ISSN 1067-4136, Russian Journal of Ecology, 2015, Vol. 46, No. 4, pp. 377–380. © Pleiades Publishing, Ltd., 2015.
Original Russian Text © E.L. Vorobeichik, D.V. Nesterkova, 2015, published in Ekologiya, 2015, No. 4, pp. 308–312.

SHORT COMMUNICATIONS

Technogenic Boundary of the Mole Distribution in the Region of Copper Smelter Impacts: Shift after Reduction of Emissions

E. L. Vorobeichik and D. V. Nesterkova

Institute of Plant and Animal Ecology, Ural Branch, Russian Academy of Sciences,
ul. Vos'mogo Marta 202, Yekaterinburg, 620144 Russia
e-mail: ev@ipae.uran.ru

Received December 26, 2014

Keywords: European mole, *Talpa europaea*, earthworms, soil, forest litter, forest ecosystems, industrial pollution, heavy metals, copper smelter, recovery, Middle Urals

DOI: 10.1134/S1067413615040165

Long-term atmospheric emissions from metallurgic works result in technogenic geochemical anomalies. The levels of heavy metals in the epicenters of such anomalies are sometimes several orders of magnitude higher than in background areas, which has a deadly effect on the biota of terrestrial ecosystems. Specific features of impact regions, i.e., sets of ecosystems situated near point polluters, are determined by the gradient nature of the underlying factor: doses of the toxic load decrease with distance from the works, forming the characteristic spatial pattern that consists of a sequence of areas with different levels of pollution and, accordingly, different degrees of ecosystem transformation (Vorobeichik and Kozlov, 2012). In some cases, pollution results in complete disappearance of some components of the biota, e.g., epiphytic lichens (Mikhailova and Vorobeichik, 1995) or earthworms (Vorobeichik, 1998), in large areas around the polluter; in such cases it is easy to draw the technogenic boundaries of the distribution of these components in the impact region. The European mole (*Talpa europaea* L.) can be regarded as one of such components.

It is well known that the mole lives only in those areas abounding in large soil invertebrates, especially earthworms, which form the bulk of the mole's diet (Funmilayo, 1979). Therefore, the presence or absence of the mole can be regarded as an "alternative" indicator of the state of the soil macrofauna and the functions it performs in the ecosystem (above all, participation of saprophages in cycles of nutrients). The alternative nature of this indicator is also evidenced by the fact that the abundance of the mole decreases stepwise under the impact of pollution (Nesterkova, 2014). The disappearance of the mole near polluters results from depleted food supplies, rather than from direct toxic effects of heavy metals (Nesterkova et al., 2014). Hence changes in the position of the technogenic boundary of the mole distribution in the impact region, the boundary that determines the size of the "mole desert," may reflect qualitative shifts in the state of the soil macrofauna community.

The emissions of many plants into the atmosphere have been decreasing over the last few decades, making it possible to analyze the natural processes of ecosystem recovery. Some estimations of the rates of such recovery processes contradict each other: there are examples of absence of positive trends in the changing state of the biota over long periods after reduction of emissions (Zverev, 2009; Tanasevich et al., 2009; Vorobeichik et al., 2014) as well as examples of relatively rapid recovery (Eeva and Lehikoinen, 2000; Chernen'kova et al., 2011; Chernen'kova and Bochkarev, 2013).

The purpose of this study was to analyze the shift in the technogenic boundary of the mole distribution in the impact region of a large copper smelter after considerable reduction of its emissions. This study is based on repeated observations of the mole presence in the same localities separated in time by 15–18 years.

This study was performed in the area affected by the Middle Ural Copper Smelter (MUCS), situated in the environs of Revda, 50 km west of Yekaterinburg (Sverdlovsk oblast). Emissions reached 140000 t per year in the late 1980s and decreased to 71–96000 t/year in 1995–1998, 24–34000 t/year in 2003–2008, and 3–5000 t/year in 2010–2013. In 1995–1998 the average levels of mobiles forms of heavy metals in the forest litter in the most strongly polluted zone were as follows (μg/g): Cu 5535, Pb 1311, Cd 31, Zn 1736; these values were higher than the regional background values of the same parameters by factors of 132, 38, 14, and 6, respectively (Vorobeichik, 2003).

We mapped the distribution of the mole in the MUCS area for the first time in 1995 to 1998 (Vorobeichik, 2004), in forest biotopes of a 40 × 50 km area with the smelter in the center, we established 188 test plots (25 × 25 m) that differed not only in pollution levels, but also in topographic position (eluvial, transitional, and accumulative landscapes), soil type

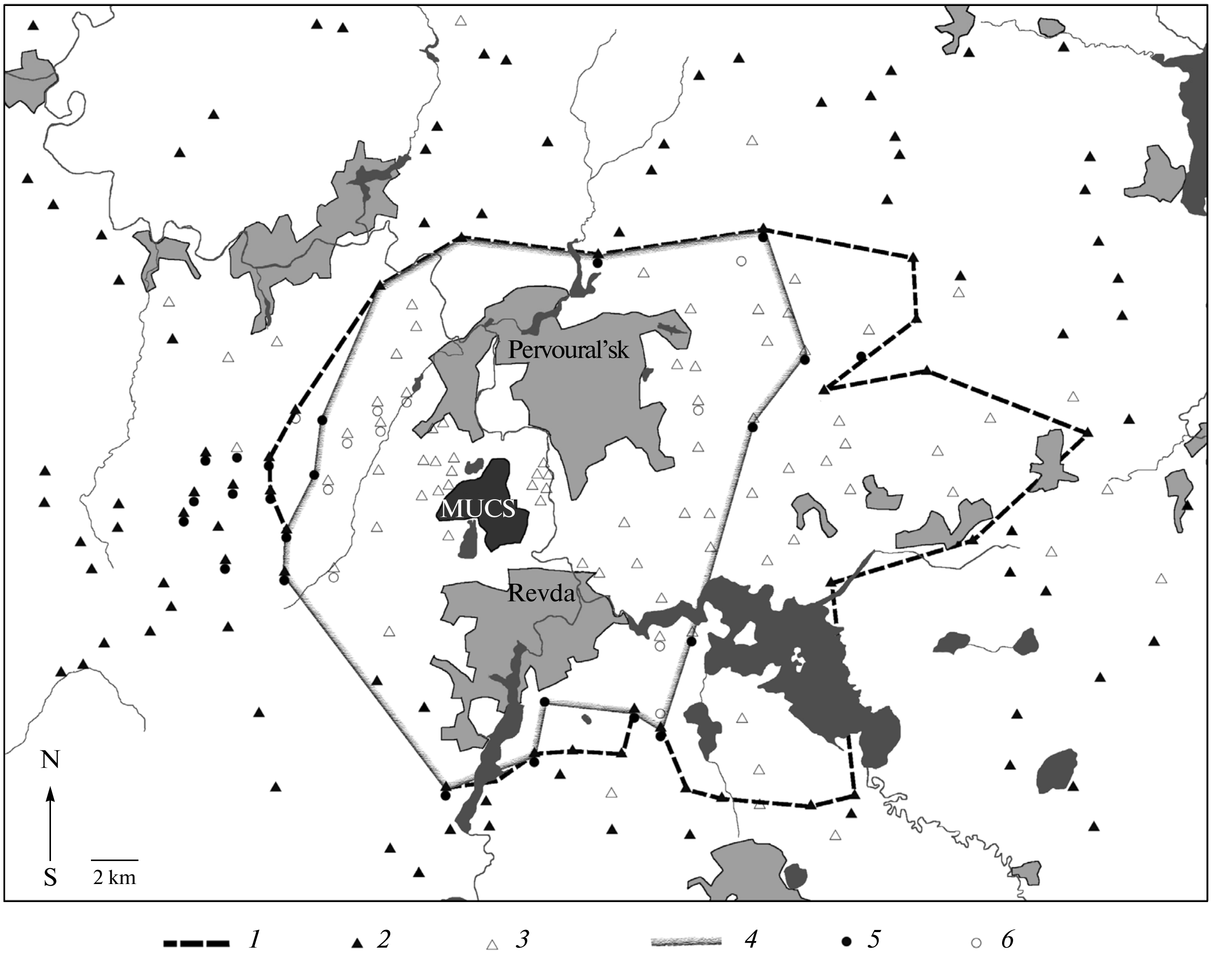

Fig. 1. Changes in the technogenic boundary of the mole distribution in the zone of impact from the MUCS over the past 15–18 years: (*1*) "mole desert" boundary in 1995–1998; (*2*) areas with mole burrows sampled in 1995–1998; (*3*) areas without mole burrows sampled in 1995–1998; (*4*) "mole desert" boundary in 2013; (*5*) areas with mole burrows sampled in 2013; (*6*) areas without mole burrows sampled in 2013.

(lithozems, rzhavozems, and brown, gray, and soddy podzolic soils), and vegetation (birch, pine, birch–pine, and birch–spruce–fir forests of different plant associations). The test plots were selected considering the following criteria: absence of strong local anthropogenic disturbances unrelated to pollution or recent (less than 5-year-old) pyrogenic areas; distance to nearest highways at least 100 m; age of dominant tree species at least 60 years. The presence of the mole was recorded in each sampling plot based on visible evidence of its digging activity (molehills and burrows).

The first mapping revealed a large area, extended eastward from the smelter, in which the mole was totally absent (Vorobeichik, 2004). This "mole desert" enveloped a smaller "lumbricid desert" in which earthworms were totally absent (Vorobeichik, 1998, 2004). The asymmetry of these two areas is accounted for by the pattern of heavy metal dispersal determined by the eastward direction of prevailing winds in the study area.

Mapping was repeated in 2013 in exactly the same localities; data were obtained on 34 plots (including three additional ones) situated near the previously determined technogenic boundary of the mole distribution. It was found that, compared to 1995–1998, the area of the "mole desert" decreased by 37%: from 563 to 352 km^2 (Fig. 1). It is noteworthy that the shift of the boundary was mainly eastward and southeastward from the plant (by 5–10 km, 91% of the total area of all changes). Small (1–2 km) westward and southward shifts were recorded, in essence, only because of the inclusion of additional test plots to determine the position of the boundary more precisely; if the additional plots are excluded, no shift in these directions is recorded.

It should be emphasized that the boundary of the mole distribution in the impact region, as well as any other boundary drawn in natural habitats, should not be considered absolute: first, its position depends on the spatial resolution of the pattern in which the test plots are established (i.e., on the number of test plots

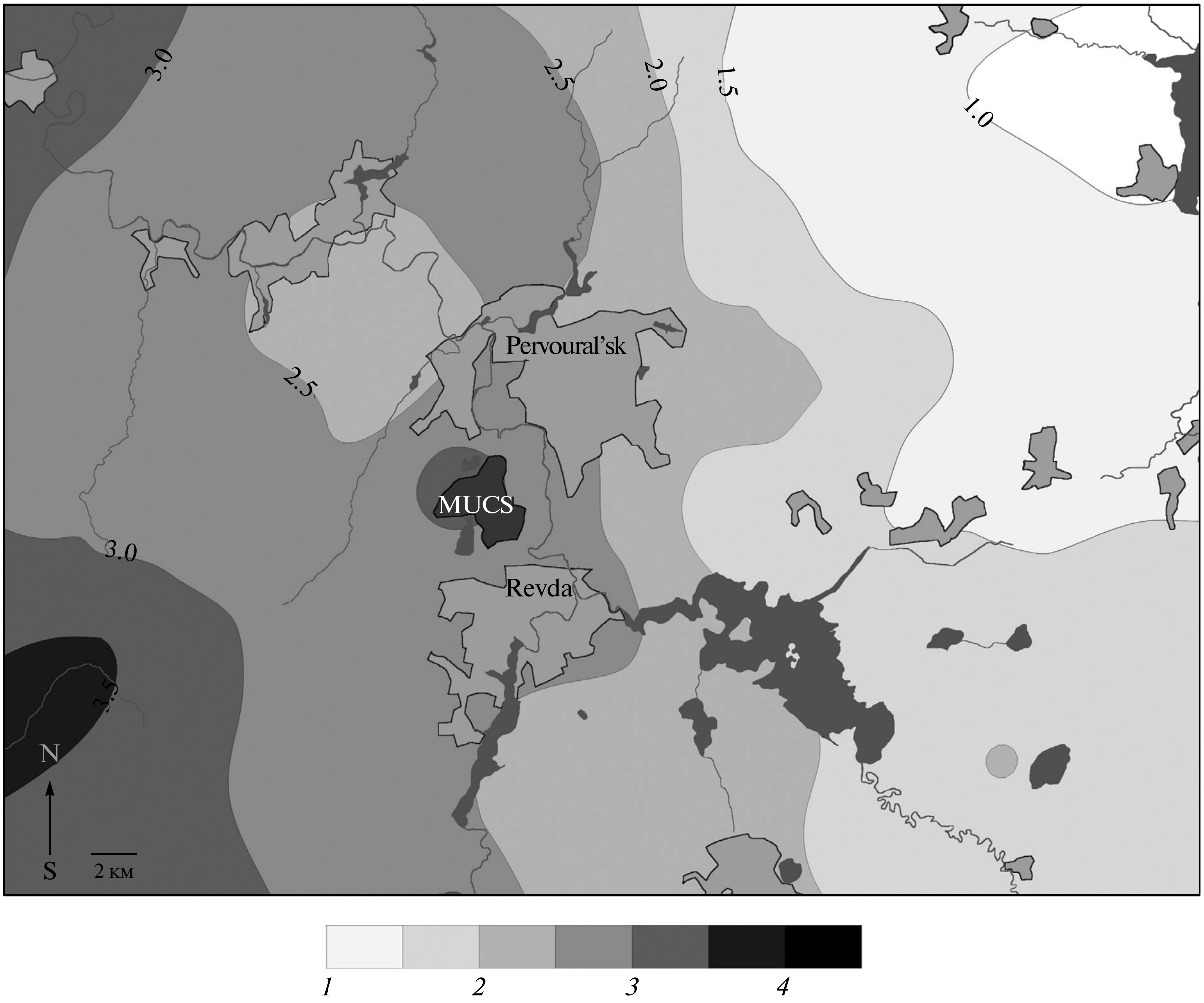

Fig. 2. Soil texture in mineral horizons at depths of 20–30 cm in the MUCS region: (*1*) sandy loam, (*2*) light loam, (*3*) loam, (*4*) heavy loam. Spatial interpolation for data of 1995–1998 was performed by Kriging using the program Surfer 10.

and the evenness of their distribution); second, because of biotopic variation, the area on both sides of the boundary is heterogeneous with respect to the presence of the mole. In this study, the boundary was drawn using points situated at 1–2 km from each other and exclusively in the forest. If other biotopes are added by including meadow and floodplain areas, the boundary shifts closer to the smelter and the absolute area of the "mole desert" decreases, as we have shown in another series of censuses of the mole abundance (Nesterkova, 2014). However, in the context discussed here, relative changes rather than the absolute values of the area of the "desert" are important. In addition, the shift of the boundary should not be regarded as one-direction movement in a "continuous front line." Because of the above-mentioned biotopic variation, the area is also colonized from "refugia" present in the "mole desert" in which moles were preserved.

The most interesting results of this study are the cardinal differences revealed between the western sector and the eastern sector. In our opinion, these differences are explained as follows. Kapustin (2009) in his study on the modern physiographical zoning of Sverdlovsk oblast draws the boundary between two natural areas, namely lower mountains of the Middle Urals (with dark coniferous forests dominating west of the boundary) and eastern foothills of the Urals (with light coniferous forests dominating east of the boundary), approximately 10 km east of the line Pervoural'sk–Revda. Gafurov (2008) draws the boundary between two soil provinces, namely the Middle Ural southern taiga province (west) and the Transural southern taiga province (east), somewhat east of that line. The former is characterized by soils of heavier texture (the proportion of physical clay in horizons A and B is 40–77%), while the latter is characterized by soils of lighter texture (10–30%). Mapping of the area based on our field diagnostics of soil texture in mineral horizons at depths of 20–30 cm also showed distinct differentiation of the western sector and eastern sector (Fig. 2).

It is well known that the capacity of soil to retain heavy metals is determined by soil texture as well as by the content of organic matter, acidity, and several other parameters (Dube et al., 2001; Kabala and Singh, 2001). In soils of coarse texture, *ceteris paribus*, the mobility of heavy metals is higher, facilitating more rapid self-purification of upper soil horizons from heavy metals. This is important to earthworms, because dominant species in our region (above all, *Perelia diplotetratheca*, endemic to the Urals) are especially abundant in the litter and in the humus-accumulative horizon (Vorobeichik, 1998). Since the main reason for the suppression of earthworms, up to their complete disappearance near the MUCS, was the high toxicity of the soil, associated both with the levels of metals and with acidity (Vorobeichik, 1998), it is logical to suggest that decrease of toxicity should have led to resurgence of the abundance of earthworms. When their abundance exceeded some threshold level, the mole could reappear, and thus the boundary of the mole distribution shifted.

Therefore, in the area with soils of coarse texture (sandy loam and light loam) the technogenic boundary of the "mole desert" strongly and rather rapidly shifted closer to the smelter following the reduction of emissions, while in the area with soils of fine texture (loam and heavy loam) the position of the technogenic boundary of the mole distribution remained constant almost for 20 years, although the amount of emissions at the beginning of this period was many times as high as it was at the end. We suggest that this difference is associated with the difference in the degree of self-purification of soil from heavy metals, higher in the first case and lower in the second. If our hypothesis is right, it follows that the rate of soil biota recovery depends on those properties of the soil that determine the durability of the fixation of heavy metals in it. Although this conclusion is to some extent trivial, it can reconcile the two contradicting views on the rates of recovery processes: prolonged suppression or rapid recovery of the biota following the cessation of emissions.

ACKNOWLEDGMENTS

We are grateful to A.V. Nesterkov for his help in field work and to E.A. Bel'skii, N.V. Zolotareva, S.Yu. Kaigorodova, and M.R. Trubina for valuable discussion and comments on the manuscript.

This study was supported by the Russian Foundation for Basic Research (project no. 14-05-00686), the Scientific School Support Program (project no. NSh-2840.2014.4), and the Program for Basic Research of the Ural Branch, Russian Academy of Sciences (project nos. 12-M-23457-2041 and 15-12-4-26).

REFERENCES

Chernen'kova, T.V. and Bochkaryev, Yu.N. Dynamics of spruce stands in the northern Kola Peninsula under the effects of natural and anthropogenic environmental factors, *Zh. Obshch. Biol.*, 2013, vol. 74, no. 4, pp. 283–303.

Chernen'kova, T.V., Kabirov, R.R., and Basova, E.V., Progressive successions in northern taiga spruce forests upon reduction of industrial air pollution, *Lesovedenie*, 2011, no. 6, pp. 49–66.

Dube, A., Zbytniewski, R., Kowalkowski, T., et al., Adsorption and migration of heavy metals in soil, *Pol. J. Environ. Stud.*, 2001, vol. 10, no. 1, pp. 1–10.

Eeva, T. and Lehikoinen, E., Pollution: Recovery of breeding success in wild birds, *Nature*, 2000, vol. 403, no. 6772, pp. 851–852.

Funmilayo, O., Food consumption, preference and storage in the mole, *Acta Theriol.*, 1979, vol. 24, no. 27, pp. 379–389.

Gafurov, F.G., *Pochvy Sverdlovskoi oblasti* (Soils of Sverdlovsk Oblast), Yekaterinburg: Ural. Gos. Univ., 2008.

Kabala, C. and Singh, B.R., Fractionation and mobility of copper, lead, and zinc in soil profiles in the vicinity of a copper smelter, *J. Environ. Quality*, 2001, vol. 30, no. 2, pp. 485–492.

Kapustin, V.G., Physiographic zoning of Sverdlovsk oblast, *Geografiya i sovremennye problemy estestvennonauchnogo poznaniya: Mat-ly konf.* (Geography and Current Problems of Natural Science Knowledge: Proc. Conf., Yekaterinburg, 2009, pp. 11–24.

Mikhailova. I.N. and Vorobeichik, E.L., Epiphytic lichenosynusia under conditions of chemical pollution: Dose–effect dependencies, *Russ. J. Ecol.,* 1995, vol. 26, no. 6, pp. 425–431.

Nesterkova, D.V., Distribution and abundance of European mole (*Talpa europaea* L.) in areas affected by two Ural copper smelters, *Russ. J. Ecol.*, 2014, vol. 45, no. 5, pp. 429–436.

Nesterkova, D.V., Vorobeichik, E.L., and Reznichenko, I.S., The effect of heavy metals on the soil–earthworm–European mole food chain under the conditions of environmental pollution caused by the emissions of a copper smelting plant, *Contemp. Probl. Ecol.*, 2014, vol. 7, no. 5, pp. 587–596.

Tanasevich, A.V., Rybalov, L.B., and Kamaev, I.O., Dynamics of soil macrofauna in the sone of technogenic impact, *Lesovedenie*, 2009, no. 6, pp. 630072.

Vorobeichik, E.L., Populations of earthworms (Lumbricidae) in forests of the Middle Urals in conditions of pollution by discharge from copper works, *Russ. J. Ecol.*, 1998, vol. 29, no. 2, pp 85–91

Vorobeichik, E.L., Reaction of forest litter and its relationship with soil biota under toxic pollution, *Lesovedenie*, 2003, no. 2, pp. 32–42.

Vorobeichik, E.L., Ecological rating of technogenic loads on terrestrial ecosystems, *Extended Abstract of Doctoral (Biol.) Dissertation*, Yekaterinburg, 2004.

Vorobeichik, E.L. and Kozlov, M.V., Impact of Point Polluters on Terrestrial Ecosystems: Methodology of Research, Experimental Design, and Typical Errors. *Russ. J. Ecol.*, 2012, vol. 43, no. 2, pp. 89–96.

Vorobeichik, E.L., Trubina, M.R., Khantemirova, E.V., and Bergman, I.E. Long-term dynamic of forest vegetation after reduction of copper smelter emissions, *Russ. J. Ecol.*, 2014, vol. 45, no. 6, pp. 498–507.

Zverev, V.E., Mortality and recruitment of mountain birch (*Betula pubescens* ssp. *czerepanovii*) in the impact zone of a copper-nickel smelter in the period of significant reduction of emissions: The results of 15-year monitoring, *Russ. J. Ecol.*, 2009, vol. 40, no. 4, pp. 254–260.

Translated by P. Petrov