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Soil Arthropoda of Post-Fire Successions in Northern Taiga of West Siberia

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Abstract—The soil arthropoda population of northern taiga was investigated in the primary pine forest which had not been subject to any fire for at least 100 years and at two burnt sites of different opost-fire successions. The population of the primary nonburnt forest is represented by 54 microarthropoda species. The mesofauna is composed almost exceptionally of spiders: 10 species of them were identified.

The foliage underwood develops on young burnt sites; the soil is covered with thick mossy cushions, with spots of reedgrass. The density of collembolan and oribatid mite population there is about two times lower than in nonburnt pine forests; gamasid mites are absent. The microarthropoda population is represented by the species which are common in the surrounding primary pine forests. The mesofauna consists mainly of ground beetles, open-land predators, and myxophytophagans. Spiders are represented by some widespread mobile species of low density.

A mixed forest with mossy-lichen cover is formed on old burnt sites (of an age of about 50 years). Diversity and density of microarthropoda increase reaching the values characteristic of the primary forest; however, the species composition and dominance are still different. The fraction of spiders in mesofauna increases. The ground beetle population is the most abundant and diverse.

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The Russian forest fund includes most of the boreal forests of Eurasia, 400–600 million hectares [1]. According to the decoded satellite imagery, every year fire affects on average 8 million hectares of forest plantation in the boreal zone of Russia [2]. Analysis of the fire activity dynamics based on satellite data shows that the areas under fire are significantly growing every year [1].

Forest fires are an important factor of local, regional, and global ecodynamics [4]. They are a necessary element of forest dynamics which ensures their renewal. In addition, century after century the anthropogenic influence leads to an increase in intensity and frequency of fires and in area under fire [3]. Considerable pyrogenic changes happen on the margins of the taiga zone, where the global warming and anthropogenic impact most actively interact reinforcing each other. As a result, in light coniferous forests on light-textured soils the burnt sites are the dominating type of ecosystem rather than spots against the landscape background [2].

Changes in vegetation lead to large transformations in composition and functioning of communities of soil animals, triggering specific post-fire successions. Study of soil fauna of post-fire successions is the subject of this work.

MATERIALS, METHODS, STUDY AREAS

The studies were carried out in 1999–2002 in the vicinity of the town of Noyabr'sk, in the subzone of northern taiga of the West Siberian plain in the zone of Sibirskie Uvaly, which is a terminal moraine of the Quaternary Sartan glaciation. In the series of post-fire succession the population of soil arthropoda was studied on two areas.

The young burnt site is an area of pine forest that underwent a strong fire about ten years ago. The vegetation is at the initial stage of recovery succession, the pine undergrowth is small, but the quickly growing birch trees appear. The soil is covered with a dense layer of green moss with spots of reedgrass, and fructiferous shrubs of cowberry grow there.

The old burnt site (about 50 years) is overgrown with a park pine-birch forest with Iceland moss cover. The stand is composed of pine, larch, scarce aspen and spruce; the shrub level consists of juniper, dwarf birch, and blueberry; on the soil, fruticose lichen (Iceland moss) grows. The soil is soddy-podzolic, with the sod horizon 5–7 cm thick and podzolic horizon 5–6 cm thick; the soil contains coals.

The control was a primary pine forest with white moss and an insignificant admixture of cedar and larch on the humic podzol which has not undergone strong fires, at least, for the last 100 years.

In July, 1999 we studied microarthropoda (collembolan, oribatid, and gamasid mites). We took soil samples with a cylindrical drill 5 cm in diameter from a depth of 5 cm, repeating the sampling ten times. The organisms were driven out with the help of Tullgren funnels up to complete drying up of the substrate. Mesofauna of pedobionts (ground beetles and spiders) was registered using soil traps, ten for each biotope in July–August of 1999–2002.

The calculations were carried out with the help of programs “Stadia”, “Statistica”, and ”Ecos” [4].

RESULTS AND DISCUSSION

Consequent on fires at the northern boundary of taiga in West Siberia, ecosystems of three types form: areas of wind-drifted sands without vegetation, burnt sites with dry tree stands and fragmentary ground vegetation, and deciduous or mixed forests aged tens of years.

Primary Pine Forest

Population of soil invertebrates of the control pine forest with white moss is numerous and diverse. It includes 54 species of microarthropoda with a general density of 48 520 of individuals per square meter. Oribatid mites are more numerous than collembolan mites both in number of species and in density. All groups of microarthropoda form polydominant groups typical of mature forest biotopes (see Tables 1 and 2).

The community is characterized by the highest indices of diversity (see Table 3) and uniformity of species structure. The rank distribution of species in the given biotope is described with the broken rod model [5], typical of balanced communities of simple structure, which consist of small ecologically similar groups, limited by one resource.

In the control biotope mesofauna of pedobionts is represented almost exclusively by spiders of the families Lycosidae and Gnaphosidae (migrating large spiders). In total, 10 species were documented (every year 5–7 species were registered). Spiders reach a high density (47.7 individuals per 100 trap-days in 2000), while only one individual of ground beetle (*Carabus canaliculatus* Ad.) was found in four years (1999–2002). This ratio of densities for ground beetles and spiders is quite typical of lichen thin pine forests of the studied area. In 2002 in two adjacent biotopes of similar pine forest with white moss four species of spiders were collected (five species in total) and no species of ground beetles were found (see Table 4).

Young Burnt Site

The studied young burnt site preserves dead stand, which creates the forest image and provides steady arrival of high-ash and organic elements from fallen branches and trunks. On the soil cover, the litter and moss recover in 2–3 years, and the heather dwarf subshrubs, in 7–10 years.

The community of microarthropoda of young burnt site is poor, with only 25 species registered (see Table 1), which makes up a half of the species documented in the control biotope. The structure of communities of collembolan and oribatid mites is simple comparing with the control: There are one dominating species, two subdominants, and the rest is low in number. Most profoundly fires affect gamasid mites (inhabitants of the litter), which are represented here by only two species composed of few individuals. In general, the community of microarthropoda is characterized by a high degree of domination of several species and low uniformity (Shannon index is 0.53). The rank distribution of species in the given biotope is described with a hyperbolic model [6], which characterizes communities

Table 1. Population of microarthropoda in biotopes of post-fire succession series

Population characteristic	Young burnt site	Old burnt site	Control
	Oribatid mites		
Number of species	15	28	28
Density, thousands of individuals per m^2	11.00	18.92	30.20
	Gamasid mites		
Number of species	2	11	11
Density, thousands of individuals per m^2	0.08	3	2.76
	Collembolan mites		
Number of species	9	12	15
Density, thousands of individuals per m^2	3.48	15.04	15.56
Total number of species	25	55	54
Total density	14.56	36.96	48.52

Table 2. Population of microarthropoda in biotopes of post-fire succession series, total number of individuals in 10 samples (dominant species are bold-typed, subdominant species are italicized)

Species	Young burnt site	Old burnt site	Control
1	2	3	4
Collembola			
Folsomia quadrioculata	**67**	177	**158**
Protaphorura sp.	*6*	*37*	**70**
Isotomiella sp.	2	5	*34*
Folsomia sp. gr. diplophthalma	1	93	0
I. (P.) notabilis	0	34	*34*
I. (D.) sp.	2	12	*40*
Tomocerus sp.	0	3	10
Arrhopallites sp. 2	0	1	7
Friesea mirabilis	1	1	0
Micranuruda pigmaea	*0*	*0*	*13*
Willemia anophthalma	0	0	3
Sminthurinus sp.	0	11	0
Entomobrya sp.	0	0	9
Xenyllodes arnatus	6	0	0
Lepidocyrtus violaceus	0	1	2
Megalothorax minimus	0	0	3
Pseudachorutes subcaccus	0	0	3
Onychiurus sp.	0	0	2
Anurophorua sp.	1	0	0
Mesaphorura macrochaeta	0	0	1
Pseudachorutes dubuis	0	1	0
Sminthurides sp.	1	0	0
Total	87	376	389
Oribatei			
Tectocepheus velatus	**173**	**85**	**175**
Carabodes labyrinticus	**53**	**105**	35
Carabodes forsslundi	0	*45*	**98**
Conchogneta tragardhi	11	5	**102**
Oppiella sp.	0	4	*63*
Nanhermannia sellnicki	0	4	**113**
Oppiella nova	10	16	4
Scheloribates latipes	3	*55*	8
Trhypochthonius cladonicola	0	4	30
Moritzoppiella microdentata	4	4	4
Ceratozetes thienemanni	0	5	*35*
Oribatula pallida	0	*39*	4
Suctobelbella sp. 1	2	14	4
Suctobelbella sp. 2	3	*21*	4
Rhysotritia ardua	0	15	4
Nothrus pratensis	0	0	0
Epidamaeus paraspinosus	0	4	15

Table 2. (Contd.)

1	2	3	4
Suctobelbella sp. 3	0	4	10
Microppia minus	2	4	4
Belba sp.	4	4	4
Liochthonius lapponicus	2	4	4
Ceratoppia quadridentata	0	4	3
Heminothrus peltifer	2	4	4
Oppia sp.	2	4	4
Phthiracarus globosus	0	4	6
Steganacarus sp.	2	4	4
Birsteinius perlongus	*0*	*4*	*5*
Scheloribates sp.	0	4	5
Galumna sp.	0	0	0
Gymnodamaeus bicostatus	0	4	4
Ceratozetes minutussimus	2	0	0
Total	275	473	755
Gamasina (LL — larvae)			
Parazercon radiatus	0	4	**17**
Veigaia nemorensis	0	9	*8*
Veigaia sibirica	1	0	*3*
Zercon schweizeri	0	**23**	*8*
Zercon acanticus	0	**19**	0
Gamasellus silvestris	0	1	**17**
Caurozercon duplex	0	0	1
Amblyseius sp.	0	9	0
Neozercon smirnovi	0	2	*5*
Gamasellus sp. LL	0	0	1
Gamasellus tundriensis	0	1	*6*
Veigaia sp. LL	0	3	2
Zercon sp. LL	0	3	0
Rhodacarellus sp.	0	1	0
Veigaia igolkini	0	0	1
Zercon sp. 1	1	0	0
Total	2	75	69

Table 3. Indicators of diversity of microarthropoda communities in biotopes of post-fire succession series

Post-fire succession stage	Shannon index	Uniformity (after Shannon)	Model of range distribution
Young burnt site	2.71	0.58	Hyperbolic
Old burnt site	3.82	0.73	Broken rod – II
Control	4.24	0.79	The same

with few species and pronounced domination formed at the first stages of successions.

Three species of collembolan mites were registered solely at the young burnt site, but only *Xenyllodes armatus* Axelson reached significant number and can be considered specific for the given biotope (see Table 2). In general, the group of microarthropoda on a young burnt site can be characterized as distinctly de-

Table 4. Seasonal average number of mesofauna of pedobionts in biotopes of post-fire succession series and control, ind. per 100 trap-days

Species	Young burnt site	Old burnt site	Control
Aranei			
Gnaphosa lapponum	0	0	11.3425
Gnaphosa muscorum	0.4625	1.906667	6.5125
Gnaphosa leporina	0.1575	0	0.1575
Pardosa cf. palustris	0	0	0.1575
Alopecosa aculeata	0	1.48	5.5625
Zelotes cf. clivicola	0	0.476667	2.7875
Xerolycosa nemoralis	0.625	0	0
Pardosa paludicola	0	0	0.8325
Gnaphosa sp.	0.1575	0	1.3575
Pardosa sp.	0	0	1.445
Pardosa cf. schenkeli	0.3125	0	0
Pardosa eiseni	0	0	0.47
Zelotes subterraneous	0	0.37	0
Evarcha sp.	0	0.37	0
Zora sp.	0	0.37	0
Carabidae			
Cicindela sylvatica	6.7725	0	0
Pterostichus dilutipes	0	8.78	0
Notiophilus aquaticus	0	3.95	0
Calathus micropterus	0	4.66	0
Amara brunnea	0.3125	4	0
Pterostichus adstrictus	1.9	0.66	0
Curtonotus hyperboreus	0	2	0
Carabus canaliculatus	0.25	0.66	0.8325
Amara quenseli	0.7825	0	0
Carabus aeruginosus	0	1.33	0
Bembidion obliquum	0	0.66	0
Bembidion quadrimaculatum	0	0.66	0
Poecilus lepidus	0.4175	0	0
Harpalus solitaris	0.4175	0	0
Miscodera arctica	0.4075	0	0
Amara praetermissa	0	0.33	0
Notiophilus germinyi	0	0.17	0

pleted variant of natural community. However, it significantly differs from both old burnt site and control forest in average number of species as well as in number of individuals of microarthropoda (apart from oribatid mites) (see Table 5).

In different years one to five species of ground beetles were found on young burnt site (8 species in total). The tiger-beetle *Cicindela sylvatica* L. dominates there, living in open bright-lit biotopes with bare sand areas. Myxophytophagans *Amara quenseli* (Schoen.) and *Harpalus solitaries* Dej. are also numerous, feeding on herb seeds, particularly, reedgrass that occupies post-fire biotopes. The rest of ground beetle fauna represents the "debris" of usual boreal fauna (see Table 4) [7].

Spiders began to be recorded there in a noticeable number only in the 10th year after fire (in 2002). *Xerolycosa nemoralis* (West.) is typical of anthropo-

Table 5. Abundance of microarthropoda in various biotopes

Abundance		Young burnt site	Old burnt site	Control
	Oribatid mites			
	Number of individuals per sample	27.1	44.1***	73.6**
	Number of species per sample	4.8*	8.5***	10.3**
	Gamasid mites			
Average	Number of individuals per sample	0.2*	3.6	4.5
	Number of species per sample	0.2*	1.7	1.5**
	Collembolan mites			
	Number of individuals per sample	17.0*	74.6	77.8**
	Number of species per sample	3.0*	7.0	7.2**

* Values significantly differ for young and old burnt site ($p < 0.01$).
** Values significantly differ for young burnt site and control ($p < 0.01$).
*** Values significantly differ for old burnt site and control ($p < 0.01$).

genic biotopes (various dry open pits), and *Pardosa schenkeli* Less. was found only in one more biotope, near an associated-gas flare (2002). Inhabiting of young burnt sites with prevalent ecologically plastic species of spiders is also described by authors studying the fire influence on spider community of deciduous forests of Swiss Alps [8].

Old Burnt Site

The microarthropoda community of old burnt site is quite different from the above community and is similar to the population of nonburnt forest. The group of the given biotope is very close to the control in number of species, although the density of microarthropoda is still 1.3 times lower. The community structure still differs from that of the nonburnt forest. In spite of rather high coefficient of faunistic similarity (70%), the coefficient of qualitative similarity is low (see Table 6). Only one species of collembolan mites (*Folsomia quadrioculata* (Axelson)) and one species of oribatid mites (*Tectocepheus velatus* (Michael)) dominate in both biotopes. The dominating collembolan mites *Folsomia* sp. gr. *diplophthalma* and gamasid mites *Zercon schweizeri* (Bhatt.) and *Zercon acanticus* Blaszak, as well as subdominant collembolan mites *Parisotoma notabilis* Schaffer, oribatid mites *Scheloribates latipes* (C. L. Koch), *Oribatula pallida* Banks and *Suctobelbella* sp. 2 are rare to absent in other biotopes (see Table 2).

On the whole, the microarthropoda community of old burnt site is characterized by high values of the basic parameters of diversity (see Table 3): larger number of species and density, higher index of Shannon and uniformity of species structure. The rank distribution of species in the given biotope, like in a nonburnt forest, is described by the MacArthur model (broken rod, type II), typical of communities with niche overlapping.

Old burnt site significantly differs from the control forest only in the average number of species and in the number of individuals per sample for oribatid mites, while for gamasid and collembolan mites the difference is insignificant (see Table 5).

The ratio of ground beetles and spiders at an old burnt site changes: They alternate in domination in different years. However, on the whole at the old burnt site a community of 12 species of ground beetles and only 6 species of spiders were registered. The dominating ground beetles here are the forest mesophiles *Pterostichus dilutipes* (Motsch.), *Calathus micropterus* (Duft.). It is evident that at old burnt site aged several tens of years a particular community of ground beetles is formed, significant in density, rich in species, and resembling in composition communities of middle-taiga forests rather than those of northern taiga.

Among spiders the species abundant in a nonburnt forest prevail (*Gnaphosa muscorum* (L. Koch), *Alopecosa aculeata* (Clerck)). However, the dominant of native pine forest *Gnaphosa lapponum* (L. Koch) is absent from old burnt site. The total density of spiders is lower than that of ground beetles, although it is higher than at burnt site (see Table 4). Spiders show the same regularity as microarthropoda: After 50 years of recovery the northern pine taiga only partly resembles the

Table 6. Coefficients of quantitative and qualitative similarity (Jacquard and Jacquard-Naumov) of biotopes of post-fire succession series, %

	Young burnt site	Old burnt site	Control
	Collembolan mites		
Young burnt site	100	**40.00**	**20.00**
Old burnt site	*20.57*	100	**42.10**
Control	19.30	*48.80*	100
	Oribatid mites		
Young burnt site	100	**50.00**	**50.00**
Old burnt site	*31.46*	100	100
Control	*31.90*	*28.18*	100
	Gamasid mites		
Young burnt site	100	**0**	**8.33**
Old burnt site	*0*	100	**46.60**
Control	*1.43*	*22.00*	100
	Microarthropoda on the whole		
Young burnt site	100	**35.08**	**31.14**
Old burnt site	*25.04*	100	**69.35**
Control	*26.16*	*34.40*	100

Note. Coefficient of qualitative similarity (Jacquard) is bold-typed; coefficient of quantitative similarity (Jacquard-Naumov) is italicized.

natural forest with respect to spider population. Spiders tend to biotopes with high complexity of environment, for example, with lichen cover, as well as to moister biotopes, especially under tree crowns, while ground beetles are numerous at the earlier stages of post-fire succession.

Thus, the principal effect of fire in north taiga, besides the immediate influence on the flora and fauna [9], is expressed in the destruction of the litter and lichen cover, which play an important role in preserving moisture and serve as a habitat for microarthropoda and spiders. Fires also lead to a drastic change in composition of soil microorganisms and microbiological activity of soil [10]. In spite of arrival of big amount of high-ash nutrients after fire [11], they are quickly washed out of soil profile given a high degree of drainage and no litter. The additional arrival of high-ash elements into soil and decrease in acidity of the litter as a result of fire lead to lower diversity and biomass of microscopic fungi due to stronger competition from bacterial microflora [10]. As a result, the density of bacterio- and mycetophages is low. The suitable microhabitats are populated by widespread highly mobile ground beetles [12], mostly myxophytophagans. Predatory pedobionts are still rare.

As a burnt site becomes older, a mixed forest forms there. The tree waste is quickly mineralized enriching the soil with nutrients, which leads to an increase in the biomass of soil fungi and growth of microarthropoda density, mostly mycetophages. At the same time the density of spiders, which eat microarthropoda, is not as high here as in primary pine forests. The recovery of vegetation cover creates favorable conditions for pedobionts, which results in a large number of predatory ground beetles.

In primary pine forests a large number of predatory pedobionts (spiders) is likely to limit the growth of microarthropoda density and, even with thick layer of lichen, the density of the latter is only slightly higher than at an old burnt site. According to the data of field experiment conducted in the given biotope the density of microarthropoda significantly differs when the soil is isolated from large predatory invertebrates with the help of cellular fabric [13]. Similar data for the litter is given by Hunter et al. [14]: The density of isolated collembolan mites is 34% higher.

The absence of ground beetles from such biotopes can be explained by aggravation of competitive relations with spiders for food, as well as by the fact that they do not find suitable habitats among lichen cover.

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