sciendo

Ekológia (Bratislava) - Journal of the Institute of Landscape Ecology, Slovak Academy of Sciences Vol. 41, No. 2, p. 135–146, 2022

DOI:10.2478/eko-2022-0014

ASSESSMENT OF NATURALNESS: THE RESPONSE OF SOCIAL BEHAVIOR TYPES OF PLANTS TO ANTHROPOGENIC IMPACT

NADIYA YORKINA[1], IGOR GONCHARENKO[2], OLENA LISOVETS[3,4], OLEXANDER ZHUKOV ✉[5]

[1]Department of Ecology, General Biology, and Environmental Management, Bogdan Khmelnitsky Melitopol State Pedagogical University, Hetmanska st., 20, Melitopol, 72318, Ukraine; e-mail: nadyayork777@gmail.com

[2]Institute for Evolutionary Ecology of NAS of Ukraine, 37 Academician Lebedev str, Kyiv, 03143, Ukraine; e-mail: goncharenko.ihor@gmail.com

[3]Department of Geobotany, Pedology, and Ecology, Faculty of Biology and Ecology, Oles Honchar Dnipro National University, Gagarin Ave. 72, 49010 Dnipro, Ukraine; e-mail: lisovetselena@gmail.com

[4]Department of Garden and Park Art and Landscape Design, Faculty of Agronomics, Dnipro State Agrarian and Economic University, Serhii Efremov Str., 25, 49600 Dnipro, Ukraine; e-mail: lisovetselena@gmail.com

[5]Department of Botany and Horticulture, Bogdan Khmelnitsky Melitopol State Pedagogical University, Hetmanska st., 20, Melitopol, 72318, Ukraine; e-mail: zhukov_dnipro@ukr.net

✉ Corresponding author

Received: 4.11.2021 / **Accepted:** 18.3.2022

Abstract

Yorkina N., Goncharenko I., Lisovets O., Zhukov O.: Assessment of naturalness: the response of social behavior types of plants to anthropogenic impact. Ekológia (Bratislava), Vol. 41, No. 2, p. 135–146, 2022.

The aims of this research are to assess the relationship between the concepts of hemeroby and naturalness of plant communities and to test the hypothesis about the ordinal nature of the response of social behavior types of plants under anthropogenic influence. Study area is the recreational zone of the Botanical Garden of Dnipro National University, named after Oles Gonchar, Dnipro City, Ukraine (48.43°N 35.05°E). Four polygons (105 relevés in each) were examined. Two polygons were in the zone after park reconstruction, and two were in the zone without reconstruction. The vegetation community ordination was performed using RLQ analysis. The Q-table was represented by eight dummy variables, which indicated social behavior types. The most important predictors of naturalness were aggressive alien species and invaders and weeds (positive dependence) and disturbance tolerants (negative dependence). The most important predictors of hemeroby were aggressive alien species (negative dependence) and ruderal competitors, invaders, and disturbance tolerants (positive dependence). Naturalness and hemeroby reflect different strategies for transforming a plant community and are not completely symmetrically opposed concepts. The response of a plant community is multivariate, so the naturalness metric based on the social behavior types is only able to distinguish well between the extreme states of a plant community, but is a poor measure for a more detailed assessment of naturalness.

Key words: vegetation, anthropogenic transformation, naturalness, hemeroby, RLQ ordination, plant indicator scales.

Introduction

The concept of naturalness reflects the degree of degradation of the natural state of the ecosystem and consists in comparing the current and natural states. Assessing naturalness or habitat degradation is one of the most important challenges of conservation biology (Erdős et al., 2017, 2018) because it helps in the designation of protected areas (Moravčík et al., 2010), supports management activities (Goncharenko, Yatsenko, 2020; Lykholat et al., 2021), and facilitates effective monitoring of restoration projects (Sengl et al., 2017; Yao et al., 2019; Côté et al., 2021). The naturalness is inversely related to degradation: the more degraded the habitat, the lower its naturalness (Winter, 2012). Naturalness should be considered in the context of a continuum from completely intact ecosystems to completely altered, man-made ecosystems (Machado, 2004). The concept of hemeroby is also related to anthropogenic impact (Yorkina et al., 2020; Zinnen et al., 2021). Narrower grades are defined for a higher level of anthropogenic transformation within the concept of hemeroby. In turn, narrower grades are defined for a lower level of anthropogenic transformation within the concept of naturalness (Winter, 2012). Degradation cannot be measured directly (Kowarik, 1990). Some of the parameters related to degradation can be measured. But degradation as such cannot be measured with any technical equipment because degradation can involve a complex combination of several different factors such as pollution, noise exposure, trampling, logging, removal of forest litter, and fire (Erdős et al., 2017). Naturalness correlates with the structural diversity of the ecosystem (Winter, 2012).

The response of plant species to different levels of anthropogenic impact can be identified (Sukopp, 1969). Some species prefer degraded areas, while others are more frequent or

© The Author(s) 2022. This is an open access article licensed under the Creative Commons Attribution-NonCommercial-NoDerivs License (http://creativecommons.org/licenses/by-nc-nd/3.0/).

more abundant in natural or near-natural conditions (Erdős et al., 2017). Plant species indicate the level of degradation (Terwayet Bayouli et al., 2021). The varying tolerance of species to degradation can be used to assess the naturalness of a given site (Wulf, 1997; Müller et al., 2007). The theoretical approach to determining the values of naturalness indicators is very similar to the procedure for determining the indicator values of ecological factors (Erdős et al., 2017). Anthropogenic disturbances mimic natural disturbances, but have a number of specific properties that allow them to be identified. These features are the contrasting type, scale, frequency, and intensity (Yuan et al., 2016). Two approaches are used to identify anthropogenic disturbances. An assessment of the degree of transformation can be made by measuring the distance of a particular community from its pristine state («nature I») (Westhoff, 1971; Wulf, 1997). Alternatively, the transformation can be estimated by the distance to some future self-regulating state of the community («nature II») (Sukopp, 1969, 1972). Succession can lead to stages without connections to pristine vegetation in highly altered areas. For this reason, the concepts concerning pristine vegetation are not suitable for assessing anthropogenic stress. In such cases, nature II concepts are appropriate because they allow for a differentiated assessment of the natural development even in heavily modified areas. In areas not affected by severe anthropogenic impact, the use of nature I or nature II concepts leads to similar results (Kowarik, 1990). Plant species indicate the naturalness of their habitat, which is due to their different resistance to habitat degradation (Kowarik, 1990; Wulf, 1997; Kim et al., 2002; Hill et al., 2002). Analogous to the relative values of ecological indicators (Ellenberg et al., 1991; Didukh, 2011), species are suggested to be assigned scores on an ordinal scale according to whether they prefer degraded or natural habitats (Domnich et al., 2021). The average of ordinal indicator values is proven to be effective and is widely used in vegetation science (Dzwonko, 2001; Seidling, Fischer, 2008; Tölgyesi, Körmöczi, 2012). Hemeroby and naturalness need to be quantifiable if they are to become well-defined concepts. A number of different scales have been proposed to characterize hemeroby (Sukopp, 1969). One method of examining the ecological index is to find out whether its values are similar for associated species in plant communities (Hill et al., 2002). The values of Borhidi's relative naturalness indicator (Borhidi, 1995) can be applied to assess the naturalness of ecosystems; species were assigned «naturalness scores» on an ordinal scale that ranged from –3 (plant species that are able to survive in highly degraded habitats) to +6 (species that occur exclusively in pristine environments) (Borhidi, 1995). However, the ordinal nature of the scale is accepted by default and has not been proven.

The aims of the study were:

1. to assess the relationship between the concepts of hemeroby and naturalness of plant communities and
2. to test the hypothesis about the ordinal nature of the response of social behavioral types of plants under anthropogenic impact.

Material and methods

Study area

The study was carried out in the recreational zone of the Botanical Garden of Dnipro National University, named after Oles Gonchar, Dnipro City, Ukraine (48.43°N 35.05°E). The urban park was created after World War II on the site of a natural thermophilous oak forest (Goncharenko, Kovalenko, 2019; Goncharenko et al., 2020). The reconstruction of the 2.8-ha section of the park was carried out in 2019 (Kunakh et al., 2021a). Walkways were restored, shrubs and old or damaged trees were removed, and tree crowns were trimmed during the reconstruction. In place of the removed old trees, young trees were planted. Also, the old outbuildings, which greatly affected the esthetics of the park, were removed. Transport and construction machinery was used in the reconstruction. Thus, the vegetation in the park area with and without reconstruction differs significantly in terms of the level of anthropogenic transformation, which makes the comparison between the polygons reasonable with respect to the study in terms of naturalness and hemeroby.

Data collection

The vegetation description was performed at four polygons, two of which were placed in the reconstruction zone and two in a similar area of the park where no reconstruction was performed. Polygons 1 and 2 were in the area which was reconstructed, and polygons 3 and 4 were in the area without reconstruction. Each polygon contained 105 sampling plots. Vascular plant species lists were recorded for each 3×3 m sampling plot, along with a visual assessment of species coverage using a Braun-Blanquet scale (Westhoff, Van Der Maarel, 1978). The plots were arranged in a regular order within the polygons with a dimension of 7 by 15 plots. The projective cover of plant species was measured at soil level, in the understory (up to 2 m in height) and in the canopy (above 2 m in height). Seedlings (including the seedlings of tree species) were subsequently excluded from the analysis. Grass height was measured with a ruler in 10-fold replications within each plot. Within a plot, the grass height measurement points were randomly placed. Plant taxonomic names follow the Euro + Med Plantbase resource (http://ww2.bgbm.org/EuroPlusMed).

Hemeroby and naturalness scales

Scales were used to assess hemeroby according to Frank and Klotz (1990). The original scales were converted calculating the half-sum of the minimum and maximum values for each species, and then they were rescaled to 100-point scales. To assess naturalness, social behavior types of plants according to Borhidi (1995) were used with the application of the following categories: specialists (S), natural competitors (C), generalists (G), natural pioneers (NP), disturbance tolerants and indigenous weeds (DT + W), indigenous ruderal competitors (RC), and alien competitors and introduced species (AC + I). The species *Veronica arguteserrata* and *Viola hissarica* are absent from the Borhidi list. Species are designated as quarantine and invasive (Kurdyukova, 2015), so they were evaluated as "invader" (–3). The species *Lactuca tatarica* is also absent from the list. This species is reported as a weed (Kurdyukova, 2015), so it was rated as a "ruderal competitor" (–2). The species *Tilia cordifolia* is artificially cultivated in gardens and parks, so it was evaluated as "introduced alien/adventive" (–1). The weighted

average of the hemeroby scale, taking into account projective plant coverage, was used to characterize the hemeroby of each sample (Hm). Also, the weighted value of the social behavior type scales with regard to projective plant coverage was used to characterize the naturalness of each sample (Nv).

Soil properties measurement

The following soil properties were measured at each test point of the polygons. The soil mechanical resistance was measured in the field using the Eijkelkamp manual penetrometer to a depth of 100 cm at 5 cm intervals (Zhukov, Gadorozhnaya, 2016; Zhukov et al., 2019b). The average error of the measurement results of the device is ±8%. Measurements were made with a cone with a cross section of 1 cm^2. At each measurement point, the soil mechanical resistance was performed in only one replication. To measure the electrical conductivity of soil *in situ*, the HI 76305 sensor (Hanna Instruments, Woodsocket, RI, USA), working in conjunction with the portable instrument HI 993310 was used (Yorkina et al., 2018; Kunakh et al., 2020). Soil moisture was measured under field conditions using a dielectric digital moisture meter MG-44 (vlagomer.com.ua).

Statistical analysis

Soil properties and vegetation characteristics were subjected to principal component analysis. The initial soil data were log-transformed before the analysis. The principal components whose eigenvalues exceeded unity were applied for subsequent analysis.

The vegetation community ordination was performed using RLQ analysis (Dray et al., 2014). RLQ is a multivariate technique that evaluates the joint structure between three tables: L (species distribution across samples), R (ecological characteristics of samples), and Q (species traits). The L-table is represented by a table of 56 columns (species) and 420 rows (samples). The R-table is represented by 11 columns (weights of five principal components, four discrete variables indicating that the sample point belongs to one of the four polygons, assessment of the plant community naturalness Nv and hemeroby Hem). The Q-table is represented by eight dummy variables, which indicate social behavior types. The value "1" of the variable indicates that the species belongs to this type and the value "0" indicates the opposite. Also, in the Q-table, there is a continuous variable, which indicates the score value of hemeroby of the species. Statistical procedures for RLQ analysis were performed using the ade4 library (Dray, Dufour, 2007) for the R environment (R Core Team, 2020). The significance of the RLQ axes was estimated using the randtest function (Dray, Dufour, 2007).

The response function of the naturalness index Nv in the RLQ space of the axes was approximated by a third-order polynomial. The computation of the local maximum and minimum of a polynomial function was performed using an online calculator WolframAlpha (https://www.wolframalpha.com/).

Results

A total of 56 plant species were found in the studied polygons in the grass layer (Table 1). Weeds dominated in the park area which was reconstructed, both in the number of species and in the projective

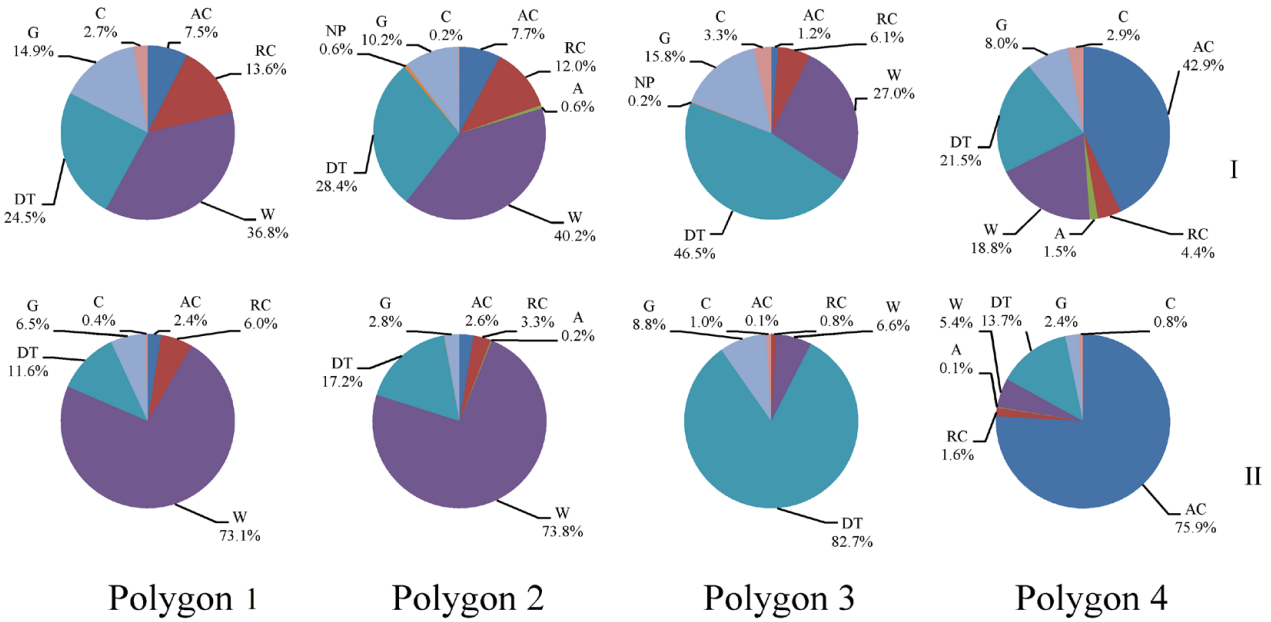


Fig. 1. Distribution of Borhidi's social behavior types in the structure of herbaceous layer of vegetation within the polygons with (polygon 1 and 2) and without (polygon 3 and 4) reconstruction: I – the structure based on number of species (in % of the number of species); II – the structure based on projective cover (in % of projective cover); C – competitors; G – generalists; NP – natural pioneers; DT – disturbance tolerant; W – weeds; A – adventives or introduced alien species; RC – ruderal competitors; AC – aggressive alien species or invaders.

Table 1. Species diversity and projective cover of the herbaceous layer.

Species	Naturalness value, Nv*	Hemeroby index, Hm**	Projective cover of the grass layer, % (mean ± standard error, N = 105; "+" denotes the single presence of the species)			
			Polygon 1	Polygon 2	Polygon 3	Polygon 4
Acer negundo L.(seedlings)	–3	62	–	–	–	3.6 ± 0.24
Alliaria petiolata (M. Bieb.) Cavara et Grande	+1	34	1.2 ± 0.21	1.6 ± 0.32	2.3 ± 0.28	0.1 ± 0.05
Allium oleraceum L.	+4	36	–	–	–	+
Anthriscus sylvestris (L.) Hoffm.	+2	46	0.2 ± 0.06	0.2 ± 0.02	29.1 ± 2.52	0.5 ± 0.27
Arctium minus (Hill) Bernh.	+1	48	1.3 ± 0.2	3.6 ± 0.57	+	0.6 ± 0.18
Asperugo procumbens L.	+1	79	8.4 ± 1.17	4.7 ± 0.62	0.1 ± 0.05	0.1 ± 0.04
Ballota nigra subsp. *ruderalis* (Sw.) Briq.	–2	56	+	0.1 ± 0.05	0.1 ± 0.03	0.7 ± 0.20
Anisantha tectorum (L.) Nevski	+2	89	0.2 ± 0.04	0.4 ± 0.10	0.1 ± 0.03	0.1 ± 0.03
Capsella bursa-pastoris (L.) Medik.	–3	80	0.2 ± 0.04	0.3 ± 0.04	–	–
Carex spicata Huds.	+2	33	0.6 ± 0.10	0.2 ± 0.04	0.3 ± 0.06	0.2 ± 0.05
Chaerophyllum temulum L.	+2	46	0.1 ± 0.02	0.1 ± 0.03	+	0.2 ± 0.06
Chelidonium majus L.	+1	48	3.4 ± 0.48	16 ± 1.27	0.6 ± 0.19	0.8 ± 0.17
Chenopodium album L.	–2	91	–	+	–	0.3 ± 0.09
Cirsium arvense (L.) Scop.	–2	59	0.1 ± 0.02	0.1 ± 0.03	+	+
Clematis vitalba L.	+2	34	–	–	–	+
Corydalis solida (L.) Clairv.	+5	25	0.5 ± 0.10	+	+	0.1 ± 0.07
Dactylis glomerata L.	+2	46	0.1 ± 0.07	4.2 ± 0.81	+	+
Elytrigia repens (L.) Nevski	–2	68	–	+	–	–
Erigeron annuus (L.) Desf.	–3	34	+	–	+	+
Erigeron canadensis L.	–3	79	–	–	–	+
Fragaria viridis (Duch.) Weston	+4	28	–	–	+	–
Fumaria schleicheri Soy.-Will.	+3	63	–	+	–	–
Galium aparine L.	+1	38	28.6 ± 1.68	26.4 ± 1.55	0.6 ± 0.07	1.5 ± 0.29
Geum urbanum L.	+2	33	2.2 ± 0.29	2.5 ± 0.31	3.2 ± 0.62	8.6 ± 1.05
Hordeum murinum L.	+1	89	0.1 ± 0.03	+	0.1 ± 0.05	–
Humulus lupulus L.	+2	34	+	0.2 ± 0.04	–	0.3 ± 0.06
Impatiens parviflora DC.	–3	38	1.6 ± 0.31	2.2 ± 0.4	1.1 ± 0.26	42.8 ± 2.7
Jacobaea vulgaris Gaertn.	+1	34	–	+	–	–
Lactuca serriola L.	+1	81	+	+	–	–
Lactuca tatarica (L.) C.A.Mey	–2	100	0.1 ± 0.03	–	–	–
Lamium amplexicaule L.	+1	48	+	–	–	–
Lamium purpureum L.	+1	70	+	–	0.5 ± 0.04	–
Lapsana communis L.	+2	15	–	0.7 ± 0.12	–	+
Myosotis sparsiflora Pohl	+4	38	0.7 ± 0.12	1.1 ± 0.13	0.2 ± 0.04	–
Oxalis dillenii Jacq.	–1	36	–	0.2 ± 0.09	–	–
Parthenocissus quinquefolia (L.) Planch.	–1	25	–	+	–	+
Plantago major L.	+1	15	+	+	–	–
Poa angustifolia L.	+2	34	0.1 ± 0.04	0.1 ± 0.03	0.1 ± 0.05	+
Poa annua L.	–2	91	+	0.1 ± 0.04	–	–
Poa bulbosa L	+3	31	–	+	+	–
Poa nemoralis L.	+5	25	0.1 ± 0.05	–	0.8 ± 0.15	0.9 ± 0.19
Poa pratensis L.	+4	38	+	–	+	–
Potentilla norvegica L.	+4	36	–	–	+	+
Rumex confertus Willd.	+2	89	–	+	+	–
Silene latifolia Poir.	+1	62	–	–	–	+
Solidago canadensis L.	–3	62	+	–	0.1 ± 0.02	1.4 ± 0.21
Sonchus oleraceus L.	+1	80	+	–	–	–
Stellaria media (L.) Vill	+2	46	3.1 ± 0.44	4.6 ± 0.7	25.1 ± 2.13	1.7 ± 0.25
Taraxacum officinale agg.	–2	69	3 ± 0.17	2.1 ± 0.15	0.4 ± 0.08	0.1 ± 0.04
Tilia platyphyllos subsp. *cordifolia* (Besser) C.K.Schneid.	–1	25	–	–	–	0.1 ± 0.02
Urtica dioica L.	+2	46	–	0 ± 0.02	1.1 ± 0.08	–
Veronica arguteserrata Regel & Schmalh	–3	90	3.2 ± 0.35	0.1 ± 0.04	–	–
Veronica hederifolia L.	+1	48	+	+	–	–
Veronica persica Poir.	+1	80	–	+	–	–
Viola hissarica Juz.	–3	85	–	+	–	–
Viola odorata L.	+4	38	2.9 ± 0.2	0.7 ± 0.08	3.7 ± 0.33	1.1 ± 0.17

Notes: *Naturalness values according A. Borhidi (1995): +5 – competitors (C); +4 – generalists (G); +3 – natural pioneers (NP); +2 – disturbance tolerant (DT); +1 – weeds (W); –1 – adventives or introduced alien species (A or I); –2 – ruderal competitors (RC); –3 – aggressive alien species or invaders (AC); **hemeroby values according to Frank and Klotz (1990) rescaled to the 0–100 range.

Table 2. Principal component analysis of soil properties and vegetation characteristics.

Variable	PC 1 (λ = 15.3, 61.5%)	PC 2 (λ = 1.95, 7.8%)	PC 3 (λ = 1.88, 7.5%)	PC 4 (λ = 1.65, 6.6%)	PC 5 (λ = 1.11, 4.4%)
Soil electrical conductivity	0.43	–0.22	0.11	0.52	–0.26
Soil wetness	–0.21	–	–0.43	0.69	–0.19
Crown closure	–0.29	0.29	0.28	0.31	–
Height of herbaceous layer	0.20	–0.38	–0.66	0.18	0.33
Projective cover of herbaceous layer	–	–0.20	–0.59	–0.21	0.57
Soil mechanical impedance in the layer, cm					
0–5	0.71	–0.38	0.40	–0.24	–
5–10	0.77	–0.43	0.31	–0.20	–
10–15	0.84	–0.43	0.24	–	–
15–20	0.85	–0.41	0.18	–	–
20–25	0.87	–0.33	0.11	0.21	–
25–30	0.87	–0.22	–	0.33	–
30–35	0.86	–	0.10	0.39	0.19
35–40	0.83	0.23	0.13	0.36	0.27
40–45	0.79	0.41	0.16	0.22	0.30
45–50	0.80	0.48	0.14	–	0.24
50–55	0.85	0.41	0.10	–0.12	0.16
55–60	0.89	0.29	–	–0.19	–
60–65	0.92	0.22	–	–0.20	–
65–70	0.93	0.17	–0.14	–0.16	–0.12
70–75	0.94	–	–0.16	–0.12	–0.15
75–80	0.93	–	–0.23	–0.11	–0.17
80–85	0.91	–	–0.28	–	–0.22
85–90	0.90	–	–0.27	–	–0.23
90–95	0.91	–	–0.24	–	–0.24
95–100	0.92	–	–0.26	–	–0.21

Note: PC – principal component.

cover. Disturbance-tolerant species dominated in polygon 3, and aggressive alien species or invaders dominated in polygon 4 (Fig. 1).

The principal component analysis of the soil properties and vegetation characteristics allowed to identify the five principal components whose eigenvalues exceed unity (Table 2). Principal component 1 describes 61.5% of the variation of the feature space and reflects a consistent change in the soil penetration resistance at all measured depths. This feature suggests that principal component 1 is a marker of the recreational load. An increase in recreational load was accompanied by an increase in soil penetration resistance, soil electrical conductivity, and grass height and a decrease in soil moisture and tree crown closure. Other principal components describe 4.4–7.8% variation of the feature space and reflect the naturally induced soil and vegetation features. Principal component 2 was sensitive to the opposite direction of variation in the soil penetration resistance in the upper soil layer (0–30 cm) and in the middle soil layer (45–75 cm). Principal component 3 was sensitive to the opposite direction of change in the soil penetration resistance in the upper soil layer (0–25 cm) and in the lower soil layer (70–100 cm). Principal component 4 was sensitive to variability in soil penetration resistance in the middle soil layer (30–45 cm). Principal component 5 was sensitive to the opposite direction of variation in soil penetration resistance in the middle soil layer (35–55 cm) and in the lower soil layer (70–100 cm).

Accounting for the ecological properties of the plants led to an ordinal solution that differed from the random alternative under different permutation methods (Fig. 2, I and II). The social behavior types of plants had different associations with polygons. Weeds, adventives or introduced alien species, and ruderal competitors increased their abundance after park reconstruction (polygons 1 and 2). The hemeroby index of weeds and ruderal competitors as a trait of individual plant species was positively correlated with principal component 1 and the integral hemeroby index of individual sample sites (Fig. 2, III and IV).

RLQ axis-1 was most sensitive to plant community naturalness and differentiated polygons 3 and 4 well (Fig. 2, V). Note that both these polygons are in the area outside of reconstruction. RLQ axis-2 was sensitive to hemeroby index and the principal component 1. This axis differentiated polygons 1 and 2 from polygons 3 and 4. Polygons 1 and 2 were associated with weeds, polygon 3 was associated with disturbance-tolerant plants, and polygon 4 was associated with aggressive alien species or invaders.

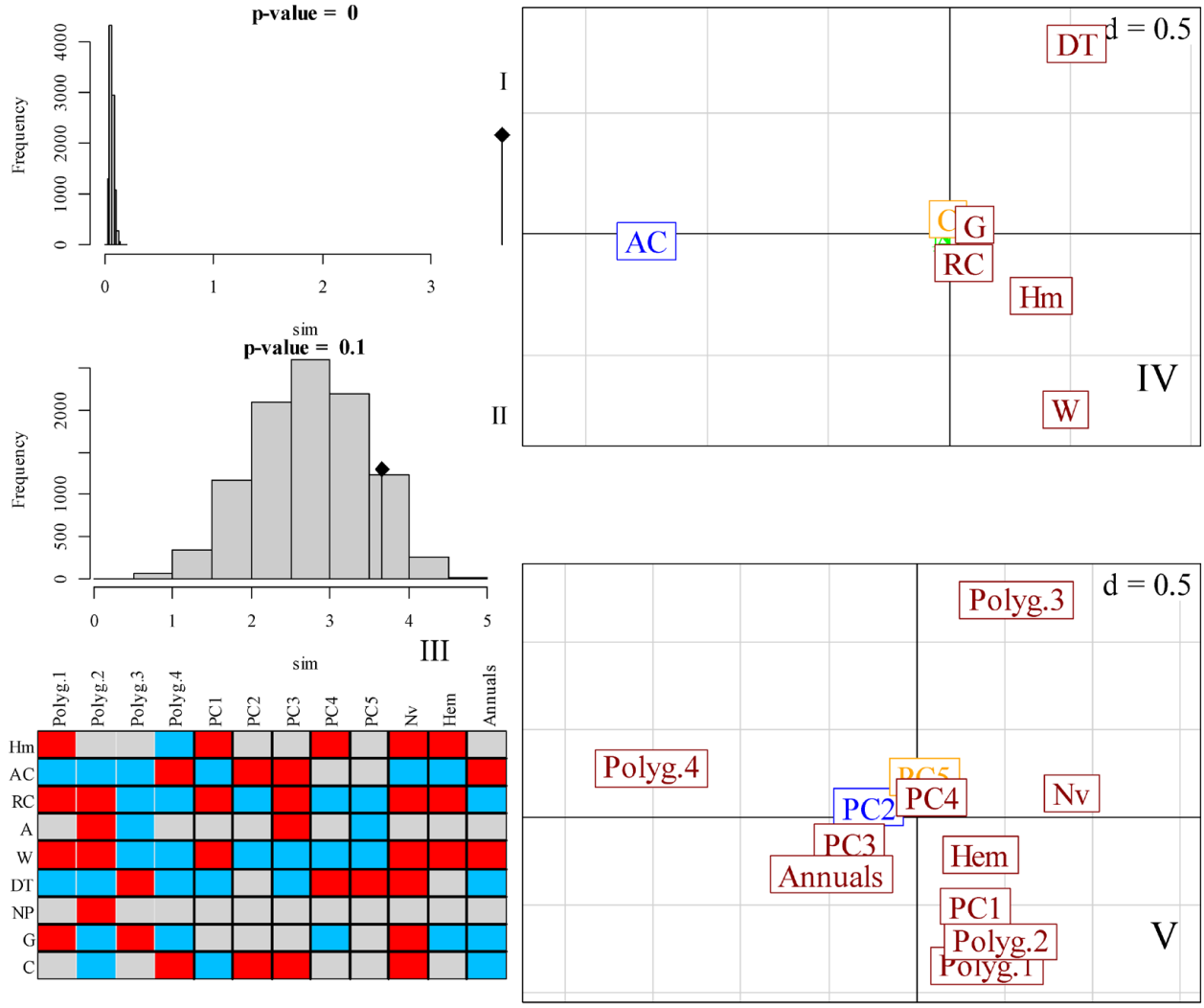


Fig. 2. Results of the RLQ analysis: I – the global test of the significance of the relationship between the structure of the plant community and the ecological traits of plant species as a result of permutation of site values (i.e., permutation of the entire rows of table L): the histogram shows the distribution of simulated values of total inertia (sim) for the permuted values of sites compared to the observed value of total inertia; II – the global test of the significance of the relationship between the structure of the plant community and the ecological traits of plant species as a result of permutation values of species (i.e., permutation of the entire columns of table L): the histogram shows the distribution of simulated values of total inertia (sim) for the permuted values of species compared to the observed value of total inertia; III – correlation between the ecological properties of plant species and the environmental factors (red color is positive correlation, blue color is negative correlation, gray color denotes correlation which is not statistically significant); IV – the location of plants' ecological traits in the space of RLQ1 and RLQ2 axes (blue color represents statistically significant association with RLQ1 axis; orange color represents statistically significant association with RLQ2 axis; dark red color represents statistically significant association with both axes); V – the location of ecological predictors in the space of RLQ1 and RLQ2 axes (blue color represents statistically significant association with RLQ1 axis; orange color represents statistically significant association with RLQ2 axis; dark red color represents statistically significant association with both axes); Polyg.1, …, Polyg.4 are polygons 1, ¼, 4; PC1, …, PC5 are principal components 1, ¼, 5, which represent the variation of soil properties; Hm is the index of hemeroby; Nv is the naturalness value; C – competitors; G – generalists; NP – natural pioneers; DT – disturbance tolerant; W – weeds; A – adventives or introduced alien species; RC – ruderal competitors; AC – aggressive alien species or invaders.

The naturalness index varies in a pattern in the space RLQ1 and RLQ2 axes (Fig. 3). The occurrence of two extrema indicates that the response surface of the naturalness index in the space of ordinal RLQ-axes can be described using a third-degree polynomial. This function had two extrema: the local maximum (–0.0047; 2.18) and the local minimum (–6.70; –1.97). The distance of a particular plant community in ordination space from the local maximum indicated the degree of its difference from the natural state, or its naturalness. In turn, the distance of the community in ordination space from the local minimum indicates the degree of its difference from the most transformed state, or its hemeroby. The mentioned dis-

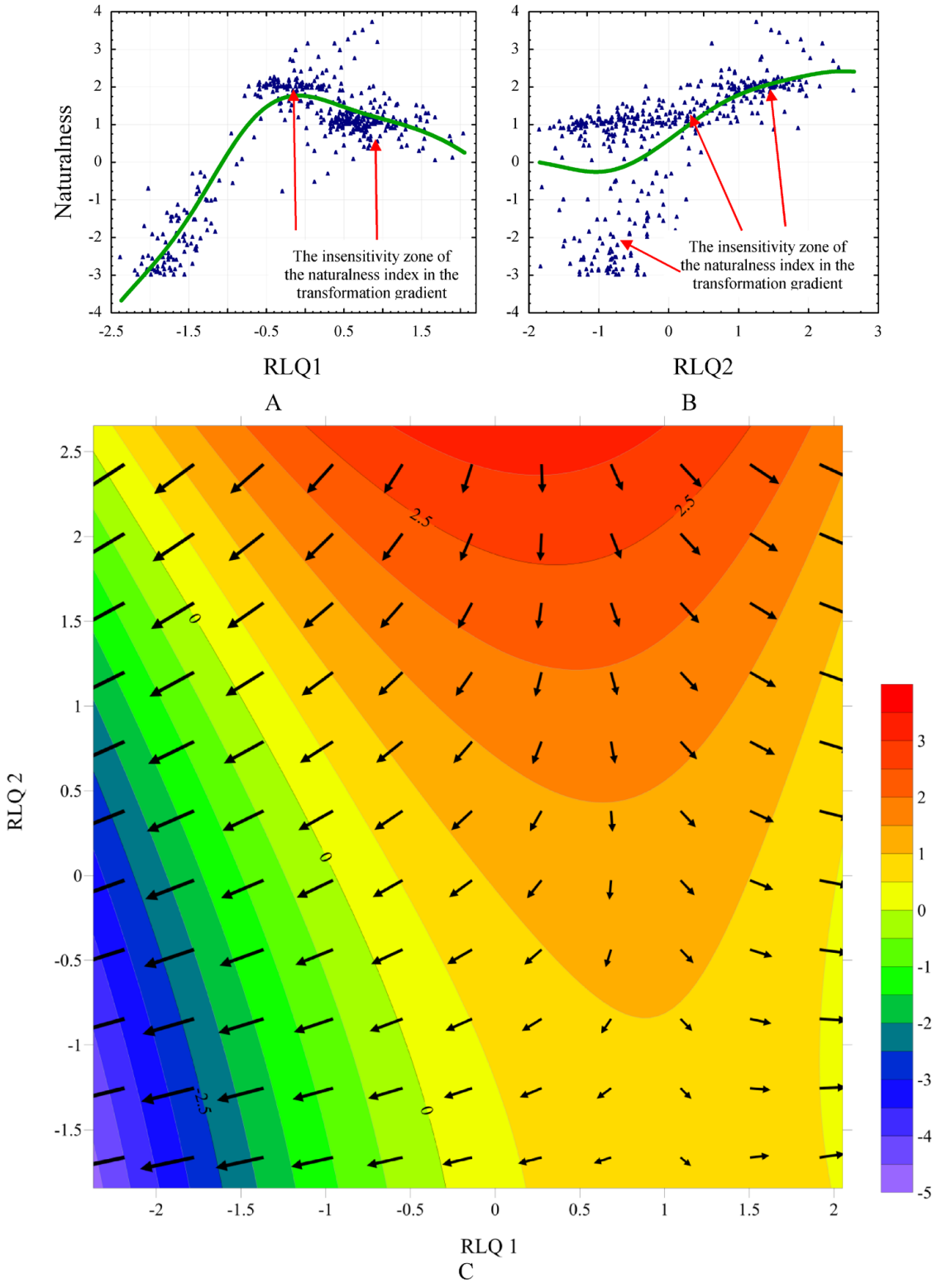


Fig. 3. Variation of the naturalness of plant communities on the RLQ1 axis (the approximation line was obtained using the distance-weighted least-squares method) (A); dependence of the naturalness of plant communities on the RLQ2 axis (the approximation line was obtained using the distance-weighted least-squares method) (B); the variation of naturalness index in the space of RLQ1 and RLQ2 axes (C). The arrows indicate the gradient of the increase in the level of anthropogenic load. The variation can be approximated by a third-degree polynomial equation: naturalness = $1.045 + 0.78 \times RLQ1 - 0.26 \times RLQ1 \times RLQ2 - 0.046 \times RLQ1 \times RLQ2^2 - 0.48 \times RLQ1^2 + 0.77 \times RLQ2 + 0.15 \times RLQ2^2 - 0.1002 \times RLQ2^3 + 0.0102 \times RLQ1^2 \times RLQ2 - 0.058 \times RLQ1^3$ transformation, which was estimated using the coefficient of naturalness.

Table 3. Regression dependence of the plant community distance in the space of RLQ1 and RLQ2 axes from the local maximum of the naturalness (regression I) and from the local minimum of the naturalness (regression II) on the proportions of the social behavior types.

Effect*	*F*-ratio	Partial eta-squared	Regression coefficient	*p*-level	β-regression coefficient
Regression I (R_{adj}^2 = 0.78, F = 192.1, p < 0.001)					
Intercept	0.11	0.00	0.68 ± 2.00	0.74	–
–3	83.81	0.17	0.12 ± 0.01	<0.001	0.47 ± 0.05
–2	8.05	0.02	–0.05 ± 0.02	<0.001	–0.08 ± 0.03
–1	0.73	0.00	–0.06 ± 0.07	0.39	–0.02 ± 0.02
+1	57.61	0.12	0.11 ± 0.01	<0.001	0.37 ± 0.05
+2	93.13	0.18	–0.15 ± 0.02	<0.001	–0.45 ± 0.05
+3	0.11	0.00	–0.08 ± 0.25	0.74	–0.01 ± 0.02
+4	10.44	0.02	–0.05 ± 0.01	<0.001	–0.09 ± 0.03
+5	11.82	0.03	–0.08 ± 0.02	<0.001	–0.09 ± 0.02
Regression II (R_{adj}^2 = 0.83, F = 257.8, p < 0.001)					
Intercept	17.38	0.04	7.12 ± 1.71	<0.001	–
–3	225.80	0.35	–0.17 ± 0.01	<0.001	–0.69 ± 0.05
–2	115.86	0.22	0.16 ± 0.01	<0.001	0.27 ± 0.02
–1	2.89	0.01	0.10 ± 0.06	0.09	0.04 ± 0.02
+1	9.06	0.02	0.04 ± 0.01	<0.001	0.13 ± 0.04
+2	1.71	0.00	0.02 ± 0.01	0.19	0.05 ± 0.04
+3	0.40	0.00	–0.13 ± 0.21	0.53	–0.01 ± 0.02
+4	1.39	0.00	0.01 ± 0.01	0.24	0.03 ± 0.03
+5	0.26	0.00	0.01 ± 0.02	0.61	0.01 ± 0.02

Notes: *Logit-transformed proportions of the social behavior types according to Borhidi (1995): +5 – competitors (C); +4 – generalists (G); +3 – natural pioneers (NP); +2 – disturbance tolerant (DT); +1 – weeds (W); –1 – adventives or introduced alien species (A or I); –2 – ruderal competitors (RC); –3 – aggressive alien species or invaders (AC).

tances can be modeled by means of logit-transformed proportions of social behavior types of plants (Table 3). Regression I described the distance of the plant community from its most natural state (local maximum) and was able to explain 78% of the variation in this indicator. The most important predictors were aggressive alien species and invaders and weeds (positive dependence) and disturbance tolerants (negative dependence). Regression II described the distance of the plant community from the most transformed state and was able to explain 83% of the variation in this indicator. The most important predictors were aggressive alien species (negative dependence) and ruderal competitors, invaders, and disturbance tolerants (positive dependence).

Discussion

The vegetation cover of an urban park is subject to different types of anthropogenic impact and therefore it is transformed by distancing from the natural state. The level of transformation of the plant community can be characterized by such a concept as naturalness. The process of park reconstruction is also one of the significant factors of anthropogenic impact, as it is associated with a significant change in the light regime of the plantation, as well as the direct impact of technological processes on the soil and vegetation cover. Markers of the relation of plants to the level of plant community transformation are the social behavior types of plants. Traditionally, an obvious metric for the level of naturalness of a community is the weighted average of these indicators. Such a metric is based on the assumption that the different plant behavior types successively replace each other in a gradient of anthropogenic impact, and that vegetation exhibits a single trajectory in the process of transformation. Obviously, such an assumption does not correspond to reality and the traditional metric can be considered an indicator of naturalness in a very broad sense. We assumed that the social behavior types of plants are plant traits and included them in the ordination procedure.

The structure of the plant community is subject to the complex influence of physical, chemical, and anthropogenic factors (Paudel et al., 2017; Zhukov et al., 2019a). The RLQ ordination procedure showed that social behavior types are essential for describing the pattern of community response to anthropogenic impact. The RLQ-1 axis allows to distinguish polygon 4 from all other polygons. Principal components 2 and 3 are strongly correlated with this axis, which are sensitive to the opposite dynamics of soil penetration resistance in the upper versus middle soil layer or in the upper versus lower soil layer. Such features of profile variation in soil penetration resistance parameters can be considered a consequence of recreational loading (Budakova et al., 2021; Zhukov et al., 2021). Polygon 4 differs from all other polygons by a higher proportion of aggressive alien species or invaders that can be a result of transformation of the plant community as a consequence of recreational pressure.

The RLQ-2 axis is capable of differentiating polygons that have been reconstructed from other polygons. This axis is

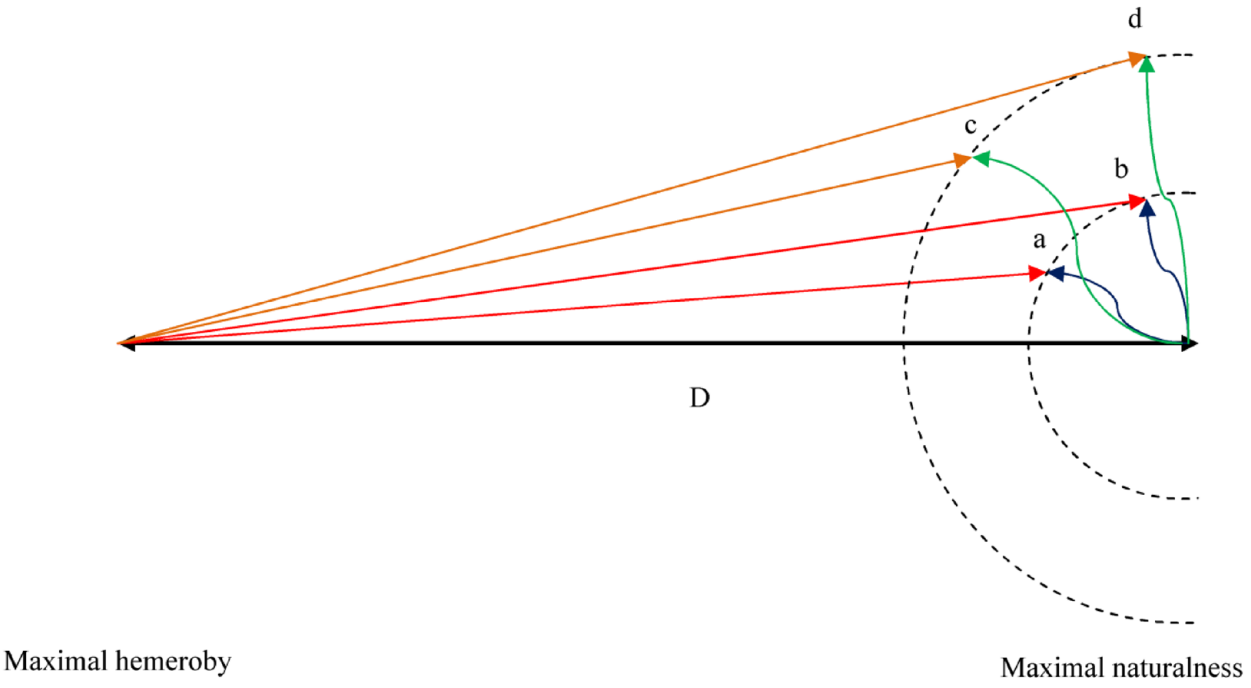


Fig. 4. Conceptual diagram showing the relationship between naturalness and hemeroby. The behavior of the plant community in the space of possible states, which is determined by ordinal axes, is represented. D is the gradient of anthropogenic transformation. The communities a and b moved away from the state with the highest naturalness along different trajectories. $Naturalness_a = naturalness_b$, but $hemeroby_a \neq hemeroby_b$ ($hemeroby_a < hemeroby_b$). Thus, there can be different levels of hemeroby for equal naturalness. The converse is true: with equal hemeroby, there can be different community naturalness. The length of the semicircle is proportional to the β-diversity of communities with a given level of naturalness (or hemeroby).

strongly correlated with principal component 1, which is sensitive to the synchronous variability of the soil penetration resistance along the profile. The presence of this dependence can be explained by the result of the impact of technological equipment during the reconstruction process. Also, the result of reconstruction is a decrease in the density of tree crowns, which causes an increase in solar energy reaching the soil surface, contributing to an increase in evaporation of soil moisture (Kunakh et al., 2021a). In turn, drier soils have a higher penetration resistance. This explanation is also confirmed by direct measurements of soil moisture (Zhukov, Zadorozhnaya, 2016; Kunakh et al., 2021b). Soil moisture was lower in the reconstruction zone. The transformation of environmental properties due to reconstruction affects the plant community. The park reconstruction contributed to an increase in the abundance of weeds (+1), while other polygons were dominated by disturbance tolerants (+2). Thus, the social behavior types that are on the ordinal variable adjacent to each other demonstrate the different patterns of response to anthropogenic impact. Other social behavior plant types show no significant patterns in response to park reconstruction. Thus, the plant community reacts differently in response to an anthropogenic impact of a complex nature. An increase in recreational pressure causes an increase in the proportion of aggressive alien species or invaders, while reconstruction leads to an increase in the proportion of weeds.

The traditional indicator of naturalness is able to distinguish extreme levels of anthropogenic transformation of the plant community. But the response of this indicator is not monotonic in the whole range of anthropogenic load levels. Obviously, this is due to the multivariate transition of the system from the natural state to the strongly anthropogenically transformed one. A wide range of states of the community has been established when its species composition strongly changes in the transformation gradient, and the traditional naturalness indicator appears to be insensitive to these changes. One interpretation of the differences between naturalness and hemeroby is the different sensitivity of these indicators to the levels of anthropogenic impact. The traditional naturalness index is more sensitive to changes in plant community structure near the natural state, while the hemeroby index is more sensitive to changes in the highly transformed state. Our results show that the naturalness index when approaching the community to the natural state has a weak sensitivity to the very significant changes in the plant community. The absence or low representation of plant species in urban environments, which are indicators of naturalness, may be responsible for this effect. The plant communities close to the natural state were not represented among those studied. The urban park conditions lacked representatives of social behavior types which could differentiate levels of community naturalness.

Nevertheless, the traditional indicator of naturalness is able to detect very well the extreme communities in the range of anthropogenic load. The localization of the zone of maximum and minimum naturalness along different RLQ-axes indicates the invalidity of the idea of the ordinal nature of transformation of the plant community under the influence of anthropogenic load. This result also changes the understanding of naturalness and hemeroby. The naturalness and hemeroby have a different sensitivity to different levels of anthropogenic pressure. The difference from the state of naturalness may be not only along some axis (the gradient of anthropogenic transformation), but also within some plane (or even hyper-volume) (Fig. 4). Then, some state of naturalness, which is characterized by a distance from the natural state, may correspond to several states of hemeroby or distances from the most transformed state (the points a, b or c, d in Fig. 4 have an equal distance from the state of maximum naturalness, but have an unequal distance from the state of maximum hemeroby). The reverse is true: equal levels of hemeroby can correspond to different naturalness. Obviously, marginal community states are forbidden, so there is an inverse correlation between naturalness and hemeroby indices.

The flora of habitats subjected to the highest level of anthropogenic impact had a high proportion of annual species, but not the highest proportion of non-native species (Kim et al., 2002). The naturalness of the plant community increases during restoration succession at the reclamation site, which was confirmed using the quasi-mean naturalness value (Cseresnyés et al., 2014). Our results suggest that as the community approaches the middle part of the hemeroby/naturalness gradient, the number of possible community states increases, so diversity of the community in the middle part of the disturbance gradient is the greatest. This result is in accordance with the intermediate disturbance hypothesis (Connell, 1978; Hobbs, Huenneke, 1992). Furthermore, we can explain this hypothesis as a consequence of the distinction between hemeroby and naturalness.

At a high level of naturalness, the transformation of the community under anthropogenic influence follows the trajectories that the community follows under natural disturbances. This behavior of the plant community can be considered a nonspecific response to anthropogenic impact. Both under natural disturbances and minor anthropogenic disturbances, the ratio of different social behavior types of plants of natural habitats may change, which may be reflected in different values of community naturalness; but at the same time, the level of community hemeroby will not change significantly. A complex of other environmental factors affects the plant community at high levels of anthropogenic load. At the same time, natural factors can significantly change their importance. Urbanization is associated with modifications in the light regime, soil moisture and acidity, and thermal regime. Conditions are created under which only some species are able to survive, which are equally «unnatural» (urban or ruderal species). These species may be differently sensitive to the level of hemeroby, but do not distinguish the level of naturalness. Therefore, changes in hemeroby can occur without significant changes in community naturalness.

The multivariate pattern of plant community transformation under the influence of anthropogenic load makes the distance in multidimensional space to the state of greatest naturalness an adequate metric of naturalness and the distance to the state of greatest transformation an adequate metric of hemeroby. The distance in ordination space reflects changes in the structure of the plant community, while the social behavior types represent the behavioral strategies of individual plant species. The hemeroby and naturalness reflect the state of the plant community as a whole. Therefore, the assessment of hemeroby and naturalness should be based on the indicators of the community level. Nevertheless, changes in hemeroby and naturalness, expressed through the distance in ordination space, are associated with changes in the proportions of social behavior types. However, the nature of the regression relationships does not correspond to the intuitive perception of the ordinal character of changes in the structure of communities, which is subject to the order of the scores assigned to the different types.

The properties of the regression models of distances to the state of naturalness or the state of greatest transformation are different, which emphasizes the fact that hemeroby and naturalness are not symmetrically opposite concepts. The greatest contribution to the estimation of hemeroby is made by aggressive alien species or invaders. Also, the natural species, such as competitors and generalists, influence the assessment of naturalness the most.

Conclusion

Social behavior types of plants as ecological traits of plants show regular patterns of variability in the gradient of anthropogenic impact. However, these patterns do not support the notion that the plant community response to anthropogenic disturbance is ordinal. The response of a plant community is multivariate, so the naturalness metric based on the social behavior types is only able to distinguish well between the extreme states of a plant community, but is a poor measure for a more detailed assessment of naturalness.

Naturalness and hemeroby reflect different strategies for transforming a plant community and are not completely symmetrically opposed concepts. A community's naturalness can be changed without significant changes in its hemeroby, or a community's hemeroby can be changed without changes in its naturalness. The corresponding models for naturalness and hemeroby are different. For quantifying hemeroby, aggressive alien species or invaders are important. For the quantification of naturalness, the relationship between the different social behavior types is important.

References

Borhidi, A. (1995). Social behaviour types, the naturalness and relative ecological indicator values of the higher plants in the Hungarian flora. *Acta Bot. Hung.*, 39, 97–181.

Budakova, V.S., Yorkina, N.V., Telyuk, P.M., Umerova, A.K., Kunakh, O.M. & Zhukov O.V. (2021). Impact of recreational transformation of soil physical properties on micromolluscs in an urban park. *Biosystems Diversity*, 29(2), 78–87. DOI: 10.15421/012111.

Connell, J.H. (1978). Diversity in tropical rain forests and coral reefs. *Science*, 199(4335), 1302–1310. DOI: 10.1126/science.199.4335.1302.

Côté, S., Beauregard, R., Margni, M. & Bélanger L. (2021). Using naturalness for assessing the impact of forestry and protection on the quality of ecosystems in life cycle assessment. *Sustainability*, 13(16), 8859. DOI: 10.3390/su13168859.

Cseresnyés, I., Cseresnyés-Bózsing, E., Tamás, J., Barina, Z. & Csontos P. (2014). Effect of Austrian pine on naturalness and succession of vegetation in reclaimed bauxite quarries. *Applied Ecology and Environmental Research*, 12(4), 931–946. DOI: 10.15666/aeer/1204_931946.

Didukh, Y.P. (2011). *The ecological scales for the species of Ukrainian flora and their use in synphytoindication*. Kyiv: Phytosociocenter.

Domnich, V.I., Domnich, A.V. & Zhukov O.V. (2021). Phytoindication approach for assessing factors determining the habitat preferences of red deer (Cervus elaphus). *Biosystems Diversity*, 29(3), 3–13. DOI: 10.15421/012124.

Dray, S., Choler, P., Dolédec, S., Peres-Neto, P.R., Thuiller, W., Pavoine, S. & Ter Braak C.J.F. (2014). Combining the fourth-corner and the RLQ methods for assessing trait responses to environmental variation. *Ecology*, 95(1), 14–21. DOI: 10.1890/13-0196.1.

Dray, S. & Dufour A.B. (2007). The ade4 package: Implementing the duality diagram for ecologists. *Journal of Statistical Software*, 22(4), 1–20. DOI: 10.18637/jss.v022.i04.

Dzwonko, Z. (2001). Assessment of light and soil conditions in ancient and recent woodlands by Ellenberg indicator values. *J. Appl. Ecol.*, 38(5), 942–951. DOI: 10.1046/j.1365-2664.2001.00649.x.

Ellenberg, H., Weber, H.E., Dull, R., Wirth, V., Werner, W. & Paulissen D. (1991). Zeigerwerte von Pflanzen in Mitteleuropa. *Scripta Geobotanica*, 18, 1–248.

Erdős, L., Bátori, Z., Penksza, K., Dénes, A., Kevey, B., Kevey, D., Magnes, M., Sengl, P. & Tölgyesi C. (2017). Can naturalness indicator values reveal habitat degradation? A test of four methodological approaches. *Pol. J. Ecol.*, 65(1), 1–13. DOI: 10.3161/15052249PJE2017.65.1.001.

Erdős, L., Kröel-Dulay, G., Bátori, Z., Kovács, B., Németh, C., Kiss, P.J. & Tölgyesi C. (2018). Habitat heterogeneity as a key to high conservation value in forest-grassland mosaics. *Biol. Conserv.*, 226, 72–80. DOI: 10.1016/j.biocon.2018.07.029

Frank, D. & Klotz S. (1990). Biologisch-ökologische Daten zur Flor der DDR. *Wissenschaftliche Beiträge der Martin-Luther-Universit at Halle*, 32, 1–167.

Goncharenko, I. & Kovalenko O. (2019). Oak forests of the class *Quercetea pubescentis* in Central-Eastern Ukraine. *Thaiszia - Journal of Botany*, 29(2), 191–215. DOI: 10.33542/TJB2019-2-05.

Goncharenko, I., Semenishchenkov, Y., Tsakalos, J.L. & Mucina L. (2020). Thermophilous oak forests of the steppe and forest-steppe zones of Ukraine and Western Russia. *Biologia*, 75(3), 337–353. DOI: 10.2478/s11756-019-00413-w.

Goncharenko, I.V. & Yatsenko H.M. (2020). Phytosociological study of the forest vegetation of Kyiv urban area (Ukraine). *Hacquetia*, 19(1), 99–126. DOI: 10.2478/hacq-2019-0012.

Hill, M.O., Roy, D.B. & Thompson K. (2002). Hemeroby, urbanity and ruderality: bioindicators of disturbance and human impact. *J. Appl. Ecol.*, 39(5), 708–720. DOI: 10.1046/j.1365-2664.2002.00746.x.

Hobbs, R.J. & Huenneke L.F. (1992). Disturbance, diversity, and invasion: Implications for conservation. *Conserv. Biol.*, 6(3), 324–337. DOI: 10.1046/j.1523-1739.1992.06030324.x.

Kim, Y.-M., Zerbe, S. & Kowarik I. (2002). Human impact on flora and habitats in Korean rural settlements. *Preslia*, 74(4), 409–419.

Kowarik, I. (1990). Some responses of flora and vegetation to urbanization in Central Europe. In H. Sukopp, S. Hejny & I. Kowarik (Eds.), *Plants and plant communities in the urban environment* (pp. 45–74). Hague: SPB Academic Publishing.

Kunakh, O.M., Lisovets, O.I., Yorkina, N.V. & Zhukova Y.O. (2021a). Phytoindication assessment of the effect of reconstruction on the light regime of an urban park. *Biosystems Diversity*, 29(3), 84–93. DOI: 10.15421/012135.

Kunakh, O.M., Yorkina, N.V., Turovtseva, N.M., Bredikhina, J.L., Balyuk, J.O. & Golovnya A.V. (2021b). Effect of urban park reconstruction on physical soil properties. *Ecologia Balkanica*, 13(2), 57–73. http://eb.bio.uni-plovdiv.bg

Kunakh, O.M., Yorkina, N.V., Zhukov, O.V., Turovtseva, N.M., Bredikhina, Y.L. & Logvina-Byk T.A. (2020). Recreation and terrain effect on the spatial variation of the apparent soil electrical conductivity in an urban park. *Biosystems Diversity*, 28(1), 3–8. DOI: 10.15421/012001.

Kurdyukova, O.N. (2015). *Botanical and biological characteristics of weed sinusia of agrophytocenoses of the left-bank steppe of Ukraine and methods of their control*. Lugansk: Lugansk National Taras Shevchenko University.

Lykholat, Y., Khromykh, N., Didur, O., Kotovych, O., Kovalenko, I., Kovalenko, V., Tsyliuryk, O. & Lykholat T. (2021). The study of transformed herbaceous vegetation in the area flooded due to coal mine workings. *Ekológia (Bratislava)*, 40(3), 222–229. DOI: 10.2478/eko-2021-0024.

Machado, A. (2004). An index of naturalness. *J. Nat. Conserv.*, 12(2), 95–110. DOI: 10.1016/j.jnc.2003.12.002.

Moravčík, M., Sarvašová, Z., Merganič, J. & Schwarz M. (2010). Forest naturalness: Criterion for decision support in designation and management of protected forest areas. *Environ. Manag.*, 46(6), 908–919. DOI: 10.1007/s00267-010-9506-2.

Müller, J., Engel, H. & Blaschke M. (2007). Assemblages of wood-inhabiting fungi related to silvicultural management intensity in beech forests in southern Germany. *European Journal of Forest Research*, 126(4), 513–527. DOI: 10.1007/s10342-007-0173-7.

Paudel, S., Benavides, J.C., MacDonald, B., Longcore, T., Wilson, G.W.T. & Loss S.R. (2017). Determinants of native and non-native plant community structure on an oceanic island. *Ecosphere*, 8(9), e01927. DOI: 10.1002/ecs2.1927.

R Core Team (2020). A language and environment for statistical computing. In *R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/*. (Vol. 2, p. https://www.R-project.org). http://www.r-project.org

Seidling, W. & Fischer R. (2008). Deviances from expected Ellenberg indicator values for nitrogen are related to N throughfall deposition in forests. *Ecological Indicators*, 8(5), 639–646. DOI: 10.1016/j.ecolind.2007.09.004.

Sengl, P., Magnes, M., Erdős, L. & Berg C. (2017). A test of naturalness indicator values to evaluate success in grassland restoration. *Community Ecol.*, 18(2), 184–192. DOI: 10.1556/168.2017.18.2.8

Sukopp, H. (1969). Der Einfluss des Menschen auf die Vegetation. *Vegetatio Acta Geobotanica*, 17(1), 360–371. DOI: 10.1007/BF01965917.

Sukopp, H. (1972). Wandel von Flora und Vegetation in Mitteleuropa unter dem Einfluß des Menschen. *Ber. Landwirtsch.*, 50, 112–139.

Terwayet Bayouli, I., Terwayet Bayouli, H., Dell'Oca, A., Meers, E. & Sun J. (2021). Ecological indicators and bioindicator plant species for biomonitoring industrial pollution: Eco-based environmental assessment. *Ecological Indicators*, 125, 107508. DOI: 10.1016/j.ecolind.2021.107508.

Tölgyesi, Cs. & Körmöczi L. (2012). Structural changes of a pannonian grassland plant community in relation to the decrease of water availability. *Acta Bot. Hung.*, 54(3–4), 413–431. DOI: 10.1556/ABot.54.2012.3-4.17.

Westhoff, V. (1971). The dynamic structure of plant communities in relation to the objectives of conservation. In E. Duffey & A.S. Watt (Eds.), *The scientific management of animal and plant communities for conservation* (pp. 3–14). Oxford: Blackwell.

Westhoff, V. & Van Der Maarel E. (1978). The Braun-Blanquet Approach. In R.H. Whittaker (Ed.), *Classification of plant communities* (pp. 287–399). Dordrecht: Springer. DOI: 10.1007/978-94-009-9183-5_9.

Winter, S. (2012). Forest naturalness assessment as a component of biodiversity monitoring and conservation management. *Forestry*, 85(2), 293–304. DOI: 10.1093/forestry/cps004.

Wulf, M. (1997). Plant species as indicators of ancient woodland in northwestern Germany. *J. Veg. Sci.*, 8(5), 635–642. DOI: 10.2307/3237367.

Yao, H., Ma, J., Fan, Y., Chen, X. & Tian M. (2019). Assessing the naturalness of a restored coal mine area on the Loess Plateau, China. *PLOS ONE*, 14(7), e0219447. DOI: 10.1371/journal.pone.0219447.

Yorkina, N., Maslikova, K., Kunah, O. & Zhukov O. (2018). Analysis of the spatial organization of Vallonia pulchella (Muller, 1774) ecological niche in Technosols (Nikopol manganese ore basin, Ukraine). *Ecologica Montenegrina*, 17(1), 29–45.

Yorkina, N.V., Podorozhniy, S.M., Velcheva, L.G., Honcharenko, Y.V. & Zhukov O.V. (2020). Applying plant disturbance indicators to reveal the hemeroby of soil macrofauna species. *Biosystems Diversity*, 28(2), 181–194. DOI: 10.15421/012024.

Yuan, Z.Y., Jiao, F., Li, Y.H. & Kallenbach R.L. (2016). Anthropogenic disturbances are key to maintaining the biodiversity of grasslands. *Sci. Rep.*, 6(1), 22132. DOI: 10.1038/srep22132.

Zhukov, A. & Gadorozhnaya G. (2016). Spatial heterogeneity of mechanical impedance of a typical chernozem: The ecological approach. *Ekológia (Bratislava)*, 35(3), 263–278. DOI: 10.1515/eko-2016-0021.

Zhukov, A.V. & Zadorozhnaya G.A. (2016). Spatio-temporal dynamics of the penetration resistance of recultivated soils formed after open cast mining. *Visnyk of Dnipropetrovsk University. Biology, Ecology*, 24(2), 324–331. DOI: 10.15421/011642.

Zhukov, O., Kunah, O., Dubinina, Y., Zhukova, Y. & Ganzha D. (2019a). The effect of soil on spatial variation of the herbaceous layer modulated by overstorey in an Eastern European poplar-willow forest. *Ekológia (Bratislava)*, 38(3), 253–272. DOI: 10.2478/eko-2019-0020.

Zhukov, O.V., Kunah, O.M., Dubinina, Y.Y., Fedushko, M.P., Kotsun, V.I., Zhukova, Y.O. & Potapenko O.V. (2019b). Tree canopy affects soil macrofauna spatial patterns on broad- And meso-scale levels in an Eastern European poplar-willow forest in the floodplain of the River Dnipro. *Folia Oecologica*, 46(2), 101–114. DOI: 10.2478/foecol-2019-0013.

Zhukov, O., Yorkina, N., Budakova, V. & Kunakh O. (2021). Terrain and tree stand effect on the spatial variation of the soil penetration resistance in Urban Park. *International Journal of Environmental Studies*, 1–17. DOI: 10.1080/00207233.2021.1932368.

Zinnen, J., Spyreas, G., Erdős, L., Berg, C. & Matthews J.W. (2021). Expert-based measures of human impact to vegetation. *Appl. Veg. Sci.*, 24(1). DOI: 10.1111/avsc.12523.