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# Arachnids (Aranei, Opiliones) in Meadows: Response to Pollution with Emissions from the Middle Ural Copper Smelter

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**Abstract**—Arachnids living in the herbaceous layer have been studied in 2006–2008 in secondary upland meadows along the gradient of pollution with emissions from the Middle Ural Copper Smelter (Revda, Sverdlovsk oblast). It has been shown that absolute abundance and general diversity decrease with increasing levels of technogenic pressure. Direct toxic effect of heavy metals is especially strong on taxa closely associated with soil and litter; this effect is the most likely cause of the absence of harvestmen near the smelter. The other groups of arachnids are more strongly affected by environmental changes (depletion of species diversity, simplification of architecture of the herbaceous layer, and modification of the hydrothermal regime of this layer) indirectly caused by pollution.

*Keywords*: spiders, harvestmen, meadow communities, diversity, abundance, Middle Urals, copper smelter, industrial pollution, heavy metals, sulfur dioxide

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Metallurgic works in the Ural region are historically concentrated in large industrial centers, which in terms of their effects on the environment can be treated as point sources of pollution. Copper smelters that perform primary smelting of metals emit polymetallic dust and sulfur compounds, causing acidification of precipitation and soil and thus increasing the toxic effects of heavy metals. The Middle Ural Copper Smelter (MUCS) is one of the largest sources of such emissions.

All component of natural ecosystems have undergone transformations in the area affected by MUCS (Vorobeichik et al., 1994). The nature of responses to industrial pollution has been especially thoroughly described in forest invertebrates—herpetobionts (Ermakov, 2004; Zolotarev and Bel'skaya, 2012) and pedobionts (Vorobeichik et al., 2012), including arachnids that belong to these two layer groups. The responses to pollution in the fauna of open habitats, which in the study area are usually of secondary origin associated with human activities, remain rather poorly studied. However, it is known that the species richness of plants (Mirkin et al., 2001) and invertebrates (Lagunov, 1990) is considerably higher in meadow phytocenoses than in forest phytocenoses. In the environs of MUCS, meadow arachnids were partly treated in studies on the responses to pollution in all invertebrates living in the herbaceous layer (Vorobeichik et al., 1994; Nesterkov and Vorobeichik, 2009). Overview of published data clearly shows that changes in arachnids caused by technogenic pollution remain on the whole insufficiently known. We know only a few studies on the responses of arachnids in meadow communities to pollution (Rabitsch, 1995; Hunter et al., 1987; Perner et al., 2003).

Arachnids are predaceous animals of high taxonomic diversity and high ecological plasticity; they display a broad range of responses to environmental changes and various external influences, including technogenic pollution. Resistance to pollutants, including heavy metals, varies among arachnid species, reflecting peculiar features of their mechanisms of accumulation and excretion of toxins (Rabitsch, 1995; Butovskii, 2001). As a result, the responses of the entire arachnid community to pollution are often ambivalent, and these responses should therefore be comprehensively analyzed at the species level. Such analysis is considerably complicated by the insufficient knowledge of ecological preferences of particular invertebrate species (including arachnids) in connection with the species structure of communities in ecosystems of different types.

The purpose of this study was to analyze the responses of arachnids in meadow communities to ling-term pollution with emissions from a copper smelter at different levels of taxonomic resolution (species and family) and in different aspects (taxonomic and functional) of community structure.

## STUDY AREA

The study was performed in the environs of the Middle Ural Copper Smelter (MUCS), located near the town of Revda, Sverdlovsk oblast. The smelter has been in operation since 1940 and is placed among the largest sources of industrial pollution in Russia. The main components of its emissions are $SO_2$ and heavy metals (Cu, Zn, Cd, and Pb). The nature of technogenic transformation of ecosystems was described in detail by Vorobeichik et al. (1994). Samples were taken in the impact, buffer, and background zones (1, 4, and 30 km west of the smelter, respectively) in secondary upland meadows formed in glades of 300–5000 $m^2$ resulting from forest clear-cutting around 60 years ago. The floristic compositions of the meadows strongly differ between the three zones, with more sensitive herb species being replaced by grasses. Characteristic of the background zone are multilayered herb meadows with dense plant cover and a complex architecture formed by branching and intertwining herbaceous plants. The meadows of the buffer zone are herb–grass meadows; characteristics of the plant cover are similar to those in the background meadows. The meadows of the impact zone are of a grass type, with absolute dominance of *Agrostis tenuis*; the architecture and stratification of the plant cover are simplified; the coverage and total biomass are strongly decreased (Khantemirova, 2010). The meadows of the three zones are subject to different agricultural use. Neither hay harvesting nor livestock grazing took place in the study area in 2006–2008. Earlier, until 2004, meadows in the background zone were annually cut for hay in midsummer. Annual hay harvesting was terminated in the buffer zone in the mid-1990s and in the impact zone in the mid-1980s. A more detailed description of the study area was provided by Nesterkov and Vorobeichik (2009).

## MATERIAL AND METHODS

The material was collected in 2006, 2007, and 2008, using a modified Konakov–Onisimova's biocenometer (base area 0.25 $m^2$). Samples of every year were taken in three rounds, in the second half of each summer month; during rains sampling was suspended.

Sampling plots 50 × 50 m in size, three plots per zone, were positioned at distances of 100–300 m from each other. The temperature regime in the herbaceous layer of sampling plots was assessed during the period from July 23 to August 31, 2008 using iButton DS 1921 thermochrons (minimum gradation 0.5°C) mounted on supports at the middle of herbage height in three areas distant from each other in each sampling plot. The points for installing the biocenometer were chosen randomly but at intervals of no less than 5 m. All censuses were taken in the daylight period, approximately from 10 a.m. to 20 p.m. local time. The material was fixed in 70% ethanol. The design of the biocenometer, method and sampling sequence were described in more detail by Nesterkov and Vorobeichik (2009). Ten samples per plot were taken during each round. The invertebrates of each sample were collected from the surface of the meadow equal in area to the base of the biocenometer (0.25 $m^2$). This method made it possible to compare parameters of abundance and density for the studied groups of chortobionts. A total of 810 samples (270 each year) were taken and 3824 specimens of spiders and 333 specimens of harvestmen were collected over the study period. The species were placed in functional groups according to data provided by S.L. Esyunin. Arachnids that could not be identified to species (mostly immature specimens) and therefore could not be placed in any functional group were placed in the category "Unknown".

Three variants of dividing the arachnid community of the herbaceous layer into functional groups are used. The first is based on feeding types: *web-building* (tangle-web spiders and orb-weaver spiders) and *non-web-building* (wandering hunters and ambush predators). Harvestmen were excluded from this classification because of their peculiar biology. The second variant is based on preferences for particular layers of terrestrial ecosystems. According to Lagunov (1994), arachnids occurring in the herbaceous layer can be divided into chortobionts (closely associated with this layer at all stages of their life cycles), chortophiles (species living in other layers, but regularly visiting the herbaceous layer), and "tourists" (species occurring in the herbaceous layer only accidentally). Chortophilous stratobionts, herpetobionts, tamnobionts, and dendrobionts belong to layer-mobile groups that perform regular migrations between layers of terrestrial ecosystems and often make up considerable proportions of arachnids in the herbaceous layer. A priori exclusion of any of these groups can distort conclusions about the structure and diversity of the herbaceous layer. The third variant is based on preferred humidity levels: hygrophiles, mesophiles, and xerophiles.

To estimate the significance of differences between years, rounds, and zones, we used the nonparametric counterpart of ANOVA, the Scheirer–Ray–Hare test (Sokal and Rohlf, 1995). The Shannon (*H*) and Berger–Parker (*B-P*) diversity indices were calculated using the program Past 1.82 (Hammer et al., 2001).

## RESULTS

The temperature regime of the herbaceous layer changed closer to the smelter. The average values of highest daily temperature in meadows in the middle of this layer during the study period were 26.5 ± 1.0°C in the background zone, 26.7 ± 1.0°C in the buffer zone, and 30.0 ± 1.1°C in the impact zone; the average ranges of daily temperatures were 19.0 ± 0.9, 19.7 ± 0.9, and 23.3 ± 1.0°C, respectively.

Zones and sampling rounds significantly differed in the total abundance of arachnids; years had no significant differences in this parameter (Table 1). The

**Table 1.** Results of ANOVA (Scheirer–Ray–Hare test) for differences in abundance of different structural groups of arachnids between zones, years, and sampling rounds (numbers in brackets: df1; df2)

| | Structural group | zone (2; 54) | year (2; 54) | round (2; 54) | zone × year (4; 54) | zone × round (4; 54) | year × round (4; 54) |
|---|---|---|---|---|---|---|---|
| | Taxonomic | | | | | | |
| | Spiders | 27.4*** | 2.9 | 13.4** | 2.8 | 1.4 | 5.1 |
| | Harvestmen | 7.1** | 0.6 | 26.3*** | 0.2 | 0.7 | 0.6 |
| | All arachnids | 31.1*** | 3.1 | 14.3*** | 1.7 | 2.9 | 4.1 |
| | Functional | | | | | | |
| LF | Web-building | 22.6*** | 6.6* | 14.5*** | 3.3 | 0.6 | 2.6 |
| LF | Non-web-building | 41.0** | 0.7 | 5.9* | 0.9 | 6.9 | 1.6 |
| LG | Stratobionts | 6.8* | 10.8** | 9.1** | 1.5 | 6.5 | 12.7** |
| LG | Herpetobionts | 34.4*** | 2.1 | 1.3 | 1.0 | 7.9 | 0.7 |
| LG | Chortobionts | 33.8*** | 8.5** | 2.7 | 1.5 | 7.7 | 2.1 |
| LG | Thamnobionts | 4.3 | 6.0 | 3.5 | 7.0 | 2.2 | 5.5 |
| LG | Dendrobionts | 11.3** | 2.0 | 5.5 | 5.1 | 3.3 | 11.5* |
| HG | Hygrophiles | 36.0*** | 1.1 | 1.8 | 3.2 | 5.1 | 2.4 |
| HG | Mesophiles | 11.7** | 2.3 | 0.6 | 11.1* | 0.5 | 6.8 |
| HG | Xerophiles | 41.9*** | 5.8 | 4.0 | 0.4 | 5.9 | 2.5 |

* LF, life form; LG, layer group; HG, humidity-related group; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

abundance of spiders in the background and buffer zones was similar and 1.7 times as high as in the impact zone. The abundance of harvestmen in the background zone was 3.0 times as high as in the buffer zone; in the herbaceous layer of the impact zone no harvestmen were found (Table 2).

### *Taxonomic Structure*

A total of 134 species of spiders (20 families) and seven species of harvestmen (two families) have been recorded in the study area. Ten abundant arachnid families have been recognized; their share in the total abundance of arachnids was 90.9% in the background zone, 93.1% in the buffer zone, and 97.2% in the impact zone (Table 3). The rest of the families have been categorized as "Others": spiders Corinnidae, Dictynidae, Hahniidae, Heteropodidae, Liocranidae, Mimetidae, Miturgidae, Oxyopidae, Pisauridae, Tetragnathidae, and Zoridae; harvestmen Nemastomatidae. All ten abundant families were present in each of the three zones, except Phalangiidae, not found in the impact zone. The proportion of Philodromidae in the total abundance increased closer to the smelter, while the proportions of Lycosidae, Clubionidae, and Phalangiidae decreased. The proportions of the other families changed nonlinearly: the lowest proportions of Salticidae, Theridiidae, and Gnaphosidae were recorded in the buffer zone; the highest proportions of these families were recorded in the impact zone. The highest proportion of Thomisidae was recorded in the buffer zone; the lowest, in the impact zone; in Linyphiidae the opposite pattern was revealed. The lowest proportion of Araneidae was in the background zone; the highest was in the buffer zone (Table 3).

In spiders total species richness and species saturation decreased in the impact zone (Table 2). In harvestmen species richness was similar in the background and buffer zones, but the species saturation in the background zone was 3.3 times as high as in the buffer zone. The degree of dominance increased along the gradient of pollution (*B-P* increased by a factor of 1.1 in the background zone and 1.7 in the impact zone), while diversity decreased (*H* decreased by a factor of 1.1 and 1.7, respectively).

### *Functional Structure*

**Life forms.** Zones and rounds significantly differed in abundance of spiders of both life forms. Years also differed in abundance of "web-building" spiders (Table 1). The proportion of "web-building" spiders increased along the gradient of pollution, peaking in the buffer zone (58.2%) and somewhat decreasing in the impact zone (52.1%). The proportion of "web-building spiders" was similar in all zones in rounds I and II and considerably increased in round III (Table 4).

**Table 2.** Parameters of different arachnid taxa in different zones and sampling rounds (I–III) average in 3 years of study

| Taxon and parameter | Zone and round | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | background | | | buffer | | | impact | | |
| | I | II | III | I | II | III | I | II | III |
| **Spiders** | | | | | | | | | |
| Abundance, ind./m$^2$ | 17.3 ± 1.3 | 19.3 ± 2.3 | 25.9 ± 0.7 | 20.2 ± 2.0 | 20.4 ± 2.0 | 30.2 ± 3.8 | 11.6 ± 1.8 | 9.9 ± 1.0 | 15.2 ± 2.4 |
| Number of individuals collected | 392 | 435 | 575 | 464 | 466 | 680 | 262 | 217 | 333 |
| Species saturation per 0.25 m$^2$ | 1.6 ± 0.1 | 1.2 ± 0.1 | 1.7 ± 0.2 | 1.6 ± 0.2 | 1.1 ± 0.2 | 2.1 ± 0.2 | 1.0 ± 0.3 | 0.6 ± 0.1 | 0.5 ± 0.1 |
| Number of species: | | | | | | | | | |
| round | 54 | 42 | 62 | 57 | 37 | 50 | 34 | 21 | 24 |
| zone | 90 | | | 91 | | | 48 | | |
| **All arachnids** | | | | | | | | | |
| Abundance, ind./m$^2$ | 0.4 ± 0.2 | 4.3 ± 1.2 | 6.4 ± 0.9 | 0.04 ± 0.04 | 0.5 ± 0.2 | 3.1 ± 0.7 | – | – | – |
| Number of individuals collected | 10 | 96 | 145 | 1 | 12 | 69 | – | – | – |
| Species saturation per 0.25 m$^2$ | 0.11 ± 0.04 | 0.7 ± 0.2 | 0.9 ± 0.1 | 0.01 ± 0.01 | 0.11 ± 0.05 | 0.4 ± 0.1 | – | – | – |
| Number of species: | | | | | | | | | |
| round | 3 | 7 | 5 | 1 | 3 | 6 | – | – | – |
| zone | 7 | | | 6 | | | – | | |
| **Spiders** | | | | | | | | | |
| Shannon index: | | | | | | | | | |
| round | 2.5 ± 0.1 | 2.30 ± 0.05 | 2.3 ± 0.1 | 2.3 ± 0.1 | 1.9 ± 0.2 | 2.2 ± 0.1 | 1.5 ± 0.3 | 1.3 ± 0.3 | 1.3 ± 0.2 |
| zone* | 2.4 ± 0.1 | | | 2.1 ± 0.1 | | | 1.4 ± 0.1 | | |
| Berger–Parker index: | | | | | | | | | |
| round | 0.17 ± 0.02 | 0.24 ± 0.02 | 0.34 ± 0.04 | 0.23 ± 0.02 | 0.3 ± 0.1 | 0.29 ± 0.04 | 0.4 ± 0.1 | 0.4 ± 0.1 | 0.5 ± 0.1 |
| zone* | 0.25 ± 0.02 | | | 0.29 ± 0.03 | | | 0.4 ± 0.1 | | |

Dash indicates absence; data for abundance, number of species, diversity indices, and dominance include average value ± error of average, $n = 9$ (* census unit: year × round × plot; $n = 27$).

**Table 3.** Percentage of the most abundant arachnid families in the total abundance of arachnids in different zones and sampling rounds on average in 3 years of study

| Family | Zone and round | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | background | | | buffer | | | impact | | |
| | I | II | III | I | II | III | I | II | III |
| Linyphiidae | 31.3 | 28.9 | 31.7 | 46.5 | 47.3 | 48 | 38.3 | 34.3 | 58.1 |
| Lycosidae | 20.6 | 16.3 | 11.9 | 21.9 | 14.7 | 10 | 16.9 | 7.4 | 4.8 |
| Salticidae | 14.4 | 9.4 | 9 | 6.3 | 9.9 | 5.7 | 25.3 | 29.2 | 16.3 |
| Phalangiidae | 2.6 | 17.3 | 18.7 | 0.2 | 2.5 | 9.2 | 0 | 0 | 0 |
| Thomisidae | 4.0 | 4.7 | 5.6 | 6.7 | 8.8 | 8.7 | 3.1 | 6 | 2.7 |
| Clubionidae | 7.2 | 7.2 | 8.9 | 3.5 | 1.9 | 3.2 | 0.8 | 0.5 | 0.3 |
| Philodromidae | 2.5 | 2.8 | 2.8 | 1.9 | 4.2 | 3.5 | 6.1 | 10.1 | 8.5 |
| Araneidae | 1.2 | 3 | 2.6 | 2.6 | 4.6 | 4.5 | 1.5 | 3.2 | 3.3 |
| Theridiidae | 4.0 | 0.9 | 1.3 | 1.5 | 0.8 | 0.4 | 1.9 | 4.2 | 2.4 |
| Gnaphosidae | 0.7 | 0 | 0 | 0 | 0 | 0.1 | 3.4 | 1.9 | 0.9 |
| Others | 11.5 | 9.5 | 7.5 | 8.9 | 5.3 | 6.7 | 2.7 | 3.2 | 2.7 |

**Table 4.** Percentage of functional groups of arachnids in the total abundance of arachnids in different zones and sampling rounds

| | Functional group | Zone and round | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | background | | | buffer | | | impact | | |
| | | I | II | III | I | II | III | I | II | III |
| LF | Web-building | 40.8 | 41.9 | 46.1 | 55.6 | 56.1 | 61.3 | 42.2 | 41.8 | 66.2 |
| | Non-web-building | 59.2 | 57.6 | 53.7 | 43.7 | 43.5 | 38.4 | 57.4 | 57.7 | 33.2 |
| | Unknown | – | 0.5 | 0.2 | 0.7 | 0.4 | 0.3 | 0.4 | 0.5 | 0.6 |
| LG | Stratobionts | 12.5 | 7.7 | 12.4 | 17.5 | 10.8 | 16.0 | 27.6 | 13.1 | 10.8 |
| | Herpetobionts | 17.5 | 25.5 | 22.4 | 15.6 | 11.5 | 13.2 | 15.3 | 12.2 | 5.2 |
| | Chortobionts | 26.0 | 21.5 | 16.4 | 15.1 | 23.3 | 23.7 | 19.5 | 13.1 | 10.8 |
| | Thamnobionts | 1.5 | 1.32 | 1.24 | 0.9 | 0.9 | 1.2 | 0.4 | 0.9 | 1.8 |
| | Dendrobionts | 2.0 | 0.2 | 0.4 | 0.2 | – | – | 0.4 | – | 0.3 |
| | Unknown | 40.5 | 43.8 | 47.2 | 50.7 | 53.5 | 45.9 | 36.8 | 60.7 | 71.1 |
| HG | Hygrophiles | 6.8 | 6.8 | 5.5 | 9.7 | 3.4 | 6.0 | 2.3 | 1.8 | – |
| | Mesophiles | 48.0 | 45.7 | 44.5 | 35.3 | 39.2 | 45.8 | 36.4 | 19.4 | 15.7 |
| | Xerophiles | 4.8 | 3.8 | 2.6 | 4.4 | 3.8 | 2.0 | 22.6 | 17.1 | 12.2 |
| | Unknown | 40.4 | 43.7 | 47.4 | 50.6 | 53.6 | 46.2 | 38.7 | 61.7 | 72.1 |

LF, life form (feeding type); LG, layer group; HG, humidity-related group. Dash indicates absence.

**Layer groups.** Zones significantly differed in abundance of layer groups (except thamnobionts). Rounds significantly differed only in abundance of stratobionts; years significantly differed only in abundance of stratobionts and chortobionts (Table 1). The most abundant layer groups in the herbaceous layer were chortobionts, herpetobionts, and stratobionts. Dendrobionts and tamnobionts were facultative members of this community (their total share was at most 3.5%) and therefore excluded from analysis. The proportion of stratobionts increased along the gradient of pollution from 10.9% in the background zone to 15.0% in the buffer zone and 16.7% in the impact zone. By contrast, the proportion of herpetobionts decreased: 22.2% in the background zone, 13.4% in the buffer zone, and 10.3% in the impact zone. The proportion of chortobionts was 20.4% in the background zone, somewhat higher (21.2%) in the buffer zone, and lower again (14.2%) in the impact zone.

**Humidity-related groups.** Zones significantly differed in abundance of humidity-related groups of arachnids (Table 1). The proportions of all three groups in the background and buffer zones were similar (Table 4); in the impact zone, the proportions of hygrophiles and mesophiles strongly decreased (from 6.3% to 1.2% and from 41.1% to 23.2%, respectively), while the proportion of xerophiles strongly increased (from 3.2% to 16.8%).

## DISCUSSION

The abundance and diversity of chortobiont arachnids decreases with increasing levels of technogenic pollution. Similar changes were already recorded in the MUCS area in the course of earlier studies. A complex study on chortobiont invertebrates performed in 1989 revealed a considerable decrease in the proportion of spiders in the impact zone (Vorobeichik, Sadykov, and Farafontov, 1994). Data from 2006–2007 give evidence of clearly decreased abundance of Phalangiidae in the buffer zone. At the same time, Nesterkov and Vorobeichik (2009) could not reveal any clear trend of changes in abundance along the gradient of pollution for spiders (by the example of Salticidae).

Similar trends have been found in arachnids of other layers. A strong decrease in dynamic density was recorded among herpetobionts of forest biotopes: in the impact zone for spiders and even farther from the smelter, in the buffer zone, for harvestmen. Dynamic density decreased closer to the smelter in Clubionidae and Linyphiidae and increased in Gnaphosidae and Lycosidae (Zolotarev, 2009). Among soil macroinvertebrates, density was shown to decrease in Theridiidae, Linyphiidae, Lycosidae, and Clubionidae in the impact zone and in harvestmen in the buffer zone (Vorobeichik et al., 2012). At the same time, in spite of the differences in trends of changes in abundance, taxa of higher rank (families and orders), with few exceptions, were represented in all above-given examples in all three zones. At the same time, zones considerably differed in species compositions. Thus, 37 spider species were recorded among soil macroinvertebrates in the background zone; 26 of them disappeared in the impact zone, but two others appeared (Vorobeichik et al., 2012).

These changes in the taxonomic structure of arachnids are apparently related to effects of technogenic pollution. The likely causes of these changes include, first, direct effects of toxic components of emissions (toxic effect), and second, indirect effects of pollution through environmental changes (environmental effect). In the latter category we include changes in phytocenosis structure and combinations of microclimatic conditions.

The nature of the toxic effects of pollutants on particular arachnid species is largely determined by their peculiar ecological preferences, which can be partly characterized by their life forms and layer groups. Direct toxic effect is probably more pronounced in those spider species that live in close contact with soil. In the environs of metallurgical works in Avonmouth, England, the abundance of such wandering hunters as Lycosidae in polluted areas decreased, and near the source of emissions these spiders completely disappeared, while the abundance of Linyphiidae, Agelinidae, and Theridiidae, which build nets and seldom touch the soil, considerably increased closer to the works (Read, Martin, and Rayner, 1998). The soil macroinvertebrates of the impact zone of the MUCS included only "web-building" spiders (Vorobeichik et al., 2012). The active mode of life of wandering spiders probably facilitates accumulation of heavy metals and decreases glutathione levels and activity of detoxicant enzymes (Wilczek et al., 2004).

"Web-building" spiders are dominant among chortobionts in the buffer zone. This is probably explained by the increased total abundance of invertebrates in this zone, including potential food of spiders. The abundance of spiders of both life forms in the impact zones is comparable. This proportion results from simultaneous stimulation (increased abundance of potential prey) and suppression (toxic and environmental effects) of spiders in the polluted area. The toxic effect is especially strong on harvestmen, which lay their eggs directly into soil or litter, rather than into web cocoons, and, in contrast to spiders, consume not only the liquid content of their prey, but also fragments of integument, which can contain dust particles with absorbed metals (Zolotarev, 2009). The absence of harvestmen in the impact zone is therefore probably caused by toxic effect. Dependence of the nature of response to pollution on the degree of association with soil has also been revealed in other invertebrates of the herbaceous layer. For instance, terrestrial gastropods, closely associated with upper soil horizons, are also absent in the impact zone of MUCS because of peculiar features of their locomotion and feeding (Nesterkov and Vorobeichik, 2009). In the area affected by the Kosaya Gora Iron Works (Tula, Russia) geobiont forms of ground beetles were shown to respond to pollution more strongly than herpetobiont forms (Gongal'skii et al., 2007).

The environmental effect of pollutants on arachnids is determined mainly by changes in plant communities. The abundance and species richness of meadow phytocenoses decrease and their architecture becomes considerably simpler along the gradient of pollution with emissions from MUCS (Khantemirova, 2010), strongly increasing the range of temperature changes in the herbaceous layer.

The thinning herbaceous layer and changes in its temperature regime can be viewed as a kind of aridization of microclimatic conditions, reflected in proportional changes in humidity-related groups of spiders. Closer to the source of pollution, the abundance of mesophiles and hygrophiles decreased, while the abundance of xerophiles increased (Table 4). Of the 48 species recorded by us in the impact zone, 37.5% prefer arid habitats (steppe–meadow, meadow–steppe, and forest–steppe biotopes). The increased proportion of stratobionts in the impact zone (from 10.9 to 16.7%), surprising in the light of their above-mentioned close association with litter, is explained by the dominance of xerophilous stratobionts near the smelter: the dominant *Minicia marginella* (Wider) and the codominant *Sibianor larae* Logunov.

The thinner herbaceous layer of the impact zone is potentially favorable to spiders and usually leads to their increased abundance. However, our study has revealed a considerable decrease in their abundance along the gradient of pollution. We explain this decrease by the decreased accessibility of food. The prey of herpetobiont spiders largely consists of springtails and other detritophagous insects (Sanders and Planter, 2007). The abundance and diversity of springtails in the impact zone and in the litter of forest areas adjacent to the studied meadows are strongly decreased (Kuznetsova, 2009). No such studies have been performed in meadow areas, but it can be expected that the response is similar.

The meadow communities of the impact zone demonstrate a very strongly pronounced monodominance tendency: the herbaceous layer is dominated by only one grass species, making the community somewhat similar to agrocenoses. However, agrocenoses are free of pronounced effects of industrial pollution, and therefore, if they are not treated with insecticides, their structure can be considered the strongest factor affecting their invertebrate communities. It is known that changes in the species composition, diversity, and architecture of the herbaceous layer of meadows lead to changes in the structure of both phytophagous and predaceous communities (Woodcock et al., 2007). Many observations of natural ecosystems and many experiments have shown that the species composition and diversity of vegetation are the principal determinants of the structure and diversity of the invertebrate community (Reid and Hochuli, 2007). Grass associations, typical of agrocenoses and the impact zone of MUCS, are distinguished by vertical linear organization, weak branching of stems, and narrow leaves, which simplifies the whole architecture of the herbaceous layer. The diversity of microstations accessible to invertebrates in such communities is strongly decreased (Reid and Hochuli, 2007; Woodcock et al., 2007). This conclusion is also indirectly confirmed by the considerably greater species diversity of spiders in cotton, alfalfa, and soy agrocenoses, the architecture of which is more complex, compared to grass agrocenoses (Uetz et al., 1999).

Changes similar to those observed in impact meadows have been documented also in agrocenoses: the general diversity decreases, while the abundance of phytophagous insects increases (Bei-Bienko, 1961); in grass monocultures, aridization of the microclimate takes place, leading to an increased proportion of xerophilous arachnid species (Seifulina and Chernyshev, 2001). The abundance and diversity of arachnids in agrocenoses only decreases with time, in spite of the gradually increasing abundance of their potential prey (Kirilenko, 1984). In agrocenoses of the Southern Urals, the diversity of arachnids was higher in the culture of the legume *Onobrychis sibirica* (Sirj.) and lower in the culture of the grass *Bromus inermis* Leys. (Chichkov, 2001). It should also be noted that harvestmen are common in most agrocenoses (Chichkov, 2001), but completely disappear in the herbaceous layer of the impact zone of the MUCS. This is an additional argument in favor of the above-given suggestion that this taxon has an increased sensitivity to the toxic effect of pollutants.

## CONCLUSIONS

This study is part of a complex project for investigating invertebrate communities of the herbaceous layer in a zone affected by a large copper smelter. As technogenic pressure increases, absolute abundance and general diversity of arachnids living in the herbaceous layer considerably decrease. In the communities of the most strongly polluted area, the proportion of xerophilous species and abundance of stratobiont spiders increase, while harvestmen entirely disappear.

The effects of industrial pollution on arachnids can be either direct (toxic effect) or indirect, through environmental changes (environmental effect). The toxic effect is especially strong on arachnids closely associated with soil and litter (harvestmen), substrates with the highest levels of pollutant deposition. The environmental effect through depletion of species diversity, simplification of architecture of the herbaceous layer, and modification of the hydrothermal regime in this layer can be considered the principal effect of pollution on most groups of arachnids.

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