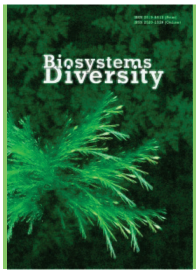

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Which index is better for assessing the success of reclamation: Naturalness or hemeroby?

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The destruction of soil and vegetation caused by mining, if not prevented through careful planning, is usually extreme, as the original ecosystems have been grossly disturbed or buried in the mining process. A radical reconstruction is therefore necessary. In nature, this happens through the well-known processes of primary succession, without human intervention. In the interests of the economy and the preservation of our natural resources, reclamation should try to involve the same processes. When planning reclamation, it is crucial to clearly define goals, objectives and success criteria to allow for systematic reclamation. The need for methods to assess the effectiveness in achieving environmental and social goals is increasing, especially if agricultural land is to be restored. Over time, reclamation goals may need to be modified depending on the direction of the reclamation succession. The reclamation of mined areas requires the application of monitoring tools to understand the achievement of potential success. This problem can be solved by studying the biodiversity of plant communities and soil factors of mining areas as habitats in industrialized post-mining landscapes. Thus, the reclamation of territories disturbed by industrial activities is planned with the need to correct the trajectory of the restoration process, so it requires indicators that can be used to monitor the success of the planned process. The article tests the following hypotheses: 1) the dynamics of the reclamation process can be monitored using the indices of naturalness and hemeroby; 2) at the initial stages of reclamation, the hemeroby index has an advantage due to its greater sensitivity in this range of anthropogenic transformation levels. The plant community formed as a result of spontaneous growth of the reclamation sites was represented by 70 species of vascular plants. The projective vegetation cover was 22.0 ± 0.30%. In one test plot, 8.4 ± 0.1 plant species were found. The analysis of the synoptic phytosociological table revealed that the vegetation cover of the reclamation site was represented by nine associations from the vegetation classes *Artemisietea vulgaris* and *Stellarietea mediae*. The hemeroby of the communities averaged 85.0 ± 0.22. The lowest level of hemeroby was found within the *Cirsio-Lactucetum serriolae* association. The average level of hemeroby was found for the associations *Medicagini lupulinae-Agropyretum repentis*, *Ambrosio artemisiifoliae-Cirsietum setosi* and *Carduo acanthoidis-Onopordetum acanthi*. The highest level of hemeroby was found for the associations *Agropyretum repentis* and *Convolvulo arvensis-Agropyretum repentis*. The highest level of hemeroby was observed in those plant communities formed on lithozems on the red-brown clays, and the lowest formed on the pedozems. A negative correlation was found between hemeroby and naturalness for all lithozems. No statistically significant correlation was found for pedozems. For the classification of associations, environmental factors such as salt content in the soil solution, nitrogen content, ombroclimate, light regime, and naturalness are of greatest importance. The traditional application of the hemeroby scale is to assess the level of anthropogenic transformation of an ecosystem, i.e. to quantify how far the ecosystem has deviated from its natural state. In our study, we use the hemeroby index to observe how the plant community returns to its natural state, which can be considered as a marker of the effectiveness of the reclamation process. This approach allows us to contrast the indicators of naturalness and hemeroby, which are formally symmetrical: the higher the hemeroby, the lower the naturalness should be. In a wide range of levels of anthropogenic pressure, this pattern is certainly true. The peculiarity of the naturalness index is that it is more sensitive in the range of anthropogenic transformation that occurs at the initial stages of deviation of the natural community from the natural state at low levels of anthropogenic impact. In turn, the hemeroby index is more sensitive to changes in the community under conditions of a high level of anthropogenic transformation.

Keywords: recultivation; phytoindication; plant ecology; biometry; syntaxonomy; classification.

Introduction

Pollution and the transformation of agricultural landscapes into degraded land is one of the major environmental challenges of the Anthropocene, endangering economic development, food security, ecosystem health and human well-being (Abdel Rahman, 2023). Mining causes the destruction of natural ecosystems by removing soil and vegetation and burying it under waste dumps (Bradshaw, 1997). The restoration of degraded ecosystems is currently the focus of increased attention, which can contribute to improving ecosystem health (Pichtel et al., 1994). The reclamation process provides for the restoration of degraded mine lands by converting them to alternative states that enhance biodiversity and ecological services (Souza et al., 2016). The use of vegetation cover is a cost-effective and environmentally sustainable method of stabilizing and reclaiming disturbed land (Tordoff et al., 2000). The damage to soil and vegetation caused by mining, if not prevented through careful planning, is usually extreme, as the original ecosystems have been grossly disturbed or buried in the mining process. A radical reconstruction is therefore necessary. In nature, this happens through the well-known processes of primary succession, without human intervention. In the interests of the economy and the preservation of our natural resources, reclamation should attempt to engage the same processes (Bradshaw, 2000). Planning for reclamation is essential to clearly define goals, objectives and success criteria that will allow for systematic reclamation (Coppin, 2013). The need for methods to assess the effectiveness in achieving environmental and social goals is growing, especially when agricultural land is to be restored (Street, 1985). Reclamation goals may need to be modified over time depending on the direction of the reclamation succession (Amirshenava & Osanloo, 2021). A restored site should be considered as a long-term experiment, as the uncertainty of the restoration trajectory can never be overcome, so environmental monitoring is important in the restoration process. There are limited opportunities to improve the theory and practice of ecological restoration in the mining industry due to the lack of post-restoration monitoring (Cooke & Johnson, 2002). The restoration of mined areas requires the application of monitoring tools to understand the achievement of potential success. This problem can be solved by studying the biodiversity of plant communities and soil factors of mining areas as habitats in industrialized post-mining landscapes (Hendrychová et al., 2020). The importance of the relative naturalness indicator is a simple but reliable tool to assess the degradation of habitats (Erdős et al., 2017). The naturalness indicator can also be used to measure the success of ecosystem restoration (Sengl et al., 2017).

Plant communities can be created especially on reclamation sites (Bauman et al., 2015) or be the result of spontaneous self-growth, as is the case on abandoned lands (Gaw & Richards, 2021). Spontaneous vegetation succession can be useful for restoring sites after mining (Prach et al., 2001), but it is very rarely used due to its low predictability (Mudrák et al., 2016). The restoration of vegetation on abandoned fields starts with primary communities and develops towards natural vegetation. Spontaneous succession can be an inexpensive but effective means of land reclamation (Sojneková & Chytrý, 2015), but its trajectory is difficult to predict, as it depends, especially in the early stages, on many stochastic processes (Mudrák et al., 2016). Spontaneous secondary succession leads to the formation of semi-natural vegetation (Csecserits & Rédei, 2001). The spontaneous development of native vegetation seems to be an appropriate way to rehabilitate areas after mining. The islands of native vegetation increase the biodiversity of degraded areas (Szarek-Łukaszewska, 2009). Species with short life spans, mostly annuals and biennials, dominate the initial stages of herbaceous community succession (Monk, 1983), which form a large number of seeds (Silvertown, 1983). The diversity of communities and the variation of succession trajectories reaches a high level, which correlates with a high proportion of annual plant species in the initial stages of spontaneous succession (Mudrák et al., 2016). The replacement of labile annual species by more stable perennial species occurs during succession, and the variation in succession trajectories decreases (Myster & Pickett, 1990). The species composition of herbaceous communities during spontaneous succession becomes similar to the structure of natural communities (Ruprecht, 2006). The vegetation cover formed as a result of spontaneous succession on the reclaimed territory is capable of significantly enriching the technosol with organic carbon. The vegetation caused a considerable intake of organic material into the ground. The vegetation, including plants with extensive root systems (Shakirov et al., 2022), has a positive effect on the physical condition of the soil, thereby improving the stability of the soil ecosystem (Kołodziej et al., 2017).

The vascular plants are the dominant primary producers of terrestrial ecosystems and are fairly accurate indicators of the abiotic environment in which they grow. The herbs have a significant potential for adaptation to extreme habitats. The herbaceous vegetation communities on reclamation sites differ in species preferences for light, moisture, fertility and soil reaction, which is an indicator of the wide variety of microclimatic conditions in the territory (Błońska et al., 2019). An integrated approach with simultaneous analysis of soils, lithotypes, landforms, edaphic parameters and plant species was applied to assess the conservation status of a nature reserve (Yakovenko et al., 2023). The direct assessment of disturbance and anthropogenic impacts is usually difficult. However, the hemeroby index has been successfully applied to study the changes in community and species composition to assess the response of vegetation to disturbance (Yorkina et al., 2020). The plant ecoindicators represented by the Ellenberg bioindicator model and the hemeroby index were used to determine the relationship between soil and vegetation (Sicuriello et al., 2014). The phytoindication method in combination with the syntaxonomic classification of vegetation has been shown to be effective for assessing the condition of land disturbed by amber mining (Churilov et al., 2020). The richness and diversity of plant species play an important role in assessing the success of a restoration project (Solomou et al., 2023). Plant communities in spontaneous revegetation of abandoned lands contaminated with heavy metals were evaluated in terms of their syntaxonomic structure and Ellenberg's indicator scales (Turisová et al., 2016).

The lands to be reclaimed form very specific habitats (Bradshaw, 2000). There is often no organic layer of soil and vegetation cover, due to the absence of a soil seed bank and the absence or low amount of nutrients in the substrate (Chmura et al., 2011). They can be typified by high absolute temperature and its high level of fluctuation, salinity, significant humidity fluctuations, and thermal activity. The instability of the coarse-grained substrate makes it vulnerable to water or mass erosion (Markowicz et al., 2015). The extreme environmental factors restrict the colonization of both plant and animal species on the reclaimed land (Zadorozhnaya et al., 2018). There are species that can inhabit this area in the process of spontaneous succession and form plant communities that often differ from those recorded on other anthropogenic sites (Błońska et al., 2019).

The concept of hemeroby was introduced into ecology to classify plant species according to their relation to the category of neophyte or therophytic species (Jalas, 1955). The concept was later extended to plant communities (Kowarik, 2020) and the geosphere (Blume & Sukopp, 1976). The degree of heterogeneity is defined as an integrative measure of the impact of all human interventions on ecosystems, whether intentional or not (Hill et al., 2002). The degree of hemeroby is the result of the impact on a particular area and the organisms that inhabit it (Yorkina et al., 2020). The hemeroby increases with increasing human impact (Zajicek & Wolter, 2018). The degree of hemeroby is measured by indicators such as the proportion of neophytic and therophytic species (Zinnen et al., 2021), morphological and chemical features of soils (Sicuriello et al., 2014), and land use types (Fehrenbach et al., 2015). The plant communities on degraded lands are highly hemerobic communities characterized by high specialization and pioneering nature. The most common species are polyhemerobes and metahemerobes (Pawul et al., 2023). Thus, the reclamation of territories disturbed by industrial activities is planned with the requirement to correct the trajectory of the restoration process, and therefore involves indicators that can be used to monitor the success of the planned process. The aim of this article is to test the following hypotheses: 1) the dynamics of the reclamation process can be monitored using the indices of naturalness and hemeroby; 2) at the initial stages of reclamation, the hemeroby index has an advantage due to its greater sensitivity in this range of anthropogenic transformation levels.

Material and methods

The field studies were conducted at the research station of the Dnipro State Agrarian and Economic University in the city of Pokrov (Dnipro region, Ukraine) (47°39'03" N, 34°08'40.3" E) (Zadorozhnaya et al., 2018). The research was conducted on an artificial edaphotope, which was a planned overburden 2 m thick, taken from different depths. The experimental site for conducting research and determining the optimal thickness of the bulk soil layer was created in the period from 1968 to 1970. The climate is continental, with an average annual temperature of 11.14 ± 0.30 °C. The average annual precipitation is 329–507 mm. The landscape is dominated by vast, slightly undulating plains. The most common geologic surface rock is loess and loess-like loams, which are several tens of meters thick. The study area belongs to the Central Pontic Grassland Zone (EuroVegMap). The natural vegetation cover is dominated by cereals and herbs. Two types of technozems were studied: lithozems and pedozems. The profile of pedozems consists of two horizons: the upper one is made up of bulk soil mass, and the lower one is made up of redeposited rocks or a dumped mixture of rocks (Yorkina et al., 2018). The lithozems are composed of rocks and their profile consists of one horizon. Lithozems formed on loess-like loams, gray-green and red-brown clays were studied (Zhukov & Gadorozhnaya, 2016). The presence of all vascular plant species was recorded at four test plots within the respective technozem type (pedozems and lithozems on red-brown, gray-green clays and loess-like loams) in May 2019–2021. Surveys were conducted within 105 sample plots of 3 × 3 m within each polygon. The sample plots were placed along seven transects with 15 sample plots in each transect. The plots were adjacent to each other, so each plot measured 21 × 45 m with a total area of m^2. The projective cover of plant species was recorded as a percentage. The species were usually considered to be infraspecific taxa for the purposes of this study. The critical specimens were collected and identified by microscopy. The plant taxonomy was based on Euro+ Med Plantbase (http://ww2.bgbm.org/EuroPlusMed). The vegetation was classified using the TWINSPAN software (Hill, 1979). The fidelity of diagnostic species for clusters was determined using the fidelity coefficient (phi coefficient) with a threshold of 25 (for highly diagnostic species – 50), species with a frequency of occurrence > 25% (for highly constant species > 50%) were considered constant, and species with projective cover > 10% were considered dominant (Lavrinenko et al., 2023). The phi coefficient was calculated using the indicspecies library (Cáceres, 2013). The syntaxa are identified to the level of associations, the names of the syntaxa are given according to the vegetation identifier (Mucina et al., 2016) and the Prodrom of Vegetation of Ukraine (Dubina et al., 2019). The phytoindication assessment of ecological factors was carried out in accordance with the method of synphytoindication by Didukh (2011), and calculations were made using the method of ideal indicators (Buzuk, 2017). For the purpose of clarity, the scores were converted to equivalent physical values. The Frank and Klotz scale was used to assess hemeroby (Frank & Klotz, 1990). The original scales were converted by calculating the half-sum of the minimum and maximum values for each species, and then converted to a 100-point scale (Table 1). The weighted average of the hemeroby scores, taking into account the predicted vegetation cover, was used to characterize the hemeroby of each sample (Yorkina et al., 2022). The types of social behavior of plants are derived from the role that plant species perform in communities. They reflect the way in which the plant is connected to the habitat, as well as the informativeness and naturalness of this connection. The properties of the types found in a community can be used to infer the richness of ecological information in the community, its stability and naturalness, the degree of niche filling, the regeneration capacity or capacity of the community, and the degree of disturbance, transformation, or deviation from the natural state (Borhidi, 1995). The descriptive statistics, ANOVA, analysis of components of relative variance, were calculated.

Table 1
Classification of human impacts on ecosystems and corresponding degrees of hemeroby and naturalness (after Sukopp (1976) as amended)

Degree of hemeroby	Degree of naturalness	Human impact	Hemeroby index	Naturalness index
Ahemerobe	Natural	None, conservation areas	0–25	5–6
Oligohemerobe	Close to natural	Limited removal of wood, pastoralism, emissions through air and water; buffer zone of conservation areas	25–50	4–5
Mesohemerobe	Seminatural	Clearing and occasional ploughing, clear cut, occasional slight fertilization; naturalized city parks	50–60	3–4
β-euhemerobe	Relatively far from natural	Application of fertilizers, lime and pesticides, ditch drainage; the final phases of land reclamation	60–70	2–3
α-euhemerobe	Far from natural	Deep ploughing, drainage, application of pesticides and intensive fertilization; intermediate phase of land reclamation	70–80	1–2
Polyhemerobe	Strange to natural	Single destruction of the biocenosis and covering of the biotope with external material at the same time; first phase of land reclamation	80–90	0 – 1
Metahemerobe	Artificial biocenosis	Destroyed; the initial phase of land reclamation	90–100	–3 – 0

Results

Vegetation cover of technozems. The plant community formed as a result of spontaneous growth of the reclamation sites was represented by 70 species of vascular plants. The projective cover of vegetation was 22.0 ± 0.30%, and in 95% of cases this indicator was in the range of 7.4–43.6%. The type of technozem was able to explain 17.8% of the variation in this indicator ($F = 91.6$, $P < 0.001$). The projected cover of lithozems on loess-like loams was statistically significantly higher than in other types of technozems (planned comparison $F = 269.5$, $P < 0.001$) and reached the level of 29.8 ± 0.62%. There were 8.4 ± 0.1 plant species in one sample plot, and in 95% of cases this indicator was in the range of 5–14 species. The type of technozem was able to explain 6.9% of the variation in this indicator ($F = 32.3$, $P < 0.001$). The species richness of lithozems on red-brown clays was statistically significantly higher than in other types of technozems (planned comparison $F = 87.9$, $P < 0.001$) and reached the level of 9.4 ± 0.1 species. Other types of technozems did not differ in species richness of vegetation cover (planned comparison $F = 0.05$, $P = 0.81$). Shannon's diversity index was 2.20 ± 0.02 bits/species, and in 95% of cases this index was in the range of 0.8–3.3 bits/species. The type of technozem was able to explain 28.6% of the variation in the diversity index ($F = 169.5$, $P < 0.001$). The Shannon diversity index of lithozems on loess-like loams was statistically significantly lower than in other types of technozems (planned comparison $F = 494.3$, $P < 0.001$) and was at the level of 1.6 ± 0.1 bits/species. Other types of technozems did not differ from each other by the values of the Shannon diversity index (planned comparison $F = 0.16$, $P = 0.68$). The Piellou evenness index was 0.720 ± 0.004, and in 95% of cases this index was in the range of 0.31–0.97. The type of technozem was able to explain 31.3% of the variation in the Piellou evenness index ($F = 192.7$, $P < 0.001$). The Piellou evenness index of lithozem on loess-like loams was statistically significantly lower than on other types of technozems (planned comparison $F = 573.1$, $P < 0.001$) and was at the level of 0.55 ± 0.01. Other types of technozems did not differ from each other by the values of the Piellou evenness index (planned comparison $F = 1.58$, $P = 0.21$).

Syntaxonomical structure of vegetation cover. The analysis of the synoptic phytosociological table (Table 2) revealed that the vegetation cover of the reclamation site was represented by nine associations from two classes of vegetation.

Class *Artemisietea vulgaris* Lohmeyer et al. in Tx. ex von Rochow 1951
Ordo *Agropyretalia intermedio-repentis* T. Müller et Görs 1969
Union *Convolvulo arvensis-Agropyrion repentis* Görs 1967
Ass. *Falcario vulgaris-Elytrigietum repentis* T. Müller et Görs 1969
Ass. *Agropyretum repentis* Felföldy 1942
Ass. *Medicagini lupulinae-Agropyretum repentis* Popescu et al. 1980
Ass. *Melico transsilvanicae-Agropyretum* T. Müller in Görs 1966
Ass. *Convolvulo arvensis-Agropyretum repentis* Felföldy 1943
Union *Onopordion acanthii* Br.-Bl. et al. 1936
Ass. *Carduo acanthoidis-Onopordetum acanthii* Soó ex Jarolímek et al. 1997
Class *Stellarietea mediae* Tx. et al. in Tx. 1950
Ordo *Sisymbrietalia sophiae* J. Tx. ex Görs 1966
Union *Hordeion murini* Br.-Bl. in Br.-Bl. et al. 1936
Ass. *Brometum tectorum* Bojko 1934
Ordo *Atriplici-Chenopodietalia albi* (Tx. 1937) Nordhagen 1940
Union *Polygono-Chenopodion* Koch 1926
Ass. *Ambrosio artemisiifoliae-Cirsietum setosi* Marjushkina et Solomakha 1985
Union *Sisymbrion officinalis* Tx. et al. ex von Rochow 1951
Ass. *Cirsio-Lactucetum serriolae* Mucina 1978

Association *Falcario vulgaris-Elytrigietum repentis* T. Müller et Görs 1969 was represented by 47 plant species. The basis of the community was made up of *Achillea millefolium*, *Bromus squarrosus*, *Medicago sativa*, *Vicia cracca*, and *Elytrigia repens*. The projective cover of the community was 22.3 ± 0.52% (in 95% of cases it was in the range of 12.7–33.5%). The species richness of the community was 8.9 ± 0.2 species per plot (in 95% of cases this indicator was in the range of 5–14 species per plot). The diversity of the community was 2.2 ± 0.1 bits/species per plot. The evenness was 0.69 ± 0.01. The association was most often found in the lithozems on red-brown clays (Fig. 1). The association favored soils with an available moisture content of 36.2 ± 6.2 mm and a moisture contrast index of 0.29 ± 0.04 (Table 3). The phytoindication assessment of soil acidity in the area of the association resulted in pH = 7.07 ± 0.01. The content of water-soluble salts in the soil was 38.6 ± 2.9 μg/L.

Table 2
Synoptic phytosociological table (the table shows the percentage of species occurrence in the respective associations; diagnostic species of the corresponding associations are marked with asterisks)

Species	1	2	3	4	5	6	7	8	9	Fidelity
	92	78	88	81	246	108	103	238	226	
Senecio leucanthemifolius	67.4*	62.8	61.4	2.5	34.1	–	1.0	1.7	–	0.34
Falcaria vulgaris	62.0*	24.4	25.0	1.2	12.2	8.3	59.2	29.4	30.1	0.27
Sanguisorba officinalis	5.4*	1.3	3.4	–	–	–	1.0	1.7	0.4	0.12
Securigera varia	13.0*	–	–	12.3	4.1	2.2	–	–	2.7	0.17
Xeranthemum annuum	21.7*	1.3	12.5	–	2.8	2.8	4.9	1.3	11.5	0.22
Artemisia absinthium	34.8*	23.1	12.5	22.2	28.0	10.2	10.7	2.9	8.0	0.17
Achillea millefolium	91.3*	62.8	76.1	3.7	51.6	38.9	26.2	24.4	38.1	0.32
Melilotus albus	35.9	52.6*	30.7	–	15.4	–	1.0	–	–	0.37
Xanthium strumarium	3.3	24.4*	14.8	–	2.4	–	1.9	16	9.3	0.21
Elytrigia repens	34.8	89.7*	11.4	–	5.7	4.6	35	58.8	25.7	0.47
Agropyron cristatum	5.4	11.5	53.4*	–	18.3	11.1	28.2	5.9	37.6	0.31
Medicago lupulina	–	–	45.4*	3.7	–	–	–	–	–	0.38
Bromus hordeaceus	5.4	21.8	55.7*	–	10.6	6.5	2.9	1.7	19	0.43
Crepis tectorum	–	–	–	2.5*	0.4	–	–	–	–	0.13
Melica transsilvanica	–	–	1.1	71.1*	4.5	10.2	1	0.8	0.4	0.56
Sonchus arvensis	–	–	–	14.8*	0.4	–	–	1.3	–	0.34
Convolvulus arvensis	6.5	1.3	6.8	61.7*	52.2	7.4	5.8	26.1	9.7	0.46
Lotus ucrainicus	–	–	–	13.6*	2.4	13	1.0	2.5	2.7	0.18
Seseli campestre	38	39.7	48.9	96.3*	80.5	91.7	84.5	68.9	58	0.22
Lepidium perfoliatum	–	–	–	4.9*	1.2	3.7	–	0.4	2.7	0.10
Anisantha tectorum	1.1	–	1.1	2.5	52.8*	2.8	–	–	0.9	0.45
Bromus squarrosus	97.8	94.9	87.5	100	100	100*	86.4	97.5	85.8	0.09
Atriplex micrantha	–	–	–	–	0.4	–	7.8*	3.4	–	0.20
Cirsium arvense	–	–	–	1.2	2	3.7	39.7*	14.7	12.4	0.16
Filipendula vulgaris	–	–	–	–	0.4	–	6.8*	4.6	–	0.17
Thesium ramosum	–	–	–	–	0.4	–	1.9*	–	–	0.12
Consolida regalis	20.7	25.6	20.5	69.1	42.7	2.8	94.2*	58	35.4	0.38
Medicago sativa	76.1	65.4	70.5	88.9	87.8	90.7	92.2*	70.2	67.3	0.12
Ambrosia artemisiifolia	–	–	–	6.2	1.2	10.8	48.7*	15.7	16.9	0.17
Helichrysum arenarium	–	–	–	–	–	–	3.9	4.6*	–	0.13
Hieracium virosum	–	–	–	–	–	–	1.9	4.6*	–	0.16
Hypericum elegans	1.1	–	–	–	–	–	–	2.5*	–	0.12
Onobrychis viciifolia	25	20.5	9.1	11.1	14.6	23.1	14.6	68.1*	21.7	0.38
Lactuca serriola	52.2	79.5	54.5	80.2	48.8	50	89.3	93.7*	79.6	0.18
Anthemis arvensis	–	2.6	3.4	–	1.2	0.9	–	–	5.8*	0.12
Erysimum diffusum	29.3	28.2	15.9	1.2	22.4	9.3	2.9	3.8	45.1*	0.26
Carduus acanthoides	4.3	1.3	1.1	–	1.2	–	–	–	36.2*	0.53
Centaurea diffusa	45.7	30.8	10.2	1.2	12.6	13.9	8.7	8.4	57.5*	0.32
Silene dichotoma	21.7	23.1	10.2	1.2	14.6	16.7	–	0.4	26.1*	0.14
Vicia cracca	17.4	2.6	10.2	3.7	2.4	13	1.9	0.4	19.5*	0.15
Jacobaea vulgaris	3.3	2.6	4.5	12.3	12.2	50.9	1	14.7	75.2*	0.49
Tragopogon dubius	8.7	2.6	14.8	2.5	11.4	50.9	32	29.4	61.9*	0.32
Melilotus officinalis	1.1	2.6	5.7	1.2	10.6	83.3	2.9	13.4	87.2*	0.54
Echium vulgare	–	–	1.1	–	–	–	–	0.4	4.4*	0.16
Euphorbia stepposa	1.1	–	2.3	–	0.4	2.8	–	–	7.1*	0.16
Lactuca tatarica	–	–	–	–	–	–	–	–	4.0*	0.19
Alyssum desertorum	–	–	–	–	4.1	3.7	–	7.1	33.6*	0.44
Reseda lutea	2.2	11.5	9.1	3.7	13.8	7.4	15.5	6.3	23.0*	0.15

Note: associations: 1 is the *Falcario vulgaris-Elytrigietum repentis*; 2 is the *Agropyretum repentis*; 3 is the *Medicagini lupulinae-Agropyretum repentis*; 4 is the *Melico transsilvanicae-Agropyretum*; 5 is the *Convolvulo arvensis-Agropyretum repentis*; 6 is the *Brometum tectorum*; 7 is the *Ambrosio artemisiifoliae-Cirsietum setosi*; 8 is the *Cirsio-Lactucetum serriolae*; 9 is the *Carduo acanthoidis-Onopordetum acanthi*; other species: *Dactylis glomerata* (1), *Euphorbia esula* (1, 3, 5), *Pilosella officinarum* (1, 8), *Elaeagnus angustifolia* (1, 9), *Aegilops cylindrica* (2, 3), *Linaria genistifolia* (2, 5), *Rosa canina* (4, 5, 6, 9), *Agrimonia eupatoria* (6, 9), *Poa pratensis* (6, 9), *Medicago falcata* (1, 2, 3, 4, 5, 7, 8), *Chondrilla juncea* (7), *Galium verum* (5, 7, 8), *Stellaria holostea* (9), *Koeleria cristata* (9), *Erigeron acris* (5, 8), *Pyrus communis* (8), *Prunus armeniaca* (8), *Eryngium campestre* (8), *Taraxacum campylodes* (1, 2, 4, 5, 6, 7, 8, 9), *Festuca valesiaca* (4, 5, 8, 9), *Rumex confertus* (2), *Rhaponticum repens* (3, 8).

The carbonate content was 2.9 ± 1.2% in terms of calcium and magnesium oxides. The content of nitrogen compounds was 1.65 ± 0.39 g/kg. The soil aeration was 69.2 ± 7.8%. This plant association preferred radiation conditions at the level of 1.87 ± 0.12 gJ/m year. The optimal regime of atmospheric moisture was characterized by a balance between precipitation and evaporation –1.35 ± 0.14 mm per year. The optimal continentality regime was 161 ± 18 points. The average temperature of the coldest month of the year was –3.1 ± 1.2 °C. The optimal light regime was characterized by a value of 8.86 ± 0.05 scores. The naturalness of the association was –1.8 ± 0.7, indicating the artificial nature of the biocenosis. The hemeroby was 91 ± 4, which indicates a metahemerobic community under conditions of significant anthropogenic disturbance and the initial phase of reclamation. The metahemerobic communities within this association were found in 62.0% of cases, and the polyhemerobic communities were found in 37.0% of cases.

Association *Agropyretum repentis* Felföldy 1942 was represented by 39 species of grasses. *Elytrigia repens*, *Bromus squarrosus*, *Achillea millefolium*, *Lactuca serriola*, *Medicago sativa* formed the basis of the assemblage. The projective cover of the community was 20.9 ± 0.70% (in 95% of cases it was in the range of 8.6–37.7%). The species richness of the community amounted to 8.5 ± 0.2 species per plot (in 95% of cases this indicator was in the range of 5–14 species per plot). The community diversity was 2.2 ± 0.1 bits/species per plot. The evenness was 0.73 ± 0.01. The association was most often found in the pedozems. The association preferred soils with an available moisture content of 37.5 ± 5.2 mm and a moisture contrast index of 0.29 ± 0.03. The phytoindication assessment of soil acidity in the area of the association resulted in a pH of 7.06 ± 0.12. The content of water-soluble salts in the soil was 41.7 ± 2.8 μg/L. The carbonate content was 3.0 ± 1.2% in terms of calcium and magnesium oxides. The content of nitrogen compounds was 1.38 ± 0.38 g/kg. The soil aeration was 77.3 ± 7.2%. This plant association preferred radiation conditions at the level of 1.95 ± 0.13 gJ/m^2 year. The optimal regime of atmospheric moisture characterized by a balance between precipitation and evaporation was 1.25 ± 0.15 mm per year. The optimal continentality regime was 162 ± 13 points. The average temperature of the coldest month of the year was 2.32 ± 1.3 °C. The optimal light regime was characterized by a value of 8.87 ± 0.04 points. The naturalness of the association was –0.8 ± 0.7, indicating the artificial nature of the biogeocenosis. The hemeroby index was 89 ± 5, which indicates a polyhemerobic community that is in the first phase of reclamation. The metahemerobic communities within this association were found in 46.2% of cases, and the polyhemerobic communities were found in 50.0% of cases.

Table 3
Descriptive statistics of phytoindicative assessments of ecological factors, naturalness and hemeroby (mean ± standard deviation)

Variables*	Associations**								
	1	2	3	4	5	6	7	8	9
Hd	36.2 ± 6.2	37.5 ± 5.2	40.2 ± 5.9	43.7 ± 5.4	40.5 ± 5.9	42.3 ± 5.3	36.0 ± 6.8	38.1 ± 6.7	38.7 ± 6.0
fH	0.29 ± 0.04	0.29 ± 0.03	0.28 ± 0.04	0.29 ± 0.04	0.32 ± 0.04	0.31 ± 0.03	0.31 ± 0.04	0.31 ± 0.04	0.32 ± 0.04
Rc	7.07 ± 0.1	7.06 ± 0.12	7.06 ± 0.11	7.03 ± 0.14	7.07 ± 0.11	7.05 ± 0.12	7.08 ± 0.11	7.08 ± 0.12	7.08 ± 0.12
Sl	38.6 ± 2.9	41.7 ± 2.8	39.6 ± 2.2	43.0 ± 1.5	42.2 ± 2.3	44.3 ± 2.9	41.6 ± 2.9	43.6 ± 2.8	43.4 ± 3.0
Ca	2.9 ± 1.2	3.0 ± 1.2	2.5 ± 1.2	3.5 ± 1.4	3.5 ± 1.5	3.8 ± 1.8	4.3 ± 1.5	4.6 ± 1.7	3.6 ± 1.7
Nt	1.7 ± 0.4	1.4 ± 0.4	1.3 ± 0.4	1.4 ± 0.4	1.5 ± 0.4	1.8 ± 0.4	0.8 ± 0.4	1.2 ± 0.4	1.4 ± 0.4
Ae	69.2 ± 7.8	77.3 ± 7.2	79.4 ± 7.8	84.1 ± 6.4	77.5 ± 7.8	79.1 ± 7.8	72.6 ± 9.8	71.6 ± 8.6	77.2 ± 7.7
Tm	1.9 ± 0.1	2.0 ± 0.1	2.0 ± 0.1	2.0 ± 0.1	1.9 ± 0.1	1.9 ± 0.1	2.0 ± 0.1	2.0 ± 0.1	1.9 ± 0.1
Om	–1.4 ± 0.1	–1.3 ± 0.2	–1.3 ± 0.2	–1.2 ± 0.2	–1.2 ± 0.1	–1.0 ± 0.2	–1.4 ± 0.1	–1.1 ± 0.2	–1.1 ± 0.2
Kn	161 ± 18	162 ± 13	152 ± 15	153 ± 22	152 ± 20	153 ± 21	177 ± 20	172 ± 20	160 ± 18
Cr	–3.1 ± 1.2	–2.3 ± 1.3	–3.1 ± 1.3	–2.8 ± 1.2	–2.7 ± 1.2	–3.2 ± 1.3	–3.2 ± 1.1	–3.2 ± 1.2	–3.6 ± 1.4
Lc	8.9 ± 0.1	8.9 ± 0.1	8.9 ± 0.1	8.9 ± 0.1	8.9 ± 0.1	8.9 ± 0.03	8.9 ± 0.07	8.9 ± 0.06	8.9 ± 0.05
Naturalness	–1.8 ± 0.7	–0.8 ± 0.7	–0.5 ± 0.6	–1.5 ± 0.5	–1.5 ± 0.5	–1.6 ± 0.5	–1.6 ± 0.7	–1.7 ± 0.7	–1.2 ± 0.7
Hemeroby	91 ± 4	89 ± 5	84 ± 7	84 ± 7	88 ± 6	84 ± 7	84 ± 9	85 ± 8	79 ± 9
β-euhemerobe, %	–	–	4.5	2.5	0.4	5.6	2.9	3.4	15.5
α-euhemerobe, %	1.1	3.8	19.3	25.9	8.5	25.0	33.0	19.3	37.6
Polyhemerobe, %	37.0	50.0	59.1	50.6	48.8	50.0	33.0	50.4	32.3
Metahemerobe, %	62.0	46.2	17.0	21.0	42.3	19.4	31.1	26.9	14.6

Note: * are phytoindication scores: Hd is the water regime of the soil, fH is the variability of moisture, Ae is soil aeration, Rc is soil acidity, Sl is the total salt regime, Ca is the carbonate content of the soil, Nt is the nitrogen content of the soil, Tm is the thermal regime, Om is the humidity regime, Cr is the cryoclimate regime, Kn is the continental climate, Lc is the light regime; ** – associations: 1 is the *Falcario vulgaris-Elytrigietum repentis*; 2 is the *Agropyretum repentis*; 3 is the *Medicagini lupulinae-Agropyretum repentis*; 4 is the *Melico transsilvanicae-Agropyretum*; 5 is the *Convolvulo arvensis-Agropyretum repentis*; 6 is the *Brometum tectorum*; 7 is the *Ambrosio artemisiifoliae-Cirsietum setosi*; 8 is the *Cirsio-Lactucetum serriolae*; 9 is the *Carduo acanthoidis-Onopordetum acanthi*.

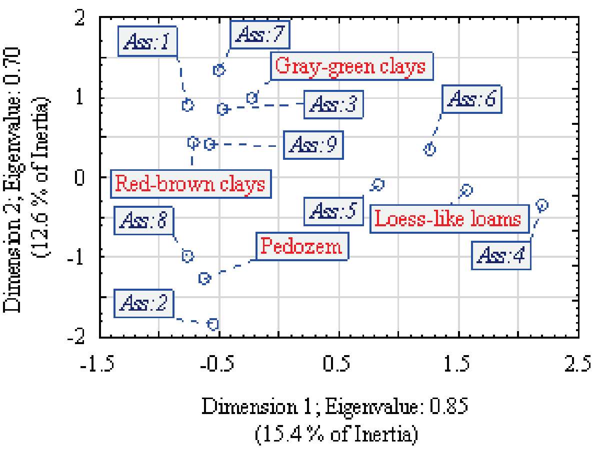

Fig. 1. Multiple correspondence analysis of technozem types and plant associations: types of technozems: red-brown clays are lithozems on red-brown clays; loess-like loams are lithozems on loess-like loams; pedozem are pedozems with a humified bulk layer; gray-green clays are lithozems on gray-green clays; associations: Ass:1 is the *Falcario vulgaris-Elytrigietum repentis*; Ass:2 is the *Agropyretum repentis*; Ass:3 is the *Medicagini lupulinae-Agropyretum repentis*; Ass:4 is the *Melico transsilvanicae-Agropyretum*; Ass:5 is the *Convolvulo arvensis-Agropyretum repentis*; Ass:6 is the *Brometum tectorum*; Ass:7 is the *Ambrosio artemisiifoliae-Cirsietum setosi*; Ass:8 is the *Cirsio-Lactucetum serriolae*; Ass:9 is the *Carduo acanthoidis-Onopordetum acanthi*

Association *Medicagini lupulinae-Agropyretum repentis* Popescu et al. 1980 was represented by the 39 species of grasses. *Achillea millefolium*, *Agropyron cristatum*, *Bromus squarrosus*, *B. hordeaceus*, *Medicago sativa*, *M. lupulina*, *Senecio leucanthemifolius* formed the basis of the assemblage. The projective cover of the community was 20.4 ± 0.8% (in 95% of cases it was in the range of 9.2–33.5%). The species richness of the community was 7.8 ± 0.2 species per plot (in 95% of cases, this indicator was in the range of 5–11 species per plot). The community diversity was 2.3 ± 0.1 bits/species per plot. The evenness was 0.77 ± 0.01. The association was most often found on the lithozems on gray-green clays. This association preferred soils with an available moisture content of 40.2 ± 5.9 mm and a moisture contrast index of 0.28 ± 0.04. The phytoindication assessment of soil acidity in the area of association distribution was pH = 7.06 ± 0.11. The content of water-soluble salts in the soil was 39.6 ± 2.2 µg/L. The carbonate content was 2.5 ± 1.2% in terms of calcium and magnesium oxides. The content of nitrogen compounds was 1.3 ± 0.4 g/kg. Soil aeration was 79.4 ± 7.8%. This plant association preferred radiation conditions at the level of 2.0 ± 0.1 gJ/m^2 year. The optimal regime of atmospheric moisture was characterized by a balance between precipitation and evaporation –1.3 ± 0.2 mm per year. The optimal continentality regime was 152 ± 15 points. The average temperature of the coldest month of the year was –3.1 ± 1.3 °C. The optimal light regime was characterized by a value of 8.9 ± 0.1 points. The naturalness of the association was –0.5 ± 0.6, indicating the artificial nature of the biogeocenosis. The hemeroby was 84 ± 7, which indicates a polyhemerobic community that is in the first phase of reclamation. The communities of this association were most often polyhemerobic (in 59.1% of cases). Also, the communities were often classified as alpha-hemerobic (in 19.3% of cases).

Association *Melico transsilvanicae-Agropyretum* T. Müller in Görs 1966 was represented by the 33 species of grasses. *Bromus squarrosus*, *Seseli campestre*, *Medicago sativa* formed the basis of the assemblage. The projective cover of the community was 29.7 ± 1.8% (in 95% of cases it was in the range of 12.7–47.2%). The species richness of the community was 6.8 ± 0.1 species per plot (in 95% of cases, this indicator was in the range of 5–10 species per plot). The community diversity was 1.3 ± 0.1 bits/species per plot. The evenness was 0.45 ± 0.02. The association was most often found on the lithozems on loess-like loams. The association favored soils with an available moisture content of 43.7 ± 5.4 mm and a moisture contrast index of 0.29 ± 0.04. The phytoindication assessment of soil acidity in the area of the association's distribution resulted in a pH of 7.03 ± 0.14. The content of water-soluble salts in the soil was 43.0 ± 1.5 µg/L. The carbonate content was 3.5 ± 1.4 % in terms of calcium and magnesium oxides. The content of nitrogen compounds was 1.4 ± 0.4 g/kg. The soil aeration index was 84.1 ± 6.4%. This plant association preferred radiation conditions at the level of 2.0 ± 0.1 gJ/ m^2 year. The optimal regime of atmospheric moisture was characterized by a balance between precipitation and evaporation – 1.2 ± 0.2 mm per year. The optimal continentality regime was 153 ± 22 points. The average temperature of the coldest month of the year was 2.8 ± 1.2 °C. The optimal light regime was characterized by a value of 8.9 ± 0.1 points.

The naturalness of the association was –1.5 ± 0.5, indicating the artificial nature of the biogeocenosis. The hemeroby was 84 ± 7, which indicates a polyhemerobic community that is in the first phase of reclamation. The communities of this association were most often polyhemerobic (in 50.6% of cases). Also, the communities were often classified as alpha-hemerobic (in 25.9% of cases).

Association *Convolvulo arvensis-Agropyretum repentis* Felföldy 1943 was represented by the 33 species of grasses. *Bromus squarrosus*, *Medicago sativa*, *Seseli campestre*, *Achillea millefolium* formed the basis of the assemblage. The projective cover of the community was 25.5 ± 0.5% (in 95% of cases it was in the range of 10.9–41.8%). The species richness of the community was 7.6 ± 0.1 species per plot (in 95% of cases, this indicator was in the range of 5–11 species per plot). The community diversity was 1.7 ± 0.1 bits/species per plot. The alignment was 0.59 ± 0.01. The association was most often found on the lithozem on loess-like loams. The association preferred soils with an available moisture content of 40.5 ± 5.9 mm and a moisture contrast index of 0.32 ± 0.04. The phytoindication assessment of soil acidity in the association area was pH = 7.07 ± 0.11. The content of water-soluble salts in the soil was 42.2 ± 2.3 μg/L. The carbonate content was 3.5 ± 1.5% in terms of calcium and magnesium oxides. The content of nitrogen compounds was 1.5 ± 0.4 g/kg. The soil aeration was 77.5 ± 7.8%. The association preferred radiation conditions at the level of 1.9 ± 0.1 gJ/m^2 year. The optimal regime of atmospheric moisture was characterized by a balance between precipitation and evaporation –1.2 ± 0.1 mm per year. The optimal continentality regime was 152 ± 20 points. The average temperature of the coldest month of the year was –2.7 ± 1.2 °C. The optimal light regime was characterized by a value of 8.9 ± 0.1 points. The naturalness of the association was –1.5 ± 0.5, indicating the artificial nature of the biogeocenosis. The hemeroby was 88 ± 6, which indicates a polyhemerobic community that is in the first phase of reclamation. The communities of this association were most often polyhemerobic (in 48.9% of cases). The communities were also often classified as metaheterobic (in 42.3% of cases).

Association *Brometum tectorum* Bojko 1934 was represented by 37 plant species. *Bromus squarrosus*, *Medicago sativa*, *Seseli campestre*, *Melilotus officinalis* formed the basis of the community. The projective cover of the community was 27.6 ± 0.7% (in 95% of cases it was in the range of 16.3–42.4%). The species richness of the community was 8.0 ± 0.2 species per plot (in 95% of cases, this indicator was in the range of 5–11 species per plot). The diversity of the community was 2.0 ± 0.1 bits/species per plot. The alignment was 0.67 ± 0.01. The association was most often found on the lithozems on loess-like loams. The association preferred soils with an available moisture content of 42.3 ± 5.3 mm and a moisture contrast index of 0.31 ± 0.03. The phytoindication assessment of soil acidity in the association area resulted in a pH of 7.05 ± 0.12. The content of water-soluble salts in the soil was 44.3 ± 2.9 μg/L. The carbonate content was 3.8 ± 1.8% in terms of calcium and magnesium oxides. The content of nitrogen compounds was 1.8 ± 0.4 g/kg. The soil aeration was 79.1 ± 7.8%. The association preferred radiation conditions at the level of 1.9 ± 0.1 gJ/m^2 year. The optimal regime of atmospheric moisture was characterized by a balance between precipitation and evaporation –1.0 ± 0.2 mm per year. The optimal continentality regime was 153 ± 21 points. The average temperature of the coldest month of the year was –3.2 ± 1.3 °C. The optimal light regime was characterized by a value of 8.9 ± 0.1 points. The naturalness of the association was –1.6 ± 0.5, indicating the artificial nature of the biogeocenosis. The hemeroby was 84 ± 7, which indicates a polyhemerobic community that is in the first phase of reclamation. The communities of this association were most often polyhemerobic (in 50.0% of cases). Also, the communities were often classified as alpha-hemerobic (in 19.4% of cases).

Association *Ambrosio artemisiifoliae-Cirsietum setosi* Marjushkina et Solomakha 1985 was represented by 39 plant species. The basis of the community was formed by *Bromus squarrosus*, *Medicago sativa*, *Seseli campestre*, *Lactuca serriola*, *Consolida regalis*. The projective cover of the community was 11.5 ± 0.3% (in 95% of cases it was in the range of 5.6–21.0%). The species richness of the community was 8.1 ± 0.2 species per plot (in 95% of cases, this indicator was in the range of 6–12 species per plot). The community diversity was 2.7 ± 0.1 bits/species per plot. The alignment was 0.90 ± 0.01. The association was most often found in the lithozems on gray-green clays. The association preferred soils with an available moisture content of 36.0 ± 6.8 mm and a moisture contrast index of 0.31 ± 0.04. The phytoindication assessment of soil acidity in the association distribution zone revealed a pH of 7.08 ± 0.11. The content of water-soluble salts in the soil was 41.6 ± 2.9 μg/L. The carbonate content was 4.3 ± 1.5% in terms of calcium and magnesium oxides. The content of nitrogen compounds was 0.8 ± 0.4 g/kg. Soil aeration was 72.6 ± 9.8%. The association preferred radiation conditions at the level of 2.0 ± 0.1 gJ/m^2 year. The optimal regime of atmospheric moisture was characterized by a balance between precipitation and evaporation –1.4 ± 0.1 mm per year. The optimal continentality regime was 177 ± 20 points. The average temperature of the coldest month of the year was –3.2 ± 1.1 °C. The optimal light regime was characterized by a value of 8.9 ± 0.1 points. The naturalness of the association was –1.6 ± 0.7, indicating the artificial nature of the biogeocenosis. The hemeroby was 84 ± 9, which indicates a polyhemerobic community that is in the first phase of reclamation. This community was distributed in almost equal proportions between alpha-hemerobic (33.0% of cases), polyhemerobic (33.0%) and metahemerobic (31.1%) levels of anthropogenic transformation.

Association *Cirsio-Lactucetum serriolae* Mucina 1978 was represented by 49 plant species. The basis of the community was formed by *Bromus squarrosus*, *Elytrigia repens*, *Lactuca serriola*, *Medicago sativa*, *Onobrychis viciifolia*, *Seseli campestre*. The projective cover of the community was 14.4 ± 0.4% (in 95% of cases it was in the range of 6.2–30.5%). The species richness of the community amounted to 7.7 ± 0.1 species per plot (in 95% of cases, this indicator was in the range of 5–11 species per plot). The community diversity was 2.4 ± 0.1 bits/species per plot. The evenness was 0.81 ± 0.01. The association was most often found on the pedozem. The association preferred soils with an available moisture content of 38.1 ± 6.7 mm and a moisture contrast index of 0.31 ± 0.04. The phytoindication assessment of soil acidity in the association distribution zone resulted in a pH of 7.08 ± 0.12. The content of water-soluble salts in the soil was 43.6 ± 2.8 μg/L. The carbonate content was 4.6 ± 1.7% in terms of calcium and magnesium oxides. The content of nitrogen compounds was 1.2 ± 0.4 g/kg. The soil aeration was 71.6 ± 8.6%. The association preferred radiation conditions at the level of 2.0 ± 0.1 gJ/m^2 year. The optimal regime of atmospheric moisture was characterized by a balance between precipitation and evaporation –1.1 ± 0.2 mm per year. The optimal continentality regime was 172 ± 20 points. The average temperature of the coldest month of the year was –3.2 ± 1.2 °C. The optimal light regime was characterized by a value of 8.9 ± 0.1 points. The naturalness of the association was –1.7 ± 0.7, indicating the artificial nature of the biogeocenosis. The hemeroby was 85 ± 8, which indicates a polyhomoecious community that is in the first phase of reclamation. The communities of this association were most often polyhemerobic (in 50.4% of cases). The communities were also often classified as metaheterobic (in 26.9% of cases).

Association *Carduo acanthoidis-Onopordetum acanthii* Soó ex Jarolímek et al. 1997 was represented by 46 plant species. The basis of the community was *Melilotus officinalis*, *Bromus squarrosus*, *Medicago sativa*, *Agropyron cristatum*, *Lactuca serriola*, *Seseli campestre*, *Elytrigia repens*, *Centaurea diffusa*, *Jacobaea vulgaris*, *Medicago lupulina*. The projective cover of the community was 26.6 ± 1.0% (in 95% of cases it was in the range of 8.0–79.8%). The species richness of the community amounted to 10.7 ± 0.19 species per plot (in 95% of cases, this indicator was in the range of 6–17 species per plot). The community diversity was 2.6 ± 0.1 bits/species per plot. The evenness was 0.75 ± 0.01. The association was most often found in lithozems on red-brown clays. The association preferred soils with an available moisture content of 38.7 ± 6.0 mm and a moisture contrast index of 0.32 ± 0.04. The phytoindication assessment of soil acidity in the area of the association showed pH = 7.08 ± 0.12. The content of water-soluble salts in the soil was 43.4 ± 3.0 μg/L. The carbonate content was 3.6 ± 1.7% in terms of calcium and magnesium oxides. The content of nitrogen compounds was 1.4 ± 0.4 g/kg. The soil aeration was 77.2 ± 7.7%. The association preferred radiation conditions at the level of 1.9 ± 0.1 gJ/m^2 year. The optimal regime of atmospheric moisture was characterized by a balance between precipitation and evaporation –1.1 ± 0.2 mm per year. The optimal continentality regime was 160 ± 18 points. The average temperature of the coldest month of the year was –3.6 ± 1.4 °C. The optimal light regime was characterized by a value of 8.9 ± 0.1 points. The naturalness of the association was –1.2 ± 0.7, indicating the artificial nature of the biogeocenosis. The hemeroby was 79 ± 9, which indicates an α-eugemerobic community that is in the intermediate phase of reclamation. The communities of this association were most often alpha-eugemerobic (in 37.6% of cases). Also, the communities were often classified as polyhemerobic (in 32.3% of cases).

Phytoindication of edaphic properties. The average level of available moisture content for plants based on the results of phytoindication was 39.2 ± 0.2%, and in 95% of cases this indicator was in the range from 26.8% to 51.4%. The association allowed us to explain 6.9% of the variation in available moisture content (F = 5.38, P < 0.001). The interannual features explained 1% of the variation in this indicator (F = 3.34, P = 0.036), and the type of technozem was able to explain 19.8% of the variation in the content of available moisture for plants (F = 66.0, P < 0.001). The association *Ambrosio artemisiifoliae-Cirsietum setosi* was characterized by a 26.9% lower level of plant available moisture compared to other associations (planned comparison F = 31.3, P < 0.001) (Fig. 2). Other associations did not differ from each other in this indicator (planned comparison F = 0.05, P = 0.82). The level of contrast of the soil moisture regime was characterized by the coefficient ω, which averaged 0.31 ± 0.01 and in 95% of cases was in the range from 0.23 to 0.38. The association allowed us to explain 6.0% of the variation in the contrast of the moisture regime (F = 11.32, P < 0.001). The interannual characteristics explained 5.1% of the variation in this indicator (F = 10.2, P < 0.001, and the type of technozem was able to explain 3.0% of the variation in the contrast of soil moisture regime (F = 9.3, P < 0.001). The group of associations (*Falcario vulgaris-Elytrigietum repentis*, *Agropyretum repentis* та *Medicagini lupulinae-Agropyretum repentis*) was characterized by a 38.7% lower contrast index than the other associations (planned comparison F = 51.5, P < 0.001). The level of soil acidity was characterized by a pH value that averaged 7.07 ± 0.01 and in 95% of cases was in the range from 6.81 to 7.28. The association and the year were not statistically significant predictors of soil acidity (F = 1.43, P = 0.18 and F = 2.64, P = 0.07, respectively). The type of technozem was able to explain 2.3% of the variation in soil acidity (F = 9.30, P < 0.001). The lithozems on red-brown clays statistically significantly differed from other soil types by having a higher pH value (planned comparison F = 13.21, P < 0.001). The average level of salts dissolved in the soil solution was 42.44 ± 0.09 μg/L and in 95% of cases was in the range from 35.98 to 47.84 μg/L. The association explained 19.6% of the variation in the content of dissolved salts in the soil solution (F = 11.32, P < 0.001). The interannual characteristics explained 11.4% of the variation in this indicator (F = 3.6, P = 0.028), and the type of technozem was able to explain 55.3% of the variation in the contrast of soil moisture regime. The associations differed in the level of salinity of the soil solution into associations with relatively low salt content (*Medicagini lupulinae-Agropyretum repentis*, *Melico transsilvanicae-Agropyretum*, and *Convolvulo arvensis-Agropyretum repentis*) (planned comparison F = 722.2, P < 0.001), with an average salt content (*Falcario vulgaris-Elytrigietum repentis*, *Agropyretum repentis*, *Brometum tectorum* та *Ambrosio artemisiifoliae-Cirsietum setosi*) (planned comparison F = 338.7, P < 0.001), and high levels of dissolved salts (*Cirsio-Lactucetum serriolae* and *Carduo acanthoidis-Onopordetum acanthi*) (planned comparison F = 890.7, P < 0.001). The lowest content of dissolved salts was found in lithosols not red-brown clays, and the highest was found in the lithosols on loess-like loams. Other technozems are in an intermediate position by this indicator. The average level of carbonate content was 3.66 ± 0.05% and in 95% of cases ranged from 1.05% to 7.13%. The association explained 5.5% of the variation in carbonate content (F = 9.3, P < 0.001). The interannual characteristics explained 15.3% of the variation in this indicator (F = 24.4, P < 0.001), and the type of technozem was able to explain 13.5% of the variation in the carbonate content of the soil (F = 68.6, P < 0.001). The lowest carbonate content was found within the *Falcario vulgaris-Elytrigietum repentis* association (planned comparison F = 16.8, P < 0.001). An intermediate level of carbonate was found for the associations *Agropyretum repentis*, *Medicagini lupulinae-Agropyretum repentis*, *Melico transsilvanicae-Agropyretum*, and *Carduo acanthoidis-Onopordetum acanthi* (planned comparison F = 34.2, P < 0.001). The carbonate content was highest in other associations. Lithozems on red-brown clays were characterized by the highest carbonate content in the soil. The average level of nitrogen compounds was 1.37 ± 0.01 g/kg and in 95% of cases was in the range from 0.38 to 2.30 g/kg. The association explained 19.2% of the variation in nitrogen content (F = 29.2, P < 0.001). The interannual features were not a statistically significant predictor of soil nitrogen content (F = 0.49, P = 0.62), and the type of technozem was able to explain 5.8% of the variation in soil carbonate content (F = 18.0, P < 0.001). The lowest level of nitrogen compounds was found within the *Ambrosio artemisiifoliae-Cirsietum setosi* association (planned comparison F = 137.9, P < 0.001). An intermediate level of nitrogen content in the soil was found within the associations *Agropyretum repentis*, *Medicagini lupulinae-Agropyretum repentis*, *Melico transsilvanicae-Agropyretum*, *Convolvulo arvensis-Agropyretum repentis*, *Cirsio-Lactucetum serriolae*, and *Carduo acanthoidis-Onopordetum acanthi* (planned comparison F = 113.1, P < 0.001). The content of nitrogen compounds was highest in the *Falcario vulgaris-Elytrigietum repentis* and *Brometum tectorum* associations. The nitrogen content in lithozems on red-brown clays and gray-green clays was significantly lower than in lithozems on the loess-like loams and pedozems (planned comparison F = 42.5, P < 0.001). The average level of soil aeration was 76.0 ± 0.3% and in 95% of cases ranged from 58.1% to 91.4%. The association explained 8.9% of the variation in aeration (F = 14.8, P < 0.001). The interannual features were not a statistically significant predictor of soil aeration (F = 0.09, P = 0.91), a and the type of technozem was able to explain 27.7% of the variation in soil aeration (F = 74.7, P < 0.001). The lowest level of soil aeration was found within the *Falcario vulgaris-Elytrigietum repentis*, *Ambrosio artemisiifoliae-Cirsietum setosi* та *Cirsio-Lactucetum serriolae* associations (planned comparison F = 77.7, P < 0.001). An intermediate soil aeration was found within the associations *Agropyretum repentis*, *Medicagini lupulinae-Agropyretum repentis*, *Convolvulo arvensis-Agropyretum repentis*, *Brometum tectorum*, and *Carduo acanthoidis-Onopordetum acanthi* (planned comparison F = 56.5, P < 0.001). The level of soil aeration was the highest within the *Melico transsilvanicae-Agropyretum association*. The level of aeration of lithozems on red-brown clays was the lowest among all studied soils (planned comparison F = 206.3, P < 0.001).

Phytoindication of climatic regimes. The average level of radiation balance according to phytoindicative estimates was 1.93 ± 0.01 gJ/m^2 year and in 95% of cases was in the range from 1.70 to 2.20 gJ/m^2 year. The association explained 3.1% of the variation in the radiation regime (F = 5.3, P < 0.001). The interannual features were able to explain 4.6% of the variability of the radiation balance (F = 6.6, P < 0.001), and the type of technozem was able to explain 19.9% of the variation in this indicator (F = 79.9, P < 0.001). The lowest level of radiation balance was found within the *Convolvulo arvensis-Agropyretum repentis* та *Brometum tectorum* (planned comparison F = 19.8, P < 0.001, Fig. 3). An intermediate level of radiation balance was found within the associations *Falcario vulgaris-Elytrigietum repentis*, *Agropyretum repentis*, *Cirsio-Lactucetum serriolae*, and *Carduo acanthoidis-Onopordetum acanthi* (planned comparison F = 6.0, P < 0.015). The radiation balance within the associations *Medicagini lupulinae-Agropyretum repentis*, *Melico transsilvanicae-Agropyretum*, and *Ambrosio artemisiifoliae-Cirsietum setosi* was the highest. The radiation balance in the lithozems on red-brown clays was the lowest, and in the pedozems it was the highest.

The average level of the atmospheric moisture regime according to phytoindication estimates (ombroregime) was 1.20 ± 0.01 mm and in 95% of cases was in the range from –1.54 to –0.86 mm. The associations allowed us to explain 26.4% of the variation in ombroregime (F = 51.3, P < 0.001). The interannual features were able to explain 12.1% of the variability of the ombroregime (F = 6.7, P < 0.001), and the type of technozem was able to explain 9.1% of the variation in this indicator (F = 59.3, P < 0.001).

The lowest level of atmospheric moisture regime was found within the associations *Falcario vulgaris-Elytrigietum repentis*, *Agropyretum repentis*, *Medicagini lupulinae-Agropyretum repentis*, *Melico transsilvanicae-Agropyretum*, and *Ambrosio artemisiifoliae-Cirsietum setosi* (planned comparison F = 213.3, P < 0.001). An intermediate level of atmospheric moisture regime was established within the associations *Melico transsilvanicae-Agropyretum*, *Convolvulo arvensis-Agropyretum repentis*, *Cirsio-Lactucetum serriolae*, and *Carduo acanthoidis-Onopordetum acanthi* (planned comparison F = 159.5, P < 0.001).

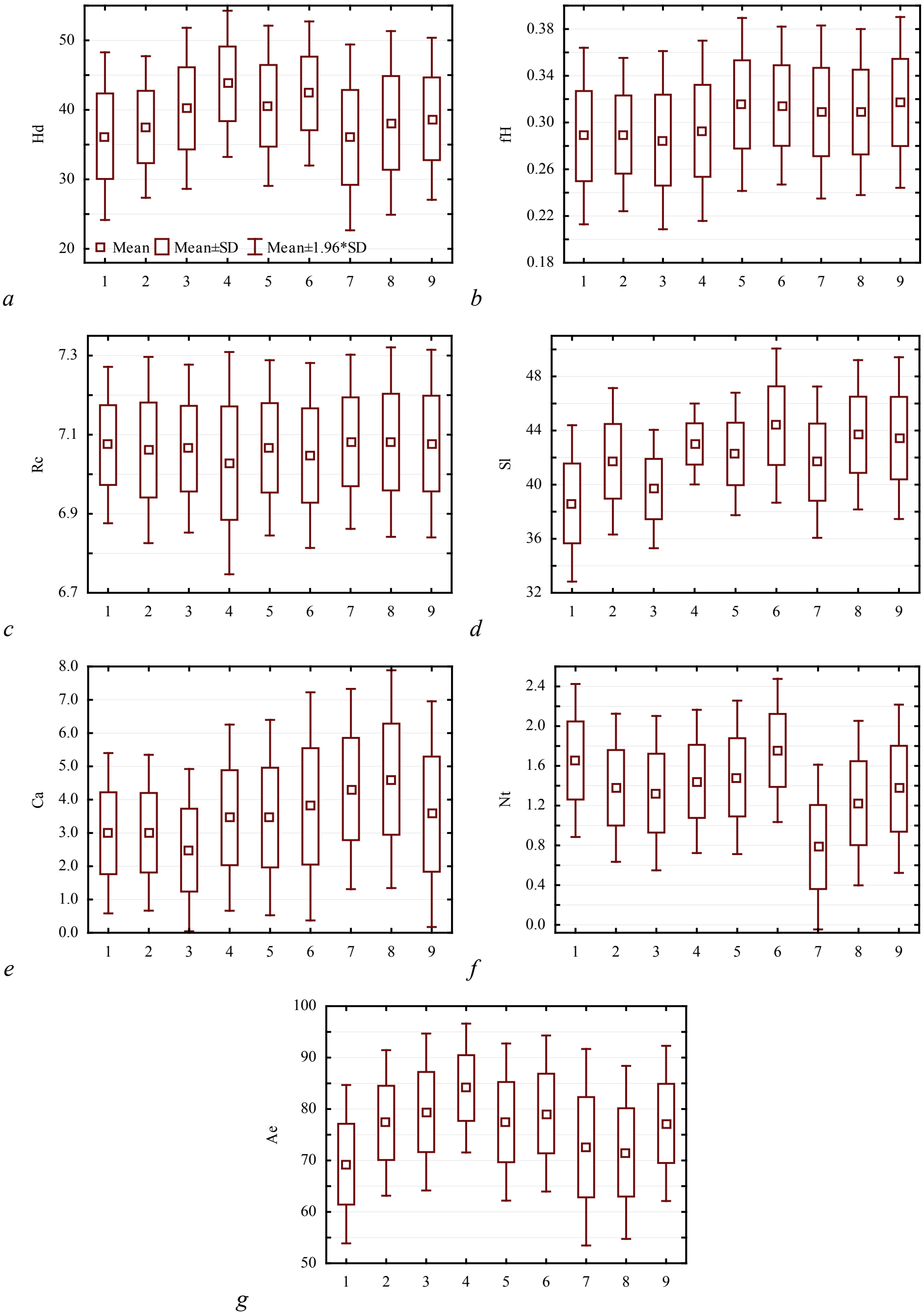

Fig. 2. Box-and-whisker plot of variability of phytoindicator scores of soil edaphic properties depending on vegetation cover association: the abscissa is the association: 1 is the *Falcario vulgaris-Elytrigietum repentis*; 2 is the *Agropyretum repentis*; 3 is the *Medicagini lupulinae-Agropyretum repentis*; 4 is the *Melico transsilvanicae-Agropyretum*; 5 is the *Convolvulo arvensis-Agropyretum repentis*; 6 is the *Brometum tectorum*; 7 is the *Ambrosio artemisiifoliae-Cirsietum setosi*; 8 is the *Cirsio-Lactucetum serriolae*; 9 is the *Carduo acanthoidis-Onopordetum acanthi*; the ordinates are phytoindicative estimates of edaphic properties: *a* is the soil water regime (Hd); *b* is the variability of damping (fH), *c* is the soil acidity (Rc), *d* is the total salt regime (Sl), *e* is the carbonate content in soil (Ca), *f* is the nitrogen content in soil (Nt), *g* is the soil aeration (Ae)

The level of atmospheric moisture regime was the highest within the association *Ambrosio artemisiifoliae-Cirsietum setosi*. The atmospheric moisture regime in lithozems on red-brown clays was the lowest, and in pedozems it was the highest. The average level of continentality according to phytoindication estimates was 161 points and in 95% of cases was in the range from 115 to 203 points. The association allowed us to explain 2.2% of the variation in the continentality regime (F = 4.5, P < 0.001). The interannual features were able to explain 18.2 % of the variability in continentality scores (F = 51.6, P < 0.001), and the type of technozem was able to explain 16.9% of the variation in this indicator (F = 42.7, P < 0.001). The continentality scores were significantly higher for the *Agropyretum repentis* association compared to the average. In turn, the continentality scores for the *Medicagini lupulinae-Agropyretum repentis* and *Melico transsilvanicae-Agropyretum* associations were lower than the average. The average level of cryoregime according to phytoindication estimates was –3.8 °C and in 95% of cases was in the range from –5.7 to –0.5 °C. The associations allowed us to explain 2.0% of the variation in cryoregime (F = 3.6, P < 0.001). The interannual features were not statistically significant predictors of cryoregime (F = 0.70, P = 0.49), and the type of technozem was able to explain 17.1% of the variation in this indicator (F = 53.8, P < 0.001). The cryoclimate scores were significantly higher for the *Falcario vulgaris-Elytrigietum repentis* and *Agropyretum repentis* compared to the average. In turn, the cryoclimate scores for the *Carduo acanthoidis-Onopordetum acanthi* association were lower than the average. The level of the lighting regime averaged 8.9 ± 0.1 points and in 95% of cases was in the range from 8.7 to 9.0 points. The association allowed us to explain 4.8% of the variation in lighting conditions (F = 11.0, P < 0.001). The interannual characteristics were able to explain 7.1% of the variation in light regime (F = 21.1, P < 0.001), and the type of technozem was able to explain 40.4% of the variation in this indicator (F = 238.3, P < 0.001). The estimates of the lighting regime were significantly higher for the *Melico transsilvanicae-Agropyretum* association compared to the average level. In turn, the estimates of the lighting regime for the *Agropyretum repentis* association were lower than the average level. The average level of radiation balance according to phytoindicative estimates was 1.93 ± 0.01 gJ/m^2 year and in 95% of cases was in the range from 1.70 to 2.20 gJ/m^2 year. The association explained 3.1% of the variation in the radiation regime (F = 5.3, P < 0.001). The interannual features were able to explain 4.6% of the variability of the radiation balance (F = 6.6, P < 0.001), and the type of technozem was able to explain 19.9% of the variation in this indicator (F = 79.9, P < 0.001). The lowest level of radiation balance was found within the *Convolvulo arvensis-Agropyretum repentis* and *Brometum tectorum* (planned comparison F = 19.8, P < 0.001, Fig. 3).

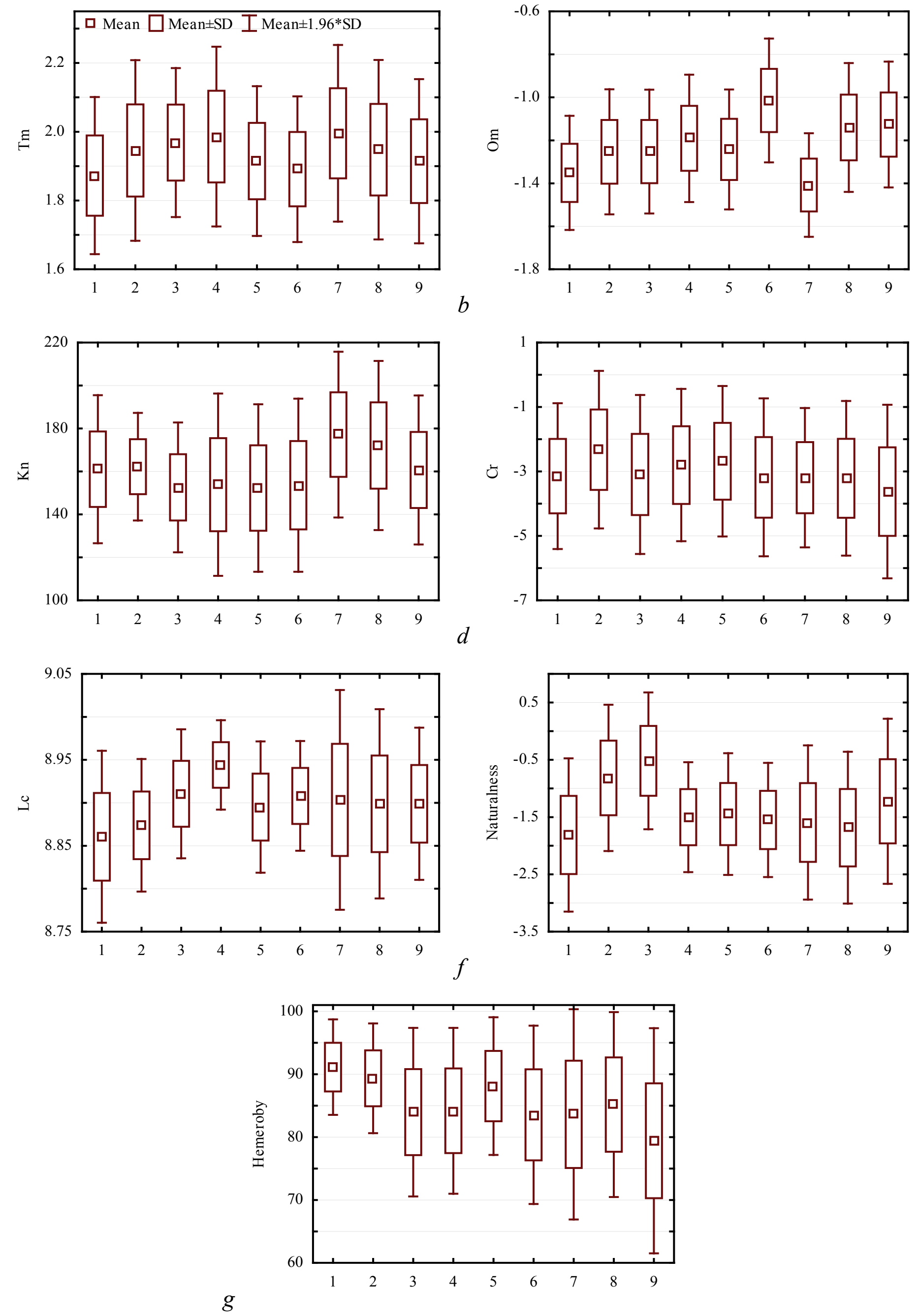

Fig. 3. Box-and-whisker plot of variability of phytoindication scores for climate regimes, naturalness, and hemeroby as a function of vegetation cover association: the abscissa is the association: 1 is the *Falcario vulgaris-Elytrigietum repentis*; 2 is the *Agropyretum repentis*; 3 is the *Medicagini lupulinae-Agropyretum repentis*; 4 is the *Melico transsilvanicae-Agropyretum*; 5 is the *Convolvulo arvensis-Agropyretum repentis*; 6 is the *Brometum tectorum*; 7 is the *Ambrosio artemisiifoliae-Cirsietum setosi*; 8 is the *Cirsio-Lactucetum serriolae*; 9 is the *Carduo acanthoidis-Onopordetum acanthi*; the ordinates are phytoindication estimates of climate regimes: *a* is the thermal climate (Tm), *b* is the humidity (Om), *c* is the continentality of climate (Kn), *d* is the cryoregime of climate (Cr), *e* is the light regime (Lc), *f* is the naturalness, *g* is the hemeroby

An intermediate level of radiation balance was established within the associations *Falcario vulgaris-Elytrigietum repentis*, *Agropyretum repentis*, *Cirsio-Lactucetum serriolae*, and *Carduo acanthoidis-Onopordetum acanthi* (planned comparison F = 6.0, P < 0.015). The radiation balance within the associations *Medicagini lupulinae-Agropyretum repentis*, *Melico transsilvanicae-Agropyretum*, and *Ambrosio artemisiifoliae-Cirsietum setosi* was the highest. The radiation balance in lithozems on red-brown clays was the lowest, and in pedozems it was the highest.

Phytoindication of naturalness and hemeroby. The naturalness of the communities averaged –1.39 ± 0.02 and in 95% of cases was in the range from –1.74 to –0.06. The association allowed us to explain 11.8% of the variation in the naturalness of the plant community ($F = 37.7$, $P < 0.001$). The interannual features were able to explain 4.5% of the variability in naturalness ($F = 9.5$, $P < 0.001$), and the type of technozem was able to explain 51.7% of the variation in this indicator ($F = 425.8$, $P < 0.001$). The lowest level of naturalness was found for *Cirsio-Lactucetum serriolae* association (planned comparison $F = 65.3$, $P < 0.001$). The highest level of naturalness was found for the association *Medicagini lupulinae-Agropyretum repentis* (planned comparison $F = 109.8$, $P < 0.001$). The highest level of naturalness was observed in those plant communities formed on the pedozems and lithozems on gray-green clays (planned comparison $F = 827.9$, $P < 0.001$). The hemeroby of the communities averaged 85.0 ± 0.22 and in 95% of cases ranged from 66.7 to 96.8. The association allowed us to explain 7.9% of the variation in plant community hemeroby ($F = 14.7$, $P < 0.001$). The interannual features were able to explain 21.2% of the hemeroby variability ($F = 30.7$, $P < 0.001$), and the type of technozem was able to explain 13.8% of the variation in this indicator ($F = 82.2$, $P < 0.001$). The lowest level of hemeroby was found within *Cirsio-Lactucetum serriolae* association (planned comparison $F = 65.3$, $P < 0.001$). The average level of hemeroby was found for the associations *Medicagini lupulinae-Agropyretum repentis*, *Ambrosio artemisiifoliae-Cirsietum setosi*, and *Carduo acanthoidis-Onopordetum acanthi* (planned comparison $F = 71.2$, $P < 0.001$). The highest level of hemeroby was found for the associations *Agropyretum repentis* and *Convolvulo arvensis-Agropyretum repentis* (planned comparison $F = 20.0$, $P < 0.001$). The highest level of hemeroby was observed in those plant communities formed on the lithozems on red-brown clays, and the lowest was observed on the pedozems (planned comparison $F = 202.7$, $P < 0.001$). A negative correlation was found between hemeroby and naturalness for all lithozems (Fig. 4). No statistically significant correlation was found for pedozems.

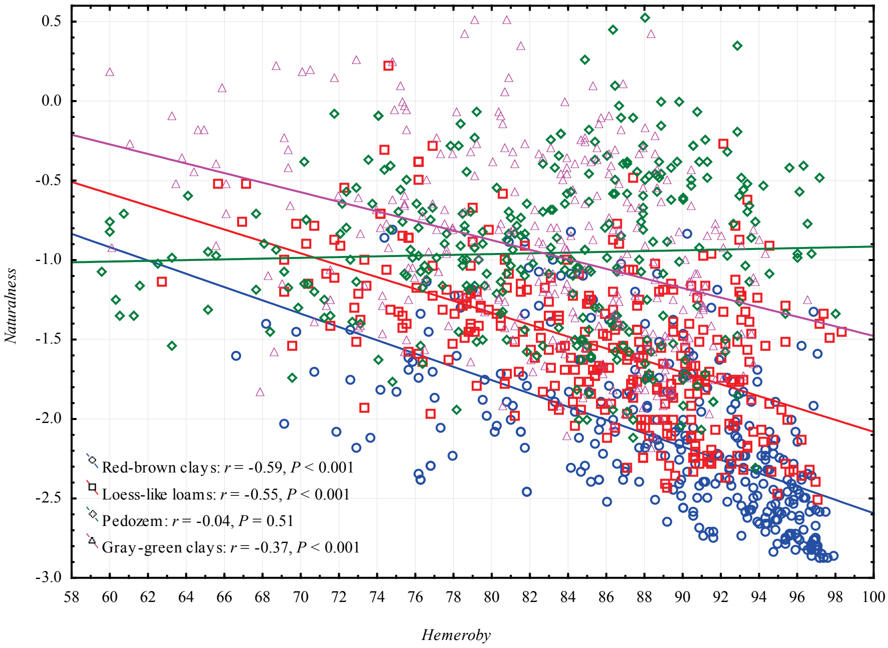

Fig. 4. Relationship between the hemeroby index (abscissa) and naturalness (ordinate) of plant communities: regression for the lithozems on red-brown clays: Naturalness $= 1.59 - 0.042 \times$ Hemeroby, $R^2 = 0.35$; for the lithozems on loess-like loams: Naturalness $= 1.66 - 0.037 \times$ Hemeroby, $R^2 = 0.30$; for the pedozems: Naturalness $= -1.15 + 0.0024 \times$ Hemeroby, $R^2 = 0.0014$; for the lithozems on gray-green clays: Naturalness $= 1.54 - 0.030 \times$ Hemeroby, $R^2 = 0.14$

Discussion

Syntaxonomic analysis allowed us to identify nine associations within the reclaimed area. In fact, all associations can be placed along the gradient defined by hemeroby conditions. The traditional use of the hemeroby scale is to assess the level of anthropogenic transformation of an ecosystem (Yorkina et al., 2022), i.e. to quantify how far the ecosystem has deviated from its natural state (Fanelli & De Lillis, 2004). In our study, the hemeroby index is used to monitor how the plant community returns to its natural state, which can be considered as a marker of the effectiveness of the reclamation process. This approach provides a contrasting comparison of naturalness and hemeroby indicators, which are formally symmetrical: the higher the hemeroby, the lower the naturalness should be (Erdős et al., 2022). In a wide range of levels of anthropogenic pressure, this pattern is certainly true. The peculiarity of the naturalness index is that it is more sensitive in the range of anthropogenic transformation that occurs at the initial stages of deviation of the natural community from the natural state at low levels of anthropogenic impact. In turn, the hemeroby index is more sensitive to changes in the community under conditions of high levels of anthropogenic transformation. The starting condition of habitats in the process of reclamation of territories disturbed by mining is actually a "lunar" landscape formed by rocks, and only pedozems are created with the application of topsoil, which has been preserved for a long time after the development of mineral resources. While measures of hemeroby and naturalness usually assess the deviation of an ecosystem from its natural state, in the case of monitoring the dynamics of reclamation, monitoring is carried out in the opposite direction: from the most transformed states to more natural ones. To a certain extent, the dynamics of vegetation recovery in the process of reclamation resemble the phenomena of spontaneous revegetation of abandoned lands. The general scheme of spontaneous succession of herbaceous vegetation within the steppe zone includes a number of successive stages: initial phase (or weed stage) → intermediate phase (rhizome-grass stage) → final phase (bush stage) → secondary steppe stage. Despite the simplicity of the classical scheme, the succession process is complex, has a considerable duration, and is not clearly defined and consistent due to a variety of factors that affect its course (Lavrenko, 1940).

There is an almost complete spectrum of plant associations within each type of technozem, which is typical for the territory as a whole. The specificity of the technozem consists in a certain range of associations that occur within its boundaries. The correspondence analysis allowed us to identify the most typical associations for a particular type of technozem. The level of hemeroby within a particular association does not depend on the type of technozem, so the observed level of technozem hemeroby is a function of the proportion of associations represented in it. For example, the associations with a high level of hemeroby are predominantly represented within lithozems on red-brown clays, which results in a high overall level of hemeroby in these technozems. In other technozems, the associations with lower hemeroby are more represented, and, accordingly, the level of hemeroby of these technozems is lower. However, the drivers of hemeroby decrease are specific to each type of technozem. Such drivers for the lithozems on loess-like loams are the associations *Medicagini lupulinae-Agropyretum repentis* and *Ambrosio artemisiifoliae-Cirsietum setosi*. Such drivers for pedozems are the associations *Ambrosio artemisiifoliae-Cirsietum setosi* and *Carduo acanthoidis-Onopordetum acanthi*. The associations *Medicagini lupulinae-Agropyretum repentis* and *Carduo acanthoidis-Onopordetum acanthi* are the drivers for lithosols on gray-green clays. Thus, in general, the drivers of the decrease in the hemeroby of technozems are three associations that form three pairwise combinations within the three technozems.

Thus, the hemeroby indicator is quite suitable for monitoring the dynamics of the reclamation process and allows one to assess what processes are taking place during the restoration of the disturbed ecosystem. It was found that the species richness, Shannon's diversity, and Pielou's community evenness increased during the reclamation process. This result indicates the importance of species diversity indices as proxies for the level of hemeroby/naturalness and is consistent with the idea that anthropogenic pressure usually leads to a decrease in biological diversity, and the processes of restoration of disturbed ecosystems are accompanied by the reproduction of their diversity. The pedozems show the greatest increase in species richness during reclamation. The increase in Shannon and Pielou diversity in the lithozems on gray-green clays was the largest during the reclamation.

An important phenomenon in the process of reclamation is the increase in soil moisture available to plants, as evidenced by the negative correlation between the hemeroby index and the phytoindicative assessment of moisture content. Obviously, the fundamental difference is that the initial soil conditions in ecosystems undergoing reclamation are much more extreme for plant life than in abandoned lands (Polevoy et al., 2023). The nutrient deficit is an ecosystem filter for plants that can grow on reclaimed land (Korotkova et al., 2023). Weeds are plants that are usually demanding of soil nutrients and are a kind of r-strategists that can quickly occupy new ecological niches, but for this purpose the environment must provide them with significant nutrient resources. The reclaimed areas do not have such resources. It should be noted that during the reclamation process, the nutrient content did not change significantly in the lithozems on loess-like loams and pedozems, increased in the lithozems on red-brown clays, and decreased in the lithozems on gray-green clays. Thus, a favorable trend of changes in conditions and nutrient regimes during reclamation was observed only in the lithozems on red-brown clays, since it was in these soils that the reclamation process was accompanied by the accumulation of nutrients. The trend of changes in the nutrient regime in the lithozems on gray-green clays should be recognized as the worst. The decrease in nutrient content in these soils can be explained by the unfavorable physical condition of the soil and the high activity of the pedoturbation soil formation process (Fey & Schaetzl, 2017). In general, no significant changes in the projected vegetation cover depending on the stage of reclamation were found. Additional research is needed to determine the dynamics of the phytomass of the vegetation cover.

Organic matter deficit is also a prerequisite for the dynamic physical state of technozems (Murindangabo et al., 2023). It is manifested in the low water resistance of soil aggregates (Zhang, 1994), resulting in a significantly contrasting aeration regime in technozems, when the state of excessive soil aeration during its drying is replaced by a state of soil air deficit during its moistening (Kochiieru et al., 2020). This changes the conditions of soil respiration of the root systems of plants and soil animals (Ben-Noah & Friedman, 2018), and also disrupts the integrity of root systems due to the alternation of soil swelling and shrinkage (Assadollahi & Nowamooz, 2020). A common feature of techno-soils is their significant fracturing, which results in the topsoil, where organic matter is usually concentrated, constantly falling into large cracks. The organic matter is distributed along a significant soil depth due to this phenomenon, which is also identified as pedoturbation soil forming process. The concentration of organic matter in the top layer remains almost always low, even though the reclamation process itself has been going on for more than half a century. This causes another feature of technozems: the constant creation of catastrophic ecosystems in locations of significant soil collapse in places where powerful crevices have formed. This is the reason for the significant mosaic of technozem conditions and plant communities that are at different stages of the restoration succession, although spatially located adjacent to each other. Also, the pedoturbation soil formation process may be the reason why phytoindication assessments of the contrast in moisture conditions of technozems are quite significant, although the territory is not under floodplain conditions (Tsvetkova & Saranenko, 2007, 2010; Saranenko, 2011; Tsvetkova et al., 2015).

The progress of reclamation is associated with a decrease in soil pH from slightly alkaline to neutral and a decrease in the content of carbonates in the soil. Obviously, root exudate, which is usually slightly acidic (Ström & Strom, 1997), contributes to the leaching of carbonates and a decrease in soil alkalinity. The usual marker of the soil formation process for natural and semi-natural soils is the accumulation of organic matter (Błońska & Lasota, 2017), which we do not observe. The leaching of carbonates from the soil profile and a decrease in the pH of the soil solution are markers of the soil-forming process. Also, there is an increase in the mineralization of the soil solution during reclamation, mainly due to a decrease in the level of variation of this indicator. Obviously, the homogenization of soil properties and regimes is also a phenomenon that progresses during reclamation.

Soil aeration indicators increase during reclamation for all lithozems and do not change in pedozems. The overall trend of aeration growth cannot be recognized as favorable due to the risks of soil hyperaeration and excessive soil moisture loss (Biniak-Pieróg et al., 2020). The increase in aeration can be explained by the influence of abiotic processes of swelling and shrinkage, which result in cracking of monolithic pads and formation of aggregates. These aggregates are not water-resistant due to their low organic matter content and are destroyed by moisture. The content of organic matter in the upper layer is much higher in pedozems, which contributes to the formation of a water-resistant aggregate structure that is a factor in the stability of the soil air regime. This can explain the finding that the aeration regime of pedozems does not change significantly during the reclamation process.

The naturalness can be considered as an opposite and in this sense symmetrical indicator in relation to hemeroby. Naturally, there is an opposite correlation between hemeroby and naturalness for all types of lithozems. But there was no such correlation for pedozems. According to the results, if we consider hemeroby as a marker of the reclamation process, then we can say that in pedozems, naturalness did not change during reclamation. The naturalness and hemeroby indices are diametrically opposed in the case of lithozems, so the answer to the question of which one is better makes no sense: they both show the trend of changes in plant communities during reclamation. The specificity of the indices is evident in the situation with pedozems. The naturalness is actually an insensitive indicator to changes in the community at high levels of hemeroby, while hemeroby is able to reflect the transformation of the plant community during reclamation.

Conclusion

Hemeroby and naturalness indicate general trends in the transformation of plant communities under the influence of anthropogenic factors. These indicators can also be used to monitor the reverse process: restoration and naturalization as a result of land reclamation measures. The biological stage of reclamation begins after the technological stage and the creation of soil-like bodies (technozems) with no vegetation cover. The general criterion for the success of reclamation can be the naturalization of plant communities that either emerged spontaneously or were created artificially on the reclaimed territories. Hemeroby is a more sensitive indicator of changes in the structure of communities that are under significant anthropogenic pressure. Therefore, although conceptually, in a wide range of transformation conditions, the indicators of naturalness and hemeroby are equivalent, the hemeroby indicators have more suitable properties in the context of solving the issues of monitoring the reclamation processes.

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