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RESEARCH ARTICLE

Discovery of new habitats and ecological characteristics of endemic earthworm species (Clitellata: Lumbricidae) in the southeast of Western Siberia

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Abstract

The Altai Mountains in Western Siberia constitute a center of endemism for earthworms in Russia, comparable to the Ural and Caucasus Mountains. The aim of our study was to determine the ecological characteristics of habitats of endemic earthworms in southeastern Western Siberia. During the research, two species *Eisenia salairica* and *Eisenia altaica* were found outside their previously known ranges. Since the description of these species in the 1960s, their ecology and distribution have not been studied. Our field studies on the collection of endemic earthworms have been conducted since 2014. We surveyed various locations within the Altai Krai and Kuzbass regions. In the habitats of the earthworms, soil and vegetation cover were examined. This is the first report providing updated information on current distribution and habitat ecological characteristics of these endemics. The results facilitate the development of targeted conservation measures for these Altai endemics, which are listed in the Red Data Books of the Russian Federation and regional Red Data Books. All of these factors significantly contribute to the preservation of biodiversity in Western Siberia.

Keywords
Anthropogenic impact, Altai, *Eisenia altaica*, *Eisenia salairica*, endemism, Kuzbass, Red Data Book, soil

Introduction

There are approximately 60 species and subspecies of earthworms in the fauna of Russia. In the Asian part of the country, 29 species have been recorded, of which five are endemic to the Altai Mountains and three are endemic to the Ural Mountains (Vsevolodova-Perel 1997; Golovanova et al. 2021). Thus, the Altai Mountains are a significant center of endemism for the Lumbricidae fauna of Siberia and Eastern Kazakhstan (Perel, 1985). Rare earthworm species, such as *Eisenia salairica* Perel, 1968; *Eisenia altaica* Perel, 1968; *Eisenia magnifica* Svetlov, 1957; *Eisenia tracta* Perel, 1985; and *Eisenia malevici* Perel, 1962, have been described from this region. These species are listed in the Red Data Book of the Russian Federation, the Red Data Book of Kazakhstan, and various regional Red Data Books (Perel 2003; Sergeev 2017a, 2017b; Golovanova 2016, 2021a, 2021b, 2021c; Zubko and Skalon 2021).

Our study area is located in the southeastern part of Western Siberia. The main geomorphological features here are the southeastern part of the West Siberian Lowland and the Altai-Sayan Mountain System, represented by the Altai Mountains and the Salair Ridge (Shvetsov 2021).

During our research conducted in this area, we discovered new habitats of two endemic earthworm species: *E. altaica* and *E. salairica*. The results of the study on the ecological characteristics of the habitats of these species are presented.

E. altaica was first discovered and described from collections in the Altai Republic, in the vicinity of the villages of Mayma, Kyzylozek, Choya, and Rybalka, where it occurs in soils of meadows and birch forests on the northern and northwestern slopes along the Katun River (Perel 1968). Subsequently, this species was found near Ulus-Cherga Village on the left bank of the Sema River, in soils of meadow steppe and grass-forb meadows on the slopes of the Chergin Range (Vsevolodova-Perel 1997). M.G. Sergeev (2017) suggested the potential presence of *E. altaica* in regions adjacent to the Altai Republic within Altai Krai, that was subsequently confirmed by our later findings.

E. salairica was first discovered and described from collections in the vicinity of Zhernovo Village, Novokuznetsk District, Kemerovo Oblast (Kuzbass), where it occurs in soils of mixed fir and aspen forests (dark coniferous taiga) (Perel 1968). Our subsequent findings of this species were made in similar habitats located north and south of the original site, within other administrative districts of the region.

A comprehensive study of earthworm fauna in Western Siberia was initiated in the 1960s and has been ongoing since then (Perel 1962, 1968, 1979, 1985; Shekhovtsov et al. 2015). However, very few studies have focused on endemic species in that area (Golovanova et al. 2015, 2020, 2021). Therefore, the aim of our study was to investigate the ecology and distribution of endemic earthworm species, which is of great significance for the conservation of biodiversity in Western Siberia.

Materials and methods

Field studies were conducted annually from May to September during the years 2014–2025. We investigated different habitats in Kuzbass and Altai Krai (Fig. 1).

Quantitative samples of earthworms were collected according to standard methods (Gilyarov 1975; Anderson and Ingram 1993). For each habitat, we sampled at least five soil monoliths measuring 25 cm × 25 cm and 30 cm deep. After removing the litter, we divided the soil monoliths into three layers, 0–10 cm, 10–20 cm, and 20–30 cm, which were then hand-sorted for earthworms. All individuals of *E. salairica* were found in forest litter or directly beneath it. All individuals of *E. altaica* were found at depths of 10–30 cm. Earthworms were preserved in 70% ethanol. Their identification was performed using the key by T. S. Vsevolodova-Perel (1997). The new localities of *E. altaica* and *E. salairica* in the territories of Altai Krai and Kemerovo Oblast (Kuzbass) are listed in Table 1.

Table 1. Earthworm density in different habitats in Altai Krai and Kemerovo Oblast (Kuzbass)

No	Location	Latitude, N Longitude, E	Altitude, m	Habitat	Density (Mean±SE), individuals/m^2	
					E.a.	***E.s.***
1	Nikolaevka r. valley, upstream of the Nikolskoye v., Altai d., Altai Krai	51°48.762333' 85°3.021167'	609	Floodplain meadow, motley grass	48±7.5	–
2	Nikolaevka r. valley, upstream of the Nikolskoye v., Altai d., Altai Krai	51°48.110167' 85°3.973333'	631	Dry land meadow, motley grass	6±2.4	–
3	Barancha r. valley, downstream of Nikolskoye v., Altai d., Altai Krai	51°46.703667' 84°55.426167'	535	Pine and birch forest	single occ.	–
4	Floodplain of the Kamenka r., upstream of the Altaiskoye v., Altai d., Altai Krai	51°48.787500' 85°11.863667'	523	Floodplain meadow, motley grass	16±1.7	–
5	Mzas r. valley in the vicinity of the Chuazas v., Mysky d., Kuzbass	53°29.253000' 87°43.121000'	279	Birch, fir, and spruce forest	10±2.1	–
6	Vicinity of Zhernovo v., Novokuznetsk d., Kuzbass	54°10.860000' 87°15.622000'	314	Dark coniferous forest (taiga)	–	single occ.

No	Location	Latitude, N Longitude, E	Altitude, m	Habitat	Density (Mean±SE), individuals/m²	
					E.a.	*E.s.*
7	Chernovoy Naryk r. valley, Prokopyevsk d., Kuzbass	54°15.216167' 87°19.224167'	266	Dark coniferous forest	–	16±2.9
8	Chernovoy Naryk r. valley, Prokopyevsk d., Kuzbass	54°18.978667' 87°12.076833'	371	Dark coniferous forest	–	10±1.9
9	Chernovoy Naryk r. valley, Prokopyevsk d., Kuzbass	54°16.801333' 87°21.762500'	185	Dark coniferous forest	–	48±7.5
10	Azhendarovsky Ridge, at the estuary of the Bugas r., Krapivinsky d., Kuzbass	54°42.533167' 87°2.269833'	184	Dark coniferous forest	–	28±1.2
11	Vicinity of Orton v., Mezhdurechensk d., Kuzbass	53°15.628333' 88°42.871000'	709	Dark coniferous forest	–	single occ.

Note: v. – village; d. – district; r. – river; *E.a.* – *Eisenia altaica*; *E.s.* – *Eisenia salairica*; single occ. – single occurrence.

After the discovery of new habitats of *E. salairica* and *E. altaica*, specimens were subjected to molecular genetic analyses. The *cox1* gene sequences of *E. salairica* from Kemerovo Oblast (Kuzbass) and the mitochondrial genome of *E. altaica* from Altai Krai have been deposited in the GenBank database (https://www.ncbi.nlm.nih.gov/genbank/) (Zubko et al. 2019; Leonov et al. 2024).

Soil samples were collected from six sites, where the rare earthworm species were found (see Table 1 for site numbers: 1, 2, 3, 7, 8, 9). The selected soil samples underwent preliminary preparation for physical and chemical analysis through the following stages: air-drying, removal and accounting of inclusions, crushing, quartering, grinding to fine earth, and formation of the analytical sample. Particle size analysis was conducted using the hydrometer method (Beverwijk 1967). The determination of macroaggregate composition was performed using dry sieving analysis of soil with a vibratory sieve shaker (Fomin et al. 2019). The water-holding capacity of soil aggregates was determined according to the method based on their breakdown under a water layer (Öhlinger and Kandeler 1996). Additionally, we measured the following properties of soil samples: pH (pH-150 MI), colorimetric measurements of humic follow conventional procedures for extracting humic acids from soils (Mehlich,1984), and soil humidity (by the thermostated weight method).

We also determined geographical coordinates (Locus Map 4.32.4) and made vegetation descriptions. The maps were produced using Google Earth Pro 7.3.6.10441 (64-bit) and the online resource https://www.mapz.com/. Statistical processing of the results was performed using descriptive statistics. The calculations were performed using Minitab 19.1.1 (64-bit).

Figure 1. Locations of discovery of *E. altaica* and *E. salairica*. Black dots, places of description and early discovery of *E. altaica* (according to Perel 1968; Vsevolodova-Perel 1997); red dot, place of description of *E. salairica* (according to Perel 1968); numbered circles (numerals refer to Table 1), our findings.

Results

Morphological analysis. The morphological characteristics of the identified individuals of *E. altaica* and *E. salairica* correspond to the diagnostic features indicated in the identification key by Vsevolodova-Perel (1997). Their populations did not differ in morphological characteristics.

Other species of earthworms found in the habitats of these endemics are represented by the following taxa: *Octolasion lacteum* (Örley, 1885), *Aporrectodea caliginosa* (Savigny, 1826), *Eisenia nordenskioldi nordenskioldi* (Eisen, 1879), and *Eisenia nordenskioldi pallida* Malević, 1956 (Fig. 2).

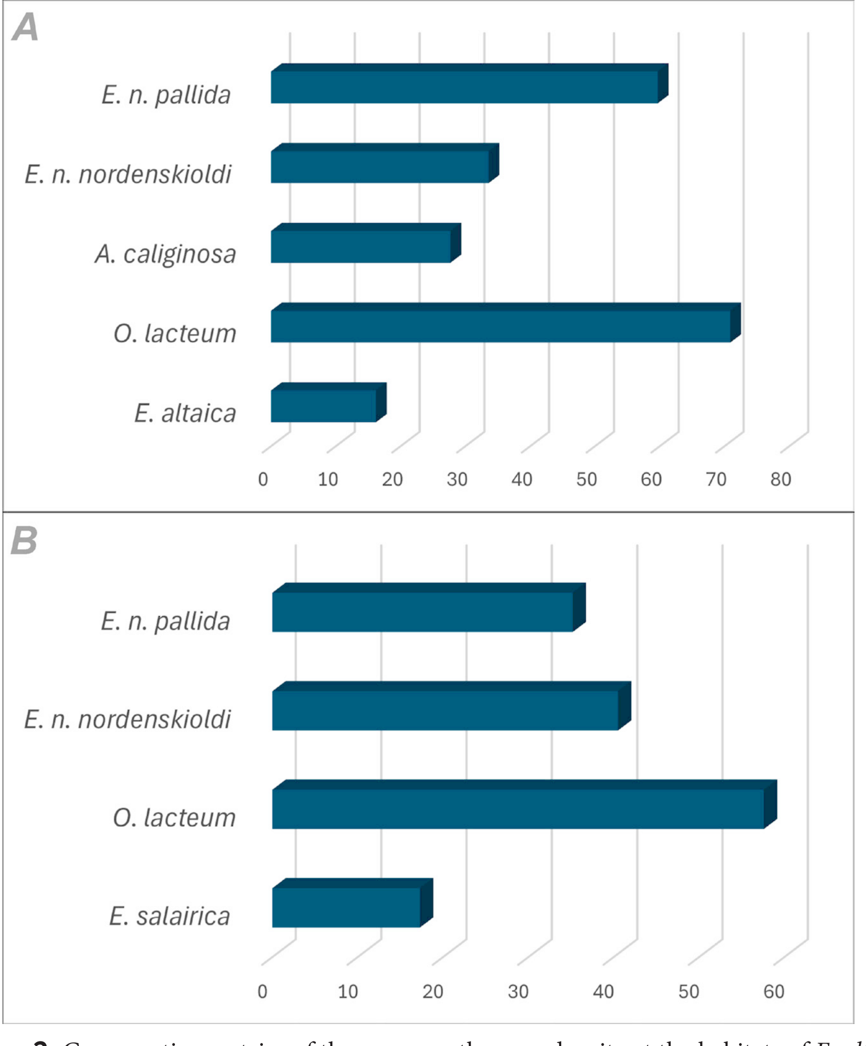

Figure 2. Comparative metrics of the mean earthworm density at the habitats of *E. altaica* (**A**) and *E. salairica* (**B**).

Soil characteristics. The results of the physical and chemical analyses of soil samples collected from the habitats of *E. altaica* and *E. salairica* are presented in Table 2.

Table 2. Habitat soil characteristics of the studied earthworms

Soil parameter	*E. altaica* (sites No. 1, 2, 3)	*E. salairica* (sites No. 7, 8, 9)
Water-holding capacity of soil aggregates (Mean±SE, n=3), %	58.6±17.0	45.7±1.08
pH (Mean±SE, n=3)	6.37±0.17	5.86±0.14
Humidity (Mean±SE, n=3), %	36.77±3.99	13.36±0.78
Humic matter content (Mean±SE, n=3), %	6.40±0.59	16.73±1.7

Discussion

Distribution and density. Prior to our study, *E. altaica* was only known from the Katun River valley within the administrative boundaries of the Republic of Altai (Perel 1968; Vsevolodova-Perel 1997). New habitats of *E. altaica* outside the previously known range were discovered by us in the valleys of the Peschanaya and Kamenka rivers. Additionally, *E. altaica* was for the first time found by us in the southern part of Kuzbass, in the Gornaya Shoria Mts., approximately 180 km northeast of the northernmost known occurrence of the species in the Katun River valley. In all identified habitats, *E. altaica* is less abundant than other species. The highest density was observed in floodplain meadow communities (Figs 1, 2; Table 1).

New habitats of *E. salairica* were discovered by us in Kuzbass, within the basin of the Chernovoy Naryk River in the Prokopyevsk District; near the mouth of the Bugas River within the Bungarapsko-Azhandarovsky Reserve in the Krapivinsky District; and near the settlement of Orton in the Mezhdurechensk Urban District. In all identified habitats, *Eisenia salairica* is less abundant than other species. All occurrences of this species were found within the taiga zone (Fig. 1, 2; Table 1).

Habitat soil characteristics and ecology. The habitats of the studied earthworm species are characterized by different soil types. *E. altaica* was found in Luvic Chernozems and Luvic Phaeozems, whereas *E. salairica* was encountered in Luvic Stagnosols (European Commission 2009). The main soil characteristics at the habitats of *E. altaica* significantly differ from those at the habitats of *E. salairica* (Fig. 3).

The studied endemics belong to different morpho-ecological groups and occupy distinct ecological niches. *E. altaica* is a soil-dwelling species, while *E. salairica* is associated with the soil-litter dwellers (Perel, 1979). According to another widely accepted classification (Bouché 1972), *E. altaica* is an endogeic earthworm, whereas *E. salairica* is an epigeic one. This explains the soil and habitat preferences of *E. altaica* and *E. salairica* observed in our studies. *E. altaica* inhabits soils of floodplain meadow and forest-meadow communities. *E. salairica* occurs in taiga soils with a thick litter layer, predominantly composed of aspen leaf litter and fir needles. And their ranges do not overlap.

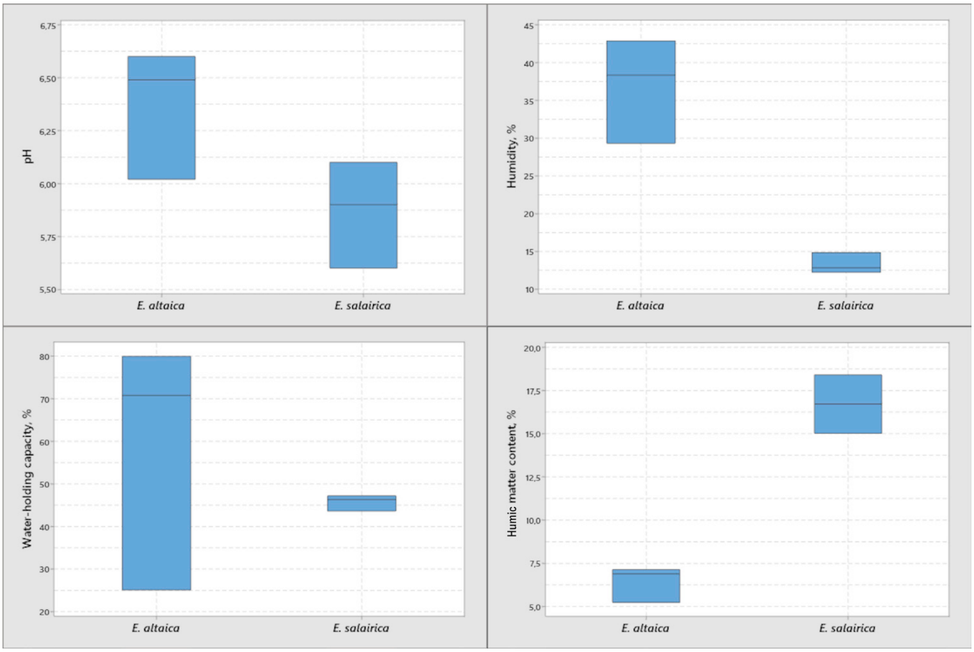

Figure 3. Ranges of soil characteristics in the habitats of the studied earthworm species.

The morphological and chemical analyses of the soils indicated low variability of the studied parameters in soil samples from the habitats of *E. altaica*. The granulometric composition ranged from heavy loamy to medium loamy, with a predominance of aggregates having a favorable granular structure, representing 47.9% to 67.7%, and exhibiting varying degrees of water-holding capacity, ranging from 25% to 80%. No presence of carbonates was detected in any of the samples. The soil-absorbing complexes should be characterized as stable and saturated with bases ranging from 75% to 89%, indicating an organic-accumulative soil formation process and ensuring structural integrity of the soil mass. A common feature across all soil samples was the presence of mineral inclusions in the form of stones measuring from 8 to 40 mm in diameter, accounting for up to 29.12%. However, plant residues and remnants observed on the sites indicated a return of mineral elements to the soil and a good accumulation of humic matter, ranging from 5.22% to 7.13%.

Soil study in the habitats of *E. salairica* likewise did not reveal high variation in the parameters. These sites are characterized by a crumb-granular structure with aggregate sizes ranging from 0.25 to 10 mm in diameter, which exhibit high porosity, gas exchange, and moisture content. The content of aggregates of these fractions in the A1 horizon amounted to 63.7–66.2 % of the average soil sample. This indicates an active soilforming process, both due to the substantial input of dead plant material into the soil and, probably, due to the elevated content of fine dispersed particles.

Due to the relatively high density, the water-holding capacity of the soil ranged from 43.6% to 47.2%. These values account for the relatively stable moisture content of the middle soil horizons even during prolonged dry periods and the stabilization of habitat conditions for earthworms at the study sites.

In structuring the ecological niche of the pedobiont community, significant importance is attributed to such edaphic characteristics as vegetation cover and its species diversity, litter thickness (which creates the microclimate of the biocenosis), as well as soil hardness, acidity, moisture, aeration, and others (Kunah et al. 2013).

The morphological structure of the soil indicates a high degree of accumulation of plant litter and its slow decomposition by soil inhabiting animals and microorganisms. This creates and maintains a favorable hydrothermal regime for earthworms in the litter layer and throughout the entire soil profile. As our research has shown, *E. salairica* is more strongly associated with these habitats, which is most likely due to more favorable living conditions. These are provided by a more optimal biotope structure, a combination of soilprofile differentiation processes, and high accumulation of organic matter. The loose structure of the upper genetic horizon and the less compacted underlying layers allow the animals to migrate vertically through the soil profile and inhabit different depths from the surface in different seasons with varying hydrothermal conditions. The average bulk density of the horizons and relatively high porosity ensure adequate aeration and sufficient oxygen for the favorable development of various earthworm species.

Anthropogenic impact and conservation measures. The habitats of *E. salairica* along the Chernovoy Naryk River are located within the central Kuznetsk Basin and are actively exploited by coal mining companies. Experimental methane extraction from coal seams is also conducted in this area.

Populations of *E. altaica* are negatively impacted by gold mining activities, localized deforestation, and agricultural practices. As a result of this activity, large areas have been excluded from the biomass production process.

According to regulatory requirements, these areas should be rehabilitated and restored to forest management. However, due to the lack of forest reclamation technologies, they have been left to undergo natural regeneration over an extended period, which is deemed unacceptable by environmental protection agencies and resource-extracting companies (Cortet et al. 1999; Sedykh 2004). To address this issue, research is being carried out to develop innovative and effective methods of forest reclamation for disturbed lands (Sheppard et al. 1992) in the territory of Western Siberia (Ufimtsev 2013, 2017; Manakov and Kupriyanov 2018; Kovalevskiy et al. 2021).

Protected areas play a crucial role in the conservation of *E. salairica* and *E. altaica*. Most of the findings of these endemic earthworms were made within the territories of the state reserves: Relictovy, Bungarapsko-Azhendarovsky, and Chernovoy Naryk.

Regional Red Data Books also play an important role in the conservation of these species. The new habitats of *E. altaica* were found for the first time within Kuzbass and the Altai Krai. Therefore, we recommend including this critically endangered relict species in the relevant regional Red Data Books.

Conclusion

As a result of our research, new habitats of *Eisenia altaica* and *Eisenia salairica* were found. All of these are outside the previously known range. In these locations, the population densities of both species are low compared to other lumbricids. Morphological, physical, and chemical analyses of the soil primarily revealed favorable conditions for further soil structural development, the associated growth of the soil-vegetation cover, and the establishment of earthworm habitats. The main anthropogenic impact threatening populations of endemics are placer gold mining, coal extraction, as well as agricultural and forestry activities. State reserves and regional Red Data Books play an important role in the conservation of these species.

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