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Response of soil macrofauna to urban park reconstruction

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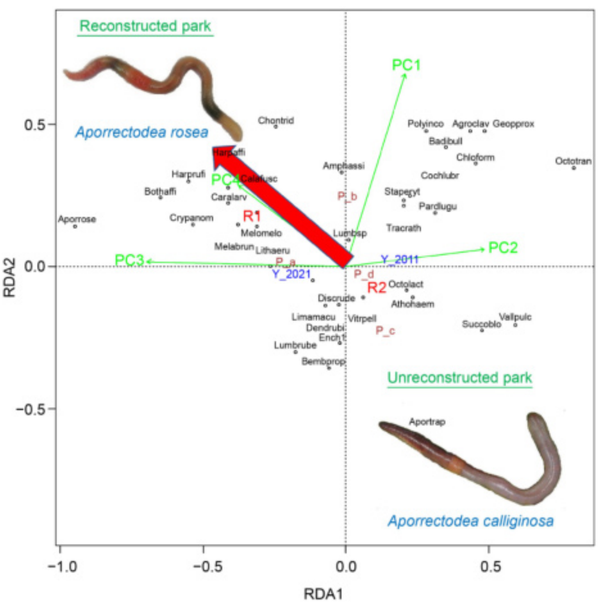
ABSTRACT

- Soil penetration resistance increases as a result of park reconstruction.
- Soil compaction explains one-third of the variability in soil macrofauna.
- The abundance of the earthworm *Aporrectodea rosea* increases after reconstruction.
- The abundance of the earthworm *A. calliginosa* decreases after reconstruction.

This study is based on a park in an industrial city in Ukraine. In 2019, a 2.8 ha area of the park was reconstructed. The park's reconstruction aimed to create a comfortable environment for visitors and to improve the efficiency of ecosystem services, and thereby enhance the quality of life of citizens. The reconstruction of the park was found to cause changes in the physical properties of soils and the structure of the soil macrofauna community. The increases of soil compaction in the layers at depth 5–20 cm and the soil electrical conductivity were a consequence of technological operations during reconstruction. The park reconstruction activities can also explain 29% of the variation in the soil macrofauna community. Extracting the variation induced by the park reconstruction from the community variation induced by other causes was a major challenge. The specific changes in the community of soil macrofauna following the reconstruction of the park were revealed. The abundance of soil animal species *A. rosea*, *A. trapezoides*, *H. affinis*, *H. rufipes*, *B. affinis* was found to increase after the reconstruction. The earthworm *A. trapezoides* decreased in abundance due to the park reconstruction.



Keywords ecosystem services, soil physical properties, community ordination, urban park management, variation partitioning

1 Introduction

The main components of the anthropogenic load in large industrial cities are chemical (Power et al., 2018), thermal pollution (Burkart et al., 2011), light pollution (Schirmer et al., 2019), fragmentation of biotopes (Zambrano et al., 2019), invasion of introducers (Santana Marques et al., 2020; Malloch et al., 2020), and recreation (Kang et al., 2021). Recreation leads to a mechanical disturbance of the soil (Nawaz et al., 2013) and vegetation cover (Erfanian et al., 2021), as well as compaction and eutrophication of the soil (Ermakov and Vorobeichik, 2013; Kuddus et al., 2020). Urban parks are places of intense recreation (Santos et al., 2016; Stępniewska, 2021) and also perform important ecosystem services in the urban environment (Mexia et al., 2018). Ecosystem services include water and air purification, wind and noise reduction, carbon sequestration, microclimate regulation, wildlife habitat, and social and psychological well-being (Chiesura, 2004). Many of these ecosystem services are dependent on the condition and functioning of the soil cover of park plantations (Brussaard, 2021).

Soil animals are involved in many soil-related ecosystem services (Brussaard, 1997; Heemsbergen et al., 2004; De Vries et al., 2013). The soil animals contribute to plant nutrition, carbon turnover, detoxification, and soil quality (Wardle et al., 2004; Nielsen et al., 2011). Furthermore, soil ecosystem services in anthropogenic landscapes can be indicated by the soil macrofauna (Velasquez and Lavelle, 2019). The productivity of ecosystems depends on water supply, which is a function of infiltration and water storage in soil pore systems. Soil animals create a system of stable soil channels

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and form the soil aggregates that provide soil infiltration (Jacot, 1936; VandenBygaart et al., 2000). These animals are also involved in the nutrient cycling process (Sagi and Hawlena, 2021) and are important in the decomposition and humification of organic matter (Verhoef and Brussaard, 1990). Urbanization has both positive and negative effects on the feeding activity of soil saprophages, while the recreational load has a negative effect on this feeding activity (Bergman et al., 2017). Pedoturbation, the deposition of coprolites on the soil surface, the selection of soil particles, and the formation of water-resistant aggregates occur during the zoogenic pedogenesis (Yakovenko and Zhukov, 2021). Urban environmental stresses contribute to the particular soil biodiversity dynamics in urban plantations and can impede the nutrient recycling and energy flow in these ecosystems (Vitsousek, 1984).

The biodiversity of natural ecosystems is essential for maintaining ecosystem services (Hector and Bagchi, 2007). The loss of biodiversity significantly reduces a number of ecosystem services, changing the functioning and stability of ecosystems, especially at the large temporal and spatial scales (Isbell et al., 2017). Considerable experimental evidence shows the positive effects of biodiversity on ecosystem functioning (Cardinale et al., 2011). However, this result requires confirmation for urban ecosystems (Schwarz et al., 2017). The relationship between the biodiversity of urban ecosystems and ecosystem services depends on the composition of species in urban communities, functional traits, or structures. The value of a particular biodiversity indicator correlates less with the ecosystem functions (Ziter, 2016). Supporting urban ecosystem service delivery is possible if the loss of biodiversity is minimized in urban expansion planning (Schwarz et al., 2017).

The success of the park's ecosystem services is due to a good management structure (Mexia et al., 2018). Urban park management is considered as a tool for achieving the social interaction goals (Hajzeri, 2021). The ecosystem service value of urban parks becomes an important target function of urban green space management (Xie et al., 2019). Harmonizing the recreational function and maximizing the environmental benefits is an important challenge in park management (Cohen et al., 2014; Vieira et al., 2018), and reconstruction is an important tool for park management (Mäntymaa et al., 2021).

The temporal dynamics of the soil properties of urban parks are induced by both natural processes (Sarah et al., 2015) and human-managed processes, such as green space management and park reconstruction (Van den Berg et al., 2014). Soil quality is a major goal in urban park management (Pavao-Zuckerman, 2008) and the transformation of vegetation structure is considered to be the most important outcome of park reconstruction (Li, 2020). Indeed, intensive reconstruction can improve the chemical properties of soils (Hou et al., 2015). Information on the spatial distribution of the key soil properties (acidity, organic carbon and nutrient content) can be used to predict the possible land cover changes resulting from the green space reconstruction, which is needed to support urban planning and soil management decisions in sustainable cities (Romzaykina et al., 2017). Providing good soil quality is important for promotion of plant growth in urban parks and creation of an ecologically sustainable urban landscape (Millward et al., 2011).

Thus, the activity of the soil macrofauna is the most important factor that provides the key ecosystem services of urban soil. Little attention has been given to reveal the changes in the biodiversity of soil macrofauna communities, which are important contributors to the soil naturalization processes that can have a prolonged effect on the dynamics of urban soil quality, when assessing the results of park reconstruction. Also, the condition of soil macrofauna is a reliable indicator of soil properties and regimes. Therefore, finding out the nature of the impact of park reconstruction on the soil macrofauna is of great importance for planning the optimal management strategies for park plantations.

The aim of this article is to elucidate: 1) the patterns of impact of park reconstruction on the soil physical properties; 2) trends in the soil macrofauna community in response to reconstruction; and 3) an importance of changes in the soil physical properties resulting from the park reconstruction on the soil macrofauna.

2 Materials and methods

2.1 Soil and vegetation features of the park

An artificial tree plantation was created in the recreational area of the Botanical Garden of the Oles Honchar Dnipro National University (Ukraine) after the Second World War, on the location of a thermophilous natural oak forest (Goncharenko and Kovalenko, 2019; Goncharenko et al., 2020). The soil classification was determined by this study to be, according to World Reference Base, WRB: Calcic Chernozem (Siltic, Tonguic) (Yakovenko and Zhukov, 2021). This study recorded 65 plant species in the study area, among which phanerophytes were represented by 11 species, non-25 phanerophytes by two species, hemicryptophytes by 29 species, therophytes by 16 species, and geophytes by 7 species (Kunakh et al., 2021a). The *Acer platanoides*, *Fraxinus excelsior*, *Gleditsia triacanthos*, *Robinia pseudoacacia* were dominated among the tree plants. The *Alliaria petiolata*, *Chelidonium majus*, *Geum urbanum*, *Viola mirabilis*, *Galium aparine* were dominated among the herbaceous plants (Kunakh et al., 2021b).

2.2 Reconstruction of the park

The park reconstruction work that took place in 2019 included the restoration of walkways, the removal of shrubs and old, damaged trees, and the trimming of tree crowns. Young trees were planted in the place of the removed old trees. The old outbuildings, which significantly impaired the aesthetic perception of the park, were also removed. Transport and construction machinery was involved in the reconstruction. The works were carried out during the whole warm period of the year.

2.3 Preliminary studies in the park and selection of control sampling sites

The choice of control point locations is important for assessing the impact of park reconstruction on soil macrofauna. Selecting the location of the sampling control points, we proceeded from the assumption that the control points and the points where the treatment was performed should differ minimally before the treatment. We had at our disposal the results of a preliminary soil macrofauna survey and soil measurements that were conducted at 20 sampling sites in this park between 2011 and 2013 (Fig. 1A). The sampling sites in 2011−2013 were designated by numbers, and the sampling sites in the current study are designated by letters. The soil macrofauna communities were classified using the cluster analysis based on species composition (Fig. 1B).

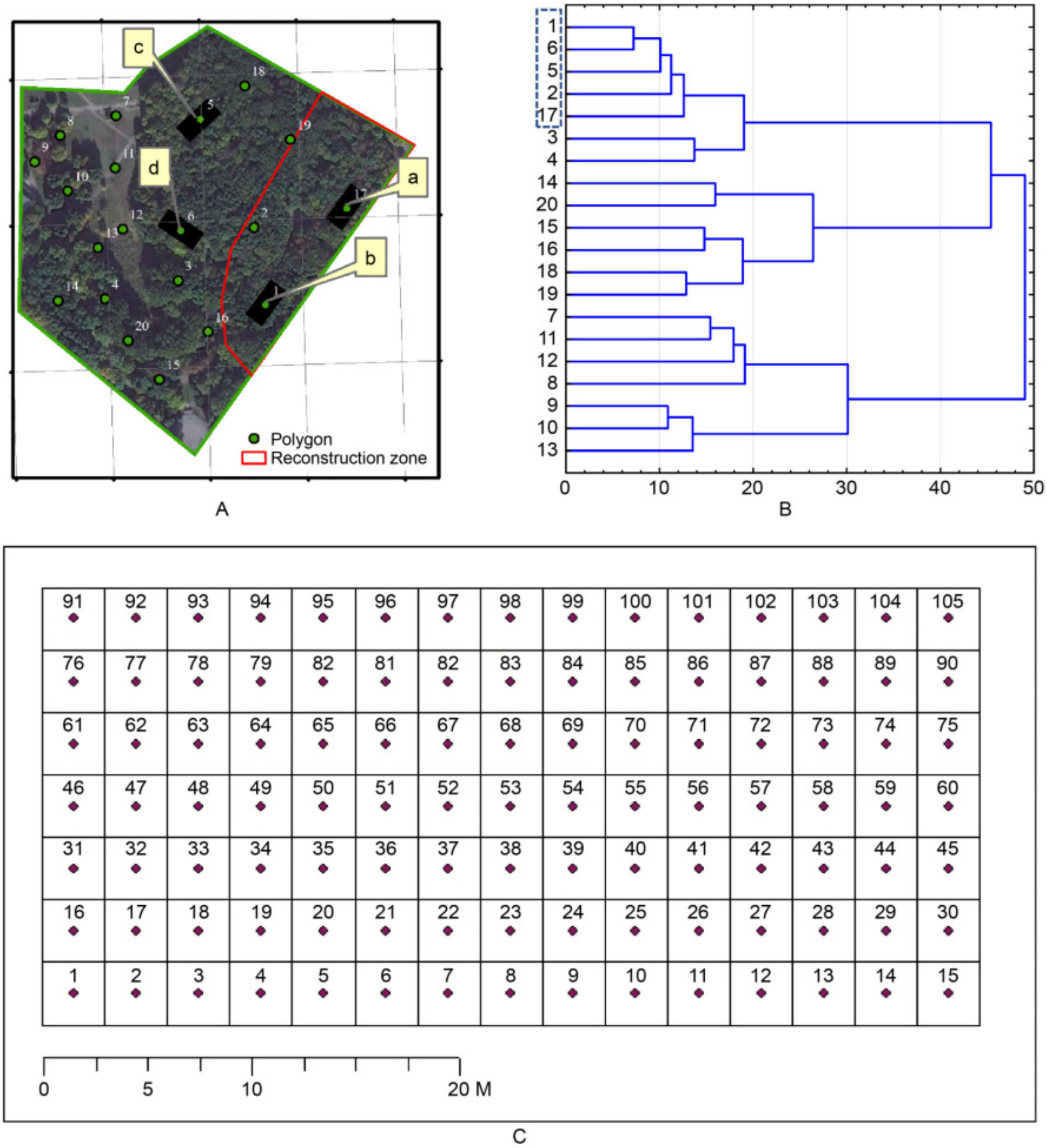

Fig. 1 The location of sampling sites in 2011–2013 (sites 1–20 are shown as dots) and the location of sites in 2021 (sites a, b, c, and d are shown as polygons). (A) The cluster analysis of soil macrofauna communities based on the species composition. (B): an abscissa axis is Euclidean distance (Ward's method); an ordinate axis represents the sampling sites 1–20. The cluster of homogeneous sites by species composition of soil macrofauna considered in this study is indicated by a dashed line. Location of sampling points within the site (C).

There were four sampling sites in or adjacent to the area that later became the park's reconstruction zone: 1, 2, 17, and 19. The sites 2 and 19 were on the edge of the reconstruction zone, and the sites 1 and 17 were within the reconstruction zone.

In 2021, further sites a and b were within the original sites 1 and 17. Thus, the sites a and b represent the reconstruction experimental impact zone. From the remaining 18 sites (of the total of 20), similar soil macrofauna species composition was considered as control candidates. The proximity of sites in the cluster dendrogram was a criterion for the similarity of soil macrofauna communities. The cluster analysis showed the sites 2, 5, and 6 to be the most appropriate for control. Site 2 was rejected as being on the edge of the reconstruction zone. Thus, sites 5 and 6 were considered "Control" (area without reconstruction). The further sites c and d were placed in 2021 in the location of sites 5 and 6. The sampling at sites 1, 5, 6, and 17 was conducted on May 20–25, 2011.

2.4 Sampling design

The soil sampling for the soil invertebrate extraction and the measurements of soil properties were performed from May 15–25, 2021 at four sampling sites, 2 of which were placed in the reconstruction area and 2 of which were placed in a similar area of the park where no reconstruction had taken place. A total of 105 soil-zoological samples were collected at each sampling site in both 2011 and 2021 (Fig. 1C). The soil-zoological samples were collected on a regular grid with 3 m between sampling points. This sampling design was followed in both 2011 and 2021.

2.5 Macroinvertebrate community assessment

The soil animal sampling and soil property measurements in the 2011–2013 and 2021 sampling series were performed using the same techniques. The soil macrofauna was collected using ISO 23611–5 (Anderson and Ingram, 1993). Each sampling site consisted of 105 sample points. The points were located along 7 transects with 15 sample points in each transect (Fig. 1C). The distance between points in the transect as well as the distance between transects was 3 m. The soil blocks 25 cm × 25 cm and 30 cm deep were sampled in each of the 4 sampling sites. Macroinvertebrates visible to the naked eye were collected by the hand sorting of leaf litter and soil. They were preserved in 75% alcohol and the earthworms were preserved in 4% formaldehyde. The animals were identified to the species level if possible. The results of the quantitative surveys were reported as the number of individuals per sample with a soil surface area of 25 cm × 25 cm (Table S1).

2.6 Measurement of environmental indicators

The soil classification was made according to the IUSS Working Group WRB 2015 (WRB 2015). The soil penetration resistance was measured in the field using a hand-held *Eijkelkamp* penetrometer to a depth of 100 cm with an interval of 5 cm. The average error of the measurement results of the device was ± 8%. The measurement was made with a cone with a cross-sectional size of 2 cm^2. Within each sampling point, the soil penetration resistance was measured with a single repetition. An HI 76305 sensor (Hanna Instruments, Woodsocket, RI) was used to measure the electrical conductivity of the soil *in situ*. This sensor works together with a portable HI 993310 tester. The tester evaluates the total electrical conductivity of the soil, i.e., the combined conductivity of air, water and soil particles. The measurement results of the device are presented in units of soil salt concentration, i.e., g L^{-1}. The comparison of HI 76305 measurements with laboratory data allowed estimation of the unit conversion factor as 1 dS m^{-1} = 155 mg L^{-1} (Pennisi and van Iersel, 2002). The height of forest litter was measured with a ruler with a division value of 1 mm in triplicate in each test point (Vorobeichik, 1997). The soil bulk density was estimated by Kachinsky, the soil moisture was estimated by weight method (Karpachevsky, 2005). The soil physical property data were subjected to the principal component analysis performed in the software STATISTICS (2014).

2.7 Community ordination procedure

A partial redundancy analysis was applied to ordinate the soil macrofauna community with the variables "Year," "Site," and "Reconstruction" and the principal component scores extracted after analysis of soil physical properties as predictors. The soil animal abundance data were subjected to a prior χ^2-transformation. The influence of various predictors on the ordinal solution was assessed by comparing the focal ordinal solution obtained for all the predictors mentioned with the solution in which the predictor of interest was applied as conditional. Applying the predictor as conditional allows evaluation of the influence of other factors on the community if the influence of the conditional predictor is excluded. The comparison of ordinal solutions was performed using the Procrustean analysis procedure (Peres-Neto and Jackson, 2001). The ordination and partitioning of the variation of the soil macrofauna community were performed using the *vegan* library (Oksanen, 2017). Scaling of *A. trapezoides* to *A. rosea* in-transformed abundances was analyzed with the standardized major axis (SMA) regression (Warton et al., 2012). The standard major axis slopes were calculated as the aim was to summarize the relationship between species abundance, rather than to produce equations for predicting the abundance of one species based on information about the abundance of another species.

The following factors were considered as the categorical predictors of the soil macrofauna community:

– the "Year" factor took two values: 2011 and 2021 and modeled the temporal aspect of community variability;

– the “Site” factor took four values: a, b, c, and d and modeled the spatial aspect of community variability;

– the “Reconstruction” factor took two values: an area after reconstruction and an area without reconstruction and modeled the impact of reconstruction.

Accordingly, all sites were under conditions without reconstruction in 2011, while the sites a and b were under conditions after reconstruction and the sites c and d were under conditions without reconstruction in 2021.

2.8 Climatic features

The average daily air temperature data were used to describe the temperature regime, and the data on accumulated precipitation were used to describe the precipitation regime for the period from the beginning of the year to the end of spring (Koshelev et al., 2021). The assumption taken was the climatic conditions affecting the soil macrofauna were those existing from the beginning of spring until the time of soil animal data collection. Information about the quantity of precipitation and temperature was obtained for the city of Dnipro from NOAA using the library *rnoaa* (Chamberlain, 2020) for a language and environment for statistical computing R (R Core Team, 2020).

Annual precipitation for 2011 was 307 mm and for 2021 was 378 mm. From the beginning of the year to the end of spring, the 2011 precipitation was 136 mm and the 2021 precipitation was 138 mm (Fig. 2). In 2011, a significant amount of precipitation occurred during the short period of February 12–13 (42 mm), but the springtime precipitation in 2011 was significantly less (47 mm) than in 2021 (82 mm). The trend of cumulative precipitation for both years of observations from 61 to 150 days of the year (throughout the spring) was linear and could be described by the equation:

$$\mathrm{CP} = 0.83D,$$

where CP is the cumulative precipitation during spring, mm, D is the ordinal number of the day from the beginning of spring. The differences between the deviations from the trend between years were statistically significant ($t = -20.6$, $p < 0.01$, F-ratio of variations was 1.05, $p = 0.82$), which confirms the spring of 2021 had more precipitation than the spring of 2011.

The average annual temperature in 2011 was 9.1°C, and in 2021 this parameter was 9.4°C. The sharp temperature fluctuations were typical of the winter period. Years differed in the timing of the winter’s cold spell or warming spell. Both years showed a linear trend of increasing temperature in spring:

$$T = 0.21D,$$

where T is the mean daily temperature during spring, °C, D is the ordinal number of the days since the beginning of spring. The differences between the deviations from the trend between years were not statistically significant ($t = 1.4$, $p = 0.16$, F-ratio of variations was 1.05, $p = 0.80$), which confirmed that there were no differences in the temperature regime in the springs of 2011 and 2021.

3 Results

3.1 Variation of soil physical properties

The general pattern of the profile distribution of soil penetration resistance was characterized by a tendency for this index to increase with the soil depth and the presence of a local maximum at a depth of 5–35 cm (Table S1). A conditional critical level of soil penetration resistance of 3 MPa, which can significantly limit plant root growth (Medvedev, 2009), was regularly observed from a depth of 20–50 cm. The soil electrical conductivity was lower in 2011 (0.19 ± 0.006 dSm m^{-1}), than in 2021 (0.31 ± 0.006 dSm m^{-1}) (F = 206.5, p < 0.001). The height of forest litter in 2011 was lower (0.89 ± 0.02 cm) than in 2021 (2.44±0.02 cm) (F = 3984.9, p < 0.001). The soil moisture content in 2011 was lower (31.40±0.14%) than in 2021 (F = 90.7, p < 0.001).

Year, site, and reconstruction were able to explain 16% –80% of the variation in soil physical properties. Accounting for the variable “Year” as a conditional predictor led to a decrease in the explained variation to the level of 5%–57% (Fig. S1). The most significant decrease in the explained

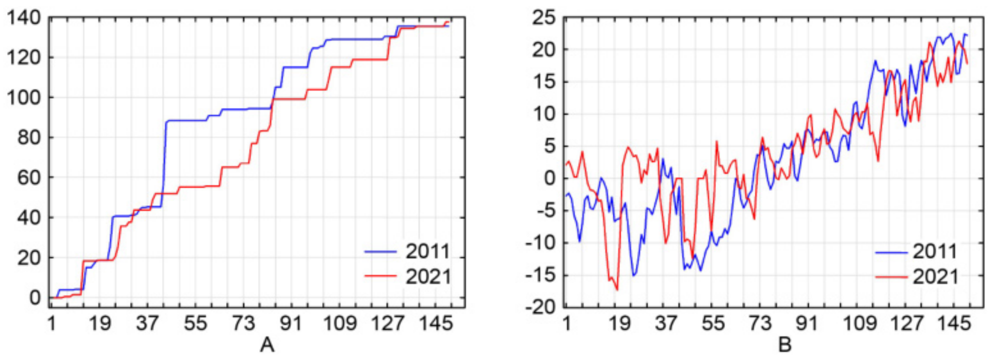

Fig. 2 Cumulative precipitation (A) and mean daily temperature (B) during 2011 and 2021 from January 1 to May 30 of each year: abscissa axis is the order of days since January 1; ordinate axis A is cumulative precipitation since the beginning of the year, mm; B is mean daily temperature, °C.

variation was observed for the soil electrical conductivity and forest litter height, as well as for the soil penetration resistance at 0–5 cm depth and in the 20–45 cm depth range. Accounting for the site variable as a conditional predictor resulted in a decrease in the explained variation to the level of 9%–76%. The most significant decrease in explained variation was observed for the soil penetration resistance at the depth of 10–15 cm and in the depth range of 55–100 cm. Accounting for the variable “Reconstruction” as a conditional predictor led to a decrease in the explained variation to the level of 16%–59%. The most significant decrease in the explained variation was observed for the soil electrical conductivity and forest litter height, as well as for the soil penetration resistance at a depth of 5–20 cm.

The principal component analysis of the soil physical properties variation allowed identification of four principal components, the eigenvalues of which exceeded unity (Table S2). The principal component 1 described 66.4% of the variation of soil physical properties and reflected the trend of coordinated change in the soil penetration resistance along the whole soil profile. Also, this principal component indicated an increase in the soil penetration resistance with a decrease in the soil moisture content, and showed that an increase in the soil penetration resistance was positively correlated with an increase in the electrical conductivity of the soil. The principal component 2 described 11.2% of the variation in soil physical properties. This principal component reflected a trend of opposite dynamics of the soil penetration resistance in the upper soil layers (0–35 cm) on the one hand and in the lower soil layers (50–100 cm) on the other hand. The principal component 3 described 5.9% of variation in soil physical properties. This principal component indicated a tendency for the soil electrical conductivity to increase with increasing forest litter height. It also showed an increase in electrical conductivity correlated with increase in soil penetration resistance at a depth of 5–25 cm but increase in electrical conductivity occurring with decreasing solid penetration at a depth of 35–55 cm. The principal component 4 described 5.0% variation in soil physical properties. This principal component indicated a trend toward inverse correlation between the soil moisture and litter height. The litter height correlated positively with the soil penetration resistance at a depth of 0–15 cm, and the soil moisture correlated positively with the soil penetration resistance at a depth of 20–45 cm.

3.2 Soil macrofauna

A total of 20 143 individual animals were sampled in the ecosystems studied and 56 species or taxa of the soil macrofauna species level were found during the study period (Table S3). Earthworm cocoons were also recorded. The species *Harpalus (Pseudoophonus) griseus* (Panzer, 1796) was detected in the imaginal and larval phases of development. The earthworms were represented by 8 species, among which the most abundant were *Aporrectodea caliginosa trapezoides* (Duges, 1828) and *Aporrectodea rosea* (Savigny, 1826). *Enchytraeidae* were defined to the family level. *Arthropoda* were represented by 38 species, among which *Geophilus proximus* C.L. Koch, 1847 and *Trachelipus rathkii* (Brandt, 1833) were the most abundant. Mollusca were represented by 9 species, the most abundant of which were *Cochlicopa lubrica* (O.F. Muller, 1774) and *Vallonia pulchella* (O.F. Muller, 1774).

3.3 Soil macrofauna community ordination

Of the 56 species or species-level taxa, 35 species had more than 10 occurrences. They were used for further analysis. Redundancy analysis and canonical analysis are two alternatives for the community ordination procedure. To choose the best one, we must first perform a detrended analysis. The length of the first axis extracted after the detrended analysis will be able to indicate the best choice. If the length of the first axis exceeds 2, then the best alternative is the canonical analysis. Otherwise, it is better to use a redundancy analysis (ter Braak and Šmilauer, 2002). The length of the first extracted axis after the previously performed detrended analysis was 1.83, so the redundancy analysis was the most appropriate ordination procedure. The constrained redundancy analysis (Fig. 3) allowed 29% of the variation in the soil macrofauna community to be described (Table S4). The RDA1 axis reflected the time-dependent differences in the soil macrofauna community. These differences were modulated by the variability in soil properties, which were described by the principal components 2 and 3 (outlined above). The RDA2 axis reflected the variability of the soil macrofauna community, which was driven by the differences in environmental conditions in the sites. The drivers of these features were the changes in soil properties, which were described by the principal component 1. The upper left quadrant of the space, which was defined by the RDA1 and RDA2 axes, corresponded to the communities and species groups specific to the park reconstruction area. The corresponding pattern of the soil macrofauna community was formed under the influence of changes in soil properties described by the principal component 4.

3.4 Partitioning of soil macrofauna community variation

The time factor described 7.3% of variation in the soil macrofauna community ($R_{adj}^2 = 0.073$, $p < 0.001$), of which the importance of the pure contribution of this factor was 1.1%. The spatial heterogeneity factor described 11.2% of the variation in the soil macrofauna community ($R_{adj}^2 = 0.112$, $p < 0.001$), of which the importance of the pure contribution of this factor was 7.3%. The soil properties factor described 18.9% of the variation in the soil macrofauna community ($R_{adj}^2 = 0.189$, $p < 0.001$), of which the importance of the pure contribution of this factor was 6.5%. The park reconstruction factor described 8.7% of variation in the soil macrofauna community ($R_{adj}^2 = 0.087$, $p < 0.001$), of which the importance of the pure contribution of this factor was

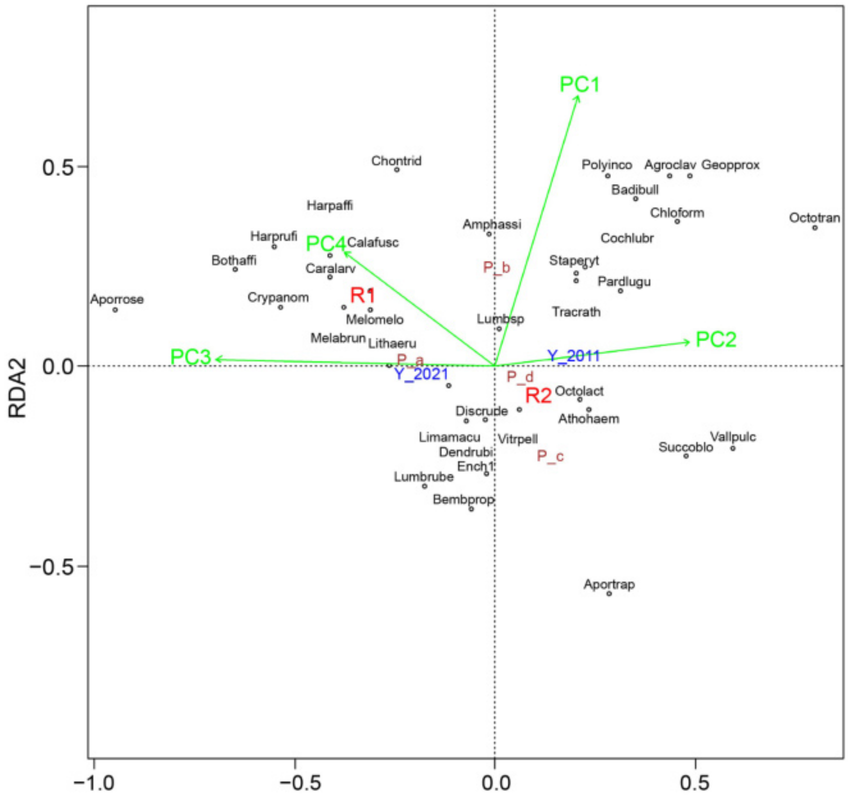

Fig. 3 Constrained redundancy analysis with year, polygon, and reconstruction as the categorical predictors and principal components derived after analysis of the soil physical properties as the continuous predictors: Aporrose – *Aporrectodea rosea*; Aportrap – *Aporrectodea trapezoides*; Dendrubi – *Dendrodrilus rubidus*; Lumbsp – *Lumbricidae* sp.; Lumbrube – *Lumbricus rubellus*; Octotran – *Octodrilus transpadanus*; Octolact – *Octolasion lacteum*; Ench1 – *Enchytraeus* sp. 1; Pardlugu – *Pardosa lugubris;* Geopprox – *Geophilus proximus;* Lithaeru – *Lithobius aeruginosus;* Crypanom – *Cryptops anomalans*; Polyinco – *Polydesmus inconstans*; Badibull – *Badister bullatus*; Bembprop – *Bembidion properans*; Calafusc – *Calathus fuscipes*; Harpaffi – *Harpalus affinis*; Harprufi – *Harpalus rufipes*; Caralarv – *Carabidae* sp. (larv.); Bothaffi – *Bothynoderes affinis*; Athohaem – *Athous haemorrhoidalis*; Melabrun – *Melanotus brunnipes*; Staperyt – *Staphylinus erythrocephalus*; Melomelo – *Melolontha melolontha*; Amphassi – *Amphimallon assimile*; Chloform – *Chloromyia formosa*; Agroclav – *Agrotis clavis*; Tracrath – *Trachelipus rathkii*; Cochlubr – *Cochlicopa lubrica*; Chontrid – *Chondrula tridens*; Limamacu – *Limacus maculatus*; Succoblo – *Succinella oblonga*; Vallpulc – *Vallonia pulchella*; Vitrpell – *Vitrina pellucida*; Discrude – *Discus ruderatus.*

3.1%. The transformation of soil properties due to the reconstruction explained 1.1% of the community variation. The differences in the soil properties between sampling sites that were subjected to the reconstruction explained 1.5% of the community variation. The temporal non-stationarity of the community response to the transformation of soil properties due to the reconstruction explained 2.8% of the community variation. The temporal and spatial non-stationarity of the community response to the transformation of soil properties after reconstruction explained 0.7% of the community variation. The temporal and spatial non-stationarity of the community response to the action of reconstruction explained 0.2% of the community variation.

3.5 Transformation of the soil macrofauna community induced by various factors

The application of the variable “Year” as a conditional predictor resulted in an ordinal solution that differs from the original one (Fig. 4). Species such as *A. rosea*, *O. transpadanus*, *L. rubellus*, *S. oblonga*, and *V. pulchella* contribute the most to the rotation of ordination solutions. In 2011, the abundance of *A. rosea*, *L. rubellus*, *S. oblonga*, and *V. pulchella* was higher than in 2021. In 2021, the abundance of *O. transpadanus* was higher than in 2011. The rotation of the ordination solution due to the application of the Site variable as a conditional predictor was caused by the response to the spatial heterogeneity of the studied area of the park by species *S. oblonga*, *V. pulchella*, *B. bullatus*, *A. clavis*, and *P. inconstans*. Site a was characterized by the greatest abundance of *S. oblonga* and *V. pulchella*. Site c was characterized by the highest abundance of *B. bullatus*, *P. inconstans*, and *A. clavis*. The lowest abundance of *S. oblonga* was found in site b. Site d had the lowest abundance of *V. pulchella*. The specific changes in the community of soil macrofauna induced after the reconstruction of the park were revealed. The abundances of soil animal species *A. rosea*, *A. trapezoides*, *H. affinis*, *H. rufipes*, *B. affinis* were found to increase after the reconstruction. The abundance of *A. trapezoides* decreased, while the abundance of other

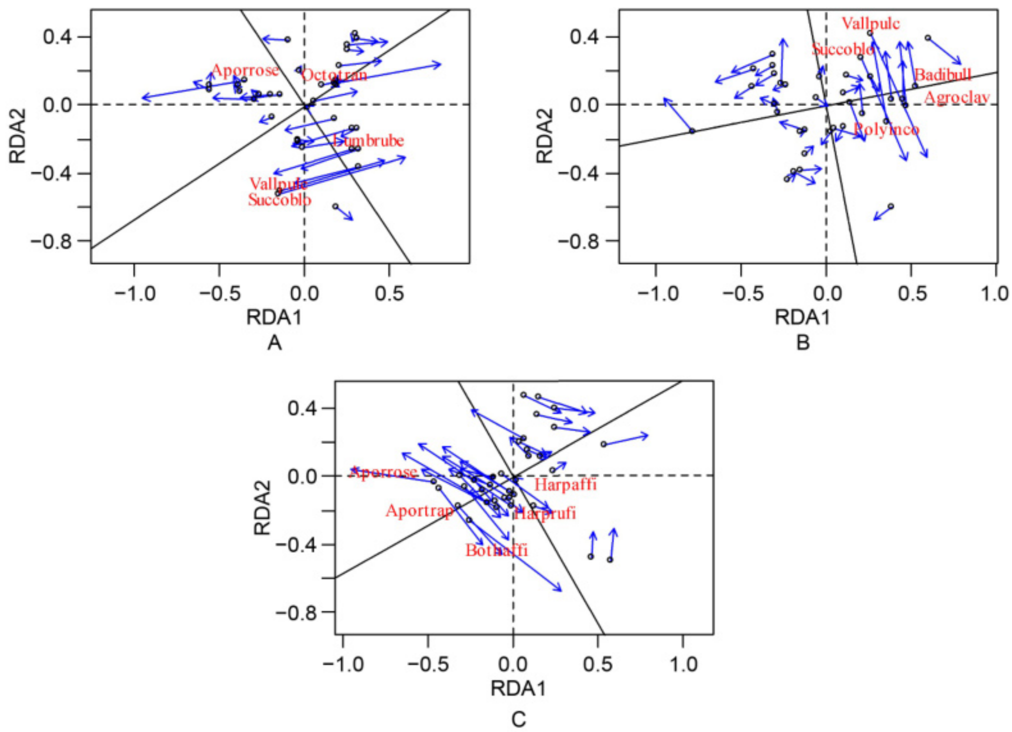

Fig. 4 Procrustean analysis of ordination solutions obtained after the RDA procedure with different covariates as partial predictors. The point indicates the position of the species after rotation, the arrow indicates the position of the species before rotation. The first five species that make the greatest contribution to the difference between ordinal solutions: A – "Year" partial effect (procrustes sum of squares 3.04), Aporrose – *Aporrectodea rosea*, Octotran – *Octodrilus transpadanus*, Lumbrube – *Lumbricus rubellus*, Succoblo – *Succinella oblonga*, Vallpulc – *Vallonia pulchella*; B – "Polygon" partial effect (procrustes sum of squares 2.31) , Succoblo – *Succinella oblonga*, Vallpulc – *Vallonia pulchella*, Badibull – *Badister bullatus*, Agroclav – *Agrotis clavis*, Polyinco – *Polydesmus inconstans*; C – "Reconstruction" partial effect (procrustes sum of squares 3.87), Aporrose – *Aporrectodea rosea*, Aportrap – *Aporrectodea trapezoides*, Harpaffi – *Harpalus affinis*, Harprufi – *Harpalus rufipes*, Bothaffi – *Bothynoderes affinis.*

species from the above list, on the contrary, increased under the influence of park reconstruction. The abundances of earthworms *A. trapezoides* and *A. rosea* correlated positively with each other (Fig. 5). The pattern of the relationship between the abundance of these species was stable over time, as evidenced by the slope of the regression relationship for unreconstructed conditions, which was practically unchanged over time. The elevation of the regression model increased, and the slope of the model decreased for the relationships between populations in the post-reconstruction park conditions.

4 Discussion

4.1 Drivers of soil macrofauna community structure

Urban park plantations perform important ecosystem functions and provide a desirable living environment for residents. The parks may be formed in the place of natural forest ecosystems, but man-made plantations are a significant feature of parks. The artificial origin of parks and the significant anthropogenic impact in the urban environment makes it necessary to employ intensive parkland management. Three sets of factors are considered to influence the soil physical properties: the factors causing temporal variability, spatial dynamics, and the factors caused by the reconstruction of park plantations. These factors also directly affect the soil macrofauna community, but the effect of these factors on the soil macrofauna can also be indirect through the modification of soil physical properties.

Time, spatial heterogeneity, soil physical properties, and park reconstruction affect the soil macrofauna community. The factor of soil physical properties, of all considered, has the strongest influence on soil macrofauna. The importance of factors of spatial and temporal heterogeneity is much less, and this is to be expected since their minimization was the goal of the experiment plan. In a laboratory experiment, the effect of these factors is reduced to zero. In a field experiment, however, the influence of the factor of interest can be estimated only when the spatial and temporal heterogeneity of the medium is minimized, but not when other disturbing factors are completely excluded. The temporal non-stationarity and the spatial heterogeneity are also evident in the pattern of community response to the impact of reconstruction. The significance of temporal non-stationarity is only probable, as the impact of reconstruction was assessed for only one event. Therefore, the temporal aspect may indeed be related to the non-stationarity of the community's response to the impact of reconstruction. The temporal

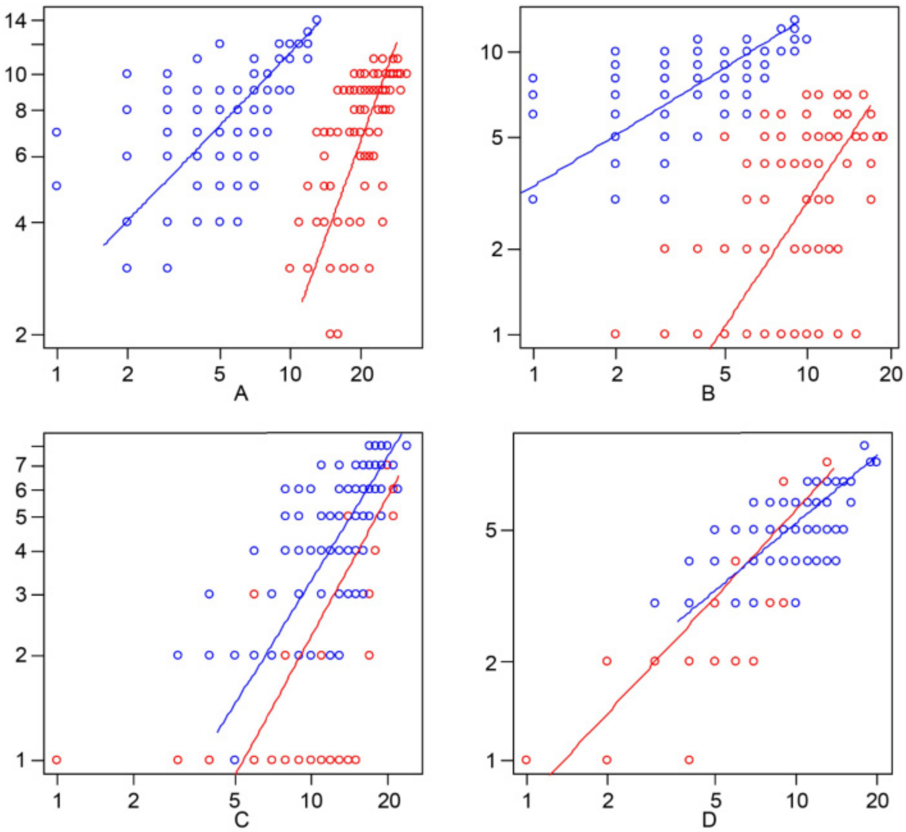

Fig. 5 Scatter diagram of earthworm species abundance and allometric relationships. The abscissa axis is the abundance of earthworm *A. trapezoides* (ind./sample), the ordinate axis is the abundance of *A. rosea* (ind./sample). The red line is the data for 2011, the blue line is the data for 2021.

non-stationarity can be simulated by other temporal processes that had a spatial scale coinciding with the reconstruction zone. Whatever the origin of temporal non-stationarity is, the procedure of variation partitioning makes provides a way to distinguish it and assess the importance of park reconstruction as a factor influencing the soil macrofauna community.

The ecological features of species that make a key contribution to the ordination shift with the temporal variable as a partial predictor allow interpretation of the nature of changes in the macrofauna community over time. The temporal sensitive group includes epigeic species (earthworm *Lumbricus rubellus*, mollusks *Succinella oblonga*, *Vallonia pulchella*), endogeic earthworm *Aporrectodea rosea*, and anecic *Octodrilus transpadanus*. It should be noted that the activity of earthworms is in general limited by the hydromechanical conditions of the soil, which allow deformation of the earthworm hydroskeleton at a maximum pressure (≈0.2 mPa) (Ruiz et al., 2021). The endogeic and anecic earthworms are sensitive to the soil compaction (Jégou et al., 2002; Ruiz and Or, 2018) which explains the effect of temporal changes in the soil penetration resistance at mid-depth on the soil macrofauna. The mollusk *Vallonia pulchella* is sensitive to the soil compaction and soil electrical conductivity in the upper soil layers (Yorkina et al., 2021). These physical properties also demonstrate variability, which can be described by a temporal predictor. The mollusk *Succinella oblonga* and earthworm *Lumbricus rubellus* are sensitive to soil moisture. The epigeic species demonstrates the temporal dynamics that are induced by the properties of forest litter and topsoil.

The group of species that are sensitive to the spatial heterogeneity of soil includes the epigeic species. These are the mollusks *Succinella oblonga* and *Vallonia pulchella*, the beetle *Badister bullatus*, the butterfly larva *Agrotis clavis*, and the millipede *Polydesmus inconstans*. The epigean animals are very sensitive to the condition of the litter, so these ecological features can be explained by the spatial heterogeneity of litter management. In urban parks, the forest litter can be managed according to the requirements of the area. In some parks, litter is swept up and removed off-site. In other parks, the litter remains part of the forest soil. These different methods of managing leaf litter can affect the dynamics of the soil animals that feed, hide, and hunt within these fractions of leaf material (Ashford et al., 2013). A layer of litter can reduce water loss from urban soil (Smith et al., 2006).

4.2 Response of soil macrofauna to park reconstruction

The variation of soil properties under the influence of technological processes during the park reconstruction can be expected to be a key factor that affects the community of soil macrofauna. Our results confirm this assumption, but it turns out that the importance of changes in soil properties is inferior to almost three times the importance of the pure influence of reconstruction. The increase of soil compaction under the influence of technological machines and the performance of other processes leads to a decrease in the pore space of the soil at a given moisture content. The effect of park reconstruction, on its own, on the soil macrofauna involves the mechanisms of influence that differ from the effect of reconstruction by influencing the physical properties of the soil. The chemical contamination in the process of reconstruction can be excluded, as the reconstruction was carried out in compliance with safety standards and during the visual inspection of the territory that no sites of technological liquid spills were noted. The most likely mechanism may be a change in the light regime of the park plantation after the reconstruction. The trimming of tree crowns and the removal of old trees and branches led to an increase in lighting in the area where the reconstruction was carried out (Kunakh et al., 2021a). A greater amount of solar radiation that reaches the soil surface can lead to the increased evaporation of water from the soil surface and worsen the water regime of the soil animals (Monteith 1965; Zhukov et al., 2021). On the other hand, the increased illumination can provide earlier heating of the soil and accelerate the phenological phases of the soil animal dynamics for the period when the soil in spring is more saturated with the moisture after snow melting and living conditions are favorable for the active life of soil animals. The species richness of soil macrofauna communities in urban ecosystems may be higher than in their natural analogs (Smith et al., 2006). This effect can be explained by a higher diversity of habitats (Rebele, 1994). Also, urban environments may offer the favorable conditions for species that are more demanding to thermal conditions and usually inhabit locations much farther south.

The impact of park reconstruction leads to a restructuring of the soil macrofauna community at the endogeic block level. Two endogeic species of earthworms respond in an opposite direction to the park reconstruction. The earthworm *A. rosea* increases its abundance, while the earthworm *A. trapezoides* decreases its abundance due to the park reconstruction. The slope of the regression relationship of the abundance of these earthworm species is also sensitive to the park reconstruction. This slope is significantly lower in the post-reconstruction conditions, which may be a consequence of the increased competitive success of *A. rosea*. Food is an object of competition in earthworms (Abbott, 1980), so the success of interspecific competition in earthworms depends on the availability of resources (Winsome et al., 2006). An increase in the availability of food resources can be assumed to be the result of park reconstruction. A short-term source of the additional food of earthworms can be the increased amount of forest litter, which appears after the mechanical impact in the process of pruning tree crowns and cutting down old branches and trees. In the long-term, the source of additional food can be the root system of herbaceous plants, which actively develop when the light regime increases after reconstruction.

In addition to the availability of food resources, the compactness of the soil can affect the result of competition between earthworm species (Butt, 1998). The competition for food resources is important for the litter dwelling earthworm species, whereas for the soil dwelling species under the conditions of food surplus, the competition for space is of leading importance (Uvarov et al., 2019). The ecological niches of these earthworm species show the divergence along the gradient of moisture conditions. The earthworm *A. trapezoides* prefers the sufficient soil moisture and is often found in mesophilic forests or meadows (Sekulić et al., 2022). The earthworm *A. rosea* is often found in mesophilic conditions (Chalkia et al., 2021), but can also inhabit very arid conditions such as steppe (Yakovenko and Zhukov, 2021). However, the patterns of the response of these species to the changes in soil moisture are different. For the earthworm *A. rosea*, the matrix suction, not the soil water content, is the cue by which the earthworm recognizes dry soil. The response of *A. trapezoides* to the soil moisture is texture dependent (Doube and Styan, 1996). Thus, the increased compactness and decreased soil moisture, and to a lesser extent, the increased food availability after the park reconstruction led to the success of the endogeic earthworm *A. rosea* in competing with the ecologically close *A. trapezoides*.

The endogeic larva *Bothynoderes affinis* and epigeic imago of the beetles *Harpalus affinis* and *H. rufipes* are the indicator of park reconstruction. They are indicators based on the observation that these species were recorded in the park either exclusively after the reconstruction, or their abundance increased significantly after the reconstruction. The larva *Bothynoderes affinis* is a phytophage that prefers to feed on plant roots, which are a source of water for this species. this explains the ability of this species to inhabit rather xerophilic conditions (Volovnik, 2008; Yunakov et al., 2018). The imago of the beetles *Harpalus affinis* and *H. rufipes* inhabit the forest edge or open habitats (Putchkov et al., 2019). Thus, the ecological features of the soil macrofauna that is sensitive to the park reconstruction confirms our assumption that the changes in the light regime can significantly affect the soil macrofauna.

The results raise new questions, the answers to which can be found in future studies. First, of interest is the problem of the ability of the soil macrofauna to restore the physical properties of the soil after recreational load or technological procedures in the urban parks. Also of importance is the problem of the spatial variability of the soil macrofauna community and the evaluation of the role of neutral nature factors in the organization of the soil macrofauna community of urban parks.

5 Conclusion

Reconstruction is an element of park management. The short-term effect of reconstruction is an increase in compaction and electrical conductivity in the upper soil horizon. These changes in the soil physical properties determine only about one-third of the variation in the soil macrofauna community caused by the park reconstruction. The main part of the soil macrofauna response is caused by the "pure" effect of the reconstruction. The park reconstruction results in favorable conditions for the xerophilic endogeneous species *Aporrectodea rosea* and *Bothynoderes affinis*. The deterioration of humidity conditions after the reconstruction leads to a decrease in the abundance of hygrophilic endogeneous species *A. trapezoides*. A change in the light regime of the park after the pruning of tree crowns and the removal of shrubs stimulates an increase in the populations of the epigeic light-loving beetle adults *Harpalus affinis* and *H. rufipes*.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author contributions

NY, OK – the acquisition of data; OK, OZ, AT – The contributed substantially to the conception and design of the study; NY, OZ, AT – The analysis and interpretation.

Ethical statements

The authors guarantee that all studies presented in the manuscript were conducted in an ethical and responsible manner, and in full compliance with all relevant codes of experimentation and legislation.

Electronic supplementary material

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