

Springtail (Hexapoda: Collembola) fauna in the burnt boreal forests of European Russia

R.A. Saifutdinov^{1,2}, K.B. Gongalsky¹, A.S. Zaitsev^{1,3}

¹ *A.N. Severtsov Institute of Ecology and Evolution, Russian Academy of Sciences, Leninsky pr., 33, Moscow 119071 Russia. E-mail: gongalsky@gmail.com*

² *Kazan Federal University, Kremlyovskaya str. 18, Kazan 420008 Russia. E-mail: saifutdinov@biogeo.ru*

³ *Institute of Animal Ecology, Justus-Liebig-University, Heinrich-Buff-Ring 26, 35392 Giessen, Germany. E-mail: andrey.zaitsev@biogeo.ru*

ABSTRACT: We investigated fauna and community composition of springtails in the burnt and unburnt boreal forests of European Russia. We also analyzed ecoregional differences in the effect of fire disturbance on collembolan community faunistic similarity on an example of three different ecoregions of the boreal forest biome in the study territory. We collected and identified 6799 springtail individuals representing 14 families, 41 genera and 94 species. In the burnt plots we observed consistent shifts in the springtail community dominance structure across all studied ecoregions. The effect of fire on the faunistic similarity of springtail communities was strongly modulated by ecoregion: within-ecoregion similarity between plots was always higher than the between-region similarity. Fires resulted in the moderate decrease of the total abundance of springtails with trans-holarctic distribution in all ecoregions and additionally in increase of springtails with west-palaearctic distribution in southern ecoregion. We conclude that five years after burning it is very important to standardize fire-induced changes in the faunistic composition of springtail communities to the actual geographic location within spatially extensive biomes.

How to cite this article: Saifutdinov R.A., Gongalsky K.B., Zaitsev A.S. 2018. Springtail (Hexapoda: Collembola) fauna in the burnt boreal forests of European Russia // *Invert. Zool.* Vol.15. No.1. P. 115–130. doi: 10.15298/invertzool.15.1.09

KEY WORDS: soil fauna, taiga, fire disturbance, collembolans, European Russia.

Фауна ногохвосток (Hexapoda: Collembola) в сгоревших бореальных лесах европейской части России

Р.А. Сайфутдинов^{1,2}, К.Б. Гонгальский¹, А.С. Зайцев^{1,3}

¹ *Институт проблем экологии и эволюции им. А.Н. Северцова РАН, Ленинский пр., 33, Москва 119071 Россия. E-mail: gongalsky@gmail.com*

² *Казанский федеральный университет, ул. Кремлёвская 18, Казань 420008 Россия. E-mail: saifutdinov@biogeo.ru*

³ *Институт экологии животных, Университет им. Юстуса-Либиха, Хайнрих-Буфф-Ринг 26, 35392 Гиссен, Германия. E-mail: andrey.zaitsev@biogeo.ru*

РЕЗЮМЕ: Исследовали фауну и структуру сообществ ногохвосток в сгоревших и естественных бореальных лесах европейской части России. На примере трёх разных

экорегиионов анализировали влияние различий в экорегиионах при воздействии лесных пожаров на фаунистическую структуру таксоценов коллембол. Всего было собрано и определено 6799 экземпляров коллембол, представляющих 14 семейств, 41 род и 94 вида. Сгоревшие участки всех исследуемых экорегиионов характеризуются нарушенной структурой доминирования таксоценов коллембол. Таксоцены коллембол в большей степени определяются региональными факторами, нежели влиянием на них лесных пожаров: фаунистическое сходство таксоценов коллембол между участками внутри экорегиионов было выше сходства участков между экорегиионами. Пожары привели к сокращению общей численности ногохвосток с трансголарктическим распределением во всех экорегиионах и дополнительно, к увеличению численности ногохвосток с западно-палеарктическим распределением в южном экорегиионе. Мы пришли к выводу, что спустя пять лет после лесного пожара важна стандартизация изменений, вызванных пожаром, в фаунистическом составе сообществ ногохвосток к фактическому географическому местоположению в пределах крупных зональных биомов.

Как цитировать эту статью: : Saifutdinov R.A., Gongalsky K.B., Zaitsev A.S. 2018. Springtail (Hexapoda: Collembola) fauna in the burnt boreal forests of European Russia // *Invert. Zool.* Vol.15. No.1. P. 115–130. doi: 10.15298/invertzool.15.1.09

КЛЮЧЕВЫЕ СЛОВА: почвенная фауна, тайга, лесной пожар, коллемболы, Европейская часть России.

Introduction

Springtails are small invertebrates that inhabit almost any soil type around the globe (Hopkin, 1997; Rusek, 1998). They form a considerable part of soil microarthropod biodiversity and contribute to soil decomposition and mineralization processes, particularly in the boreal forests (Petersen, Luxton, 1982; Seastedt, 1984; Huhta *et al.*, 1998). At the same time, springtail community composition may vary considerably across this biome depending on climate and dominating species in tree stands (Juceviča, Melecis, 2002; Kuznetsova, 2002). Despite numerous studies published with this respect (see e.g. Kuznetsova, Potapov, 1997; Kuznetsova, Krest'yaninova, 1998; Chernova, Kuznetsova, 2000; Taskaeva, 2009, 2011), not much is still known on the impact of different disturbances on fauna and taxonomic composition of collembolans (Malmström, 2012). Given that wildfires are one of the most important disturbances in the boreal forests, they remain unstudied in terms of soil faunal recovery with respect to macrogeographic gradients present-

ed within NW Russia's boreal forests (see e.g. Zaitsev *et al.*, 2016 for review).

We tried to address this knowledge gap by studying the effect of forest fires which are frequent in the boreal forests of European Russia. We aimed at understanding, how forest fires alter faunistic composition and the diversity of soil microarthropod communities at the local scale and how consistent are the revealed effects at the ecoregion scale.

Material and methods

Study sites

The study was conducted along a 1500 km-long latitudinal gradient in the boreal forests of European Russia (Fig. 1). We selected three ecoregions in the European Russia: Kola-Karelian, Pribaltiiskiy-Vetluzhskiy and Smolensk-Priuralskiy ecoregions (Ogureeva *et al.*, 2015). Studied ecoregions corresponds to the different type of forest within boreal forest biome as follows: Kola-Karelian — northern taiga, Pribaltiiskiy-Vetluzhskiy — middle taiga and Smolensk-Priuralskiy — southern taiga.



Fig. 1. Schematic map of the studied ecoregions (Kola-Karelian, Pribaltiiskiy-Vetluzhskiy and Smolensk-Priuralskiy) within the boreal biome in NW Russia. Gray dots indicate pairs of forest plots (burnt and control) sampled within each ecoregion. Numbers in parentheses refer to respective plots as shown in Table 1.

Рис. 1. Схематическая карта исследуемых экорегионов (Кольско-Карельский, Прибалтийско-Ветлужский, Смоленск-Приуральский) биома бореальных лесов северо-западной части России. Серые точки обозначают пары лесных участков (сгоревших и контрольных), отобранных в каждом экорегионе. Номера чисел в скобках обозначают пары исследуемых участков, и соответствуют участкам в таблице 1.

Plots of Kola-Karelian ecoregion are located in the Murmansk Region, Kola Peninsula (Fig. 1) and are represented by pine (*Pinus sylvestris* L., 1753) or pine-spruce (*P. sylvestris*, *Picea abies* H. Karst., 1881) forest stands (Table 1). The ground vegetation is formed predominantly by red bilberry (*Vaccinium vitis-idaea* L., 1753) and blueberry (*V. myrtillus* L., 1753). Soil type is Albic Podzols according to World Reference Base for Soil Recourses classification (WRB, 2015).

Pribaltiiskiy-Vetluzhskiy ecoregion plots are located in the Republic of Karelia and the Leningrad Region. They are represented by pine for-

ests (*P. sylvestris*) with blueberry (*V. myrtillus*) and red bilberry (*V. vitis-idaea*) in the undergrowth. Soil types are Lithic Leptosols or Albic Podzols (WRB, 2015).

Smolensk-Priuralskiy ecoregion forests are located in the Moscow and Tver Regions and are formed by spruce-birch (*P. abies*, *Betula pendula* Roth, 1788), pine-birch (*B. pendula*, *P. sylvestris*) or spruce-pine-birch stands (*B. pendula*, *P. abies*, *P. sylvestris*). Ground vegetation is dominated mainly by red bilberry (*V. vitis-idaea*) and blueberry (*V. myrtillus*). Soil type is Umbric Albeluvisol (WRB, 2015).

Table 1. Brief description of investigated forest plots. Even plot numbers refer to the burnt and odd numbers to the control forests within the respective plot pair.
Таблица 1. Краткая характеристика исследуемых лесных участков. Чётные номера обозначают сгоревшие и нечётные — контрольные участки в пределах соответствующей пары.

Plot pair No	Ecoregion	Locality	Geographic coordinates	Dominating tree species
NT-01,02	Kola-Karelian	Umba	66.82928°N 34.03890°E	<i>Pinus sylvestris</i>
NT-03,04	Kola-Karelian	Umba	66.79567°N 34.18753°E	<i>P. sylvestris</i> , <i>Picea abies</i>
NT-05,06	Kola-Karelian	Umba	66.78124°N 34.19601°E	<i>P. sylvestris</i>
NT-07,08	Kola-Karelian	Kolvitsa	67.07881°N 33.17981°E	<i>P. sylvestris</i>
MT-09,10	Pribaltiiskiy-Vetluzhskiy	Petrozavodsk	61.99292°N 34.17444°E	<i>P. sylvestris</i> , <i>Betula pendula</i>
MT-11,12	Pribaltiiskiy-Vetluzhskiy	Petrozavodsk	61.85056°N 34.41325°E	<i>P. sylvestris</i> , <i>Sorbus aucuparia</i>
MT-13,14	Pribaltiiskiy-Vetluzhskiy	Pasha	60.33975°N 33.13269°E	<i>P. sylvestris</i>
MT-15,16	Pribaltiiskiy-Vetluzhskiy	Pasha	60.32878°N 33.14875°E	<i>P. sylvestris</i>
ST-17,18	Smolensk-Priuralskiy	Taldom	56.647912°N 37.443685°E	<i>P. abies</i> , <i>B. pendula</i>
ST-19,20	Smolensk-Priuralskiy	Taldom	56.521919°N 37.62822°E	<i>P. abies</i> , <i>P. sylvestris</i> , <i>B. pendula</i>
ST-21,22	Smolensk-Priuralskiy	Nelidovo	56.155257°N 32.817537°E	<i>P. abies</i> , <i>S. aucuparia</i>
ST-23,24	Smolensk-Priuralskiy	Nelidovo	56.140112 N 32.718251 E	<i>P. abies</i> , <i>B. pendula</i>

In each ecoregion, we selected four forest plots burnt in 2010 and four respective controls. In total we examined 12 pairs of plots (burnt-control). Some further details on the investigated plots are provided in Table 1. For a more detailed description of particular plots please refer to the project webpage: <https://forestfire.biogeo.ru/index.php/en/>.

Sampling

The sampling was performed between May 25 and June 20, 2015. Exact sampling dates were chosen for each ecoregion with the aim of their phenological synchronization. We referred to the beginning of bird cherry (*Prunus padus* L., 1753) flowering (World atlas..., 1964) to calculate the lag in sampling between the re-

gions. At each plot we randomly collected four intact soil samples for springtails with a soil corer. To avoid possible edge effect during sampling we took soil monoliths not closer than 3 m from the plot edge. Each soil sample had the diameter of 5 cm and a depth of 6–8 cm (depending on the thickness of the organic horizon). In total we collected 96 samples. Collected samples were put into plastic bags and transferred to the laboratory in isothermic containers at a temperature below +10°C.

Extraction and Identification

In the laboratory soil samples were extracted using Tullgren funnels into the mixture of alcohol, water and ethylene glycol with a ratio of 80:15:5 respectively. Extraction lasted for

four days. This time was sufficient for the substrate to reach air-dry condition. All springtails were slide-mounted in the cavity slides using a mixture of lactic acid and glycerol with a ratio of 3:1 respectively. Animals were then identified to the species level using applicable determination keys (Babenko et al., 1994; Fjellberg, 1998, 2007; Bretfeld, 1999; Potapov, 2001; Hopkin, 2007). After identification we assigned each species to one of the biogeographic distribution types (trans-holarctic, trans-palaeartic, western-palaeartic, eastern-palaeartic, cosmopolitan or unknown) following Babenko and Fjellberg (2006) and Babenko (2012).

Statistical analysis

Samples collected within the same forest plot were considered pseudoreplicates (Kozlov, 2014). Thus all values derived from them were averaged to represent a single data unit per plot. Differences between the means in burnt and control forests were tested with a two-way ANOVA with the categorical factors “Fire” and “Ecoregion” and their interaction. Data normality and heterogeneity were tested prior to the analysis. Because abundance of most species had non-normal distribution, we performed $\ln(x+1)$ transformation of data. In a case of testing the collembolans abundance belonging to different biogeographic distribution types, we left the data untransformed. If ANOVA returned significant results, we further tested the significance of differences between the means with the Tukey HSD test ($p < 0.05$). ANOVAs were done using Statistica 10.0 software package. For the analysis of the dominance structure of collembolan communities we recognized species with the relative abundance not less than 12.4% as dominant ones (Engelmann, 1978). Shannon diversity index (H') and Pielou evenness index (J') were calculated according to Shannon-Pielou index (Magurran, 1988). Similarity of springtail communities of the studied ecoregions was assessed with the cluster analysis (Bray-Curtis similarity index, complete linkage design). Before the analysis, the abundance of all species was square root transformed for

normalization. Clustering was performed using Biodiversity Pro 2.0 software.

Results

Ecoregional differences in the species composition

In total we collected and identified 6799 springtail individuals representing 14 families, 41 genera and 94 species. Data on the average species abundance and their biogeographic distribution type are provided in Appendix 1.

Total springtail abundance significantly increased from north (18608 ind. m^{-2}) to south (57152 ind. m^{-2}) (ANOVA, $F=15.8$, $P < 0.0001$), but was not affected by “Fire” treatment. Average species richness in the same manner increased from north (12 species) to south (21 species) (ANOVA, $F=9.1$, $P < 0.002$), with no effect of “Fire”. The highest total number of species was observed in Smolensk-Priural'skiy ecoregion (68 species); it was a bit lower in Pribaltiiskiy-Vetluzhskiy ecoregion (55 species) and the lowest in Kola-Karelian ecoregion (35) species. No significant difference in springtail diversity measured by Shannon diversity index was found between treatments. Highest Shannon diversity was observed in burnt plots of Smolensk-Priural'skiy and in control plots of Pribaltiiskiy-Vetluzhskiy ecoregions and lowest in burnt plots of Kola-Karelian ecoregion. Pielou evenness index was higher in burnt plots of Kola-Karelian ecoregion and lowest in control plots of Smolensk-Priural'skiy ecoregion (Appendix 1).

The most frequent species found in all studied ecoregions were *Isotoma viridis*, *Lepidocyrtus lignorum*, *L. lanuginosus*, *Entomobrya nivalis*, *Folsomia quadrioculata*, *Parisotoma notabilis*, *Pygmarrhopalites cf secundarius*, *Isotomiella minor*, *Micraphorura absoloni*, *Willemitia anophthalma*, *W. denisi*, *Mesaphorura yosii*, *M. tenuisensillata*, and *Micranurida pygmaea*. Among them *I. minor*, *M. yosii*, *P. notabilis*, *F. quadrioculata* and *W. anophthalma* dominated (Bold in Appendix 1).

The average abundance of *I. minor* and *W.*

anophthalma was significantly lower in the burnt plots than in the controls (ANOVA, $F=4.46$, $P<0.049$ and $F=6.73$, $P<0.018$, respectively). In addition, total abundance of *I. minor* was significantly higher in middle and southern ecoregions, than in northern taiga ecoregion (ANOVA, $F=5.96$, $P<0.01$), while the abundance of *W. anophthalma* fluctuated between the ecoregions. It was the highest in Pribaltiiskiy-Vetluzhskiy ecoregion (ANOVA, $F=12.02$, $P<0.0005$). The average abundance of *F. quadrioculata*, *P. notabilis* and *M. absoloni* significantly increased from northern to southern ecoregion (ANOVA, $F=6.21$, $P<0.009$; $F=49.9$, $P<0.000001$ and $F=25.06$, $P<0.00001$ respectively). Other species did not show significant differences between the treatments.

The dominance structure of springtail communities was also affected by fire. Control plots were always dominated by *I. minor*. Dominant species in the burnt plots varied across ecoregions. *M. yosii* was the most abundant species in Kola-Karelian, *I. minor* in Pribaltiiskiy-Vetluzhskiy and *Mesaphorura hylophila* in Smolensk-Priuralskiy ecoregion respectively.

In Kola-Karelian ecoregion *I. minor* was clearly more numerous in the control plots (ANOVA, $F=9.128$, $P<0.02$), than in the burnt ones. The decrease of the abundance of *W. anophthalma* in the burnt plots was only marginally significant (ANOVA, $F=4.74$, $P<0.072$). Several species like *Mesaphorura krausbaueri*, *Protaphorura subarctica* and *P. pseudovanderdrifti* were recorded only in the burnt plots (Appendix 1).

In Pribaltiiskiy-Vetluzhskiy ecoregion, none of the springtail species were significantly affected by "Fire" treatment. Although many species with low abundance were found only in burnt plots: *Chouretinula inermis*, *Xenylla tullbergi*, *Friesea truncata*, *Cryptopygus* cf. *bipunctatus*, *Desoria hiemalis*, *Folsomia dovrensis*, *Proisotoma minima*, *Vertagopus haagvari*, *Entomobrya nicoleti*, *Orchesella cincta* and *Sminthurinus concolor*.

In Smolensk-Priuralskiy ecoregion the abundance of *Pygmarrhopalites principalis* was significantly higher in control than in the burnt

plots (ANOVA, $F=6.57$, $P<0.04$). Also, some species such as *Mesaphorura critica*, *M. hylophila*, *M. macrochaeta*, *P. pseudovanderdrifti*, *C. inermis*, *Xenylla* cf. *maritima*, *Desoria nivea*, *Folsomia fimetarioides*, *Pachyotoma crassicauda*, *E. nicoleti*, *Lepidocyrtus pallidus*, *Sminthurides malmgreni*, *S. cf. signatus*, *S. schoetti*, *Pygmarrhopalites* cf. *secundarius* and *Sminthurus viridis* were found only in burnt plots. (Appendix 1).

At the species level we found only few significant differences in the abundance between burnt and control forests. In addition, some springtail individuals (e.g. most of juveniles) were identified only to a family level. To include them into the analysis we also studied the effect of burning on the abundance of collembolan families. The abundance of collembolans from Arrhopalitidae family was significantly lower in burnt plots (ANOVA, $F=6.25$, $P<0.02$) with no effect of "Ecoregion" on it. The abundance of Onychiuridae springtails was significantly affected by "Ecoregion" and by its interaction with "Fire". It was much higher in the burnt plots of Smolensk-Priuralskiy ecoregion, but lower in the burnt plots of Pribaltiiskiy-Vetluzhskiy ecoregion compared to the respective controls (ANOVA, $F=4.53$, $P<0.02$). The abundance of springtails belonging to Isotomidae and Neelidae families significantly increased from north to south (ANOVA, $F=4.66$, $P<0.02$ and $F=4.44$, $P<0.03$ respectively), however, their abundance was not significantly affected by burning. Other families were significantly affected by none of the factors nor their interaction.

Faunistic similarity

The cluster analysis revealed considerable modulation effect of "Ecoregion" on the fire-induced changes in the faunistic composition of collembolan assemblages. Burnt and unburnt plots from Kola-Karelian ecoregion were clearly dissimilar to the others and formed a separate cluster (Fig.2). The communities from burnt and unburnt forests of Pribaltiiskiy-Vetluzhskiy ecoregion served as the core of the second cluster and were the most similar between each

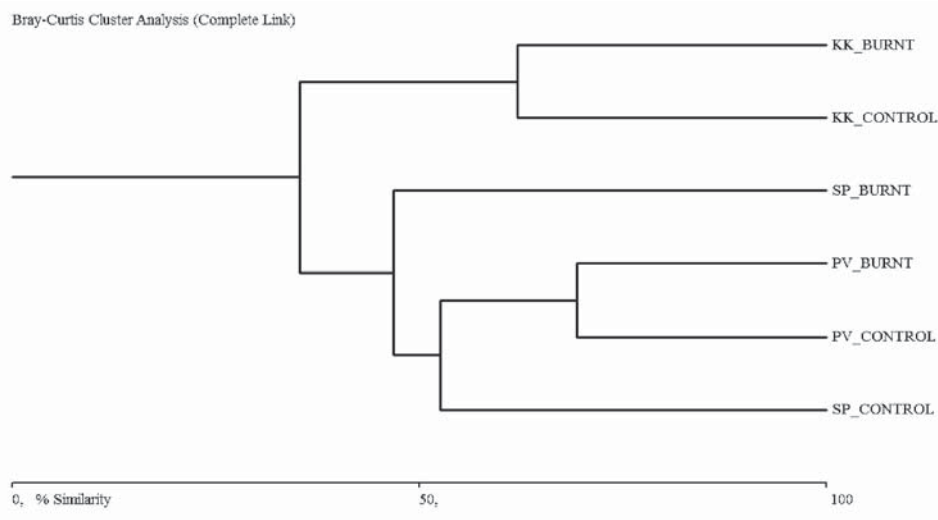


Fig. 2. Cluster analysis of springtail communities in the burnt and unburnt forests of the three studied ecoregions (Bray-Curtis index of similarity, Complete linkage). Data is square root transformed. Ecoregions are abbreviated as follows: KK — Kola-Karelian, PV — Pribaltiiskiy-Vetluzhskiy, SP — Smolensk-Priuralskiy.

Рис. 2. Дендрограмма кластерного анализа сообществ коллембол в сгоревших и контрольных лесах, трёх исследуемых экорегионов (индекс сходства Брея-Кёртиса, метод полной связи). Данные трансформированы извлечением квадратного корня. Сокращения: KK — Кольско-Карельский экорегион, PV — Прибалтийско-Ветлужский экорегион, SP — Смоленск-Приуральский экорегион.

other among all plots included into the analysis (Bray-Curtis similarity level of 70%) (Fig. 2). Similarity between the communities in the Smolensk-Priuralskiy burnt and unburnt plots was the lowest and these communities were more similar to those from the Pribaltiiskiy-Vetluzhskiy ecoregion (Bray-Curtis similarity level 47% between each other) (Fig. 2).

Biogeographic distribution types

The abundance and species richness of springtail species sharing certain biogeographic distribution types was significantly different between the studied ecoregions (Fig. 3 and Fig. 4). Total abundance of west-palaeartic species was significantly affected by interaction of “Ecoregion” and “Fire” treatments. It was considerably higher in the burnt plots than in the controls in Smolensk-Priuralskiy ecoregion and in the Kola-Karelian ecoregion abundance of west-palaeartic springtail was higher in the

controls (ANOVA, $F=4.7$, $p<0.02$) (Fig. 3). “Ecoregion” had a strong effect on the total abundance of cosmopolitan, trans-palaeartic and trans-holarctic species. Their abundance significantly increased from northern to southern ecoregion (ANOVA, $F=24.4$, $p<0.00001$; $F=4.49$, $p<0.03$ and $F=12.33$, $p<0.0004$, respectively) (Fig. 3). Also, abundance of trans-holarctic species was higher in the control plots than in the burnt forests (ANOVA $F=6.52$, $p<0.02$).

Average species richness of cosmopolitan species significantly increased from north to south (ANOVA, $F=18.3$, $p<0.00005$) (Fig. 4). Species richness of west-palaeartic species was affected by interaction of factors “Ecoregion” and “Fire”. It was higher in controls than in burnt plots of Kola-Karelian ecoregion, while in Smolensk-Priuralskiy ecoregion was reverse situation (ANOVA, $F=4.28$, $p<0.03$). Average species richness of trans-palaeartic and trans-

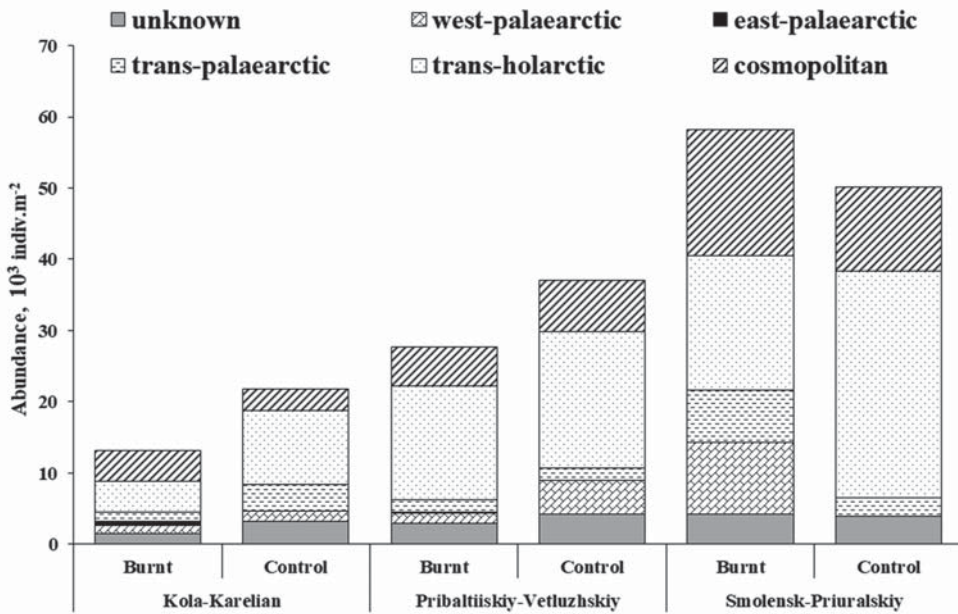


Fig. 3. Abundance of springtails (10^3 ind. m^{-2} , $n=4$) sharing different biogeographic distribution types in the burnt and control forests of the three studied ecoregions.

Рис. 3. Численность ногохвосток (10^3 экз. m^{-2} , $n=4$) с разными типами биогеографического распространения в сгоревших и контрольных лесах, трёх исследуемых экорегионов.

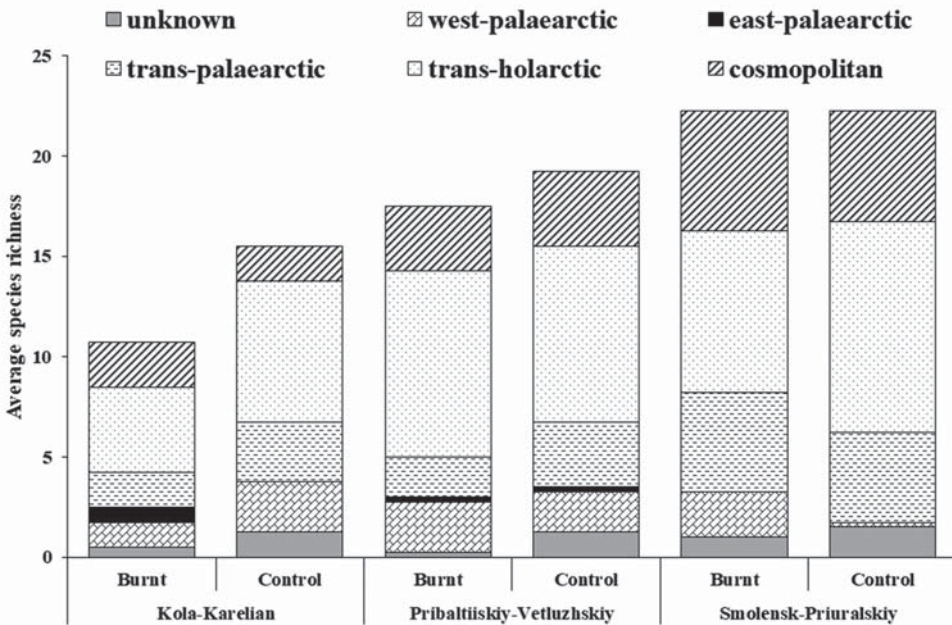


Fig. 4. Average species richness of springtails ($n=4$) sharing different biogeographic distribution types in the burnt and control forests of the three studied ecoregions.

Рис. 4. Среднее число видов ногохвосток ($n=4$) с разными типами биогеографического распространения в сгоревших и контрольных лесах, трёх исследуемых экорегионов.

holartic species was lower in northern taiga ecoregion than in southern and middle ecoregions (ANOVA, $F=3.8$, $p<0.04$ and $F=9.33$, $p<0.002$, respectively). In addition, the number of trans-holarctic species in control plots was higher than in burnt forests, but this effect was only marginally significant (ANOVA, $F=4.28$, $p<0.053$). Average species richness of species with unknown distribution was lower in burnt plots than in controls (ANOVA, $F=5.9$, $p<0.025$) (Fig. 4).

Discussion

In our study we revealed approximately one half of the total springtail species richness known by now for the European Russia's boreal forests (Kuznetsova, 1985; Chernova, Kuznetsova, 2000; Kuznetsova, 2002). According to Kuznetsova and Krest'yaninova (1998), indigenous springtail communities in this biome are mainly dominated by *I. minor*, which shows the clear preference to forested habitats. The absence of this species among dominants of soil microarthropod communities is assumed to indicate soil disturbance (Kuznetsova, Krest'yaninova, 1998). Our findings on the effects of fire on the springtail dominance structure further support this assumption for two ecoregions, as the abundance of *I. minor* considerably decreased in the burnt forests in Kola-Karelian and Smolensk-Priural'skii ecoregions. Similar pattern was discovered for the abundance of *W. anophthalma*. Relatively high abundance and good representation of the mentioned species allows supposing them as good indicators of disturbances associated with recent forest fires. Indeed Malmström (2012) during her long-term study of the post fire recovery of springtail communities also found this species among ones who demonstrated reduced abundance for many years after a fire event. Nevertheless, in Pribaltiiskiy-Vetluzhskiy ecoregion, total abundance of *I. minor* was slightly higher in burnt plots than in controls. We explain this by higher thermal insulation of the lower soil layer, which could provide better survival for soil living species

like *I. minor*. Probably, this is ensured by thicker layer of ground litter made of needles, the level of which is higher in middle taiga in comparison with other subregions of boreal forest (Bazilevich, 1993; Borisov, Ganzhara, 2008).

It is remarkable that several species with relatively low abundance were found mainly in burnt plots (e.g. *P. subarctica*, *P. armata*, *C. inermis*, *M. macrochaeta*, *F. quadrioculata*, *E. corticalis* and others). Perhaps, that could be explained as after moderate disturbances proportion of non-dominant species is increased and this leads to diversification of springtail community structure (see Kuznetsova, Potapov, 1997). Moreover, proportion of species founded only in burnt plots is increasing from north to south, suggesting that in middle and southern taiga regions with more favorable climatic conditions, colonization rate of disturbed habitats by collembolans is relatively higher compared to northern taiga. This further points at the importance of considering ecoregional differences during the analysis of the effect of fire on springtails. The revealed ecoregional specificity is even more important if we analyze collembolan communities at the family level. The reduction of Arrhopalitidae abundance in the burnt plots and the respective increase of the number of Onychiuridae only in Smolensk-Priural'skii ecoregion further highlights a very complex interaction between the effect of macroenvironmental factors and fire effects across extensive biomes like boreal forests (Hennig-Sever et al., 2001; Urbanovičova et al., 2013).

Unlike the abundance, forest fires have a quite moderate effect on the springtail community faunistic composition five years after burning. Fire-induced shifts in the faunistic composition are overruled by ecoregional differences. This points at the necessity of considering local environmental conditions when making spatially extensive projections of the fire effects on soil communities and soil biodiversity in particular (Zaitsev et al., 2016). Despite that, fires had the ecoregion-specific impact on the springtail abundance and richness of species sharing certain biogeographic distribution types. The increase

of west-palaearctic species richness and abundance in the burnt forest plots of Smolensk-Priuralskiy ecoregion suggests that this group is biogeographically more closely bound to the study biome. More consistent decrease of trans-holarctic species richness and abundance in burnt plots could be explained by wider distribution of this group, which probably leads to reduced resistance to regional-specific disturbances.

We conclude that five years after burning, springtail community faunistic composition in the Russian North-West taiga forest is only slightly affected by fire-induced disturbances and is rather determined by ecoregional differences. There is a certain group of springtail species, which benefit from the post-fire effects. Obviously, this positive response of some species to burning occurred due to lack of predation and higher ecological plasticity of these springtail species. However, even slight shifts in the species composition after fire result in the changes of the spectra of the species biogeographic distribution types in pyrogenic forests. It is very important to encounter for the type of disturbance when estimating the sensitivity of species to the environmental degradation processes.

Acknowledgments

The authors are grateful to the regional forest authorities of the Murmansk, Moscow, and Tver Regions, as well as the Republic of Karelia for providing us with the data on the location and history of burnt forests. We express our gratitude to Dr. Arne Fjellberg and Dr. Mikhail Potapov for valuable taxonomic advice during this work. We thank D. Korobushkin, S. Shakhov, T. Yazrikova, A. Gorbunova, and A. Zaytseva for the assistance during sampling and extraction of animals.

The study was supported by the Russian Science Foundation grant # 14-14-00894.

References

Babenko A.B. 2012. Springtails (Hexapoda, Collembola) of tundra landscapes of the Kola Peninsula // *Entomol. Rev.* Vol.92. No.5. P.497–515.

Babenko A.B., Chernova N.M., Potapov M.B., Stebaeva S.K. 1994. [Collembola of Russia and adjacent countries: Family Hypogastruridae]. Moscow: Nauka. 335 p. [In Russian]

Babenko A.B., Fjellberg A. 2006. Collembola Septentrionale. A catalogue of springtails of the Arctic regions. Moscow: KMK Scientific Press. 190 p.

Bazilevich N.I. 1993. [Biological Productivity of Ecosystems in Northern Eurasia]. Moscow: Nauka. 293 p. [In Russian]

Borisov B.A., Ganzhara N.F. 2008. Geographical features of the distribution and renewal of easily decomposable organic matter in virgin and arable zonal soils of European Russia // *Eurasian Soil Sci.* Vol.41. No.9. P.946–952.

Bretfeld G. 1999. Synopses on Palearctic Collembola. *Symphyleona* // *Abh. Ber. Naturkundemus. Görlitz.* Vol. 71. No.1. P.1–318.

Chernova N.M., Kuznetsova N.A. 2000. Collembolan community organization and its temporal predictability // *Pedobiologia.* Vol.44. No.3. P.451–466.

Engelmann H.D. 1978. Zur Dominanzklassifizierung von Bodenarthropoden // *Pedobiologia.* Vol.18. P.378–380.

Fjellberg A. 1998. Collembola of Fennoscandia and Denmark: Poduromorpha. Part I. Leiden: Brill. 184 p.

Fjellberg A. 2007. Collembola of Fennoscandia and Denmark: Entomobryomorpha and Symphyleona. Part II. Leiden: Brill. 266 p.

Henig-Sever N., Poliakov D., Broza M. 2001. A novel method for estimation of wild fire intensity based on ash pH and soil microarthropod community // *Pedobiologia.* Vol.45. No.2. P.98–106.

Hopkin S.P. 1997. Biology of the springtails (Insecta: Collembola). Oxford: Oxford University Press. 340 p.

Hopkin S.P. 2007. A key to the Collembola (springtails) of Britain and Ireland. Shrewsbury: Field Studies Council. 245 p.

Huhta V., Persson T., Setälä H. 1998. Functional implications of soil fauna diversity in boreal forests // *Appl. Soil Ecol.* Vol.10. No.3. P.277–288.

IUSS Working Group WRB. 2015. World Reference Base for Soil Resources 2014, update 2015 International soil classification system for naming soils and creating legends for soil maps // *World Soil Resources Reports No. 106.* FAO. Rome. 193 p.

Juceviča E., Melecs V. 2002. Long-term dynamics of Collembola in a pine forest ecosystem: Proceedings of the Xth international Colloquium on Apterygota, ěeské Budějovice 2000: Apterygota at the Beginning of the Third Millennium // *Pedobiologia.* Vol.46. No.3. P.365–372.

Kozlov M.V. 2014. [Planning of ecological research: theory and practical recommendations]. Moscow: KMK Scientific Press. 171 p. [In Russian]

Kuznetsova N.A. 1985. [Fauna and population of springtails in coniferous forests of the European part of the USSR] [Candidate's Dissertation in Biology]. Moscow. 286 p. [In Russian]

- Kuznetsova N.A. 2002. Classification of collembolan communities in the east-european taiga // *Pedobiologia*. Vol.46. No.3. P.373–384.
- Kuznetsova N.A., Krest'yaninova A.I. 1998. Dynamics of springtail communities (Collembola) in hydrological series of pine forests in southern taiga // *Entomol. Rev.* Vol.78. No.8. P.969–981.
- Kuznetsova N.A., Potapov M.B. 1997. Changes in structure of communities of soil springtails (Hexapoda: Collembola) under industrial pollution of the south-taiga bilberry pine forests // *Russian J. Ecol.* Vol.28. No.6. P.386–392.
- Magurran A.E. 1988. Ecological diversity and its measurement. Dordrecht: Springer Science+Business Media. 179 p.
- Malmström A. 2012. Life-history traits predict recovery patterns in Collembola species after fire: A 10 year study // *Appl. Soil Ecol.* Vol.56. P.35–42.
- Ogureeva G.N., Leonova N.B., Emelyanova L.G., Buldakova E.V., Kadetov N.G., Arkhipova M.V., Miklyayeva I.M., Bocharnikov M.V., Dudov S.V., Ignatova E.A., Ignatov M.S., Muchnik E.E., Urbanavicius G.P., Danilenko A.K., Rummyantsev V.Yu., Leontyeva O.A., Romanov A.A., Konstantinov P.I. 2015. [Map "Biomes of Russia" (scale 1: 7 500 000) In: A series of nature maps for highschoools]. Moscow: Finansovy and Organizatsionny Konsalting. 200 p. [In Russian]
- Petersen H., Luxton M. 1982. A comparative analysis of soil fauna populations and their role in decomposition processes // *Oikos*. Vol.39. P.288–388.
- Potapov M. 2001. Synopses on Palearctic Collembola. Vol.3. Isotomidae // *Abhandl. Berich. Naturkund. Mus. Görlitz. Appendix*. Vol.73. No.2. P.1–590.
- Rusek J. 1998. Biodiversity of Collembola and their functional role in the ecosystem // *Biodivers & Conserv.* Vol.7. No.9. P.1207–1219.
- Seastedt T.R. 1984. The role of microarthropods in decomposition and mineralization processes // *Ann. Rev. of Entomol.* Vol.29. No.1. P.25–46.
- Taskaeva A.A. 2009. Springtail (Collembola) assemblages in Floodlands of the taiga zone of the Republic of Komi // *Entomol. Rev.* Vol.89. P.956–974.
- Taskaeva A.A. 2011. [Collembola of pine forests in a pollution gradient of timber industry complex emission] // *Izv. Penz. gos. pedagog. univ. im.i V.G. Belinskogo*. Vol.25. P.453–461 [in Russian].
- Urbanovičová V., Miklisová D., Kováč I. 2013. The effect of windthrow, wild fire, and management practices on epigeic Collembola in windthrown forest stands of the High Tatra Mts (Slovakia) // *Biologia (Bratislava)*. Vol.68. No.5. P.941–949.
- World Atlas of Physical Geography. 1964. USSR Academy of Sciences. Moscow: Main Office of Geodesy and Cartography. 294 p. [In Russian]
- Zaitsev A.S., Gongalsky K.B., Malmström A., Persson T., Bengtsson J. 2016. Why are forest fires generally neglected in soil fauna research? A mini-review // *Appl. Soil Ecol.* Vol.98. P.261–271.

Responsible editor K.G. Mikhailov

Appendix 1

Species list of springtails found in the studied ecoregions (indiv. m⁻², mean ± SE, n=4). Biogeographic distribution types are provided according Babenko and Fjellberg (2006) and Babenko (2012). The abundance of the most frequent and abundant collembolan species found in all studied ecoregions shown in bold. Species range: C — cosmopolitan, TH — trans-holarctic, TP — trans-palaearctic, WP — west-palaearctic, G — goenlandic, EP — east-palaearctic, Unk — unknown distribution.

Список видов ногохвосток найденных в исследуемых экорегионах (экз. м⁻², среднее ± станд. ошибка, n=4). Типы биогеографического распространения представлены по Бабенко и Фьельбергу (2006) и Бабенко (2012). Численность часто встречающихся и распространенных видов, найденных во всех исследуемых экорегионах выделена жирным шрифтом. Тип распространения: С — космополит, ТН — транс-голарктический, ТР — транс-палеарктический, WP — западно-палеарктический, G — гренландский, EP — восточно-палеарктический, Unk — с неизвестным распространением.

Species	Kola-Karelian		Pribaltiitskiy-Vetluzhskiy		Smolensk-Priuralskiy	
	Burnt	Control	Burnt	Control	Burnt	Control
Family Tullbergiidae						
<i>Mesaphorura critica</i> Ellis, 1976	—	—	128±128	416±416	96±96	—
<i>M. hylophila</i> Rusek, 1982	—	—	—	928±928	9664±8123	—
<i>M. krausbaueri</i> Börner, 1901	32±32	—	—	—	3008±1885	608±402
<i>M. macrochaeta</i> Rusek, 1976	—	32±32	—	288±211	832±444	—
<i>M. sylvatica</i> Rusek, 1971	—	—	96±96	672±672	96±96	64±64
<i>M. tenuisensillata</i> Rusek, 1974	192±192	288±168	1088±662	896±768	2432±1889	1280±1115
<i>M. yosii</i> (Rusek, 1967)	4128±2895	3008±632	1376±737	2592±1037	6752±3303	1728±1178
<i>M. juveniles</i>	256±215	128±73	320±242	224±183	896±384	128±73
<i>M. undefined*</i>	384±188	352±151	896±517	512±209	1824±750	448±263
<i>Metaphorura affinis</i> (Börner, 1902)	—	—	—	32±32	—	—
Family Onychiuridae						
<i>Hyumenaphorura polonica</i> Pomorski, 1990	—	64±64	—	—	—	—
<i>Microphorura absoloni</i> (Börner, 1901)	32±32	96±96	960±297	448±110	1728±1091	1408±567
<i>Protaphorura armata</i> (Tullberg, 1869)	352±310	160±160	—	—	2624±2624	—
<i>P. cancellata</i> (Gisin, 1956)	—	—	—	—	—	96±96
<i>P. pseudovanderdrifti</i> (Gisin, 1957)	160±160	—	—	—	160±160	—
<i>P. subarctica</i> (Martynova, 1976)	576±413	—	96±96	32±32	—	128±128
<i>P. sp. 1</i>	—	—	—	—	64±64	160±160
<i>P. sp. 2</i>	—	—	—	—	224±224	—
<i>P. sp. 3</i>	96±96	128±128	—	—	—	—

Species	Kola-Karelian		Pribaltiitskiy-Vetluzhskiy		Smolensk-Priural'skiy	
	Burnt	Control	Burnt	Control	Burnt	Control
<i>Protaphorura juveniles</i>	Unk	32±32	-	-	352±352	-
Family Hypogastruridae						
<i>Ceratophysella denticulata</i> (Bagnall, 1941)	C	-	-	-	-	160±121
<i>C. engadinensis</i> (Gisin, 1949)	C?	-	-	-	-	96±61
<i>C. gibbosa</i> (Bagnall, 1940)	C	-	-	-	-	160±160
<i>Chouretinula inermis</i> (Tullberg, 1871)	TP	-	480±480	-	96±96	-
<i>Willemia anophthalma</i> Börner, 1901	TH	128±52	2336±825	4320±2678	-	2080±1419
<i>W. denisi</i> Mills, 1932	TH	-	128±73	1440±980	512±512	256±215
<i>W.</i> undefined *	Unk	32±32	-	-	-	-
<i>Xenylla boernerii</i> (Axelson, 1905)	WP	-	96±96	1664±1664	-	-
<i>X. brevicauda</i> Tullberg, 1869	WP	-	-	-	-	-
<i>X. cf. maritima</i> Tullberg, 1869	C	-	-	-	32±32	-
<i>X. tullbergi</i> (Börner, 1903)	TP?	-	160±160	-	-	-
Family Neanuridae						
<i>Fritesea claviveta</i> Axelson, 1900	C	-	448±448	1024±1024	416±416	32±32
<i>F. cf. danica</i> (Fjellberg, 1993)	Unk	-	-	-	-	32±32
<i>F. mirabilis</i> (Tullberg, 1871)	C	-	-	32±32	-	-
<i>F. truncata</i> Cassagnau, 1958	TP?	-	32±32	-	960±457	960±382
<i>Micranurida granulata</i> (Agrell, 1943)	TP?	-	-	-	-	64±36
<i>M. pygmaea</i> Börner, 1901	TH	160±121	224±109	960±399	256±147	224±131
<i>Neanura cf. coronifera</i> (Axelson, 1905)	Unk	-	480±224	-	-	-
<i>N. muscorum</i> (Templeton, 1835)	TH?	-	128±90	-	64±36	64±64
<i>Pseudachorutes boernerii</i> (Schött, 1902)	TP	-	32±32	-	32±32	-
<i>P. corticicolus</i> (Schäffer, 1896)	TP	-	64±64	-	-	64±64
<i>P. parvulus</i> Börner, 1901	Unk	-	-	-	-	64±64
<i>P. subcrassus</i> Tullberg, 1871	WP?	-	-	32±32	-	-
<i>P.</i> juveniles	Unk	-	-	-	-	32±32
Family Odontellidae						
<i>Xenyllodes armatus</i> Axelson, 1903	TH	-	-	-	-	736±736
Family Isotomidae						
<i>Anurophorus septentrionalis</i> Palissa, 1966	WP	992±297	1184±378	1504±1027	-	-
<i>Cryptopygus cf. bipunctatus</i> (Axelson, 1903)	TH?	-	96±96	-	-	-

Species	Kola-Karelian		Pribaltiiskiy-Vetluzhskiy		Smolensk-Priuralskiy	
	Burnt	Control	Burnt	Control	Burnt	Control
<i>Desoria hiemalis</i> (Schött, 1893)	—	—	64±64	—	—	32±32
<i>D. nivea</i> (Schäffer, 1896)	—	—	—	—	32±32	—
<i>D. olivacea</i> (Tullberg, 1871)	—	—	—	—	—	96±96
<i>Folsomia bisetosa</i> Gisin, 1953	—	—	—	—	—	160±160
<i>F. bisetosa</i> juveniles	—	—	—	—	—	1312±1312
<i>F. dovrensis</i> Fjellberg, 1976	—	32±32	32±32	—	—	—
<i>F. fimetarioides</i> (Axelson, 1903)	960±960	1248±1248	—	—	4288±4288	—
<i>F. quadrioculata</i> (Tullberg, 1871)	1472±1229	64±64	640±484	64±64	7616±5902	1984±931
<i>F. quadrioculata</i> juveniles	1056±849	416±336	288±183	96±61	960±636	2400±1574
<i>F. sp. 1</i>	—	—	—	—	224±224	—
<i>Isotoma viridis</i> Bourlet, 1839	96±61	192±110	—	64±36	32±32	96±96
<i>I. viridis</i> juveniles	—	704±483	960±554	3456±2225	32±32	1696±1696
<i>Isotomiella minor</i> (Schäffer, 1896)	1472±662	6656±2127	9088±2547	7776±2977	6912±1751	16704±6718
<i>Isotomurus fucticola</i> (Schött, 1893)	—	—	—	—	—	256±256
<i>Pachyotoma crassicauda</i> (Tullberg, 1871)	—	—	—	—	32±32	—
<i>Parisotoma notabilis</i> (Schäffer, 1896)	32±32	32±32	3008±1897	2880±632	4832±1305	8128±2411
<i>Proisotoma minima</i> Absolon, 1901	—	—	32±32	—	128±128	—
<i>P. cf. ripicola</i> (Linmaniem, 1912)	—	—	64±64	32±32	—	—
<i>Pseudanurophorus binoculatus</i> Kseneman, 1934	—	—	352±310	96±61	288±288	1280±783
<i>Tetracanthella wahlgreni</i> Axelson, 1907	704±619	3168±1770	—	—	—	—
<i>Vertagopus haagvari</i> (Fjellberg, 1996)	—	—	64±64	—	—	—
Family Tomoceridae						
<i>Pogonognathellus flavescens</i> (Tullberg, 1871)	—	—	512±239	64±64	64±36	64±64
Tomoceridae juveniles	—	—	—	—	32±32	32±32
Family Entomobryidae						
<i>Entomobrya corticalis</i> (Nicolet, 1842)	—	—	—	—	544±462	32±32
<i>E. nicolei</i> (Lubbock, 1868)	—	32±32	32±32	—	32±32	—
<i>E. nivalis</i> (Linnaeus, 1758)	96±32	32±32	128±90	32±32	896±896	128±52
Entomobryidae juveniles	—	544±306	576±212	2176±1837	64±36	1088±817

Species	Kola-Karelian		Pribaltiyskiy-Vetluzhskiy		Smolensk-Prutalskiy	
	Burnt	Control	Burnt	Control	Burnt	Control
<i>Lepidocyrtus cyaneus</i> (Tullberg, 1871)	TH?	—	—	—	32±32	—
<i>L. lanuginosus</i> (Gmelin, 1790)	Unk	480±278	64±64	64±36	256±156	32±32
<i>L. lignorum</i> (Fabricius, 1793)	TH?	320±212	352±141	256±256	—	224±224
<i>L. pallidus</i> (Reuter, 1890)	C?	—	—	—	704±704	—
<i>L. cf. paradoxus</i> (Uzel, 1890)	TH?	—	—	32±32	—	—
<i>L. cf. violaceus</i> (Geoffroy, 1762)	TP?	—	—	32±32	—	—
<i>L. juveniles</i>	Unk	640±362	992±480	1152±570	192±192	704±513
<i>Orchesella bifasciata</i> (Bourlet, 1839)	WP	—	160±160	128±73	160±96	32±32
<i>O. cincta</i> (Linnaeus, 1758)	TP	—	32±32	—	—	—
<i>O. flavescens</i> (Bourlet, 1839)	TP	32±32	—	32±32	32±32	64±36
<i>O. spectabilis</i> Tullberg, 1871	TP	—	—	32±32	—	—
<i>Willowsia cf. platani</i> (Nicolet, 1842)	TH?	32±32	—	—	—	—
Family Neelidae						
<i>Megalothorax minimus</i> Willem, 1900	C	—	—	32±32	192±36	224±183
Family Sminthurididae						
<i>Sminthurides aquaticus</i> (Bourlet, 1842)	TH	—	—	—	—	128±128
<i>Sminthurides malmgreni</i> (Tullberg, 1876)	TH	—	—	—	64±64	—
<i>Sminthurides cf. signatus</i> (Krausbauer, 1898)	TP?	—	—	32±32	96±96	—
<i>Sminthurides schoetti</i> Axelson, 1903	TP	—	—	—	96±96	—
<i>Sphaeridia pumilis</i> (Krausbauer, 1898)	C?	—	480±306	256±256	128±128	544±323
Family Katiannidae						
<i>Sminthurinus aureus</i> (Lubbock, 1862)	TP	—	—	—	672±515	32±32
<i>S. concolor</i> (Meinert, 1896)	WP+G	160±121	64±36	—	64±64	—
<i>S. niger</i> (Lubbock, 1868)	TP	—	—	—	64±64	96±96
<i>S. signatus</i> (Krausbauer, 1898)	TP	—	—	288±288	—	—
<i>S. sp. 1</i>	Unk	—	—	32±32	—	—
<i>S. juveniles</i>	Unk	—	—	32±32	192±192	—
Family Arrhopalitidae						
<i>Pygmarhophaltes principalis</i> (Stach, 1945)	TH	192±110	—	—	96±61	928±363
<i>P. cf. secundarius</i> (Gisin, 1958)	TH	160±160	32±32	64±64	64±64	—
<i>P. juveniles</i>	Unk	160±80	64±64	32±32	64±36	800±592

Species	Kola-Karelian		Pribaltiiskiy-Vetluzhskiy		Smolensk-Priuralskiy	
	Burnt	Control	Burnt	Control	Burnt	Control
Family Bourletellidae						
Bourletellidae juveniles	Unk	–	–	–	128±128	32±32
<i>Deuterosminthurus cf. bicinctus</i> (Koch, 1840)	TP?	–	–	64±36	–	–
Family Sminthuridae						
<i>Allacma fusca</i> (Linnaeus, 1758)	TH	–	32±32	32±32	32±32	288±168
<i>Sminthurus viridis</i> (Linnaeus, 1758)	C	–	–	–	32±32	–
Family Dicyrtomidae						
<i>Dicyrtomina minuta</i> (Fabricius, 1783)	TH	–	–	32±32	–	–
<i>Ptenothrix atra</i> (Linnaeus, 1758)	TP	32±32	–	–	96±96	64±36
Total abundance, indiv. m⁻²	14112±2337	23104±4771	27968±5884	37472±5541	63328±10583	50976±11792
Average number of species per plot	10±0.6	15±1.7	17±2.3	18.7±3	21.7±0.7	21.2±2.9
Total number of species	19	31	37	43	50	47
Shannon diversity index(H')	2.1514	2.2983	2.4519	2.6622	2.7428	2.3917
Evenness (J')	1.6824	1.5269	1.5520	1.6199	1.6062	1.4226

* species was not identified due to missing body parts or groups of setae relevant for identification.

* виды не определены ввиду отсутствия частей тела или групп хет, значимых для идентификации.