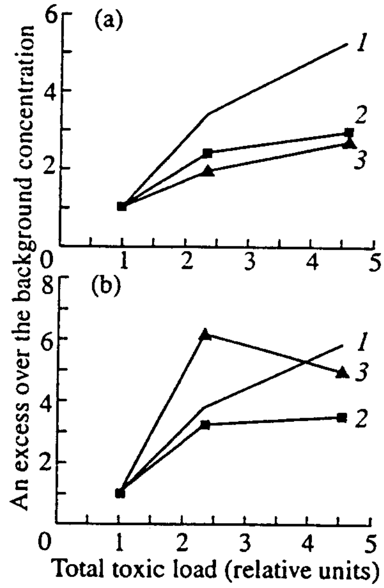

Fig. 3. Lead accumulation (a) in the skeleton and cadmium accumulation (b) in the liver of bank voles in different functional–temporal groups: (*1*) overwintered animals; (*2*) mature animals born in the current year; (*3*) immature broods.

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