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Changes in the Trophic Activity of Leaf-Eating Insects in Birch along the Pollution Gradient near the Middle Ural Copper Smelter

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Abstract—Foliar damage to white birch (*Betula pubescens*) caused by leaf-chewing insects and miners was assessed in 2005, 2006 and 2008 in the vicinity of a large copper smelter in the Middle Urals (Revda, Sverdlovsk oblast). The following indices were considerably smaller near the smelter than in the background and buffer zones: the overall leaf area removal (3–11 times), proportion of damaged leaves (up to 4 times), and average area removed per damaged leaf (2 times). The effect sizes were similar for all three parameters and remained stable with time. Both groups of leaf pests showed lower trophic activity in the impact zone, but the effects of pollution for leaf-chewing insects were greater than for miners.

Keywords: leaf-chewing insects, miners, white birch, trophic activity, copper smelter, industrial pollution, heavy metals, Middle Urals

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INTRODUCTION

Atmospheric emissions of large industrial enterprises, especially plants with primary smelting of nonferrous metals, have a negative impact on the environment. As a result of longstanding pollution, vast technogenic geochemical anomalies are formed around them; high levels of the toxic load can dramatically alter the structure and functioning of terrestrial biota. Impact regions, i.e., complex of ecosystems located near the point source of emission of pollutants and exposed to its emissions, are convenient model objects for solving many theoretical and practical issues of ecology (Vorobeichik and Kozlov, 2012). These include an analysis of resistance to external influences of trophic interactions in the "plant–phytophagous" system.

Although the impact of air pollution on leaf-eating insects has been studied for a long period of time (Alstad et al., 1982; Heliövaara and Väisänen, 1993), surprisingly little is known about the change in the trophic activity of the group in terms of pollution, especially outside the period of outbreaks (Zvereva and Kozlov, 2010). In addition, most of the results were obtained for phytophagous of coniferous species (Zvereva and Kozlov, 2010). Prior to the 1990s, the idea of increasing abundance of leaf-eating insects in the vicinity of point sources of industrial emissions was dominant (Alstad et al., 1982; Heliövaara and Väisänen, 1993). Subsequent studies showed that this conclusion cannot be considered universal: both positive and negative effects of pollution were documented, as well as absence of reaction (Kozlov et al., 2009; Zvereva and Kozlov, 2010). This determines the importance of finding the reasons for this diversity of reactions of leaf-eating insects, which requires the accumulation of more information—both concerning different types of host trees and various impact regions. In this search special efforts should be directed to analysis of the variability of foliar damage at different spatial scales: individual, biotopic, local, and geographic (Bogacheva, 1990). In addition, direct comparisons (i.e., within the same study area) of trophic activity of leaf-eating insects occupying different types of host trees are important.

The impact region of the Middle Ural Copper Smelter (MUCS) is well studied with respect to the response to pollution of many invertebrate groups: herpetobionts (Ermakov, 2004; Belskaya and Zinoviev, 2007), geobionts (Vorobeichik, 1998; Vorobeichik et al., 1994, 2012), chortobionts (Nesterkov and Vorobeichik, 2009; Nesterkov 2013), and necrobionts (Ermakov, 2013). However, the reaction of dendrobionts is well documented only for leaf-eating insects of aspen (Belskaya and Vorobeichik, 2013). The trophic activity of leaf-eating insects of white birch in the impact zone of MUCS was assessed only by proportion of damaged leaves and only in one year (Kozlov et al., 2009).

Long-term studies are of great importance because they allow to estimate reliably the effect of pollution by separating it from a variety of other factors. Studies of this kind are particularly in demand in the context of the analysis of the possible restoration of ecosystems after reducing industrial emissions. First, they form a

Table 1. Concentrations (μg/g, dry weight) of metals in birch leaves (total content) and in forest litter (movable forms) at different distances from the smelter

Metal	Distance from smelter, km		
	27	6	1
	Leaves (data of 2008)		
Cu	5.2 ± 0.2**	10.2 ± 0.3**	74.9 ± 4.1
Pb	2.9 ± 0.3**	20.2 ± 0.8**	263.9 ± 43.5
Fe	141.8 ± 4.0**	145.6 ± 5.2**	508.8 ± 29.7
Zn	311.1 ± 13.0**	698.7 ± 33.6**	1124.7 ± 7.1
Cd	0.7 ± 0.01**	1.6 ± 0.1**	5.9 ± 0.6
	Forest litter (data of 2004)		
Cu	18.7 ± 0.5**	867.5 ± 69.5*	3787.9 ± 266.3
Pb	46.1 ± 1.9**	676.2 ± 23.8*	2157.6 ± 91.1
Fe	898.2 ± 100.9**	1809.9 ± 107.3**	5003.4 ± 481.0
Zn	310.5 ± 8.2**	798.4 ± 48.0*	1884.9 ± 90.0
Cd	2.6 ± 0.1**	23.6 ± 1.1	38.2 ± 1.8

Mean ± SE is given; experimental unit: for litter: sample ($n = 30$) and for leaves: tree ($n = 30$).
Significance of difference from the impact site: $*p < 0.05$; $**p < 0.01$ (Tukey multiple comparison test).

“reference point” for future monitoring studies and, second, the registration within several years allows us to evaluate the scale of interannual variability, which is necessary to separate long-term trends from short-term fluctuations.

The purpose of this work is to analyze changes in the trophic activity of leaf-eating insects of white birch along the pollution gradient of the Middle Ural Copper Smelter.

MATHERIALS AND METHODS

Foliar damage of white birch (*Betula pubescens* Ehrh.) was recorded in 2005, 2006, and 2008 within the impact area of the Middle Ural Copper Smelter (MUCS) located on the outskirts of the city of Revda (Sverdlovsk oblast), 50 km west of Yekaterinburg. MUCS is one of the largest enterprises of nonferrous metallurgy in Russia; it has been in operation since 1940, blowing sulfur and nitrogen oxides, fluorine compounds, and polymetallic dust into the atmosphere (Cu, Pb, Cd, Zn, Fe, and others). The maximum level of emissions fell in the 1980s, reaching 140 000–200 000 t per year (Yusupov et al., 1999). Beginning in the late 1990s, emissions gradually decreased: in 2005 they amounted to 27 500 t, in 2008 they were 24 100 t (*O sostoyanii*, 2006, 2009). According to the content of metals in soil and snow, as well as the state of higher vegetation, three zones of pollution had been previously identified: impact up to 3 km west of the pollution source, buffer from 3 to 7 km, and background further than 7 km (Vorobeichik et al., 1994).

The material was collected at three sites at different distances from the smelter, each with an area of about 10 ha. At all sites, an aspen–birch forest of different plant associations is represented: in the background (27 km west of MUCS) and buffer (6 km west) zones mixed herbs and *Calamagrostis obtusata* Trin. dominate; in the impact zone (1 km southwest) *Agrostis tenuis* Sibtb. dominate. In each site 30 single (usually along the forest roads and glades) well-lighted trees of about the same height (5–10 m) were randomly selected. Within this site, the trees were located at a distance of no less than 10–20 m from each other; particular trees did not coincide in different years. In late July to early August (i.e., when the foliar damage reflected cumulative effect caused by insects during spring and summer), one branch of 20–30 cm long was cut off the south side of each tree 1.5-2.0 m above the ground (on average, with about 40 leaves) and subsequently examined in a laboratory. Such an approach was used to reduce the variation in the degree of foliar damage, depending on differences in microclimate within the site and within the tree crown, and to minimize the indirect effect of pollution via the thinning of the stand in the impact zone. Both the collection of the material and assessment of damage were done by the same person. During the 3-year study period, a total of 9282 leaves from 270 trees were examined.

Three types of damage were distinguished: (1) hole feeding, (2) window feeding, and (3) mines. The results of gall counts are not considered in this study (i.e., a leaf with galls having no other damage was considered intact). For each leaf, the damage score was estimated separately for all three damage types. The scale by

Table 2. Indices of total (mean ± SE) foliar damage of white birch in different years and at different distances from MUCS

Year	Distance from smelter, km		
	27	6	1
Overall leaf-area removal, %			
2005	5.9 ± 0.7*	10.0 ± 1.7*	0.9 ± 0.2
2006	2.7 ± 0.3*	3.8 ± 0.6*	0.7 ± 0.1
2008	4.6 ± 1.0	5.0 ± 0.6*	1.5 ± 0.2
AVG	4.4 ± 0.9 (36.2)	6.2 ± 1.9 (52.8)	1.0 ± 0.2 (40.4)
Extensity, %			
2005	76.7 ± 3.2**	76.4 ± 3.2**	19.1 ± 2.6
2006	68.0 ± 3.5**	72.7 ± 3.9**	32.4 ± 3.4
2008	74.2 ± 3.5**	84.9 ± 2.9**	51.8 ± 3.6
AVG	73.0 ± 2.6 (6.1)	78.0 ± 3.6 (8.0)	34.4 ± 9.5 (47.8)
Intensity, %			
2005	7.5 ± 0.9	12.2 ± 1.8*	5.1 ± 1.3
2006	3.9 ± 0.4	4.9 ± 0.5*	2.1 ± 0.2
2008	5.7 ± 1.1	5.6 ± 0.6*	3.0 ± 0.4
AVG	5.7 ± 1.0 (31.7)	7.6 ± 2.3 (53.8)	3.4 ± 0.9 (45.5)

Experimental unit for each year of study: tree ($n = 30$). AVG: mean ± SE between years ($n = 3$); coefficient of variation (%) characterizing interannual variability is in parentheses.
Significance of difference from the impact site: $*p < 0.05$; $**p < 0.01$ (Tukey multiple comparison test).

Bogacheva (1979) was used: (0) no damage, (1) one small hole, (2) up to three larger holes or several smaller ones, (3) several large holes cut into principal veins, (4) multiple damage with less than 50% removal of leaf area, (5) more than 50% removal of leaf area, and (6) 100% removal of leaf area (only petiole left). Damage scores of the second and third type were determined by the same scale taking into account the size of window feeding or mining area. The first type of damage belongs exclusively to open-living leaf-eating insects; the third one belongs to miners. Damage of the second type is caused by both open-living larvae and feeding on the leaf surface in shelters, including those which change mode of life during individual development. Younger larvae of these species feed in the mine and older ones on the surface of a leaf in shelters.

To evaluate the relationship between the damage score and the percentage of the removed leaf lamina, leaves with damage scores of 1 to 4 with a maximum well-preserved contour were selected; they were scanned after drying under press. The images were processed in the program SIAMS Photolab (http://www.siams.com) to estimate for each leaf its total area, value of area removed from it, and percentage of leaf area removed. Since the leaves with the 5th score were presented by only solitary fragments, the removal was calculated as the difference between the average area of the intact leaf and the area of fragment. The average percentage of removal was used in subsequent calculations (mean ±SE): 1 score,0.8 ± 0.1% ($n = 32$); 2, 2.2 ± 0.2% ($n = 53$); 3, 10.6 ± 0.8% ($n = 31$); 4, 35.8 ± 4.7% ($n = 14$); and 5, 84.9 ± 1.9% ($n = 9$).

In all cases, one tree was taken as an experimental unit for data analysis. Three parameters of foliar damage were considered: overall leaf-area removal (C, the proportion of removed area taking into account all analyzed leaves, both damaged and undamaged), extensity (E, the proportion of damaged leaves, regardless of the degree of damage), and intensity (S, the proportion of removed area only in damaged leaves). Both total damage (by the whole assemblage of leaf eaters) and separately by two groups (leaf-chewing insects and miners) were estimated. Separation of leaf-eating insects on these groups was carried out based on the mode of life of larvae: the first group includes mainly insects feeding on the leaf surface (open-living and using the cover) and the second includes insects living inside the leaf. Damage caused by leaf-eating insects with mixed mode of life were distributed between the two groups in accordance with the mode of life of the larvae: damage caused by younger larvae living in the mines was attributed to miners, and damage caused by the same larvae after leaving the mines (window feeding on leaf surface in shelters) was attributed to leaf chewers.

Average values of damage in different sites and years were compared by heteroscedacity consistent

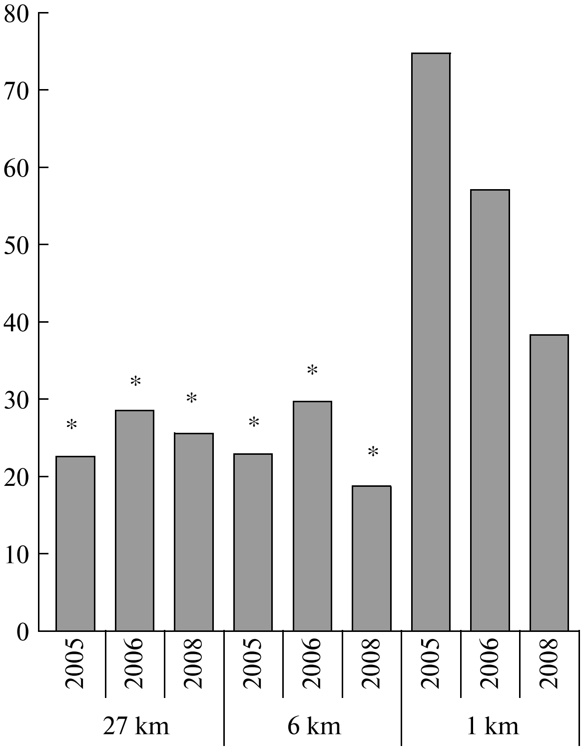

Fig. 1. Coefficient of variation (%) of extensity of foliar damage of white birch at different distances from the plant.

Along the abscissa axis are years and distance from the smelter. Experimental unit for each year: tree ($n = 30$). *Significance of difference from the impact site ($p < 0.01$) (pairwise comparisons with a z-test).

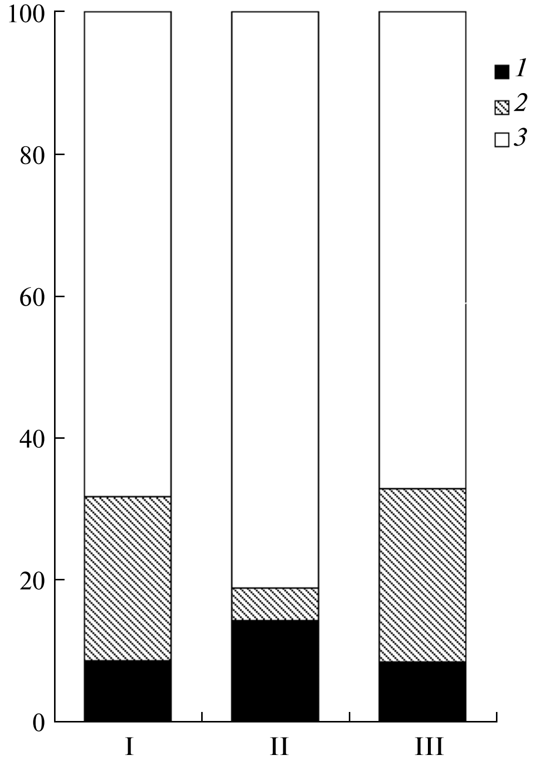

Fig. 2. Components of variance in the overall leaf-area removal by (I) leaf-chewing insects, (II) miners, and (III) both groups.

Proportion of variance is along the ordinate axis (%).

Proportions of variance determined by differences between (*1*) years, (*2*) pollution zones, and (*3*) residual variance are shown.

two-way ANOVA with White–Huber correction for heterogeneity of variance, algorithm HC3 (Long and Ervin, 2000). Multiple comparisons were made by the Tukey test; variance was partitioned into components according to Snedecor. To estimate the variability of indices, the variation coefficients were used, which were compared by z-test, an analog of Student's t-test (Zar, 2010). In addition to ANOVA, the effect of pollution was estimated by calculating the mean effect size (ES) according to Hedges (Borenstein et al., 2009): the data were averaged by years using a model with random effects; confidence intervals were determined by bootstrapping (10 000 iterations) and the significance of interannual heterogeneity (Q) was estimated using χ^2 distribution. Calculations were made in the program MetaWin v. 2.0.

Leaves for chemical analysis (ten leaves per tree) were sampled in 2008 from the same trees used for damage assessment.The petioles were removed, and the leaves were dried at 60°C. Leaves from the same tree were pooled into one sample (on average 0.1 g air-dry weight, measured to a nearest 0.001 g), which was digested in a mixture of 7 mL concentrated HNO_3 and 1 mL deionized H_2O in a Teflon bomb in a MWS-2 microwave digestion system (Berghof, Germany). Forest litter pollution was assessed in 2004: 30 samples evenly spaced over the area were selected from each site. The extraction of mobile forms of metals was performed with 5% HNO_3 (ratio of litter to the same extractant by mass is equal to 1 : 10; extraction time is 24 h after a single shaking). Concentrations of metals (Cu, Pb, Cd, Zn, and Fe) were measured with an AAS 6 Vario atomic absorption spectrometer (Analytik Jena, Germany). Our laboratory is certified for technical competence (certificate no. ROSS RU.0001.515630). A total of 90 samples of leaves and forest litter were analyzed.

RESULTS

The level of pollution in the study area, estimated from the concentrations of metals in the forest litter and in birch leaves, increased with a decrease in distance from the source of emissions (Table 1). An increase in concentrations in leaves was observed for both biogenic (Cu, Zn, and Fe) and toxic (Pb and Cd) elements. As was expected, the content of metals in forest litter was considerably higher than in leaves. For both substrates, metal concentrations in the impact zone were higher compared to other sites. The concentration of copper in the litter of the impact zone exceeded the background level 203 times, that of lead 47 times, that of cadmium 15 times, and that of iron and zinc 6 times. In leaves compared to litter, the impact/background ratio was less for zinc and iron (3.6 times), cadmium (8.4 times), and copper (14.4 times), but more for lead (91 times).

Parameters of total foliar damage of white birch by leaf-eating insects at different levels of pollution are presented in Table 2. Differences in overall leaf-area removal between sites were significant ($F_{2;261} = 71.3$, $p < 0.0001$). The overall leaf-area removal in the impact zone was less (3.1–11.1 times) than in background and buffer sites in all years. In 2005, only the buffer and impact sites differed significantly. The background and buffer sites almost did not differ from year to year. No significant differences in the coefficients of variation of overall leaf-area removal between zones were found.

The values of overall leaf-area removal significantly differed between years ($F_{2;\ 261} = 7.9$, $p = 0.0005$); the interaction "zone pollution × year" was also significant ($F_{4;\ 261} = 5.9$, $p = 0.0001$). In the background and buffer sites, differences were significant between the maximum value of the parameter registered in 2005 and the minimum registered in 2006; at the impact site differences were significant between 2008 (maximum damage) and 2006 (minimum).

Extensity of damage depended both on the zone of pollution ($F_{2;\ 261} = 182.3$), and on the year ($F_{2;\ 261} = 15.0$, $p < 0.0001$), and the interaction of these factors was significant ($F_{4;261} = 8.3$, $p < 0.0001$). From year to year, the proportion of damaged leaves was 1.4–4.0 times lower in the impact territory when compared to the background and buffer sites. The maximum value of extensity in the background area was noted in 2005, and those in the buffer and impact sites were in 2008; minimum values in the background and buffer sites were in 2006 and, in the impact site, in 2005.

Decrease in the extensity of foliar damage in the impact zone was accompanied by an increase in the relative variability between trees: the coefficient of variation in the impact zone was significantly higher (1.5–3.3 times) when compared to the background and buffer zone in all years (Fig. 1).

The intensity of the damage also depended on the zone of pollution ($F_{2;\ 261} = 28.6$) and on the year ($F_{2;\ 261} = 16.7$, $p < 0.0001$), but the interaction of factors was insignificant ($F_{4;\ 261} = 1.2$, $p = 0.304$). In each year the intensity of the damage in the impact site was lower compared to the buffer and background sites (1.5–2.4 times). The highest intensity values in all sites were registered in 2005; the lowest were in 2006. Variability of this parameter in the impact zone was higher than in the background zone only in 2005 ($z = 2.3$, $p < 0.05$).

A comparison of the two sites most contrasting in level of pollution—the background and impact—by the effect size (ES) clearly demonstrated the negative impact of pollution on all indices studied (95% confidential interval in all cases does not include zero). The ES index generalized to all years came to −1.37 (confidential interval −1.74 to −0.79) for overall leaf-area removal, −2.20 (−3.65 to −1.16) for extensity, −0.70 (−1.10 to −0.41) for intensity (in all cases the effect is homogeneous in time ($Q = 1.9$–2.4, $p = 0.299$–0.364)).

Analysis of damage types was based on the separation of leaf-eating insects into two groups: leaf-chewers and miners. In the studied area, the damage caused by leaf-chewing insects was the most common. Miners removed (averaged over 3 years) 0.2 ± 0.1, 0.3 ± 0.1, and 0.1 ± 0.1% of the surface of white birch leaves in the background, buffer, and impact zones, respectively (at an extensity of damage of 10 ± 4, 16 ± 8, and 5 ± 2%, respectively). The overall leaf-area removal caused by leaf-chewing phyllophages equaled 4.2 ± 0.9, 5.9 ± 1.9, and 0.9 ± 0.2% at extensity 70.2 ± 2.8, 74.6 ± 3.1, and 31.7 ± 8.8% respectively. Extensity of damage caused by leaf-eating insects with a mixed mode of life was very small: in the background zone it was 0.1%, in the buffer zone 0.8%, and in the impact zone 0.3%.

Both groups responded to the pollution unidirectionally. In a heavily polluted site, extensity ($F_{2;\ 261} = 176.7$, $p < 0.0001$), intensity ($F_{2;\ 261} = 28.0$, $p < 0.001$), and overall leaf-area removal ($F_{2;\ 261} = 61.1$, $p < 0.0001$) by leaf-chewing insects, extensity ($F_{2;\ 261} = 8.0$, $p = 0.0004$) and the overall leaf-area removal ($F_{2;\ 261} = 24.3$, $p < 0.0001$) by miners decreased significantly.

Variability of the extensity of damage caused by miners in the background site was significantly higher when compared to that of leaf-chewing insects ($z = 5.1$, $p < 0.001$ in 2005; $z = 3.9$, $p < 0.001$ in 2006 and 2008). In the impact site, this pattern remained, but the differences between these groups were less because of the increased coefficient of variation for leaf-chewers compared to the background site ($z = 4.9$, $p < 0.001$ in 2005; $z = 3.0$, $p = 0.01$ in 2006; in 2008, insignificantly, $z = 1.4$, $p > 0.05$) and the lack of significant differences between the background and impact sites in the coefficient of the extensity variation caused by miners.

The differences between sites were more important for leaf-chewing insects, explaining 23% of the variance of overall leaf-area removal, compared to miners (5%) (Fig. 2).

DISCUSSION

The high content of heavy metals in the soil and leaves of white birch of the impact zone determines the high toxic load on the wood vegetation and leaf-eating insects. This allows us to interpret the observed changes in the trophic activity of the complex of leaf-eating insects as a result of direct or indirect effects of pollution caused by emissions from the smelter. The decrease in all indices of foliar damage of white birch in the impact site is consistent with the conclusion of Kozlov et al. (2009) on the generally negative effect of industrial pollution on the trophic activity of leaf-eating insects, which is based on a meta-analysis of own studies of the cited authors around 18 polluters (from 1 to 6 species of trees or shrubs near each polluter, 51 effect in total). The decrease in the proportion of damaged leaves similar to our study was reported in 7 cases out of 18: near aluminium plants in Bratsk, Nadvoitsy, Straumsvik and Volkhov; copper smelters in Harjavalta and Karabash; and an iron-ore dressing in Kostomuksha (Kozlov et al., 2009). In the meta-analysis based on a quantitative processing of a large array of literature data, the opposite conclusion was made: there was a generally positive effect of pollution on leaf-eating insects (Zvereva and Kozlov, 2010). To a certain extent, this conclusion may be due to errors in the methodology of research related to the problem of pseudoreplications and subjective selection of compared sites (Zvereva and Kozlov, 2010), but in any case it shows a considerable diversity in the spectrum of reactions of the group under consideration to industrial pollution.

In our paper (Belskaya and Vorobeichik, 2013) we discussed in detail the possible reasons for the decrease of foliar damage of aspen (*Populus tremula* L.) under high toxic load, among which we mentioned the direct toxic effect of metals on insects, decreased food quality, change in relationships between leaf-eating insects and their natural enemies, and the transformation of phytoclimatic conditions. A decrease in all indices of foliar damage of white birch in the gradient of pollution by emissions of MUCS coincides with the trend for aspen, indicating a similarity in the mechanisms of action of pollutants on complexes of leaf-eating insects of these two tree species.

We noted that the reaction of the whole complex of leaf-eating insects of aspen to pollution in the vicinity of MUCS is determined by leaf-chewing insects: both because of their greater contribution to all indices of damage and greater sensitivity to pollution when compared to miners. This statement is true for leaf-eating insects of white birch: leaf-chewing insects respond to pollution more strongly than miners. Reasons for the different sensitivity of both groups of leaf-eating insects to external factors are described in the literature and, above all, a result of different types of diet and mode of life (Baranchikov and Yermolaev, 1998; Koricheva et al., 1998; Pincebourde and Casas, 2006; Mulder and Breure, 2006; Vehviläinen et al., 2007; Cornelissen et al., 2008). The influence of the year on all indices of foliar damage is small, although significant (the contribution of interannual differences in the variance of the overall leaf-area removal is less than 10%).

It is well known that the level of foliar damage caused by leaf-eating insects depends largely on the characteristics of habitat, above all, the composition and density of a stand determining a phytoclimate (Vorontsov, 1963; Bogacheva, 1990; Yarnes and Boecklen, 2005). At a large number of diverse sites and in the absence of strict standardization in the selection of trees, the spatial variability of damage increases, which can neutralize the effects of pollution. Perhaps this is why Kozlov et al. (2009), who in 2003 studied the trophic activity of leaf-eating insects of white birch in the vicinity of MUCS, have not found any dependence of foliar damage either on the content of heavy metals or on the distance from the smelter. In the cited paper, ten sites in the pollution gradient were surveyed which vary greatly in composition of the stand; in addition, surveys were carried out on small samples of trees (five individuals) located in the center of the site, i.e., in phytoclimate conditions typical for a particular biotope, which is also likely to vary greatly. As for us, we attempted to minimize the local variability by choosing forest sites which are similar in species composition of the stand and by examining only well-lighted single trees. The implementation of this approach allowed us to separate more clearly the effect of pollution from the effects of other factors and showed that the differences between sites (i.e., between different levels of industrial pollution) determine nearly a quarter of the variance of overall leaf-area removal.

In our paper, the focus was on individual variability characterizing the differences between individual trees: we studied a small number of forest sites, but we carried out surveys over large areas (i.e., in many points of a site) and a large number of trees. The study revealed another phenomenon: an increase in the relative variation (coefficient of variation) of extensity of foliar damage between trees along the gradient of pollution. The increased coefficient of variation partly reflects the decreased average extensity in the impact site; nevertheless, the cause of this phenomenon is not only that: although standard deviation decreased in some years from the background zone to the impact zone (see Table 2), but to a much lesser extent than the mean resulting in increased relative variation.

It is logical to assume a positive relationship between the variability of foliar damage and variability of morphological, physiological, and biochemical parameters of host trees, determining the quality of food for leaf-eating insects. It is known that, under unfavorable conditions, including industrial pollution, the variability of morphological features of birches (*Betula pendula* Roth and *B. pubescens* Ehrh.) increases (Makhnev and Mamaev, 1975; Vasfilov, 1988; Franiel and Więski, 2005). The increase in morphological variability may not be associated with an increase in genetic diversity in populations of birch. At least, in canoe birch (*B. papyrifera*), growing on soils polluted with heavy metals, there was no positive relationship between genetic diversity and metal content in the soil and leaves (Theriault et al., 2013). Special studies are necessary to determine particular characteristics of trees responsible for increased variability of foliar damage in the heavily polluted areas.

CONCLUSIONS

In this paper we estimated the effect of industrial pollution on the trophic activity of leaf-eating insects on the white birch in the area near the Middle Ural Copper Smelter. It was shown that the level of pollution explains about a quarter of the variance of overall leaf-area removal. The leading role in the reaction of the whole complex of leaf-eating insects belongs to leaf-chewing insects, which damage a larger proportion of leaves and seize a larger leaf area than miners. It was found that the proportion of damaged leaves and the overall leaf-area removal significantly decrease in the impact site when compared to the background site, while the relative variation of the damage increases. Increasing variability in the proportion of damaged leaves among the trees at a high level of pollution may be due to the increase in the variability of morphological, physiological, and biochemical parameters of the trees.

In a study of leaf-eating insects under conditions of industrial pollution, it is important to standardize the selection of trees by conditions of growth in the compared sites, because, due to the high spatial variability of the trophic activity of leaf-eating insects, microbiotopic differences can mask the effects of pollution.

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