Russian Journal of Ecology, Vol. 35, No. 6, 2004, pp. 403–408. Translated from Ekologiya, No. 6, 2004, pp. 450–455.

Structural Changes in the Carabid Fauna of Forest Ecosystems under a Toxic Impact

A. I. Ermakov

Institute of Plant and Animal Ecology, Ural Division, Russian Academy of Sciences, ul. Vos'mogo Marta 202, Ekaterinburg, 620144 Russia

Received August 5, 2003

Abstract—Changes in the abundance, species composition, and biomorphological structure of the carabid fauna were studied in birch and fir–spruce forests growing in a zone exposed to emissions from a copper-smelting plant in the Middle Urals. The dynamic density of carabids decreased and their species composition and the ratio of life forms changed along the pollution gradient, but the principle of organization of carabidocenoses and the structure of dominance in them remained undisturbed.

Key words: carabids, herpetobiontic invertebrates, population structure, life forms, industrial pollution, heavy metals, copper-smelting plant, the Middle Urals, forest ecosystems.

The responses of invertebrates, including ground beetles (Carabidae), to technogenic pollution are being actively investigated (Aleinikova, 1976; Gilyarov, 1982; Pristavko, 1984; Emets, 1986; Kozlov, 1990; Krivolutskii, 1994; Butovskii, 2001). Many studies of this kind have been made at the organism and population levels but using a small number of model indicator species (Emets and Zhulidov, 1985; Emets and Kulmatov, 1983; Butovsky, 1997; Lagisz *et al.*, 2002). Responses at the cenotic level (e.g., that of carabidocenoses) are no less interesting, especially under conditions of long-term exposure to chemical pollutants emitted from point sources, such as metallurgical plants (Khot'ko *et al.*, 1982; Bengtsson and Rundgren, 1984; Chlodny *et al.*, 1987; Read *et al.*, 1987; Nekrasova, 1993; Vorobeichik *et al.*, 1994; Vorobeichik, 1995; Gongalsky and Butovsky, 1999).

The purpose of this study was to reveal changes in the taxonomic and ecological structure of forest carabidocenoses along a gradient of chemical pollution from emissions from a copper-smelting plant.

MATERIAL AND METHODS

Studies were performed in the zone of the Middle Ural Copper-Smelting Plant (MUCSP) located near the city of Revda (Sverdlovsk oblast), in the southern taiga subzone. The plant has been in operation since 1940, with sulfur dioxide and toxic elements adsorbed on solid particles (Cu, Zn, As, Pb, Cd, etc.) being the main pollutants emitted from it. Test plots were established in two types of biotopes (birch and fir–spruce forests) in the zones of transformation of forest ecosystems that were delimited previously (Vorobeichik *et al.*, 1994).

The technogenic desert adjoining the plant from the east is at the final stage of technogenic digression: there are evident eroded areas with fragments of thinned woody vegetation (birch and aspen), the herb–dwarf shrub and moss layers are absent, and a thick layer of nondecomposing litter has accumulated in depressions.

The impact zone is located 1–1.5 km west of the MUCSP. The plots were established in a mesophytic secondary birch forest and a small remaining spot of fir–spruce forest with a herb–dwarf shrub layer consisting of horsetail and grasses (lime grass and bent grass), well-developed monospecific moss layer, and an increased depth of the litter.

The buffer zone lies 6 km west of the MUCSP. Phytocenoses: primary wood-sorrel fir–spruce forest and secondary bilberry birch forest with a weak understory. The herb–dwarf shrub layer consists of small herbs; the litter is thin.

The background zone is located 16–20 km west of the plant. Phytocenoses: herb–wood sorrel fir–spruce forest and herb–fern birch forest with a well-developed understory and shallow litter.

A line of ten Barber traps (neck diameter 85 mm) with ethylene glycol as a fixative was set in each biotope. The traps were checked every week throughout the growing season (from May to September). The total amount of work was 8300 trap-days; more than 18000 specimens of herpetobiontic invertebrates (without ants) were trapped, including 4200 adult and 1000 larval ground beetles.

The relative abundance of insects was characterized using the index of dynamic density recalculated per ten trap-days. Classification of species by their abundance

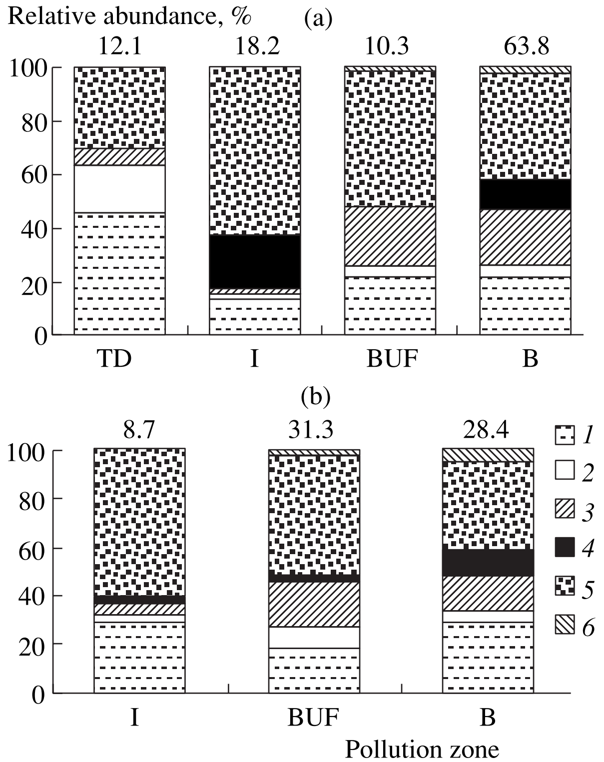

Fig. 1. Structure of the herpetobiontic complex of invertebrates in (a) birch and (b) fir–spruce forests along the pollution gradient: (*1*) adult carabids, (*2*) larval carabids, (*3*) staphylinids, (*4*) other insects, (*5*) spiders, and (*6*) other invertebrates. Pollution zones: TD, technogenic desert; I, impact zone; BUF, buffer zone; and B, background zone. Figures above columns show the total dynamic density of the herpetobium (ind./10 trap-days).

in the test plot was made using a limited logarithmic scale of relative abundance (Pesenko, 1982): the species accounting for less than 5% of the total sample were classified as rare; for 5–20%, as background species; and for more than 20%, as dominant species. The species complexes were compared using the Simpson and Berger–Parker diversity indices (Magurran, 1988), and a biomorphological analysis of the structure of ground beetle fauna was performed using the system of life forms by Sharova (1981).

RESULTS AND DISCUSSION

The proportion of adult ground beetles averaged over the season varied in different plots from 15 to 45% of the total abundance of herpetobiontic invertebrates (Fig. 1), being second only to spiders (30–60%). Such a high abundance of ground beetles (including their larvae) in the impact areas may be indicative of their "success in adaptation" to the corresponding conditions.

During the period of trapping, 54 species of ground beetles belonging to 24 genera were recorded (Table 1). Virtually all these species are widespread and typical of the southern taiga. Of faunistic interest are a single finding of the Eastern Siberian species *Bradycellus glabratus* and the occurrence in test plots of numerous populations of the European–Siberian *Bembidion humerale* and the European–Western Siberian *Pterostichis quadrifoveolatus.* To date, only a few representatives of the last two species have been found in the Middle Urals. It is also noteworthy that a dead specimen of *Calosoma sycophanta*, a rare and protected species (included in the Red Data Lists of Russia and the Middle Urals) was found near the plant in the summer of 1997. These species, some of which are capable of active flight, may be attracted to polluted territories by a combination of factors (an open terrain with rare vegetation, swamping, artificial illumination, etc.). A similar phenomenon has also been noted for other groups of insects. For example, a population of a rare clearwing moth included in the Red Data List of Finland as an extinct species was found near the nickel smeltery in the Kola Peninsula (Kozlov and Jalava, 1994).

The dynamic density of ground beetles decreased along the pollution gradient by a factor of two to three, reaching in the impact zone only 2.5 and 2.6 ind./10 trap-days in the birch and fir–spruce forests, respectively. At the same time, the carabidocenoses of the technogenic desert were twice as abundant as those of the impact zone. This fact could be explained by an increased activity of ground beetles and, consequently, a higher frequency of their trapping upon exposure to unfavorable factors characteristic of this area (insolation, dry soil and litter, and shortage of shelters and food). However, any conclusions concerning a "true" change in the abundance of ground beetles in the technogenic desert will be premature.

It is known that the carabid fauna of the deciduous and dark coniferous forests differs in the species composition (Gryuntal', 1978; Voronin, 1999). The carabid fauna of undisturbed birch forests is generally richer than the fauna of fir–spruce forests, and the dynamics of species richness under conditions of pollution in these forest types have different trends. The high species richness of the birch forest carabidocenoses in heavily polluted areas is accounted for by the presence of some mesoxerophilic (for the technogenic desert) and hygrophilous (for the impact zone) species of the genera *Pterostichus, Clivina, Broscus, Bembidion*, and *Nitiophilus*, as well as of visiting species. The decrease in the number of species along the pollution gradient is more apparent in the fir–spruce forest.

In general, the core of carabidocenosis in any test plots consisted of one or two dominant and two or three background species, with the remaining species being rare. In the background areas, the core was formed by stenotopic species (*Pterostichus melanarius* and *Epaphius secalis*); in polluted areas, mainly by eurytopic species (*Pterostichis oblongopunctatus, Poecilus versicolor*, and *Bembidion lampros*). However, stenotopic species proved to appear and gain dominance upon extreme technogenic degradation of biotopes. Thus, the

Table 1. Species composition and dynamic density (ind./10 trap-days) of carabids in zones with different toxic loads

No.	Species	Biotope and zone						
		birch forest				spruce–fir forest		
		technogenic desert	impact zone	buffer zone	background zone	impact zone	buffer zone	background zone
	Species recorded in zones with a background pollution level							
1	*Pterostichus niger* Schall.	–	–	–	0.72	–	–	0.14
2	*Badister lacertosus* Sturm.	–	–	–	0.12	–	–	0.01
3	*Carabus glabratus* Payk.	–	–	–	0.07	–	–	0.04
4	*Carabus schoenherri* F.-W.	–	–	–	0.06	–	–	0.05
5	*Leistus terminatus* Hell. & Panz.	–	–	–	0.01	–	–	0.01
6	*Pterostichus uralensis* Motsch.	–	–	–	0.20	–	–	–
7	*Curtonotus gebleri* Dej.	–	–	–	0.18	–	–	–
8	*Calathus micropterus* Duft.	–	–	–	0.03	–	–	–
9	*Agonum fuliginosum* Panz.	–	–	–	0.01	–	–	–
10	*Harpalus quadripunctatus* Dej.	–	–	–	0.01	–	–	–
11	*Amara* sp.	–	–	–	0.01	–	–	–
12	*Pterostichus aethiops* Pz.	–	–	–	–	–	–	0.10
13	*Pterostichus strenuus* Pz.	–	–	–	–	–	–	0.01
	Species recorded in the zone with an intermediate pollution level							
14	*Pterostichus urengaicus* Jur.	–	–	–	0.32	–	0.04	0.49
15	*Cychrus caraboides* L.	–	–	–	0.27	–	0.09	0.27
16	*Carabus aeruginosus* F.-W.	–	–	–	0.01	–	0.08	0.01
17	*Pterostichus melanarius* Ill.	–	–	–	2.73	–	0.42	–
18	*Harpalus latus* L.	–	–	–	0.53	–	0.01	–
19	*Bradycellus caucasicus* Chaud.	–	–	–	–	–	0.01	–
	Species recorded in zones with a high pollution level							
20	*Pterostichus quadrifoveolatus* Letz.	2.17	0.12	–	–	0.01	–	–
21	*Bembidion lampros* Hbst.	1.44	0.02	–	–	–	–	–
22	*Clivina fossor* L.	0.24	–	–	–	–	–	–
23	*Broscus cephalotes* L.	0.13	–	–	–	–	–	–
24	*Asaphidion pallipes* Duft.	0.09	–	–	–	–	–	–
25	*Bembidion quadrimaculatum* L.	0.08	0.01	0.01	–	–	–	–
26	*Poecilus versicolor* Sturm.	0.02	0.64	–	–	–	–	–
27	*Amara bifrons* Gyll.	0.04	0.01	0.40	–	0.06	0.18	–
28	*Amara brunnea* Gyll.	0.02	0.01	0.23	–	1.04	0.50	–
29	*Notiophilus palustris* Duft.	0.01	0.04	–	–	–	0.01	–
30	*Sericoda quadripunctatum* Deg.	0.02	–	–	–	0.01	–	–
31	*Harpalus rufipes* Deg.	0.01	0.01	–	–	–	–	–
32	*Microlestes maurus* Sturm.	0.01	0.01	–	–	–	–	–
33	*Amara familiaris* Duft.	0.01	–	–	–	–	–	–
34	*Stenolophus mixtus* Hbst.	0.01	–	–	–	–	–	–
35	*Bradycellus glabratus* Rtt.	0.01	–	–	–	–	–	–
36	*Harpalus calceatus* Duft.	0.01	–	–	–	–	–	–
37	*Agonum sexpunctatum* L.	–	0.22	–	–	–	–	–
38	*Bembidion humerale* Sturm.	–	0.19	–	–	–	–	–

Table 1. (Contd.)

No.	Species	Biotope and zone						
		birch forest				spruce–fir forest		
		technogenic desert	impact zone	buffer zone	background zone	impact zone	buffer zone	background zone
39	*Notiophilus aquaticus* L.	–	0.03	–	–	–	–	–
40	*Pterostichus vernalis* Panz.	–	0.02	–	–	0.02	–	–
41	*Calathus melanocephalus* L.	–	0.01	0.04	–	–	–	–
42	*Cicindela campestris* L.	–	0.01	–	–	–	–	–
	Species recorded in all zones							
43	*Pterostichus oblongopunctatus* F.	0.03	0.85	1.09	2.14	0.78	1.85	0.43
44	*Amara communis* Panz.	0.43	0.25	0.08	0.52	0.14	0.12	0.01
45	*Calathus erratus* C. Sahlb.	0.63	–	–	–	0.45	1.32	0.08
46	*Notiophilus biguttatus* F.	0.01	–	0.02	0.02	0.04	0.34	0.02
47	*Amara erratica* Duft.	0.02	–	0.01	0.01	0.01	–	0.02
48	*Loricera pilicornis* F.	0.01	–	0.01	0.05	–	0.02	0.50
49	*Synuchus vivalis* Payk.	0.06	–	0.30	0.09	–	–	–
50	*Carabus granulatus* L.	0.01	–	0.01	0.04	–	–	–
51	*Amara aenea* Deg.	0.01	–	–	0.13	–	–	–
52	*Carabus cancellatus* Ill.	0.01	–	–	0.03	–	–	–
53	*Epaphius secalis* Payk.	–	0.01	0.03	5.35	–	0.80	5.94
54	*Pterostichus nigrita* F.	–	0.03	–	0.05	–	–	–
Total number of carabid species		26	18	12	27	10	15	17
Including: dominant species		2	2	1	1	2	2	1
background species		2	3	2	3	2	4	3
rare species		22	13	9	23	6	9	13
Dynamic density (average for the season), ind./10 trap-days		5.5	2.5	2.2	13.7	2.6	5.8	8.1
Berger–Parker index (1/*d*)		2.6	2.9	2.1	2.6	2.5	3.1	1.4
Simpson index (1/*D*)		4.1	4.8	3.4	4.5	3.5	5.3	1.8

main dominant in the technogenic desert was *P. quadrifoveolatus*, a pyrophilous species (Whitehouse and Eversham, 2002; Gongalsky *et al.*, 2003), which was replaced by the closely related *Pt. oblongopunctatus* at a larger distance from the pollution source. *Stericoda quadripunctata*, another pyrophilous species (Burakowski, 1989; Gongalsky *et al.*, 2003) was also characteristic of the technogenic desert. This may be related to similarity with respect to abiotic parameters of the environment between the extreme variants of technogenic digression and the initial stages of pyrogenic succession.

The structure of dominance in the species complexes of ground beetles did not change significantly along the pollution gradient: the Berger–Parker index reflecting the degree of population uniformity had similar values in the test plots (2.1–3.1). The only exception was the carabidocenosis of the background fir–spruce forest (1.4), where the forest–meadow species *Epaphis secalis* characteristic of the southern taiga carabid faunas (Gryuntal', 1981) gained superdominance, accounting for up to 73% of the total abundance.

The life forms of carabids in the study area were represented by two classes, zoophages and mixophytophages (Table 2). The first class comprised three subclasses and nine groups of life forms, and the second class, three subclasses and three groups. It is noteworthy that the spectrum of life forms broadened along the pollution gradient: 5 groups of life forms were recorded in the background plots; 6 groups, in the buffer plots; and 11 groups, in the technogenic desert. Only the plots with a high pollution level were inhabited by groups such as running and flying epigeobionts, litter–crack stratobionts, and geobionts. Evidently, these forms are better adapted to life under the conditions of this biotope. The epigeobionts moving in the daytime on the soil surface actively avoid the adverse environmental influence by constantly searching for moisture, food, and shelter. Geobiontic forms and litter–crack strato-

Table 2. Spectrum of life forms of carabids (proportion of their total abundance, %) in birch and spruce–fur forests in growing in zones with different toxic loads

Life form*			Biotope and zone**						
			birch forest				spruce–fir forest		
class	subclass	group	TD	I	BUF	B	I	BUF	B
Zoophages (38)	Epigeobios (8)	Walking (6)	0.3	–	0.4	3.5	–	2.9	4.6
		Running (1)	1.7	–	–	–	–	–	–
		Flying (1)	–	0.4	–	–	–	–	–
	Stratobios (28)	Surface–litter (6)	2.0	10.7	1.7	0.5	1.5	6.5	6.3
		Litter (10)	38.4	2.5	16.8	40.0	18.3	36.7	74.2
		Litter–cracks (1)	0.2	0.4	–	–	–	–	–
		Litter–soil (11)	40.5	74.8	48.7	45.9	31.2	39.9	14.5
	Geobios (2)	Running (1)	4.3	–	–	–	–	–	–
		Digging (1)	2.4	–	–	–	–	–	–
Mixophytophages (15)	Stratobios (5)	Intersticial (5)	0.9	0.4	10.5	–	40.7	8.7	–
	Stratohortobios (1)	Stratohortobionts (1)	0.2	0.4	–	–	–	–	–
	Geohortobios (9)	Harpaloids (9)	9.1	10.4	21.9	10.8	8.3	5.3	0.4

* Figures in parentheses show the number of species.
** Zones: TD, technogenic desert; I, impact zone; BUF, buffer zone; and B, background zone.

bionts, on the contrary, use the strategy of passive avoidance and ascend to the soil surface at night, when the humidity of the soil and the ground air layer increases. A similar situation was observed upon grass stand cutting or thinning in forest–meadow biotopes (Pristavko, 1984).

The numerical prevalence of zoophages from the litter layer, a zonal feature of carabidocenoses of the forest zone (Sharova, 1981), was also observed in this study: the proportion stratobiontic zoophages reached 50–80% of the total abundance. In some cases, stratobiontic mixophytophages were highly abundant: their proportion in the fir–spruce forest in the impact area reached approximately 40% due to the forest species *Amara brunnea.*

CONCLUSIONS

Taking into consideration the relatively high abundance of carabids in polluted areas, it may be assumed that pollution influences the structure of carabidocenosis indirectly, via modification of environmental conditions. The species living under conditions of a technogenically transformed environment manifest the same adaptation mechanisms as in the undisturbed habitats in which natural ecological factors are at the pessimum. The mechanisms of resistance to adverse climatic factors (low humidity, high temperature, and increased insolation) developed in the course of evolution may be also efficient in case of exposure to a historically new factor, such as chemical pollution.

ACKNOWLEDGMENTS

The author is grateful to scientists of the Institute of Plant and Animal Ecology (Ural Division, Russian Academy of Sciences) E.A. Bel'skii and M.E. Grebennikov for their help in collecting material, E.V. Zinov'ev for identification of several species, and E.L. Vorobeichik and E.A. Bel'skaya for their valuable comments on the manuscript.

This study was supported by the Russian Foundation for Basic Research, project no. 03-04-49135.

REFERENCES

Aleinikova, M.M., Animal Population of Soil and Its Transformation under the Influence of Anthropogenic Factors, *Pedobiologia*, 1976, vol. 16, no. 3, pp. 195–206.

Bengtsson, G. and Rundgren, S., Ground-Living Invertebrates in Metal-Polluted Forest Soils, *Ambio*, 1984, vol. 13, no. 1, pp. 29–33.

Burakowski, B., *Agonum (Sericoda) quadripunctatum* (De Geer)—a Pyrophilous Beetle and Its Immature Stages (Coleoptera, Carabidae), *Ann. Zool.*, 1989, vol. 42, no. 6, pp. 181–195.

Butovsky, R.O., Heavy Metals in Ground Beetles (Coleoptera, Carabidae), *Agrokhimiya*, 1997, no. 11, pp. 78–86.

Butovsky, R.O., *Ustoichivost' kompleksov pochvoobitayushchikh chlenistonogikh k antropogennym vozdeistviyam* (Resistance of Complexes of Soil Arthropods to Anthropogenic Effects), Moscow: Den' Serebra, 2001.

Chlodny, J., Matuszczyk, I., Styfi-Bartkiewicz, B., and Syrek, D., Catchability of the Epigeal Fauna of Pine Stands as a Bioindicator of Industrial Pollution of Forests, *Ekol. Pol.*, 1987, vol. 35, no. 2, pp. 271–290.

Emets, V.M., Using of Population Parameters of Predaceous Insects in the Background Ecosystem Monitoring, *Byull. Mosk. O–va Ispyt. Prir., Otd. Biol.*, 1986, vol. 91, no. 6, pp. 38–43.

Emets, V.M. and Kulmatov, R.A., Individual Variations of Zink Concentrations in the Body of Imago of Different Age in the Populations of *Pterostichus oblongopunctatus* F. (Coleoptera, Carabidae) in the Background and Polluted Territories, *Dokl. Akad. Nauk SSSR*, 1983, vol. 271, no. 5, pp. 1274–1276.

Emets, V.M. and Zhulidov, A.V., Variations of Zinc Concentrations in Populations of Ground Beetle *Pterostichus oblongopunctatus* F. (Coleoptera, Carabidae) in the Conditions of Preservation Regime and Combined Effect of Pollution and Recreation, *Dokl. Akad. Nauk SSSR*, 1985, vol. 283, no. 3, pp. 760–763.

Gilyarov, M.S., Soil Invertebrates as Indicators of Soil Regime and Its Changes under the Effect of Anthropogenic Factors, in *Bioindikatsiya sostoyaniya okruzhayushchei sredy Moskvy i Podmoskov'ya* (Bioindication of Environmental State in Moscow and Moscow Region), Moscow: Nauka, 1982, pp. 8–12.

Gongalsky, K.B. and Butovsky, R.O., The Impact of a Metallurgical Plant on Ground Beetle (Coleoptera, Carabidae) Communities, in *Pollution-Induced Changes in Soil Invertebrate Food-Webs*, Amsterdam: Elsevier, 1999, vol. 2, pp. 71–76.

Gongalsky, K.B., Vikarsh, L.-U., and Pershon, T., Effect of the Fires in Boreal Forests of Sweden on the Communities of Ground Beetles (Coleoptera, Carabidae), in *Raznoobrazie bespozvonochnykh zhivotnykh na Severe* (Diversity of Invertebrate Animals in the North), Syktyvkar, 2003, p. 19.

Gryuntal', S.Yu., Distribution of Ground Beetles (Coleoptera, Carabidae) in the Forests of the Hairy-sedge Cycle in the Conditions of Moscow Region, in *Fauna i ekologiya bespozvonochnykh zhivotnykh* (Fauna and Ecology of Invertebrate Animals), Moscow, 1978, pp. 68–77.

Gryuntal', S.Yu., Distribution of Ground Beetles (Coleoptera, Carabidae) in the Forests of Southern Taiga, *Vestn. Zool.*, 1981, no. 5, pp. 20–24.

Khot'ko, E.I., Vetrova, S.N., Matveenko, A.A., and Chumakov, L.S., *Pochvennye bespozvonochnye i promyshlennye zagryazneniya* (Soil Invertebrates and Industrial Pollution), Minsk: Nauka i Tekhnika, 1982.

Kozlov, M.V., *Vliyanie antropogennykh faktorov na populyatsii nazemnykh nasekomykh* (Effects of Anthropogenic Factors on Populations of Terrestrial Insects), *Itogi Nauki Tekhn.*, Moscow: VINITI, 1990, vol. 13.

Kozlov, M.V. and Jalava, J., Lepidoptera of Kola Peninsula, Northwestern Russia, *Entomol. Fennica*, 1994, vol. 5, pp. 65–85.

Krivolutskii, D.A., *Pochvennaya fauna v ekologicheskom kontrole* (Soil Fauna in Ecological Control), Moscow: Nauka, 1994.

Lagisz, M., Kramarz, P., Laskowski, R., and Tobor, M., Population Parameters of the *Pterostichus oblongopunctatus* F. from Metal Contaminated and Reference Areas, *Bull. Environ. Contam. Toxicol.*, 2002, vol. 69, pp. 243–249.

Magurran, A.E., Ecological Diversity and Its Measurement. London: Croom Helm, 1988. Translated under the title *Ekologicheskoe raznoobrazie i ego izmerenie*, Moscow: Mir, 1992.

Nekrasova, L.S., Effect of Copper-smelting Plant on Soil Fauna, *Ekologiya*, 1993, no. 5, pp. 83–85.

Pesenko, Yu.A., *Printsipy i metody kolichestvennogo analiza v faunisticheskikh issledovaniyakh* (Principles and Method of Quantitative Analysis in Faunistic Investigations), Moscow: Nauka, 1982.

Pristavko, V.P., Life Forms of Insects as a Criterion for Selection the Indicating Species for Ecological Monitoring (By the Example of Ground Beetles—Coleoptera, Carabidae), *Entomol. Obozr.*, 1984, vol. 63, no. 1, pp. 52–56.

Read, H.J., Wheater, C.P., and Martin, M.H., Aspects of the Ecology of Carabidae (Coleoptera) from Woodlands Polluted by Heavy Metals, *Environ. Pollut.*, 1987, vol. 48, pp. 61–76.

Sharova, I.Kh., *Zhiznennye formy zhuzhelits (Coleoptera, Carabidae)* [Life Forms of Ground Beetles (Coleoptera, Carabidae)], Moscow: Nauka, 1981.

Vorobeichik, E.L., Response of Soil Biota in Forest Ecosystems of Middle Urals to the Emissions of Copper-smelting Works, *Extended Abstract of Cand. Sci. (Biol.) Dissertation*, Yekaterinburg, 1995.

Vorobeichik, E.L., Sadykov, O.F., and Farafontov, M.G., *Ekologicheskoe normirovanie tekhnogennykh zagryaznenii nazemnykh ekosistem* (Ecological Standardization of Technogenic Pollutants in Terrestrial Ecosystems), Yekaterinburg: Nauka, 1994.

Voronin, A.G., *Fauna i kompleksy zhuzhelits (Coleoptera, Trachypachidae, Carabidae) lesnoi zony Srednego Urala (ekologo-zoogeograficheskii analiz)* [Fauna and Complexes of Ground Beetles (Coleoptera, Trachypachidae, Carabidae) in Forest Zone of Middle Urals (Ecological–Zoogeographical Analysis)], Perm: Perm. Univ., 1999.

Whitehouse, N.J. and Eversham, B.C., A Fossil Specimen of *Pterostichus angustatus* (Duftschmid) (Carabidae): Implications for the Importance of Pine and Fire Habitats, *The Coleopterist*, 2002, vol. 11, no. 3, pp. 107–114.