Spatial distribution of micromollusks under the impact of recreation

O Kunakh\textsuperscript{1}, A Umerova\textsuperscript{2} and E Degtyarenko\textsuperscript{3}

\textsuperscript{1} Oles Honchar Dnipro National University, 72 Gagarin Av., Dnipro, 49000, Ukraine
\textsuperscript{2} Bogdan Khmelnitsky Melitopol State Pedagogical University, 20 Hetmanska Str., Melitopol, 72300, Ukraine
\textsuperscript{3} National University of Life and Environmental Sciences of Ukraine, 19 Henerala Rodimtseva Str., Kyiv, 03041, Ukraine

E-mail: kunah\textunderscore olga@ukr.net

Abstract. Anthropogenic impacts lead to a decrease in the abundance and diversity of communities of living organisms. The rate of recovery of populations is inversely proportional to size: the smaller the size, the greater the potential for population recovery after negative impact. Therefore, under conditions of extremely high levels of anthropogenic impact, small-sized animals are a reliable source of ecosystem state. The aim of the work is to: 1) to evaluate rates of the micromollusc \textit{Vallonia pulchella} (Müller, 1774) abundance in ecosystems that are subject to extremely high levels of recreational pressure; 2) to identify factors that influence the spatial patterns of soil micromollusks; and 3) to investigate the possibility of using micromollusks for the purposes of bioindication of recreational pressure. The soil sampling was performed on a regular grid with recording of local coordinates. The micromollusks were extracted from the soil samples by hand sorting. Physical properties of soil sensitive to recreational load were also measured. Micromollusks were found to exhibit a non-linear response to recreational impact. The maximum abundance of animals is observed at a certain distance from recreational trails. This distance is specific for different species of micromollusks. Micromollusks have high population abundance even under conditions of high recreational load. The regular spatial patterns of these animals are caused by changes in the soil habitat, which are induced by recreational load. This circumstance allows to consider micromollusks as a reliable indicator of the level of recreational load.

1. Introduction

Sustainable environmental solutions require discussion on a wide range of urban ecology issues [1]. Cities are home to the majority of the world’s population and concentrate enormous flows of matter and energy. The biota that exist in urban environments are under the significant anthropogenic pressure, yet continue to perform important ecological functions. Management, including environmental management, must be based on the quantitative indicators of the state of the managed object. In this regard, the bioindication is a source of ecologically relevant information that is the basis for the development of environmental protection strategies. The methods and principles of biological indication of ecological regimes in natural conditions have been developed over a long period of time and have shown their effectiveness. Under conditions of anthropogenic impact, many ecological relationships undergo significant transformation, so methodological approaches that are relevant for natural conditions cannot be extended to
anthropogenic conditions without additional adaptation. Anthropogenic factors occur within a background of the natural gradients, forming a complex mosaic of ecological regimes in the urban environment. Soil moisture, precipitation, wind speed, atmospheric temperature, atmospheric humidity and atmospheric pressure have been shown to be informatively important predictors of the ecological niche of terrestrial invertebrates of anthropogenically transformed ecosystems [2, 3]. The moisture content of technosols is the most important factor determining the temporal dynamics of the terrestrial invertebrate community under semi-arid climate and reclamation-formed ecosystem conditions [4, 5]. The response of species to soil water content is influenced not only by soil water content, but also by a complex of other environmental, temporal and spatial factors [6].

Urbanization takes many forms and recreational load is an important aspect of anthropogenic influence in the urban environment [7]. An important aspect of anthropogenic transformation in the urban environment is recreation. Urbanization affects environmental factors that are essential for terrestrial molluscs. Terrestrial gastropods, especially snails, can be used as the potential bioindicator organisms for assessing the environmental quality and thus for predicting the potential hazards to human health [8]. Hemeroby is a degree of deviation of ecological conditions from the natural state [9]. This deviation can result from the various anthropogenic influences, including recreation [10]. Recreational load leads to soil compaction, which causes negative trends for the urban environment. Topography and tree stand densities influence the spatial variation of soil penetration resistance [11] and soil electrical conductivity [11] in an urban park. The recreational impacts in the form of spontaneous pathways significantly alter the soil properties in the artificial park spaces. The zone of influence of this transformation was shown to be significantly larger than the visible edges of the pathways [12]. The main tendencies of transformation are the increase of penetration resistance and soil density, deterioration of the air and water regime, and negative changes in the aggregate structure of the soil [13]. This transformation affects the living conditions of soil micromolluscs [14]. Their abundance and diversity is significantly higher in undisturbed conditions. Living conditions deteriorate when approaching pathways, leading to a sharp decrease in micromollusc abundance. The micromollusc Vallonia pulchella (Müller, 1774) was sensitive to recreational pressure [15].

Hemeroby is a comprehensive indicator for measuring human impacts on ecological systems. Hemeroby have a complex nature and a variety of mechanisms for impact on ecosystems. Under natural forest conditions, tree placement leads to multiscale spatial structuring and is important in shaping the spatial patterns of soil macrofauna [16,17]. The vegetation ecological factors are more important for the broad-scale component, edaphic factors for the medium-scale component, and both vegetation and edaphic factors for the fine-scale component [18]. For litter-dwelling animals the most typical spatial patterns occur at the broad-scale and medium-scale levels. For endogeic and anecic animals, the most significant variability is observed at the fine-scale level [19, 20]. The role of the hemeroby gradient was shown to structure the soil macrofauna community. Species of soil macrofauna differed in their optimum and specialization to the hemeroby factor. A regular change in the abundance and diversity of the soil macrofauna community in the gradient of hemeroby was recorded [21]. Soil macrofauna is a bioindicator of urban soil contamination with heavy metals [22].

Anthropogenic disturbances have a central importance in forming the species diversity and community structure of terrestrial snails [23]. The mechanical resistance of the soil, the size distribution of aggregates, the electrical conductivity of the soil, the physiological characteristics of the vegetation and the Didukh phytoindication scale were used as ecogeographic predictors of the ecological niche properties of Brephulopsis cylindric molluscs. The ecological niche of the mollusc is determined by both edaphic factors and ecological features of the vegetation [24]. The ecological niche of the micromollusk Vallonia pulchella in reclaimed soils was found to be determined by both edaphic factors and ecological features of the vegetation. The optima
of the ecological niche were represented by integral variables such as the axes of marginality and specialization, which exhibit regular patterns of geographical space [25]. Morphometric data from molluscs are widely used to estimate intraspecific and inter-population variability as well as for bioindication and environmental assessment. The vegetation type and humidity was shown to influence the variation in shell shape of *Chondrula tridens* [26]. Shell shape also changes according to the level of anthropogenic pressure [27].

2. Research aim and objectives
Snails are organisms with a low dispersal capacity, so they have no ability to escape negative impacts and are very susceptible to anthropogenic activities. Micromolluscs (<5 mm in diameter) are very sensitive to disturbance due to their very restricted mobility and dispersal ability, and their high dependence on microenvironmental conditions [28]. This suggests to consider the micromolluscs as potentially useful indicators for assessing the impact of recreation [29].

The aim of our work was therefore to solve two tasks:

(i) to evaluate rates of the micromollusc *Vallonia pulchella* (Müller, 1774) abundance in ecosystems that are subject to extremely high levels of recreational pressure;
(ii) to identify factors that influence the spatial patterns of soil micromollusks;
(iii) to investigate the possibility of using micromollusks for the purposes of bioindication of recreational pressure.

3. Material and methods

3.1. Study area
The research was conducted within two polygons, which were located in Novooleksandrivski Park (Melitopol, Ukraine) [15]. Each polygon consisted of 7 transects with 15 sampling points each. The spacing between the points in the transect, like the spacing between the transects, was 3 metres. The total area of the polygons was 1134 m$^2$. The tree stand in the park plantation was represented by *Quercus robur*, *Sophora japonica*, and *Acer campestre*. Shrubs were represented by *Ulmus laevis*, *Tilia cordata*, *Celtis occidentalis* and *Morus nigra*.

3.2. Mollusc collection
The sampling was conducted in October 2020 (in one polygon only) and in May 2021 (in two polygons). At each sampling point, a cylindrical shaped soil sample (9 cm diameter, 8 cm height, volume ≈ 500 cm$^3$) was collected from the soil surface to a depth of 8 cm. From this sample 10 sub-samples of 10 grams of soil were taken. Each sub-sample was examined with the help of a dissecting needle to extract micromolluscs [25].

3.3. Soil properties measurement
The soil penetration resistance was measured in the field using the Eijkelkamp manual penetrometer, to a depth of 50 cm at 5 cm intervals. The average error of the measurement results of the device is ± 8%. The measurements were made with a cone with a cross section of 1 cm$^2$. At each measurement point, the soil penetration resistance was performed in only one replication. The soil aggregate fractions size distribution was determined in accordance with the Soil Sampling and Methods of Analysis recommendations [30]. To measure the electrical conductivity of soil in situ the HI 76305 sensor (Hanna Instruments, Woodsocket, R. I.), working in conjunction with the portable instrument HI 993310 were used. The tester estimates the total electrical conductivity of the soil, i.e. combined conductivity of soil air, water and particles [25]. Soil moisture was measured under field conditions using a dielectric digital moisture meter MG-44 (vlagomer.com.ua). The core method was used for measurement of the soil bulk density [31].
3.4. Statistical analysis
The descriptive statistics were calculated using the program Statistica (Statsoft). Huisman-Olff-Fresco (HOF) [32] models were used to explain the responses of species to environmental gradients. Huisman-Olff-Fresco (HOF) models allow to achieve a statistical correctness, flexibility and possibility of ecological interpretation for modeling the responses of species to environmental gradients [33]. They were first developed by Huisman et al. [32] as a set of the five hierarchical models with an increasing complexity. The following types of models were identified: no response (I), increasing or decreasing response without (II) or with (III) a plateau, and asymmetric (IV) and symmetric (IV) unimodal responses. This list of models was extended to include seven ecological models [34]. In addition to the five model types mentioned above, bimodal asymmetric (VI) and symmetric (VII) response forms were included to deal with species that are constrained to the extreme gradient values due to competition. The parameters of the ecological niche of species can be calculated from the models and be used for further analysis [33]. To improve simulation results, model selection stability was tested using bootstrapping (100 samples, default package setting) to ensure model robustness, and using Akaike’s information criterion corrected for small data sets (AICc, default setting) [35]. Where the two procedures differed in choosing the best type of model, the bootstrapping model was preferred [33]. The Huisman-Olff-Fresco models were computed using the statistical program R (v. 3.6.3; R Developmental Core Team) [36], with the package “eHOF” (version 1.9) [34].

4. Results
The abundance of Vallonia pulchella (Müller, 1774) was higher in autumn than in spring (Planned comparison $t = -5.19$, $p < 0.001$) (table 1). Polygons I and II had no statistically significant difference in mollusc abundance (Planned comparison $t = 0.13$, $p = 0.90$).

| Polygon          | Mean±st.error | Median | Q1  | Q3  |
|------------------|---------------|--------|-----|-----|
| I (Spring 2021)  | 2818±262      | 1096   | 1644| 3836|
| II (Spring 2021) | 2732±278      | 1041   | 1562| 2603|
| I (Autumn 2020)  | 5215±367      | 1129   | 4516| 8468|

The aggregate structure of the soils in the different polygons and at different times exhibited a certain level of similarity. The structure was dominated by the size fractions $> 10$ mm, 1–2 mm, and $< 0.25$ mm (figure 1). In autumn the proportion of fractions $< 0.25$, 0.25–0.5, and 0.5–1.0 mm increased significantly while the larger fractions decreased. In autumn, the soil water content was significantly lower than in spring (Planned comparison $t = 32.2$, $p < 0.001$), which explains the decreased pore volume of soil occupied by air in spring (Planned comparison $t = -15.3$, $p < 0.001$) and the greater electrical conductivity of soil (Planned comparison $t = 16.6$, $p < 0.001$) (figure 2). The soil bulk density was slightly higher in autumn than in spring (Planned comparison $t = -6.2$, $p < 0.001$). The differences between polygons in spring were statistically significant only for the moisture content (Planned comparison $t = -6.6$, $p < 0.001$) and the soil bulk density (Planned comparison $t = 4.6$, $p < 0.001$). The spring differences in soil volume occupied by air and soil electrical conductivity were not statistically significant (Planned comparison $t = -0.4$, $p = 0.67$ and $t = -1.7$, $p = 0.09$ respectively). The profile distribution of soil penetration resistance in autumn was characterised by a sharper increase in layers 5–10, ..., 30–40 cm than that observed in spring (figure 3).
The soil predictors and distance from the walkways and trees were able to explain 23–83% of the variation in the proportions of aggregate fractions (table 2).

**Table 2.** General linear model of dependence of proportions of aggregate fractions on soil properties and distance from trees and walkways (beta regression coefficients ± st.error).

| Predictors | Fraction size, mm ($R_{adj}^2$) | 0.56 | 0.23 | 0.62 | 0.63 | 0.63 | 0.51 | 0.51 | 0.46 | 0.83 |
|------------|---------------------------------|------|------|------|------|------|------|------|------|------|
| 0-5        | -                               | -    | -    | -    | -    | -    | -    | -    | -    | -    |
| 5-10       | -                               | -    | -    | -    | -    | -    | -    | -    | -    | -    |
| 10-15      | -                               | -    | -    | -    | -    | -    | -    | -    | -    | -    |
| 15-20      | -                               | -    | -    | -    | -    | -    | -    | -    | -    | -    |
| 20-25      | -                               | -    | -    | -    | -    | -    | -    | -    | -    | -    |
| 25-30      | -                               | -    | -    | -    | -    | -    | -    | -    | -    | -    |
| 30-35      | -                               | -    | -    | -    | -    | -    | -    | -    | -    | -    |
| 35-40      | -                               | -    | -    | -    | -    | -    | -    | -    | -    | -    |
| 40-45      | -                               | -    | -    | -    | -    | -    | -    | -    | -    | -    |
| 45-50      | 1.6 ± 0.35                     | 0.5 ± 0.26 | - | - | - | - | - | - | 0.8 ± 0.28 | - | 1.0 ± 0.15 |
| 50-55      | -1.3 ± 0.40 – 1.4 ± 0.45       | -    | -    | -    | -    | -    | -    | -    | -    | -    |
| 55-60      | 1.2 ± 0.39                     | -    | -    | -    | -    | -0.7 ± 0.33 – 0.8 ± 0.34 | - | - | - | - |
| 60-65      | 1.5 ± 0.50, 0.9 ± 0.39         | 1.4 ± 0.3 | 1.2 ± 0.38 | - | - | -3 ± 0.40 | - | - | -1.3 ± 0.21 |
| 65-70      | -1.6 ± 0.52                    | -    | -    | -    | -    | -1.4 ± 0.40 | - | - | -1.5 ± 0.4 | 1.0 ± 0.22 |
| 70-75      | -0.8 ± 0.40, 0.9 ± 0.45        | -    | -    | -    | -    | -    | - | - | -0.9 ± 0.19 |
| 75-80      | -                               | -    | -    | 0.8 ± 0.38 | - | 0.8 ± 0.40, 0.9 ± 0.42 | - | - | - |
| 80-85      | -                               | -    | -    | -    | -    | -    | - | - | 0.8 ± 0.18 |
| 85-90      | -                               | -    | -    | -    | -    | -    | - | - | - |
| 90-95      | -                               | -    | -    | -    | -    | -    | - | - | - |
| 95-100     | -2.2 ± 1.1                     | -    | -    | -    | -    | -    | - | - | - |

Soil properties

| Wetness | - | - | - | - | - | - | - | - | - | -2 ± 0.05 |
| Density | 0.3 ± 0.07 | - | 0.2 ± 0.06 – 0.2 ± 0.06 – 0.2 ± 0.06 – 0.3 ± 0.06 | - | 0.2 ± 0.06 | 0.1 ± 0.03 |

Distance

| Trail | - | - | - | - | - | - | - | - | - | - |
| lTrail² | - | - | - | - | - | 0.4 ± 0.15 | - | - | - | 0.4 ± 0.15 | - | - |
| Tree | - | -0.2 ± 0.07 | - | - | - | -0.2 ± 0.06, 0.2 ± 0.06, 0.2 ± 0.06 | - | - | -0.2 ± 0.06, 0.2 ± 0.06 | - | - |

Polygon*

| 1 | 0.9 ± 0.14 | 0.4 ± 0.15 | - | - | -0.3 ± 0.12 | - | -0.8 ± 0.12 | - | -0.6 ± 0.07 |
| 2 | 0.4 ± 0.15 | 0.3 ± 0.16 | - | - | - | - | -9 ± 0.13 | - | -0.3 ± 0.07 |

* Polygon I (Autumn 2020) is the reference polygon against which the influence of other polygons is evaluated: a positive coefficient indicates that the compared polygon exceeds the reference polygon by this parameter; a negative coefficient indicates the opposite.

An increase in moisture content led to a decrease in the proportion of aggregate fractions of <0.25 mm. A change in soil bulk density affected the proportion of all fractions. The increase in soil bulk density was associated with an increase in aggregate fractions sized >10 mm and less than 0.5 mm and a decrease in fractions sized 1 to 7 mm. The effect of distance from walkways was nonlinear for fractions <0.25, 0.25–0.5, and 2–3 mm. At distances of 1–4 m from the walkway, a local maximum of <0.25 and 0.25–0.5 mm fractions was observed.
At a distance of 2–8 m, a local minimum of 2–3 mm fractions was observed. The proportion of 1–2 and 3–5 mm fractions decreased monotonically with the distance from the walkway. As the distance from the trees increased, the proportion of fractions sized 0.25–0.5, 1–2, and 7–10 mm decreased and the proportion of < 0.25 and 0.5–1 mm fractions increased. The aggregate structure in the 0–5 cm soil layer correlated with the variation in soil properties in the soil column.

The soil penetration resistance negatively affected the abundance of *V. pulchella* (figure 4). The limiting effect of soil compactness manifested itself from maximum values up to a level of 3–3.5 MPa. Other factors influenced the abundance of micromolluscs at lower levels of soil penetration resistance. The effect of soil moisture on *V. pulchella* abundance was obviously non-linear. Low soil moisture was an extremely negative factor.
At 15–18% moisture content the abundance of molluscs reached maximum values. With further increase in humidity the abundance of mollusks decreased monotonically.
The soil air supply had a strong influence on the abundance of micromolluscs. The abundance of micromolluscs was very low when the soil volume filled with air was less than 25%. With increasing soil air volume, there was an increase in the abundance of micromolluscs. In the immediate proximity of walkways the abundance of micromolluscs decreased sharply. However, already at a distance of 3–4 m a local maximum of animal abundance was observed. As the distance from the trees increased, the abundance of mollusks increased.

At soil electrical conductivity of 0.8–0.9 dS/m, a local maximum of micromollusc abundance was observed. Increasing or decreasing soil electrical conductivity from this range led to a decrease in micromollusc abundance. The abundance of mollusks decreased monotonically with increasing soil bulk density.

The proportion of aggregate fractions > 10 and 7-10 mm had a negative effect on the abundance of *V. pulchella* micromolluscs (figure 5).

**Figure 3.** Profile distribution of soil penetration resistance. The abscissa axis is the soil penetration resistance, MPa; the ordinate axis is the depth of soil layers, cm.
Figure 4. Response of V. pulchella abundance in a gradient of aggregate fraction proportions. The ordinate axis is the number of micromollusc individuals in a 100 g soil sample; the abscissa axis is the soil properties: 1 – soil penetration resistance in the soil layer 0–5 cm, MPa; 2 – soil penetration resistance in the soil layer 5–10 cm, MPa; 3 – soil penetration resistance in the soil layer 10–15 cm, MPa; 4 – soil water content, %; 5 – soil air content, %; 6 – trail distance, m; 7 – tree distance, m; 8 – soil electrical conductivity, dSm/m; 9 – soil bulk density, g/m$^3$.

The increase in the proportions of aggregate fractions of 0.5–1 and 2–3 mm had a positive effect on the micromolluscs. The response of micromollusk to the proportions of fractions 0.25–0.5, 3–5, 5–7, and <0.25 mm was bell-shaped with the presence of an optimum zone.
Figure 5. Response of *V. pulchella* abundance in a gradient of aggregate fraction proportions. The ordinate axis is the number of micromollusc individuals in a 100 g soil sample; the abscissa axis is the proportion of aggregate fractions; 1 – fractions > 10 mm; 2 – fractions 7-10 mm; 3 – fractions 5-7 mm; 4 – fractions 3-5 mm; 5 – fractions 2–3 mm; 6 – fractions 1–2 mm; 7 – fractions 0.5–1 mm; 8 – fraction of size 0.25–0.5 mm; 9 – fraction of size <0.25 mm; model II – monotonic response; IV – symmetrical bell-shaped response; V – asymmetrical bell-shaped response (response models from the HOF list of functions [15,34]).

5. Discussion
A lot of investigation was carried out on habitat preference by terrestrial snails on a broad scale level [37–44]. Humidity and available calcium content were found to be the most significant
ecological drivers controlling the species richness and composition of terrestrial mollusk communities [45]. The species richness and abundance of terrestrial mollusk communities respond positively to the calcium available and negatively to soil acidity [46, 47]. The effect of calcium on snail distribution is mediated by vegetation [40]. A study of the microspatial distribution of mollusk species within a patch is of great importance and practical significance [48–58]. The selection of suitable micro-habitats within the biotope avoids extreme environmental conditions [59–61]. The humidity and productivity of the ecosystem are the most important environmental conditions structuring mollusc communities [62]. The spatial distribution of molluscs was studied in relation to forest litter moisture, shading, air humidity, and groundwater level [54, 55, 63]. Particular mollusc species prefer the leaves of different tree species, so the diversity of mollusc communities depends on the diversity of the litter [54, 64]. Calcium content in soils is a strong regulator of species composition, total community abundance and the abundance of species on a fine scale [52]. Land snail species tend to cluster in the most favourable habitats, rather than replacing one species with another [65–68].

Our research revealed that the abundance of the micromollusc Vallonia pulchella (Müller, 1774) population reaches very high levels under recreational conditions. The population abundance is $2.7-2.8 \times 10^3$ ind./m$^2$ in spring and $5.2 \times 10^3$ ind./m$^2$ in autumn. Within the same ecosystem, the abundance of micromolluscs can vary by a factor of two. The high abundance and variability in population density suggest that this species has a high potential as an indicator of environmental properties and is also highly important in soil ecosystem functioning. The abundance of V. pulchella is significantly lower in spring than in autumn. Of all the predictors considered, the volume of soil that is occupied by air can be recognized as the most probable cause of the variation in population abundance. In spring, a considerable volume of soil pore space is occupied by water, so the level of supply of soil biota with air is very low. In autumn, the soil moisture level decreases and the pore space that is released is filled with air. Thus, at least 20-25% of the soil pore space must be filled with air for normal life of the V. pulchella population. In addition to moisture content, soil density is an important factor that controls the volume of the pore space. The soil compaction that occurs as a result of recreational use leads to an increase in soil density and soil penetration resistance.

A linear and bell-shaped relationship was found between the soil moisture and the number of land snail species [49]. The plant cover determines the environmental conditions of the molluscs [69]. Soil electrical conductivity is a sensitive indicator of recreational load [11]. Soil electrical conductivity is a good predictor of V. pulchella population density. The electrical conductivity of soil depends on the distribution of soil phases: solid, liquid and gaseous. Gaseous phase practically does not conduct electric current while liquid phase conducts current in the best way. The ratio of the gaseous and liquid phase of the soil determines the living conditions of micromolluscs in the soil. This explains the correlation between the electrical conductivity of the soil and the abundance of V. pulchella. Thus, the pattern of micromollusk response to soil electrical conductivity integrates the animal response to both the soil density and soil moisture. The labor intensity of instrumental determination of soil moisture and soil electrical conductivity, should be noted to be commensurate, whereas the labor intensity of the soil density determination is very high and requires soil sampling and processing in the laboratory. In this regard, the soil electrical conductivity can be regarded as a convenient and reliable predictor of soil conditions for soil animals.

The important drivers of soil heterogeneity in urban parkland conditions are trees and recreational pathways. The most important environmental factor affecting the qualitative and quantitative features of mollusk populations at the landscape level is the soil calcium content [38, 44]. The thickness of forest litter, the organic matter content of the topsoil and the average annual temperature are important environmental conditions affecting molluscs [44]. Moisture levels in forest litter are particularly important for micromolluscs [51, 54, 55, 67]. Within
recreational pathways and in their proximity the abundance of micromollusc populations is at a very low level. Obviously, the high soil compactness due to recreational load leads to a reduction in pore space volume, which has a negative effect on the living conditions of the soil animals. The abundance of micromolluscs increases sharply at a distance of up to 5 metres from the recreational pathway and reaches its maximum. The reason is undoubtedly the greater supply of air to the soil in this area. An increase in micro-relief in the form of a scarp is formed near the walkway. The scarp is subjected to more drainage, so its moisture content is lower, and therefore the supply of air to the soil is greater. Thus, the impact of walkways on the surrounding soil far exceeds their visible limits. This impact is multidirectional. There is a decrease in the abundance of the micromollusc population close to the walkways, while at greater distances there is a sharp increase in the abundance of the population. Walkways are an important factor in the spatial heterogeneity of the $V.\ pulchella$ population under recreational load conditions. An increase in soil mechanical impedance has a negative impact on the abundance of $V.\ pulchella$ population [25].

The pure influence of structured tree space on the soil animal community was represented by large-scale and mesoscale components. The soil animal community exhibited patterns of change in the structured tree space. The spatial heterogeneity induced by trees was found to affect the vertical stratification of the soil animal community. The complex nature of soil animal community variability as a function of distance from trees depended on tree species interactions in their impact on soil animals. The importance of spatial patterns interacting with soil, plant and tree factors in the formation of soil macrofauna communities has been shown [17]. Trees also influence the spatial variability of soil properties, which is reflected in the abundance of $V.\ pulchella$. Near the tree trunks the abundance of micromolluscs decreases and increases monotonically with distance from the trees. In autumn, the aeration regime is the most important driver of such changes. As one moves away from the tree trunk, the volume of soil air increases due to a decrease in the soil density. Thus, the superposition of the effects of heterogeneity induced by the recreational load and the positioning of trees in the park plantation forms heterogeneous conditions to the variability of which the $V.\ pulchella$ population responds with its abundance.

The response of micromolluscs to the gradient of the soil properties considered is of a common pattern. A range of factor can be identified at which the abundance of micromolluscs is very low and there is a critical point after which this factor has almost no effect on the micromollusc. Obviously, in addition to the overall distribution between the solid, liquid and gaseous phases of the soil, the structure of the pore space is important. This structure is characterised by the distribution of the size fractions of the soil aggregates. The aggregates larger than 10 mm are negatively influenced by soil micromolluscs. Their high proportion is formed in very compact soils, where the soil space limits the living possibilities of micromolluscs. The small pores in large aggregates are predominantly filled with water, which displaces the air required for respiration. In addition, the pores themselves are smaller than the molluscs, so the opportunities for animal movement in such soils are extremely limited. The large cracks between the macroaggregates drain quickly and hyperaeration and rapid desiccation of the soil areas in contact with them occurs. Such an ecological regime is extremely unfavourable for the soil micromolluscs. Apparently, there is an optimum distribution of inter- and intra-aggregate pore space at which micromolluscs achieve their greatest abundance. Such a soil condition is achieved when the proportion of mesoaggregates in the soil is sufficient. It is important to note that the optimality criteria are close for both micromolluscs and plant roots. Such conditions are the provision of moisture to the roots for nutrition and air for respiration. Our results are in line with the evidence which indicates that an increased content of 1–3 mm aggregates in the soil coincides with a higher abundance of $B.\ cylindrical$ individuals. The $B.\ cylindrical$ individuals avoid areas with increased alkalinity and soil salinity, identified by both the phytoindication
approach and soil conductivity data [24]. The *V. pulchella* was shown to prefer the microsites with higher soil electrical conductivity, larger aggregate fractions with low mechanical resistance and low temperature at 0–10 cm depth, with a more developed layer of dead plants, low light and low values of the hygro- and heliomorphic vegetation index [56]. Under habitat conditions in reclaimed soils, *V. pulchella* prefers microstations dominated by soil aggregates 2–10 mm in size and avoids conditions where aggregates smaller than 2 mm predominate in the soil structure [25]. For micromolluscs, adequate humidity (100% moisture content in the soil air) is necessary as a protection factor against drying out, as the thin shell coverings of the mollusk with a relatively high body surface due to its small size are not a sufficient protection against drying out. Molluscs need air in the same way as plants do, to breathe. In general, mollusc abundance increases with increasing mesoaggregates and decreases with increasing macroaggregates.

### 6. Conclusion

The high abundance of the soil micromollusc *V. pulchella* in the anthropogenic soils and its sensitive response to the change of soil properties makes it a reliable indicator of the recreational load. The high abundance of the population (over $2.5-3\times10^3$ ind/m$^2$ in spring and over $8.4\times10^3$ ind/m$^2$ in autumn) indicates optimal soil conditions both for the life of the micromolluscs and for the life of the soil biota as a whole. The decrease in abundance of micromolluscs under the influence of recreational load occurs mainly as a consequence of a decrease in soil air volume. This effect results from the compactness of the soil and changes in the aggregate structure of the soil. Under significantly transformed conditions, the proportion of the microaggregates increases and the proportion of the mesoaggregates decreases.

### ORCID iDs

O Kunakh https://orcid.org/0000-0002-3631-8884

A Umerova https://orcid.org/0000-0001-6208-7218

E Degtyarenko https://orcid.org/0000-0002-8040-4608

### References

[1] Childers D L, Bois P, Hartnett H E, McPhearson T, Metson G S and Sanchez C A 2019 *Elementa: Science of the Anthropocene* 7 URL https://doi.org/10.1525/elementa.385

[2] Koshelev O I, Koshelev V O, Fedushko M P and Zhukov O V 2020 *Biosystems Diversity* 28 433–444 URL https://doi.org/10.15421/012056

[3] Kunah O M, Zelenko Y V, Fedushko M P, Babchenko A V, Sirovatko V O and Zhukov O V 2019 *Biosystems Diversity* 27 156–162 URL https://doi.org/10.15421/011921

[4] Domnich V I, Domnich A V and Zhukov O V 2020 *Biosystems Diversity* 28 433–444 URL https://doi.org/10.15421/012124

[5] Shcherbyna V V, Maltseva I A, Maltseva H V and Zhukov O V 2021 *Biosystems Diversity* 29 3–9 URL https://doi.org/10.15421/012101

[6] Zhukov O, Kunah O, Fedushko M, Babchenko A and Umerova A 2021 *Ekológia (Bratislava)* 40 178–188 URL https://doi.org/10.2478/eko-2021-0020

[7] Kunakh O M, Lisovets O I, Yorkina N V and Zhukova Y O 2021 *Biosystems Diversity* 29 84–93 URL https://doi.org/10.15421/012135

[8] El-Gendy K, Gad A and Radwan M 2021 *Environmental Research* 193 110558 URL https://doi.org/10.1016/j.envres.2020.110558

[9] Hill M O, Roy D B and Thompson K 2002 *Journal of Applied Ecology* 39 708–720 URL https://doi.org/10.1046/j.1365-2664.2002.00746.x

[10] Ihtimanski I, Nedkov S and Semerdzhieva L 2020 *One Ecosystem* 5 URL https://doi.org/10.3897/oneeco.5.es54621

[11] Kunakh O M, Yorkina N V, Zhukov O V, Turovtseva N M, Bredikhina Y L and Logvina-Byk T A 2020 *Biosystems Diversity* 28 3–8 URL https://doi.org/10.15421/012001

[12] Zhukov A and Gadorozhnaya G 2016 *Ekológia (Bratislava)* 35 263–278 URL https://doi.org/10.1515/eko-2016-0021
