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Species Composition and Abundance of Earthworms in the Tundra Biocenoses of Denezhkin Kamen' Mountain (*Northern Urals*)

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Abstract—Taxonomic composition of earthworms was analyzed and their abundance in the tundra belt of Denezhkin Kamen' Mt. in the Northern Urals was estimated. Four species were revealed: *Perelia diplotetratheca* (Perel, 1976), *Eisenia nordenskioldi* (Eisen, 1879), *E. atlavinyteae* Perel et Graphodatsky, 1984 and *Dendrobaena octaedra* (Savigny, 1826). It was shown that earthworms dominate in biomass over other groups of soil mesofauna under the mountainous conditions.

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Earthworms (Oligochaeta, Lumbricidae) are crucially important for the soil formation in the land ecosystems. The complex studies of sub-Arctic regions initiated in the last century (B. A. Tikhomirov, V. P. Dadykin, I. V. Stebaev, Yu. I. Chernov, and others), showed that even in the extreme conditions lumbricids contribute to soil biocenoses.

The study of Lumbricidae in high-mountain regions is especially interesting. The harsh climate of the mountains regions, which makes them barely suitable for life similar to zonal tundras and arctic deserts, favored the formation of similar biota in the high-latitude and high-mountain regions. It is also characteristic of the mountainous landscapes that all stages of soil formation are present there: from the initial accumulations of clastics and fine earth on the slopes to the formation of developed grass sods and peat layers on plateaus and intermountain depressions.

The data on the distribution and abundance of earthworms in mountainous regions of the Urals are scarce and restricted to a few brief publications [1–4]. In these publications earthworms are regarded in the rank of family, as a distinct zoological component of earth-dwelling biota. Regarding the species composition, for mountains of the Northern and Polar Urals only one species is mentioned, *Eisenia nordenskioldi* (Eisen, 1879).

MATERIAL AND METHODS

The area under study is Denezhkin Kamen' Mountain, located at the Eastern ridge of the Northern Urals (60°20′N; 59°29′E). The investigation was largely focused on the biocenoses found above the timberline (850–900 m asl) and represented by various alpine tundras, cryophilic grassplots and zones of goletz placers (Fig. 1). The flora of alpine tundras was represented by shrubs (*Betula nana*, *Salix* spp.), dwarf shrubs (*Vaccinium uliginosum*, *Empetrum hermaphroditum*, *Dryas octopetala*), herbaceous plants (*Carex* spp., *Lagotis uralensis*, *Anemonastrum biarmiense*, and others), mosses (*Hylocomium*, *Pleurosium*), and lichens. The projective cover varies greatly; a frequent phenomenon is a mosaic structure of the vegetative cover of alpine tundras, when vegetation spots alternate with naked soil. The soils are typical of mountainous tundra, poorly developed and stony-loamy, often with traces of gleization.

We have studied the samples and records of soil mesofauna, conducted in the mountainous tundra biocenoses of the range. In 1996–1998, soil samples were collected and analyzed in the field by A. I. Ermakov; in 2005 the samples were gathered and initially analyzed by the employees of the Institute of Plant and Animal Ecology UrB RAS, after which they were further studied in the laboratory. A total of 192 samples sized 0.25×0.25 m were taken in 1996–1998; in 2005, 30 samples sized 0.2×0.2 m were taken. The sampling was restricted to a depth at which mesofauna can appear, as a rule, 20–25 cm. In 2005, each sample was divided into two soil horizons: the "upper" organic horizon (grass sods consisting of sedge and moss) and the "lower" mineral horizon (soil proper). Mesofauna was selected from samples by hand, using conventional techniques [5]. Earthworms were fixed in 4% formalin, cocoons, in 70% alcohol. The species were identified

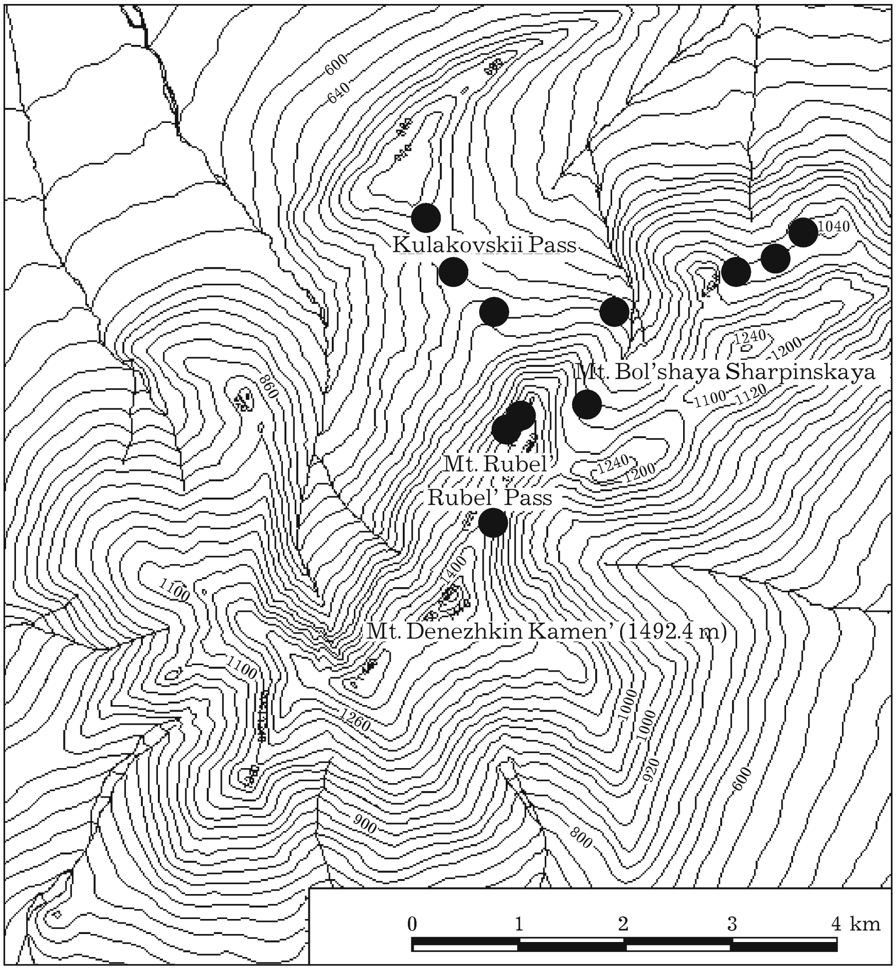

Fig. 1. Scheme of the area under study (places where soil samples were taken are shown by dots).

with the species identifier of Vsevolodova-Perel' [6]. The abundance of worms and their cocoons was recorded as their density (ind/m^2). The biomass (mg/m^2) was determined from the fixated material: worms were taken from the fixator, dried on absorbent paper and weighted on a torsion balance WT-1000 (max = 1 g, d = 1 mg). If the fixated material was not stored for long, this measure although slightly lower is comparable to the mass of living organisms (83–90%). We studied a total of 323 individuals of Lumbricidae from mountainous tundras (some of the 1996–1998 material and all 2005 material), including 90 sexually mature specimens.

RESULTS AND DISCUSSION

Four species of earthworms from the family Lumbricidae have been found: *Perelia diplotetratheca*, *Eisenia nordenskioldi*, *E. atlavinyteae*, and *Dendrobaena octaedra*. Below we give an annotated list of these species, accompanied by the data from the literature [6–8] as well as our own.

Perelia diplotetratheca (Perel, 1976). This species is endemic to the Urals and can be found up to the Polar Urals. It is the only species among Lumbricidae inhabiting the dark coniferous forests and subalpine meadows of the Urals. It belongs to soil-litter species. We have investigated 154 of its specimens. In the study area it was the most abundant species, found in all altitudinal belts.

Eisenia nordenskioldi (Eisen, 1879). It occurs mainly in the Asian part of Russia (from Far East to Urals). In the north its range reaches the shores of the Arctic Ocean. It is one of the few Lumbricidae species which is found in permafrost regions. In the Urals it is represented by a nominative subspecies. It usually occurs in soil and litter. It has a well-developed purple pigmentation, which allows it to feed on vegetative waste on the soil surface. Under the conditions of mountain-tundra this species is capable of optional phytophagy [9]. We have studied 145 specimens, the great majority of which was collected in 1996–1998. For unknown reasons the samples of 2005 contained only one individual.

Eisenia atlavinyteae Perel et Graphodatsky, 1984. Siberian species which is also found in Polar, Subpolar, and Central Urals. It belongs to soil-litter worms. Nineteen specimens have been studied.

Dendrobaena octaedra (Savigny, 1826). Cosmopolitan. In the Urals it is encountered from polar ridges to Zilair plateau. It inhabits the forest litter and is one of the few species of earthworms that can be found in northern coniferous forests and tundra. It is one of the species that tend to dwell on the soil surface. It occurred in all investigated altitudinal belts. Four specimens have been studied.

The population of earthworms in mountainous tundras is abundant (Table 1). The density of the population of sexually mature and impuberal worms in the mountain-tundra belt is 4 times higher than the corresponding values for mountainous taiga and subgoletz birch crooked forests. For cocoons of worms this density is 2.5–3 times higher.

One of the indicators of functional importance of Lumbricidae in the ecosystems of tundras is the increased altitudinal gradient of their percentage in the soil mesofauna and of their occurrence in soil samples. Earthworms have been found in almost all samples taken in tundra and only in 40–43% of samples from the subgoletz and mountain-taiga belts. For cocoons this distribution is less regular.

In general, high abundance of cocoons in the samples taken in 2005 seems to represent the real situation better than the data from 1996–1998 (Table 2). Such significant (one or two orders of magnitude) difference may be caused by the imprecision of our methods: when the blocks of soil are analyzed in the field by a person, he or she may easily miss a large number of immobile and shapeless objects such as empty cocoons. Other reasons are also possible: biotopical differences between fields, hydrothermal differences between the reference periods, etc. Our records of worms in adult stages of life, unlike the records of cocoons, may be considered complete and objective.

During the reference period of 1996–1998 the density of worms in different types of mountainous tundra varied from 20 to 160 ind/m^2. The number of worms as a fraction of the total number of organisms in soil mesofauna also varied greatly: from 6.2 to 61.2%. However, at that stage we were unable to discover any clear and undeniable correlation between the density of worms and biotopical characteristics of the fields used in our investigation or the time when it took place, or, in any case, we could not find any indisputable pattern. The density and biomass of earthworms inhabiting particular biocenoses appear to be such unstable parameters that a few records of their numbers cannot be considered a reliable picture of their abundance.

The mosaic structure of the vegetative and soil cover of mountainous tundras leads to the corresponding lack of regularity in the distribution of soil mesofauna, in particular, earthworms. In places where a lot of fine earth and vegetative waste is accumulated (which are food recourses), for example in the rhizosphere of dwarf shrubs or the sod cover of herbaceous plants, the density of worms is one or two orders of magnitude greater than the corresponding density in places where the projection of the vegetative cover is only slightly above 50%.

At spots which are void of vegetative cover due to cryogenic weathering there are rather few earthworms, with their density not exceeding 25 ind/m^2. This is largely caused by humidity, as well as the temperature and soil aeration related to humidity: earthworms are rare in the places that suffer from frequent floods. In mesophytic biotopes, earthworms tend to inhabit the places with a developed layer of mosses and lichens, which keeps the soil moist during the dry period. The same pattern in the distribution of earthworms was ear-

Table 1. Numerical measurements of abundance and frequency of occurrence of earthworms and their cocoons in the altitudinal gradient of Denezhkin Kamen’ Mt. in July 2005

Measurement	Altitudinal belt, height asl, m		
	mountain taiga 320–530	subgoletz 630–760	mountain tundra 1010–1030
Average density ind/m^2 ± error of mean			
Earthworms	21.7 ± 6.3	18.3 ± 5.2	78.3 ± 9.3
Cocoons	174.2 ± 33.1	181.7 ± 32.6	436.7 ± 61.4
Fraction of total abundance of soil mesofauna, %			
Earthworms	2.1	1.9	6.7
Cocoons	17	20.1	34
Occurrence in samples sized 0.2 × 0.2 m, %			
Earthworms	43.3	40	96.7
Cocoons	90	93.3	96.7

Table 2. Density and biomass of earthworms in soils of different types of mountainous tundra of Denezhkin Kamen' Mt. in 1996–1998

Biocenose, height asl (date; number of samples and their area)	Density, ind/m^2 (fraction of total abundance of mesofauna, %)		Biomass, mg/m^2 (fraction of total biomass of mesofauna, %)	
	earthworms	cocoons	earthworms	cocoons
Dryad-cancer-mitridae lapideous mountainous tundra, 860 m (4.07.1997; 10 by 0.625 m^2)	51.2 (53.7)	6.4 (6.7)	18 227.2 (94.3)	128 (0.7)
The same (8.08.1997; 8 by 0.5 m^2)	108 (49.3)	4 (1.8)	32 196 (94)	52 (0.1)
The same (19.06.1998; 12 by 0.5 m^2)	56 (34.8)	26.7 (16.6)	14 320 (94)	512 (3.4)
The same (4.08.1998; 8 by 0.5 m^2)	160 (48.8)	12 (3.7)	46 028 (95.6)	180 (0.4)
Dwarf-birch-hylolumpy mountainous tundra, 900 m (22.07.1996; 8 by 0.5 m^2)	32 (22.9)	4 (2.9)	9672 (88.8)	104 (1)
The same (29.06.1997; 10 by 0.625 m^2)	27.2 (20.4)	33.6 (25.2)	6374.4 (88.5)	289.6 (4)
The same (8.08.1997; 10 by 0.625 m^2)	60.8 (26.8)	19.2 (15.1)	16 902.4 (95.2)	396.8 (2.2)
The same (19.06.1998; 12 by 0.75 m^2)	160 (42.6)	13.3 (3.5)	76 296 (98)	274.7 (0.3)
The same (4.08.1998; 8 by 0.5 m^2)	64 (6.2)	68 (6.6)	33 244 (75.8)	1577.6 (3.6)
Dryad lapideous mountainous tundra, 1100 m (28.06.1997; 10 by 0.625 m^2)	56 (24.7)	62.4 (27.5)	10232 (87.3)	708.8 (6)
The same (6.08.1997; 10 by 0.625 m^2)	73.6 (61.2)	28.8 (24)	29 897.6 (97.4)	547.2 (1.8)
Dryad-cancer-mitridae blotched mountainous tundra, 1250 m (3.07.1997; 10 by 0.625 m^2)	81.6 (54.1)	8 (5.3)	20 155.2 (95.6)	166.4 (0.8)
The same (5.08.1998; 8 by 0.5 m^2)	52 (34.2)	28 (18.4)	28 968 (97.3)	388 (1.3)
The same (7.08.1997; 6 by 0.375 m^2)	96 (59.4)	2 (1.2)	20 581.3 (97)	47 (0.2)
Sedge-aulolumpy mesophytic mountainous tundra, 1300 m (7.07.1997; 8 by 0.5 m^2)	80 (51.3)	4 (2.7)	22 664 (94.2)	72 (0.3)
The same (7.08.1997; 8 by 0.5 m^2)	20 (16.7)	16 (13.3)	7304 (90.8)	400 (5)
The same (20.06.1998; 8 by 0.5 m^2)	92 (48.9)	4 (2.1)	16 644 (98.2)	76 (0.4)
The same (6.08.1998; 8 by 0.5 m^2)	124 (37.8)	4 (1.2)	31 720 (93)	60 (0.2)
Sedge-aulolumpy hygrophyte mountainous tundra, 1270 m (20.06.1998; 8 by 0.5 m^2)	68 (38.6)	8 (4.5)	33 532 (97.4)	188 (0.5)
The same (6.08.1998; 8 by 0.5 m^2)	36 (21.9)	16 (9.8)	18 248 (92.6)	405.2 (2.1)

lier noted by Berman [10] in high mountains of southern Siberia.

In the vertical projection the distribution of earthworms is also irregular (Fig. 2). The great majority of soil-dwelling invertebrates is concentrated in the upper organogenic soil horizon (which does not exceed 5 cm in mountainous tundras). Depending on moisture, as well as mechanical and temperature conditions in soil substrate, worms and their cocoons may occur somewhat deeper. Some individuals can even reach the depth of 25–30 cm. In the upper soil horizon only two species of worms have been found: surface-dwelling *D. oc-*

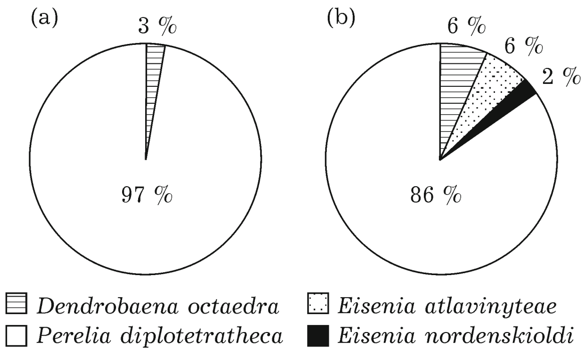

Fig. 2. The vertical structure of the complex of earthworms in soils of grass-moss mountainous tundra in July 2005. (a), Upper and (b), lower soil horizons.

taedra and soil and litter-dwelling *P. diplotetratheca*. In the lower horizons all four species have been noted.

The vertical structure of soil-dwelling mesofauna is transformed according to changes in the environment: when soil is excessively damp, earthworms move to its upper horizons and its surface. The use of Barber's soil-based traps in 1997–1998 gave the following data: the dynamic density (frequency of entrapment) of earthworms varied from 0.1 to 0.8 individual per 10 trap-days on the same fields. Their average number was 1.3% of the total number of the captured pedobionts (large enough to be classified as mesofauna), whereas their biomass was 3.7%.

CONCLUSIONS

The biomass of earthworms, varying only slightly (76–98%), forms the core of soil-dwelling zoomass in alpine biocenoses. Lumbricidae prove not only their role in soil formation, but also their importance as a building block at the base of the trophic pyramid—a condition necessary for maintaining a high number of obligatory zoophages in mountain–tundra ecosystems, even such "energy-consuming" as insectivore mammals (common shrews).

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