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Ground-Dwelling Invertebrates in a Large Industrial City: Differentiation of Recreation and Urbanization Effects

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Abstract—Community of ground-dwelling invertebrates in natural pine forest of the city Yekaterinburg and its vicinities was studied. The compared sites were contrast in respect of the urbanization (mainly air pollution) and recreation (the frequency of visits). The abundance of the most numerous taxa (ground and road beetles, spiders, harvestmen) increases in the urban sites as compared of to the rural sites. Changes in the species diversity under the influence of urbanization are ambiguous. Decrease in species richness is accompanied by an increased dominance and a decreased dominance in carbides. The evenness of the road beetles population does not change in the urban sites compared to rural sites. Relative low impact of recreation on ground-dwelling invertebrates was evident. Recreation effects were significant in carabids (decreased abundance and species richness under high pressure) and arachnids (increased abundance)

Keywords: urbanization, recreation, ground dwelling invertebrates, Carabidae, Staphylinidae, Aranei, Opiliones

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INTRODUCTION

Urbanization is a complex phenomenon of superordinate factors related to a high population density and economic activity in a limited territory. This group of factors includes industrial and car traffic pollution, recreation, fragmentation of habitats, specific microclimate, introduction of plants, etc. In the end the impact of these factors leads to formation of specific ecosystems different from original ecosystems by many characteristics (Klausnitzer, 1990; McDonnell et al., 1997; Sattler et al., 2011).

There is still strong interest in the impact of urbanization on communities of ground-dwelling invertebrates, although this subject has already been studied for a long time; moreover, new aspects appear which require more careful consideration. For example, one and the same taxons show different reactions in different cities, which is most possibly due to different relations among anthropogenic factors (Niemelä, et al., 2002; Niemelä and Kotze, 2009). The specifics of reactions may be related to a city's geographical position, its area, number of inhabitants, industrial and traffic level, housing density, and type of studied biotope. The problem consists, therefore, in differentiating urbanization factors and defining the extent of their impact on communities of invertebrates, considering the geographical position of the studied territory. One of its possible solutions is to expand the geographical coverage of the studies of the impact of urbanization on communities of terrestrial invertebrates. Most of the studies in the northern hemisphere were performed in Europe and America, in contrast to few studies in Russia (Babenko and Eremeeva, 2007; Semenova, 2008, Sukhodol'skaya et al., 2009), though this country occupies a vast part of firm land.

Recreation is the phenomenon that has been studied in urban ecology most thoroughly by now but its key significance has not been proven. The results presented in most works on evaluating the abundance and diversity of invertebrates in urban sites are related exclusively to recreation (Galinovskii and Aleksandrovich, 2004; Lehvävirta et al., 2006; Semenova, 2008). However, it is also necessary to take into account other factors determining the overall urbanization effect. The contribution of recreation and its relation to other factors and to air pollution, in particular, can be appraised by comparing sites with contrasting levels of these factors. This task is quite realistic because sites with high and low recreational load can be found both, in the city and outside, whereas the impact of pollution is reduced to the city area and is minimal in the suburban area (given sufficient remoteness from motorways and large factories).

In addition, urban environment is characterized by high biotopical diversity, which determines increased diversity of and abundance in invertebrate species. To identify regularities in reactions by invertebrates to some anthropogenic factor in pure form, it is therefore

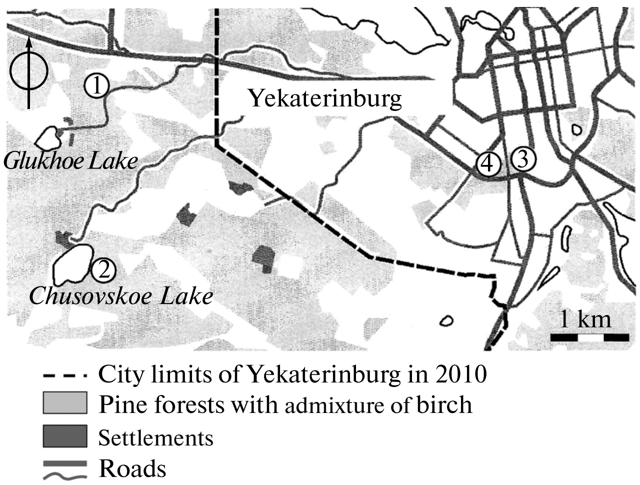

Fig. 1. Location of study sites with different U/R ratios: 1 is the vicinity of Lake Glukhoe (U–R–), 2 is the vicinity of Lake Chusovskoe (U–R+), 3 is the botanic garden (U+R–), 4 is the South-Western woodland park (U+R+).

necessary to minimize natural variation by choosing the same habitats both, in the city and outside.

Another significant problem is to choose an object for research. In many studies on the impact of urbanization on terrestrial invertebrates the attention is given to one or two taxons, mainly ground beetles. There is not much data on reactions of other mass numerous ground-dwelling invertebrates, for example, arachnids or rove beetles (Alaruikka et al., 2002; Shochat et al., 2004; Deichsel, 2006; Magura et al., 2010; Varet et al., 2002). At the same time, these data alone will not be enough to get a full understanding of the reaction of the whole community of ground-dwelling invertebrates to urbanization.

This work is aimed to identify the reactions of all the assemblages and the most numerous taxonomic groups of ground-dwelling invertebrates of forest ecosystems to urbanization as well as estimate the role of recreation in the complex of urbanization factors in a large industrial city.

The questions the answers to which are sought for in this study are: 1) Is there any difference between the abundance and diversity of ground-dwelling invertebrates in the city and outside? 2) What taxons are most sensitive to urbanization? 3) What is the contribution of recreation to the overall urbanization effect?

STUDY AREA, MATERIALS AND METHODS

The study was conducted in the territory and vicinity of Yekaterinburg, the administrative capital of the Sverdlovsk region (the city's area is about 498 sq. km and its population exceeds 1.4 million people). Yekaterinburg is classified as one of heavily polluted Russian cities (Sturman, 2008). The main part of atmospheric emissions (163,100 tons a year or 86.6%) comes from car traffic (about 656,000 units). Stationary sources (about 60 different enterprises including machine-building, metallurgical, chemical and heating plants) produce 25,300 tons of emissions or 13.4% of the overall amount (*Public report...*, 2011).

To separate effects of recreation and urbanization on the abundance and species diversity of invertebrates, the same habitats, namely natural pine forests, were studied. In terms of basic taxation characteristics of tree stand, all the surveyed sites of natural pine forests are similar and represented by 120–140 year old high-density tree stands of growth classes II and III (Shavnin et al., 2011). In the city and outside there are two forest sites with different combinations of anthropogenic factors chosen in each case. These factors are recreation (R) and urbanization (U): the former means intensity of visits by people, and the latter is a complex of other hardly divisible factors typical of urban environment, including pollution of air by car traffic and industrial facilities (Fig. 1). The active factor had two degrees: higher level (marked as +) and lower level (marked as –).

The study sites are described in brief below.

Site one is the vicinity of Lake Glukhoe (U–R–) which is a rarely visited forest area located four kilometers away from the city limits (as of 2010) and at quite a distance from major motorways.

Site two is the vicinity of Lake Chusovskoe (U–R+) which is a forest area frequently visited by people and located in the neighborhood of summer cottages 9 km away from the limits of Yekaterinburg.

Site three is an enclosed pine forest in Yekaterinburg in the botanic garden of the Ural Branch of the Russian Academy of Sciences. People have been forbidden to visit this site for the past 50 years. It is situated close to major motorways and the industrial area.

Site four is the South-Western woodland park which is a forest area within the city limits and a popular place for rest among the citizens. It is situated right near the botanic garden and close to motorways and the industrial area.

In the study sites susceptible to trampling, the forest litter capacity is 1.5–1.8 times lower than in the reference site (R–U–), the density of upper horizons of soil is 1.2–1.5 higher, and the litter and the humic horizon destroy and erode (Veselkin and Kaigorodova, 2013). In terms of phytocoenotic characteristics the difference between the urban and the suburban forest sites consists in the smaller vegetation coverage and biomass of the field layer. At the same time, the larger vegetation coverage and biomass of synanthropic species are registered in the city limits. In the R+U+ site they reach their peak levels, indicating high recreational load in this site. Another distinct feature of the city's territory is high abundance of successfully naturalized adventive species in the structure of underwood that affect changes in ground cover parameters. This leads to decreased illumination and increased air humidity under the forest

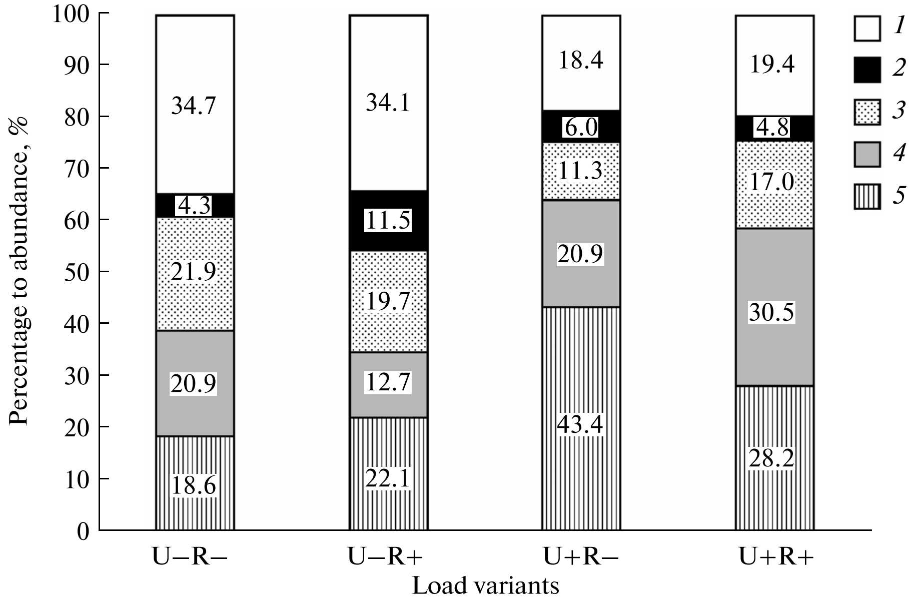

Fig. 2. Population structure of ground-dwelling invertebrates by abundance in sites with different R/U combination. The groups are (*1*) other invertebrates (without random invertebrates, see Table 1), (*2*) harvestmen, (*3*) spiders, (*4*) rove beetles, and (*5*) ground beetles.

canopy in the city (Zolotareva et al., 2012). The air in the urban sites is polluted mainly with highly toxic and cancerogenic contaminants: benzpyrene, formaldehyde, phenyl hydrate, ammonia, and fine dust (*Public report*..., 2011). Agrochemical soil properties change in the city. The upper horizons get alkalinized by 0.2–0.5 pH units and the accumulation of exchangeable bases is observed. The forest litter and humic horizon now contain far more forms of easily hydrolizable nitrogen which are better available for plants (Veselkin and Kaigorodova, 2013).

Ground-dwelling invertebrates were collected in 2010–2011 using soil traps (plastic cups with a neck of 9 cm in diameter and 3% acetic acid used as fixer). To define the species structure of invertebrates as fully as possible, the counts were conducted in two periods, i.e., during increased activity of spring-and-summer and summer-and-fall species (in the third decade of May and in the first decade of August). In each of the four sites there were three sampling plots (SP) situated at 70–150 m from each other. In each SP a line of five traps was set up with an exposure time of five days. The distance between the traps was 2–3 meters. During the two years of the study 232 out of 240 samples were collected (8 traps were destroyed by the city dwellers) and 4643 invertebrate individuals were collected. The effect of urbanization and recreation on ground-dwelling invertebrates was investigated using the dominant taxa constituting the core of herbetobiont complex (Table 1): insects (Carabidae and Staphylinidae) and arachnids (Aranei and Opiliones). Rare taxa were excluded from the analysis. The activity density referred to hereinafter as abundance was evaluated in individuals per five trap/days. The species diversity (only for 2010 year) was characterized by the Shannon index, Berger-Parker index, and interpolated number of species calculated in the PAST software by rarefying the minimal number of specimen per site (http://nhm2.uio.no/norlex/past).

Differences in abundance and diversity between years, count periods and sites (n=3 SP per site) were analyzed by the heteroscedacity-consistent three-way ANOVA with White-Huber correction for heterogeneity of variance, algorithm HC3 (Long and Ervin, 2000). To normalize the distributions, the $\ln(x + 1)$ transformation was used for the abundance. The variance decomposition was performed according to Snedecor.

RESULTS

Change in the abundance of ground-dwelling invertebrates. Within the city abundance of ground-dwelling invertebrates is generally higher than outside, at the same time recreation does not affect the overall abundance of ground-dwelling invertebrates (Tables 1 and 2). There are significant differences in abundance between years and count periods ($F_{(1;32)} = 31.4$ $p \ll 0.001$ and $F_{(1;32)} = 7.0$ $p < 0.01$, respectively).

Despite the significant effect of the "year" on the total abundance of all ground-dwelling invertebrates, the total abundance of Aranei, Opiliones, Carabidae and Staphylinidae imagoes did not differ between years ($F_{(1;32)} = 1.9$, $p = 0.8$). Only the abundance of Carabidae and Opiliones appeared to be year-dependent ($F_{(1;32)} = 12.5$, $p \ll 0.001$, $F_{(1;32)} = 35.7$, $p \ll 0.001$, respectively). The count period affected only Carabidae. In late summer their abundance is much lower

Table 1. Abundance of invertebrates in sites with different recreation-to-urbanization (R/U) combination (individual per 5 trap/days ± SE, $n = 3$)

Taxon	2010								2011							
	I tour				II tour				I tour				II tour			
	U–R–	U–R+	U+R–	U+R+	U–R–	U–R+	U+R–	U+R+	U–R–	U–R+	U+R–	U+R+	U–R–	U–R+	U+R–	U+R+
Ground-dwelling community core																
Carabidae, imago	3.9 ± 0.7	6.9 ± 1.2	19.4 ± 1.0	11.6 ± 0.6	1.3 ± 0.7	0.7 ± 0.5	9.9 ± 0.1	5.3 ± 1.0	2.3 ± 1.1	5.1 ± 0.7	10.3 ± 3.2	12.0 ± 2.3	0.9 ± 0.1	0.7 ± 0.3	5.5 ± 1.2	1.3 ± 0.1
Staphylinidae, imago	5.3 ± 0.8	2.9 ± 0.7	7.3 ± 1.4	13.0 ± 3.3	0.8 ± 0.3	0.9 ± 0.1	1.1 ± 0.4	2.0 ± 0.2	1.6 ± 0.3	1.8 ± 0.7	3.3 ± 0.2	5.9 ± 2.0	1.4 ± 0.2	2.1 ± 0.5	10.1 ± 1.1	11.8 ± 2.5
Aranei	2.8 ± 0.7	4.2 ± 1.2	0.7 ± 0.4	0.9 ± 0.4	1.5 ± 0.5	2.4 ± 0.7	2.4 ± 1.2	3.3 ± 0.3	3.1 ± 0.2	4.0 ± 0.2	0.6 ± 0.1	0.7 ± 0.3	2.4 ± 0.9	1.4 ± 0.3	8.0 ± 2.1	13.4 ± 4.5
Opiliones	0.2 ± 0.1	0.1 ± 0.1	4.1 ± 0.9	4.1 ± 0.4	0.5 ± 0.2	1.3 ± 0.3	1.7 ± 0.7	0.3 ± 0.1	0.8 ± 0.4	0.6 ± 0.2	0.1 ± 0.1	0.1 ± 0.1	0.5 ± 0.3	5.0 ± 1.1	0.3 ± 0.1	0.6 ± 0.1
Other invertebrates																
Carabidae, Staphylinidae, larvae	0	0	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.3 ± 0.1	0.1 ± 0.1	0.3 ± 0.1	0	0	0	0	0	0	0	0
Coleoptera, other	0.5 ± 0.1	0.3 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.2 ± 0.1	0	0	0	1.0 ± 0.5	1.0 ± 0.0	0.5 ± 0.4	0.3 ± 0.3	0	0.3 ± 0.3	1.0 ± 0.5	1.4 ± 0.2
Myrmicidae	0	0	0	0	1.5 ± 0.3	2.6 ± 1.3	1.3 ± 0.8	1.5 ± 0.2	3.3 ± 0.5	4.0 ± 1.7	1.0 ± 0.4	4.6 ± 1.1	3.9 ± 0.6	4.6 ± 0.4	5.0 ± 0.5	4.7 ± 1.1
Heteroptera	0	0.1 ± 0.1	0	0	0.1 ± 0.1	0.1 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	0	1.5 ± 0.7	0.3 ± 0.3	0	0.8 ± 0.3	0.3 ± 0.3	2.4 ± 2.0	1.3 ± 0.3
Blattoptera	0	0	0	0	0	0	0	0	0.1 ± 0.1	0	0	0	0	0	0	0
Psocoptera	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1 ± 0.1
Acari	0.3 ± 0.2	0.5 ± 0.1	0.4 ± 0.1	0.7 ± 0.5	0	0.1 ± 0.1	0.1 ± 0.1	0.3 ± 0.1	0.7 ± 0.3	0.5 ± 0.4	0	0	0	0	0	0.3 ± 0.3
CHILOPODA	0.1 ± 0.1	0.5 ± 0.3	0.1 ± 0.1	0.1 ± 0.1	0.2 ± 0.1	0.7 ± 0.3	0.2 ± 0.1	0.5 ± 0.3	0.1 ± 0.1	0	0.2 ± 0.1	0.1 ± 0.1	0.6 ± 0.1	1.1 ± 0.8	1.9 ± 0.3	2.0 ± 0.3
ONISCIDEA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1 ± 0.1	0
MOLLUSCA	0.1 ± 0.1	0	0.1 ± 0.1	0	0	0	0	0	0.7 ± 0.3	0	0	0	0	0.3 ± 0.3	0	0
LUMBRICIDAE	0.2 ± 0.1	0.1 ± 0.1	0.2 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.1 ± 0.1	0.2 ± 0.1	0.1 ± 0.1	0.8 ± 0.4	0.7 ± 0.3	1.6 ± 0.2	0.7 ± 0.5	0	1.0 ± 0.0	1.7 ± 0.3	1.0 ± 0.4
Random taxa*	1.3 ± 0.3	1.7 ± 0.6	0.9 ± 0.2	0.9 ± 0.8	0.9 ± 0.4	0.7 ± 0.1	0.3 ± 0.1	0.5 ± 0.2	8.1 ± 3.3	4.0 ± 0.0	2.6 ± 0.5	1.7 ± 1.0	4.7 ± 0.3	2.3 ± 1.5	1.0 ± 0.5	1.7 ± 0.3
General abundance of herpetobionts	14.6 ± 0.7	17.2 ± 3.1	33.5 ± 2.0	31.7 ± 5.6	7.2 ± 1.9	10.0 ± 3.0	17.6 ± 2.3	14.3 ± 1.6	22.6 ± 2.4	23.1 ± 2.4	20.5 ± 4.1	25.9 ± 4.9	15.1 ± 1.4	19.3 ± 1.3	37.2 ± 1.0	39.9 ± 2.3

* Random taxa are uncharacteristic of the community of ground-dwelling invertebrates (Diptera, Lepidoptera imagines and larvae, Homoptera, Neuroptera, Thysanoptera, Mecoptera, and Hymenoptera.

Table 2. Results of the dispersion analysis of the influence of anthropogenic factors on the abundance and diversity of invertebrate herpetobionts

Taxons	Source of variation					
	urbanization		recreation		urbanization * recreation	
	F	*p*	*F*	*p*	*F*	*p*
	Abundance $df = 1$, $df_{\text{Error}} = 32$ (2010–2011)					
Carabidae	75.0	≤0.001	27.5	≤0.001	13.7	0.001
Staphylinidae	59.6	≤0.001	0.8	0.4	1.6	0.2
Aranei	56.3	≤0.001	5.1	0.03	0.1	0.7
Opiliones	25.3	≤0.001	0.2	0.6	2.9	0.1
Total abundance	91.3	≤0.001	0.8	0.4	1.9	0.2
	Shannon index(H') $df = 1$, $df_{\text{Error}} = 16$ (2010)					
Carabidae	19.5	≤0.001	5.0	0.04	0.002	1.0
Staphylinidae	0.05	0.8	1.5	0.2	1.2	0.3
Aranei + Opiliones	7.8	0.01	0.3	0.6	0.9	0.3
General diversity	0.2	0.7	1.1	0.3	0.1	0.8

($F_{(1;32)} = 142.0$, $p \leqslant 0.001$), and the total abundance of the four enumerated taxa decreases as well. In the city their total abundance is three times as high as in the suburban sites (Table 1). This regularity is observed in both count periods, and the *period* × *urbanization* interaction is insignificant ($F_{(1;32)} = 3.8$, $p = 0.06$). Urbanization makes the greatest contribution to the variance of the total abundance of the four considered taxa (54.7 %), whereas recreation, count period, year, and unaccounted factors make only 0.9, 11.5, 1.2, and 31.7 %, respectively.

The reaction of Carabidae and Staphylinidae to urbanization is similar, i.e., their abundance is higher in the urban sites than in the suburban sites (Table 1). Only Carabidae are significantly affected by recreation, whereas the abundance of Staphylinidae is affected insignificantly (Table 2). At the same time, Carabidae is the only one of the four considered taxa, which abundance varies significantly depending on the combination of urbanization and recreation (Table 2): in the city recreation contributes to decreased abundance of Carabidae, whereas in the suburban areas their abundance increases in the first count period and decreases slightly in the second count period.

Aranei and Opiliones differ in their response to urbanization. For example, the abundance of Aranei in the urban territories decreases in the first count period and increases in the second count period in both study years. Whatever the count period, their abundance increases due to recreation. The only exception was observed in the first count period in 2011, when the abundance of spiders in the suburban site decreased due to recreation (Tables 1 and 2). The urbanization-related changes in the abundance of *Opiliones* depended on the year and count period: whereas the *year* × *urbanization* and *period* × *urbanization* interactions were significant ($F_{(1;32)} = 84.9$, $p < 0.001$ and $F_{(1;32)} = 33.3$, $p < 0.001$, respectively), the effect of recreation was not (Table 2).

The change in the abundance of particular taxa due to the considered factors results in a modified community structure of ground-dwelling invertebrates: whereas the proportion of Carabidae and Staphylinidae in the city increases, the proportion of Aranei decreases (Fig. 2). The proportion of Opiliones is more or less the same in all the considered sites except for the U–R+ site, where it is almost twice as high. The proportion of other ground-dwelling invertebrates (rare taxa) in the city limits is about twice as low.

Change in the diversity of ground-dwelling invertebrates. The core of the herpetobiont complex includes 92 species: 27 Carabidae species, 29 Staphylinidae species, 33 Aranei species, and 3 Opiliones species (Table 3). The total number of these four taxa is similar in all the sites, though the interpolated number of species is far lower in the city than outside. Spiders and harvestmen decreased their abundance most of all. Results of individual rarefaction show also that species richness of Staphylinidae is less in the city's woodland parks than outside the city. The number of species of ground beetles depends on recreational load. The recreation affects Carabidae more strongly outside the city resulting in decreased species richness.

The effect of two anthropogenic factors on diversity (Shannon index) is significant only in some taxa (Table 2). Thus, the diversity of ground beetles in the city is higher than outside and the degree of dominance in the urban sites decreases (Tables 2 and 3). Compared to the rarely visited forest sites both, in the city and outside, the diversity of ground beetles in the recreational sites is poorer. The diversity indices of rove beetles are slightly affected by a combination of the considered factors. In the city the total diversity of spiders and harvest-

Table 3. Species diversity indexes of model groups of ground-dwelling invertebrates on sites with different recreation-to-urbanization combination

Taxon	Diversity indexes	Possible combinations of two factors			
		U–R–	U–R+	U+R–	U+R+
Carabidae (27 species)	*N*	77	117	438	254
	S	13	9	16	15
	S /75	12.8	6.8	10.5	9.9
	H'	1.27 ± 0.25	0.94 ± 0.11	1.94 ± 0.05	1.59 ± 0.09
	B-P	0.60 ± 0.09	0.67 ± 0.06	0.29 ± 0.04	0.41 ± 0.05
Staphylinidae (29 species)	*N*	87	57	122	221
	S	15	14	11	16
	S /55	12.0	13.8	9.0	9.8
	H'	1.42 ± 0.33	1.71 ± 0.17	1.50 ± 0.13	1.70 ± 0.10
	B-P	0.55 ± 0.10	0.37 ± 0.06	0.47 ± 0.10	0.37 ± 0.04
Aranei + Opiliones (36 species)	*N*	35	70	63	60
	S	19	21	11	13
	S/35	19.0	14.6	8.5	10.1
	H'	1.95 ± 0.29	2.04 ± 0.23	1.30 ± 0.14	1.37 ± 0.30
	B-P	0.21 ± 0.04	0.32 ± 0.05	0.58 ± 0.06	0.52 ± 0.16
Total (92 species)	*N*	199	244	623	535
	S	47	44	38	44
	S/195	46.5	39.1	26.7	29.7
	H'	2.48 ± 0.13	2.46 ± 0.14	2.58 ± 0.06	2.53 ± 0.08
	B-P	0.28 ± 0.03	0.32 ± 0.07	0.21 ± 0.03	0.20 ± 0.02

N is the number of individual per site, *S* is the number of species per site, S/n_{min} is the interpolated number of species (for the clarification of the calculations see the method), *H'* is the Shannon index ($n = 3$), and *B-P* is the Berger–Parker index ($n = 3$).

men considerably decreases while the value of Berger–Parker index increases. Their diversity is unaffected by recreational load (Tables 2 and 3). The peak Shannon index for all arachnids is observed in the U–R+ site. In the insects this index is highest in the sites disturbed by anthropogenic activity: it is U+R– and U–R+ for ground and rove beetles, respectively. It is notable that in the urban forests the Shannon indices become more similar, especially in the U+R+ site.

DISCUSSION

The registered increase in the abundance of ground-dwelling athropods in the urban forests compared to the suburban sites is generated mainly by representatives of the four most numerous taxa, especially Carabidae. This growth can result from favorable microclimate conditions and rich food supply. In the studied urban forests projective cover of underwood and shrubs is higher than in the suburban forest sites, which is due to the expansion of adventive or introduced species of deciduous plants. As a result, the air in the surface layer becomes more humid and its humidity is stable. Moreover, forest litter consists of easily destructable leaf debris resulting in intensified soil nitrification (Zolotareva et al., 2012), which is favorable for earthworms (McDonnell et al., 1997). In the urban sites soil mesofauna is more abundant, including Enchytraeidae, Chilopoda, Mollusca, and Acari (Ermakov and Vorobeichik, 2013) which are prey for Carabidae and other predator invertebrates.

Increased abundance is one possible response of ground-dwelling invertebrates to urbanization, although it is rarely mentioned in specialized literature. For example, in Canada abundance of Carabidae in urban areas is greater than in suburban territories. In the considered case, however, the greater abundance of Carabidae in the urban biotopes was determined by the single dominant species, namely *Pterostichus melanarius* (Illiger) (Niemelä et al., 2002). Other studies showed either no reaction in the city at all (Alaruikka et al., 2002; Elek and Lövei, 2007) or decreased abundance in the city compared to the suburban territory (Ishitani et al., 2003; Gaublomme et al., 2008). One of the reasons for differently directed respones to urbanization may result from the differences in the species composition and structure of dominance in the community of Carabidae in different study areas.

The diversity of ground-dwelling invertebrates is also affected by urbanization. The species richness of arachnids and rove beetles is less in the city than in the suburban forests, whereas the effect of urbanization on the species richness of ground beetles is not uniform and depends on the intensity of recreational load in the compared urban and suburban forest sites. According to other authors, the species abundance of arachnids and rove beetles is either unaffected by urbanization at all (Alaruikka et al., 2002; Deichsel, 2006), or the number of species increases in the city (Magura et al., 2010). For ground beetles both decreased species richness (Niemelä et al., 2002; Ishitani et al., 2003) and no differences with suburban sites were registered (Alaruikka et al., 2002; Deichsel, 2006; Elek and Lövei, 2007). In our study the urbanization-related changes in the Shannon index differ in ground beetles and arachnids: in the urban sites the diversity of ground beetles increases and that of arachnids decreases, respectively. This means that the communities of ground beetles in the urban forests are more evened than their suburban communities, whereas in the urban communities of arachnids the level of dominance of particular species increases. The observed similarity in the Shannon indices in the city for the considered taxa is determined by the more intensive change in the number of individuals as compared to the number of species. According to other studies, ground beetles and spiders respond to urbanization in the same manner: their abundances decrease (Gibb, Hochuli, 2002; Babenko and Eremeeva, 2007). Urbanization effects are obviously determined by structure of background communities consisting of species with different ecological requirements, and conditions of particular cities as well. That is why the effect of urbanization would be analyzed with better efficiency at the level of ecological groups, but this is beyond the scope of this article.

The determination of the contribution of recreation to the change in the abundance of ground-dwelling invertebrates as compared to other urbanization factors reveals that recreation plays only a minor role in this process. Of the four considered taxa only spiders and ground beetles displayed explicit reaction to this factor. The effect of recreation on the diversity of ground-dwelling invertebrates is even less expressed: only ground beetles appeared to decrease in diversity due to recreation. On the whole, the overall diversity of the four taxa constituting the core of the herpetobiont complex remains relatively stable in all the study sites. These results well agree with results of other studies. For example, the decreased diversity of ground beetles subject to recreation was observed by O. V. Semenova (2008) in the urban forests of Nizhnii Tagil (Middle Urals). In the pine forests of the Moscow oblast recreation had no effect on the number of beetles and changed mainly the species composition and ecological structure of their community (Gruntal', 1987). Like in the instance of soil mesofauna (Ermakov and Vorobeichik, 2013), the insignificant recreation effects in our study may be due to the specifics of visitation in urban and suburban forests in the Middle Urals. In the period of increased activity (May–June) of acarines that transmit dangerous infections the visitation of suburban forests and urban forests is limited and people walk mostly along the path. It considerably decreases the degree of trampling that negatively affects soil invertebrates. The soil density outside the network of paths and roads was comparable in all the four sites (Veselkin and Kaigorodova, 2013), facilitating successful reproduction and nutrition of ground-dwelling and soil invertebrates in urban forests.

CONCLUSIONS

In the natural pine forests of Yekaterinburg both, positive (increased abundance) and negative (decreased species diversity) effects of urbanization on ground-dwelling invertebrates are observed. Increased abundance is a common type reaction to urbanization by the most numerous taxa (Carabidae, Staphylinidae, Aranei and Opiliones).

Changes in species diversity of different taxa as affected by urbanization may occur in different ways: the species diversity of arachnids and rove beetles decreases in the city, and the communities of arachnids become less evened; while the species diversity of ground beetles in the city decreases as well, their community becomes more evened. To reveal the reasons for the difference in reactions to urbanization, further analysis of the ecological structure of herpetobiont community is necessary.

Our research shows also that the recreational load on the study sites is subcritical, which is proven by insignificant effects of recreation on ground-dwelling invertebrates as compared to other urbanization factors.

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