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Distribution and Abundance of European Mole (*Talpa europaea* L.) in Areas Affected by Two Ural Copper Smelters

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Abstract—The abundance of moles has been studied in 2007–2010 along the gradient of pollution by emissions from the Middle Ural (Middle Urals) and Karabash (Southern Urals) Copper Smelters. It has been estimated by the routing method with regard to the number of inhabited burrows per 1 km. Not a single mole has been recorded in heavily polluted areas near these copper smelters. Under conditions of moderate pollution, the abundance of moles decreased 1.5–1.8 times. The smallest "mole desert" near the source of emissions extends for 90–100 km^2. A dramatic decrease in the abundance of earthworms, which are the main food object of moles, is considered a possible reason for these changes.

Keywords: European mole, *Talpa europaea*, relative abundance, route counting, industrial pollution, copper smelter, Ural.

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Industrial pollution of the environment, often catastrophic near smelters, substantiates the urgency of studies on the stability of natural populations. The majority of surveys on populations affected by various anthropogenic factors have been based on common species of small-sized mammals, such as murine rodents and shrews (Luk'yanova et al., 1994; Mukhacheva et al., 2012; Kataev et al., 1994). Probable reactions of other mammals that require specific counting and trapping methods have been insufficiently studied.

The European mole is a highly specialized species, which is well adapted to relatively constant microclimatic conditions in the soil. *Talpa europaea* used to be a commercial species and was of interest to many researchers, who studied in detail its reproduction, feeding, molting, daily activity, and biotopic distribution. Moles have been successfully used as indicators of heavy metal contents in the environment (Komarnicki, 2000; Ma, 1987; Pankakoski et al., 1993) and are considered an appropriate object for studying the accumulation of these agents under conditions of moderate pollution. In addition, fluorides in mole skeletons near an aluminum reduction plant have been studied (Walton, 1986). It was also shown that roadside soils under the burrow network of moles can accumulate heavy metals and other pollutants (Bykov and Lysikov, 1991). Data on moles near smelters are fragmentary (Vorobeichik, 2003). As far as we know, their population structure, distribution, and abundance have not been studied. The purpose of this study was to analyze the spatial and temporal dynamics of mole abundance under conditions of air pollution with emissions produced by large point sources.

STUDY AREA

The study was performed near two copper smelters characterized by the same type of pollution spectrum: SO$_2$ and polymetallic dust, which is dominated by Cu, Pb, Zn, Cd, As, etc. The smelters are comparable based on their emission strength, form of pollution, and heavy metal contents in deposit environments near them. In the late 1980s, each of these smelters emitted about 160 000 t of pollutants every year. In the mid-2000s, this amount decreased to about 30 000–40 000 t (Smorkalov and Vorobeichik, 2011). Impact (0–5 km), buffer (6–18 km), and background (farther than 20 km) zones were singled out around the smelters (Vorobeichik et al., 1994; Kozlov et al., 2009).

The Middle Ural Copper Smelter (MUCS) has been in operation since 1940. It is located near the city of Revda, Sverdlovsk oblast. According to physical and geographic zoning, the territory belongs to the southern taiga subzone, low-mountain area of the Middle Urals. The studied sites are located at distances of 4, 7, 10, 20, 30 km west and 9, 13, 26, 34 km south of the smelter. Additional control sites were located near the village of Merkitasikha, Pervouralsk district, (40 km northwest of the MUCS) and the village of Shigaevo, Shalinskii district (89 km northwest). Fir–spruce forests mixed with birch, aspen, and pine prevail in the

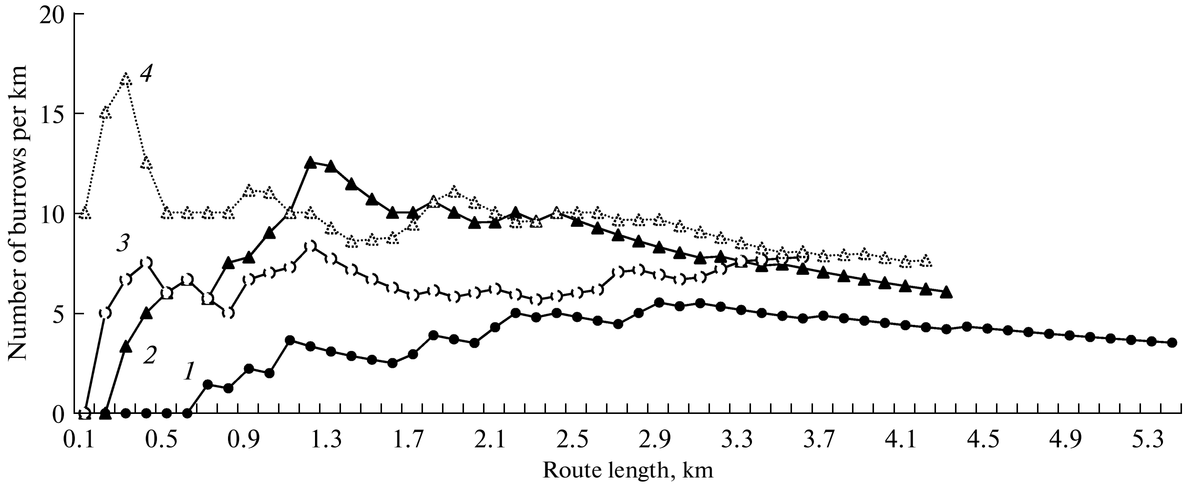

Fig. 1. Dependence of the number of burrows per kilometer on route length at distances of (*1*) 7 km, (*2*) 13 km, and (*3*, *4*) 20 km (in different years) from the MUCS.

western and northwestern directions. The city of Revda with small forest islands inside adjoins the MUCS. For this reason, the site nearest to the MUCS was located at a distance of 9 km. Pine–spruce forests prevail in this direction.

The Karabash Copper Smelter or Karabashmed (KCS), in operation since 1910, is located in the Southern Urals, Chelyabinsk oblast. The territory belongs to the pre-forest–steppe pine–birch forest subzone of the forest zone. The studied sites are located in the northern (11, 18, and 32 km from the source of pollution) and southern (9, 12, 26, and 27 km) directions from the KCS.

MATERIALS AND METHODS

Mole censuses were taken in May and October: in 2007–2011 near the MUCS (the number of surveys is lower for some sites); in 2009–2011 near the KCS. Spring censuses are needed to describe the abundance of moles taking part in reproduction. Autumn censuses make it possible to estimate their abundance at the end of the breeding season. Summer censuses were not carried out, because the number of inhabited burrows in July and August depends not on the abundance of moles but rather on the high activity of young of the year leaving them at this time.

The abundance of moles was determined by the route method (Bashkirov and Zharkov, 1934). The routes were laid out across trails and little-used roads with moderately dense soil in forest biotopes. Clearings, waterlogged areas, abandoned glades with a loose mat, as well as rocky, active, and broken roads, were not surveyed.

The census was taken in two stages: on the first day, we recorded the covered distance and GPS coordinates of all mole burrows crossing the trail, and a small section of each burrow was stamped down; on the following day, we counted the restored (i.e., inhabited) burrows, with newly dug burrows also considered as inhabited.

The route census method was developed to estimate the commercial stock of moles in large areas. Thus, each route should be no less than 10 km long (*Metodicheskie ukazaniya...*, 1988). There are certain difficulties associated with application of this method near industrial plants. First, it is necessary to estimate the abundance of moles within the limited area at a certain distance from the source of pollution in the intended direction. For this reason, we reduced the route length and the distance to the source of pollution was approximated (±1 km). Second, many variants of the biotope cannot be subjected to our census due to the small length of the route. Other counting methods, such as labeling and repeated trapping or detection of individual habitats, are of little value for us, because they require too much effort.

In order to determine the necessary route length, we used the dependence of the number of burrows (on conversion to 1 km) on route length based on the data of long routes at three sites in the autumns of 2008 and 2009 (Fig. 1). The results of a route census become relatively stable if the route length exceeds 1.5 km and finally stabilize if it exceeds 3 km. Most of the 18 routes satisfied this condition (the average route length at one site was 2.8 ± 0.1 km); only five of them (4, 30, 89 km near the MUCS and 9, 12km near the KCS) were 0.7–1.5 km long due to the absence of trails.

The boundaries of areas inhabited by moles near the MUCS were determined by unrestricted search for any traces of mole digging activity (burrows and mole hills), regardless of the period of their use and current presence of moles.

The number of moles using the same main burrow was calculated in 2007 and 2009 based on the results of

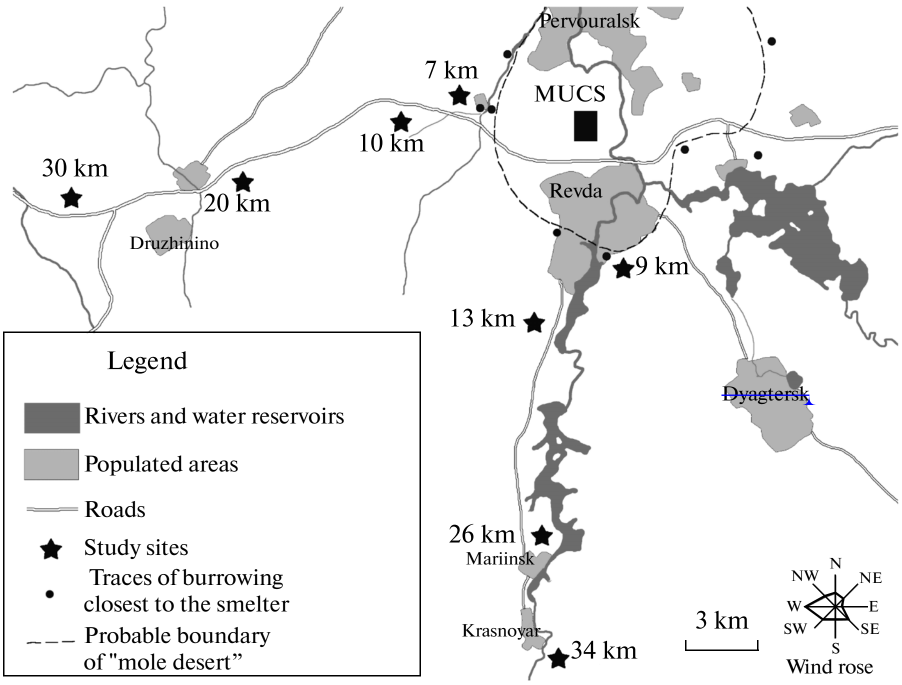

Fig. 2. Geographic locations of study sites and of burrows and molehills most proximal to the MUCS.

trappings in May, July, and October. Falkenstein–Popov's crush and live traps for moles were placed at each site within one to six burrows for 2–3 days; a total of 106 burrows were observed; 243 moles were caught during the period under study.

RESULTS

Both regions were characterized by the absence of moles in their heavily polluted (impact and buffer) zones. In the vicinity of the MUCS, the nearest molehills and burrows were found 4.5 km to the west and 7 km to the south, whereas those in the vicinity of the KCS were located 9 km to the north and 11 km to the south. The "mole desert" near the MUCS is no less than 90–100 km^2 (Fig. 2). The molehills nearest the MUCS were recorded in a small river floodplain and near vegetable gardens of human settlements. In spring, the boundary between uninhabited and occupied by moles territories often shifts farther from the smelter, because *T. europaea* in unfavorable biotopes either cannot make it through the winter or it migrates.

Figures 3 and 4 show the relative abundance of moles inhabiting the studied sites. In the vicinity of the MUCS, the number of burrows during the autumn period varied from 1 to 12.6 per 1 km (6.9 ± 1.9 on average, $n = 20$) in the background zone and from 0 to 8.1 per 1 km (3.8 ± 1.3, $n = 18$) in the buffer zone. Maximum 5-year-long fluctuations of this parameter at one site were 1.2–7.6 (3.4 on average). In the vicinity of the KCS, the number of burrows during the autumn period varied from 0.7 to 4.9 (2.0 ± 0.8, $n = 6$) in the background zone and from 0 to 5.3 (1.3 ± 1.0, $n = 10$) in the buffer zone. In 2010, in contrast to 2009, the number of burrows was lower due to the hot and dry summer: the air temperature deviation from the long-term average annual one reached 2.5–3.5°C, the precipitation amount was 60% of the normal one (data of the Institute of Global Climate and Ecology: http://climatechange.igce.ru) or 78% of the amount of precipitation in 2009 (data from Miass weather station: http://rp5.ru/).

The influence of the pollution level, region of study, and annual and seasonal dynamics on the number of mole burrows was estimated with the help of four-way analysis of variance. The highest effect was produced by the toxic load zone (20% of explained variance, $F_{1;95} = 20.6, p < 0.0001$) and the region (17.7%, $F_{1;95} = 11.4$, $p < 0.01$). The contribution of seasonal (5.3%, $F_{1;95} = 5.9, p < 0.05$) and annual (5.2%, $F_{4;95} = 2.8, p < 0.05$) variability is significantly lower. The said factors taken together account for up to 48.2% of the total variance.

Four regression dependences of the number of burrows on the source of pollution were estimated for each region, month, and year of study (y = const, linear, logarithmic, and logistic) using the Akaike information criterion (Table 1). A clear logarithmic dependence was recorded only near the MUCS during the autumn period; in spring, the number of burrows is low at all sites, regardless of the pollution level. In the vicinity of the KCS, there was no relationship between the number of burrows and the distance to the smelter

Table 1. Dependence of the number of mole burrows (y) on distance to pollution source (x)

Year	Month	MUCS				KCS			
		model	w	w_i/w_0	R^2	model	w	w_i/w_0	R^2
2007	May	$y = \text{const}$	0.667	1	0	–	–	–	–
	October	$y = a + b\lg(x)$	0.666	44	0.85***	–	–	–	–
2008	May	$y = \text{const}$	0.536	1	0	–	–	–	–
	October	$y = a + b\lg(x)$	0.677	7	0.62***	–	–	–	–
2009	May	$y = \text{const}$	0.762	1	0	$y = \text{const}$	0.896	1	0
	October	$y = \text{const}$	0.885	1	0	$y = \text{const}$	0.863	1	0
2010	May	$y = \text{const}$	0.442	1	0	$y = \text{const}$	0.538	1	0
	October	$y = a + b\lg(x)$	0.431	1.3	0.54**	$y = a + b\lg(x)$	0.501	4	0.70**
2011	October	$y = a + b\lg(x)$	0.711	15	0.88**	–	–	–	–
All censuses		$y = a + b\lg(x)$	0.956	6.4×10^5	0.37***	$y = \text{const}$	0.896	1	0

w is model weight by Akaike's information criterion (CAIC); w_i/w_0 is the ratio between weights of the most successful model and y = const; R_2 is the determination coefficient; asterisks indicate that the regression equation is statistically significant at ** $p < 0.01$ or *** $p < 0.001$; (–) no data available.

or it was weak due to few burrows at certain background sites.

There are modifications of the route census method based on the use of conversion factors for calculating the abundance. To convert the number of burrows into the number of moles, the results of route census are multiplied by coefficients—fixed (Zharkov, 1952) or recalculated in each case based on the average number of animals captured in one burrow (Deparma, 1951; Metodicheskie ukazaniya, 1988). Thus, I.V. Zharkov (1952) assumed that about four moles can be caught in one burrow. However, as is seen from Table 2, the number of moles using the same main burrow can vary depending on the month ($F_{2;94} = 18.98$, $p < 0.001$) and year ($F_{1;94} = 19.89$, $p < 0.001$). On the other hand, this parameter was the same in different zones of toxic load ($F_{1;94} = 1.73$, $p = 0.19$) and changed asynchronously in the studied time periods. Differences between years were significant only for the number of moles in July, i.e., when young of the year leave the nest and the number of recorded moles depends not only on their abundance but rather on the activity and phase of migration. If July is excluded from the analysis, the effect of year becomes insignificant ($F_{1;52} = 0.91$, $p = 0.35$).

Therefore, the number of moles using the same burrow is mainly determined by the month in which they are counted. After recalculation in terms of abundance and season constituent and repeated analysis, the impact of the seasonal constituent (22.2% of dispersion, $F_{1;95} = 24.9$, $p < 0.0001$) on changes in the abundance of moles increases, the influence of a particular zone (16.9%, $F_{1;95} = 20.1$, $p < 0.0001$) and smelter location (12.6%, $F_{1;95} = 9.5$, $p < 0.01$) decreases insignificantly, and the year produces no effect.

DISCUSSION

It was found that the abundance of *T. europaea* in the background territories of the Middle and Southern Urals is low: about seven and two burrows per kilometer, respectively. According to quality evaluation of mole habitats in northwestern Russia (Rusakov, 1965), favorable habitats are those where there are more than 15 burrows per kilometer; five to ten burrows are indicative of satisfactory habitats, and less than five burrows. of unfavorable habitats. Satisfactory habitats are highly dense coniferous–deciduous forests. Unfavorable habitats are coniferous (spruce and pine) forests with various stand densities. These forest types (birch, spruce, and pine) are dominant in the study area. Thus, the abundance of moles is low, compared to that in European Russia. However, according to the commercial stock data, Chelyabinsk oblast used to lead in this respect: from 100 to 2350 mole pelts were obtained annually in 1935 to 1990 (Latyushkin and Shapkin, 1992). The inconsistency between the low abundance of *T. europaea* in 2009–2010 and its large-scale captures in the past can be attributed to occasional severe winters and summer droughts. It is known that the abundance of moles in the Southern Urals varies greatly due to the high freezing of the soil in some winters (Kirikov, 1946). Food resources for moles can undergo considerable changes caused by summer droughts: earthworms become less frequent in

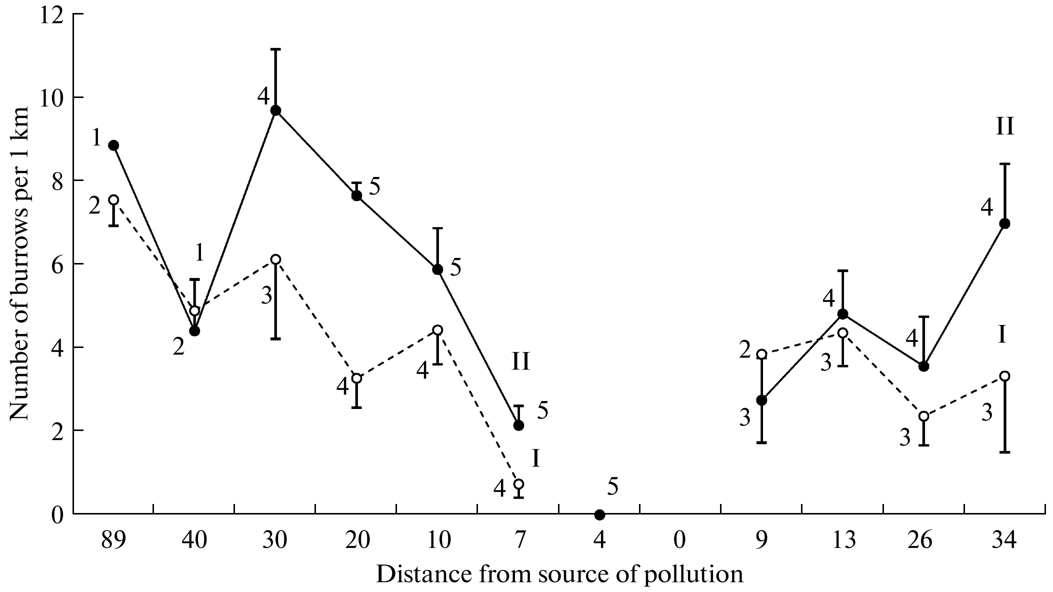

Fig. 3. Number of inhabited burrows in western (left) and southern (right) directions from the MUCS during (I) spring and (II) autumn periods. Mean values with standard errors (error bars) are presented. Numerals near dots show the number of observation years.

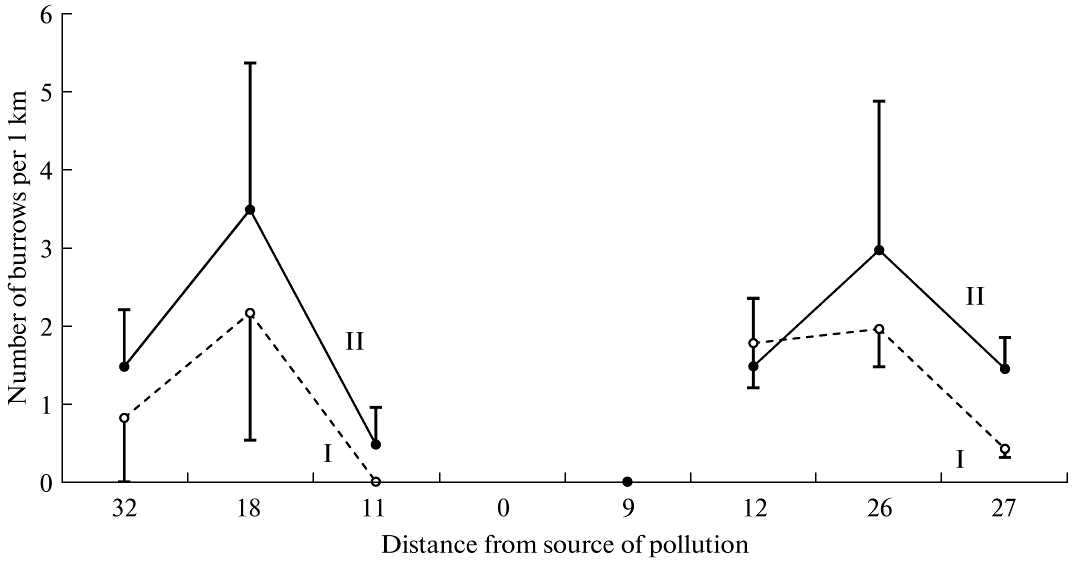

Fig. 4. Number of inhabited burrows in northern (left) and southern (right) directions from the KCS during (I) spring and (II) autumn periods. Mean values with standard errors (error bars) for two observation years are shown.

their diet, while the proportion of insects becomes higher, thereby increasing parasite infestation rates of moles (Shaposhnikov, 1946).

The number of mole burrows was determined by toxic load zone, area of study, and season and year in which they were counted. The study area has a significant influence, because it is characterized by climatic and biotopic variations. In addition to those considered in this work, there were other factors that were not covered. For example, the number of mole burrows was low in some background territories. This can be explained by the local soil properties (high density, rockiness), making it hard to dig through, or by the low abundance of moles due to lack of earthworms

Table 2. Number of moles using the same burrow depending on year, month, and toxic load zone (combined data on the two copper smelters)

Year	Month	*n*	Number of moles in one burrow		
			background	buffer	mean value
2007	May	7	1.0 ± 0 (1–1)	1.5 ± 0.3 (1–2)	1.3 ± 0.2
	July	16	4.1 ± 0.8 (2–9)	5.7 ± 0.7 (3–8)	4.8 ± 0.6
	October	29	2.6 ± 0.4 (1–6)	2.1 ± 0.3 (1–5)	2.3 ± 0.3
2009	May	10	1.0 ± 0 (1–1)	1.5 ± 0.2 (1–2)	1.3 ± 0.2
	July	30	1.8 ± 0.2 (1–4)	1.7 ± 0.2 (1–3)	1.7 ± 0.2
	October	14	1.6 ± 0.3 (1–3)	1.8 ± 0.2 (1–2)	1.7 ± 0.2
2007 + 2009	May	17	1.0 ± 0	1.5 ± 0.2	1.3 ± 0.1
	July	46	2.7 ± 0.4	3.0 ± 0.5	2.8 ± 0.3
	October	43	2.2 ± 0.3	2.1± 0.2	2.1 ± 0.2

Data are presented as mean ± error, with minimum and maximum values in parentheses; *n* is number of burrows in which animals were caught.

unrelated to soil pollution. Concerning the relationship between the number of burrows to the abundance of moles, let us emphasize that fixed coefficients are not desirable because of seasonal and yearly variations. When studying the effect of pollution on the abundance of moles, this parameter can be neglected to simplify the procedure, because the number of animals captured in one burrow does not depend on the level of pollution.

The abundance of moles is more affected by heavy metals than the abundance of other small-sized mammals. Thus, the impact zones of the MUCS and KCS are each inhabited by eight species of small-sized mammals (Mukhacheva and Davydova, 2012; Mukhacheva et al., 2012). The mole forms permanent populations only in a territory that is a buffer for other species. If background sites are favorable for moles, changes in their abundance are described by a logarithmic curve. The abundance of moles near the MUCS and KCS changes unevenly: it can vary within a wide range at background and slightly polluted sites, but the critical level of pollution makes moles move away.

A possible reason for the absence of moles in the vicinity of copper smelters is the direct toxic effect of their emissions. In this case, there should have been serious abnormalities in the animals captured in close proximity to the smelter. However, we showed earlier (Nurtdinova, 2010; Nesterkova et al., 2012) that moles from the background and buffer zones are characterized by the same complex of morphophysiological and hematological features.

Another possible reason is the indirect effect of changes in the environment, mainly in food resources. Earthworms are the main food for moles; larvae of coleopterans and dipterans are consumed less frequently and in smaller amounts (Godfrey and Crowcroft, 1960; Ivanter, 1968). Having a high metabolic rate, *T. europaea* consumes about 50 g of food per day (Pavlinin, 1959), which amounts to about 18 kg wet weight of earthworms per year. Therefore, the presence of moles in a certain biotope is determined primarily by the availability of earthworms. In fact, researchers who studied the biotopic distribution of moles (Ivanter, 1968; Rusakov, 1965) regularly found that their abundance was strongly correlated with the abundance of soil macrofauna.

The study of earthworms near the MUCS (Vorobeichik, 1998) showed that their abundance sharply decreases as the toxic load increases. When some critical level is reached, they disappear. In the impact zone of the MUCS, the total density of soil macrofauna is 8–60 times lower. Earthworms are not found at a distance closer than 3.8 km from the smelter. Thus, this territory can be considered an "earthworm desert." At a distance of 4–6 km from the smelter, in spruce–fir forests, the density of earthworms is 39.5 ind/m^2 (Vorobeichik et al., 2012). Here, molehills are confined to river floodplains and vegetable gardens of human settlements. It can be assumed that earthworms in these biotopes are more abundant, because their resistance to heavy metals is significantly higher in soils rich in organic matter (Streit and Jaggy, 1983). In forest biotopes, moles are found at a distance of at least 6–7 km from the MUCS, where the abundance of earthworms is close to its background values (212.5 and 261.5 ind/m^2, respectively) (Vorobeichik et al., 2012), even though heavy metals are still detected in high concentrations. In contrast to rodents occupying microsites in the impact zone, which are favorable for them (Mukhacheva et al., 2012), moles disappear completely in the heavily polluted zone, even if its periphery is still occasionally inhabited by earthworms.

The interrelated spatial distribution of earthworms and moles near the MUCS during the mid-1990s (Fig. 5) was demonstrated by Vorobeichik (2003). When comparing the "mole desert" zone to our data,

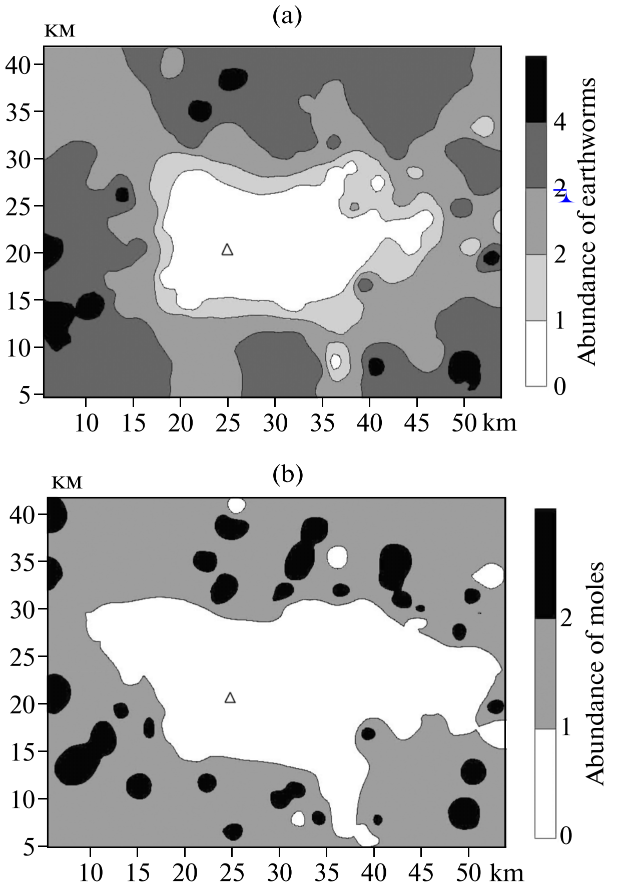

Fig. 5. Spatial distribution of (a) earthworms and (b) moles near the MUCS in 1995–1999 according to Vorobeichik (2003). Grades of abundance for earthworms: (0) absent, (2) medium, (3) high, (4) very high; for moles: (0) absent, (1) medium, (2) high; Δ is MUCS.

a significant reduction in it can be pointed out (from 650 to 90–100 km^2). This can be caused by a reduction in emissions from the MUCS over the recent decade. It still has to be taken into account that the work of E.L. Vorobeichik is based on spot estimations of the number of molehills and that they were counted only in forest biotopes meeting certain requirements (trees of dominant species at least 60 years old, no less than 20% of birch in the tree stand, etc.).

Therefore, industrial pollution of the environment by heavy metals and sulfur dioxide has a very negative effect on the abundance of *T. europaea*. This species disappears completely from heavily polluted areas. Moreover, its abundance in moderately polluted areas decreases 1.5–1.8 times. The main reason for the disappearance of moles is the reduction of their food resources. Moles are as sensitive to heavy metals as lichens and even more sensitive than earthworms, being superior to any other small mammals in this respect. Thus, the absence of moles can be regarded an indicator of heavy industrial pollution.

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