

Spatial Organization of the Micromollusc Community under Recreational Load

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Abstract

The recreational load is an important factor in transforming the living conditions of living organisms in the urban environment. This article examines the role of recreation as a driver of the changing habitat of soil micromolluscs in the park environment in an urban landscape. The hypothesis that recreational exposure changes the hierarchical organization of the spatial distribution of the micromollusc community was tested. An experimental polygon was located in Novooleksandrivskiy Park (Melitopol, Ukraine) and represented 7 transects with 18 test points in each. The set of soil properties explained 24.7% of the variation in the mollusc community. The distance from trees was able to explain 6.8% of mollusc community variation. The distance from recreational pathways was able to explain 12.2% of the variation in the mollusc community. The spatial eigenfunctions were able to explain 54.2% of mollusc community variation. The spatial patterns of variation in the structure of the assemblage of molluscs were found to be due to various causes. Thus, the broad-scale component was due to the distance from trees and the distance from the recreational pathways and was associated with the variability of soil penetration resistance, aggregate structure, electrical conductivity, soil moisture and density. The recreational load is the cause of this pattern formation. In turn, the medium-scale component reflected the influence of soil aggregate composition on the mollusc community and components independent of soil properties. The fine-scale component reflected the variability of the mollusc community, which was independent of soil properties.

Keywords

Urban ecology; Micromolluscs; Soil aggregates; Soil compaction; Urban park

Introduction

In the urban environment there is a significant transformation of various components of the landscape, which worsens the modes of existence of biotic components of ecosystems and human living conditions. Urban parks perform a number of the most important ecological services: carbon sequestration, seed dispersal, erosion prevention, water purification, air purification and habitat quality (Kunakh *et al.*, 2020; Mexia *et al.*, 2018). Functional efficiency of forest plantations in urban environment depends on sustainability and diversity of ecosystems formed within them. The urban environment is stressed not only by pollution, but also by heat and drought, creating arid conditions. Trees are passively exposed to the microclimate, but they also actively modify it, and they perform important ecosystem services of the city (Lüttge and Buckeridge, 2020). The destruction of habitat occurs as the intensity of urbanization increases (Yorkina, 2016). The growth of population and the expansion of built-up areas caused by urbanization can have a significant impact on the supply and distribution of critical ecosystem services. A correlation between urbanization and ecosystem services has been established. Urbanization causes a general decline in ecosystem services, where urbanization and ecosystem services showed a negative spatial correlation (Wang *et al.*, 2020). The hotspots that retain biota become increasingly fragmented in urban environments and diminish as the gradient of urbanization increases (Collins *et al.*, 2000). Soil invertebrates in urban environments are taxonomically and functionally diverse. This is contributed to by the specific features of the soil as a habitat. The soil has protective properties, which facilitates the survival of pedobionts even under conditions of significant anthropogenic impact (Byrne *et al.*, 2008; Byrne and Bruns, 2004; Joimel *et al.*, 2017; Rochefort *et al.*, 2006; Schrader and Böning, 2006). Nevertheless, the communities of invertebrates of urban soils are sensitive to the variability of physical and chemical properties of urban soils and land-use practices (Bray *et al.*, 2019).

The soil invertebrates respond to many human activities (Yorkina *et al.*, 2020). Recreation is a factor that significantly transforms the living conditions of soil invertebrates. Recreation affects not only the vegetation cover and soil properties, but also the condition of the complex of soil invertebrates. Recreation contributes to soil compaction, the growth of a network of footpaths and the formation of a special structure of soil cover, consisting of an alternation of dense footpaths and areas outside the footpaths. In the short term, diversity and abundance of soil invertebrate communities will decline due to urbanization. In the long term, the increasing tolerance of an increasing number of species may lead to changes in the structure and size of communities (Salminen *et al.*, 2001). The physical disturbance of the soil, heavy metal contamination, pesticide contamination, the timing and magnitude of human exposure, and the history of land use affect the soil animals (Jones and Leather, 2012; McIntyre *et al.*, 2000; Pavao-Zuckerman, 2008; Pavao-Zuckerman and Coleman, 2007; Yorkina *et al.*, 2019). The formed network of footpaths violates the integrity of forest ecosystems, the spatial continuity of grass cover, litter, and soil, leading primarily to changes in populations of soil invertebrates as a result of fragmentation of habitats of living organisms. In recreational forests, soil invertebrates are directly impacted, which is mainly expressed in their mechanical destruction and indirectly transforms their ecological niches (reduction of living space and food reserves). In urban forest parks, with increasing recreational pressure, the number, biomass, and diversity of soil invertebrates can differ many times from their original values (Kuznetsov *et al.*, 2017; Kuznetsov and Ryzhova, 2019). A variety of anthropogenic activities suppress the abundance and diversity of soil invertebrate communities. The direction and magnitude of the response depends on the taxonomic group (Nahmani and Lavelle, 2002; Pey *et al.*, 2014; Pouyat *et al.*, 2015; Santorufo *et al.*, 2012). For example, isopods in urban soils show a negative abundance response to heavy metal pollution (Pouyat *et al.*, 2015). Air pollutants and pesticides affect soil properties, which also negatively affects the abundance of invertebrates (Byrne *et al.*, 2008; Fedoniuk *et al.*, 2020; Gan and Wickings, 2017; S. Joimel *et al.*, 2016; Joimel *et al.*, 2017; Peck, 2009; Smetak *et al.*, 2007).

The soil invertebrates respond sensitively to disturbance of soil regimes, so they are valuable biological indicators of the level of anthropogenic transformation of ecosystems (Nahmani and Lavelle, 2002; Santorufo *et al.*, 2012).

Molluscs are an important component of terrestrial ecosystem communities (Kramarenko *et al.*, 2016). Their biological features allow maintaining high diversity and abundance under conditions of anthropogenic impact. These animals are quite common in urban environments. However, hotspots of high abundance and diversity of molluscs are extremely limited by the influence of a variety of environmental factors, a mosaic of which is observed in the urban environment. The habitat preference of terrestrial molluscs depends on vegetation, soil type, moisture level, and the degree of anthropogenic transformation of ecosystems. The preferential importance of environmental factors varies at different levels of the spatial hierarchy. At the broad spatial level, among the climatic factors, temperature and humidity have the greatest influence on terrestrial molluscs. Other climatic factors affect molluscs much less or indirectly, but due to changes in humidity and temperature (Kunakh *et al.*, 2018; Martin and Sommer, 2004b; Millar and Waite, 1999; Pakhomov *et al.*, 2019). At the landscape level, calcium concentration and its dependent pH value are the most significant soil parameters that affect snails (Hotopp, 2002; Schilthuizen *et al.*, 2003). The soil moisture was also found to be a significant factor in the diversity of the terrestrial snail fauna (Čejka and Hamerlík, 2009; Martin and Sommer, 2004a; Silvan *et al.*, 2000). The degree of anthropogenic transformation of an ecosystem can be assessed by studying the diversity of land snail communities and the response of individual species to environmental factors (Douglas *et al.*, 2013). A number of models that best explain the distribution of mollusc species abundance were shown to be species-specific and soil type-specific and tended to be invariant over time (Kunakh *et al.*, 2020; Pakhomov *et al.*, 2019; Zhukov *et al.*, 2016a). Hutchinson's concept was shown to be useful for the simulation of the ecological niche of the mollusc in the biotopes resulting from reclamation of degraded lands (Kunakh *et al.*, 2020; Kunakh *et al.*, 2018; Teluk *et al.*, 2020; Yorkina *et al.*, 2018; Yorkina *et al.*, 2019; Yorkina, 2016; Yorkina *et al.*, 2019).

The aim of this study is to investigate the role of recreation as a factor in transforming the living conditions of soil micromolluscs in a park environment in an urban landscape. The hypothesis is that recreational exposure changes the hierarchical organization of the spatial distribution of micromolluscs.

Materials and Methods

Study area and mollusc sampling

An experimental polygon was laid down in Novooleksandrivskiy Park (Melitopol, Ukraine) that represented 7 transects with 18 test points in each (Figure 1). The interval between points in transect, as well as the interval between transects, was 3 meters. The total area of the polygon was 1,134 m². Sampling was conducted in October 2020. In each sampling point, a soil sample of cylindrical shape (diameter – 9 cm, height – 8 cm, volume \approx 500 cm³) was taken from the surface to a depth of 8 cm. From this sample, 10 soil sub-samples weighing 10 grams were taken. Each sample was examined with a dissecting needle to collect micromolluscs (Yorkina *et al.*, 2018).

Soil variables

Measurement of soil penetration resistance was carried out in the field using a hand penetrometer *Eijkelkamp*, to a depth of 50 cm at intervals of 5 cm (Zhukov and Zadorozhnaya, 2016). The average error of the measurement results of the device is \pm 8%. The measurements were made by a cone with a cross-sectional dimension of 2 cm². Within each measurement point, the soil penetration resistance was made in a single replication. To measure the electrical conductivity (EC) of the soil *in situ*, the sensor HI 76305 was used (Hanna Instruments, Woonsocket, R. I.) (Scoggins and van Iersel, 2006). This sensor works in conjunction with the portable device HI 993310. Soil water content was measured under field conditions using a dielectric digital moisture meter MG-44 (vlagomer.com.ua). The aggregate structure was evaluated in accordance with the 'Soil Sampling and Methods of Analysis' recommendations. The percentage content of such fractions was established: <0.25, 0.25–0.5, 0.5–1, 1–2, 2–3, 3–5, 5–7, 7–10, >10 mm. The soil bulk density estimated by the core method (Al-Shammary *et al.*, 2018).

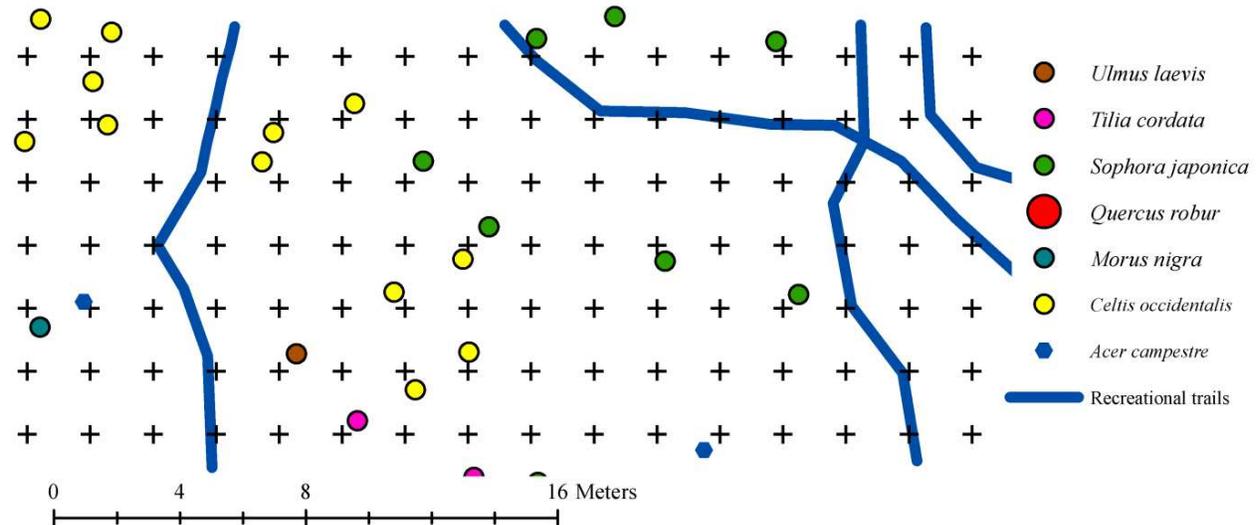


Figure 1: The experimental polygon within Novooleksandrivsky Park (Melitopol): crosses show sampling points; circles show location of the trees and bushes within the polygon; x-axis and y-axis are the local coordinates of the polygon.

Statistical analysis

The Redundancy Analysis (RDA) was applied to examine the variance in the species composition of molluscs (Rao, 1964). The soil penetration resistance, soil electrical conductivity, soil moisture and soil bulk density were logarithmically transformed before analysis. The significance of RDA global model was first tested. The soil models were based on the forward selection and were built with double stopping rule (alpha significance level and the R^2_{adj} calculated using all explanatory variables) (Blanchet *et al.*, 2008). The variables were retained only with a significant relationship to community composition ($p < 0.05$, 9999 permutations). The models' marginal effect was computed, in which each selected soil variable was used separately as a predictor of community composition and the significance of all the models was tested and R^2_{adj} was extracted. The geographic coordinates of sampling locations were used to generate a set of orthogonal eigenvector-based spatial variables (dbMEMs), each of them representing a pattern of particular scale within the extent of the sampling area (Borcard and Legendre, 2002). The forward-selection procedure on partial RDAs was applied to the subset of spatial variables. The significance of soil models was tested by the Monte Carlo permutation test (9999 permutations). In the next phase of the study, the dbMEMs were forward-selected directly on community data to explore patterns in community variation by variance partitioning between environmental and spatial influence. The significance of pure spatial and environmental fractions was tested by Monte Carlo permutation tests with 9999. The scalogram approach was applied to inspect in detail the spatial scaling of community variation. To do this, the two sets of RDA analyses were carried out with each of the dbMEM variables as a predictor. As a response variable, the first set of RDA analyses used raw species data, while the second set used residuals of the environmental model in which forward-selected environmental variables acted as predictors (Chudomelová *et al.*, 2017). From each RDA we extracted R^2_{adj} for individual dbMEMs and plotted them into juxtaposed bar plots (Chang *et al.*, 2013).

All statistical analyses were conducted in R (v. 3.5.0., R Foundation for Statistical Computing, Vienna, AT), using the following packages: *vegan* (v. 2.5-2, <https://CRAN.R-project.org/package=vegan>) (Oksanen *et al.*, 2019), *adespatial* (v. 0.3-2, <https://CRAN.R-project.org/package=adespatial>) for the forward selection and for the generation of spatial filters (Dray *et al.*, 2018).

Results

A total of 787 individuals of *Vallonia pulchella* (Muller 1774), 193 individuals of *Cochlicopa lubrica* (Muller 1774), and 74 individuals of *Acanthinula aculeata* (Muller 1774) were collected. The samples with *Vallonia pulchella* represented 88.9% of all samples, the samples with *Cochlicopa lubrica* represented 81.7% of all samples, and the samples with *Acanthinula aculeata* represented 42.1% of all samples (Figure 1). The maximum number of *Vallonia pulchella* individuals per sample was 24, *Cochlicopa lubrica* – had 7 individuals per sample, and *Acanthinula aculeata* – contained 3 individuals per sample (Figure 2). The abundance of the mollusc was distributed unevenly over the studied area (Figure 3). The aggregation index indicates an aggregated spatial distribution of *Vallonia pulchella* and *Cochlicopa lubrica* and a neutral distribution of *Acanthinula aculeata* (Figure 4).

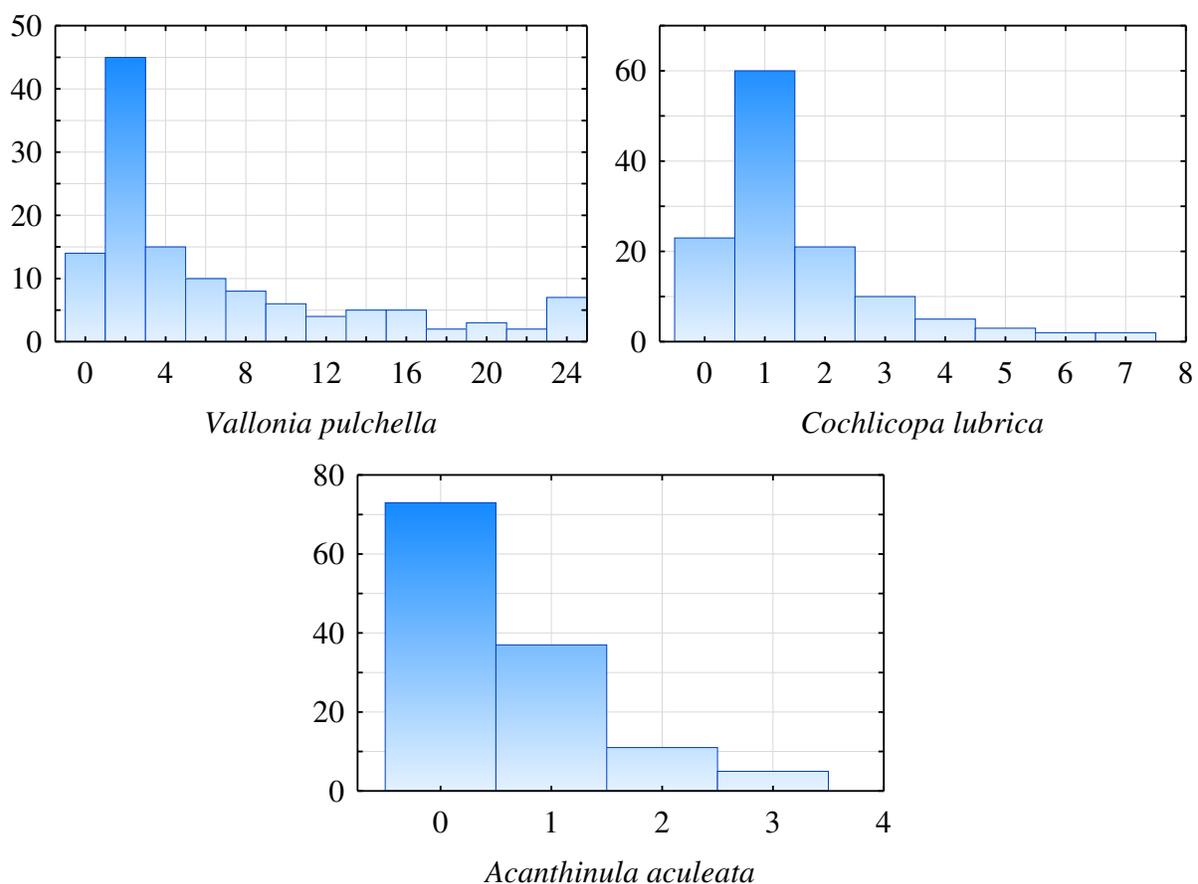


Figure 2: Histograms of mollusc abundance distribution. Abscissa axis – the number of individuals in the soil sample, ordinate axis – the number of occurrences.

The set of soil properties explained 24.7% of the variation in the mollusc community ($F = 2.87$, $p = 0.001$). After the forward selection procedure, such variables as the soil mechanical resistance at a depth of 5–10 cm, the proportion of aggregates of size 0.25–0.5, 2–3, and 3–5 mm were chosen as the most informative for describing the structure of the mollusc community. These soil variables together were able to explain 18.4% of mollusc community variation ($F = 8.12$, $p = 0.001$). The distance from trees was able to explain 6.8% of mollusc community variation ($F = 10.12$, $p = 0.001$). The distance from recreational pathways was able to explain 12.2% of the variation in the mollusc community ($F = 18.4$, $p = 0.001$).

The spatial patterns were modeled by 62 dbMEM spatial eigenfunctions. These dbMEM spatial eigenfunctions were able to explain 54.2% of mollusc community variation ($F = 3.39$, $p = 0.001$). The

forward selection procedure allowed the identification of the 13 most informative dbMEM spatial eigenfunctions, which were variables 1, 2, 3, 6, 9, 10, 11, 14, 23, 26, 34, 53, and 61. Together they were able to explain 27.9% of the variation in the mollusc community ($F = 4.73, p = 0.001$). All of the predictors considered together can explain 65.4% of the variation in the mollusc community (Figure 5). The pure influence of soil properties on molluscs is not significant (1.1%). The influence of soil is spatially structured (11.9%) and also spatially structured by trees (10.9%). The pure influence of spatial factors is 30.1%. The pure influence of trees is 1.5%. Also the influence of trees is manifested through the structuring of the soil properties (2.3%).

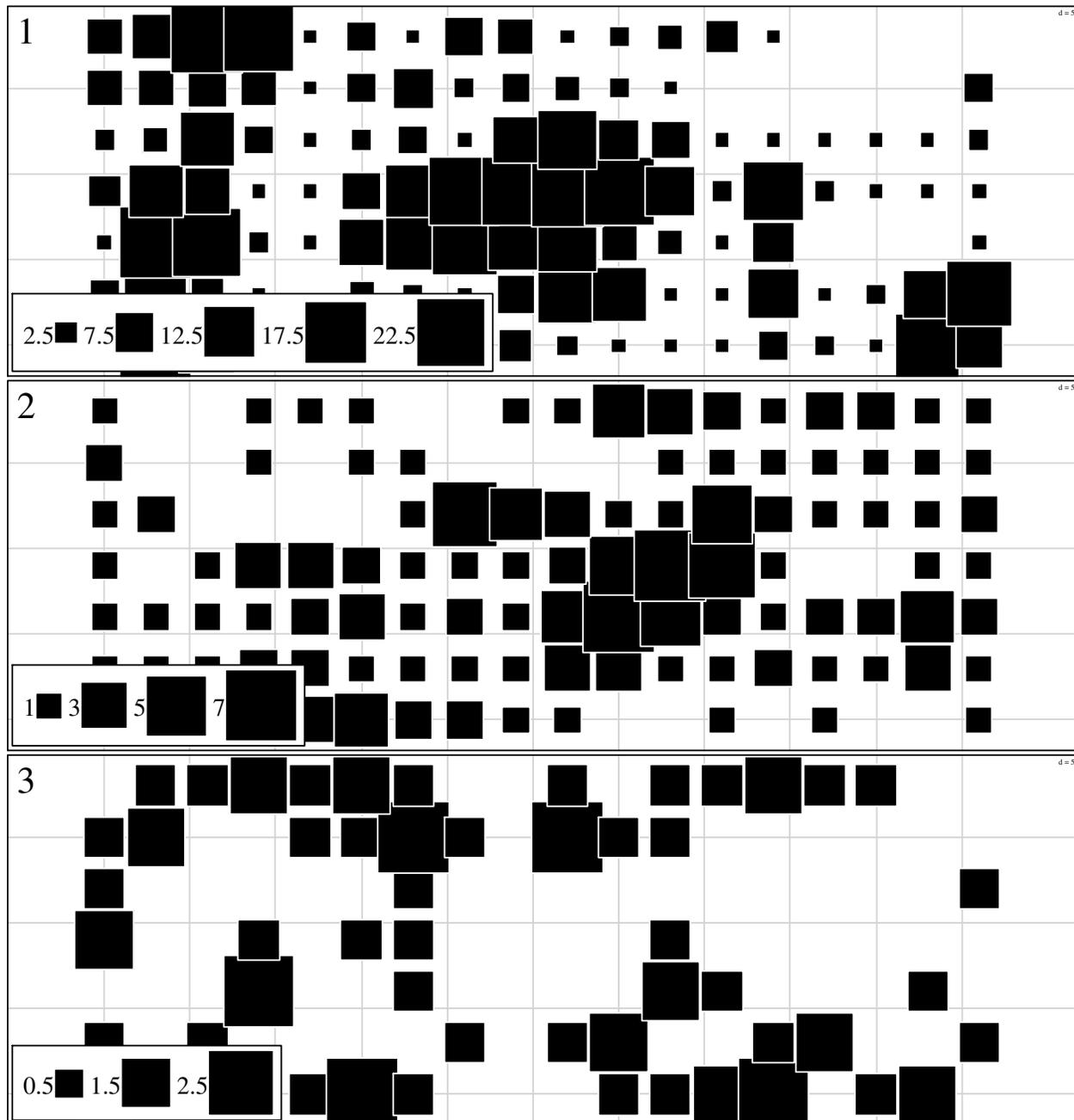
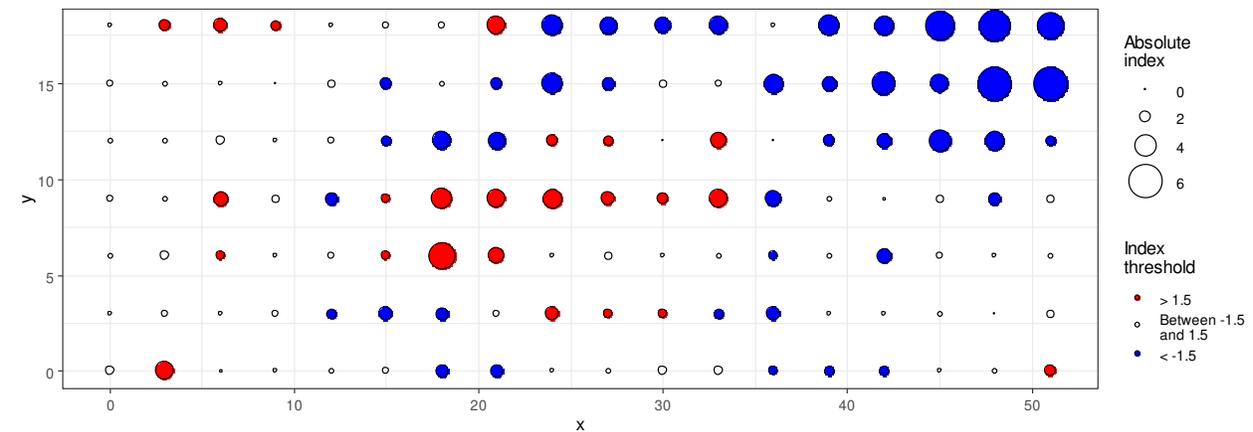


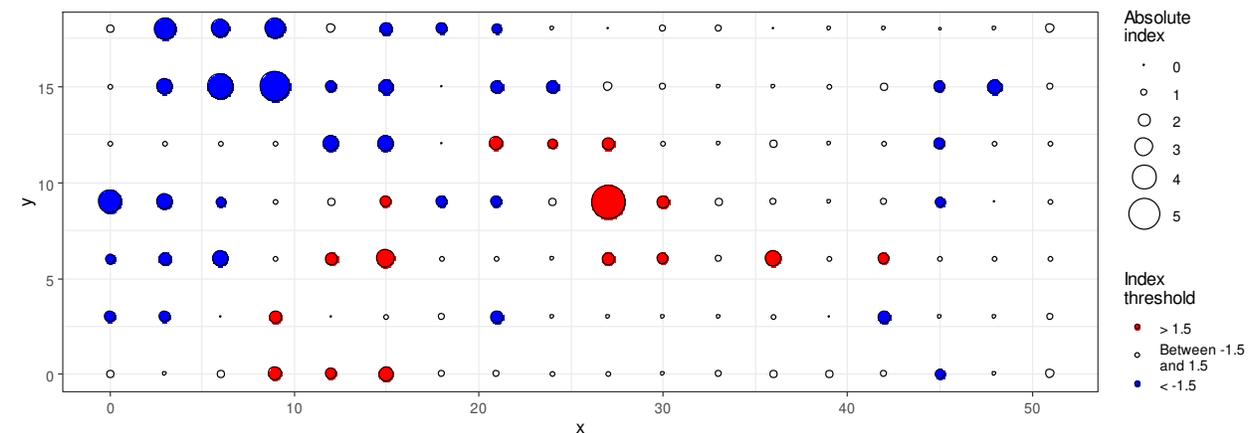
Figure 3: Spatial distribution of molluscs: 1 – *Vallonia pulchella*, 2 – *Cochlicopa lubrica*, 3 – *Acanthinula aculeata*. Axis of abscissa and ordinates are local coordinates.

The role of recreational paths manifests itself through the influence on soil properties (6.4%), through the spatial structuring of soil properties (4.5%) and through the spatial structuring of soil properties under the influence of the tree stand (10.9%).

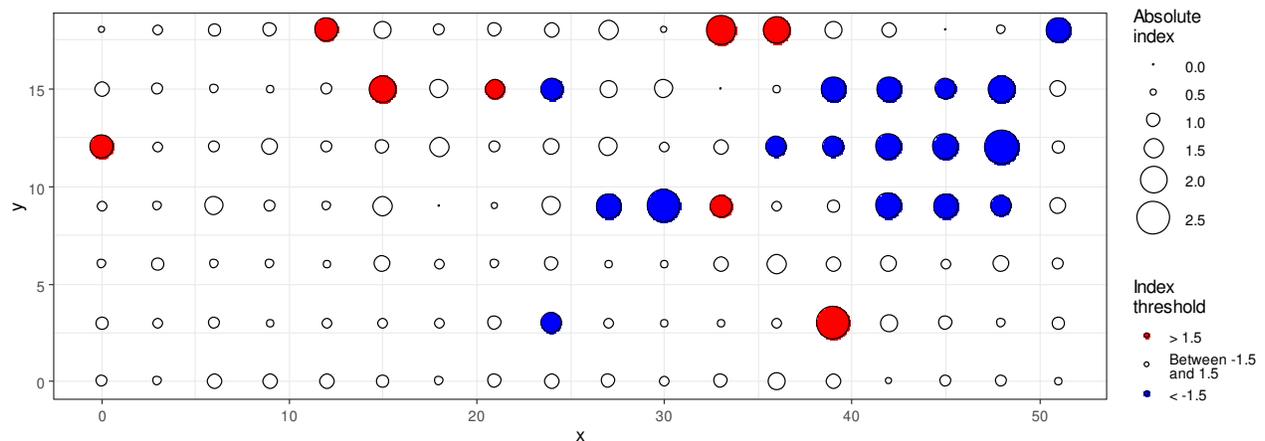
The dbMEM spatial eigenfunctions with different ordinal numbers (the larger the ordinal number, the greater the characteristic frequency of the oscillatory process which the function models) made different contributions to the variation of the mollusc community structure (Figure 6). Accordingly, broad-scale, medium-scale, and fine-scale spatial components of community variation were distinguished. The application of the soil properties as covariates did not significantly alter the nature of the spatial patterns. The distance from recreational trails conditioned the large-scale component. The use of distance from the recreational as a covariate revealed an additional spatial pattern of variability in mollusc community structure. Paths indicated that recreational influence was a source of "disinformation" and its removal allowed previously hidden patterns to be revealed predominantly at the fine-scale range.



A



B



C

Figure 4: Red–blue plots for detecting clusters in mollusc abundance data: A – *Vallonia pulchella* ($I_a = 1.777$, $P_a < 0.001$), B – *Cochlicopa lubrica* ($I_a = 1.365$, $P_a = 0.05$), C – *Acanthinula aculeata* ($I_a = 1.068$, $P_a = 0.28$).

A similar argument can be made for the influence of trees, but this influence had a predominant manifestation in the medium-scale range. The pure spatial pattern of variability in the mollusc community structure had distinct broad-scale and fine-scale components.

The broad-scale pattern of variation in mollusc community structure was modeled using dbMEM spatial eigenfunctions 1, 5, 6, 9, 10, 14, 16, 19. The broad-scale spatial pattern was able to describe 25.3% of the variation in mollusc community structure (Table 1). The medium-scale pattern of variation in mollusc community structure was modeled using dbMEM spatial eigenfunctions 23, 26, 32, 36, 37. The medium-scale spatial pattern described 10.5% of clam community structure variation.

The detailed-scale pattern of variation in mollusc community structure was modeled using dbMEM spatial eigenfunctions 46, 52, 61. The detailed spatial pattern described 4.7% of mollusc community structure variation.

The spatial features of the broad-scale and partly medium-scale patterns were largely driven by soil properties (Figure 7). The broad-scale component was driven by distance from trees and distance from recreational paths. This pattern also reflected variability in soil penetration resistance, aggregate structure, electrical conductivity, moisture, and soil density. The medium-scale pattern had a component that reflected variability in soil aggregate composition and a component that was independent of soil properties. The detailed-scale component reflected variability in the clam community, which was independent of soil properties. The variability of the mollusc community was mainly due to the variability in the abundance of *Cochlicopa lubrica* and *Acanthinula aculeata* (Figure 8).

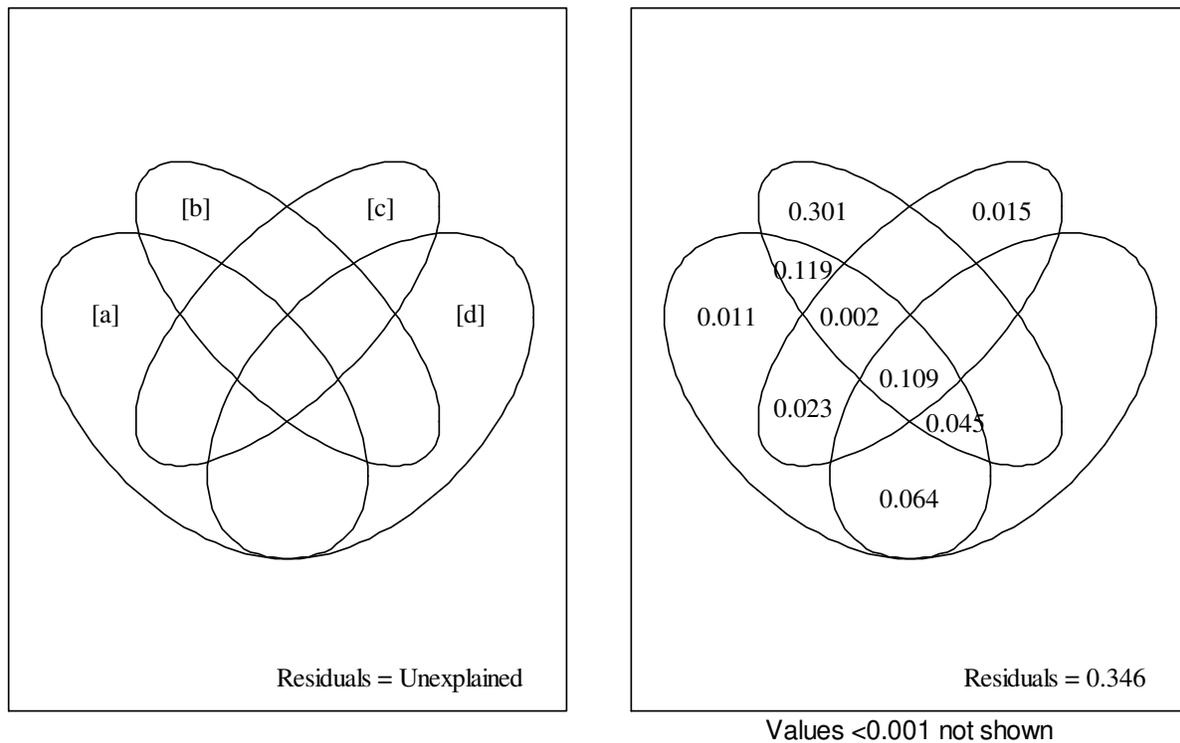


Figure 5: Variance partitioning between spatial, soil, plant and tree distance explanatory variables
 Notes: [a] – variation explained solely by soil variables; [b] – variation captured by spatial (dbMEM) variables corresponds to pure space (residual spatial component); [c] – variation captured by distances from tree stems; [d] – explained solely by distances from tree recreation pathways. The intersection of the ellipses corresponds to the variations explained by the respective sources together. All the variance fractions shown are significant ($p < 0.001$).

Discussion

The ecological factors influencing the distribution of species are usually spatially structured, so the species community also has a spatial structure (Andrushenko and Zhukov, 2016; Pinkina *et al.*, 2019; Thuiller *et al.*, 2004; Zhukov *et al.*, 2015). The micromollusc community in the park plantation in the city of Melitopol is represented by three species, among which *Vallonia pulchella* significantly dominates, *Cochlicopa lubrica* is significantly less abundant and *Acanthinula aculeata* almost 10 times less abundant. Factors such as recreational pressure and spatial location of trees may be responsible for the aggregated distribution of mollusc species (Kunakh *et al.*, 2018). These factors influence patterns of the spatial variability of soil properties, which, in turn, acts as a driver of the micromollusc community structure. An obvious consequence of recreational load is soil compaction. The spatial heterogeneity of soil properties, which are induced by the spatial distribution of plants, is a factor that organizes the spatial distribution of soil animals. In this respect, the tree layer, the structure of the herbaceous and dead cover is important. This transformation leads to a set of other changes in soil properties and regimes.

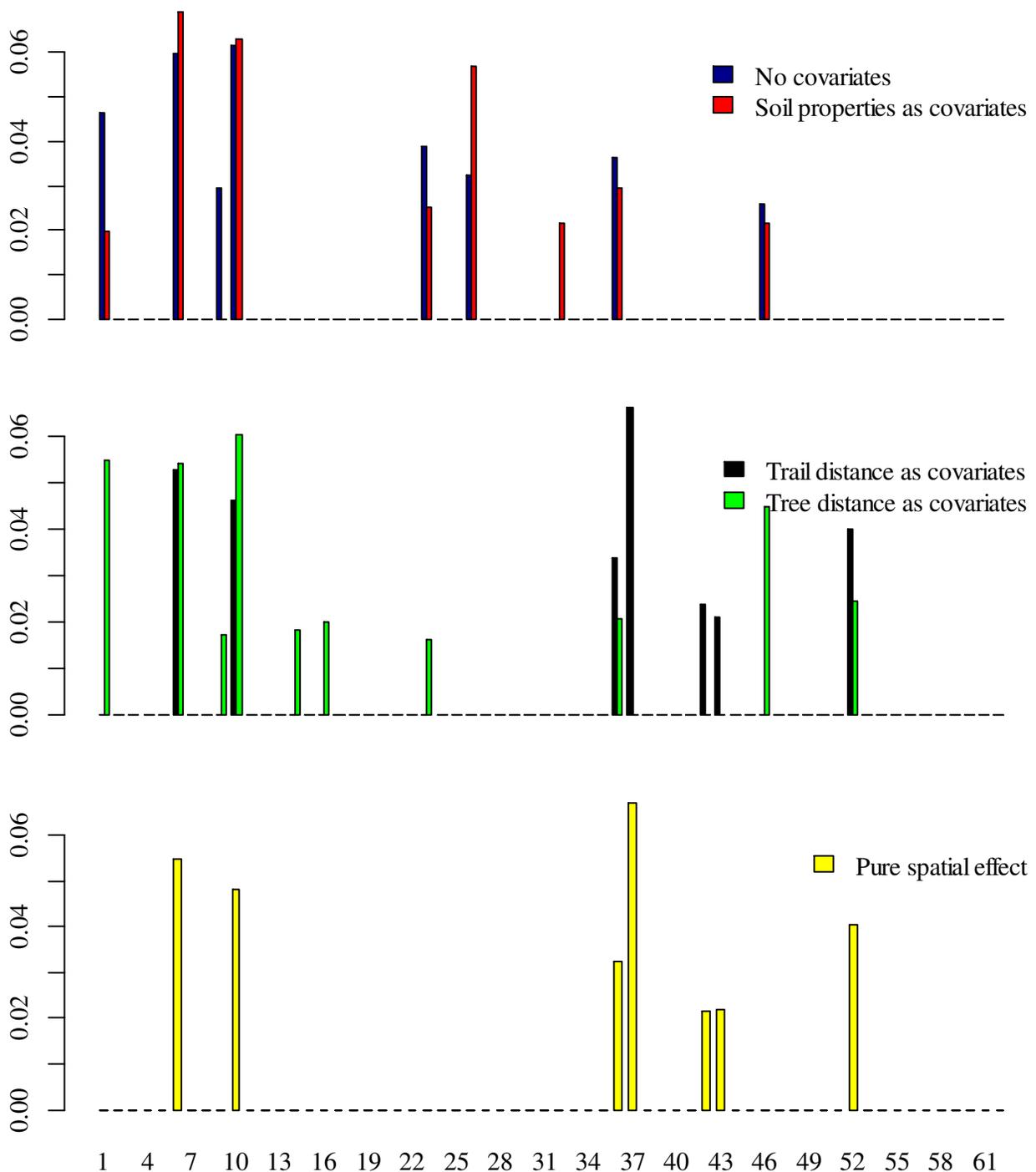


Figure 6: Scalograms illustrating the scaling of spatial structured variation in community data (No variables as covariates, blue bars) and soil models (red bars), residuals of the trail distance models (black bars), tree distance models (green bars) and pure spatial effect (yellow bars). The value of R^2_{adj} is the variation explained by individual dbMEM variables. The dbMEMs are ordered decreasingly according to the scale of spatial patterns they represent (x -axis is the number of dbMEM; dbMEM 1 represents the broadest scale, dbMEM 61 represents the finest scale).

Soil with increased density presents less space for both the storage of soil moisture and the storage of soil air. The available soil water is an important environmental factor for the biota of anthropogenically transformed lands. Obviously, a decrease in the amounts of these two most important soil parameters leads

to a deterioration of the living conditions of soil animals, including micromolluscs. The recreational compaction of soil increases soil penetration resistance mainly in the upper soil horizons, which are predominantly inhabited by soil animals. Soil penetration resistance depends on soil moisture, soil organic matter content, the composition of accumulated cations, the ratio of structural aggregates, and, very noticeably, on the granulometric composition (Bécel *et al.*, 2012; Zhukov, 2015b). All this makes the use of soil penetration resistance in both soil-genetic and agronomic studies promising. From the soil-physical factors influencing soil penetration resistance, the water content of the soil and its energy state should come first (Young *et al.*, 2000). Next from the physical factors are the granulometric composition, density of the composition, structural composition, pore size and the ratio of large and fine pores, and others (Bennie and du Burger, 1988; Bennie and Krynauw, 1985; Quiroga *et al.*, 1999). The factors listed have a decisive influence on the cone strength index and the ability of the soil to compress. The correlation between the clay and sand content of the soil and the change in the so-called cone index value (i.e., soil resistance) due to its wetting was revealed (Arriaga *et al.*, 2011). As one would expect, the soil resistance increases with decreasing soil moisture regardless of the clay-sand ratio. However, such processes in the soil as cementation and crust formation, and dynamics of density of the soil during tillage made adjustments to the established dependencies. In particular, the data collected showed that the cone strength index in soils of different genesis is not the same for the same values of density and moisture. Soils of light granulometric composition as well as well humus-covered, structured, freshly ploughed soils with increasing clay particles in the granulometric fraction have the least penetration resistance.

Increased soil density has a negative effect on the living conditions of higher plants because it limits the development of plant root systems. Living conditions for lower plants, including algae, which are a trophic target for micromolluscs, are also deteriorating (Maamar *et al.*, 2018). Thus, recreation is an essential factor that structures the spatial organization of the community of soil micromolluscs. Molluscs may also be the cause of the spatial heterogeneity of environmental regimes. The substantial contribution of snails to the nitrogen cycle was proved in nitrogen-limited ecosystem which can be a source of spatial heterogeneity of the higher plant production (Jones *et al.*, 1994; Jones and Shachak, 1990). Some terrestrial gastropod communities cause of the changes in the content of the nitrogen and phosphorus in the soil. This result reveals that the spatial and temporal dynamics of plant communities are dependent on the detritivore food chain structure (Thompson *et al.*, 1993).

The aggregates are the main component of the soil structure, which allows to measure its physical state as an environment for living organisms (Kunah *et al.*, 2019). Soil structure affects soil moisture content, infiltration capacity, erodibility, circulation of nutrients, stabilization of organic matter, root penetration, productivity of natural plant communities and crop yields (Bronick and Lal, 2005; Chaplot and Cooper, 2015; Chrenková *et al.*, 2014). The aggregate stability is used as an indicator of the soil structure (Mustafa *et al.*, 2020). The structure and stability of soil aggregates is most important to consider as a condition for increasing agronomic productivity and reducing soil erosion (Xu *et al.*, 2016). Aggregation of soil was studied mainly in agricultural context. The role of tillage, soil texture and the presence of carbon in the agricultural land as factors that influence the aggregate structure was estimated (Wilpiseszki *et al.*, 2019; Zhang *et al.*, 2012). In the process of land reclamation, it is important to select optimal management strategies to create not only the desired vegetation cover, but also to promote the preservation of macro-aggregate structure in soils to improve long-term nutrient supply and physical properties of the soil (Klimkina *et al.*, 2018; Wick *et al.*, 2009, 2016). Aggregation processes in soil are the result of interaction of a number of physical, chemical and biological factors with the complex feedback mechanisms (Oades and Waters, 1991; Rivera and Bonilla, 2020; Sodhi *et al.*, 2009). The soil aggregation is considered as a process regulated by the biota (Duchicela *et al.*, 2013; Rillig and Mummey, 2006; Tisdall and Oades, 1982). In soils where organic matter is a major aggregate binding agent, a link can be established between aggregate size distribution and soil's biological functions. The role of biodiversity in soil aggregation is of particular interest (Delgado-Baquerizo *et al.*, 2017; Wagg *et al.*, 2014). There are different mechanisms of soil biota influencing the aggregation of soil (Lehmann and Kleber, 2015). Bacteria are known to be able to synthesize a biopolymer that acts as a binder to form aggregates (Deng *et al.*, 2015), and the mushroom mycelium can

entangle the soil particles to keep them together (Griffiths, 1965). The earthworms, insect larvae and other large soil animals may stabilize the aggregate structure (Bertrand *et al.*, 2015; Fonte *et al.*, 2007; Mummey *et al.*, 2006; Zhukov *et al.*, 2016b). Soil saprophages consume the soil and mix it with the intestinal contents (Maraun *et al.*, 2003; Ponge, 1991). After digestion, the resulting mixture takes the form of a highly structured formation such as casts or coprolites (Tisdall and Oades, 1982).

Table 1: Descriptive statistics of the soil properties and distances from the trees and from the route trails

Variables	Mean± st.error	Broad-scale, $R_{adj}^2 = 0.25$		Medium-scale, $R_{adj}^2 = 0.11$		Fine-scale, $R_{adj}^2 = 0.05$	
		CCA1 $F =$ 39.3, $p =$ 0.001	CCA2 $F = 15.1,$ $p = 0.024$	CCA1 $F = 18.0,$ $p = 0.001$	CCA2 $F = 2.1,$ $p = 0.818$	CCA1 $F = 8.8,$ $p = 0.003$	CCA2 $F = 0.38,$ $p = 0.943$
Soil penetration resistance at a depth of, cm in MPa							
0–5	2.97±0.09	0.35	0.22	–	–	–	–
5–10	4.72±0.12	0.35	0.20	–	–	–	–
10–15	6.10±0.14	0.35	0.21	–	–	–	–
15–20	6.93±0.14	0.27	–	–	–	–	–
20–25	7.67±0.12	–	0.21	–	–	–	–
25–30	8.19±0.11	–	–	–	–	–	–
30–35	8.35±0.08	–	–	–	–	–	–
35–40	8.66±0.08	–	–	–	–	–	–
40–45	8.48±0.09	–	–	–	–	–	–
45–50	8.17±0.09	–	–	–	–	–	–
Aggregate fraction, in %							
>10 mm	11.25±0.37	–	–	–0.38	–	–	–
7–10 mm	7.23±0.09	–	–	–0.41	–	–	–
5–7 mm	8.08±0.12	–0.30	–0.19	–	–	–	–
3–5 mm	10.68±0.17	–0.40	–	–	–	–	–
2–3 mm	9.58±0.18	–0.32	–	0.21	–	–	–
1–2 mm	13.18±0.25	–	–	–	–	–	–
0.5–1 mm	2.45±0.04	–	–	–	–	–	–
0.25–0.5 mm	12.59±0.26	0.24	–	–	–	–	–
<0.25 mm	25.00±0.40	0.23	–	0.27	–	–	–
Other soil properties							
Electrical conductivity, dSm/m	0.07±0.001	–0.19	–	–	–	–	–
Soil moisture, %	9.31±0.10	–0.19	–0.18	–	–	–	–
Soil bulk density, g/cm ³	1.10±0.01	0.34	0.19	–	–	–	–
Distance, m							
From the trees	2.54±0.15	0.24	0.24	–	–	–	–
From the route trails	3.25±0.22	–0.41	–	–	–	–	–

The spatial variation of soil aggregate structure can influence the organization of the soil macrofauna community. The soil aggregates also help form the unique ecological isolation of the microbial community in the soil (Rillig *et al.*, 2017). Soil aggregates can serve as a refuge for the microbes from the predators (Rillig *et al.*, 2017). There are practically no research highlighting influence of the soil aggregate structures on the functional features of the mollusc populations. It is possible, that the organic substances in the soils indirectly impact on the molluscs, which requires the deep understanding of the structure and formation of the aggregates. The aggregate composition of the soil also changes in accordance with the changes in the soil density. More solid soils are represented either by relatively coarse aggregates larger than 10 mm or by fine aggregates that effectively fill in the gaps between the coarse ones. An optimal water and air regime of soils can be maintained with aggregates between 0.25 and 7 mm in size. The results of this study indicate a positive effect on micromolluscs of increasing the proportion of aggregates of 0.25–5 mm size.

Trees are also an important factor that structures ecological conditions (Zhukov, 2015a; Zhukov *et al.*, 2016). The crown of trees regulates the inflow of solar energy to the soil surface, which determines the temperature regime of the soil and the intensity of moisture evaporation from the soil surface. The root system of trees has a significant capacity to change soil properties. It should be noted that trees and recreational paths are antagonists: spontaneous paths are formed at some distance from the trunks of tree plants. Thus, a structuring gradient is formed: recreational pathway-tree plants.

This gradient determines the broad-scale component of the spatial variability of the molluscan community. The broad-scale nature implies a significant impact zone in the radial direction from the trees, which is quite consistent, as commensurate with the spatial distribution of above-ground and below-ground phytomass of the tree plant. Also widespread is the impact of recreational load, which is not trivial. This result indicates that the effects of recreational load extend well beyond the geometric boundaries of recreational pathways. In part, the widespread nature may be due to the antagonism of trees and walkways and may be a consequence of the structuring influence of the park stand. Nevertheless, the direct impact of recreation is a significant structuring factor that has a significant extent that extends well beyond the footpaths. There is a consistent widespread pattern of recovery of normal values of soil density, moisture, and aggregate composition as one moves away from the walkways. Such changes are also associated with the recovery of micromollusc abundance; and sharp decrease was noted for all species near the walkway.

Medium-scale patterns of variation in the mollusc community are due to either soil conditions, which primarily depend on soil aggregate composition, or to causes that do not depend on measured soil properties. In turn, it may be due to either other soil properties that are not measured or to causes that are neutral in nature. Medium-scale patterns that are dependent on soil properties may most likely result from natural variability in soil properties, which is determined by mechanisms other than recreational load. Thus, natural and anthropogenic patterns have different scale levels of manifestation. Anthropogenic patterns are broad-scale, while natural patterns are both broad-scale and medium-scale. The fine-scale patterns are independent of measured soil properties. The fine-scale patterns can either be caused by other soil properties that were not measured in this study. The most attractive explanation is the structuring of the community as a result of inter-species interactions. For this reason, the emergence of the structural organization of the community may not have a significant extent in view of the local nature of inter-specific interactions, which probably explains its detailed nature.

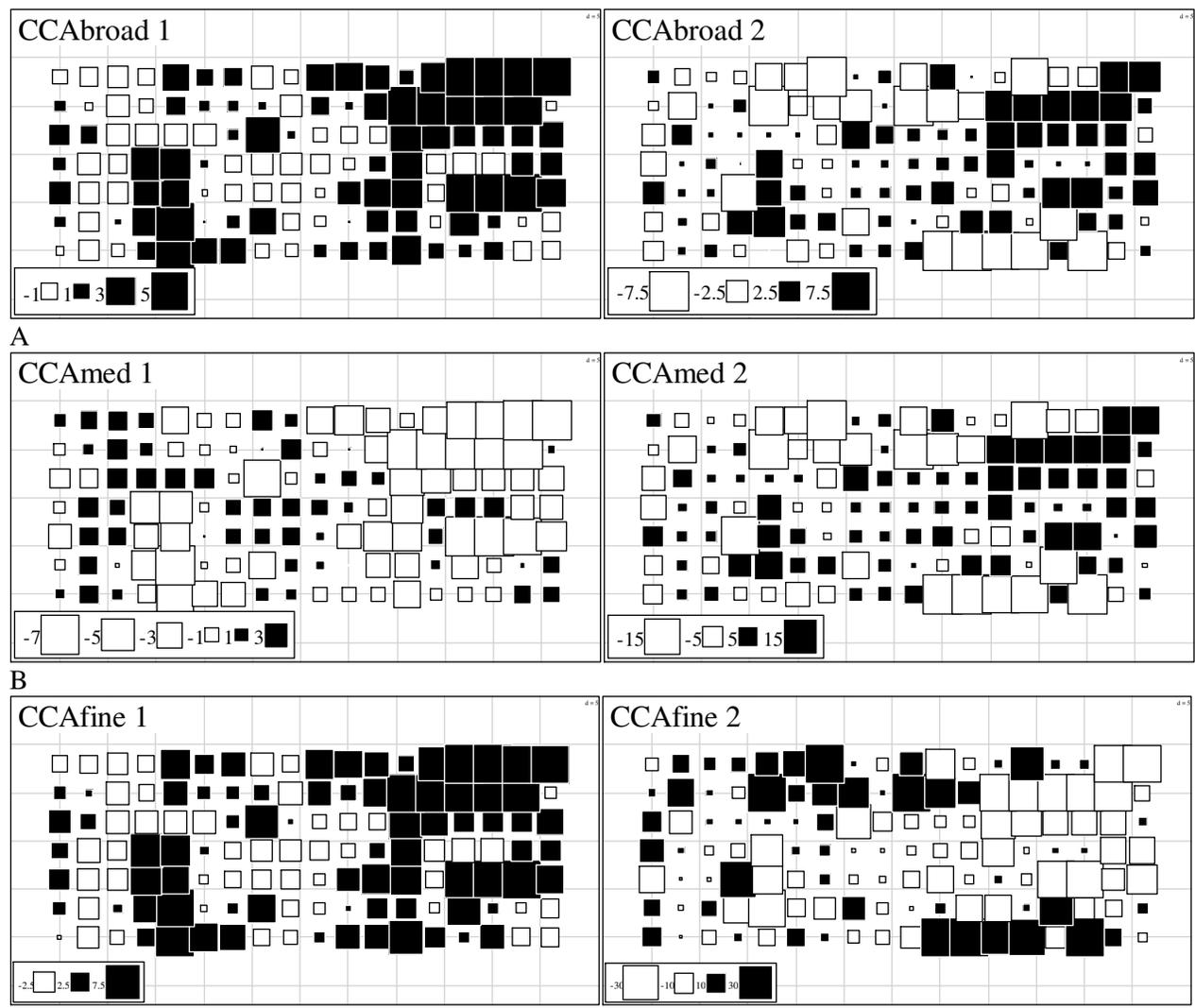


Figure 7: Variation of broad-scale (A), medium-scale (B), and fine-scale (C) components of spatial variability in the mollusc community.

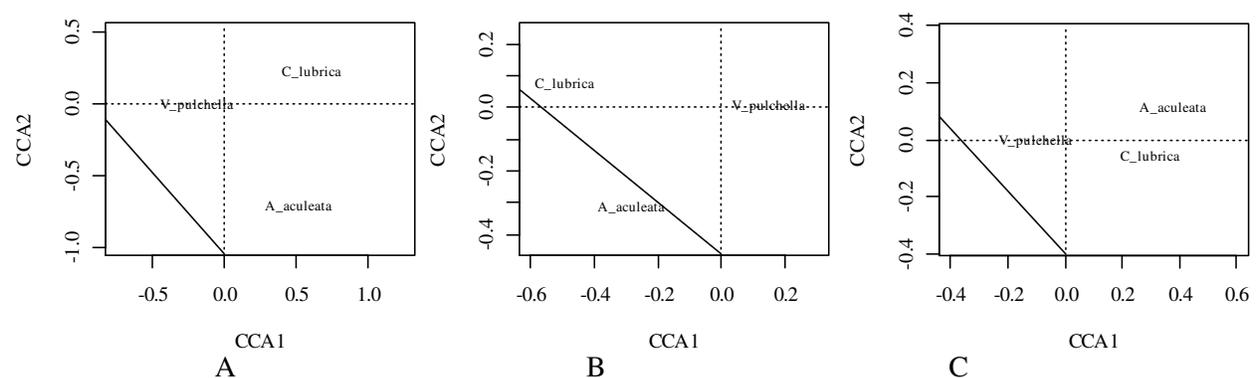


Figure 8: Species correlation with the broad-scale (A), medium-scale (B), and fine-scale (C) components of spatial variability in the mollusc community.

Conclusion

In the soils of the urban park, micromolluscs are represented by three species with a relatively high abundance. The micromolluscs are sensitive biological indicators of soil conditions and the direction of their transformation under the influence of recreation. The spatial variability of the micromollusc community has a hierarchical organization and is represented by the broad-scale, medium-scale, and fine-scale components. The key drivers of the broad-scale component are spatial location of trees and recreational load. The influence of recreation extends well beyond the geometric boundaries of recreational paths. The medium-scale component correlates with the spatial organization of soil aggregate structure and reflects the natural variability of soil properties. The fine-scale component of the spatial variation of the molluscan community is independent of the measured soil properties and is most likely the result of the structuring influence of inter-specific interactions.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	Author 1	Author 2	Author 3	Author 4	Author 5
Conceived and designed the research or analysis	Yes	Yes	Yes	Yes	Yes
Collected the data	Yes	Yes	Yes	Yes	Yes
Contributed to data analysis & interpretation	Yes	Yes	Yes	Yes	Yes
Wrote the article/paper	Yes	Yes	Yes	Yes	Yes
Critical revision of the article/paper	Yes	Yes	No	No	Yes
Editing of the article/paper	Yes	No	No	No	No
Supervision	Yes	No	No	No	No
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