ISSN 1067-4136, Russian Journal of Ecology, 2010, Vol. 41, No. 6, pp. 513–518. © Pleiades Publishing, Ltd., 2010.
Original Russian Text © S.V. Mukhacheva, Yu.A. Davydova, I.A. Kshnyasev, 2010, published in Ekologiya, 2010, No. 6, pp. 452–458.

Responses of Small Mammal Community to Environmental Pollution by Emissions from a Copper Smelter

S. V. Mukhacheva, Yu. A. Davydova, and I. A. Kshnyasev

Institute of Plant and Animal Ecology, Ural Division, Russian Academy of Sciences, ul. Vos'mogo Marta 202, Yekaterinburg, 620144 Russia

e-mail: msv@ipae.uran.ru

Received April 9, 2010

Abstract—Analysis of the effect of emissions from the Karabash Copper Smelter (Southern Urals) on the small mammal community has shown that its abundance and structure change significantly under technogenic impact. Structural transformations are accompanied by changes in the composition of dominant species. The "dose–effect" pattern of community response to this impact is nonlinear: for most species of murine rodents and small insectivores, habitat quality becomes satisfactory at a distance of 9–11 km from the emission plume.

Keywords: small mammals, population structure, relative abundance, industrial pollution, copper smelter, heavy metals.

DOI: 10.1134/S1067413610060081

Small mammals (murine rodents and insectivores) are traditionally used as model objects for studies on a broad range of theoretical and applied ecological problems. This group of animals is most informative among mammals, sensitively responding to various changes in terrestrial ecosystems (Talmage and Walton, 1991; Stepanov et al., 1992).

Studies dealing with anthropogenic impact on ecosystems in general and on small mammals in particular and abundant, and most of them concern the behavior of xenobiotics in the natural environment (their accumulation, transformation, detoxification, excretion, and drift) and their effects at tissue and organismal levels. A few studies are devoted to the effects of toxicants on small mammals from natural populations (Wlostowski et al., 1994; Leffler and Nyholm, 1996; Moskvitina, 1999; Mukhacheva, 2001; Bezel', 2006).

Small mammals are sometimes used as indicators for estimating the degree of anthropogenic disturbance in natural habitats. The impact of anthropogenic factors is known to cause changes in the structure (species composition and proportion of individual species) and size of the small mammal population (Bezel' et al., 1986; Vol'pert and Sapozhnikov, 1998; Shilova, 1999; etc.). The magnitude and direction of changes of these parameters depend on the nature and strength of impact, as well as on the plasticity of species comprising the community. However, the responses of animal communities to this impact have not been sufficiently studied to date. Factual data on changes in the abundance of small mammals in zones affected by point sources of pollution can be found in only a few publications (Kataev et al., 1994; Mukhacheva, 1996, 2007; Luk'yanova and Luk'yanov, 1998b; Kozlov et al., 2005; Davydova, 2007). Some studies have shown that nonspecific mechanisms of transformation and repair operate in communities affected by anthropogenic factors (Mukhacheva, 1996; Luk'yanova and Luk'yanov, 1998a).

Studies on various components of terrestrial ecosystems affected by point sources of pollution are important not only for solving practical tasks but also for understanding general aspects of theoretical ecology. Analysis of responses of the small mammal community (as one of the principal components of ecosystems) under particular conditions will help to make conclusions on ecosystem tolerance to certain types of pollution and on the efficiency of natural self-regulation mechanisms.

Thus, the purpose of this study was to analyze changes in the structure of the small mammal community along the gradient of technogenic pollution in the area affected by the Karabash Copper Smelter (KCP), a large nonferrous metallurgical plant operated by ZAO Karabashmed' in the Southern Urals, 90 km northwest of Chelyabinsk.

MATERIAL AND METHODS

Characteristics of the source of emissions. The Karabash Copper Smelter, which was put in operation in 1910 and produced up to 30% of blister copper in the Soviet Union, for a long time had no modern equipment for treating dust–gas emissions and wastewaters.

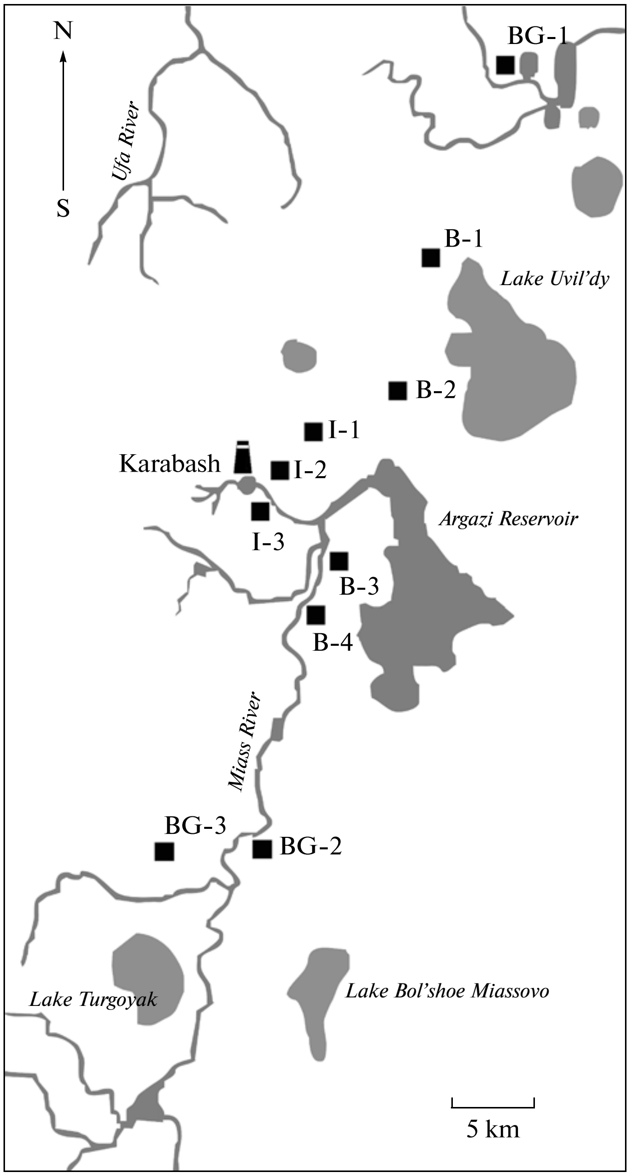

Fig. 1. Study area and plots where small mammals were trapped: BG-1, BG-2, and BG-3 are background plots located 32, 27, and 26 km from the source of emissions; B-1, B-2, B-3, and B-4 are buffer plots located 18, 11, 9, and 12 km from the source of emissions; and I-1, I-2, and I-3 are impact plots located 5, 1.5, and 3.5 km from the source of emissions.

In 1989, the town of Karabash was recognized by the UN as "the most polluted spot on the planet." The smelter was shut down and resumed operation only in 1998. The upgrade of the production process over the past few years resulted in considerable reduction of emissions. For instance, the amount of pollutants emitted into the atmosphere in 1970 exceeded 370000 t. Most of these were sulfur dioxide (364500 t) and dust (28800 t) containing absorbed heavy metals such as Cu (1530 t), Pb (2570 t), and As (1920 t). In 2005, this amount was no more than 41000 t, including 38100 t of sulfur dioxide and 1300 t of dust containing 340 t of Cu, 20 t of Pb, and 7 t of As (Stepanov et al., 1992; Kozlov et al., 2009). However, the pool of pollutants accumulated to date may still have a strong impact on the biota.

Various components of ecosystems in the zone affected by the KCP have already been studied, including the algal flora, soil microbiota and macrofauna, epiphytic lichens, higher plants, and terrestrial invertebrates (Stepanov et al., 1992; Chernen'kova, 2002; Kozlov et al., 2009; etc.). Publications on small mammals are sporadic (Chernousova, 1990; Stepanov et al., 1992), and data on their composition and abundance are lacking.

Test plots. Ten test plots were established north and south of the KCP, at different distances from the source of emissions (Fig. 1), in secondary birch forests formed in place of pine forests. These biocenoses are most common in the study region. On the basis of geobotanical releves and published data (Stepanov et al., 1992), zones qualitatively differing in the degree of ecosystem transformation were delimited: technogenic wasteland (up to 2 km from the KCP), impact zone (2–5 km), buffer zone (9–18 km), and background zone (25–32 km).

In the background zone, test plots were located in bracken–herb and herb birch forests (80–100 years old) with well-developed herbaceous layer (100% coverage in most cases) and almost without moss layer. In the buffer zone, the plots were in herb birch forests (80–100 years old) with developed herbaceous layer (60–70% coverage) and weakly developed moss layer. In the impact zone, the plots were in dead-cover birch forests (60–80 years old); mosses, represented by a single species (*Pholia nutans*), covered up to 10–15% of the area; herbaceous plants were scant, and most of the soil surface was covered with nondecomposed litter. The technogenic wasteland was a zone with the topsoil washed away, almost devoid of vegetation. Single herbaceous plants, trees, and shrubs occurred only in ditches and gullies.

Animal trapping. Small mammals were trapped in September 2008 and 2009, in all test plots simultaneously. In each plot, three lines of crush traps (25 traps at 5- to 7-m intervals) were set at a distance of at least 100 m from each other. The lines were positioned randomly, without connection to any element of biocenosis. The traps were baited with unrefined vegetable oil and exposed for three days, being checked daily in the morning. On the whole, 128 small mammals of 10 species were trapped over 2250 trap–days. To characterize the small mammal community, the following parameters were determined: (1) species composition; (2) proportion of each species; and (3) relative abundance of each species and of the community as a whole. The index of abundance was estimated as the number of individuals caught per 100 trap-days.

The results were processed statistically by standard methods using the Statistica program package (Stat-

Structure of small mammal community in the study region

Species	Zone of technogenic load					
	background		buffer		impact	
	2008	2009	2008	2009	2008	2009
Number of plots	3	3	4	4	3	3
Number of trap–days	675	675	900	900	675	675
Number of animals trapped	43	49	81	74	4	5
Number of species recorded	6	7	6	7	2	2
Total abundance*, ind./100 trap-days	$\frac{6.4 \pm 1.7}{0/14.7}$	$\frac{7.3 \pm 1.8}{1.3/17.3}$	$\frac{9.0 \pm 2.0}{0/25.3}$	$\frac{8.2 \pm 0.4}{0/24.0}$	$\frac{0.6 \pm 0.3}{0/2.7}$	$\frac{0.7 \pm 0.4}{0/5.3}$
Including:						
Common shrew (*Sorex araneus* L., 1758)	1.9	1.6	0.5	0.3	0	0
Laxmann's shrew (*Sorex caecutiens* Laxmann, 1788)	1.6	1.5	0.3	0.9	0	0
Taiga shrew (*Sorex isodon* Turov, 1924)	0	0.2	0	0	0	0
Eurasian pygmy shrew (*Sorex minutus* L., 1766)	0	0.6	0	0	0	0
Pygmy wood mouse (*Sylvaemus uralensis* L., 1771)	0.5	1.0	2.0	3.2	0	0
Striped field mouse (*Apodemus agrarius* Pall., 1771)	0	0	0	0.2	0	0
Common vole** (*Microtus arvalis* Pall., 1779)	0.5	0.2	0	0	0.2	0.2
Field vole (*Microtus agrestis* Pall., 1761)	0	0	0.3	0.2	0	0
Northern red-backed vole (*Myodes rutilus* Pall., 1779)	0	0	0.1	0.6	0.4	0.5
Bank vole (*Myodes glareolus* Schreb., 1780)	1.9	2.2	5.8	2.8	0	0

Notes: * Figures above and below the line show mean value ± error of mean and variation range (minimum/maximum), respectively; census unit, one line of 25 traps.

** Cytogenetic studies were not performed.

Soft, Inc., 2001). Population structure was analyzed using contingency tables and nonlinear regression; differences were assessed for significance with χ^2 and G^2 tests.

RESULTS

According to published data (Stepanov et al., 1992; Bol'shakov et al., 1996; Samoilova, 2003; Olenev and Kolcheva, 2007; Krashaninina and Chibiryak, 2008), the recent fauna of small mammals in the study region is represented by 13 species of murine rodents and seven species of insectivores. We have found six species of rodents and four species of red-toothed shrews (table), all of them described in the region previously.

The structure of the small rodent community changes with distance from the pollution source and is statistically uneven ($\chi^2(10) = 107.9$; $p = 0.0001$). In the background and buffer zones, small mammals are represented by six to seven species; in the impact zone, their number decreases to only two. Transformation of the community structure in disturbed areas is accompanied by changes in the composition of dominant species. In background areas, small insectivores (54%) and the bank vole (about 30%) are dominant. In buffer areas, the most abundant small mammals are the bank vole (50%), the pygmy wood mouse (30%), and small insectivores (12%). The community of the impact zone consists of the northern red-backed vole (69%) and the common vole (31%); insectivores are lacking in the catches. In the technogenic wasteland, no small mammals have been recorded.

Contingency tables were used to evaluate the species structure of the community. Differences between zones in pairwise comparisons are statistically significant: buffer vs. background, $\chi^2(1) = 3.86$; impact vs. buffer, $\chi^2(1) = 52.18$; and impact vs. background, $\chi^2(1) = 37.37$. The most distinctive feature of the community in the area affected by the smelter is that the northern red-backed vole prevails in the impact zone, while red-toothed shrews dominate in the background zone.

Comparison of zones with different pollution level shows significant differences in the index of total abundance ($G^2(2) = 69.12$). As the plume of emissions is approached, this index changes nonlinearly, reaching its maximum in the buffer zone: on average, 8.6 ind./100 trap–days. The abundance of the community is extremely low in impact plots (0.6–0.7 ind./100 trap-days) and intermediate in background plots (6.9 ind./100 trap-days) (table).

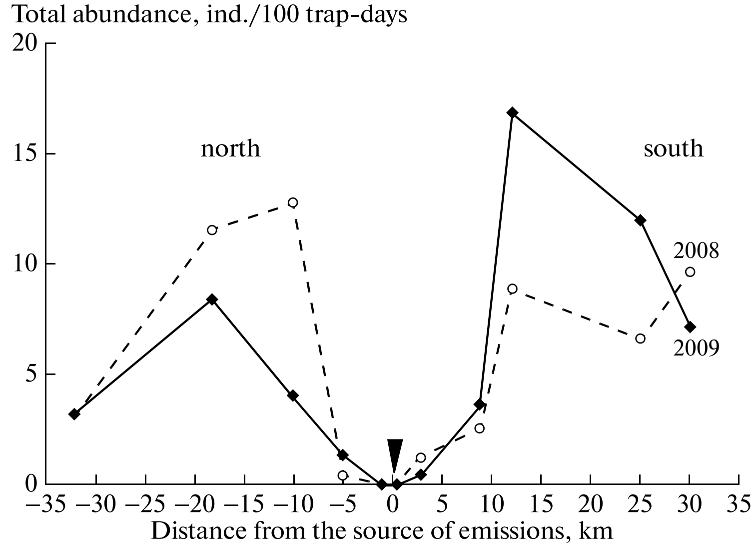

Fig. 2. Total abundance of the small rodent community in the zone affected by the Karabash Copper Smelter (filled triangle).

A more detailed analysis of the distribution of small mammals in individual plots has shown that in all areas, irrespective of the distance from the KCS, the animals were distributed unevenly. For instance, catches in the impact zone were recorded in five out of 18 lines set during two rounds of trapping, and the index of animal abundance varied from 0 to 0–5.3 ind./100 trap-days. No catches were recorded in two out of 24 lines set in the buffer zone, where animal abundance varied from 0 to 25.3 ind./100 trap-days. In the background zone, no small mammals were trapped in only one out of 18 lines, and the index of abundance varied from 0 to 17.3 ind./100 trap-days.

Changes in the index of total abundance in plots located at different distances from the pollution source are shown in Fig. 2. The highest values of this index were recorded in buffer areas, north of the KCS in 2008 and south of it in 2009. These peaks were accounted for by a high abundance of the bank vole in the former case and of the pygmy wood mouse in the latter case. The total abundance remained at the same level in the northern background zone but changed in various directions in the southern background zone. "Mirror" changes of the community were also observed in impact areas (Fig. 3).

The dependence of the total abundance index on distance from the source of emissions is well approximated ($R^2 = 0.875$) by the nonlinear function $y = 0.1/[1 + \exp(190.6 - 21.1x)]$. The transition between the impact and background states is abrupt, with the step on the curve corresponding to the distance of 9 km (Fig. 3).

DISCUSSION

According to Stepanov et al. (1992), who performed their studies in the environs of the KCS in 1983 to 1985, the zone affected by the smelter was poor in small mammals. These authors noted that "...animals visit the polluted territory only temporarily rather than live there. Red-toothed shrews were trapped at a distance of 3–4 km from the smelter, while the first voles appeared in catches made at a distance of 7–8 km."

Our study has shown that such a situation is typical only of plots classified as technogenic wasteland, which are not habitable for small mammals. A similar picture was also observed in the environs of the Middle Ural Copper Smelter (Mukhacheva, 1996). At the same time, it appears that temporary local "colonies" of small mammals do exist in the impact zone, occupying microsites where conditions are still suitable for their life. These are usually small depressions or waterlogged sites with clumps of herbaceous plants. The abundance of animals in such microsites is sometimes comparable to that in the background zone.

Similar results were obtained in the study of the bank vole population in the area affected by the Middle Ural Copper Smelter (Mukhacheva, 2007). They show that the ecological capacity of fir–spruce forest fragments preserved in impact plots is 20% lower, compared to unpolluted areas, and the local density of the vole population in these forest fragments under favorable conditions approaches that in the background zone. The proportion of such microsites in impact zones is rather small, no more than 5% of the total area, whereas in background areas voles populate up to 60% of this area (Luk'yanova and Luk'yanov, 1998b; Mukhacheva, 2007).

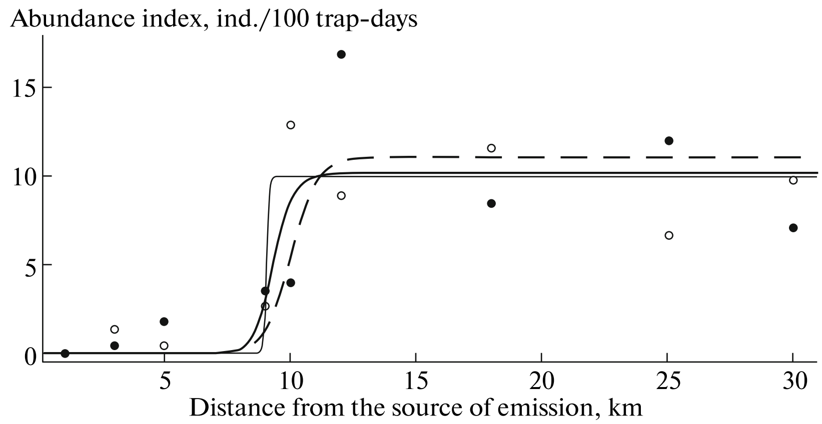

Fig. 3. Changes in the index of total abundance (ind./100 trap-days) of the small mammal community as a function of distance from the source of emissions (Karabash Copper Smelter). Open circles and thin line, 2008; filled dots and dashed line, 2009; bold line, year not taken into account; northern and southern directions were combined.

In our opinion, the total abundance reflects the integrated response of populations to a complex of external influences as well as the type of interspecific interactions within communities; the responses of different species to the same environmental gradients may be unequal. Technogenic factors are known to have a negative effect on the total abundance of animals, which markedly deceases as the source of the influence is approached (Kataev et al., 1994; Luk'yanova and Luk'yanov, 1998a; Mukhacheva, 1996, 2007; Davydova, 2007; etc.). The expected shift in abundance should reflect the degree of well-being of individual species and the community as a whole under particular conditions. The observed changes in this parameter indicate whether the environmental conditions in a particular area are favorable or unfavorable.

In our opinion, the distinctly nonlinear pattern of the response of small mammals to the gradient of anthropogenic pollution of the environment is especially noteworthy (Fig. 3). The shape of the curve matches the classic threshold dose–effect dependence. Moreover, the gradient of load is relatively strong (the abundance of animals changes by more than an order of magnitude), and the part of the gradient where the shift between levels takes place is extremely small. Habitat quality becomes satisfactory for most murine rodents and insectivores at a distance of 9–11 km from the plume of emissions. Similar responses to pollution of the environment were previously described for other components of forest ecosystems (Vorobeichik et al., 1994; Vorobeichik, 2004).

Not only the abundance of small mammal community but also its species composition changes as the source of emissions in approached, and the replacement of dominants also takes place. The community of the buffer areas is especially diverse. This is probably due to higher heterogeneity of habitats, which allows the existence of both typical forest animals and inhabitants of sparse woodland. Background areas are characterized by a high proportion of insectivores in the community. This fact is explained primarily by an abundant food supply and usually indicates that the habitat is "unpolluted" (Vorobeichik et al., 1994). No insectivores have been recorded in catches from impact plots. However, censuses of small mammals by different methods have shown that at least four insectivore species occur in impact zones.

Thus, the influence of technogenic factors leads to changes in the abundance and structure of the small mammal community. The index of total abundance changes in the gradient of pollution nonlinearly, reaching the highest values in buffer areas. The quality of habitats becomes satisfactory at a distance of 9–11 km from the plume of emissions. Transformation of population structure is accompanied by changes in the composition of dominants. The responses of different species are unequal and depend on their ecological features. In background areas, small insectivores prevail in the small mammal community, indicating the favorable state of these areas. Near the source of emission, the community is characterized by extremely low abundance and impoverished species composition. However, the data obtained suggest that local "colonies" of small mammals probably exist in impact areas.

ACKNOWLEDGMENTS

The authors are grateful to Drs. E.L. Vorobeichik, K.I. Berdyugin, and M.R. Trubina for their valuable advice and discussion of this study.

This study was supported by the Russian Foundation for Basic Research (project nos. 08-04-91766 and 10-04-01657a); the Program for Development of Science and Education Centers (contract no. 02.740.11.0279); the Biological Diversity Program of the Presidium of the Russian Academy of Sciences; and the Ural Division of the Russian Academy of Sciences (program for interdisciplinary projects).

REFERENCES

Bezel', V.S., *Ekologicheskaya toksikologiya: populyatsionnyi i biotsenoticheskii aspekty* (Ecological Toxicology: Population and Biocenotic Aspects), Yekaterinburg: Goshchitskii, 2006.

Bezel', V.S., Benenson, I.E., and Sadykov, O.F., Effects of Technogenic Pollution on Population Dynamics of Small Mammals in Mosaic Habitats, in *Tekhnogennye elementy i zhivoi organizm* (Technogenic Elements and Living Organisms), Sverdlovsk, 1986, pp. 37–42.

Bol'shakov, V.N., Vasil'ev, A.G., and Sharova, L.P., *Fauna i populyatsionnaya ekologiya zemleroek Urala (Mammalia, Soricidae)* (The Fauna and Population Ecology of Shrews in the Urals), Yekaterinburg: Nauka, 1996.

Chernen'kova, T.V., *Reaktsiya lesnoi rastitel'nosti na promyshlennoe zagryaznenie* (Responses of Forest Vegetation to Industrial Pollution), Moscow: Nauka, 2002.

Chernousva, N.F., On Assessment of the Impact of Industrial Emissions on Small Mammals, in *Zhivotnye v usloviyakh antropogennogo landshafta* (Animals in Anthropogenic Landscape), Sverdlovsk, 1990, pp. 83–91.

Davydova, Yu.A., Fine Structure of Testes in Bank Voles Exposed to Chronic Chemical Pollution of the Environment, *Extended Abstract of Cand. Sci. (Biol.) Dissertation*, Yekaterinburg, 2007.

Kataev, G.D., Suomela, J., and Palokangas, P., Densities of Murine Rodents along a Pollution Gradient from a Copper–Nickel Smelter, *Oecologia*, 1994, vol. 97, pp. 491–498.

Kozlov, M.V., Zvereva E.L., Gilyazov, A.S., and Kataev, G.D., Contaminates Zone around a Nickel–Copper Smelter: A Death Trap for Birds and Mammals?, in *Trends in Biodiversity Research*, New York: Nova Science, 2005, pp. 81–101.

Kozlov, M.V., Zvereva E.L., and Zverev, V.E., *Impact of Point Polluters on Terrestrial Biota: Comparative Analysis of 18 Contaminated Areas*, Dordrecht: Springer, 2009.

Krashaninina, Yu.V. and Chibiryak, M.V., Small Mammal Community Structure in the Eastern Ural Radioactive Trace, *Biosfera zemli: proshloe, nastoyashchee i budushchee: Mat-ly konf. molodykh uchenykh* (Proc. Young Scientists Conf. "The Biosphere: Past, Present, and Future"), Yekaterinburg, 2008, pp. 106–118.

Leffler, P. and Nyholm, N.E., Nephrotoxic Effect in Free-Living Bank Voles in a Heavy Metal-Polluted Environment, *Ambio*, 1995, vol. 25, no. 3, pp. 417–420.

Luk'yanova, L.E. and Luk'yanov, O.A., Responses to Technogenic Influences in Small Mammal Communities and Populations: 1. Communities, *Usp. Sovrem. Biol.*, 1998a, vol. 118, no. 5, pp. 613–622.

Luk'yanova, L.E. and Luk'yanov, O.A., Responses to Technogenic Influences in Small Mammal Communities and Populations: 2. Populations, *Usp. Sovrem. Biol.*, 1998b, vol. 118, no. 6, pp. 694–707.

Moskvitina, N.S., Population Ecology of Small Mammals in the Southeast of Western Siberia, *Extended Abstract of Doctoral (Biol.) Dissertation*, Tomsk, 1999.

Mukhacheva, S.V., Ecotoxicological Features and Population Structure of Small Mammals in a Gradient of Technogenic Pollution of the Environment, *Extended Abstract of Cand. Sci. (Biol.) Dissertation*, Yekaterinburg, 1996.

Mukhacheva, S.V., Bank Vole Population Reproduction in a Gradient of Technogenic Pollution of the Environment, *Zool. Zh.*, 2001, vol. 80, no. 12, pp. 1509–1517.

Mukhacheva, S.V., Spatiotemporal Population Structure of the Bank Vole in a Gradient of Technogenic Environmental Pollution, *Ekologiya*, 2007, no. 3, pp. 178–184.

Olenev, G.V. and Kolcheva, N.E., Chronographic Variation in the Composition and Abundance of Murine Rodents in the Il'men Nature Reserve, *Vestn. OGU*, 2007, vol. 75, pp. 252–257.

Samoilova, N.M., Comparative Analysis of Vertebrate Communities in Pine Stands of a City Park Forest and in a Nature Reserve, *Extended Abstract of Scand. Sci. (Biol.) Dissertation*, Yekaterinburg, 2003.

Shilova, S.A., Population Organization of Mammals under Conditions of Anthropogenic Impact, *Usp. Sovrem. Biol.*, 1999, vol. 119, no. 5, pp. 487–503.

StatSoft Inc., *STATISTICA (Data Analysis Software System)*, www.statsoft.com, 2001.

Stepanov, A.M., Kabirov, R.R., Chernen'kova, T.V., et al., *Kompleksnaya ekologicheskaya otsenka tekhnogennogo vozdeistviya na ekosistemy yuzhnoi taigi* (Comprehensive Ecological Assessment of Technogenic Impact on Southern Taiga Ecosystems), Moscow: TsEPL, 1992.

Talmage, S.S. and Walton, B.T., Small Mammals As Monitors of Environmental Contaminants, *Rev. Envir. Contam. Toxicol.*, 1991, vol. 119, pp. 47–145.

Vol'pert, Ya.L. and Sapozhnikov, G.V., Responses of Small Mammalian Fauna to Different Forms of Technogenic Influences on Arctic Landscapes, *Ekologiya,* 1998, vol. 29, no. 2, pp. 115–119.

Vorobeichik, E.L., Ecological Rating of Technogenic Loads on Terrestrial Ecosystems, *Extended Abstract of Doctoral (Biol.) Dissertation*, Yekaterinburg, 2004.

Vorobeichik, E.L., Sadykov, O.F., and Farafontov, M.G., *Ekologicheskoe normirovanie tekhnogennykh zagryaznenii nazemnykh ekosistem* (Ecological Rating of Technogenic Pollution of Terrestrial Ecosystems), Ekaterinburg: Nauka, 1994.

Wlostowski, T. and Krasowska, A., Subcellular Distribution of Metallothionein and Cadmium in the Liver and Kidneys of Bank Voles Exposed to Dietary Cadmium, *BioMetals*, 1999, vol. 12, pp. 173–179.