The extremely high diversity of Collembola in relict forests of Primorski Krai of Russia

Nataliya Kuznetsova‡, Anna Bokova‡, Alexander Kuprin§, Mikhail Potapov‡, Yulia Shveenkova¶, Natalya Ivanova¶

‡ Moscow State Pedagogical University, Moscow, Russia
§ Federal Scientific Center of the East Asia Terrestrial Biodiversity Far Eastern Branch of the Russian Academy of Sciences, Vladivostok, Russia
¶ Privolshkaya Lesostep Nature Reserve, Penza, Russia
¶¶ Institute of Mathematical Problems of Biology RAS – the Branch of Keldysh Institute of Applied Mathematics of Russian Academy of Sciences, Pushchino, Russia

Abstract

Background

The diversity of soil animals of relict forest ecosystems in East Asia continues to be insufficiently studied and almost not represented in international databases, including GBIF. This article is based on 7550 records of 175 species which were collected in Ussuriiskii, Sikhote-Alinskii and Kedrovaya Pad’ natural reserves of Russian Far East in 2016–2017. A multi-scale sampling design allowed us to estimate population densities and local species richness of Collembola at areas of different sizes. The work continues the digitization of the collections of the Moscow Pedagogical State University (MPSU) and their publication through GBIF.org, which began in 2019. This article is based on original data including 2377 specimens of springtails from eight forests and 648 soil cores.
New information

Within the framework of modern taxonomy, this work represents the first publication of lists of Collembola species of forests of Primorsky Krai. The work focused on the relict protected cedar-deciduous forests. Nine species new to science were described and data on the fauna of the region were significantly revised. Considerable contribution was made to the biogeography of Collembola of East Asia. The design of the sampling allowed us to draw conclusions about the species saturation of springtails at various spatial scales within the habitat: from a few square cm to 100 sq. m. Number of species reached record high values reflecting the benchmark state of Collembola communities of undisturbed old temperate forest ecosystems.

Keywords

sampling event, springtails, soil fauna, mesofauna, microarthropods, broad-leaf – cedar pine forests, natural reserves, multi-scale sampling design, species richness, population density, Ussuriiskii natural reserve, Sikhote-Alinskii natural reserve, Kedrovaya Pad’ natural reserve

Introduction

Collembola, or springtails, is one of the most abundant and diverse groups of soil microarthropods that play an important role in the processes of destruction of organic residues (Petersen and Luxton 1982, Hopkin 1997). We aimed to estimate the upper limit of the local species diversity of Collembola in a region known for its high species richness of various groups of organisms (Latham and Ricklefs 1993). Part of this region is located in the south of the Russian Far East, where broad-leaf – cedar pine forest ecosystems are distributed. The highest diversity of insects in the temperate zone is described for these forests (Chernov et al. 2011). UNESCO included this area in the World Heritage List (Central Sikhote-Alin) noting that “the combination of glacial history, climate and relief has allowed the development of the richest and most unusual temperate forests in the world”.

Regular research of Collembola in the south of the Primorski Krai of Russia began about half a century ago showing a great originality of the fauna (e.g. Kutyreva 1979, Kutyreva 1984, Martynova 1988). During the last decades, new approaches to taxonomy have led to the taxonomic revision of many genera of springtails (Pomorski and Sveenkova 2006, Deharveng et al. 2011, Jie et al. 2011, Jordana et al. 2011, Huang and Potapov 2012, Smolis et al. 2012, Smolis and Deharveng 2015). However, these works did not focus on the issues of local species richness.

We collected springtails in the region in the years 2016–2017. The data from 2016 was published (Kuznetsova et al. 2019). However, the species list was limited to abundant species only. The present study includes the full species list, based on samples from 2016 and 2017 taking into account the recently described new species for science. A specific
multi-scale sampling design allowed us to estimate a local species richness of Collembola at areas of different sizes.

**General description**

**Purpose:** The purpose of the paper is to present information on species composition and abundances of Collembola in relict broad-leaf – cedar pine forest ecosystems of the Russian Far East. Diversity and abundance are presented in the most detailed form of sampling-evidence.

**Sampling methods**

**Study extent:** The dataset (Kuznetsova et al. 2021) provides information on the number of individuals of springtail species collected in broad-leaf – cedar pine forests of three natural reserves in July 2016 and August 2017 (7550 occurrences). Three forests were examined in Ussuriiskii natural reserve, 2 – in Kedrovaya Pad’, 2 – in Sikhote-Alinskii natural reserve and 1 – in Chuguevsky District. The sampling plots “Fauri” and “Grabovaya” were in mountain forest, plots “Turova” and “Kedrovaya” were on a slope, plots “Pikhtovaya”, “Kema”, “Chuguev” and "Anikin" were in the river valleys. The material includes about 24 thousands individuals of 175 species from eight sampling series and 648 soil cores. They were collected by Natalia Kuznetsova, Mikhail Potapov, Anna Geraskina, Alexander Kuprin, Anastasia Korotkevich and were identified by Natalia Kuznetsova, Mikhail Potapov, Babenko Anatoly, Shveenkova Yulia.

**Sampling description:** The sampling was based on a multi-scale design to study the structure of biodiversity at different spatial scales (Lande 1996, Azovsky et al. 2000). A fractal arrangement of cores allows us to reduce sample effort because the same core is used for the analysis at different scales (Marsh and Ewers 2012). A few cases of applying the approach in soil zoology include testate amoebae (Tsyanov et al. 2014), oribatid mites (Bolger et al. 2014) and springtails (Kuznetsova and Saraeva 2018). We used the small size of the corer (8 cm² in section) to implement special attention on the diversity and spatial structure of the population at the micro level. Soil was investigated down to 20 cm. A total of 81 cores were taken in each sampling plot. Cores were placed in the corners of different-scale equilateral triangles inscribed in squares with sides 10 cm, 25 cm, 1 m and 10 m. The different-scale triangles were designed following the principles of fractal geometry. The sample design is described in detail by Saraeva et al. (2015).

**Extraction of Collembola from cores:** Plastic containers were used for storage and transportation of individual cores (Fig. 1). Each core was placed in a 0.3 litre plastic container with a vent hole covered with a gas cloth (Fig. 2). The containers were transported to MPGU (Moscow). Extraction of Collembola was performed in the laboratory using Tullgren's funnels at approximately 25°C. Extraction into 70% alcohol was continued for 4-5 days until the cores were completely dry.
Laboratory processing: All the specimens were mounted on slides in Phoera liquid according to a standard procedure (Ghirarov 1975, Potapov and Kuznetsova 2011).

Sampling plots: Short descriptions of some sampling plots (“Turova”, “Grabovaya”, “Kedrovaya”, “Pikhtovaya”) were published (Kuznetsova et al. 2019). The descriptions of the other plots are given for the first time. All the plots were located on brown soil.

The sampling plot “Turova” (Figs 3, 4) is in the Ussuriiskii natural reserve; it is a cedar pine–deciduous forest on a flat slope (Pinus koriaensis Siebold & Zucc., Acer mandshuricum Maxim., Quercus mongolica Fisch. etc.); in the undergrowth
*Lonicera maackii* (Rupr.) Maxim., *Eleutherococcus senticosus* (Rupr. & Maxim.) Maxim. etc.; in the above-soil cover *Oxalis acetosella* L., *Carex* L., *Adiantum pedatum* L. etc. The dead cover was ~10 cm.

Figure 3. Above-soil cover in broad-leaf – cedar pine forest in Ussuriiskii natural reserve (plot “Turova”), photo by N. Kuznetsova.

Figure 4. Above-soil cover in broad-leaf – cedar pine forest in Ussuriiskii natural reserve (plot “Turova”), photo by N. Kuznetsova.
The sampling plot “Grabovaya” (Fig. 5) is in the Ussuriiskii natural reserve; it is on Mount Grabovaya, in fir–hornbeam forest (Abies holophylla Maxim., Carpinus cordata Blume, Pinus koraiensis, Betula costata Trautv. etc.); in the undergrowth are Caprinus cordata, Acer tegmentosum Maxim., Acer barbinerve Maxim. ex Miq., Eleutherococcus senticosus etc.; in the above-soil cover are Oxalis acetosella, Leptorumohra amurensis (Milde) Tzvelev etc. The dead cover is > 80% and the thickness of the litter is ~ 4 cm.

The sampling plot “Kedrovaya” is in the Kedrovaya Pad’ natural reserve; it is a cedar pine–fir broadleaved forest on a slope (Pinus koraiensis, Abies holophylla, Tilia mandshurica Rupr. & Maxim., Carpinus cordata etc.); in the undergrowth are five maple species, including Acer tegmentosum and Acer barbinerve; in the above-soil cover are Leptorumohra amurensis, Dryopteris crassirhizoma Nakai, Maianthemum dilatatum (Alph.Wood) A.Nelson & J.F.Macbr., Oxalis acetosella etc. The dead cover ~ 50% and the litter thickness is 4 cm.

The sampling plot “Pikhtovaya” is in the Kedrovaya Pad’ natural reserve; it is a valley fir and deciduous forest (Abies holophylla, Juglans mandshurica Maxim., Pinus koraiensis etc.); in the undergrowth are Juglans mandshurica, Carpinus cordata, Acer mono Maxim., Acer tegmentosum, Acer mandshuricum etc.; in the above-soil cover are Leptorumohra amurensis, Dryopteris crassirhizoma etc. The dead cover is ~ 50% and the thickness of the litter is 3–4 cm.
The sampling plot “Fauri” (Figs 6, 7) is in the Sikhote-Alinskii natural reserve, Kabani station, at 932 m alt.; it is a coniferous wood (Abies nephrolepis (Trautv. ex Maxim.) Maxim., Betula platyphylla Sukaczew, Pinus koraiensis); in the undergrowth are Rhododendron faurie Franch., Acer ukurunduense Trautv. & C.A.Mey., Picea jezoensis (Siebold & Zucc.) Carrière; in the above-soil cover are Leptorumohra amurensis, Oxalis acetosella, Maianthemum bifolium (L.) F.W.Schmidt etc. The dead cover is 50–100% and the thickness of the litter is 3–7 cm.

Figure 6. doi

Above-soil cover in mountain coniferous forest with Rhododendron fauriei (plot “Fauri”) in Sikhote-Alinskii natural reserve, photo by A. Geras’kina.

Figure 7. doi

Mountain coniferous forest with Rhododendron fauriei (plot “Fauri”) in Sikhote-Alinskii natural reserve, photo by R. Naumenko.
The sampling plot “Kema” is nearby the Sikhote-Alinskii natural reserve, in the valley of Brusnichnaya River (tributary of the Kema); it is mixed forest (Pinus koraiensis, Populus maximowiczii A.Henry, Picea jezoensis, Ulmus glabra Huds., Abies nephrolepis); in the undergrowth are Acer mono, Acer barbinerve, Acer tegmentosum, Philadelphus tenuifolius Rupr. & Maxim., Eleutherococcus senticosus etc.; in the above-soil cover are Leptorumohra amurensis, Oxalis acerosella, Maianthemum bifolium, Carex siderosticta Hance, Cardamine leucantha (Tausch) O.E.Schulz, Cacalia hastata L., etc. The dead cover is 5–65% and the thickness of the litter is 7–10 cm.

The sampling plot “Chuguev” (Figs 8, 9) is in the Chuguevski District near Verkneussuriyiski Station of the Federal Scientific Center of the East Asia Terrestrial Biodiversity; it is a valley mixed forest (Abies nephrolepis, Populus maximowiczii, Fraxinus mandshurica Rupr., Betula costata, Pinus koraiensis etc.); in the above-soil cover are Abies nephrolepis, Acer mono, Acer tegmentosum, Lonicera maackii, Philadelphus tenuifolius etc.; in the above-soil cover are Oxalis acerosella, Leptorumohra amurensis, Carex campylorhina V.I.Krecz., Cardamine leucantha, Athyrium rubripes (Kom.) Kom, etc.). The dead cover is 20–85% and the thickness of the litter is 6–9 cm.

The sampling plot “Anikin” is in the Ussuriyskii natural reserve, Suvorovskoye forest district, Anikinsky station, valley of Anikin River; it is valley broadleaf forest (Juglans mandshurica, Populus maximowiczii, Fraxinus mandshurica) with Pinus koraiensis; in the above-soil cover are Carex L., Leptorumohra amurensis etc. The dead cover is 50–90% and the thickness of the litter is 3–4 cm.

Figure 8. [Image]
Valley mixed forest (plot “Chuguev”), photo by A. Geras’kina.
Quality control: We used both modern taxonomic papers and keys (Martynova 1988, Babenko et al. 1994, Potapov 2001) for the taxonomic determination of Collembola. The material was checked by leading experts in taxonomy of Collembola. Scientific names were checked using the GBIF species matching tool.

Step description: Data on species were digitised, standardised according to the Darwin Core (Wieczorek et al. 2012), the quality of the data was checked and errors were corrected and then published through GBIF.org (Kuznetsova et al. 2021).

Figure 9. doi
Litter in plot “Chuguev”, photo by A. Geras’kina.

Figure 10. doi
Geographic coverage. Study areas in the Primorski Krai (Kuznetsova et al. 2021, doi.org/10.15468/dyadwn).
**Geographic coverage**

**Description:** Primorskii Krai of the Russian Far East (Fig. 10).

**Coordinates:** 43.115 and 45.648 Latitude; 131.487 and 137.01 Longitude.

**Taxonomic coverage**

**Description:** So far, the taxonomical knowledge of different families and genera of Collembola is highly irregular in the area under study. Our identification of particular groups of Collembola, therefore, considerably depended on taxa. The species of Neelidae, Symphypleona, Lepidocyrtinae and *Entomobryini* were identified, based on the appearance (body size, colour pattern, length of limbs and other easily recognisable features), other taxa - on modern taxonomy, family Tomoceridae - on traditional characters. Families Hypogastruridae, Onychiuridae and Isotomidae were identified down mostly to species level, while the genera *Isotoma* and *Desoria* still are less certain and were differentiated as morpho-species (sp. 1, sp. 2 etc). Family Odontellidae is less understood in the area and so it was mostly represented by the "sp." in the list. Some species were described as new to science in the material: *Anurida* - 6 spp. n. (Babenko et al. 2019), *Oligaphorura* – 2 spp. n. (Xin et al. 2019); *Pseudachorutes* – 1 sp. n. and re-description of three species (Babenko et al. 2021).

**Taxa included:**

| Rank     | Scientific Name |
|----------|-----------------|
| phylum   | Arthropoda      |
| class    | Collembola      |

**Temporal coverage**

**Data range:** 2016-7-23 - 2016-7-29; 2017-8-06 - 2017-8-13.

**Usage licence**

**Usage licence:** Other

**IP rights notes:** Creative Commons Attribution (CC-BY) 4.0 License

**Data resources**

**Data package title:** Collembola of the relict forests of the Russian Far East.

**Resource link:** https://www.gbif.org/dataset/321e6294-7e96-44c2-ac5d-6b009ef17618
Number of data sets: 1

Data set name: Collembola of the relict forests of the Russian Far East.

Character set: UTF-8

Data format: Darwin Core Archive

| Column label       | Column description                                                                                                                                                                                                 |
|--------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| eventID            | An identifier for the event [https://dwc.tdwg.org/terms/#dwc:eventID](https://dwc.tdwg.org/terms/#dwc:eventID)                                                                                                |
| samplingProtocol   | Sampling protocol (Tullgren funnels) [https://dwc.tdwg.org/terms/#dwc:samplingProtocol](https://dwc.tdwg.org/terms/#dwc:samplingProtocol) See details in the Sampling methods section.                               |
| sampleSizeValue    | Size of the sampling core (8 cm$^2$). [https://dwc.tdwg.org/terms/#dwc:sampleSizeValue](https://dwc.tdwg.org/terms/#dwc:sampleSizeValue) See details in the Sampling methods section.                               |
| sampleSizeUnit     | The unit of measurement of the size sampling core (cm$^2$) [https://dwc.tdwg.org/terms/#dwc:sampleSizeUnit](https://dwc.tdwg.org/terms/#dwc:sampleSizeUnit) See details in the Sampling methods section.                               |
| decimalLatitude    | The geographic latitude in decimal degrees of the geographic centre of the data sampling place. [https://dwc.tdwg.org/terms/#dwc:decimalLatitude](https://dwc.tdwg.org/terms/#dwc:decimalLatitude)                                       |
| decimalLongitude   | The geographic longitude in decimal degrees of the geographic centre of the data sampling place. [https://dwc.tdwg.org/terms/#dwc:decimalLongitude](https://dwc.tdwg.org/terms/#dwc:decimalLongitude)                                       |
| geodeticDatum      | Spatial reference system (SRS) upon which the geographic coordinates given in decimalLatitude and decimalLongitude are based. [https://dwc.tdwg.org/terms/#dwc:geodeticDatum](https://dwc.tdwg.org/terms/#dwc:geodeticDatum) |
| coordinateUncertaintyInMetres | The maximum uncertainty distance in metres. [https://dwc.tdwg.org/terms/#dwc:coordinateUncertaintyInMeters](https://dwc.tdwg.org/terms/#dwc:coordinateUncertaintyInMeters)                                      |
| coordinatePrecision| The fraction of a degree corresponding to the number of significant digits in the source coordinates. [https://dwc.tdwg.org/terms/#dwc:coordinatePrecision](https://dwc.tdwg.org/terms/#dwc:coordinatePrecision)                                        |
| country            | Country name (Russian Federation). [https://dwc.tdwg.org/terms/#dwc:country](https://dwc.tdwg.org/terms/#dwc:country)                                                                                              |
| countryCode        | The standard code for the Russian Federation according to ISO 3166-1-alpha-2 (RU). [https://dwc.tdwg.org/terms/#dwc:countryCode](https://dwc.tdwg.org/terms/#dwc:countryCode)                                           |
| stateProvince      | Region name. The first level administrative division. [https://dwc.tdwg.org/terms/#dwc:stateProvince](https://dwc.tdwg.org/terms/#dwc:stateProvince)                                                              |
| locality           | The specific description of the place. [https://dwc.tdwg.org/terms/#dwc:locality](https://dwc.tdwg.org/terms/#dwc:locality)                                                                                      |
| locationID         | An identifier for the set of location information [https://dwc.tdwg.org/terms/#dwc:locationID](https://dwc.tdwg.org/terms/#dwc:locationID) We used this term to link cores (events) in the sampling plot. |
| habitat            | A description of the habitat in which the Event occurred [https://dwc.tdwg.org/terms/#dwciri:habitat](https://dwc.tdwg.org/terms/#dwciri:habitat) We indicated habitat type as a landscape position (valley or mountain) and tree species dominates in the canopy. |
| **verbatimEventDate** | The verbatim original date of the Event occurred. [https://dwc.tdwg.org/terms/#dwc:verbatimEventDate](https://dwc.tdwg.org/terms/#dwc:verbatimEventDate) |
|-----------------------|---------------------------------------------------------------|
| **year**              | The four-digit year of the Event occurred. [https://dwc.tdwg.org/terms/#dwc:year](https://dwc.tdwg.org/terms/#dwc:year) |
| **month**             | The integer month of the Event occurred. [https://dwc.tdwg.org/terms/#dwc:month](https://dwc.tdwg.org/terms/#dwc:month) |
| **day**               | The integer day of the month of the Event occurred. [https://dwc.tdwg.org/terms/#dwc:day](https://dwc.tdwg.org/terms/#dwc:day) |
| **eventDate**         | Field data collection date (YYYY-MM-DD). [https://dwc.tdwg.org/terms/#dwc:eventDate](https://dwc.tdwg.org/terms/#dwc:eventDate) |
| **institutionCode**   | The acronym of the Institute. [https://dwc.tdwg.org/terms/#dwc:institutionCode](https://dwc.tdwg.org/terms/#dwc:institutionCode) |
| **institutionID**     | An identifier for the institution having custody of the object(s) or information referred to in the record. [https://dwc.tdwg.org/terms/#dwc:institutionID](https://dwc.tdwg.org/terms/#dwc:institutionID) |
| **basisOfRecord**     | Basis of the record (PreservedSpecimen). [https://dwc.tdwg.org/terms/#dwc:basisOfRecord](https://dwc.tdwg.org/terms/#dwc:basisOfRecord) |
| **occurrenceID**      | An identifier for the record. [https://dwc.tdwg.org/terms/#dwc:occurrenceID](https://dwc.tdwg.org/terms/#dwc:occurrenceID) |
| **identificationRemarks** | Original identification. The [dwc:verbatimIdentification](https://dwc.tdwg.org/terms/#dwc:verbatimIdentification) was not used because it is currently not supported on the IPT. [https://dwc.tdwg.org/terms/#dwc:identificationRemarks](https://dwc.tdwg.org/terms/#dwc:identificationRemarks) |
| **scientificName**    | Scientific name. [https://dwc.tdwg.org/terms/#dwc:scientificName](https://dwc.tdwg.org/terms/#dwc:scientificName) |
| **identificationQualifier** | A brief phrase or a standard term ("cf.", "aff.") to express the determiner's doubts about the Identification. [https://dwc.tdwg.org/terms/#dwc:identificationQualifier](https://dwc.tdwg.org/terms/#dwc:identificationQualifier) |
| **taxonRank**         | The taxonomic rank. [https://dwc.tdwg.org/terms/#dwc:taxonRank](https://dwc.tdwg.org/terms/#dwc:taxonRank) |
| **kingdom**           | The full scientific name of the kingdom (Animalia). [https://dwc.tdwg.org/terms/#dwc:kingdom](https://dwc.tdwg.org/terms/#dwc:kingdom) |
| **phylum**            | The full scientific name of the phylum. [https://dwc.tdwg.org/terms/#dwc:phylum](https://dwc.tdwg.org/terms/#dwc:phylum) |
| **class**             | The full scientific name of the class. [https://dwc.tdwg.org/terms/#dwc:class](https://dwc.tdwg.org/terms/#dwc:class) |
| **identifiedBy**      | List of persons, who identified collected Collembola. [https://dwc.tdwg.org/terms/#dwc:identifiedBy](https://dwc.tdwg.org/terms/#dwc:identifiedBy) |
| **identificationReferences** | DOI of references used in the identification. Used for taxa, which did not match the GBIF Backbone. [https://dwc.tdwg.org/terms/#dwc:identificationReferences](https://dwc.tdwg.org/terms/#dwc:identificationReferences) |
| **lifeStage**         | The life stage of individuals. Here it is used for juvenile individuals indicated. [https://dwc.tdwg.org/terms/#dwc:lifeStag](https://dwc.tdwg.org/terms/#dwc:lifeStag) |
| **individualCount**   | The number of individuals represented in the core. [https://dwc.tdwg.org/terms/#dwc:individualCount](https://dwc.tdwg.org/terms/#dwc:individualCount) |
| **occurrenceStatus**  | A statement about the presence or absence of a Taxon at a Location. [https://dwc.tdwg.org/terms/#dwc:occurrenceStatus](https://dwc.tdwg.org/terms/#dwc:occurrenceStatus) |
| **language**          | A language of the resource (EN). [https://dwc.tdwg.org/terms/#dwc:language](https://dwc.tdwg.org/terms/#dwc:language) |
**Additional information**

In total, in the relict forests of the Far East, we found the highest diversity of Collembola that has ever been observed in the ecosystems of the temperate zone and possibly the world: up to 90 species per area 10 x 10 m (sampling plot). The species saturation reaches 30 species on an area of 8 square centimetres (one core) and can exceed 60 species on 1 square metre (Fig. 11).

![Figure 11](image)

Number of Collembola species in a core, on one square metre, in one sampling plot.

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The authors declare that they have no conflict of interest.
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