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SHORT COMMUNICATIONS

Impact of Industrial Pollution on the Age Structure of European Mole (*Talpa europaea* L.) Populations

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Analysis of age structure is a classical field in population ecology. Such an analysis in mammals has mainly been performed for game species. Much attention has been devoted to shifts in age structure under the impact of adverse factors such as overhunting [1, 2], selective hunting [3, 4], and climatic changes [5, 6].

Studies on the age structure of populations exposed to local industrial pollution are relatively few and deal mainly with lichens [7], plants [8, 9], fishes [10], birds [11–14], and short-lived small mammal species [15, 16]. The population demography of long-lived mammals has been studied only under conditions of regional pollution [17, 18]. Relevant information on large mammals living near industrial facilities is lacking, because these animals are highly mobile and have large home ranges, which makes it difficult to study the impact from local pollution sources on their populations. The European mole (*Talpa europaea* L.) is a long-lived species, despite a small body size [19, 20], which makes it a convenient object for the analysis of age population structure. On the other hand, this species is similar to other insectivores in having a high capacity for heavy metal accumulation, which implies the possibility of toxic effects. As shown in our previous study [21], the diet of moles in moderately polluted areas contains even greater amounts of cadmium than the diet of rodents in strongly polluted areas. Cadmium in moles is not removed through the digestive tract and accumulates in the liver to very high concentrations. Cadmium accumulation is a lifelong process [21], which suggests an increasing toxic load on older animals and the possibility of changes in the age structure of populations in polluted areas.

The purpose of this study was to estimate the impact of industrial pollution with heavy metals on the age structure of mole population. The hypothesis to test was that the proportion of young of the year in polluted areas is increased and that of elderly animals is reduced, with a consequent decrease in the population average age.

Studies were performed in the region exposed to atmospheric emissions from the Middle Ural Copper Smelter (MUCS) located in the vicinity of Revda, Sverdlovsk oblast. The main components of emissions are sulfur dioxide and polymetallic dust Cu, Pb, Zn, Cd, Fe, and As. Trends in the transformation of different components of forest ecosystems and the levels of land pollution in this region were described in detail previously [16, 22–24].

Test plots were located west and south of the MUCS (WP and SP, respectively). The area within a radius of 5 km around it is not inhabited by moles because of the absence of earthworms, their main food [24]. Stable mole populations in forest biotopes have been found only at distances of no less than 6–7 km from the MUCS [21]. Depending on the pollution level, two zones were distinguished where the plots were established at different distances from the MUCS: the background zone (WP: 30 and 20 km; SP, 34 and 26 km) and the polluted zone (WP: 10 and 7 km; SP: 13 and 9 km) [25]. Fir–spruce and mixed forests prevailed west of the MUCS, and pine forests prevailed south of it. Moles were trapped with snap and live traps set in active mole runnels across tracks (two to four traps per tunnel). Trapping was carried out in July and October of 2007–2011 (a total effort of 1820 trap–days). The age structure of population was analyzed using pooled data on summer and autumn catches (a total of 399 animals).

Trapped animals were examined to determine their sex and reproductive status. European moles reach sexual maturity at an age of 10–11 months, and individuals aged 1–2 months clearly differ from adults in the degree of reproductive development, body weight, and fur color. However, unlike in European populations of this species [26, 27], young moles in the Middle Urals haver no dark pigment on paws: their palms are light-colored, as in adults, even at the very onset of dispersal from nests.

The exact age of all adult moles and of males older than 5 months was determined from annual growth rings in cross sections of the mandible and M_3 tooth [28] stained with Mayer's hematoxylin and embedded in glycerol. A total of 177 histological preparations were examined. For an integral characterization of the age composition of samples, average age was used as an informative parameter for analyzing age distributions [19, 29]. To level off the effect of trapping dates and different contributions from summer and autumn catches, analysis was performed for age groups, instead of using the exact age in months. Young of the year aged 1.5–2 months in summer and 4.5–5 months in autumn comprised group 0+; yearlings (13.5–17 months), group 1+; 2-year-olds (25.5–29 months), group 2+; etc.

The results were processed statistically in Statistica v.8.0 (StatSoft Inc.) The significance of differences between the samples was evaluated by two-way ANOVA; the dependence between relative animal abundance and average age, by Spearman's correlation test. Cumulative curves for age groups (individual rarefaction) were plotted with PAST v.1.92.

The oldest age of a mole recorded in the study area was 6 years, which is in line with data on the maximum life span of this species in other regions [19, 20, 30, 31]. Contrary to expectation, the maximum life span of moles in the plots proved to be independent of pollution level and varied widely (from 1 to 6 years) in both background and polluted zones (Table 1). The total sample average age did not differ significantly either between the zones ($F(1, 4) = 0.4$, $p = 0.57$) (Fig. 1a) or between the plots located in different directions from the MUCS ($F(1, 4) = 3.1$, $p = 0.15$). The effect of zone × direction interaction also lacked statistical significance ($F(1, 4) = 0.6$, $p = 0.48$). Similar results were obtained for the average age of adult, sexually mature moles: $F(1, 4) = 1.2$, $p = 0.34$ for the effect of zone and $F(1, 4) = 6.3$, $p = 0.07$ for the effect of direction. The proportions of young of the year also did not differ significantly between the zones ($F(1, 4) = 0.2$, $p = 0.65$) or depending on the direction from the MUCS ($F(1, 4) = 0.2$, $p = 0.68$). It should be noted that a long life span of moles was recorded in the plot located 10 km west of the MUCS, which was justly included in the polluted zone: Cd concentrations in the liver of adult animals proved to be as high as in the plot closest to the polluter (at 7 km from it) (Table 1).

In contrast to the above situation, the age population structure was found to differ between the plots with high abundance (34, 30, 20, and 10 km) and with low abundance of moles (26, 13, 9, and 7 km) (Fig. 1b). The coefficient of correlation between the average age of adult moles and relative animal abundance was 0.79 ($p < 0.05$, $n = 8$). This may be partly due to a low probability of trapping old animals, since they are few in numbers. According to Deparma [32], the minimum sample size that may adequately reflect the actual age composition of a mole population is 40–45 animals. Nevertheless, the observed differences cannot be explained by the small sample size alone. The cumulative curves for areas with high and low animal abundance clearly differ from each other (Fig. 1b). Their inflection to a plateau corresponds to different age groups: at a fixed abundance (e.g., 50 ind.), the maximum age observed in the sample is 4+ vs. 2+, respectively.

This may be evidence that, in areas exposed to industrial pollution, biotopes with suitable soil and abundant food resources provide conditions under which moles can not only reach high abundance but also prolong their life span; in biotopes poor in food resources, conversely, both the abundance and life span of moles are relatively low. Such a trend is known for natural biotopes [19]. In other words, if heavy metal concentrations in the soil are not very high and allow earthworms to survive in large numbers, then metal accumulation in moles has no effect on their life span.

A distinct shift in the age spectrum of local populations toward younger age groups upon an increase in toxic load has been observed in lichens [7], plants [8, 9], freshwater fishes [10], and birds [11, 12]. In a lake population of common whitefish *Coregonus lavaretus,* for example, the most prevalent age group prior to the onset of wastewater discharge into the lake was 7–9 years, but 3- to 5-year-old fish gained prevalence after 80-year pollution exposure [10]. An increased mortality of old females and an unusually high proportion of young birds were observed in the snow quail population of a region exposed to cadmium pollution from mining activities [12]. A pied flycatcher population in the vicinity of a copper smelter was found to contain an increased proportion of young reproductive females [11]. The authors attributed these findings to an indirect effect of pollution, which resulted in more severe competition for space in clean areas and thereby forced young females to nest under unfavorable conditions. In subsequent studies of the same authors, no changes in the age population structure were reported either for the pied flycatcher [14], or for the great tit [13].

The influence of pollution on the age structure of mammal populations has been studied only for short-lived murine rodents. In the bank vole, for example, young of the year were found to be more sensitive to pollution with emissions from metallurgical processes, compared to overwintered animals [15, 16]. However, specific features of the life cycle in short-lived species do not allow direct extrapolation of the results to species with a life span of over 2 years.

Thus, heavy metal pollution of the environment in the region exposed to emissions from a copper smelter exerts its effect on the life span of moles only indirectly, through the impairment of habitat quality. The age structure of mole populations differs between areas with high and low abundance of these animals,

Table 1. Age structure of populations (%), average age, relative abundance, and Cd concentrations in the liver of European moles in the pollution gradient

Parameter		West of polluter				South of polluter			
		background zone		polluted zone		background zone		polluted zone	
		30 km	20 km	10 km	7 km	34 km	26 km	13 km	9 km
Age group	0+	70.0	69.7	72.4	80.5	74.3	85.7	66.7	72.7
	1+	10.0	5.6	8.6	7.3	14.3	10.7	23.3	27.3
	2+	15.0	13.5	7.6	12.2	5.7	3.6	10.0	0
	3+	3.3	6.7	6.7	0*	0	0	0	0
	4+	1.7	2.2	3.8	0	5.7	0	0	0
	5+	0	1.1	1.0	0	0	0	0	0
	6+	0	1.1	0	0	0	0	0	0
Number of trapped animals		60	89	105	41	35	28	30	11
Overall average age, years		0.57 ± 0.13	0.74 ± 0.14	0.64 ± 0.12	0.32 ± 0.11	0.49 ± 0.18	0.18 ± 0.09	0.43 ± 0.12	0.27 ± 0.14
Average age of adult animals, years		1.89 ± 0.20	2.44 ± 0.23	2.31 ± 0.22	1.63 ± 0.18	1.89 ± 0.42	1.25 ± 0.25	1.30 ± 0.15	1.00
Abundance[1], tunnels/km		9.7 ± 1.5	7.8 ± 0.4	5.9 ± 1.0	2.1 ± 0.5	7.0 ± 1.4	3.6 ± 1.19	4.8 ± 1.0	2.7 ± 1.0
Cd in the liver of adult animals[2], μg/g		103.0 ± 8.4	89.3 ± 8.0	309.3 ± 33.9	325.0 ± 40.5	–	–	–	–

* Three-year-old animals recorded in spring, means with standard errors. [1]According to [25]. [2]According to [21].

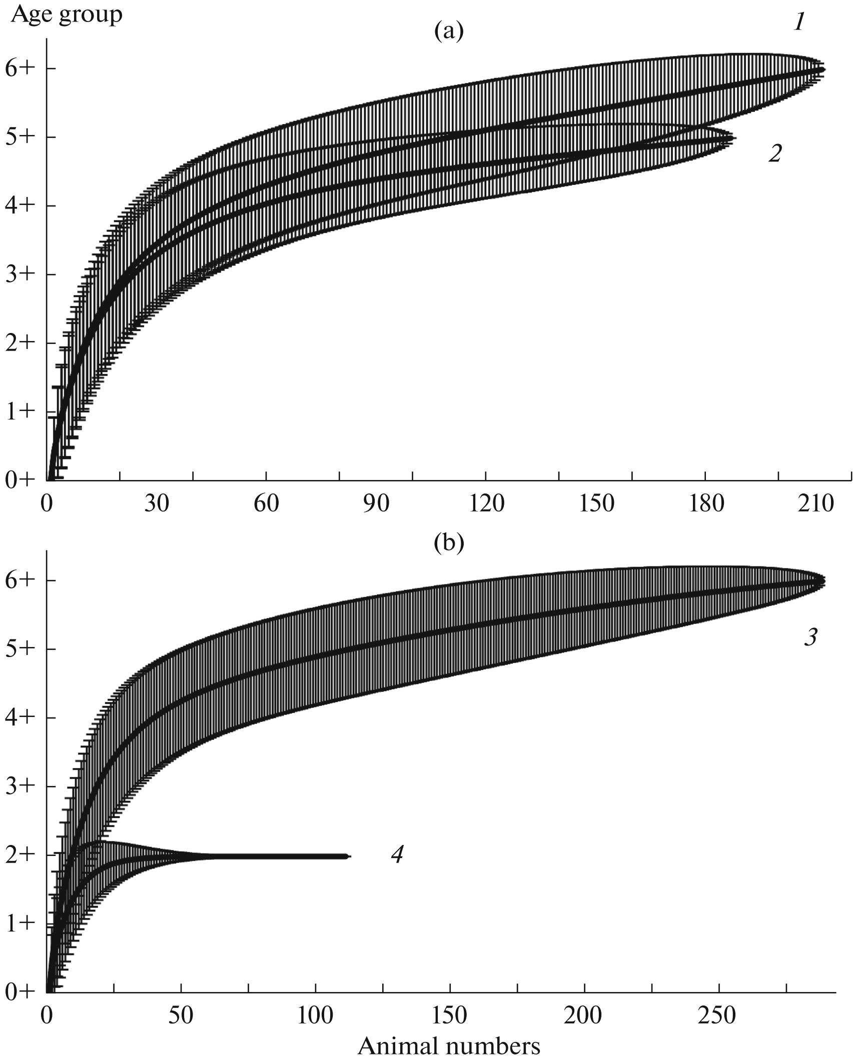

Fig. 1. Cumulative curves for the age groups of European moles in zones (a) with different pollution levels (*1*, background zone; *2*, polluted zone) and (b) with different levels of relative abundance (*3*, high abundance; *4*, low abundance). Error bars show standard deviations.

while high cadmium concentrations themselves in the mole body have no influence on its life span.

In general, the effect of industrial pollution on the age structure of animal populations has not been studied sufficiently. The results obtained are often contradictory, and the universality of conclusions is limited due to specific features of the objects studied, which implies the necessity of further research in this field.

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COMPLIANCE WITH ETHICAL STANDARDS

All applicable international, national, and institutional guidelines for the care and use of animals were followed.

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