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TRANSFORMATION OF COMMUNITIES OF SMALL MAMMALS UNDER THE ACTION OF TECHNOGENIC FACTORS (ON THE EXAMPLE OF THE TAIGA ZONE OF THE CENTRAL URALS)*

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It was shown that technogenic factors significantly affect the species diversity, structure, species distribution, and abundance of small mammals in the taiga zone of the Central Urals. The main contribution to changes in the communities' ecological characteristics is made by the action of technogenic factors refracted through destruction of the species' natural habitat. As a result of degradation of dark coniferous forests, monodominant communities of small mammals are transformed. The role of the dominant species is significantly reduced, and its place is occupied by species attracted to anthropogenic landscapes. Simultaneously with this, on the one hand, the environment's ecological capacity diminishes, leading to a reduction in total abundance of all of the community's species, and, on the other hand, to a rise in environmental diversity on account of derivative forests, leading, in the final analysis, to an increase in species diversity, as well as the species' equitability.

A community of organisms is a natural-historical unit that was formed in the course of an evolutionary process in the particular conditions of a physical-geographic environment. It is characterized by a certain set and percent participation of species that enable the community to make the fullest use of the environment's resources (Odum, 1975; Whittaker, 1980; Pianka, 1981).

In spite of the diversity of anthropogenic factors, a significant similarity is observed in the reaction of natural animal communities to their action (Kubantsev, 1976, 1978, 1979). This is primarily connected with the fact that, in the case of any anthropogenic action on natural complexes, the environment in which the animals live changes first: the level of provision with food and shelter resources, the meso- and microclimates of habitats, etc. (Benyuk et al., 1987; Samarskii, 1987). In the end, human action on natural complexes leads to overall biotopic differentiation of the territory.

As a result of anthropogenic actions, the level of existing species' domination changes; new species appear (anthropogenic simplification of the cenosis promotes their intrusion); and as a consequence, the species composition and relative abundance of species in the cenosis change (Bashenina, 1987; Kataev, 1987; Koshkina, 1987; Luk'yanova, 1990; Luk'yanova et al., 1990). Small mammals' adaptation to new habitat conditions can occur in various ways. This is primarily connected with the flexibility of ecological, behavioral, and morphophysiological parameters (Koshkina, 1987; Luk'yanov and Luk'yanova, 1990; Luk'yanova, 1990' Luk'yanova and Luk'yanov, 1990; Luk'yanova et al., 1990; Shilova, 1987; Shchipanov, 1987).

In spite of the considerable amount of factual data, which makes it possible to present the level of study of the problem in a generalized form, we have to emphasize that it has been solved primarily in conditions connected with the direct action of anthropogenic factors (cutting of timber, drainage, exploitation of mineral resources), while there have been very few investigations of the action of anthropogenic factors of a technogenic nature (for example, in the case of technogenic environmental pollution) on communities of small mammals (Kataev, 1987; Luk'yanova, 1990; Luk'yanova et al., 1990). This determines the urgency of research connected with the action of technogenic factors on communities of small mammals.

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The purpose of the present work is comparative study of the species composition, diversity, and abundance of small mammals in conditions of a technogenic action (on the example of environmental pollution from copper smelting) and in background territories.

Investigations of the effect of technogenic factors on small mammals were conducted in the Central Urals in the summer and fall field seasons of 1987-1989 in regions subjected to the action of copper-smelting enterprises. For this purpose, we chose zones adjacent to two industrial enterprises. As the control, we used territory of the Visim State Reserve located 22 and 56 km, respectively, from the sources of technogenic action. This territory was considered as the regional background zone.

The regions of the investigations are typical forest regions. Southern-taiga, dark coniferous forests and coniferous-deciduous, birch and, partly, aspen forests derivative from them are predominant (Kolesnikov et al., 1973). We studied the effect of technogenic factors on small mammals on transects located at different distances from the sources of the technogenic load. In territories adjacent to the enterprises, the transects were set up in derivative, primarily dark coniferous forests; in the background territory, in primary and arbitrarily primary forests. This choice makes it possible, on the whole, to evaluate the effect of the cumulative technogenic load on communities of small mammals.

Near the technogenic sources, depressed, derivative stands predominate; further away from them, the degree of depression gradually diminishes, and in the background, reserve territory, it practically disappears. Zoning of the given technogenic territories with respect to the amount of cumulative anthropogenic load, expressed in the degree of the phytocenoses' degradation, and pollution of the soil and air by industrial emissions, which was carried out by A. K. Makhnev and S. A. Mamaev (1979), shows that the zone of pollution, on the whole, extends 10-15 km. The zone of maximum pollution is 0.5-2-3.5 km away from the source. In this case, 1 kg of the upper layer of soil contains 100-500 mg or more of copper, zinc, and lead, 10-50 mg of arsenic, antimony, chromium, and molybdenum, and 10-20 mg of sulfur. The zone of moderate air and soil pollution is characterized by heavy destruction of natural biogeocenoses. It extends a distance of 2-3.5 to 5-8 km from the source of the pollution. The contents of heavy metals and other toxic compounds in the soil significantly exceeds the usual level (copper and zinc — 50-100 mg, lead — 10-20 mg, a significant amount of arsenic, and 5-10 mg of sulfur compounds per 1 kg of soil).

Small mammals were caught in zones of technogenic action adjacent to copper-smelting enterprises, and in the background, reserve territory. Transects were set up to the west of the industrial enterprises, primarily in insular dark coniferous forests. Since we were primarily interested in peculiarities of the small-mammal population in the technogenic and reserve territories as a whole, and not specific peculiarities of the population of zones adjacent to individual copper-smelting plants, for analysis we use combined data for small mammals from both technogenic regions.

To collect small mammals, we used the trap-line method. Break-back traps were set out in lines (50-200 traps each) at a distance of 10 m from each other, for a period from 5 to 10 days. The traps were checked daily, in the morning. Each trap had an ordinal number, which enabled us to record and map the places where animals were caught and served as the basis for further quantitative analysis of abundance and spatial structure. For the purpose of standardization, to characterize the species diversity and abundance of small mammals we use data obtained only for the first five days of trapping. In the course of the field investigations, we spent about 36,000 trap-days (of these, about 20,500 were in technogenic territories, and 15,500 in the background territory) and caught 4317 small rodents and insectivores (961 in technogenic territories, and 3356 in the background territory) of 14 species.

The greater part of the catch was made up of voles of the *Clethrionomys* genus — 3656 specimens (84.7%), among which bank vole (*Cl. glareolus*) predominated — 94.5%, while large-toothed redback vole (*Cl. rufocanus*) and ruddy vole (*Cl. rutilus*) made up only 3.0 and 2.5%, respectively. Meadow voles (*Microtus* genus) and mice (*Apodemus* genus) were uncommon; the total catch of three species of meadow voles, short-tailed (*M. agrestis*), common (*M. arvalis*), and root vole (*M. oeconomus*), was 97 individuals (2.2% of the overall catch); and of two species of mice, field (*Ap. sylvaticus*) and striped field mouse (*Ap. agrarius*), 88 specimens (2%). The least numerous among small mammals was northern birch mouse (*Sicista betulina*) — 8 specimens.

Investivores were represented primarily by shrews of the *Sorex* genus. The total catch of four species of common shrews was 463 specimens (10.7% of the overall catch). Among them, Eurasian common shrew (*S. araneus*) — 52.9% and Laxmann's shrew (*S. caecutiens*) — 38.7% were predominant. Equal-toothed (*S. isodon*) and pygmy shrew (*S. minutus*) were found in the catches significantly less often: their portions were equal to 5 and 3.4%, respectively. In boggy biotopes, water shrew (*Neomys fodiens*) was caught in an insignificant number — 5 specimens.

To characterize the small-mammal communities in technogenic and background territories we used the following indices: the list of species, their percent participation, total abundance of species per 100 trap-days, species diversity, and

TABLE 1. Characteristics of Small-Mammal Communities in Technogenic (A) and Background (B) Territories

Species	1987		1988		1989		Σ	
	A	*B*	*A*	*B*	*A*	*B*	*A*	*B*
Clethrionomys glareolus	46,2	75,7	58,2	87,9	57,4	87,1	56,1	85,8
Cl. rufocanus	—	6,8	—	3,6	—	3,2	—	3,8
Cl. rutilus	11,5	0,4	10,6	0,5	5,6	0,5	9,3	0,5
Microtus oeconomus	—	0,4	7,8	0,5	1,5	0,5	4,7	0,5
M. agrestis	—	—	3,1	—	3,6	0,4	2,7	0,2
M. arvalis	7,7	—	0,6	—	1,5	—	2,0	—
Apodemus agrarius	7,7	—	3,6	—	1,5	—	3,7	—
Ap. sylvaticus	1,0	0,4	5,6	—	13,3	0,4	7,1	0,2
Sicista betulina	2,9	—	0,3	—	—	—	0,6	—
Sorex araneus	3,9	5,1	3,9	5,3	8,2	4,6	5,2	4,9
S. caecutiens	12,5	9,8	5,9	1,9	6,7	2,0	7,1	3,1
S. isodon	—	—	—	0,2	0,5	1,4	0,2	0,8
S. minutus	1,9	1,3	0,6	—	—	0,1	0,6	0,2
Neomys fodiens	4,8	—	—	—	—	—	0,8	—
Number of individuals	104	235	359	580	195	854	658	1669
Species diversity, μ	7,6 ±0,42	3,9 ±0,26	6,8 ±0,28	2,8 ±0,14	6,4 ±0,34	3,5 ±0,16	7,0 ±0,20	3,4 ±0,11
Portion of uncommon species, h	0,24 ±0,04	0,51 ±0,03	0,38 ±0,03	0,60 ±0,02	0,36 ±0,03	0,65 ±0,02	0,32 ±0,02	0,59 ±0,01
Abundance per 100 trap-days	1,7 ±0,17	7,4 ±0,48	7,6 ±0,40	31,9 ±1,51	9,8 ±0,70	53,4 ±1,83	6,4 ±0,27	30,9 ±0,81
Number of trap-days	6000	3175	4700	1600	2000	1600	12700	6375

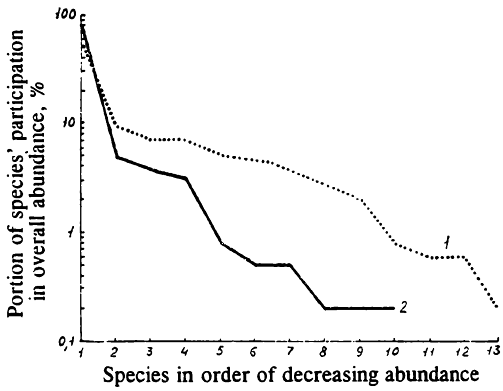

Fig. 1. Percent of species' participation in small-mammal communities in technogenic (1) and background (2) territories. Technogenic territories: 1) *Clethrionomys glareolus*, 2) *Cl. rutilus*, 3) *Apodemus sylvaticus*, 4) *Sorex caecutiens*, 5) *S. araneus*, 6) *Microtus oeconomus*, 7) *Ap. agrarius*, 8) *M. agrestis*, 9) *M. arvatis*, 10) *Neomus fodiens*, 11) *Sicista betulina*, 12) *S. minutus*, 13) *S. isodon*; background territory: 1) *Cl. glareolus*, 2) *S. araneus*, 3) *Cl. rufocanus*, 4) *S. caecutiens*, 5) *S. isodon*, 6) *Cl. rutilus*, 7) *M. oeconomus*, 8) *Ap. sylvaticus*, 9) *S. minutus*, 10) *M. agrestis*.

portion of uncommon species. As measures of species diversity and the portion of uncommon species we used the indices suggested by L. A. Zhivotovskii (1980), which have a fairly good "biological" interpretation and "good" statistical properties.

The index of species diversity (the mean number of species in a community) was calculated according to the following expression (Zhivotovskii, 1980):

$$\mu = (\sqrt{p_1} + \ldots + \sqrt{p_m})^2,$$

where p_1, ..., p_m is the frequency of species in the community; and m is the number of species. In the limiting case, when the distribution of frequencies is uniform (i.e., $p_1 = 1/m$, ..., $p_m = 1/m$), this index takes the maximum value $\mu = m$. If the distribution of frequencies is uneven, i.e., some species are found more often than others, the value of the index μ will be less than m.

The portion of uncommon species was calculated according to the formula (Zhivotovskii, 1980)

$$h = 1 - \mu/m.$$

This index is analogous to Pielou's equitability index (Pielou, 1966). If the distribution of frequencies is uniform, then $h = 0$ and uncommon species are absent. With an uneven distribution of the frequencies of species, $h > 0$. The portion of uncommon species provides new (in comparison with μ) information about the nature of species diversity. If μ evaluates the degree of species diversity, then h gives a definite characteristic of the structure of that diversity.

Analysis of the small-mammal communities in technogenic and background territories (see Table 1) shows that the number and set of species differ in the territories being compared. In technogenic territories, during the period of the investigations we recorded 13 species of small rodents and insectivores; and in the background territory, 10. The index of similarity of the species list according to Serensen (Odum, 1975) between these communities was 0.7. Differences in species composition were due, first of all, to the disappearance of large-toothed redback vole in the technogenic territories, which is one of the typical inhabitants of natural, undisturbed landscapes in the Central Urals associated with coniferous primary forests, and, secondly, to the appearance of typical representatives of anthropogenic landscapes: field mouse and common vole. In the Central Urals, as a rule, the latter two species colonize long-term derivative types of forest, keeping to open, thinned habitats (forest edges, gaps, clearings, group windfalls, etc.).

The increase in the set of species in the technogenic territories in comparison with the reserve territory is registered even more clearly by the index of species diversity. The value of the latter for communities in technogenic territories (7.0) is twice as high as in the background territory (3.4, $p \leq 0.001$). The portion of uncommon species in the technogenic zones, on the other hand, is significantly reduced, from 0.6 (background) to 0.3 ($p \leq 0.001$).

The relative spread of indices of species diversity and the portion of uncommon species between the communities† of animals in the technogenic and background territories (respectively, $R_b(\mu) = 68\%$ and $R_b(h) = 57\%$) considerably exceeds the relative spread of these indices within the communities from year to year** (respectively, $R_w(\mu) = 25\%$ and $R_w(h) = 34\%$). This underscores the primary significance of factors of a technogenic nature in formation of the species diversity and structure of the small-mammal communities.

The differences in the set of species, diversity, and portion of uncommon species in small-mammal communities in the technogenic and background territories are explained by disturbances of natural landscapes accompanied by degradation of coniferous forests, the basic forest formation of the Central Urals. Judging from the percent participation in the overall catch, the absolute dominant among species in the studied territories is bank vole (see Table 1). We should note that the predominance of bank vole in numbers over the other species in the reserve dark coniferous forests is primarily connected with their insular nature, which is not characteristic, as a rule, of continuous dark coniferous forests. But its role in the community in technogenic zones is significantly reduced (56%) in comparison with the community in the reserve territory (86%), which is evidently connected with anthropogenic transformation of dark coniferous forests, leading to an increase in favorable habitats for species connected with an anthropogenic landscape. All of this leads to a situation in which the degree of dominance of the main species is reduced in monodominant communities of small mammals under the action of technogenic factors, while the role of species that are uncommon in undisturbed cenoses grows, and in percent participation they reach the status of common species.

Additional information about the small-mammal communities being compared is provided by analysis of curves of the species' significance. Figure 1 gives the species' percent participation in the communities on a logarithmic scale, from the most to the least significant. In its form, the curve of the species' significance in the background territory best corresponds to I.

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†$R_b (\%) = 2(X_b - X_a)100/(X_a + X_b)$, where X_a and X_b are the mean values of the indices for communities in the technogenic territories (a) and the background (b).

**$R_w (\%) = (1/2)\{[X_a(max) - X_a(min)]/X_a + [X_b(max) - X_b(min)]/X_b\}100$, where $X_a(max)$, $X_a(min)$, $X_b(max)$, and $X_b(min)$ are the maximum and minimum values of the indices for communities in the technogenic territories (a) and the background (b) in different years.

Motomura's geometric series, which indirectly indicates a small number of factors limiting the structure of the community (Whittaker, 1980; Odum, 1986). The curve for the significance of the species in animal communities in the technogenic zones best corresponds to Preston's logarithmic distribution (Whittaker, 1980). This underscores the fact that the success of species' existence in these communities is determined by a considerable number of limiting factors in comparison with the undisturbed territory. In this case, a set of technogenic limiting factors is added to the natural limiting factors in disturbed communities.

Technogenic disturbances lead to a significant reduction in the overall abundance of species: the average abundance of small mammals in different years in the technogenic territories is reduced from 31 to 6 individuals per 100 trap-days in comparison with the background ($p \leq 0.001$) (see Table 1). In this case, the relative spread of abundance between the background and the technogenic communities (132%) is commensurable with the relative year-to-year spread within the communities (137%), which underscores the equal contribution of factors of natural and technogenic limitation to the abundance of small mammals in conditions of the technogenic environment.

Thus, the results of comparative analysis of small-mammal communities in zones of technogenic action and a reserve territory show that technogenic factors have a significant effect on the species diversity and abundance of Micromammalia. The main contribution to changes in the ecological characteristics of this group of animals is made by the action of technogenic factors, refracted through destruction of the species' natural environmental habitat, as a result of which dark coniferous forests, the main forest formation in the taiga zone of the Urals, degrades first. In connection with this, the species composition changes, as do the percent participation and abundance of species in the small-mammal community, and monodominant communities are significantly transformed. The role of the species that is dominant in numbers in dark coniferous insular forests (bank vole) is significantly reduced, and its place is occupied by species attracted to anthropogenic landscapes.

Simultaneously with these processes, as a result of the degradation of natural ecosystems, there is, on the one hand, a reduction in the environment's overall ecological capacity, as a result of which the total abundance of all species in the community decreases, and on the other hand, the biogeocenotic diversity rises on account of an increase in the area of derivative forests, leading, in the end, to an increase in species diversity, as well as the species' equitability.

Analysis of the distributions of species by their significance in the community indicates that the curve of the species' significance in the background territory best corresponds to I. Motomura's geometric series, which indicates a small number of factors limiting the community's structure (Whittaker, 1980; Odum, 1986). The curve for the significance of species in communities of animals in the technogenic zones best corresponds to F. W. Preston's logarithmic distribution (Whittaker, 1980). Consequently, the success of species' existence in these territories is determined by a considerable number of limiting factors in comparison with the undisturbed territory. In this case, a set of technogenic limiting factors is added to the natural limiting factors in disturbed communities. This once again underscores the significance of factors of a technogenic nature in forming the structure of small-mammal communities in zones of technogenic pollution.

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