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ECOLOGY

Transformation of Soil Organic Matter in Microarthropod Community from the Northern Taiga of West Siberia

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Abstract—Recolonization of defaunated soil by springtails as well as by gamasid and oribatid mites and the changes in organic matter content of soil were studied in the northern taiga. After a one-year exposure in gauze bags (1.7 mm mesh), the abundance of microarthropods was higher but the number of species was lower compared to the surrounding soil. Large surface and litter forms did not colonize the samples, while the number of small and/or soil forms was higher. Soil samples inaccessible for microarthropods (0.15 mm mesh) were depleted of organic carbon compared to both surrounding soil and recolonized samples. The content of humic and fulvic acids was higher in the samples inaccessible to microarthropods. Humification processes prevailed in soils in the absence of microarthropods.

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Evaluation of the role of particular functional groups of animals in a community is one of the most relevant problems of ecology. By tradition, such research is conducted either in laboratory microcosms or in field experiments involving isolation methods. Application of gauze bags or containers with different mesh size containing defaunated substrate is one of the most convenient methods to study the significance of particular size groups in ecosystem functioning in soil zoology (Heath *et al*., 1964; Gartner and Cardon, 2004). Large mesh size (1 cm and more) allows most major groups of soil animals to recolonize studied samples; medium mesh size (around 1 mm) is permeable to microarthropods but inaccessible to larger animals; while small mesh size (less than 0.1 mm) allows only microorganisms to participate in decomposition.

This approach was used to study litter decomposition for various tree species (Chapman *et al*., 1988; Hansen and Coleman, 1998; Kaneko and Salamanca, 1999). Defaunation included either biocide treatment (naphthalene etc.) (Blair *et al*., 1991; Heneghan *et al*., 1988) or freezing and drying of native material (Scheu *et al*., 1999). Samples were exposed to natural conditions for specific time periods, different humidity conditions (Taylor *et al*., 2004), different biotopes (Franklin, 2004), etc. when environmental factors were varied. After the exposure of experimental samples, representatives of target size group were isolated using conventional techniques, the decomposition rate was evaluated from sample weight decrease as well as changes the content of nitrogen, carbon, and organic compounds.

However, the described isolating methods have their limitations. Mesh size determines the microclimate in the bag (due to different water permeability) and decomposition proceeds under clearly different conditions. Long exposure of large-mesh bags can lead to washing or spilling out of the organic material, which affects the results of weighing. Use of organic material (litter or roots) with heterogeneous chemical composition can provide for different starting conditions for the development of micro- and mesofauna.

The impact of invertebrates on the chemical composition of soil is more commonly studied in laboratory microcosms. Defaunated soil with specific chemical composition is placed in containers and inoculated with specific quantities of animals, and soil is analyzed again after the exposure. Protocols of such experiments can be very complex. For instance, Scheu *et al*., compared the abundance and sexual composition of aphids on cereals and legumes grown in experimental boxes with soil lacking macroscopic animals, soil with springtails, soil with earthworms, or soil with both springtails and earthworms. Even such complex experiment convincingly demonstrated the effect of springtails on the weight proportion of the under- and overground plant parts, nitrogen content in them, and reproductive activity of aphids.

Despite the convenience of laboratory experiments, the physical conditions in microcosms considerably

differ from natural ones, primarily, due to the constant temperature and humidity, while the structure of microarthropod community can significantly differ under constant and variable thermal conditions (Huhta and Hänninen, 2001). In addition, microcosms are usually populated by just a few invertebrate species, while natural communities include tens of interacting invertebrate species of different taxonomic groups. Hence, the results obtained for microcosms should be extended to natural conditions with caution.

In this work, we tried to design a natural experiment to use the advantages of the above techniques and to minimize their limitations.

In the northern taiga zone, the biomass of soil microarthropods and mesofauna is low compared to broadleaf forests, while the biomass of microorganisms is high, so that these three indices are similar at the boundary of the forest and tundra zones (Begon *et al*., 1986; Mordkovich, 1995). Under such conditions, the major size and functional groups that affect soil processes are bacteria, protists, soil fungi, and microarthropods.

MATERIALS AND METHODS

Experiments were conducted at the southern boundary of northern taiga in West Siberia (Noyabr'sk Town environs, Yamal–Nenets Autonomous District, Tyumen Region; 63°15′ N, 74°30′ E). Sample plot was selected on the main bank of the Yanga-Yakha River (Pur basin) in a 120-year-old lichen pine forest with Siberian pine *Pinus sibirica* on humic ferruginous soil.

Soil was extracted from the A1 horizon, passed through soil sieves to eliminate large plant fragments and unify the granulometric composition, and defaunated by freezing to –18°C for 3 days and subsequent drying at 60°C for 7 days according to Scheu *et al.* (1999). The prepared soil was placed into two types of gauze bags (0.14–0.15 mm mesh). Type A bags were made of the microarthropod-proof gauze completely, while type B bags had a window (1/4 of the total area) of a coarse gauze (1.7 mm mesh), which prevented the access of mesogeobionts but allowed soil recolonization by microarthropods. Prior to experiment, bags were kept in sealed envelopes in a dry place.

On July 19 2002, the bags were placed under the A0 horizon (window down for type B samples) and exposed for 365 days. Each bag had a label from bright oilcloth on a long thread, which facilitated their finding after the exposure.

On July 19 2003, the bags were extracted. Surrounding soil samples were simultaneously extracted from the same biotope (type C). Microarthropods were extracted from all sample types within 5 days using Berlese–Tullgren funnels.

Soil volume equaled 200 ml in all cases. After microarthropod extraction, type C samples were also sieved prior to chemical analysis. The samples were assayed for organic carbon, humic and fulvic acids, as well as sulfuric acid-hydrolyzed and unhydrolyzed material by the method of Tyurin. Chemical analysis was carried out in the Laboratory of Biogeocenology (Institute of Soil Science and Agrochemistry, Siberian Division, Russian Academy of Sciences).

The biotope was described by the mesoherpetobiontic and mesogeobiontic composition in the sample plot. Mesoherpetobionts were counted using soil traps. Mesogeobionts were counted in July 2000 by visual examination of 0.25 m^2 soil layers from litter to the depth of 5 cm.

RESULTS

General description of soil arthropods. Large invertebrate herpetobionts in the sample plot were exclusively represented by predators. Single ground beetle (*Carabus canaliculatus* Ad., 3.33 ind/100 trap-days) and 10 spider species largely of Lycosidae and Gnaphosidae (26 ind/100 trap-days) were recorded. In addition, harvest mites (Trombidiformes) were captured at up to 10 ind/100 trap-days. The studied biotope differed from previously studied biotopes in the Noyabr'sk environs by low abundance of mesogeobionts (Lyubechanskii, 2002, 2005). In the floodplain fir and Siberian pine forest, the density of mesogeobionts was 52 ind/m^2; 7–9 years old fire site in pine and larch forest, 8–9 ind/m^2; abandoned sand beats of different age, 16–20 ind/m^2 (Mordkovich *et al*., 2000). In the studied region, as low as 4 ind/m^2 have been revealed. Hence, microarthropods were responsible for most zoogenic soil processes here.

Microarthropods were relatively abundant in these soils, up to 82 000 ind/m^2 or 160 ind/sample (48 species including 24 oribatid mites, 16 springtails, and 8 gamasid mites) (Mordkovich *et al*., 2003).

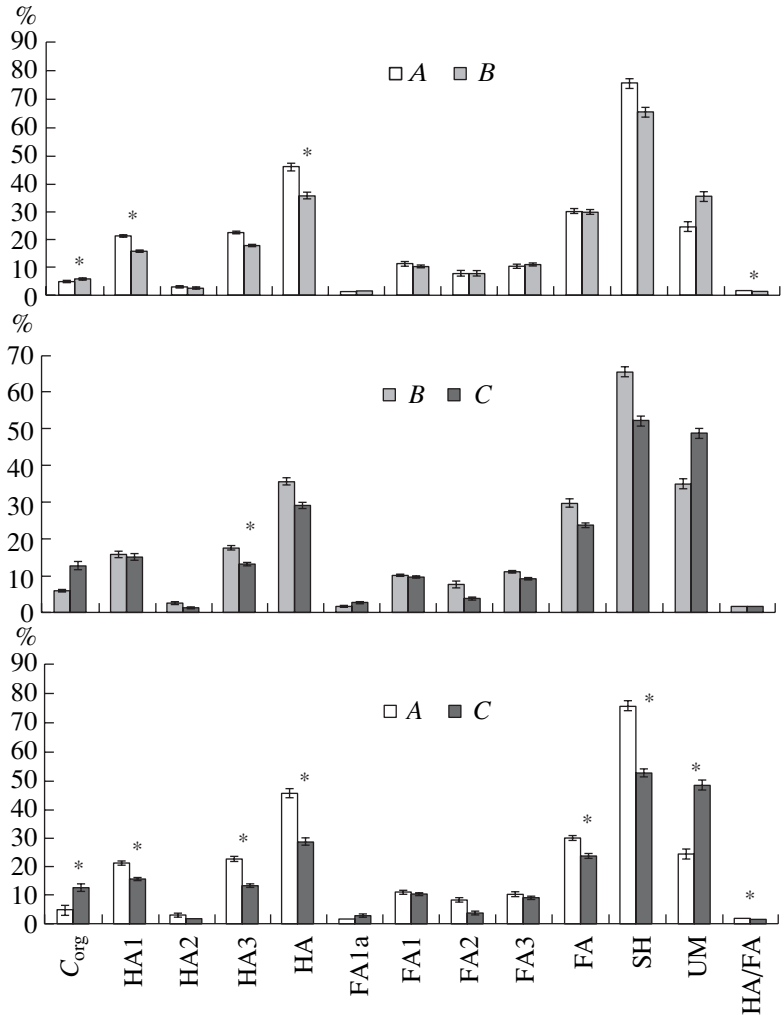
Recolonization of defaunated soil by microarthropods. Experimental of defaunated samples in bags with a coarse-mesh window were recolonized by microarthropods after a one-year exposure. Their density in the experiment exceeded that in control for both springtails and mites; the difference for springtails was significant ($p < 0.05$). Conversely, the number of species in experiment was significantly lower than in control and the difference was greater for oribatid mites than springtails. For gamasid mites, significant differences between experiment and control have been revealed for neither the mean abundance nor the mean number of individuals per sample. Similarly, no such differences have been revealed for any gamasid mite species identified in both control and experiment samples (table).

The general recolonization trend was manifested as the absence of the surface and litter forms but high numbers of small and/or soil forms in the recolonized samples. For instance, upper soil layer springtails of the genus *Protaphorura* and small deep soil layer springtail *Megalothorax minutus* were significantly more abun-

Abundance of microarthropods in experiment (type B) and control (type C), ind/sample

Species	Experiment (n = 9)	Control (n = 10)
Oribatid mites (Orbatei)		
Conchogneta tragardhi (Forsslund, 1947)	0.99 ± 0.22*	7.6 ± 0.73
Liochtonius lapponicus (Tragardh, 1910)	0.22 ± 0.05*	3.4 ± 0.28
Heminothrus humicola (Forsslund, 1955)	0.11 ± 0.04*	1.1 ± 0.12
Oppiella sp.	11.6 ± 2.5	2.3 ± 0.49
Tectocepheus velatus (Michael, 1880)	25.8 ± 6.2	8.6 ± 0.83
Suctobelbella sp.	0.3 ± 0.08	1.6 ± 0.30
Carabodes forsslundi Sellnick, 1953	0.8 ± 0.16	1.5 ± 0.13
Tetroppia sp.	1.8 ± 0.20	3.1 ± 0.48
Nanhermannia sellnicki Forsslund, 1958	0	6.5 ± 0.36
Ceratoppia asiatica Krivolutskij, 1966	0	0.1 ± 0.03
Belba sp.	0	0.1 ± 0.03
Euphthiracarus sp.	0	0.1 ± 0.03
Tetroppia maritima (Willmann, 1929)	0	0.1 ± 0.03
Mycobates parmeliae (Michael, 1884)	0.1 ± 0.04	0
Oppiella nova (Oudemans, 1902)	0.3 ± 0.08	0
Microppia minus (Paoli, 1908)	0.1 ± 0.04	0
Total	42.0 ± 6.41	25.0 ± 1.50
Species per sample	4.2 ± 0.16	7.2 ± 0.20
Gamasid mites (Gamasina)		
Veigaia nemorensis (C.L. Koch, 1892)	0.7 ± 0.09	0.56 ± 0.13
V. sibirica Bregetova, 1961	0.6 ± 0.07	0
V. kochi (Tragardh, 1901)	0.3 ± 0.07	0
V. igolkini Bregetova, 1961	0.2 ± 0.06	0
Gamasellus silvestris Halaskova, 1952	0	0.56 ± 0.11
G. montanus (Willmann, 1936)	2.0 ± 0.31	0.44 ± 0.08
Parazercon radiatus (Berlese, 1914)	1.6 ± 0.26	4.22 ± 1.04
Neozercon smirnovi Petrova, 1978	0	2.44 ± 0.38
Caurozercon duplex Halaskova, 1977	9.1 ± 0.5	4.90 ± 1.16
Zercon sp.	0	0.11 ± 0.04
Total	10.3 ± 0.56	17.44 ± 2.56
Species per sample	3.2 ± 0.16	3.00 ± 0.18
Springtails (Collembola)		
Protaphorura sp.	22.4 ± 2.28*	6.8 ± 0.64
Folsomia quadrioculata (Tullberg, 1871)	14.7 ± 1.90	11.5 ± 1.2
Megalothorax minutus Willem, 1900	14.6 ± 1.60*	4.3 ± 0.38
Desoria sp.	11.3 ± 1.0	6.8 ± 0.61
Isotomiella minor Schaffer, 1896	8.3 ± 0.59	10.5 ± 1.04
Arrhopallites sp. 1	0.1 ± 0.04	0.2 ± 0.04
Lepidocyrtus violaceus Lubbock, 1873	0.1 ± 0.04	0.1 ± 0.03
Willemia anophtalma Borner, 1901	0.9 ± 0.20	1.6 ± 0.19
Friesea mirabilis (Tullberg, 1871)	3.2 ± 0.62	0
Arrhopallites sp. 2	0.1 ± 0.04	0
Onuchiurus sp.	0	1.1 ± 0.15
Tetracanthella wahlgreni	0	0.8 ± 0.16
Neanura muscorum	0	0.1 ± 0.03
Entomobrya sp.	0	0.1 ± 0.03
Total	75.8 ± 4.32	43.9 ± 2.45
Species per sample	5.2 ± 0.11	6.5 ± 0.15

* Differences significant at $p < 0.05$.



Content of organic compounds in soil samples, %. Abscissa: organic compounds; ordinate: percentage of organic compounds; *A*, microarthropod-free samples; *B*, microarthropod-accessible samples; *C*, surrounding soil; C_{org}, organic carbon; HA1, HA2, and HA3, humic acid fractions; HA, total humic acids; FA1a, FA1, FA2, and FA3, fulvic acid fractions; FA, total fulvic acids; SH, sulfuric acid hydrolysate; UM, unhydrolyzed material; HA/FA, humic to fulvic acid ratio; differences significant at $p < 0.05$ are indicated by asterisk.

dant in experiment, while corticicolous *Tetracanthella wahlgreni*, surface *Entomobrya* sp., and upper litter *Neanura muscorum* were absent.

Among oribatid mites, large litter *Heminothrus humicola*, litter–soil *Liochtonius lapponicus*, and eurybiontic *Conchogneta tragardhi* significantly prevailed. Large litter species *Nanhermannia* sellnicki, *Ceratoppia asiatica, Belba* sp., *Euphthiracarus* sp., and *Tetroppia maritima* were not revealed in experiment (the first was abundant in control).

Among gamasid mites, control lacked relatively large predators of the genus *Veigaia* (*V. sibirica, V. kochi*, and *V. igolkini*), while the abundance of *V. nemorensis* were statistically similar in experiment and control. Largely small mycetophagous *Gamasellus silvestris, Neozercon smirnovi*, and *Zercon* sp. were found only in control.

Species not found in control were revealed among both springtails and mites. Apparently, the experimental conditions were favorable enough for their relatively high abundance (e.g., *Friesea mirabilis*) (table).

No microarthropods were found in the type A bags. Hence, the defaunation and isolation were reliable and recolonization was successful in experiment.

Content of organic compounds in soil samples. A one-year exposure of microarthropod-free samples significantly depleted soil organic carbon relative to both the surrounding soil and samples recolonized by springtails and mites (figure). Although organic carbon content in the surrounding soil was notably higher than in type A and B samples, the differences were significant only for the type A samples ($p < 0.05$). This was due to high variation in soil indices in open soil samples.

The content of sieved and mixed soil in type A and B samples was much more homogeneous. The difference between them was significant ($p < 0.05$). The content of organic carbon was higher in samples accessible for microarthropods ($p < 0.05$), while microarthropod-free samples had a higher total content of humic acids ($p < 0.05$) and the humic/fulvic acid ratio ($p < 0.05$). No other significant differences have been revealed between type A and B samples.

Samples accessible for microarthropods significantly differed from the surrounding soil only in the content of the third fraction of humic acids ($p < 0.05$). All other parameters of type A and B samples did not significantly differ.

Type A and C samples differed by nearly all indices. The open soil samples had more organic carbon, while the content of humic acids was higher in microarthropod-free samples. Type A samples also had more fulvic acids and sulfuric acid-hydrolyzed material, while the surrounding soil contained more unhydrolyzed residues (figure).

Hence, type A, B, and C soils largely differed by the content of organic carbon and humic acids, while differences in fulvic acids as well as sulfuric acid hydrolyzed and unhydrolyzed material were not significant.

DISCUSSION

Microarthropods represent a key unit in the destruction of soil organic matter. Isolation techniques exclude the impact of many factors in field experiments and expose the role of particular size groups in the ecosystem functioning. However, most published works were conducted under conditions of tropical and temperate climate, where soil animal communities are complex and the exclusion of large saprobes sharply changes the destruction pattern.

The studied northern taiga soils are relatively inert due to low annual temperature and short vegetation period (Smolentsev, 2002), accordingly, they nearly lack large invertebrate geobionts. Herpetobionts were largely represented by predators here (spiders and ground beetles), while saprobes were practically missing (Lyubechanskii, 2005). Hence, isolating sample from large invertebrates had no significant effect on the dynamics of studied organic compounds.

An increased abundance of microarthropods was observed in coarse-mesh bags relative to the surrounding soil. This could be due to the protection of microarthropods from predators (spiders in this case). On the other hand, experimental soil had a higher porosity than the surrounding soil (due to the sieving and mixing), which could create a more complex and comfortable environment for microarthropods. In addition, fine gauze of the bags decelerated water arrival, which also contributed to comfortable experimental conditions compared to natural soil. However, bags of both experimental types were filled with the same substrate, were made of the same gauze, and differed only by a relatively small coarse-mesh window. We believe that the physical conditions were comparable in them and the observed differences in organic matter composition were induced by the activity of microarthropods.

The structure of microarthropod community differed between experiment and control. For instance, *Tectocepheus velatus* predominated among oribatid mites both in experiment and control, the proportions of *Conchogneta tragarghi* significantly differed, while *Nanhermania sellnicki* predominated in control but was absent in experiment. *Opiella* sp. was abundant in experiment and had low numbers in control. The same springtail species predominated in experiment and control, although the degree of prevalence differed. At the same time, the proportion between the abundance of springtails and oribatid mites remained stable in both experimental and control samples (table).

Similar data were obtained in studies of decomposition of root mass of different herbaceous plants in conditions of technogenic ecosystems of the Kansk-Achinsk Fuel and Energy Complex (*Suktsessii*…, 1993). These studies were carried out in coal pit dumps at early succession stages, where the soil community was poor relative to intact biotopes. In this case, springtail community in the isolated samples was similar although not identical to that in control—the pattern of dominant succession was similar in the isolated samples and control.

Although the structure of microarthropod community changed in experiment, their impact on the dynamics of organic compounds in soil remained the same, as confirmed by the absence of significant differences in nearly all indices between the soil in bags with a coarse-mesh window and control soil.

Conversely, the isolation of soil from microarthropods induced significant differences. Type A and B samples differed even visually—soil in fine-mesh bags was filled with fungal hyphae and remained solid after extraction, while soil from coarse-mesh bags was loose and friable. Since most springtail and oribatid mite species identified in the studied soil were mycetophagous, their elimination likely ensured uncontrolled growth of soil fungi.

The experiment demonstrated that humus accumulation in the absence of microarthropods proceeded in the direction unusual for northern taiga soils—towards active humification rather than the usual mineralization.

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