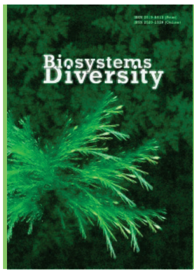

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Increased soil penetration resistance drives degrees of hemeroby in vegetation of urban parks

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Urban parks provide a variety of ecosystem services, and a range of management practices promote their maximisation. The species diversity of plant communities is a factor in the maintenance of ecosystem services. The reconstruction of parks is one of the management practices, but the environmental impact of such activities is not clear. The reconstruction of parks affects vegetation and soil cover, and the interconnection of these components of the urban park ecosystem has not been studied before. The study revealed the features of variability of physical properties of soil and vegetation cover and identified their interconnection in the conditions of urban park reconstruction. The study was conducted in the recreational area of the Botanical Garden of Oles Honchar Dnipro National University (Ukraine). The park was studied in the area where reconstruction activities had previously been carried out. During the reconstruction process, walkways were restored, shrubs were removed, old or damaged trees were excavated, and tree crowns were trimmed. Young trees were planted in place of the removed old trees. Old outbuildings that significantly impaired the aesthetic impression of the park were also dismantled. The reconstruction involved transport and construction equipment. Samples were collected within transects, two of which were located in the reconstruction area, and two other transects were located in a similar area of the park where no reconstruction was carried out. The plant community was found to consist of 65 species. The mean level of alpha diversity was 11.5 species and beta diversity was 5.7. The alpha diversity was higher in the reconstructed park. The principal component analysis of the variability of soil properties extracted four principal components with eigenvalues greater than one. The principal components 1 and 3 reflect the variability of soil properties induced by the park's reconstruction, while the principal components 2 and 4 reflect variability that may be caused by other anthropogenic factors unrelated to the park's reconstruction, or may be due to natural variability of the soil cover. The principal component 1 indicates a uniform increase in the soil penetration resistance as a result of the application of technological processes during the reconstruction. This effect may be the result of the direct technological impact of the mechanisms employed and the large number of employees involved in the park's reconstruction. The condition of the crown space of the park plantation can explain the variation in soil penetration resistance. The increase in the height and projective cover of the grass vegetation is due to a decrease in the closure of the stand crowns, but the effect of such coordinated stand and grass dynamics on soil penetration resistance is observed only at a depth of 25–55 cm. This effect can be explained by the influence of the plant root system on the physical state of the soil. The root system of herbaceous plants is capable of loosening the soil and reducing its soil penetration resistance. The reconstruction of the park led to an increase in the hemeroby of the plant community. The criterion for the success of the reconstruction may be an increase in the attractiveness of the park for visitors without the risk of increasing hemeroby. The trend of increasing hemeroby clearly coincides with the direction of transformation of soil conditions, which are indicated by the principal component 1. The increase in the soil penetration resistance is a driver of the growth of vegetation cover hemeroby. The physical environment of the soil cover acts as an important environmental filter that affects the structure of the vegetation cover and the species composition of plant species complexes.

Keywords: recreation; diversity; innovation project; environmental filter; ecosystem transformation; plant community, biometry.

Introduction

The existence and quality of urban parks is a prerequisite for sustainable and livable cities (Halecki et al., 2023). Protecting and restoring ecosystem services in cities can reduce the ecological footprint and environmental costs of cities, while increasing the resilience, health and quality of life of their residents (Gómez-Baggethun & Barton, 2013). Urban ecosystems can perform a range of ecosystem services (Mexia et al., 2018). Urban parks contribute to ecosystem services such as water and air purification, wind and noise reduction, carbon sequestration, microclimate regulation, wildlife habitat, and create conditions for social and psychological well-being of the residents, enriching human life with meanings and emotions (Chiesura, 2004). Compromises occur when choosing management options for public green spaces, so assessing the multiple ecosystem services can inform decision makers and suggest planning options that can increase the importance of urban parks as nature-based solutions for ecosystem services and improve the quality of life in urban areas (Haase et al., 2014). The variety of management practices in urban parks can influence the quantitative occurrence of ecosystem services. The different tree planting patterns may predominantly contribute to pollution removal or mitigation of thermal effects (Bodnaruk et al., 2017). The planning and management strategies of green spaces can minimise carbon emissions and maximise carbon sequestration. Mowing, pruning, irrigation and fertilisation can enhance the carbon sequestration of vegetation by stimulating the phytomass of urban ecosystems (Jo & McPherson, 1995). Soils in urban parks can act as a carbon store, and understanding the history of land use and selecting the types of vegetation cover in park planning can have a significant impact on the carbon budget of urban parks (Bae & Ryu, 2015). Carbon sequestration by urban parks has significant economic benefits (Gratani et al., 2016). The significant role of urban parks in the performance of ecosystem services is due to their high species diversity (Faly & Brygadyrenko, 2014; Speak et al., 2015; Putchkov et al., 2019). Large parks can be highly heterogeneous in terms of vegetation types and may also be subject to multiple management options. The spatially fine-grained mapping of vegetation types and orography can be useful to study the ecosystem services associated with the different vegetation types. The mapping of ecosystem services such as carbon sequestration, seed dispersal, erosion prevention, water purification, air purification and habitat quality has allowed us to distinguish the importance of different vegetation types common in urban parks in performing these functions (Derkzen et al., 2015). Both vegetation and soil can effectively filter urban runoff, reducing pollutants and nutrients, which is important to maintain the quality of groundwater as it is often used for irrigation or human consumption. This is particularly significant as urban wastewater systems often have high concentrations of nutrients that are odorous, can increase turbidity and cause eutrophication of water and soil, thus degrading water quality (Nidzgorski & Hobbie, 2016). The vegetation cover also controls erosion by reducing the lateral runoff, retaining sediments and stabilising the soil, which prevents landslides and flooding (López-Vicente et al., 2013). Air pollution is a common problem in urban environments (Bolund & Hunhammar, 1999). Urban air quality is the consequence of a complicated interaction between natural and anthropogenic environmental conditions (Mayer, 1999). Air quality can improve due to the existence of vegetation, as trees have a positive effect on it by filtering atmospheric particles (Xing & Brimblecombe, 2019).

The management challenges of urban parks have been made more complex by the fluctuating patterns of park use, the lack of innovation, the poor prioritisation and the inefficiency of the public sector, as well as by the lack of research and budgetary constraints (Pauleit et al., 2003). Park management practices such as the application of natural processes, knowledge of recreation planning and monitoring contribute to sustainable park administration (Hermy & Cornelis, 2000). Diverse indicators can be used as tools to improve the planning and management of parks (Chan et al., 2014). Conservation and sustainable management are critical for the preservation and use of urban parks (Hajzeri, 2021). Consumers focus on the greening of parks and consider the environmental quality of parks to be an important dimension of management (Chan et al., 2018). Servicing, improving maintenance, increasing staffing levels, adding plants, updating infrastructure, improving plant species selection, and managing ecosystems are the most important aspects of managing plants in parks. The common management practices in parks include the maintenance of large trees, the creation of pathways and trails for accessibility, and the removal of invasive and harmful plants. In the selection of plants to cultivate in the park it is important to include those that are more pleasant, colourful, produce flowers, are resistant to disease, are adapted to the climate and provide habitat for other species (Talal & Santelmann, 2020).

Urban parks perform important ecosystem services, the optimisation of which requires the development of adequate management procedures, including park reconstruction (Błaszczyk et al., 2020). The reconstruction of a park significantly changes the ecological regimes of this artificial ecosystem (Löf et al., 2019). The technological procedures have a significant impact on the environment, primarily on the soil cover. The aggregate structure of the soil undergoes changes as a result of the park's reconstruction (Zhang et al., 2022). The main trend of changes is a decrease in the content of aggregate fractions of 3–5 mm in size (meso-aggregates) and an increase in the content of aggregate fractions of <0.25 mm in size (micro-aggregates). Such changes are evidence of negative transformations resulting from the deterioration of urban soil quality. The procedures for the reconstruction of city parks should include the procedure for creating lawns from plants with fibrous root systems to prevent erosion and restore the aggregate state of the soil (Kunakh et al., 2022). The reconstruction of a city park brings many benefits to city residents. It improves the aesthetic perception of the territory and increases the comfort for recreation. It is also worth mentioning the restoration of tree plantations, which is an important component of managing artificial forest plantations in the urban environment. However, the reconstruction of parks is associated with a number of negative impacts on the soil cover. As a result of the technological processes carried out during the reconstruction, soil compaction increases to a considerable depth and the aggregate composition of the soil is disturbed. The thinning of the tree stand and the destruction of shrub undergrowth significantly change the microclimatic regime in city parks and increase the risk of excessive moisture evaporation from the soil surface. These changes can have negative consequences for the ecological services provided by the soil. Therefore, measures to restore the physical properties of the soil should be a mandatory element in the reconstruction of urban parks (Kunakh et al., 2021). The reconstruction of parks affects the physical properties of the soil, leading to increased compaction of the upper soil horizon, increased electrical conductivity and forest litter height. The soil macrofauna demonstrates the spatial and temporal variability, against which the response of the soil animal community to the park reconstruction was determined. Changes in the physical properties of the soil account for about a third of the variations in the soil macrofauna community caused by the reconstruction of parks. The main part of the response of soil macrofauna is caused by the " pure" effect of reconstruction, which is the result of changes in the light regime of parks after pruning of tree crowns and removal of shrubs (Zhukov et al., 2023).

Anthropogenic factors within urban ecosystems act as ecological filters and change the species composition of plant communities, promoting the spread of species with life strategies adapted to urban disturbances (Knapp et al., 2008). The composition of urban species complexes is determined by the action of environmental filters related to land use types (Ahrné et al., 2009). The management of urban parks typically prefers exotic species and disturbs succession processes through frequent disturbance, for example through activities such as mowing (Niemelä, 1999). Some habitat types used for intensive recreation have low alpha diversity as a result of high levels of anthropogenic pressure caused by mowing and trampling (LaPaix & Freedman, 2010).The heterogeneous structure of the park provides new habitats and promotes the conservation of natural vegetation. Human activity in recreation areas affects the organic carbon content of the soil, electrical conductivity, soluble salts, soil compactness and vegetation characteristics (Sarah et al., 2015). The data obtained suggest that indicators of nutrient requirements, temperature and alkalinity preferences of plants increase with urbanisation (Williams et al., 2015).

The impact of park reconstruction on the various components of the park ecosystem was studied. The effects of management activities on the soil, soil macrofauna, and vegetation cover have been determined. However, there are practically no studies that have determined the mutual influence of soil and vegetation cover in the context of park reconstruction. Therefore, the aim of the study was to reveal the features of variability of physical properties of soil and vegetation cover and to identify their interconnection in the conditions of urban park reconstruction.

Materials and methods

The study was carried out in the recreational territory of the Botanical Garden of Oles Honchar Dnipro National University (Ukraine) (48.43°N 35.05°E). The artificial tree plantation was formed after the Second World War on the site of a natural thermophilic oak forest in a ravine (Goncharenko et al., 2020; Goncharenko & Kovalenko, 2019). The park's 2.8 hectare area was reconstructed in 2019 (Kunakh et al., 2021). The renovation process involved restoring walkways, cutting back shrubs, removing old or damaged trees and trimming tree crowns. The old trees were replaced with younger trees. Old outbuildings that significantly blighted the aesthetic impression of the park were also deconstructed. The reconstruction involved transport and construction equipment. The work was carried out throughout the warm season.

The samples were collected within polygons, 2 of which were located in the reconstruction area (a, b), and 2 (c, d) were located in a similar area of the park where no reconstruction was carried out. Each polygon consisted of 105 test points. The points were located along 7 transects of 15 points each. The distance between points in a transect, as well as the distance between transects, was 3 m. The mechanical resistance of the soil was measured in the field using a hand-held Eijkelkamp penetrometer to a depth of 100 cm at 5 cm intervals (Zhukov & Gadorozhnaya, 2016; Zhukov et al., 2019). The mean measurement error of the device is ± 8%. The measurements were made with a cone with a cross-section of 1 cm^2. At each point, the soil mechanical resistance was measured only once. To measure the electrical conductivity of the soil in situ, an HI 76305 sensor (Hanna Instruments, Woodsocket, R. I.) was used in combination with an HI 993310 portable device (Yorkina et al., 2018; Kunakh et al., 2020). The distribution of soil aggregate fractions by size was identified in accordance with the recommendations of "Soil sampling and analysis methodology" (Kroetsch & Wang, 2008). Soil moisture was measured in the field using a dielectric digital moisture meter MG-44 (vlagomer. com.ua). The core method was used to measure the bulk density of the soil (Al-Shammary et al., 2018).

Vascular plant species lists were recorded for each 3×3 m sampling point, along with a visual assessment of species cover using the Braun-Blanquet scale (Westhoff & Van Der Maarel, 1978). The projective cover of plant species was measured at the level of soil, undergrowth (up to 2 m in height) and canopy (over 2 m in height). In all sites, all species were identified to the species level. Seedlings and saplings of tree species were subsequently excluded from the analysis. Plant taxonomy based on Euro+-MedPlantbase (http://ww2.bgbm.org/EuroPlusMed). The hemeroby scale was converted to a 100-point scale (Yorkina et al., 2022). The descriptive statistics, ANOVA and the principal component analysis were calculated using the software Statistica (Statsoft Inc., USA).

Results

Species diversity of plant communities. The plant community consisted of 65 species (Table 1).

Table 1
Species composition of plant communities in different zones of the city park (projective cover, % mean ± SE, N = 105)

Raunkiær plant life-form	Species	Reconstruction		Without reconstruction	
		Polygon *a*	Polygon *b*	Polygon *c*	Polygon *d*
Phanerophytes	*Acer negundo* L.	–	–	–	3.58 ± 0.24
	A. platanoides L.	9.31 ± 1.65	3.78 ± 0.72	1.91 ± 0.37	27.04 ± 1.80
	Aesculus hippocastanum L.	1.74 ± 0.79	1.83 ± 0.77	0.43 ± 0.38	5.81 ± 1.14
	Fraxinus excelsior L.	4.28 ± 0.98	–	0.64 ± 0.29	0.19 ± 0.15
	Gleditsia triacanthos L.	0.10 ± 0.10	0.29 ± 0.29	2.07 ± 0.51	0.35 ± 0.20
	Populus × canadensis Moench	0.67 ± 0.47	1.14 ± 0.82	–	–
	P. alba L.	1.14 ± 0.67	–	–	–
	Quercus robur L.	4.57 ± 1.43	0.48 ± 0.48	–	–
	Robinia pseudoacacia L.	2.52 ± 0.71	3.73 ± 0.83	9.81 ± 0.99	5.75 ± 1.35
	Tilia platyphyllos subsp. cordifolia (Besser) C. K. Schneid.	1.09 ± 0.74	–	0.38 ± 0.38	4.20 ± 1.26
	Ulmus laevis Pall.	–	0.38 ± 0.38	0.49 ± 0.31	0.09 ± 0.07
Nanophanerophytes	*Clematis vitalba* L.	–	–	–	0.02 ± 0.01
	Parthenocissus quinquefolia (L.) Planch.	–	0.03 ± 0.01	–	0.03 ± 0.03
Hemicryptophytes	*Alliaria petiolata* (M. Bieb.) Cavara et Grande	1.16 ± 0.21	1.59 ± 0.32	2.27 ± 0.28	0.13 ± 0.05
	Anthriscus sylvestris (L.) Hoffm.	0.18 ± 0.06	0.04 ± 0.02	29.06 ± 2.52	0.55 ± 0.27
	Arctium minus (Hill) Bernh.	1.30 ± 0.20	3.60 ± 0.57	0.02 ± 0.01	0.62 ± 0.18
	Ballota nigra L.	0.02 ± 0.01	0.14 ± 0.05	0.05 ± 0.03	0.70 ± 0.20
	Carex spicata Huds.	0.63 ± 0.10	0.19 ± 0.04	0.33 ± 0.06	0.20 ± 0.05
	Chaerophyllum temulum L.	0.08 ± 0.02	0.12 ± 0.03	0.01 ± 0.01	0.20 ± 0.06
	Chelidonium majus L.	3.44 ± 0.48	16.01 ± 1.27	0.65 ± 0.19	0.75 ± 0.17
	Chenopodium album L.	–	0.01 ± 0.01	–	0.26 ± 0.09
	Dactylis glomerata L.	0.11 ± 0.07	4.16 ± 0.81	0.01 ± 0.01	0.01 ± 0.01
	Fragaria viridis (Duch.) Weston	–	–	0.02 ± 0.01	–
	Geum urbanum L.	2.21 ± 0.29	2.46 ± 0.31	3.21 ± 0.62	8.62 ± 1.05
	*Jacobaea vulgaris*Gaertn.	–	0.02 ± 0.01	–	–
	Lamium purpureum L.	0.02 ± 0.01	–	0.52 ± 0.04	–
	Myosotis laxa subsp. *caespitosa* (Schultz) Hyl. ex Nordh.	0.54 ± 0.10	0.97 ± 0.12	0.17 ± 0.04	–
	Oxalis dillenii Jacq.	–	0.19 ± 0.09	–	–
	Plantago major L.	0.01 ± 0.01	0.01 ± 0.01	–	–
	Poa angustifolia L.	0.11 ± 0.04	0.07 ± 0.03	0.11 ± 0.05	0.01 ± 0.01
	P. bulbosa L	–	0.01 ± 0.01	0.01 ± 0.01	–
	P. nemoralis L.	0.13 ± 0.04	0.01 ± 0.01	0.72 ± 0.15	0.84 ± 0.18
	Rumex confertus Willd.	–	0.02 ± 0.02	0.02 ± 0.02	–
	*Silene latifolia*Poir.	–	–	–	0.02 ± 0.01
	Solidago canadensis L.	0.03 ± 0.01	–	0.06 ± 0.02	1.55 ± 0.23
	*Taraxacum campylodes*G.E.Haglund	3.03 ± 0.17	2.09 ± 0.15	0.44 ± 0.08	0.11 ± 0.04
	Urtica dioica L.	–	0.03 ± 0.02	1.12 ± 0.08	–
	Veronica hederifolia L.	0.02 ± 0.01	0.01 ± 0.01	–	–
	V. persica Poir.	–	0.01 ± 0.01	–	–
	*Viola hissarica*Juz.	–	0.01 ± 0.01	–	–
	V. odorata L.	2.76 ± 0.21	0.73 ± 0.08	3.54 ± 0.32	1.10 ± 0.18
Therophytes	*Asperugo procumbens* L.	8.41 ± 1.17	4.68 ± 0.62	0.07 ± 0.05	0.04 ± 0.04
	Capsella bursa-pastoris (L.) Medik.	0.19 ± 0.04	0.28 ± 0.04	–	–
	Erigeron annuus (L.) Desf.	0.02 ± 0.01	–	0.01 ± 0.01	0.02 ± 0.01
	E. canadensis L.	–	–	–	0.02 ± 0.01
	Fumaria schleicheri Soy.-Will.	–	0.03 ± 0.01	–	–
	Galium aparine L.	28.58 ± 1.68	26.43 ± 1.55	0.62 ± 0.07	1.49 ± 0.29
	Hordeum murinum subsp. *leporinum* (Link) Arcang.	0.07 ± 0.03	0.02 ± 0.02	0.06 ± 0.05	–
	Impatiens parviflora DC.	1.62 ± 0.31	2.79 ± 0.63	1.09 ± 0.26	42.79 ± 2.70
	Lactuca serriola L.	0.01 ± 0.01	0.01 ± 0.01	–	–
	Lamium amplexicaule L.	0.02 ± 0.01	–	–	–
	Lapsana communis L.	–	0.68 ± 0.12	–	0.01 ± 0.01
	Poa annua L.	0.00 ± 0.00	0.09 ± 0.04	–	–
	Potentilla norvegica L.	–	–	0.01 ± 0.01	0.01 ± 0.01
	Sonchus oleraceus L.	0.02 ± 0.01	–	–	–
	Stellaria media (L.) Vill	3.10 ± 0.44	4.64 ± 0.70	25.10 ± 2.13	1.68 ± 0.25
	Veronica arguteserrata Regel &Schmalh	2.90 ± 0.33	0.14 ± 0.04	–	–
	Bromus tectorum L.	0.19 ± 0.04	0.44 ± 0.10	0.06 ± 0.03	0.05 ± 0.03
Geophytes	*Allium flavescens* Besser	–	–	–	0.01 ± 0.01
	Cirsium arvense (L.) Scop.	0.06 ± 0.02	0.13 ± 0.03	0.02 ± 0.01	0.02 ± 0.02
	Corydalis solida (L.) Clairv.	0.50 ± 0.10	0.02 ± 0.01	0.01 ± 0.01	0.10 ± 0.07
	Elymus repens (L.) Gould	–	0.01 ± 0.01	–	–
	Humulus lupulus L.	0.04 ± 0.02	0.19 ± 0.04	–	0.26 ± 0.06
	Lactuca tatarica (L.) C.A.Mey	0.07 ± 0.03	–	–	–
	Poa pratensis L.	0.02 ± 0.01	–	0.05 ± 0.02	–

The estimated level of species richness of the metacommunity was in the range of 62.1–67.6 species with 95% confidence. The mean alpha diversity level was 11.5 species with a 95% confidence interval of 11.4–11.6 species. The beta diversity was 5.7 with a 95% confidence interval of 5.4–5.9. The plant community within polygon a consisted of 45 species. The estimated level of species richness of the community was in the range of 42.3–47.3 species with a 95% confidence level. The average alpha diversity level was 12.4 species with a 95% confidence interval of 12.2–12.7 species. The beta diversity was 3.6 with a 95% confidence interval of 3.4–3.8. The plant community within polygon b consisted of 48 species. The estimated level of species richness of the community was in the range of 44.3–50.8 species with a 95% probability. The average alpha diversity level was 12.6 species with a 95% confidence interval of 12.4–12.8 species. The beta diversity was 3.8 with a 95% confidence interval of 3.5–4.1. The plant community within polygon c consisted of 38 species. The estimated level of species richness of the community was in the range of 35.2–40.8 species with a 95% probability. The average alpha diversity level was 10.3 species with a 95% confidence interval of 10.1–10.5 species. The beta diversity was 3.7 with a 95% confidence interval of 3.4–4.0. The plant community within polygon d consisted of 39 species. The estimated level of species richness of the community was in the range of 35.9–41.9 species with a 95% probability. The mean alpha diversity was 10.8 species with a 95% confidence interval of 10.6–11.0 species. The beta diversity was 3.6 with a 95% confidence interval of 3.3–3.9. Alpha diversity was higher in the reconstructed park (F = 149.4, P < 0.001).

Variation in soil properties. The principal component analysis of the soil property variability extracted the four principal components with eigenvalues greater than unity (Table 2). These principal components together were able to explain 69.5% of the variation in the feature space. The principal component 1 explained 45.6% of the variation in soil properties and indicated a coherent change in the soil penetration resistance along the entire study profile. This component indicated that as the soil penetration resistance increased, the soil electrical conductivity, leaf litter thickness and soil density also increased, but the soil moisture content decreased. The increase in the scores of this principal component occurs in areas with less closed tree crowns and higher grass cover, regardless of the projective cover of herbaceous plants. An increase in the soil penetration resistance is associated with a decrease in the content of aggregates larger than 1 mm and an increase in the content of aggregates smaller than 0.5 mm. The principal component 1 scores were highest in the reconstruction zone (Fig. 1). Following the results of nested ANOVA, the reconstruction factor was found to be a statistically significant predictor of the variation in this principal component (F = 497.8, P < 0.001), whereas the differences between the polygons in this principal component were not statistically significant (F = 0.59, P = 0.55). The principal component 1 appears to be the result of the transformation of soil conditions due to the impact of the park's reconstruction.

The principal component 2 explained 10.6% of the variation in the feature space and indicated the opposite dynamics of the soil penetration resistance in the 0–10 cm layers on the one hand and 30–100 cm layers on the other. This principal component did not depend on the electrical conductivity of the soil. Its increase was accompanied by an increase in leaf litter thickness and soil density, but a decrease in soil moisture content. The higher scores of the principal component 2 are typical for the areas with greater closeness of tree canopy crowns and reduced height and projected cover of the grass cover. The higher correlations of this principal component correspond to soil conditions that increase the content of aggregates larger than 2 mm and, accordingly, decrease the content of aggregates smaller than this size. The PC2 scores were not statistically significantly different between polygons a and b, where the park was reconstructed (Planned comparison F = 3.2, P = 0.08), but differed significantly between polygons c and d (Planned comparison F = 188.9, P < 0.001). Thus, the principal component PC2 cannot be explained by the effects of the park reconstruction, and it must be assumed that the variability in the soil properties explained by this principal component has a different origin.

The principal component 3 explained 7.1% of the variation in the soil properties and was sensitive to the changes in soil penetration resistance at a depth of 25–55 cm. A decrease in the soil penetration resistance at this depth was accompanied by an increase in the soil density. The higher scores of the principal component 3 were observed under conditions of less dense crown layer and greater height and projective cover of the grass layer. The principal component 3 was sensitive to the opposite dynamics of the content of aggregates with a size of 0.5–3.0 mm on the one hand and less than 0.5 mm on the other. The soil properties described by the principal component PC3 were statistically significantly affected due to the park reconstruction (F = 71.2, P < 0.001). Scores of this principal component increased, and differences between the polygons disappeared as a result of the reconstruction (Planned comparison F = 0.22, P = 0.63). Thus, the principal component 3 can be interpreted as explaining the changes in the soil properties that were also induced by the park's reconstruction.

The principal component 4 explained 6.2% of the variation in the feature space. This principal component was sensitive to the opposite dynamics of soil penetration resistance at depths of 10–35 cm on the one hand and 40–70 cm on the other. The higher scores of the principal component 4 correspond to the lower values of electrical conductivity and soil moisture, but higher leaf litter thickness. This principal component was independent of tree canopy closure, but the higher values of principal component 4 corresponded to the lower values of height and projective cover of the grass cover. The reconstruction did not affect the variation in the soil features explained by this principal component (F = 1.8, P = 0.17).

Table 2
Principal component analysis of variation in soil and vegetation properties (the correlation coefficients are shown only for P < 0.05)

Variable	PC1, λ = 16.4, 45.6%	PC2, λ = 3.8, 10.6%	PC3, λ = 2.5, 7.1%	PC4, λ = 2.2, 6.2%
Soil penetration resistance, MPa in the soil layer, cm				
0–5	0.72	0.10	–	–
5–10	0.79	0.12	–	–
10–15	0.85	–	–	–0.20
15–20	0.86	–	–	–0.28
20–25	0.87	–	–	–0.33
25–30	0.86	–	–0.19	–0.35
30–35	0.84	–0.14	–0.27	–0.28
35–40	0.80	–0.19	–0.36	–
40–45	0.76	–0.22	–0.37	0.11
45–50	0.79	–0.19	–0.30	0.28
50–55	0.83	–0.16	–0.18	0.34
55–60	0.89	–0.13	–	0.30
60–65	0.92	–0.12	–	0.25
65–70	0.92	–0.13	–	0.18
70–75	0.93	–0.13	–	–
75–80	0.92	–0.13	–	–
80–85	0.90	–0.13	–	–
85–90	0.89	–0.12	–	–
90–95	0.91	–0.12	–	–
95–100	0.91	–0.13	–	–
Soil properties				
Electrical conductivity, dSm/m	0.43	–	–	–0.35
Litter depth, cm	0.13	0.30	–	0.61
Soil moisture, %	–0.23	–0.25	–	–0.49
Soil bulk density, g/cm^3	0.61	0.36	0.29	–
Plant cover properties				
Tree crown closure, %	–0.29	0.21	–0.46	–
Grass height, m	0.19	–0.28	0.40	–0.49
Grass projective cover, %	–	–0.20	0.29	–0.12
Soil aggregate size distribution, mm				
> 10	–0.38	–0.67	–	–0.12
7–10	–0.35	–0.79	–	–
5–7	–0.30	–0.74	–	–0.11
3–5	–0.34	–0.83	–	–
2–3	–0.28	–0.56	–0.20	0.35
1–2	–0.23	0.20	–0.74	–0.11
0.5–1	–	0.46	–0.36	–0.41
0.25–0.5	0.32	0.34	0.51	–0.11
<0.25	0.42	0.18	0.63	0.20

Plant community ordination. The eigenvalue of the principal axis extracted after the detrended correspondence analysis was 0.48, indicating that redundancy analysis was the best procedure for plant community ordination in this case.

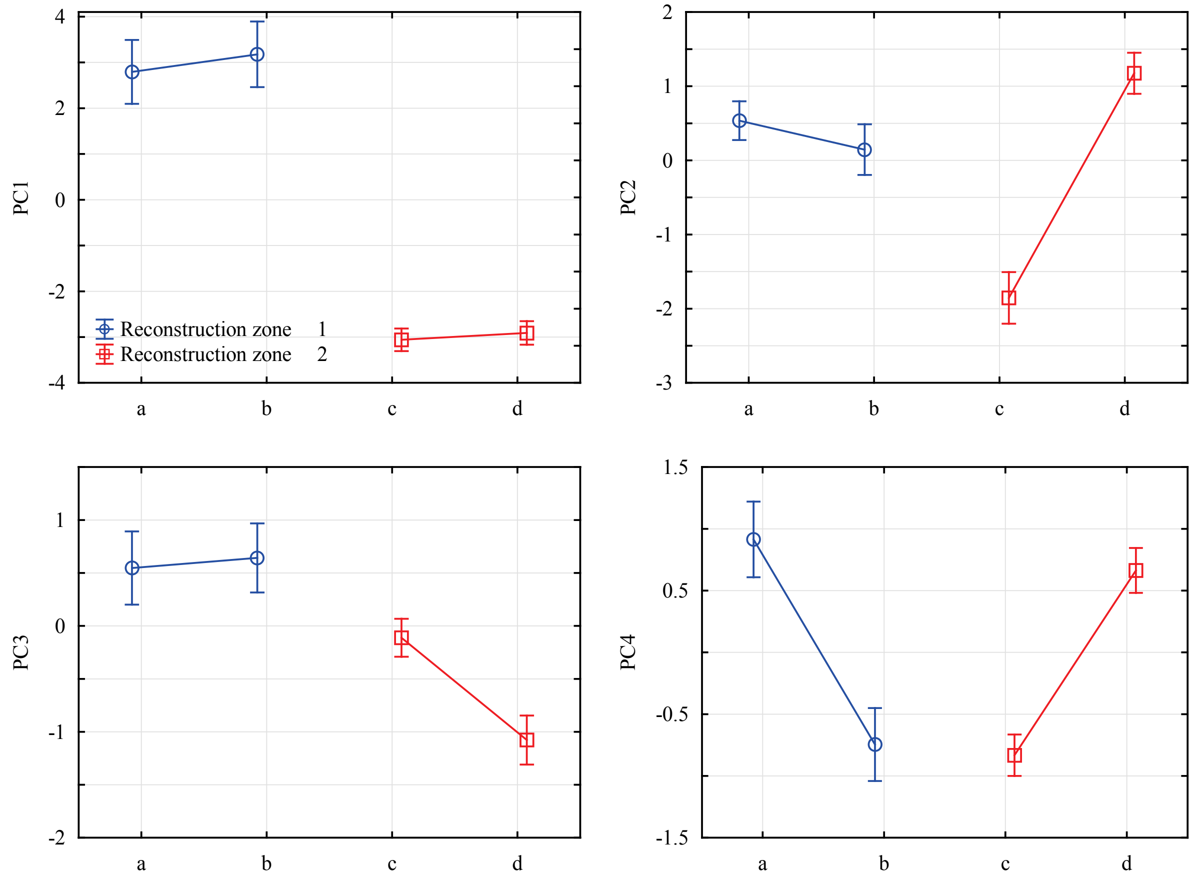

Fig. 1. The dependence of the principal component scores of soil and vegetation properties variation according to the park reconstruction (F = 267.3, P< 0.001) and polygons as nested predictors within the variable "Park reconstruction" (F = 59.4, P < 0.001): the abscissas are polygons (a, b, c, d); the variable "Park reconstruction" has two states: "Reconstruction Zone 1" is the territory where reconstruction processes took place (polygons a and b), and "Reconstruction Zone 2" is the territory where no park reconstruction processes took place (polygons c and d)

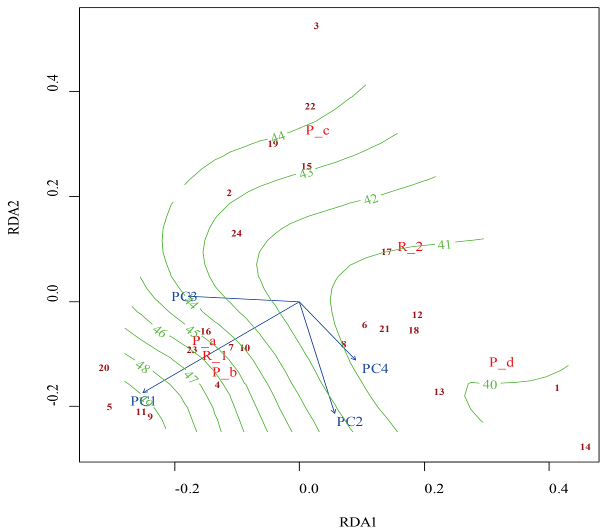

Fig. 2. Results of plant community ordination by redundancy analysis with principal components of the soil property variability and polygons and reconstruction factor as predictors: isolines indicate the variability of the plant community's hemeroby level; numbers indicate the plant scores in the ordination space (scores greater than 0.1 are represented only): 1 is *A. negundo*, 2 is *A. petiolata*, 3 is *A. sylvestris*, 4 is *A. minus*, 5 is *A. procumbens*, 6 is *Ch. majus*, 7 is *D. glomerata*, 8 is *G. aparine*, 9 is *G. urbanum*, 10 is *H. lupulus*, 11 is *I. parviflora*, 12 is *L. purpureum*, 13 is *M. laxa*, 14 is *P. nemoralis*, 15 is *S. canadensis*, 16 is *S. media*, 17 is *T. campylodes*, 18 is *U. dioica*, 19 is *V. arguteserrata*, 20 is *V. odorata*; polygons: P_a is the polygon a, P_b is the polygon b, P_c is the polygon c, P_d is the polygon d; reconstruction: R_1 is the zone after the park reconstruction, R_2 is the zone without reconstruction

The plant community ordination also indicated that the vegetation cover of the unreconstructed areas was characterised by significant diversity and heterogeneity (Fig. 2). The level of hemeroby was the lowest in the polygon d, where it usually varied in the range of 40–41. A slightly higher level of hemeroby was observed in polygon c, where the hemeroby index was in the range of 41–44. The level of hemeroby was higher than 44 in areas a and b, which were subjected to the park's reconstruction. The species complexes formed within the polygon c included *A. petiolata*, *A. sylvestris*, *L. purpureum*, *P. nemoralis*, *S. media*, and *U. dioica*. The species complexes formed within the polygon d included *A. negundo*, *G. urbanum*, *H. lupulus*, *P. nemoralis*, *S. canadensis*, and *I. parviflora*. The polygons within the reconstruction (a, b) form a homogeneous species complex consisting of *A. minus*, *A. procumbens*, *Ch. majus*, *D. glomerata*, *G. aparine*, *M. laxa*, *T. campylodes*, *V. arguteserrata*. The ordination results also emphasised the importance of a complex of soil properties, described by the principal components PC1 and PC3, as a driver of vegetation changes induced by the park's reconstruction. The principal components PC2 and PC4 indicate the role of factors of a different nature which cause heterogeneity of soil cover and vegetation.

The information on park reconstruction (Reconstruction variables), the information on the sample belonging to the respective polygon (Polygon variables) and the variability of soil properties (principal components 1–4) were able to explain 53.3% of the variation in plant community (F = 69.4, P< 0.001). Extracting the effect of reconstruction without taking into account the transformation of soil properties as a result of reconstruction (using the "Reconstruction" variable as a conditional variable) reduced the explained variability of the community to 29.6% (F = 45.2, P < 0.001). Additional extraction of the influence of soil variability induced by the park reconstruction (additional application of variables PC 1 and PC 3 as conditional variables) reduced the explained variability of the community to 25.3% (F = 57.3, P < 0.001).

The partitioning of plant community variability allowed us to identify the direct influence of the studied factors, as well as to assess the importance of their interaction (Fig. 3). Inter-polygon variability of environmental conditions was a significant factor determining the features of the vegetation cover in the park. The impact of the reconstruction was not an independent factor, but a manifestation of a complex transformation of environmental conditions at the level of soil cover and vegetation. This factor manifested itself through interactions with the other studied predictors. The impact of reconstruction was site-specific, as evidenced by the statistically significant effect of the interaction of reconstruction and polygon affiliation, which was able to explain 7.4% of the variation in plant community. The principal components of variability in soil properties 1 and 3 induced by park reconstruction were able to explain 1.5% of the variation in plant community, while variability in soil properties of other nature was able to explain 2.1% of the variation in plant community. The site-specific component of the effect of soil properties on vegetation cover is also significant and can explain 8.9% of the variability in plant community.

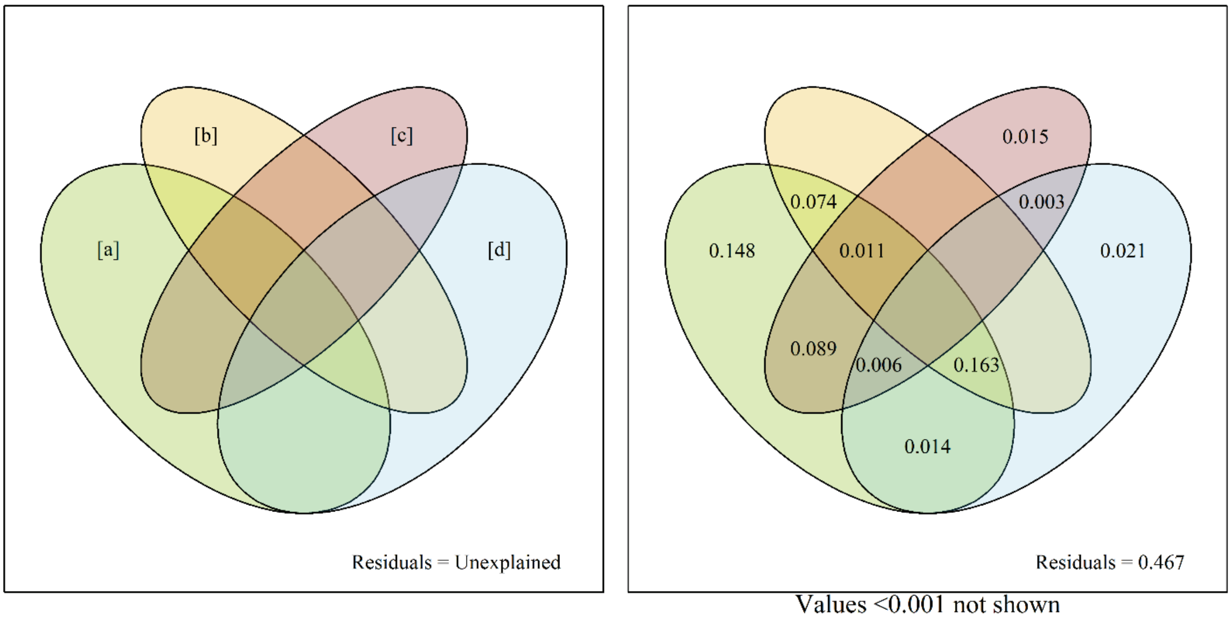

Fig. 3. Partitioning of plant community variation influenced by [a] interpolygon variability (categorical variable Polygon), [b] park reconstruction effect (categorical variable Reconstruction), [c] soil variability independent of the reconstruction effect (PCs 2 and 4) and [d] soil variability under the influence of park reconstruction (PCs 1 and 3)

Discussion

Transformation of soil properties under the influence of park reconstruction. Urban territories provide opportunities for ecosystem conservation (Speak et al., 2015). Urban parks are hotspots of biodiversity and providers of ecosystem services that are important for the functioning of the urban ecosystem and the well-being of citizens. The park management process is aimed at improving the level of ecosystem services provided by public green spaces. An important aspect of management is the reconstruction of parks. Park reconstruction has a direct impact on soil and vegetation (Setälä et al., 2017). The effects of such impacts can also be predicted, which are delayed in time. Changes in the physical properties of the soil as a result of park reconstruction should affect the structure of the vegetation cover, mainly the grass layer. In turn, changes in the structure of the tree stand after reconstruction change the overall conditions of the park environment, which also affects the functioning of the soil. The reconstruction ultimately aims to improve the conditions for park visitors, and if successful, the number of visitors and the time they spend in the park should increase, as well as the level of recreational pressure on the park environment. This may also be the cause of changes in vegetation and soil cover.

The variations in soil properties were described by the four principal components, which can be assumed to be the result of four groups of environmental factors. The principal components 1 and 3 describe the variability in soil properties induced by the park's reconstruction, while the principal components 2 and 4 indicate variability that may be due to other anthropogenic causes unrelated to the park's reconstruction, or may be due to natural variability in the soil cover. The principal component 1 indicates that the application of technological processes during the reconstruction results in a uniform increase in soil penetration resistance. This effect may be the result of the direct technological impact of the mechanisms and the large number of employees involved in the park's reconstruction (Mileusnić et al., 2022). But such an impact is unlikely to be uniform over a large area comparable to the area of the experimental polygons (Barik et al., 2014). The negative correlation between soil penetration resistance and tree canopy closure may explain the observed effect (Barik et al., 2014). The reconstruction of the park has been shown in previous studies to have led to an increase in the number of light-loving herbaceous plant species. It has also been revealed that the reconstruction results in the homogenisation of ecological conditions in certain parts of the park. The spatial organisation of tree crowns is the key factor in structuring the herbaceous layer in the untreated areas of the park. After the reconstruction, the role of tree crowns decreases, which is due to the effect of a delayed reaction of the grass cover to sudden changes in the crown condition (Kunakh et al., 2021). The removal of old trees and pruning of tree canopies were part of the park's reconstruction. As a result of these measures, the light penetration of the tree canopies has increased significantly. Additional solar radiation stimulates greater evaporation of water from the soil surface (Aydin et al., 2008). This effect is confirmed by the finding that the soil moisture content decreased with the decrease in crown closure. In turn, there is a negative correlation between soil moisture and soil penetration resistance. Thus, the state of the crown space of a park plantation can explain the variation in soil penetration resistance. The difference in soil penetration resistance between the reconstructed area and the surrounding areas can be predicted to decrease over time as the shadow light structure of the parkland is restored.

The phenomena of compensatory restoration of the physical condition of the soil, disturbed as a result of reconstruction, can occur not only as a result of a direct reduction in the effect of the primary cause. The change in light conditions can affect the state of the grass cover (Heger, 2016). The important contribution of height and projective cover to the variation in principal component 3 was found. The increase in height and projective cover of the grass cover is due to a decrease in the closure of the stand crowns, but the effect of such coherent stand and grass cover dynamics on the soil penetration resistance is observed only at a depth of 25–55 cm. This effect can be explained by the influence of the plant root system on the physical state of the soil. The root system of herbaceous plants is capable of loosening the soil and reducing its soil penetration resistance (Boldrin et al., 2022).

Response of grass cover to park reconstruction. The environmental conditions within the park, which has a certain extent and is located in a wide range of topographic diversity, are quite heterogeneous. The grass cover is a sensitive indicator of ecological conditions and regimes, and therefore also shows considerable diversity and variability. Therefore, the so-called "control" conditions largely do not correspond to the meaning given to this category in laboratory research. Usually, a control is something that is the most static compared to which the influence of the factor under study is manifested. In the case of the field experiment, the control polygons (d, c) had the most heterogeneous floristic composition, which was indicated in the ordination diagram by the larger area corresponding to these polygons. A common feature of the areas without park reconstruction was a relatively lower level of hemeroby of plant communities. The park reconstruction immediately affects this phytoindicator. The reconstruction of the park should be noted to be not the only reason for the variation in the level of hemeroby.

In addition to significant technological impacts, such as park reconstruction, proximity to the park boundaries and different levels of recreational load can be considered as the main sources of hemeroby variation in the park. The park borders are in contact with the aggressive urban environment, which is a source of various impacts on green spaces. This includes chemical pollution of industrial origin and from motor vehicles. The environment surrounding the park is also a source of noise and heat pollution. The continuous asphalt pavement causes powerful lateral water runoff during intense storms, which can also cause soil erosion within the parks. The level of comfort of a park determines its attractiveness to visitors, and since this is the case, the overall level of the park's hemeroby also depends on it. The reconstruction of the park is aimed at improving the conditions for visitors to stay in it, and thus increases the likelihood of increasing the hemeroby of the vegetation cover in the park. Obviously, the criterion for the success of the reconstruction can be an increase in the attractiveness of the park for visitors without the risk of increasing hemeroby.

Various parts of the park differ in terms of hemeroby, which can be seen as a function of the differential attractiveness of different park areas. The reconstruction promotes an increase in the level of hemeroby. This can be seen as a result of the direct impact on the vegetation of the technological processes during the reconstruction, as well as a consequence of positive changes as a result of the reconstruction aimed at increasing the attractiveness of the park for visitors. The homogenisation of ecological conditions in the reconstruction area and the increased homogeneity of plant communities in the reconstruction area should also be noted, as evidenced by the smaller area occupied by plant communities from polygons a and b, where the reconstruction took place. According to the urban homogenisation hypothesis, urbanisation has a strong homogenising effect on the species pool of cities, making vegetation in cities around the world more similar to each other than might be expected (McKinney, 2006). The intensity of homogenisation demonstrates a positive correlation with the level of disturbance (Kühn & Klotz, 2006). This hypothesis predicts a higher proportion of cosmopolitan and alien species in more disturbed habitats, which leads to a decrease in the proportion of natural flora species (Balázs et al., 2016).

The importance of soil transformation in grass cover dynamics. Hemeroby as a synthetic indicator of the level of anthropogenic transformation of vegetation cover is a consequence of the influence of various environmental factors (Fehrenbach et al., 2015). Undoubtedly, the soil conditions for plant organisms create the basis for their life activity. The trend of increasing hemeroby clearly coincides with the direction of transformation of soil conditions, which are indicated by the principal component 1. This component indicates an increase in soil penetration resistance throughout the soil profile. Thus, the increase in soil penetration resistance is a driver of the growth of vegetation hemeroby. The most resistant to the impact of the deterioration of the physical condition of the soil as a result of the park reconstruction were *A. procumbens*, *G. urbanum*, *I. parviflora*, and *V. odorata*. The influence of soil physical properties is usually studied in the context of agricultural plants in terms of their impact on yields (Moreno et al., 1997). In the context of assessing the impact of soil penetration resistance on the diversity of the vegetation cover of parks, this factor should be considered as a source of disturbance. The intermediate disturbance hypothesis suggests that diversity and disturbance are unimodally related (Connell, 1978). Above a critical level of disturbance, further increases in disturbance lead to a decrease in the diversity of plant communities. Thus, a decrease in species diversity can be expected in highly disturbed habitats. A higher proportion of weeds and species resistant to disturbance in more disturbed habitats can be considered as an indicator of disturbance (Balázs et al., 2016). The main aspect of plant resistance to anthropogenic impact is the ability to exist in conditions of significant soil compactness, which is indicated by increased soil density and soil penetration resistance. Urban conditions are one of the main environmental filters that form the species pool of urban habitats (Williams et al., 2015). The city as a whole is significantly transforming the climate regime, creating heat islands (Zhu et al., 2021). Urbanisation is also a factor in enriching urban soils with nitrogen and other nutrients (Davies & Hall, 2010). Nitrogen enrichment of urban soils affects microbiological processes (Leff et al., 2015). Such changes in environmental conditions in cities allow us to predict an increase in the proportion of heat- and nitrogen-loving species and a decrease in the proportion of moisture-loving species in urban habitats (Balázs et al., 2016). Our results suggest that the physical conditions of the soil cover also act as an important ecological filter that influences the structure of the vegetation cover and the species composition of plant species complexes.

The vegetation cover is able to counteract excessive soil compactness and loss of soil aggregate structure due to direct technological impact during the park reconstruction and as a result of the subsequent effect of reconstruction activities as a response of the soil to greater surface insolation and drying. The root systems of plants are able to restore the aggregate structure of the soil, its porosity, and contribute to the reduction of soil penetration resistance. Obviously, this process is not fast and its active providers can be species that can withstand high soil compactness. The process of restoring the physical condition of the soil may be a factor in the succession dynamics of the community, as a result of which the hemeroby of the plant community may decrease. However, this aspect of the relationship between vegetation cover and soil is hypothetical and requires further experimental verification, as such evidence has been collected mainly for agricultural plants. Information on the contribution of wild plants to soil loosening is important for understanding their role in providing ecosystem services, the maximisation of which may be one of the target functions of park planting reconstruction. In addition, it is of interest to study the relationship between hemeroby and the aesthetic appeal of park plantings. It can be assumed that more natural plant communities are more aesthetically pleasing, so soil compactness management can be one of the tools to achieve greater visitor comfort in parks.

Conclusions

The reconstruction of the park has a direct impact through technological actions during the execution of works, and also has a significant subsequent prolonged effect. The prolonged effect is due to an increase in recreational activity by increasing the comfort of the park for visitors, optimising the movement of visitors through the improvement of park infrastructure. The prolonged effect is also due to the management of tree plantations and the reduction of crown closure. Higher insolation and improved aeration lead to greater soil drying and increased soil penetration resistance within at least a metre depth. The increase in soil compactness is the most important driver that causes the restructuring of the vegetation structure due to the park's reconstruction. The impact of the reconstruction on the vegetation cover can be clearly induced by the hemeroby index. The hemeroby of the park's plant community increases with increasing soil penetration resistance. The reverse effect of the plants is likely to occur, resulting in a gradual decrease in soil compactness.

The research was carried out at the authors' own expense.

The authors declare no conflict of interest.

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