ISSN 1995-4255, Contemporary Problems of Ecology, 2008, Vol. 1, No. 1, pp. 104–110. © Pleiades Publishing, Ltd., 2008.
Original Russian Text © S.D. Seredyuk, 2006, published in Sibirskii Ekologicheskii Zhurnal, 2006, Vol. 13, No. 5, pp. 639–647.

Structure of Communities of Elateridae Family of Subzones of Middle and Southern Taiga under Technological Environmental Impact

S. D. Seredyuk
Institute of Ecology of Plants and Animals, Uralian Division of the RAS, ul. Vos'mogo Marta 202,
Yekaterinburg, 620144, Russia

Abstract—The structure of communities of Elateridae was investigated in the regions affected by copper-smelting plants in the areas located in different ecological and geographical subzones of the taiga zone. A comparison of emission sources of the same kind in forest ecosystems of different taiga subzones allowed us to analyze changes in the structural arrangement of Elateridae complexes along the gradient of chemical pollution, to reveal adaptive mechanisms of Elateridae complexes to high industrially generated load, to observe general and specific zonal features of the reaction of click beetles to this kind of anthropogenic action. We succeeded in demonstrating that the latitudinal zoning is a base of the hierarchy of the factors that determine the structural divergence of the Elateridae communities. The hydrothermal regime of the middle taiga subzone under anthropogenic modification provides more favorable conditions for mesophile groups of pedobionts in comparison with the southern taiga.

DOI: 10.1134/S1995425508010116

The anthropogenic transformation of the biosphere has reached the global scale and touches to greater or lesser degree all ecosystems, which in the majority of cases leads to structural and functional changes of animal communities of various systematic categories [1–3]. Pedobionts are among the first to react to the anthropogenic changes of the environment. The distinct reactions of communities of soil invertebrates to anthropogenic disturbances are often seen much earlier than the changes of chemical and physical parameters of soil determined by the existing methods [4, 5]. The structure of communities of soil-dwelling animals is an informative test-object for indication and classification of landscapes, because it reflects the changes of a wide range of soil-ecological conditions not only in the geographical aspect but also under the influence of anthropogenic factors. The response of soil invertebrates to changes in their environment is realized at the levels of populations and biogeocenoses [6]. Zoodiagnostics testifies to leveling of zonal and type characteristics of soil functioning at certain types of anthropogenic load [7].

Metallurgical works, particularly copper-smelting ones, contribute greatly to the man-induced pollution of the natural environment. The impact of their emission is typically expressed in the aggravated toxic effect of heavy metals, which increase environment acidity. These are the most dangerous atmospheric pollutants, influencing all components of ecosystems. The consequences include changes of water and temperature regime, physical and chemical soil characteristics, carryover of inorganic nutrition elements, and, as a result, transformation of plant communities and change of animal habitat [8, 9]. Different groups of soil mesofauna react differently to pollution, which is related to the peculiarities of their biology and ecology. The most resistant to the man-induced impact are Elateridae. Their larvae preserve in significantly modified habitats, and in some taiga subzones their numbers increase [10–13].

MATERIAL AND METHODS

The studies were carried out in the effective areas of the Krasnoural'sk (middle taiga) and Karabash (southern taiga) copper-smelting plants. Differences in provision of warmth and moisture, along with geomorphology, determine the specific climatic and edaphic characteristics of these two taiga subzones [14]. The middle taiga subzone is characterized by higher values of hydrothermal coefficient, moisture, low total temperature, shorter period with a diurnal air temperature >0, >5, >10 °C (see Fig. 1), more precipitation in comparison with southern taiga territory, according to data provided by Uralgidrometeosluzhba (Ural hydrometeoservice).

The Krasnoural'sk plant has functioned since 1932. Its emissions make up more than 83 thousand tons per year and consist predominantly of sulfurous anhydride (84%), fluoric compounds, CO_2 (1000 tons per year), dust (7250 tons per year), and heavy metals [15]. The Karabash copper-smelting plant has functioned since 1837; the copper-smelting production was expanded in 1903. By 1980 the volume of pollutant emission was more than 210 570 tons per year, including 20 276.5 tons of dust, 184 000 tons of SO_2, and more than 4300

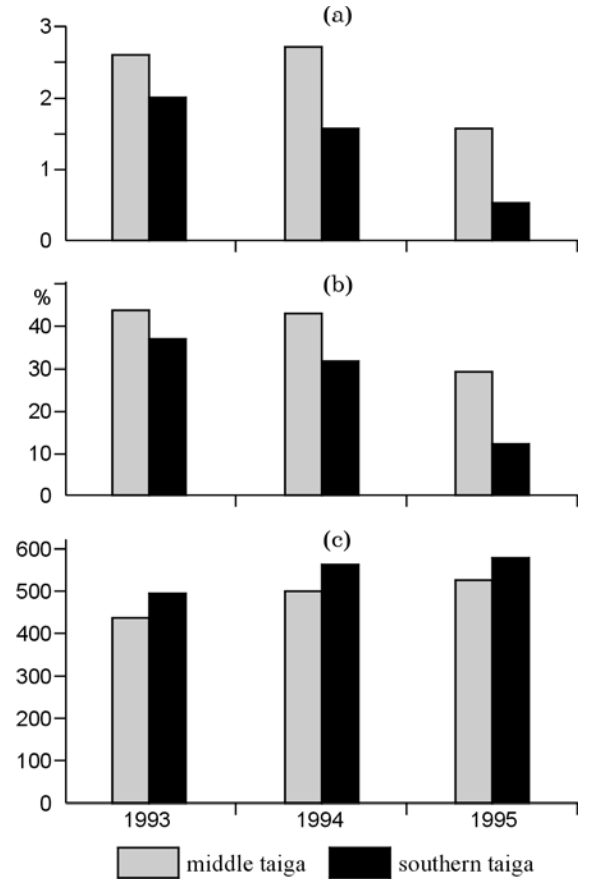

Fig. 1. Differences in provision of the studied territories with warmth and moisture: (a) hydrothermal coefficient (HTC), (b) moisture, (c) number of days with temperature above 0°C.

tons of heavy metals. After the plant was reorganized in 1990, the emissions of pollutants decreased and made up 50 681 tons per year, with sulfurous anhydride (92%), heavy metals, and CO_2 predominating [12].

The constant test areas are chosen in secondary birch forests along the gradient of pollution from herb-grass birch forests with the fully developed level and parceling structure of the background zone through birch forests with thinned ground cover and lesser number of species of grass and dwarf shrub level of a buffer zone to dead-cover birch forests with low fullness and density of stand of impact zone in both taiga subzones. A base for typification is the classic division of transformed territories (see Table 1) in accordance with transformation of landscape, distribution of pollutants in the effective area of emission sources, and degree of transformation of plant communities [15–20]. Near the plants the richness in species of the phytocenoses decreases, illumination changes due to thinning of crown and fall-out in the tree level, moisture lessens and inorganic nutrition is affected as the mechanic composition of soil is broken, the soil becomes more compact, and aeration conditions worsen [17–20].

To collect the field material, a standard method of soil excavations followed by hand sorting was used [21]. The number of the samples, sized 20 × 20 × 25 cm totals to 466, and samples sized 50 × 50 × 20 cm, to 434. The depth of sampling corresponds to the depth of penetration of the majority of soil-dwelling invertebrates (0–25 cm). The data were obtained by collecting and examining 2153 larvae and 297 imagos of click beetles. The domination degree was evaluated using the following scale: dominants, i.e species making up 10% and more of the total number of the animals in a biotope, subdominants — 3–10%, and additional species: recedents — 1–3%, rare — less than 1% [22].

We used a number of indices when studying the structure of Elateridae communities.

Species density: $d = S/\log A$, i. e., ratio of number of species (S) to logarithm of studied area (A) [23].

Shannon index of species diversity: $H' = -Spi \times \ln pi$, where $i = 1, 2, \ldots, S$, S is the number of species; pi is the relative abundance of the i-th species [24].

Uniformity according to Pielow: $E = H'/H_{\max} = H'/\ln S$, where H' is the Shannon index, S is the number of registered species [25].

Margalef index of richness in species: $DMg = (S - 1)/\ln N$, where S is the number of registered species, N is the total number of individuals of all species [26].

Simpson index: $D = 1/\Sigma(n_i / N)^2$, where n_i is the qualitative characteristic of the i-th species on the analyzed area; N is the total of qualitative characteristics on the analyzed area [27].

Berger-Parker index: $d = N_{\max}/N$, where N is the total number of individuals: $N_{\max}$ is the number of individuals of the most abundant species [28].

Zhivotovskii index of diversity: $\mu = (\Sigma\sqrt{pi})^2 = (\sqrt{p1} + \sqrt{p2} + \ldots + \sqrt{pm})^2$, where pi is the share of species.

Share of rare species: $h = 1 - \mu / m$, where μ is the Zhivotovskii index of diversity, m is the number of species.

The faults of Zhivotovskii index are calculated by the formulas: $s\mu = \sqrt{m - \mu} / N$ and $sh = \sqrt{1 - h} / N$, where N is the volume of sampling [29].

Table 1. Typification of the studied territories

Habitat	Distance from the emission source	
	Middle taiga	Southern taiga
Impact zone:		
leeward	I N (2.5 km)	I S (2.5 km)
windward		Ia S (2.5 km)
Buffer zone	II N (7.5 km)	II S (7.5 km)
Background zone	III N (14 km)	III S (14.5 km)

Coefficient of dominance: $\mathrm{Cd} = \Sigma p_{idom} / N$, where Σp_{idom} is the total abundance of empirically determined dominants, N is the total abundance of all species [30].

To determine the degree of fauna similarity of pedobionts, the Morishita index of overlap was calculated: $C_{\mathrm{M}} = 2\Sigma an_i bn_i / (da + db)NbN$, where an_i is the number of individuals of the i-th species on the A area, bn_i is the same for the B area, aN is the number of individuals on the A area, bN is the same for the B area, $da = \Sigma an_i^2 / aN^2$ and $db = \Sigma bn_i^2 / bN^2$ [31].

We analyzed the correspondence of the distribution of species abundance to the model of geometric series, in which the abundances of species from the biggest to the smallest are expressed by the formula $n_i = NC_k (1 - k)^{i-1}$, where k is the share of the available space of niche or resource for each species, n_i is the number of individuals of the i-th species, N is the total number of individuals, $C_k = [1 - (1 - k)^s]^{-1}$ is constant when $\Sigma n_i = N$ [32].

The author expresses his deep sincere gratitude to V. G. Dolin, Academician of NAN of Ukraine, who verified the accuracy of identification of click beetles.

RESULTS AND DISCUSSION

We analyzed the richness in species and diversity of Elateridae in the compared taiga subzones and in gradient of pollution. In the studied areas click beetles, whose larvae develop in soil, are presented by 17 species of 15 genera. The species composition and indices of richness in species are shown in Table 2.

At a distance of 14.5–15 km from the plants the species density is practically the same in both studied subzones. The highest species density and richness in species are registered within areas of buffer zone in middle and southern taiga, but in the southern taiga the differences between habitats of different degree of transformation are higher than in the middle taiga.

In accordance with the modern concept, the species diversity of a community is determined not only from richness in species but also from uniform distribution of individuals over species [32–34]. To analyze the structure of Elateridae communities in the most correct way, we used several measures of species diversity, based on the relative abundance of species (because their use broadens the estimates of species diversity compared with the indices of species diversity that take into account only one parameter [35]): Simpson index, which gives more weight to the common species, Shannon index, describing diversity of the parts of community both in and out of the sample [32, 33], and independent of sample size [36], Zhivotovskii diversity indices, registering changes of share in the rare species community [29].

Analysis of species diversity showed true differences (t changes from 5.88 to 12.51, $p < 0.001$) of its parameters between habitats of middle and southern taiga subzones. In spite of equal number of species registered for each subzone, the characteristics of species diversity (see Table 3) which take into account the abundance distribution of species of click beetles are lower in southern taiga than in middle taiga (Shannon index t changes from 3.21 to 13.33, $p \ll 0.001$). In addition, for habitats of middle taiga of different transformation degree there are no differences in the values of that index, while in southern taiga the territories at various distances from the plant truly differ in these parameters ($p \ll 0.001$). According to the Simpson and Zhivotovskii indices, the Elateridae complexes of polluted territories (impact and buffer zones) are more similar in middle taiga, and the Elateridae complexes of buffer zone and background territory are more similar in southern taiga.

To obtain the characteristics unrelated to number of species the index of uniformity was used, or ratio of the registered diversity to the maximum [32], as well as the index of rare species share, which allows one to evaluate not only the degree of species diversity but also its structure [29].

For the studied territories of middle taiga higher values of uniformity index E were registered. Accordingly, the rare species share by Zhivotovskii (h) is lower in middle taiga and higher in southern taiga.

The analysis of the abundance distribution of species showed that of all studied habitats the correspondence to geometric series with the constant $k = 0.715$ is observed only for a leeward habitat of impact zone of southern taiga (see Fig. 2), because there is no significant difference between actual and expected abundance of each species of click beetles (fitting criterion χ^2 takes values from 0.028 to 0.137 and $\Sigma\chi^2 = 0.295$, $d.f. = 4$).

By structure of dominance the studied complexes of Elateridae differ in composition of dominant species and their ratio (see Fig. 3, 4). In middle taiga five dominant species were registered, which occupy more than 10% of total number of click beetles, and *D. marginatus* and *Ap. tibialis* dominate in all cases (see Fig. 3). In the subzone of southern taiga four species dominate, among which *S. aeneus* is persistent. The share of species changes between the taiga subzones as well as according to gradient of pollution. In middle taiga the degree of dominance of *D. marginatus* grows with the transformation degree. Near the Krasnoural'sk copper-smelting plant, changes are recorded in the share of *S. aeneus*, which is present on all studied territories, is subdominant in background and buffer zones and becomes one of dominating species in the impact zone. Dominating in the background habitat of middle taiga, *At. subfuscus* becomes subdominant in the buffer zone, and joins the category of rare species on the territory of the impact zone.

The superdominant on the transformed territories of southern taiga is *S. aeneus*, the dominance degree of which drastically increases in the impact habitats in the southeastern and northwestern directions (see Fig. 4). In comparison with the habitat of buffer zone the share

Table 2. Indicators of richness of species

Species	Habitat						
	Middle taiga			Southern taiga			
	I N	II N	III N	Ia S	I S	II S	III S
Selatosomus aeneus	+	+	+	+	+	+	+
S. impressus	+	+	+		+	+	+
Dolopius marginatus	+	+	+	+	+	+	+
Athous subfuscus	+	+	+	+		+	+
Agriotes obscurus	+	+	+	+		+	+
Sericus brunneus	+			+			
Actenicerus sjaelandicus	+						
Aplotarsus tibialis	+	+	+				
Ctenicera cuprea	+	+					
Negastrius quadripustulatus		+					
Ampedus nigrinus			+				
S. nigricornus							+
Anostirus castaneus					+	+	
Prosternon tesselatum				+		+	+
Agrypnus murinus						+	+
Elater sp.						+	
Menanotes rufipes		+			+	+	
Species density, *d*	1.61	2.37	1.89	1.37	1.14	2.28	1.81
DMg	1.26	1.32	1.1	0.92	0.75	1.52	1.16

Table 3. Indicators of richness of species

Indicator	Habitat						
	Middle taiga			Southern taiga			
	I N	II N	III N	Ia S	I S	II S	III S
Simpson index	3.91	3.65	4.69	1.42	1.75	2.96	2.65
Shannon index (H')	2.28	2.28	2.45	0.82	1.14	1.94	1.7
Pielou uniformity (E)	0.72	0.69	0.83	0.32	0.49	0.58	0.56
Zhivotovskii coefficient (μ)	6.43±0.3	6.55±0.23	6.48±0.21	2.59±0.20	2.95±0.17	5.45±0.26	4.42±0.20
Zhivotovskii share of rare species (h)	0.36±0.03	0.34±0.02	0.20±0.03	0.57±0.03	0.41±0.03	0.46±0.03	0.45±0.02

of *An. castaneus* grows greatly on the territory of the impact zone in the southeastern direction, and *S. impressus* becomes there a codominant. There are two dominants on all studied areas of this subzone. Only in the habitat of buffer zone *P. tesselatum* becomes a dominant, being a subdominant in the background zone and practically absent in samples from the impact zone areas.

Such characteristics as the Berger-Parker index of dominating and domination coefficient are the highest for southern taiga habitats of the impact zone (0.83 and 0.73; 97.4 and 93%, correspondingly) and testify to a very high degree of their transformation, which is not true for middle taiga habitats, where the indices change from 0.3 to 0.41; 72.0–89.5%. In middle taiga the indices are also closer for the territories of the impact and buffer zones and in the southern taiga subzone the territories of the buffer and background zones show closer values.

No drastic changes in domination structure such as those recorded in the southern taiga are observed in the middle taiga. *Ap. tibialis*, which dominates in a relatively clean habitat, becomes increasingly more predominant in the transformed ones. *D. marginatus*,

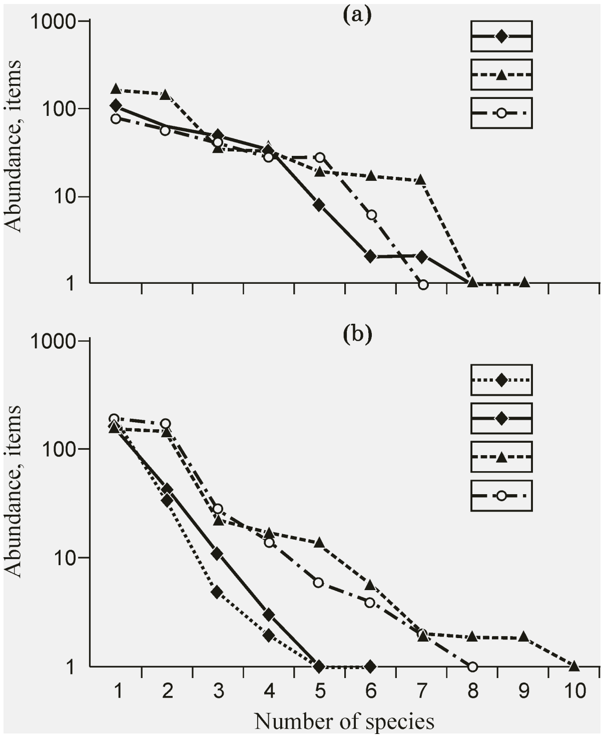

Fig. 2. Distribution of abundance of species in descending order: (a) middle taiga: I N — impact zone, II N — buffer zone, III N — background zone; (b) southern taiga: I S — impact zone (leeward area), Ia S — impact zone (windward area), II S — buffer zone, III S— background zone.

whose biotopic preferendum corresponds to the background zone of southern taiga, gains advantage over other types of the Elateridae complexes on the transformed territories of middle taiga.

Comparison of species spectra in the Morishita index (see Table 4) shows their high similarity within the subzones and poor overlapping when comparing different subzones. Only the similarity of species spectra of the transformed territories of middle taiga with the background territory of southern taiga is relatively high and exceeds the similarity of these complexes for the background territories.

The cluster analysis by the total of indices of species diversity (see Fig. 5) showed that the complexes of middle taiga are well distanced from the complexes of the southern taiga subzone. Within the subzones the distancing of the species complexes of different habitats is conditioned by the landscape peculiarities and duration of the man-induced impact.

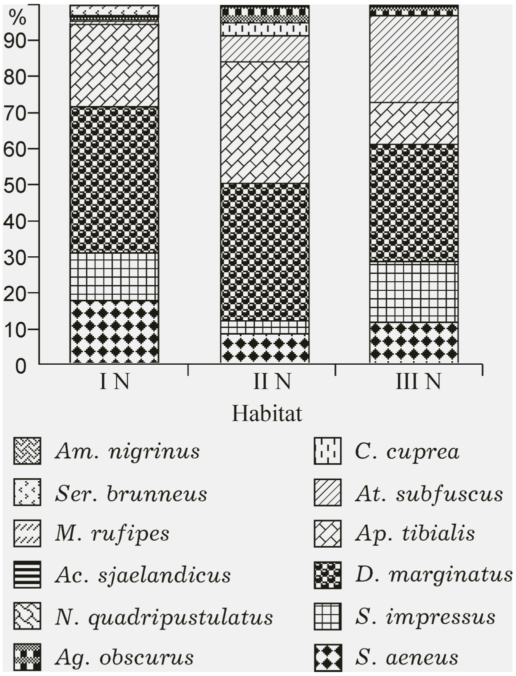

Fig. 3. Ratio of click beetle species in the subzone of middle taiga (I N — impact zone, II N — buffer zone, III N — background zone).

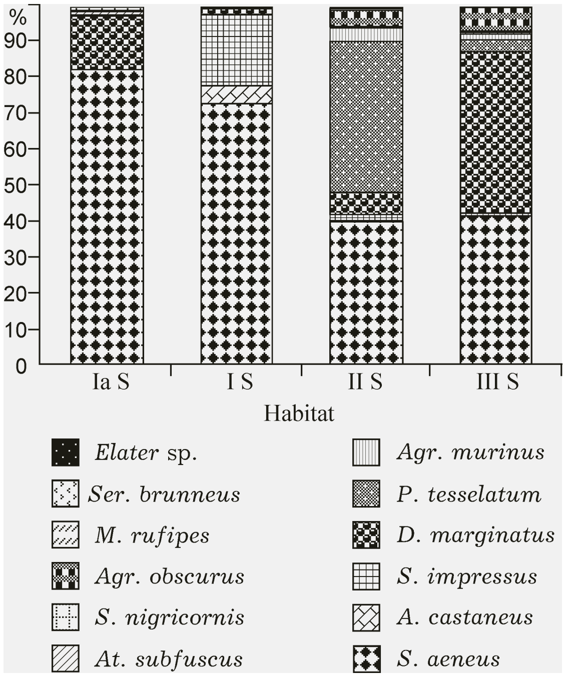

Fig. 4. Ratio of click beetle species in the subzone of southern taiga (I S — impact zone (leeward area), Ia S — impact zone (windward area), II S — buffer zone, III S — background zone).

As a higher species diversity is observed in the community which is not only composd of a larger number of species but also display a higher degree of uniformity of species by their relative abundance [32, 33], the Elateridae communities of middle taiga are more diverse than those of southern taiga. The higher values of the Shannon index in middle taiga testify to the structure of the studied community being more uniform, and vice versa, its lower values in southern taiga communities show that the structure loses its uniformity and its certain elements become more dominant [37].

In our opinion, the closeness of species complexes of the buffer and background zones in southern taiga (as

Table 4. Values of Morishita index

Habitat	Middle taiga			Southern taiga			
	I N	II N	III N	Ia S	I S	II S	III S
I N							
II N	0.94						
III N	0.79	0.76					
Ia S	0.3	0.24	0.21				
I S	0.46	0.33	0.37	0.95			
II S	0.22	0.28	0.42	0.65	0.64		
III S	0.58	0.59	0.35	0.76	0.65	0.66	

well as the higher specificity of communities in the background as compared with the polluted territories in middle taiga) is determined by the relief of each taiga subzone (hills in southern taiga and plain in middle taiga).

The determined correspondence of the abundance distribution of species and geometric series in the impact zone of south taiga testifies to a high degree of anthropogenic transformation of this community [33, 34].

As in the transformed biotopes the hydrothermal regime of habitats changes due to thinning of stand, open canopies with less foliage, degradation of grass vegetation cover [6,16, 18, 19, 38, 39], in southern taiga, given the initially higher level of insolation, lesser humidity and longer activity of the plant, the emission impact leads to higher xerotization, which is accompanied by reduction of the share of boreal and oligothermal species and gives advantage to the eurytopic and xeroresistant species. The initially polydominant structure preserved during the severe transformation of habitats determines the better resistance of communities of click beetles in middle taiga in comparison with southern taiga communities.

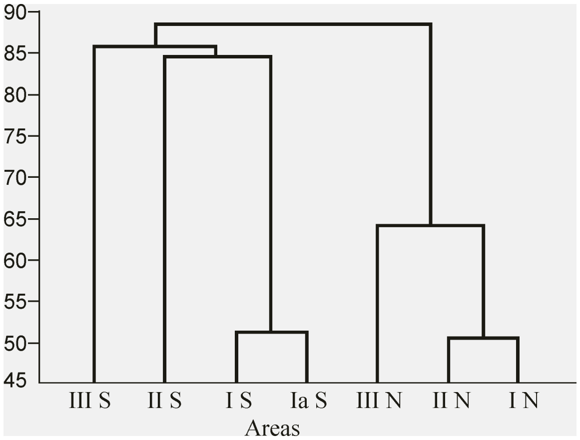

Fig. 5. Tree chart of similarity of species complexes of Elateridae (middle taiga: I N — impact zone, II N — buffer zone, III N — background zone; southern taiga: I S — impact zone (leeward area), Ia S— impact zone (windward area), II S — buffer zone, III S — background zone).

The high similarity of species spectra of the transformed territories of middle taiga with the background territory of the southern taiga subzone is related, in our opinion, to the change of zonal biotopic differentiation as a consequence of anthropogenic transformation, i.e., the studied type of impact, while changing the environment component of middle taiga territories, leads to their assimilation with the natural communities of southern taiga subzone. A similar effect of "southing" of species complex for microscopic soil fungi under high anthropogenic load is described by Marfenina [40].

Thus, the structural divergence of Elateridae communities is determined, first of all, by latitudinal zonality, i.e., by differences in warmth and moisture ratios. A prolonged anthropogenic impact is a recent but significant factor, which influences the structure of Elateridae communities through changing of habitat parameters. A local modification of habitats takes place, when the features of zonal specificity transform into characteristics typical of the biotopes of more southern subzone, leading to structural changes in the species communities of click beetles.

Under the conditions of middle taiga the anthropogenic modification of habitats by the studied type of pollution is alleviated by the latitudinal hydrothermal characteristics, which provides more comfortable conditions for mesophilic groups of pedobionts in comparison with southern taiga and makes the Elateridae complexes more stable.

REFERENCES

1. B. S. Kubantsev, in *Anthropogenic Impact on the Natural Complexes and Ecosystems* (Volgograd, 1976), pp. 3–16.
2. A. F. Alimov, Izv. RAN, Ser. Biol., No. 4, 434 (1998).
3. E. P. Bessolitsyna and V. I. Epova, in *Biodiversity of the Ground and Soil Invertebrates in the North* (Syktyvkar, 1999), pp. 23–24.
4. W. G. Dunger, in *Ann. Historico-Naturales Musei Nationalis Hungarici* (Budapest, 1982), Vol. 74, pp. 35–74.

5. M. S. Gilyarov, in *Bioindication of the State of Environment of Moscow and Its Outskirts* (Moscow, 1982), pp. 8–11.
6. E. P. Bessolitsyna, *Landscape-Ecological Analysis of the Structure of Zoocenoses of the Soils of Southern Siberia* (Irkutsk, 2001) [in Russian].
7. V. G. Mordkovich, *Principles of Zoodiagnostics of Soils*, Doctoral Dissertation in Biology (Novosibirsk, 1985).
8. Yu. A. Izrael', I. M. Nazarov, A. Ya. Pressman, et al., *Acid Rains* (Leningrad, 1983) [in Russian].
9. *Acid Precipitation and Forest Soils* (Apatity, 1999) [in Russian].
10. L. S. Nekrasova and S. D. Seredyuk, in *Animals in Anthropogenic Landscape* (Sverdlovsk, 1991), pp. 50–53.
11. L. S. Nekrasova and S. D. Seredyuk, in *Insects in Natural and Anthropogenic Biogeocenoses of Ural* (Yekaterinburg, 1992), pp. 102–103.
12. A. M. Stepanov, R. R. Kabirov, T. V. Chernen'kova, et al., *Complex Ecological Evaluation of Man-Caused Impact on Ecosystems of Southern Taiga* (Moscow, 1992) [in Russian].
13. I. V. Zenkova, *Structure of Communities of Invertebrates in Forest Podzols of Kola Peninsula*, Candidate's Dissertation in Biology (Petrozavodsk, 2000).
14. A. G. Chikishev, in *Problems of Physical Geography of Ural* (Moscow, 1966), pp. 7–84.
15. V. E. Vlasenko, S. L. Menshchikov, and A. K. Makhnev, Ekologiya, No. 3, 193 (1995).
16. G. S. Makunina, Vestn. Mosk. Univ., Ser. Geogr., No. 3, 61 (1978).
17. T. V. Chernen'kova, in *Marginal Problems of Ecology* (Sverdlovsk, 1986), pp. 116–127.
18. T. V. Chernen'kova, A. M. Stepanov, and M. M. Gordeeva, Zh. Obshchei Biologii **50** (3), 388 (1989).
19. A. K. Makhnev, M. R. Trubina, and A. S. Pryamonosova, in *Natural Vegetation of Industrial and Urbanized Territories of Ural* (Sverdlovsk, 1990), pp. 3–40.
20. A. M. Stepanov, in *Bioindication and Biomonitoring* (Moscow, 1991), pp. 59–64.
21. M. S. Gilyarov, in *Methods of Soil-Zoological Research* (Moscow, 1975), pp. 12–29.
22. E. I. Khot'ko, S. N. Vetrova, A. A. Matveenko, and L. S. Chumakov, *Soil Vertebrates and Industrial Pollution* (Minsk, 1982) [in Russian].
23. M. Begon, J. L. Harper, and C. R. Townsend, *Ecology. Individuals, Populations and Communities* (Moscow, 1989).
24. C. E. Shannon and W. Weaver, *The Mathematical Theory of Communication* (Urbana, 1949).
25. E. C. Pielou, J. Theoret. Biol. **10**, 370 (1966).
26. R. Margalef, Trans. Soc. Gen. Syst., No. 3, 36 (1958).
27. E. H. Simpson, Nature **169** (1949).
28. W. H. Berger and F. L. Parker, Science **168** (3937), 145 (1970).
29. L. A. Zhivotovskii, Zh. Obshchei Biologii **16** (6), 828 (1980).
30. Yu. I. Chernov, Zool. Zh. **50**, 1079 (1971).
31. M. Morishita, Mem. Fac. Sci. Kyushu Univ., E, No. 2, 215 (1959).
32. E. Megarran, *Ecological Diversity and Its Measuring* (Moscow, 1992).
33. Yu. A. Pesenko, *Principles and Methods of Qualitative Analysis in Faunistic Research* (Moscow, 1982) [in Russian].
34. R. Wittaker, *Communities and Ecosystems* (Moscow, 1980).
35. D. A. Krivolutskii and N. V. Lebedeva, in *Geography and Monitoring of Biodiversity* (Moscow, 2002), pp. 13–142.
36. E. P. Odum, *Fundamentals of Ecology* (Moscow, 1986).
37. A. F. Alimov, Izv. RAN, Ser. Biol., No. 4, 434 (1998).
38. A. A. Krauklis, E. P. Bessolitsyna, and L. K. Kremer, Geografiya i Prirodnye Resursy, No. 3, 14 (1985).
39. E. P. Bessolitsyna, *Structure and Dynamics of Soil Zoocenoses in Landscapes of Siberian South*, Doctoral Dissertation in Biology (Irkutsk, 2003).
40. O. E. Marfenina, "Disturbance of Ecological-Geographical Zonality of Complexes of Microscopic Fungi in Soil Under Anthropogenic Impact" (2001). http://www.soil.msu.ru/~bio/mish2001/marf.pdf.