

# STRUCTURE OF COLLEMBOLA COMMUNITIES IN THE URBAN GRADIENT OF RĪGA CITY

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*The world's increasing urbanisation and the deterioration of human quality of life in major cities have redirected the focus of urban planning toward green infrastructure improvement and, as a result, increased the research of urban ecosystems. This article analyses changes in the structure of Collembola communities in soil in the urban-rural gradient in the city of Riga, Latvia. Soil samples were collected in 21 randomly selected sample plots within six urban habitats: street edge grasslands, downtown parks, private houses, cemetery grasslands, and urban and suburban forests. Soil samples were taken at the end of September/beginning of October 2017. A steel soil corer (D 50 mm, surface area 19.6 cm<sup>2</sup>, depth 10 cm) was used. In each plot, three soil samples were taken with a soil corer. Collembola were extracted from pooled samples from each habitat using a Berlese-Tullgren extractor. Nonmetric Multidimensional Scaling (NMS) ordination of Collembola data in sample plots yielded three statistically significant axes ( $p < 0.01$ ). The first axis explaining 49% of the data variation coincided with the urban-rural gradient. Species richness declined towards the city centre, while the Simpson's Dominance Index increased. The species Mesaphorura macrochaeta predominates in the central habitats, while Parisotoma notabilis dominates in suburban forests.*

**Keywords:** species richness, dominance concentration, urban-rural gradient, green infrastructure.

## INTRODUCTION

Urban ecosystems are formed as a result of complex interactions between natural and anthropogenic factors (Kowarik, 2011). Knowledge of the structure and functioning of these ecosystems is needed to create green infrastructure capable of providing ecosystem services to citizens (Elmqvist *et al.*, 2013). Soil is the foundation of the terrestrial ecosystem on which plant and animal communities depend. The condition of the soil is characterised by the diversity of organisms living in it. Therefore, research on urban soil biodiversity receives increasing attention (Grimm *et al.*, 2008; Pavao-Zuckerman and Byrne, 2009).

Collembola are among the most important soil arthropods and can be found in various soils, including human-affected ones (Hopkin, 1997; Potapov *et al.*, 2020). They are sensitive bioindicators of soil conditions (Hopkin, 1997), but un-

til now there has been little research (Sterzynska, 1982; Krestyaninova and Kuznetsova, 1996; Eitminaviciute, 2006; Fiera, 2009; Santorufo *et al.*, 2012; Sterzynska *et al.*, 2018; Kuznetsova and Ageeva, 2020) on the presence of Collembola in urban ecosystems, which are under the pressure of a large variety of anthropogenic influences. Existing data indicates that the density of Collembola tends to decrease in soils found in central parts of cities, with typical forest species close to absent (Sterzynska, 1982; Krestyaninova and Kuznetsova, 1996; Eitminaviciute, 2006). Some authors (Kuznetsova, 1994; Guillard *et al.*, 2018) found that the density of Collembola peaks in moderately affected habitats located between the city centre and the outskirts. Urban roadside grasslands have mostly monodominant communities with the prevalence of individual eurybiontic, cosmopolitan, and specialised species (Eitminaviciute, 2006), but the species composition of urban habitats is temporally unstable (Kuznetsova and Ageeva, 2020). Some

studies give contradictory results regarding soil pollution effects on urban Collembola, either being tolerant (Fountain and Hopkin, 2004; Fiera, 2009) or having a negative reaction to it (Sterzynska *et al.*, 2018). Since various urban ecosystems have developed in different geographic and climatic conditions and receive different anthropogenic pressure and our present knowledge about the Collembola of urban ecosystems is too fragmentary and insufficient, generalised conclusions cannot be yet made. Additional research is needed. In the city of Riga, there have been studies of soil fauna, including, to a limited extent, regarding Collembola of two urban and suburban forest plots (Telnov and Salmane, 2015). Other than this study, the Collembola communities of Riga have not been studied.

The soils of Riga have formed on nutrient-poor sands, which have been transformed and improved by the addition of fertile soil material and organic matter for centuries (Danka and Stiprais, 1973). From this point of view, it is of interest to investigate the structure of Collembola communities in different urban habitats of varying anthropogenic pressure. In exploration of this, a pilot survey was performed in 2017 by sampling 21 urban habitats distributed along the urban-rural gradient. This article analyses the data obtained in that study.

## MATERIALS AND METHODS

**Novel ecosystems.** Riga is situated on the Baltic Sea's southern coast, on the Gulf of Riga (56°58'18.2" N, 24°07'42.3"E). The climate in Riga is humid continental (*Dfb* according to Köppen, 1936). The annual mean temperature is +7.9 °C, with an annual precipitation of 700–720 mm. Summers are comparatively cool and cloudy with an average temperature of +16.9 °C in July. Winters are comparatively warm with frequent thaws; the average temperature in January is –4.7 °C (Lizuma, 2008). The territory of Riga covers 307.17 km<sup>2</sup>. The city stands on glacial and post-glacial Baltic Ice Lake sediments, as well as on post-glacial dunes. Thus far, no special studies have been performed on the soil types of Riga. Soils in Riga have formed on poor dune sand bedrock. In elevated terrain zones, podzol soils have formed. In the valleys where precipitation waters accumulated sediments, peaty low marsh soils have formed (Danka and Stiprais, 1973).

It has been estimated that only 30% of the city's space is residential, while 28% is considered as "green space" (e.g., public and private lawns, city parks and urban forests), leaving the remaining 42% for city waterbodies, roads, and technogenic or industrial areas (Anonymous 2017). Undeveloped and suburban areas are covered by pine forests, subjected to varying extents of human pressure (Forest management plan, 2018). Soils in the central part of Riga can be characterised as artificial, sandy, highly heterogeneous, and compact. In general, the top-layer of the studied street soils (0–35 cm) contains 8.58% clay, 13.32% silt, 78.09% sand, and 3.55–12.27% organic matter of. Park soils are richer, containing 10.38% clay, 24.2% silt, 65.5%

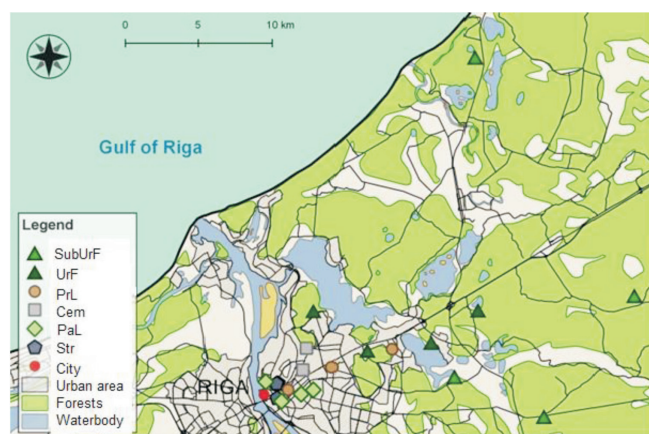


Fig. 1. Sample plot locations in Riga's city centre and periphery. Str, street surrounding soil; PaL, park lawn soil; PrL, private lawn soil; Cem, cemetery soil; UrF, urban forest soil, and SubUrF, suburban forest soil (after Grina *et al.*, 2023).

sand, and 5.70% organic matter (Cekstere and Osvalde, 2013).

**Sampling sites.** Following the classification of Klausnitzer (1987), six types of urban habitats in Riga were selected from along the urban-rural gradient from the north-east border to the city centre: lawns by streets (Str), park lawns (PaL), private house garden lawns (PrL), cemetery lawns (Cem), urban forests (UrF), and suburban forests (SubUrF) (Fig. 1). Four random plots were selected within each habitat, except for street edges and cemeteries, where the number of selected plots was three and two, respectively (Fig. 1). Two distinct groups of sample sites can be distinguished among these habitats. The habitats least affected by human disturbance are the SubUrF and UrF, with natural soils and elements of natural vegetation, which vastly differed from other habitats where soils were transformed by foreign substrates and had a specific set of governing pressures. The Str site suffered from the most intense anthropogenic influence — pollution, regular litter removal, and soil compaction. Although the PaL site experienced less pollution, it was subjected to compaction by heavy tractors during lawn mowing and removal of tree litter. The PrL site was not affected by heavy compaction. The Cem site had less frequent mowing and litter removal. These habitats could be ranked on the urban-rural gradient in the following order from high to low anthropogenic factor intensity: Str, PaL, PrL, Cem, UrF, SubUrF.

**Soil sampling.** Soil samples were taken at the end of September/beginning of October 2017. In total, 21 sample plots (approx. 5–10 m<sup>2</sup> each) were set up within the urban-rural gradient (Fig. 1). A steel soil corer (D 50 mm, surface area 19.6 cm<sup>2</sup>, depth 10 cm) was used (Melecis *et al.*, 2018). In each plot, three soil samples were taken with a soil corer. The total area sampled was 58.8 cm<sup>2</sup>. In order to avoid the influence of various adjacent factors as far as possible, the sampling plots were selected on flat lawns away from trees and shrubs, sidewalks and human trails were avoided. In forests, samples were assigned to the inter-crown areas of trees, in a spot with the most homogenous forest litter and moss cover.

Microarthropods were extracted in the laboratory from the samples using a Berlese-Tullgren funnel and 25 W bulbs as a heat source for two weeks (Dunger *et al.*, 1997). Collembola were identified to the species level using Fjellberg's keys to identification (1998, 2007).

Soil pH was measured with three replicates using KCl solution (Dunger *et al.*, 1997) and a pH-meter. The content of the organic matter (%) was determined based on the Tyurin (1951) method with three replicates for each sample. Soil moisture was not measured due to the accumulation of a large amount of moisture. This was due to prolonged rains prior to and during the collection period; therefore, this environmental factor could not be considered as limiting at that time for soil organisms.

**Data analysis.** To explore changes in the structure of Collembola communities in the urban-rural gradient, Nonmetric Multidimensional Scaling (NMS) ordination of sample plots was performed using the PC-ORD software package (McCune and Mefford, 1999; McCune and Grace, 2002). Species with a frequency of 0.1 were excluded from the main data matrix prior to analysis, and the data were log-transformed. The Sørensen index was used for the calculation of the species similarity matrix. A random starting configuration and 250 runs with real data were used for selecting dimensionality, and a Monte Carlo test with 250 runs was used to assess whether the extracted dimensions differed from a random pattern ( $p < 0.05$ ). To facilitate the interpretation of the obtained axes, a second matrix containing measurement data on soil pH and the content of organic matter was included in the analysis. In order to determine changes in the Collembola communities, the analysis of species dominance structures was performed (Henderson, 2003) and the Simpson's dominance index was calculated (Simpson, 1949).

## RESULTS

In total, 3474 individuals of Collembola from 14 families and 57 species were collected (Table 1). The family Isotomidae contributed 53% of all Collembola. The total density of Collembola in the studied soil plots varied greatly and the average densities did not significantly differ between different habitats (Table 2). Soil pH tended to decrease and organic matter content increased towards the outskirts.

The ordination of sample plots by Collembola species data yielded three statistically significant axes, explaining 49%, 26%, and 10% of the total data variation, and stress value was 9.2. In Figure 2, Axis 1 reflected an urban-rural gradient; it had high correlation ( $r = -0.736$ ) with soil pH. The polygons of sample plots represented urban habitats. Larger polygons indicated greater differences in species structure between sample plots in a site. Particularly large differences were observed among plots within each of sites Str, Cem, and PrL, while at sites UrF and PaL, the differences were much smaller. These differences were caused differing ecological conditions within a specific urban habitat type. De-

Table 1. Collembola species recorded in this study

| Species                                           | Abbreviation | Abundance |
|---------------------------------------------------|--------------|-----------|
| Hypogastruridae                                   |              |           |
| <i>Hypogastrura manubrialis</i> (Tullberg, 1869)  | Hyp_manu     | 249       |
| <i>Schoetella unungiculata</i> (Tullberg, 1869)   | Sch_unun     | 1         |
| <i>Willemia anophthalma</i> Börner, 1901          | Wil_anop     | 32        |
| <i>Willemia denisi</i> Mills, 1932                | Wil_deni     | 12        |
| <i>Willemia intermedia</i> Mills, 1934            | Wil_inte     | 2         |
| Brachystomellidae                                 |              |           |
| <i>Brachystomella parvula</i> (Schäffer, 1896)    | Bra_parv     | 5         |
| Neanuridae                                        |              |           |
| <i>Friesea afurcata</i> (Denis, 1926)             | Fri_afur     | 2         |
| <i>Friesea mirabilis</i> (Tullberg, 1871)         | Fri_mira     | 163       |
| <i>Friesea truncata</i> Caccagnau, 1958           | Fri_trun     | 14        |
| <i>Micranurida pygmaea</i> Börner, 1901           | Mic_pygm     | 9         |
| <i>Neanura muscorum</i> (Templeton, 1835)         | Nea_musc     | 8         |
| <i>Pseudachorutella assigilata</i> (Börner, 1901) | Pse_asig     | 5         |
| Onychiuridae                                      |              |           |
| <i>Micraphorura absoloni</i> (Börner, 1901)       | Mic_abso     | 50        |
| <i>Protaphorura armata</i> (Tullberg, 1869)       | Pro_arma     | 45        |
| <i>Protaphorura</i> sp.                           | Protaph      | 15        |
| Tullbergiidae                                     |              |           |
| <i>Mesaphorura critica</i> Ellis, 1976            | Mes_crit     | 16        |
| <i>Mesaphorura hylophila</i> Rusek, 1982          | Mes_hylo     | 2         |
| <i>Mesaphorura italica</i> (Rusek, 1971)          | Mes_ital     | 19        |
| <i>Mesaphorura krausbaueri</i> Börner, 1901       | Mes_krau     | 22        |
| <i>Mesaphorura macrochaeta</i> Rusek, 1976        | Mes_macr     | 586       |
| <i>Mesaphorura sylvatica</i> (Rusek, 1971)        | Mes_sylv     | 5         |
| <i>Mesaphorura tenuisensillata</i> Rusek, 1974    | Mes_tenu     | 2         |
| <i>Mesaphorura yosii</i> (Rusek, 1967)            | Mes_yosi     | 61        |
| <i>Stenaphorura quadripina</i> Börner, 1901       | Ste_quad     | 2         |
| Isotomidae                                        |              |           |
| <i>Anurophorus laticis</i> Nicolet, 1842          | Anu_lar      | 2         |
| <i>Cryptopygus bipunctatus</i> (Axelson, 1903)    | Cry_bipu     | 565       |
| <i>Desoria hiemalis</i> (Schött, 1893)            | Des_hie      | 17        |
| <i>Folsomia fimetaria</i> (Linnaeus, 1758)        | Fol_fime     | 59        |
| <i>Folsomia fimetarioides</i> (Axelson, 1903)     | Fol_fimt     | 35        |
| <i>Folsomia manolachei</i> Bagnall, 1939          | Fol_mano     | 15        |
| <i>Folsomia quadrioculata</i> (Tullberg, 1871)    | Fol_quad     | 20        |
| <i>Folsomia</i> gr. <i>fimetaria</i>              | Fol_sp       | 9         |
| <i>Isotomiella minor</i> (Schäffer, 1896)         | Iso_mino     | 307       |
| <i>Isotoma anglicana</i> Lubbock, 1862            | Iso_angl     | 100       |
| <i>Isotoma viridis</i> Bourlet, 1839              | Iso_viri     | 8         |
| <i>Isotomodes armatus</i> Naglitsch, 1962         | Iso_arma     | 4         |
| <i>Isotomodes productus</i> (Axelson, 1906)       | Iso_prod     | 20        |
| <i>Micranurophorus</i> sp.                        | Micran_sp    | 1         |
| <i>Parisotoma notabilis</i> (Schäffer, 1896)      | Par_nota     | 655       |
| <i>Proisotoma minima</i> Absolon, 1901            | Pro_mini     | 5         |
| <i>Proisotoma minuta</i> (Tullberg, 1871)         | Pro_minu     | 1         |
| <i>Proisotoma</i> sp.                             | Pro_sp       | 18        |
| Entomobryidae                                     |              |           |
| <i>Entomobrya</i> spp.                            | Ent_sp       | 15        |
| <i>Heteromurus nitidus</i> (Templeton, 1835)      | Het_niti     | 1         |
| <i>Lepidocyrtus lignorum</i> (Fabricius, 1793)    | Lep_lign     | 65        |
| <i>Lepidocyrtus violaceus</i> (Geoffroy, 1762)    | Lep_viol     | 3         |

Continuation of Table 1

| Species                                             | Abbreviation | Abundance |
|-----------------------------------------------------|--------------|-----------|
| <i>Orchesella flavescens</i> (Bourlet, 1839)        | Orc_flav     | 4         |
| <i>Pseudosinella alba</i> (Packard, 1873)           | Pse_alba     | 4         |
| Tomoceridae                                         |              |           |
| <i>Pogonognathellus flavescens</i> (Tullberg, 1871) | Tom_flav     | 50        |
| Neelidae                                            |              |           |
| <i>Megalothorax minimus</i> Willem, 1900            | Meg_mini     | 12        |
| Arrhopalitidae                                      |              |           |
| <i>Arrhopalites cochlearifer</i> Gisin, 1947        | Arr_cocl     | 4         |
| <i>Arrhopalites</i> sp.                             | Arrhop_sp    | 2         |
| Katiannidae                                         |              |           |
| <i>Sminthurinus aureus</i> (Lubbock, 1862)          | Smi_aur      | 12        |
| <i>Sminthurinus elegans</i> (Fitch, 1863)           | Smi_eleg     | 11        |
| <i>Sminthurinus</i> gr. <i>niger</i>                | Smi_nige     | 1         |
| Dicyrtomidae                                        |              |           |
| <i>Dicyrtoma fusca</i> (Lubbock, 1873)              | Dic_fusc     | 1         |
| Sminthurididae                                      |              |           |
| <i>Sminthurididae</i> gr. sp.                       | Smi_spp      | 16        |
| <i>Sphaeridia pumilis</i> (Krausbauer, 1898)        | Sph_pumi     | 104       |
| Sminthuridae                                        |              |           |
| <i>Allacma fusca</i> (Linné, 1758)                  | All_fusc     | 1         |

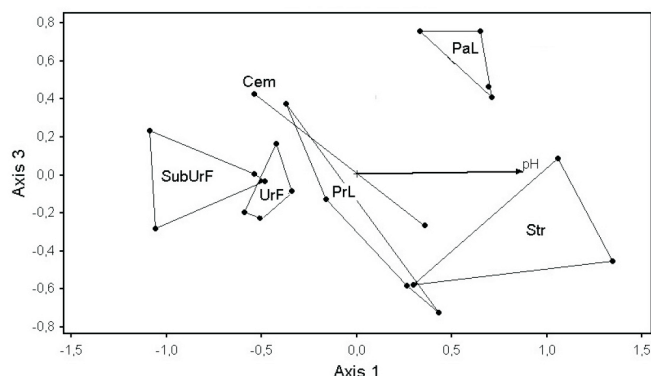


Fig. 2. Distribution of sampling plots in NMS axes obtained by ordination of Collembola data from the urban habitats arranged on the urban–rural gradient of Rīga. Points corresponding to the same habitat type form polygons. The arrow parallel to Axis 1 characterises the correlation of soil pH with this axis. See Figure 1 for abbreviations.

spite these differences within the urban habitats, one can distinguish quite pronounced pairs of habitats as Str and PaL, PrL and Cem, and UrF, and SubUrF having ordered projections on the axis describing the urban–rural gradient.

## DISCUSSION

In general, Collembola density tended to increase from the city centre to the outskirts (Fig. 3). However, this does not exclude some species-rich plots in the city centre street lawns Str1 and species-poor plots in the cemeteries Cem1 and urban forests UrF1. Given the significantly non-homogeneous spatial distribution of these arthropods, this raises the question of whether the number and amount of soil samples taken sufficiently represent the Collembola community of a given plot (Saraeva *et al.*, 2015). Adverse environ-

Table 2. Density of Collembola, pH, and organic matter content in soils of urban sample plots in the urban–rural gradient of Rīga

| Sample plot | Geographical coordinates     | Collembola ind./m <sup>2</sup> | pH   | Organic matter % |
|-------------|------------------------------|--------------------------------|------|------------------|
| Str1        | 56°57'11.9"N<br>24°06'49.4"E | 4000                           | 6.68 | 8.38             |
| Str2        | 56°57'44.7"N<br>24°06'53.0"E | 190,500                        | 6.61 | 5.46             |
| Str3        | 56°56'43.9"N<br>24°06'47.2"E | 1000                           | 6.74 | 6.12             |
| PaL1        | 56°57'05.1"N<br>24°07'07.4"E | 48,000                         | 6.77 | 11.52            |
| PaL2        | 56°57'20.9"N<br>24°08'26.8"E | 42,000                         | 6.25 | 8.32             |
| PaL3        | 56°57'48.4"N<br>24°06'03.3"E | 22,500                         | 6.56 | 6.06             |
| PaL4        | 56°57'30.1"N<br>24°09'16.4"E | 70,000                         | 6.63 | 5.39             |
| PrL1        | 56°58'05.4"N<br>24°08'56.6"E | 181,000                        | 6.79 | 7.74             |
| PrL2        | 56°57'30.,"N<br>24°7'32.3"E  | 49,000                         | 6.67 | 4.44             |
| PrL3        | 56°58'59.8"N<br>24°14'32.1"E | 87,000                         | 6.55 | 8.05             |
| PrL4        | 56°58'20.3"N<br>24°10'29.7"E | 117,000                        | 6.08 | 5.26             |
| Cem1        | 56°59'02.6"N<br>24°08'48.8"E | 125,500                        | 6.39 | 6.38             |
| Cem2        | 56°58'14.5"N<br>24°08'33.9"E | 122,000                        | 6.53 | 5.6              |
| UrF1        | 57°00'24.2"N<br>24°09'17.0"E | 44,000                         | 4.51 | 5.35             |
| UrF2        | 56°59'13.2"N<br>24°17'11.1"E | 80,500                         | 3.12 | 8.91             |
| UrF3        | 56°58'56.0"N<br>24°12'51.9"E | 139,000                        | 4.48 | 6.08             |
| UrF4        | 57°0'24.1"N<br>24°20'17.5"E  | 50,000                         | 3.25 | 20.77            |
| SubUrF1     | 56°57'57.3"N<br>24°18'45.0"E | 47,500                         | 3.26 | 14.12            |
| SubUrF2     | 57°9'44.5"N<br>24°20'10.6"E  | 85,000                         | 2.71 | 19.95            |
| SubUrF3     | 57°0'54.5"N<br>24°30'48.8"E  | 126,500                        | 3.42 | 10.38            |
| SubUrF4     | 56°56'28.1"N<br>24°24'42.8"E | 103,000                        | 5.68 | 19.45            |

mental conditions in the city centre lead to monodominant Collembola habitats (Str2 and Str3), where the species are apparently tolerant of these effects and may be considered as urban species. Similar results were also noted by Rzeszowski and Sterzyńska (2015). In our study *Mesaphorura macrochaeta*, for example, was not found in suburban woods, but was common in urban settings, including urban forests. Sterzyńska *et al.* (2018) found this species to have a negative correlation with PM<sub>10</sub>, a variable that characterises the level of pollution in the urban environment.

The greatest Simpson's index values were obtained in street grasslands, where only one to two species of Collembola were represented in two sample plots. Values of this index were also high in private garden lawns, where in most cases

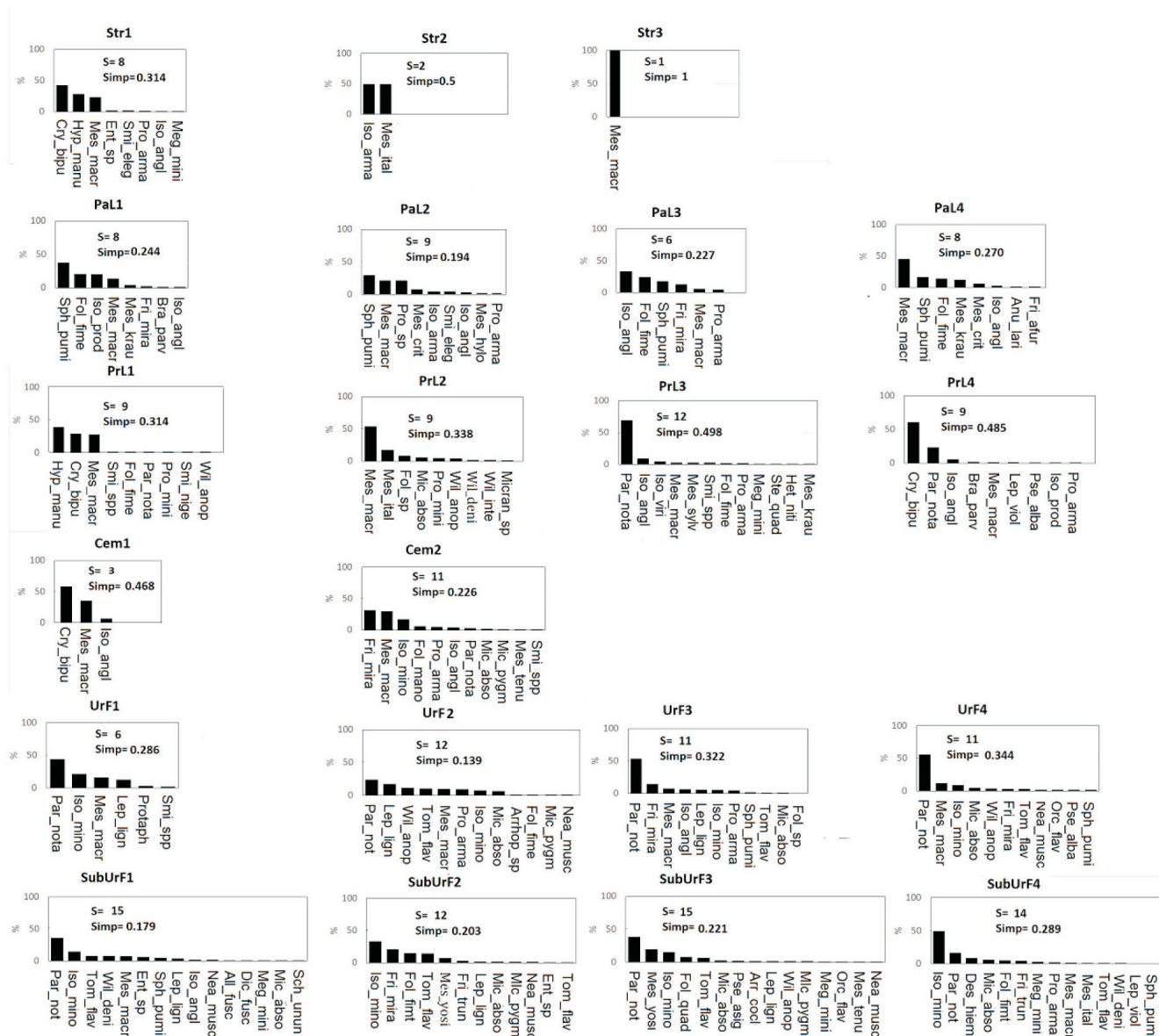


Fig. 3. Dominance structure of Collembola from sampling plots of various urban habitats arranged on the urban-rural gradient of Riga city. Abbreviations of species names see in Table 1.

only one species predominated. The lowest values of the Simpson's index were found in park grasslands and suburban forests. The parks had a higher relative abundance of co-dominants and fewer subdominants and recedent species.

There was considerable instability observed in the composition of dominant species, especially in habitats more affected by urban factors. The urban and suburban forests were almost unambiguously dominated by *Parisotoma notabilis*. From the habitats more affected by urban factors, this species was found only in private gardens and cemeteries (PrL1, PrL3, PrL4 and Cem2). Obviously, urbanisation processes are not conducive to the spread of this species.

## CONCLUSIONS

Our study on changes in the structure of Collembola soil communities on the urban-rural gradient in the city of Riga showed that these microarthropods are sensitive to the im-

pact of the urban environment and can be used for assessment of the condition of its "green infrastructure" soils. Two species were found to have opposite reaction to the urban influence. *Mesaphorura macrochaeta* dominated in urban habitats while *Parisotoma notabilis* in suburban forest soils.

## ACKNOWLEDGMENTS

The study was performed in the framework of the project Y5-AZ107 of the University of Latvia "Climate change and its impacts on sustainability of natural resources". The authors thank Holly Goldmane for improving the English of the manuscript.

## REFERENCES

- Anonymous. (2017). *The Economic Profile of the City of Riga*. Rīga City Council City Development Department, Riga, pp. 48. <https://www.riga.lv> (accessed 3.12.2023).

- Cekstere, G., Osvalde, A. (2013). A study of chemical characteristics of soil in relation to street trees status in Riga (Latvia). *Urban Forestry & Urban Greening*, **12**, 69–78. <https://doi.org/10.1016/j.ufug.2012.09.004>.
- Danka, L., Stiprais, M. (1973). Materials on insect fauna of Riga. I. Ecological characterization of the territory of Riga. *Latvijas Entomologs*, **15**, 3–7 (in Latvian).
- Dunger, W., Fiedler, G., Fiedler, H. J. (1997). *Methoden der Bodenbiologie*. Gustav Fischer Verlag, Jena. 540 pp. (in German).
- Eitminavičiute, I. (2006). Microarthropod communities in anthropogenic urban soils. I. Structure of microarthropod complexes in soils of roadside lawns. *Entomol. Rev.*, **86**, 128–135. <https://link.springer.com/article/10.1134/S0013873806110029>.
- Elmqvist, T., Fragkias, M., Goodness, J., Güneralp, B., Marcotullio, P. J., McDonald, R. I., Parnell, S., Schewenius, M., Sendstad, M., Seto, K. C., Wilkinson, C. (eds.) (2013). *Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities*. Springer Dordrecht. <https://doi.org/10.1007/978-94-007-7088-1>.
- Fiera, C. (2009). Biodiversity of Collembola in urban soils and their use as bioindicators for pollution. *Pesqui. Agropecu. Bras.*, **44**, 868–873. <https://doi.org/10.1590/S0100-204X2009000800010>.
- Fjellberg, A. (1998). *The Collembola of Fennoscandia and Denmark, Part I. Poduromorpha*. Ser. Fauna Entomologica Scandinavica, Vol. 35. Brill, 184 pp.
- Fjellberg, A. (2007). *The Collembola of Fennoscandia and Denmark. Part II: Entomobryomorpha and Symphypleona*. Ser. Fauna Entomologica Scandinavica, Vol. 42. Brill, 272 pp.
- Forest management plan. (2018). <https://www.sus.lv/sites/default/files/media/faili/mezaapsaimnplans20182026.pdf> (accessed 3.12.2023).
- Fountain, M. T., Hopkin, S. P. (2004). Biodiversity of Collembola in urban soils and the use of *Folsomia candida* to assess soil 'quality'. *Ecotoxicology*, **13**, 555–572. <https://link.springer.com/article/10.1023/B:ECTX.0000037192.70167.00>.
- Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J. G., Bai, X. M., Briggs, J. M. (2008). Global change and the ecology of cities. *Science*, **319**, 756–760. <https://doi.org/10.1126/science.1150195>.
- Grina, V., Kagainis, U., Jucevica, E., Salmane, I., Melecis, V. (2023). Soil microarthropod distribution on the urban-rural gradient of Riga city: A study with robust sampling method application. *J. Urban Ecol.*, **9** (1), juad012. <https://doi.org/10.1093/jue/juad012>.
- Guilland, C., Maron, P. A., Damas, O., Ranjard, L. (2018). Biodiversity of urban soils for sustainable cities. *Environ. Chem. Lett.*, **16** (4). <https://doi.org/10.1007/s10311-018-0751-6>.
- Henderson, P. A. (2003). *Practical Methods in Ecology*. Blackwell Publishers, Oxford. 176 pp.
- Hopkin, P. (1997). *Biology of the Springtails – Insecta: Collembola*. Oxford University Press. 344 pp.
- Klausnitzer, B. (1987). *Ökologie der Großstadt Fauna*. VEB Gustav Fisher Verlag, Jena. 225 pp.
- Köppen, W. P. (1936). *Das geographische System der Klimate, Handbuch der Klimatologie*. Borntraeger, Berlin, Bd. 1, Teil. C. 44 pp. (in German).
- Kowarik, I. (2011). Novel urban ecosystems, biodiversity, and conservation. *Environ. Pollut.*, **159** (8–9), 1974–1983. <https://doi.org/10.1016/j.envpol.2011.02.022>.
- Krestyaninova, A. I., Kuznetsova, N. A. (1996). Dynamics of collembolan (Hexapoda, Collembola) association in the soil of an urban boulevard. *Entomol. Rev.*, **76**, 1220–1230.
- Kuznetsova, N. A. (1994). Collembolan guild structure as an indicator of tree plantation conditions in urban areas. *Mem. Zool.*, **49**, 197–205. [https://rcin.org.pl/miiz/Content/41582/PDF/WA058\\_57529\\_P4753\\_Mem-Zool-49-3-5.pdf](https://rcin.org.pl/miiz/Content/41582/PDF/WA058_57529_P4753_Mem-Zool-49-3-5.pdf)
- Kuznetsova, N. A., Ageeva, T. Z. (2020). Collembola of broadleaved forests along gradient of urbanization in Moscow. *Sampling event dataset*. 1.4. Moscow Pedagogical State 14 Kuznetsova N, Ivanova N University (MPGU). Release date: 25.08.2020. <https://doi.org/10.15468/e25d3s> (accessed 3.12.2023).
- Lizuma, L. (2008). Gaisa temperatūras un atmosfēras nokrišņu mainības raksturs Rīgā [The character of variability in air temperature and atmospheric precipitation in Riga]. Doctoral dissertation, Academic Publishing House of the University of Latvia (in Latvian). <https://dspace.lu.lv/dspace/handle/7/5157> (accessed 3.12.2023).
- McCune, B., Grace, J. B. (2002). *Analysis of Ecological Communities*. MjM Software Design, Gleneden Beach, Oregon. 300 pp.
- McCune, B., Mefford, M. J. (1999). *Multivariate Analysis on the PC-ORD System*. Version 4, MjM Software, Gleneden Beach, Oregon, USA. 237 pp.
- Melecis, V., Grina, V., Kagainis, U., Jucevica, E., Salmane, I. (2018). Robust method of soil mesofauna assessment in urban environment for long-term ecological research. In: *TERENO International Conference, 8<sup>th</sup>–12<sup>th</sup> October, Umweltforum and Neue Malzerei, Berlin, Germany*. <http://www.ufz.de/tereno2018/index.php?en=44426#session-D>
- Pavao-Zuckerman, M. A., Byrne, L. B. (2009). Scratching the surface and digging deeper: Exploring ecological theories in urban soils. *Urban Ecosyst.*, **12**, 9–20. <https://doi.org/10.1007/s11252-008-0078-3>.
- Potapov, A., Bellini, B., Chown, S., Deharveng, L., Janssens, F., Kováč, L., Kuznetsova, N., Ponge, J.-F., Potapov, M., Querner, P., Russel, D., Sun, X., Zhang, F., Berg, M. P. (2020). Towards a global synthesis of Collembola knowledge: Challenges and potential solutions. *Soil Organisms*, **92** (3), 161–188. <https://doi.org/10.25674/so92iss3pp161>.
- Rzeszowski, K., Sterzyńska, M. (2015). Changes through time in soil Collembola communities exposed to urbanization. *Urban Ecosyst.*, **19** (1), 143–158. <https://doi.org/10.1007/s11252-015-0478-0>.
- Santoruf, L., van Gestel, C. A. M., Rocco, A., Maisto, G. (2012). Soil invertebrates as bioindicators of urban soil quality. *Environ. Pollut.*, **161**, 57–63. <https://doi.org/10.1016/j.envpol.2011.09.042>.
- Saraeva, A. K., Potapov, M. B., Kuznetsova, N. A. (2015). Different-scale distribution of Collembola in homogenous ground vegetation: Sphagnum moss. *Entomol. Rev.*, **95** (5), 557–577. <https://link.springer.com/article/10.1134/S0013873815050012>.
- Simpson, E. H. (1949). Measurement of diversity. *Nature*, **163**, 688.
- Sterzyńska, M. (1982). Springtails (Collembola) of Warsaw and Mazovia. *Memorabilia Zool.*, **36**, 217–223. [https://rcin.org.pl/Content/38602/PDF/WA058\\_28315\\_P4753\\_Mem-Zool-36-12.pdf](https://rcin.org.pl/Content/38602/PDF/WA058_28315_P4753_Mem-Zool-36-12.pdf).
- Sterzyńska, M., Nicia, P., Zadrozny, P., Fiera, C., Shrubovych, J., Ulrich, W. (2018). Urban springtail species richness decreases with increasing air pollution. *Ecol. Indic.*, **94**, 328–335. <https://doi.org/10.1016/j.ecolind.2018.06.063>.
- Telnov, D., Salmane, I. (2015). Ecology and diversity of urban pine forest soil invertebrates in Riga, Latvia. *Proc. Latvian Acad. Sci., Section B*, **69** (3), 120–131. <https://doi.org/10.1515/prolas-2015-0017>.
- Tyurin, I. V. (1951). Analytical procedure for a comparative study of soil humus. *Trudy Pochr. Inst. Dokuchaev*, **33**, 5–21 (in Russian).

Received 21 December 2022

Accepted in the final form 2 September 2023

## KOLEMBOLU BIODIVERZITĀTES STRUKTŪRA UZ RĪGAS PILSĒTAS URBĀNĀ GRADIENTA

Pasaulē pieaugošā urbanizācija un cilvēku dzīves kvalitātes pasliktināšanās lielākajās pilsētās ir mudinājusi pilsētplānotājus īpašu vērību piešķirt zaļās infrastruktūras uzlabošanai un līdz ar to pastiprināt pilsētu ekosistēmu izpēti. Šajā rakstā analizētas kolembolu (*Collembola*) struktūras izmaiņas augsnē uz pilsētas–piepilsētas lauku teritorijas gradienta Rīgā. Augsnes paraugi tika ievākti 21 nejauši izvēlētā parauglaukumā sešās pilsētvides dzīvotnēs: ielu malu zālajos, centra parkos, privātmāju pagalmos, kapsētu zālajos un pilsētas un piepilsētas mežos. Augsnes paraugi tika ievākti 2017. gada septembra beigās – oktobra sākumā. Paraugu ievākšanai tika izmantots tērauda augsnes urbis (D 50 mm, virsmas laukums 19,6 cm<sup>2</sup>, 10 cm dziļumā). Katrā parauglaukumā tika ievākti trīs augsnes paraugi. Kolembolas tika izdalītas no apvienotā parauga, izmantojot Berlēzes–Tullgrena ekstraktoru. Izmantojot nemetrisko daudzdimensiju skalēšanu (NMS), parauglaukumu ordinācija pēc kolembolu datiem deva trīs statistiski nozīmīgas ass ( $p < 0,01$ ). Tikai pirmā ass, kas izskaidro 49% no datu variācijas, sakrita ar pilsētas–piepilsētas lauku teritoriju gradientu. Sugu bagātība samazinājās virzienā uz pilsētas centru, savukārt Simpsona dominances koncentrācijas indeksa vērtība pieauga. Centra biotopos dominēja suga *Mesaphorura macrochaeta*, savukārt piepilsētas mežos — *Parisotoma notabilis*.