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GENERAL BIOLOGY

The Role of Heterogeneity of the Environment in Preservation of the Diversity of Small Mammals under the Conditions of Strong Industrial Pollution

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The reaction of communities of small mammals to the industrial impact, as well as that of other biotic components, are traditionally studied by comparing the population within the limits of some variant of a biotope presented in the entire load gradient that is most often dominant in the region. In the case of this approach, clear reduction in the diversity and abundance is usually ecorded when the source of industrial emissions is approached. The picture is particularly illustrative for non-ferrous metallurgy enterprises, in whose immediate proximity the population of small mammals decreases by a factor of 4–18 with respect to the background level, and species richness falls from 10–12 to 1–2 species, or this group completely disappears [1–5].

However, the territories under investigation actually represent a mosaic of various biotopes. The anthropogenic impact not only results in habitat fragmentation, but also decreases the quality of areas (primarily, the food supply and habitat quality), strengthening the heterogeneity of the habitat of small mammals. Small mammals are known to be able to form more or less isolated populations [6]. This being the case, the level of population in low-quality habitats may not reach the values that ensure the sustainable existence for a species. On the other hand, under low-quality habitat conditions, the properties facilitating the settlement of anthropogenic habitats manifest themselves: the spectrum of forage changes, the melioration activity grows, behavior becomes more plastic [7].

The role played by biotope fragmentation under the anthropogenic impact (that is not related to pollution) in the formation of the population of small mammals has been investigated in tropical forests [6, 8] and agricultural landscapes [9, 10]. As for the effect of industrial pollution, it has not been studied in this aspect.

Will our ideas of the effect of industrial pollution on the population of small mammals change if the diversity of habitats is taken into consideration? Does the heterogeneity of the environment permit a wide set of species to exist in impact territories? The goal of this work is to attempt to find answers to these questions. The initial hypothesis was as follows: if an industrial impact is intense, the convergence of communities takes place; i.e., a limited set of the most pollution-resistant species lives in an impact territory, irrespective of the existent diversity of habitats; correspondingly, the initially heterogeneous population of small mammals becomes more homogenous. This hypothesis reformulated in terms of change in β-diversity is to suppose that it decreases as pollution grows.

The investigations were performed in the impact region of the Karabash Copper Smelter (KCS) located 90 km northwest of Chelyabinsk (the Southern Urals) and has been operating since 1910. The KCS is one of the largest Russia's point sources of environment pollution with heavy metals and sulphur dioxide. An industrial barren has been formed in its immediate proximity; this is a specific "moonscape" almost deprived of vegetation. The detailed characteristic of the region was given in [5, 11].

Catches were made in two areas: the zone exposed to the intense industrial impact (the impact zone, 0.5–5 km from the factory; an area of about 30 km^2 was examined) or weakly polluted zone (the background zone, 20–25 km south of the factory, about 50 km^2). Nine variants of biotopes differing in the location in the terrain and type of vegetation were distinguished within the limits of each zone; they were typical of one zone and had an "analogue" in another one (Table 1).

Small mammals were caught in July 2011 in all biotopes simultaneously within the limits of the zone.

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Table 1. Biotope variants, number of caught individuals (*N*) and detected species (*S*) in the background and impact zones

Code of a biotope	Background zone			Impact zone		
	biotope	*N*	*S*	biotope	*N*	*S*
A	Pine forest mixed with birch-trees*	5 (0–3)	2 (0–1)	–	–	–
B	Pine forest mixed with birch-trees**	5 (0–4)	3 (0–3)	Pine forest mixed with birch-trees**	6 (0–4)	2 (0–2)
C	Grassy woodreed pine forest**	6 (0–5)	2 (0–2)	Pine forest with dead field layer**	4 (0–3)	2 (0–2)
D	Anthropogenically transformed birch forest with an adventive weed and recreation load**	2 (0–2)	1 (0–1)	Birch forest with dead field layer**	0	0
E	Near-stream areas of a forest with the dominance of willow	18 (3–9)	3 (1–3)	Near-stream areas of a forest with the dominance of willow	11 (2–5)	2 (1–2)
F	Floodplain willow forest	18 (1–11)	3 (1–2)	Flood mowed meadow	10 (2–4)	4 (1–3)
G	Bogged lake shore with the dominance of reed	6 (1–3)	4 (1–2)	Bogged lake shore with the dominance of reed	3 (0–2)	2 (0–2)
H	Upland mowed meadow	17 (1–10)	1	Domestic waste dump (non-operating)	0	0
I	Domestic waste dump (operating)	33 (6–17)	3 (2–3)	Domestic waste dump (operating)	13 (3–6)	1
K	–	–	–	Anthropogenic waste ground	0	0

Note: Landscape elements: * eluvial (the top of the slope); ** transit (the medium part of the slope); dashes: the accounting was not performed owing to the absence of the variant of a biotope in an area; the minimum and maximum values registered for the line are presented in round brackets.

Three lines of snap-traps were installed in each variant of a biotope (the beginning and direction were random; 10 traps were placed at intervals of 5–7 m, a single check was performed every day during three days; bread saturated with vegetable oil was used as a bait); the lines were at a distance of no less than 100 m from each other. In total, 1620 trap-nights were checked (54 lines); 157 individuals were caught. To characterize the population of small mammals, two spatial scales were used: a microscale (a line was an observational unit; an area of catch was about 0.1 ha) and mesoscale (a biotope was an observational unit, an area of catch was about 1 ha).

The inventory (α and γ) and differentiation (β) diversities were estimated. The β-diversity was characterized using the following: (1) the Whittaker index (the ratio of the γ-diversity to the α-diversity); (2) the average similarity for a set of lines and biotopes in all combinations (the Czekanovskii–Sorensen index with allowance for species richness; since this index does not include negative coincidences, the similarity of two observational units, where there were no small mammals, was taken to be zero); (3) the rates of plateau achievement by the cumulative curves describing the growth in the number of species according to the growth in the number of individuals/observational units) (the curves were approximated by the Michaelis–Menten equation using nonlinear estimation; the rate constant is interpreted as the number of individuals/observational units that reveals half of all species in the area; i.e., it is the higher, the greater is the β-diversity. The calculations were made in the EstimateS 8.2 software. The confidence intervals of the parameters were determined using BCA-bootstrap (1000 replications; RSXL 4.0 software). When making pairwise comparisons, a difference was considered to be significant if 95% confidence intervals did not overlap.

In total, ten species of small mammals were detected: in the background zone, 7; in the impact zone, 8. The following species were caught in the background and impact zone, respectively: *Sylvaemus uralensis* (52/19), *Clethrionomys glareolus* (17/3), *Cl. rutilus* (1/1), *Microtus arvalis* (32/1); *M. agrestis* (2/0), *M. oeconomus* (5/7), *Mus musculus* (0/14), *Arvicola terrestris* (0/1), *Sorex araneus* (0/1); *S. minutus* (1/0). The maximum population was found in a domestic waste dump (I) and in near-water biotopes (E, F), and the minimum one was found in a birch forest (D). In the impact zone, there were no small mammals in three biotopes—D, H, K (Table 1).

The growth of pollution results in a decrease in the α-diversity by a factor of 1.6–1.7 on both the micro- and mesoscales (Table 2). However, the overlapping of confidence intervals suggests randomness of this effect. Moreover, owing to the decrease in richness by a factor of 2.3 with respect to the background value (the effect is significant), an interpolated (i.e., reduced

Table 2. Parameters of the diversity of small mammals communities in the background and impact zones

Parameter	Area	
	background	impact
Observed γ-diversity, number of individuals	7	8
Number of caught individuals	110	47
Relative abundance (number of individuals per 100 trap-nights	13.6 [9.1–19.3]	5.8 [3.6–8.1]
	Microscale	
Specific saturation (α-diversity), number of individuals per line	1.33 [1.00–1.63]	0.85 [0.52–1.19]
Interpolated diversity, number of species per 40 individuals)	4.99 [2.83–7.17]	7.39 [3.78–11.00]
Whittaker index	5.25 [4.50–7.27]	9.39 [8.00–13.48]
Czekanovski–Sorensen index (average similarity, $k = 351$)	0.17 [0.14–0.19]	0.07 [0.05–0.10]
Michaelis-Menten constant (± error):		
individuals	29.95 ± 0.95	28.40 ± 1.05
lines	6.62 ± 0.23	16.32 ± 0.60
	Mesoscale	
Specific saturation (α-diversity), number of individuals per line	2.44 [1.78–2.89]	1.44 [0.67–2.22]
Whittaker index	2.86 [2.42–3.91]	5.54 [4.80–9.00]
Czekanovski–Sorensen index (average similarity, $k = 36$)	0.32 [0.25–0.40]	0.09 [0.05–0.16]
Michaelis-Menten constant (± error):		
individuals	35.48 ± 0.70	79.12 ± 16.02
biotopes	2.90 ± 0.06	15.16 ± 3.07

Note: The 95% confidence interval is in square brackets; *k* is the number of compared pairs.

to an equal number) number of species in the impact zone even grows (although confidence intervals are also overlapped). In other words, it is possible to suppose that, if sampling effort is increased, the diversity in the impact zone will be higher than in the background one. The possibility of the origin of such "paradoxes" during the transition to species density (the number of species per unit area) to species richness itself was discussed in [12].

Since the γ-diversity remains permanent, the Whittaker index in the impact territory is higher compared to the background by a factor of almost two (the effect is significant). The average similarity of the population of small mammals in the impact zone is lower than in the background zone by a factor of 2.4–3.6, which also suggests a significant growth of the β-diversity (the effect is significant). Similar differences were also found for the rate of plateauing of the cumulative curves: the sampling effort required to reveal a half of all species in the impact zone is greater than for the background zone by a factor of 2.5–5.2.

Upon transition from the microscale to the mesoscale, the differences between the pollution zones in the indicators of the β-diversity grow. This is due to a more regular biotopic distribution of different species of small mammals in the impact zone: analogous biotopes are characterized here by more "severe" conditions that restrict the presence of animals to a certain extent. For example, in the impact zone, six of eight species (from the genera *Clethrionomys, Microtus,* and *Sorex*) were found in only one biotope, *M. musculus* was found in two neighboring biotopes (C, I), and *S. uralensis* was found in five biotopes (B, C, E, F, G). It is possible to suppose that *S. urlensis* and *M. musculus* get some advantage in the settlement in impact territories owing to a greater plasticity.

Consequently, both questions formulated at the beginning of the article can be answered positively. The allowance for the existent diversity of habitats has led to principally different conclusions as regards the reaction of the population of small mammals to pollution in comparison with the traditional approach. If, for example, we had compared the population of only forest biotopes, a quite traditional conclusion about the disappearance of small mammals in the immediate proximity from an emission source would have been made. This is the conclusion that we had earlier come to for the same region [5]. In this study, we have no grounds to assert that the γ-diversity decreases in the polluted territory.

Our initial hypothesis about the convergence of population in the pollution gradient has not been proved either: a strong external impact is made by the growth in the β-diversity, which can be interpreted as the divergence of communities of small mammals. A similar result has earlier been obtained for vegetation [13].

Thus, the heterogeneity of the environment plays the key role in the preservation of the diversity of small mammals under the conditions of a strong anthropogenic impact. In the impact territory, extremely degraded, almost lifeless areas neighbor and alternate with relatively intact biotopes that ensure the existence for a wide spectrum of species, although their population is decreased compared to the background conditions. Consequently, in most cases, the "true extinction" of some species under the influence of pollution should not be spoken about: owing to the low population and confinement to the intact "fragments of suitable habitats," the probability of discovering it under the standard catching scheme can be very low. Therefore, the absence of a species in the impact territory is more correct to be interpreted as its not having been found, if there are no valid proofs of another situation.

The reduction in diversity is thought to be the most "typical' reaction of biota to industrial pollution [11]. Our results demonstrate the excessive simplicity of this point of view (at least, for communities of small mammals) that can be a consequence of both the insufficient allowance for the actual diversity of habitats and insufficient value of a sampling effort.

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