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Changes in the Taxonomic Structure of Herpetobiont Arachnids along the Gradient of Pollution with Emissions from a Copper Smelter

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Abstract—Changes in the dynamic density of herpetobiont arachnids and the ratio of spider life forms have been studied in southern taiga forests transformed under the impact of emissions from a copper smelter. Along the pollution gradient, the dynamic density of spiders decreases; web-spinning spiders are replaced by ambush spiders, since the abundance of families Lycosidae and Gnaphosidae increases while that of the family Linyphiidae decreases; and spatial variation in the abundance of arachnids increases. One harvestmen family (Nemastomatidae) completely disappears near the copper smelter.

Key words: herpetobionts, spiders, harvestmen, life forms, industrial pollution, heavy metals, copper smelter, Middle Urals.

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The impact of the nonferrous metals industry on terrestrial invertebrate communities has been studied for a long time. However, the responses of arachnids to pollution remain poorly known, since attention has been paid mainly to the contents of heavy metals in their bodies (Hopkin and Martin, 1985; Hopkin, 1989; Rabitscs, 1995; Tanasevitsch, 1999; Butovsky, 2001). There are some studies on the influence of agricultural activities on the structure of arachnid communities in agrocenoses (Siepel et al., 1989; Aukema et all., 1990; Esyunin and Batalin, 1995; Bel'skaya and Esyunin, 2003). The effect of industrial pollution on herpetobiont arachnids has been studied mostly at the cenotic level, as related to comparisons of abundance between large taxa (Hopkin, 1989; Koneva and Koponen, 1992; Ermakov, 2004; Gongalsky et al., 2007). The taxonomic structure, species composition, and ratio of life forms have been studied less actively (Koponen and Niemelä, 1995). Studies on the responses of terrestrial invertebrates to chemical pollution in the area described below were performed previously (Vorobeichik et al., 1994, 2007; Vorobeichik, 1995; Bel'skaya and Zinov'ev, 2007), but arachnids did not receive special consideration.

The purpose of this study was to describe changes in the structure of the herpetobiont arachnid community and in the ratio of functional groups within it along the pollution gradient.

MATERIAL AND METHODS

Samples were taken in the environs of the Middle Ural Copper Smelter (MUCS) located in the outskirts of Revda, Sverdlovsk oblast, which has been in operation since 1940. The main components of its emissions are SO_2 and heavy metals (Cu, Zn, Fe, As, Pb, Cd, and Hg) sorbed on dust particles. According to previous studies (Vorobeichik et al., 1994), sampling plots were established at different distances from the source of emissions, in zones with different pollution levels: background 1 (Bg1), 27–30 km from the smelter; background 2 (Bg2), 16–20 km (heavy metal and SO_2 concentration in these two zones was at the same level as the regional background); buffer (Bf), 6–7 km (zone with intermediate values of pollutant concentration); and impact (Im), 2 km (zone with maximum emission of airborne pollutants). All the plots were located southwest of the MUCS, against the prevailing wind direction.

In each zone, habitats most typical for the southern taiga subzone were studied: a primary spruce–fir forest and a secondary aspen–birch forest. In each habitat, three sampling plots were established at distances of 50–100 m from each other. Five Barber pitfall traps 8.5 cm in diameter were placed in each sampling plot and exposed for 5 days (one sampling round) at five-day intervals. Catches were fixed with 3% acetic acid. Five rounds (a total of 3160 trap-days) were conducted between May 13 and August 23, 2004: May 13–18, May 26–June 1, June 10–16, August 4–10, and

Table 1. Average dynamic density of spider and harvestman families in two forest types along the pollution gradient, ind./10 trap–days

Family	Spruce–fir forest				Aspen–birch forest			
	Bg1	Bg2	Bf	Im	Bg1	Bg2	Bf	Im
Aranei								
Agelenidae	0.17	0.29	0.15	0.00	0.00	0.09	0.00	0.00
Clubionidae	0.04	0.00	0.00	0.02	0.15	0.04	0.09	0.00
Gnaphosidae	0.03	0.12	0.79	0.50	0.02	0.09	1.11	1.06
Hahniidae	0.00	0.09	0.00	0.00	0.83	0.00	0.00	0.07
Linyphiidae	10.55	9.89	8.12	2.82	7.71	11.78	6.55	1.75
Liocranidae	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Lycosidae	0.86	0.36	0.94	3.43	12.31	1.79	7.61	7.09
Zoridae	0.02	0.02	0.00	0.00	0.02	0.04	0.07	0.00
Opiliones								
Nemastomatidae	3.12	2.06	0.27	0.00	1.97	1.31	1.72	0.00
Phalangiidae	1.39	2.40	2.84	0.31	3.20	10.23	2.92	0.21

August 19–23. For a detailed analysis of pollution (toxic pressure index, acidity and humidity of the forest litter) and the phytocenotic parameters (coverage of the herb–dwarf shrub layer and tree crown density) in the study area, see Bel'skaya and Zinov'ev (2007).

Statistical analysis of data was performed with programs Statistica v. 6 (two-way ANOVA; Mann–Whitney test) and Microsoft Office Excel (calculation of total variance according to Snedecor (see Lakin, 1990) and variation coefficient).

RESULTS AND DISCUSSION

Eight spider families (Agelenidae, Clubionidae, Gnaphosidae, Hahniidae, Linyphiidae, Liocranidae, Lycosidae, and Zoridae) and two harvestmen families (Nemastomatidae and Phalangiidae) were recorded in the zones studied. In each zone, three spider families constituting the core of the spider community were present: Linyphiidae, Lycosidae, and Gnaphosidae. Of the two harvestman families, Phalangiidae were more abundant and occurred in all zones, whereas Nemastomatidae were recorded only in the two background zones and in the buffer zone (Table 1).

Spider families differed in their response to industrial pollution. In the two habitats, the abundance of Clubionidae and Linyphiidae decreased, whereas that of Gnaphosidae and Lycosidae increased from Bg1 to Im. A similar increase in the abundance of lycosid spiders was recorded in pine forests exposed to emissions from a nickel smelter in southwestern Finland (Koponen and Niemelä, 1995). A trend toward an increase in the abundance of the family Zoridae from Bg1 to Bf was observed only in the aspen–birch forest, whereas the abundance of Agelenidae decreased from Bg2 to Bf in the spruce–fir forest. Other spider families showed no distinct changes in abundance along the pollution gradient.

Linyphiidae are web-spinning spiders, whereas other seven families are ambush spiders (*Rukovodstvo...*, 1983). Thus, web-spinning forms are replaced by ambush forms from Bg1 to Im. The proportion of ambush spiders is greater in the aspen–birch forest than in the spruce–fir forest along the entire pollution gradient. In the southern taiga subzone, birch forests are characterized by greater abundance and species richness of plants than fir forests (Degteva, 2004), and this may account for the observed differences in spider abundance.

Web-spinning spiders are dependent on a certain vertical structure and coverage of the herbaceous layer in spinning their webs. Since ambush spiders do not use webs for hunting, they prefer open habitats with sparse herbaceous layer. Increasing pollution leads to deterioration of the herb–dwarf shrub layer and impoverishment of its species composition, thereby providing for an increase in the proportion of ambush spiders and decrease in the proportion of web-spinning spiders. The structure of the pedobiont spider complex and the ratio of these two functional groups in it apparently depend not so much on pollution itself as on the structure of phytocenosis. The same assumption was made by Koponen and Niemelä (1995). They believe that differences observed in the aboveground invertebrate fauna are due to changes in the pattern of vegetation closer to the source of pollution.

The abundance of arachnid taxa in the spruce–fir forest decreased along the pollution gradient, from the background to the impact zone, with spiders prevailing in the community. In the aspen–birch forest, changes in the abundance of arachnids had no definite pattern. However, their abundance in the impact zone

Table 2. Average dynamic density of spider and harvestman families in two forest types, ind./10 trap-days ± m_s (percentage of each family is shown in brackets)

Zone	Spruce–fir forest		Aspen–birch forest	
	Spiders	Harvestmen	Spiders	Harvestmen
Background 1	11.65 ± 0.21 (72.5)	4.52 ± 0.16 (27.5)	21.02 ± 0.17 (80.3)	5.17 ± 0.16 (19.7)
Background 2	10.75 ± 0.36 (70.8)	4.46 ± 0.04 (29.2)	13.79 ± 0.40 (54.5)	11.54 ± 0.55 (45.5)
Buffer	10.00 ± 0.19 (76.5)	3.11 ± 0.08 (23.5)	15.43 ± 0.16 (76.9)	4.64 ± 0.15 (23.1)
Impact	6.77 ± 0.16 (95.4)	0.31 ± 0.01 (4.6)	9.97 ± 0.30 (98.0)	0.21 ± 0.02 (2.0)

was greater than in the first background zone (Table 2). Significant differences in abundance between habitats according to the Mann-Whitney test were revealed in two zones (Bg1 and Bf) for spiders and in two zones (Bg2 and Bf) for harvestmen (in all these cases, P = 0.0495).

Similar responses to pollutions were also observed in other groups of soil and herpetobiont invertebrates (*Kompleksnaya*..., 1992; Vorobeichik et al., 1994; Butovsky, 2001). In a pine forest near Harjavalta, Finland, no differences in total spider abundance along the gradient of pollution were observed, although differences in the ratio of families were distinct (Koponen and Niemelä, 1995)

The results of two-way ANOVA confirmed that the abundance of spiders is under statistically significant influence of both pollution ($F_{3;16} = 10.81$, $P = 0.0004$) and habitat type ($F_{1;16} = 30.11$, $P = 0.00005$). The respective factors account for 32.3 and 47.9% of the total variance of dynamic density (calculated according to Snedecor). For harvestmen, on the other hand, differences between pollution zones are more important ($F_{3;16} = 15.92$, $P = 0.00005$; 60.4% of variance) than differences between habitats ($F_{1;16} = 8.56$, P = 0.01; 15.3% of variance).

It may well be that harvestmen, having a weak detoxification system, are more vulnerable to the direct impact of pollutants, which explains their low diversity in the polluted zone. Unlike spiders, harvestmen always remain contact with the substrate; they lay eggs directly into soil and are unable to spin webs. Many authors note that concentrations of heavy metals in harvestmen are low, while those in spiders are higher than in other arthropods (Butovsky, 1993; Butovsky and Tanasevich, 1999). It is also known that spiders, unlike harvestmen, are capable of binding and excretion of heavy metals (Eremina and Butovsky, 1997). The results of studies on terrestrial invertebrate communities in the area polluted by the Kosogorsky Metallurgical Plant (Gongalsky et al., 2007) indicate that the taxonomic structure of the herpetobiont community depends mainly on the structure of cenosis, whereas geobionts, which are in close contact with the soil, are directly affected by toxicants.

Abundance is one of the most important characteristics of the herpetobiont arachnid community. Therefore, changes in the variation coefficient for this parameter can provide an idea of evenness in the spatial distribution of arachnids along the gradient of pollution in different habitats.

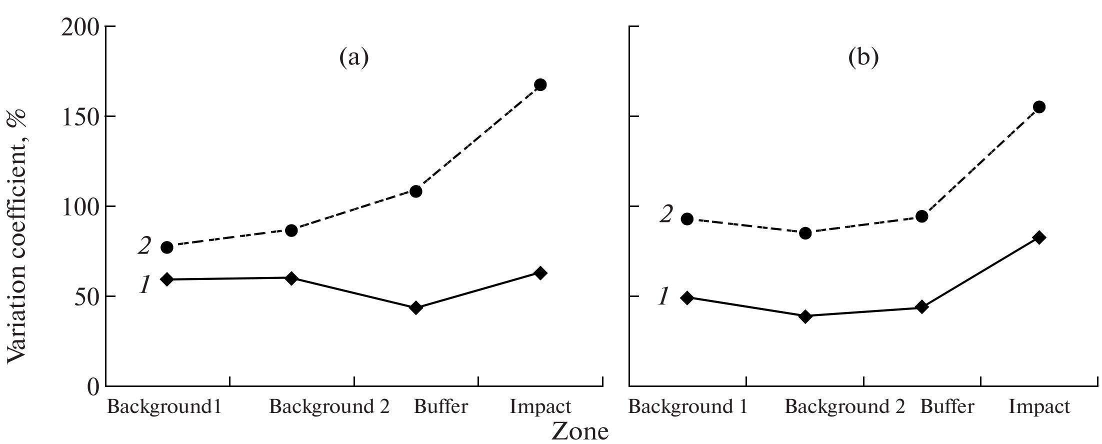

Fig. 1. Coefficients if variation in the abundance of (*1*) spiders and (*2*) harvestmen along the pollution gradient in (a) spruce–fir and (b) aspen–birch forests. The census unit is a sampling plot.

Table 3. Changes in variation coefficient during the season (%, above the line) and in the arachnid abundance (ind./10 trap–days, below the line) along the pollution gradient

Sampling round	Spruce–fir forest				Aspen–birch forest			
	Bg1	Bg2	Bf	Im	Bg1	Bg2	Bf	Im
Spiders								
1	86.03 / 10.0	69.59 / 5.7	49.56 / 9.3	89.02 / 3.2	50.77 / 14.7	36.83 / 7.9	44.09 / 15.5	77.12 / 9.7
2	58.88 / 13.7	66.46 / 11.8	38.50 / 12.3	32.17 / 13.1	36.54 / 18.3	50.98 / 11.6	20.55 / 29.9	48.96 / 18.5
3	70.72 / 3.0	57.79 / 6.6	38.12 / 10.7	48.62 / 8.6	64.83 / 38.9	39.28 / 8.0	48.60 / 14.3	47.67 / 16.2
4	38.22 / 18.6	54.02 / 14.0	50.71 / 8.8	58.98 / 5.8	34.10 / 23.9	31.42 / 16.4	58.34 / 10.1	109.97 / 3.5
5	44.25 / 13.2	54.10 / 15.8	41.96 / 8.8	87.47 / 3.2	60.40 / 9.5	35.96 / 25.3	46.19 / 7.3	124.96 / 1.9
Harvestmen								
1	–	223.61 / 0.1	223.61 / 0.4	–	223.61 / 0.4	154.84 / 3.1	136.93 / 0.8	–
2	114.98 / 2.0	99.64 / 3.1	105.54 / 6.4	–	63.06 / 3.3	52.35 / 19.6	74.11 / 6.6	136.93 / 0.2
3	81.05 / 4.0	51.50 / 7.1	73.69 / 4.4	223.61 / 0.1	58.14 / 6.7	55.48 / 22.9	110.91 / 5.8	–
4	81.00 / 2.1	79.98 / 3.2	94.11 / 2.2	154.66 / 0.8	80.84 / 4.9	86.42 / 3.7	91.84 / 4.8	55.90 / 0.4
5	61.23 / 14.5	72.44 / 8.7	122.48 / 2.0	157.45 / 0.7	81.52 / 10.5	75.68 / 8.5	53.25 / 5.3	211.80 / 0.4

Note: The census unit is a sampling plot; the average value is calculated for three plots for each sampling round.

The evenness of distribution in the aspen-birch forest from Bg1 to Bf is similar in spiders and harvestmen. The situation changes only within 2 km from the smelter, in the impact zone (Fig. 1). In general, the aspen–birch forest is characterized by comfortable conditions for the invertebrate taxa studied, which is confirmed by higher values of arthropod abundance in this habitat than in the spruce–fir forest (Table 2). In the latter, conditions are less favorable, and harvestmen, being sensitive to pollution, show a more abrupt increase in the variation of abundance upon transition from Bg1 to Im. Spiders are less dependent on this factor (due not only to their physiological and biochemical features but also to their species diversity and abundance) and are more evenly distributed along the gradient (Fig. 1, Table 2).

The coefficient of variation in the abundance of the two arachnid taxa changes similarly in both habitats during the season. For instance, it tends to decrease in the Bg1 an Bg2 zones by the end of the season (except for harvestmen in the aspen–birch forest), whereas in the impact zone it has high values both at the start and at the end of the season (except for harvestmen in the spruce–fir forest; Table 3). Differences in variation coefficient between harvestmen and spiders are probably due to the low abundance of the former. The higher abundance of spiders provides for their more even spatial distribution.

Thus, the dynamic density of spiders and harvestmen in the study area decreases closer to the source of pollution. The ratio of families also changes. The family Linyphiidae is dominant among spiders in both habitats, which is typical for forest communities; the family Lycosidae is subdominant; the family Phalangiidae is dominant among harvestmen. The abundance of linyphiids decreases and the abundance of lycosiids increases along the gradient of pollution. Increasing pollution leads to changes in the ratio of life forms among spiders: the proportion of web-spinning species increases, while that of ambush species decreases, which is typical for open habitats. The abundance of harvestmen varies more widely than the abundance of spiders in all pollution zones; the greatest variation between the two arachnid taxa is observed in the impact zone.

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REFERENCES

Aukema, B., Berg, J.H.J., Leopold, A., et al., A Method for Testing the Toxicity of Residues of Pesticides on a Standardized Substrate to Eregonid and Linyphiid Spiders, *J. Appl. Entomol.*, 1990, vol. 109, pp. 76–80.

Bel'skaya, E.A. and Esyunin, S.L., Arachnids (Arachnida) in a Spring Wheat Agrocenosis in Southern Sverdlovsk Oblast and the Effect of Treatment with Decis, a Pyrethroid Insecticide, on Their Populations, *Ekologiya*, 2003, no. 5, pp. 395–398.

Bel'skaya, E.A. and Zinov'ev, E.V., The Structure of Carabid Assemblages (Carabidae, Coleoptera) in Natural and Technogenically Disturbed Forest Ecosystems in Southwestern Sverdlovsk Oblast, *Sib. Ekol. Zh.*, 2007, no. 4, pp. 533–543.

Butovsky, R.O., Heavy Metals in Terrestrial Arthropods, *Agrokhimiya,* 1993, no. 5, pp. 104–112.

Butovsky, R.O., *Ustoichivost' kompleksov pochvoobitayushchikh chlenistonogikh k antropogennym vozdeistviyam* (Resistance of Soil-Dwelling Arthropod Assemblages to Anthropogenic Influences), Moscow: Den' Serebra, 2001.

Butovsky, R.O. and Tanasevich, A.V., Heavy Metals in Spiders (Arthroroda: Aranei), *Agrokhimiya,* 1999, no. 11, pp. 89–96.

Degteva, S.V., Floristic Complexes of Deciduous Tree Species in the Southern and Middle Taiga Subzones of the Komi Republic, in *Razvitie sravnitel'noi floristiki v Rossii: vklady shkoly A.I. Tolmacheva: Mat-ly VI rabochego soveshchaniya po sravnitel'noi floristike* (Development of Comparative Floristics in Russia: Contribution of A.I. Tolmachev's Scientific School. Proc. 6th Workshop on Comparative Floristics), Syktyvkar, 2004, pp. 78–84.

Eremina, O.Yu. and Butovsky, R.O., Biochemical Aspects of the Effects of Heavy Metals on Invertebrates, *Agrokhimiya*, 1997, no. 6, pp. 80–91.

Ermakov, A.I., Structural Changes in the Carabid Fauna of Forest Ecosystems under a Toxic Impact, *Ekologiya*, 2004, no. 6, pp. 450–455.

Esyunin, S.L. and Batalin, A.V., Effect of Irrigation Melioration on the Grassland Spider Assemblage in the Middle Urals, *Vestn. Perm. Gos. Univ.,* 1995, issue 1, pp. 92–101.

Gongalsky, K.B., Filimonova, Zh.V., Pokarzhevskii, A.D., and Butovsky, R.O., Differences in Responses of Herpetobionts and Geobionts to Impact from the Kosogorsky Metallurgical Plant (Tula Region, Russia), *Ekologiya,* 2007, no. 1, pp. 55–60.

Hopkin, S.P., *Ecophysiology of Metals in Terrestrial Invertebrates*, London: Elsevier, 1989.

Hopkin, S.P., Martin, M.H., Assimilation of Zinc, Cadmium, Lead, Cooper, and Iron by The Spider *Dysdera crocata*, a Predator of Woodlice, *Bull. Environ. Contam. Toxicol.*, 1985, vol. 34, pp.183–187.

Kompleksnaya ekologicheskaya otsenka tekhnogennogo vozdeistviya na ekosistemy yuzhnoi taigi (Comprehensive Ecological Assessment of Technogenic Impact on Southern Taiga Ecosystems), Moscow: VNIIResurs, 1992.

Koneva, G.G. and Koponen, S., Density of Ground-Living Spiders (Aranea) near Smelter in Kola Peninsula, *Aerial Pollution In Kola Peninsula: Proceedings of the International Workshop*, Petersburg–Apatity, 1992, p. 365.

Koponen, S. and Niemelä, P., Ground-Living Arthropods along Pollution Gradient in Boreal Pine Forest, *Entomol. Fenn.*, 1995, vol. 6, nos. 2–3, pp. 127–131.

Lakin, G.F., *Biometriya* (Biometrics), Moscow: Vysshaya Shkola, 1990.

Rabitscs, W., Metal Accumulation in Arthropods near a Lead/Zinc Smelter in Arnoldstein, Austria: 3. Arachnida, *Environ. Pollut.*, 1995, vol. 90, no. 2, pp. 249–257.

Rukovodstvo po entomologicheskoi praktike: uchebnoe posobie (Practical Course in Entomology: A Manual), Leningrad: Leningr. Gos. Univ., 1983.

Siepel, H., Meijer, J., Mabelis, A.A., and Boer, M.H., A Tool to Assess the Influence of Management Practices on Grassland Surface Macrofaunas, *J. Appl. Entomol.*, 1989, vol. 108, pp. 271–290.

Tanasevitsch, A.V., The Effect of Metallurgic Smelter Pollution on Spider Communities (Arachnida, Aranei): Preliminary Observations, in *Pollution-Induced Changes in Invertebrate Food-Webs*, Amsterdam, 1999, vol. 2, pp. 89–96.

Vorobeichik, E.L., *Reaktsiya pochvennoi bioty lesnykh ekosistem Srednego Urala na vybrosy medeplavil'nykh kombinatov* (Responses of the Soil Biota of Forest Ecosystems to Emissions from Copper Smelters), Yekaterinburg: Ural. Otd. Ross. Akad. Nauk, 1995.

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

Vorobeichik, E.L., Ermakov, A.I., Grebennikov, M.E., et al., Responses of Soil Macrofauna to Emissions from the Middle Ural Copper Smelter, in *Biologicheskaya rekul'tivatsiya i monitoring narushennykh zemel'* (Biological Recultivation and Monitoring of Disturbed Lands), Yekaterinburg, 2007, pp. 129–149.