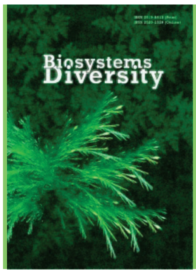

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The importance of terrain factors in the spatial variability of plant cover diversity in a steppe gully

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Information about the slope angle and its exposure is often given when describing plant communities. However, the slope angle should be noted to affect a complex of different phenomena and processes. The slope angle affects the albedo and thermal regime of the soil. The slope angle affects the redistribution of moisture and determines the moisture availability of a particular area. The slope angle also determines the risks of erosion processes. In turn, erosion processes determine the depth of the soil layer and the content of organic matter in it, which greatly affects the conditions for plant life and their dynamics. Therefore, the slope angle of the relief is a complex environmental indicator, which is its most important weakness. The information on the slope angle of the relief surface does not indicate which environmental factor is limiting and determines the characteristics of the vegetation cover. Similarly, the quantitative orientation of a slope using rhumb lines is a rather crude way to indicate the role of terrain in the redistribution of solar energy. With a certain degree of accuracy, rhumbs characterize incoming solar radiation, but are not sensitive to estimating the amount of diffuse radiation. Modern geoinformation technologies make it possible to determine the amount of solar radiation reaching the terrain surface using a digital elevation model. The aim of the article was to identify the role of relief factors in terms of topographic wetness index, erosion index, and solar radiation in the spatial variability of the vegetation diversity of a steppe gully. There was no linear correlation between the other predictors. Some correlations can be interpreted as the result of certain nonlinear patterns. In this sense, the geomorphological predictors are mostly linearly independent and thus each of them carries independent information for characterizing environmental conditions. The vegetation cover of the gully system was represented by 263 plant species. The analysis of the synoptic phytosociological table allowed us to find out that the vegetation cover of the studied gully system is represented by six classes of vegetation. The geomorphological predictors allowed for a classification of vegetation types with an accuracy of 23.8% to 100%. The topographic wetness index was the most important for classification. Altitude and insolation were also important for classification (94 and 95 respectively). The topographic wetness index provided an accurate identification of wetland vegetation of the *Phragmito-Magnocaricetea* class. Naturally, this type of vegetation preferred biotopes with the highest level of soil moisture. High insolation accurately labeled the locations where *Festuco-Brometea* steppe vegetation was most likely to be found. Some of the artificial tree plantations that occurred in the thalweg of the gully can be clearly identified by the high level of the topographic wetness index. Another group of artificial tree plantations is located on relatively high relief areas and should be differentiated from *Galio-Urticetea* communities, which prefer locations with higher light levels, and from *Molinio-Arrhenatheretea*, which prefer locations with a higher risk of erosion. The most arid locations are preferred by *Agropyretalia intermedio-repentis* vegetation. Steppe and meadow vegetation located at altitudes less than 116 meters also differ in their preferred height. Steppe vegetation is usually located at a level higher than 95 meters. Natural steppe and meadow vegetation at elevations below 116 meters differs from semi-natural *Galio-Urticetea* vegetation in that the latter usually prefers more well lit locations. Steppe communities are misclassified as meadow in 15.3% of cases, and meadow is misclassified as steppe in 18.5% of cases. Artificial tree plantations are misclassified as steppe in 42.9% of cases and 14.3% are misclassified as *Agropyretalia intermedio-repentis*. In its turn, *Agropyretalia intermedio-repentis* is misclassified as *Festuco-Brometea* in 6.7% of cases, as *Molinio-Arrhenatheretea* or *Onopordetalia acanthii* in 3.3% of cases, and as *Galio-Urticetea* in 10.0% of cases. The *Onopordetalia acanthii* community was misclassified as *Festuco-Brometea*, *Molinio-Arrhenatheretea* and *Galio-Urticetea* in 6.7% of cases, respectively.

Keywords: diversity; plant community; landforms; anthropogenic transformation; classification trees.

Introduction

Relief is a factor that determines the redistribution of moisture (Perry & Niemann, 2007) and solar energy in the landscape (Perpiña Castillo et al., 2016) and the risks of erosion processes (Iserloh et al., 2017). Soil moisture is a key component of the water cycle, and its fluctuation is closely related to the combined processes in the soil-atmosphere system (Corradini, 2014). The soil moisture content is one of the most variable components determining the environment for terrestrial ecosystems (Brygadyrenko, 2014, 2015; Tutova et al., 2023). The moisture content of soil changes and fluctuates seasonally, and often daily, in response to precipitation, evaporation, infiltration, and runoff (Daly & Porporato, 2005). The level of moisture can fluctuate both in time and space in any landscape, according to environmental conditions, plant interactions, soil properties, wetting and drying cycles, and many other factors (Vereecken et al., 2014). The soil moisture and temperature are variable, but these fluctuations can be predicted and, with long-term observation, can be rationally classified (Almendra-Martín et al., 2022). Soil climate is the recording of temporal patterns of soil moisture and temperature, which is an important component of the structure of soil taxonomy. The concept of soil climate is designed to elucidate predictable moisture patterns associated with seasonal dynamics, with the possibility of mapping (Winzeler et al., 2013). Soil moisture varies across the spatial extent of catenas or soil associations within soil and climatic regimes (de Queiroz et al., 2020). Plant height, projective cover and biomass, diversity (Shannon index, richness index and evenness) of the herbaceous plant community are positively related to the water content in the surface soil layer (An et al., 2019). Moisture at the landscape scale exhibits signs of predictable organization due to the influence of gravity through terrain topography (Winzeler et al., 2022). Self-organization of complex hydrological systems allows us to simplify watershed models, accounting for landscape functions (Brindt et al., 2022). Soil and topography are widely recognized as important factors controlling soil moisture variations (Gritsan et al., 2019; Yakovenko et al., 2023). In the practice of soil ecology, the description of soil variability in geomorphic space includes the recording of soil features associated with soil moisture variability in different positions on the terrain (Budakova et al., 2021). The distribution of soil moisture in the landscape is often considered to be controlled primarily by soil properties during dry periods and topography during wet periods (Zhu & Lin, 2011). The topographic wetness index (TWI) is a tool for quantifying the spatial variability of soil moisture under the influence of relief (Beven & Kirkby, 1979). TWI is a technique based on the concept of steady-state surface moisture distribution over variable terrain and is most relevant when infiltration rates exceed moisture storage capacity (Zhukov et al., 2017). The topographic wetness index integrates water inflow from the upper part of the catchment and water runoff from the slope for each DEM cell. In TWI, the slope gradient approximates the water runoff from the slope, and the specific catchment area, calculated as the total catchment area divided by the stream width, approximates the water supply from the upper part of the slope. Thus, TWI consists of three key components: total catchment area, stream width, and slope gradient (Chaplot et al., 2000). The total catchment area is the total slope area that flows through the cell calculated using the flow routing algorithm, the flow width is the length of the contour orthogonal to the flow from the cell, and the slope gradient is either the slope of the focal cell or the slope between the focal cell and the cell located downslope (Kopecký et al., 2021). TWI is used in soil research as an ecological proxy for the spatial variability of soil organic matter (Florinsky & Kuryakova, 2000), soil nutrients, soil texture and other soil properties (Gessler et al., 1995).

Vegetation cover is known to be a significant factor in preventing soil erosion risks (Buraka et al., 2022). Soil erosion shapes the structure of vegetation cover (Guerrero-Campo & Montserrat-Martí, 2000). Soil erosion can be estimated based on a digital elevation model using the length-slope factor (LS-factor), which is applied in the universal soil loss equation (RUSLE). It gives the value of the water erosion potential relative to a slope with a length of 22.13 m and a slope angle of 5 degrees (Moore & Wilson, 1992). A positive correlation was shown between LS and projective cover of the herbaceous plant community (Hopfensperger et al., 2006). Nevertheless, the impact of erosion on the structure and diversity of plant communities has not been studied sufficiently.

In plant ecology, the importance of solar radiation is recognized and proxy indicators derived from digital elevation model (DEM) processing are used to measure it (Piedallu & Gégout, 2008). The terrain is a significant factor that determines the redistribution of solar energy that reaches the Earth (Garnett, 1937). Photosynthetically active solar energy is used for photosynthesis and determines the level of primary production of plant communities (Alados et al., 2000). Solar radiation is controlled by the slope of the terrain and the exposure of the terrain surface, which affects the growth rate of plants (Rody et al., 2016).

Gullies and ravines form extremely diverse conditions for the existence of ecosystems due to the asymmetry of slopes as a function of slope angle and steepness (Kuhn et al., 2023). Slope angle, steepness, and elevation are considered to be the main factors that generate spatial variation in gullies and ravines (Fashae et al., 2022), causing differences in the growth and distribution of vegetation, ecosystem functioning and processes occurring in it (Cheng et al., 2023). The slope aspect has an important influence on the morphology, structure and spatial distribution of vegetation and soil properties (Zhang et al., 2022). Slope and slope aspect affect vegetation mainly indirectly through regulatory effects on soil erosion (Nadal-Romero et al., 2014). The difference in slope aspect causes differences in air and soil temperature and humidity (Bozhko & Bilova, 2020), evaporation (Gleason & Gates, 1913), which creates microclimatic zonation, and these differences are closely related to changes in the structure and composition of vegetation (Armesto & Martinez, 1978). North-facing shady slopes are supported by dense and dense vegetation with nutrient-rich soil, while south-facing sunny slopes have sparse and scattered vegetation with poorer soil development and higher erosion rates (Singh, 2018). Information about the slope angle and its exposure is often given when describing plant communities. However, the slope angle should be noted to affect a complex of different phenomena and processes. The slope angle affects the albedo and thermal regime of the soil. The slope angle affects the redistribution of moisture and determines the moisture availability of a particular area. The slope angle also determines the risks of erosion processes. In turn, erosion processes determine the depth of the soil layer and the content of organic matter in it, which greatly affects the conditions for plant life and their dynamics. Therefore, the slope angle of the relief is a complex environmental indicator, which is its most important weakness. The information on the slope angle of the relief surface does not indicate which environmental factor is limiting and determines the characteristics of the vegetation cover. Similarly, the quantitative orientation of a slope using rhumb lines is a rather crude way to indicate the role of terrain in the redistribution of solar energy. With a certain degree of accuracy, rhumbs characterize incoming solar radiation, but are not sensitive to estimating the amount of diffuse radiation. Modern geoinformation technologies make it possible to determine the amount of solar radiation reaching the terrain surface using a digital elevation model. The aim of the article was to identify the role of relief factors in terms of topographic wetness index, erosion index, and solar radiation in the spatial variability of the vegetation diversity of a steppe gully (Kunakh et al., 2023).

Materials and methods

The field investigations were carried out in the Mayorska valley (Dnipropetrovsk oblast, Ukraine) (48°16'41" N, 35°08'22" E). The climate is continental, with an average annual temperature of 9.9 ± 0.2 °C (in the range of 8.4–12.4 °C) over the period 2000–2022 with a temperature increase trend of 0.07 °C annually on average. The average annual precipitation was 555 ± 17 mm (range 429–696 mm). The landscape is dominated by extensive, slightly undulating plains. Loess and loess-like loams are the most common geological surface rock, reaching a thickness of several tens of meters (Samoilych & Mokritskaia, 2016). The study area belongs to the Central Pontic herbaceous steppe zone (EuroVegMap). The natural vegetation is dominated by cereals and grasses.

The vegetation cover of the Mayorska valley is a combination of vegetation of different levels of anthropogenic transformation. The valley is surrounded by agricultural fields, which are usually bordered by artificial tree plantations. Tree plantations are also located on the slopes of the valley, with a particularly large area of artificial forest plantations on the slope of the northern exposure. Natural steppe vegetation is found on the gully's slopes. In some cases, steppe vegetation on the slopes of the gully borders directly on agricultural fields. In the areas disturbed by anthropogenic activity, invasive tree species or ruderal grass vegetation are spreading. Ruderal herbaceous vegetation also develops in the area of degradation of artificial tree plantations or along roads. In the lower thirds of the slopes and in the thalweg, there is meadow vegetation. Wetland vegetation is found in the thalweg. Shrubs are found on the slopes of the gully among the steppe vegetation.

During the summer of 2023, we recorded the presence of all vascular plant species in 289 sample plots of 4 × 4 m (Fig. 2). The projected species coverage was determined as a percentage. For the purposes of this study, we generally took infraspecific taxa as species. Critical specimens were collected and identified by microscopy. The sample plots were distributed throughout the study area and their exact location was determined using GPS (Garmin eTrex, ± 5 m). We tried to select samples that would represent the full range of community types and plot sizes within the gully system. Plant taxonomy was based on Euro+MedPlantbase (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 fidelity 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). Syntaxa were identified up to the association level; names of syntaxa are given according to the European Vegetation of Europe (Mucina et al., 2016) and the Prodromus of Vegetation of Ukraine (Dubina et al., 2019). Descriptive statistics, ANOVA, analysis of components of relative variance, were calculated using the statistical software Statistica.

A digital elevation model (DEM) is a digital representation of the earth's surface. The data from the Advanced Land Observation Satellite – ALOS (www.eorc.jaxa.jp/ALOS/en/index.htm) were used to create the digital elevation model. The spatial resolution for this model is 12.5 meters. The DEM was resampled to a resolution of 1 m using the kriging procedure (Susetyo, 2016). The kriging procedure also made it possible to obtain a DEM appropriate for computing derived layers, such as the topographic wetness index and erosion coefficient (Zhukov et al., 2021).

The concept of the topographic moisture index (TWI) was first proposed by Beven & Kirkby (1979) which can be calculated using the formula: $TWI = ln(a/\tan\beta)$, where a is the area of elevation per unit length of the contour, β is the local slope. TWI has no unit. High TWI values indicate an area with an increased potential for accumulated surface runoff.

Terrain erosion potential (LS) is one of the components of the Universal Soil Loss Equation (USLE). LS is the product of L- and S-factors. The L-factor represents the length of the slope and the S-factor represents the steepness of the slope. The LS-factor is dimensionless and has values equal to or greater than 0 (Panagos et al., 2015). The topographic solar radiation, TWI and LS-factor were calculated in this study using the SAGA software (Conrad et al., 2015).

Results

Geomorphological predictors. The altitude of the landscape studied varied from 70 to 183 meters above sea level (mean 148 ± 22 m) (Fig. 1). The plants were recorded at points located in the altitude range from 74 to 155 meters (average 117 ± 21 m). This is due to the fact that in the highest parts of the landscape, the plateau contains agricultural fields that were not surveyed in this study. The insolation level within the landscape varied from 972 to 1770 kWh/m^2 (average1473 ± 65 kWh/m^2). The topographic wetness index within the landscape ranged from 0.35 to 23.5 (average 6.9 ± 2.0). Plants were counted at points that were located in the range of topographic moisture index values from 4.5 to 21.7 (average 7.9 ± 2.9). The erosion index ranged from 0 to 420 (average 1.3 ± 3.5). The plant plots covered erosion index values from 0 to 33 (average 5.7 ± 5.7).

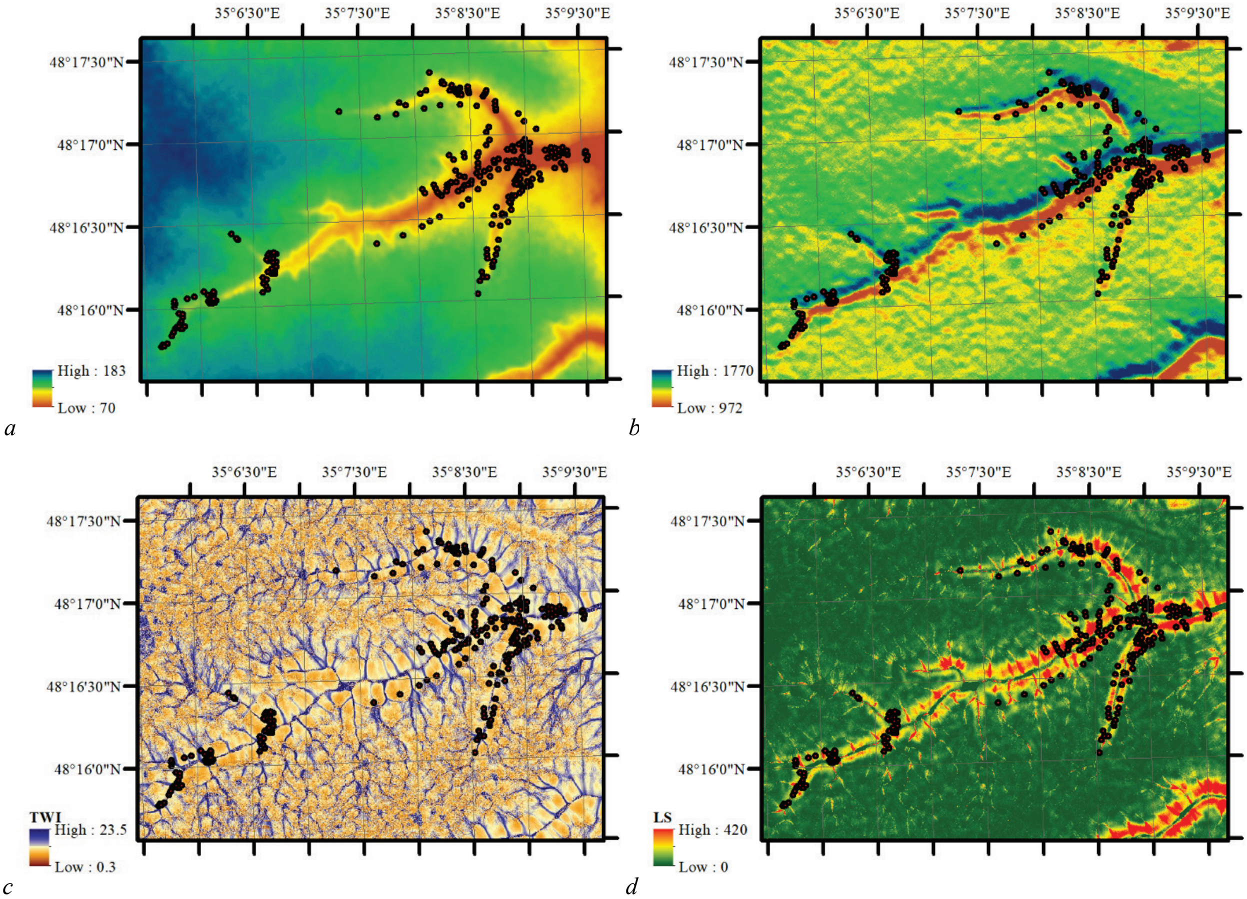

Fig. 1. Geomorphological layers within the studied landscape: *a* – digital elevation model (m), *b* – insolation level, *c* – topographic wetness index, *d* – erosion index

Only relief altitude and erosion index were statistically significantly correlated (r = –0.12, P = 0.046). There was no linear correlation between the other predictors. Some correlations can be interpreted as the result of certain nonlinear patterns (Fig. 2). In this sense, the geomorphological predictors are mostly linearly independent and thus each of them carries independent information for characterizing environmental conditions.

Vegetation cover. The vegetation cover of the gully system was represented by 263 plant species. The analysis of the synoptic phytosociological table (Table 1) revealled that the vegetation cover of the studied gully system is represented by six classes of vegetation.

Class *Festuco-Brometea* Br.-Bl. et R.Tx. in Br.-Bl. 1949
 Order *Festucetalia valesiacae* Soó 1947
  Union *Festucion valesiacae* Klika 1931
   Association *Festuco valesiacae-Stipetum capillatae* Sill 1931
   Association *Salvio nemorosae-Festucetum valesiacae* Korotchenko et Didukh 1997
  Union *Astragalo-Stipion* Knapp 1944
   Association *Stipo lessingianae-Salvietum nutantis* Vynokurov 2014

Class *Festuco-Brometea* Br.-Bl. et R.Tx. in Br.-Bl. 1949 includes xerothermic vegetation of true, meadow, petrophytic sod-grass steppes and steppe meadows. Vegetation of this class is dominated by sod grasses (*Stipa pennata*, *S. capillata*, *S. lessingiana*, *Festuca valesiaca*), short-rooted cereal *Poa angustifolia* and rhizomatous *Bromopsis inermis*. A number of xerophilic and eumesophilic herbaceous species are also characteristic of these steppes (Dubina et al., 2019). Three associations of plants belonging to the class *Festuco-Brometea* were found in the vegetation of the gully system: *Festuco valesiacae-Stipetum capillatae* Sill 1931, *Salvio nemorosae-Festucetum valesiacae* Korotchenko et Didukh 1997 and *Stipo lessingianae-Salvietum nutantis* Vynokurov 2014.

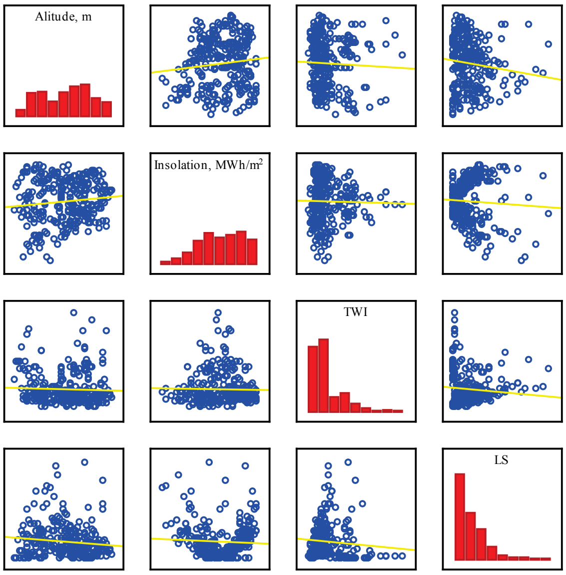

Fig. 2. Histograms of distribution and scatter plots for pairwise comparisons of geomorphological predictors: altitude is the altitude above sea level according to the digital elevation model (m); insolation is the amount of solar energy that reaches the Earth's surface depending on the terrain (kWh/m^2); TWI is the topographic wetness index; LS is the erosion index

The *Festuco valesiacae-Stipetum capillatae* association included 98 plant species. On average, 17.6 ± 2.8 species were found on the survey plot (ranging from 13 to 24 species). The total projective cover varied from 56% to 100%. The Shannon diversity of the communities was 3.3 ± 0.3 bits/species (varied from 2.6 to 3.9 bits/species). The dominant species were *Festuca pseudovina* Hack. ex Wiesb. (projective cover 7–35%), *Festuca valesiaca* Schleich. ex Gaudin (2–25%), *Poa angustifolia* L. (3–40%), *Elytrigia repens* (L.) Nevski (1–40%), *Cytisus austriacus* L. (1–25%), and *Stipa capillata* L. (1–15%). There were 5 species of the genus *Astragalus* (*A. cicer*, *A. dasyanthus*, *A. glycyphyllos*, *A. onobrychis*, *A. ponticus*). The association contains species listed in the Red Data Book of Ukraine: *Astragalus ponticus* Pall., *A. dasyanthus* Pall., *Stipa capillata* L. and in the Red List of Dnipropetrovsk oblast: *Geranium palustre* L. and *Rosa rubiginosa* L. The association occurred on the slopes of the gully in the middle and upper parts at an altitude of 118.6 ± 21.2 m (range 84.7 to 155.4 meters). The associations preferred habitats with high levels of insolation and were found under conditions of solar radiation reaching the surface of 1.5 ± 0.1 MWh/m^2 (in the range from 1.3 to 1.7 MWh/m^2). The topographic wetness index in the locations where this association was found was 7.2 ± 2.3 (in the range from 4.5 to 15.3). The erosion index had a value of 4.8 ± 4.4 (range 0.002 to 18.6). The index of naturalness of this association was 2.6 ± 1.2 (in the range of –0.01 to 4.9). The index of hemeroby of this association was 43.3 ± 9.5% (in the range from 26.9 to 66.0%).

The association *Salvio nemorosae-Festucetum valesiacae* Korotchenko et Didukh 1997 included 113 plant species. The total projective cover varied from 64% to 100%. On average, 24.8 ± 5.2 species were found on the survey plot (ranging from 14 to 37 species). The Shannon diversity of the communities was 3.8 ± 0.4 bits/species (ranging from 3.2 to 4.9 bits/species).

Table 1

Synoptic phytosociological table (the table shows the percentage of species occurrences within the respective associations)

Species	Association*															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
The number of *releve*	8	7	42	30	47	41	24	13	17	14	10	11	6	7	6	6
Bromus squarrosus	–	–	69	57	2	5	13	8	–	–	–	–	–	–	–	–
Centaurea diffusa	–	–	38	7	4	2	–	–	–	–	–	–	–	–	–	–
Crepis foetida	–	–	38	10	–	–	–	–	–	–	–	–	–	–	–	–
Euphorbia stepposa	–	–	81	63	74	49	33	–	–	–	–	–	–	–	–	–
Helichrysum arenarium	–	–	52	10	6	5	–	–	–	–	–	–	–	–	–	–
Odontites vulgaris	–	–	36	–	–	–	–	–	–	–	–	–	–	–	–	–
Pilosella echioides	–	–	60	–	11	–	–	–	–	–	–	–	–	–	–	–
Plantago lanceolata	–	–	38	3	–	–	–	–	–	–	–	–	–	–	–	–
Securigera varia	–	–	74	73	60	37	50	8	–	–	–	–	–	–	–	–
Salvia nemorosa	13	43	93	33	60	68	63	–	–	–	–	9	–	–	–	–
Euphorbia seguieriana	–	–	33	3	2	12	–	–	–	–	–	–	–	–	–	–
Stachys recta	–	–	48	40	21	2	8	–	–	–	–	–	–	–	–	–
Medicago minima	–	–	21	–	–	–	–	–	–	–	–	–	–	–	–	–
Jacobaea vulgaris	–	–	31	13	6	2	–	–	–	–	–	–	–	–	–	–
Vicia sativa	–	–	19	–	–	–	–	–	–	–	–	–	–	–	–	–
Erigeron acris	–	–	19	–	2	–	–	–	–	–	–	–	–	–	–	–
Limonium bungei	–	–	19	–	9	–	–	–	–	–	–	–	–	–	–	–
Galatella villosa	–	–	64	67	40	2	–	–	–	–	–	–	–	–	–	–
Silene wolgensis	–	–	45	63	30	–	–	8	–	–	–	–	–	–	–	–
Bromopsis riparia	–	–	14	70	28	2	–	15	–	–	–	–	–	–	–	–
Cleistogenes bulgarica	–	–	19	60	15	–	–	–	–	–	–	–	–	–	–	–
Koeleria cristata	–	–	50	63	62	5	8	–	–	–	–	–	–	–	–	–
Teucrium polium	–	–	36	50	34	12	–	–	–	–	–	–	–	–	–	–
Potentilla recta	–	–	5	37	2	7	–	23	–	–	–	–	–	–	–	–
Jacobaea erucifolia	–	–	12	27	–	–	–	–	–	–	–	–	–	–	–	–
Stipa lessingiana	–	–	12	23	–	–	–	–	–	–	–	–	–	–	–	–
Astragalus dasyanthus	–	–	26	37	23	–	–	–	–	–	–	–	–	–	–	–
Allium waldsteinii	–	–	–	13	–	–	–	–	–	–	–	–	–	–	–	–
Carduus nutans	–	–	5	23	–	–	–	–	–	14	–	–	–	–	–	–
Linaria genistifolia	–	–	21	37	23	–	4	23	18	–	–	–	–	–	–	–
Stipa capillata	–	–	29	37	91	17	–	–	–	–	–	–	–	–	–	–
Vinca herbacea	–	–	–	7	45	7	–	–	–	–	–	–	–	–	–	–
Astragalus ponticus	–	–	19	33	43	15	4	–	–	–	–	–	–	–	–	–
Veronica spicata	–	–	–	7	23	–	–	–	–	–	–	–	–	–	–	–
Achillea millefolium	–	–	79	40	62	44	96	85	12	–	–	–	–	–	–	–
Falcaria vulgaris	–	–	–	3	21	22	4	31	12	7	–	–	–	–	–	–
Fragaria viridis	–	–	7	–	2	2	21	–	–	–	–	9	–	–	–	–
Thymus pulegioides	–	–	26	30	30	27	8	–	–	–	–	9	–	–	–	–
Artemisia campestris	–	–	67	3	9	7	4	–	–	–	–	–	–	–	–	–

Species	Association*															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
The number of *releve*	8	7	42	30	47	41	24	13	17	14	10	11	6	7	6	6
Artemisia austriaca	–	–	14	77	60	12	8	–	–	–	–	–	–	–	–	–
Astragalus onobrychis	–	–	21	87	6	–	–	–	–	–	–	–	–	–	–	–
Eryngium campestre	–	–	45	27	45	12	17	–	–	–	–	–	–	–	–	–
Festuca valesiaca	–	–	98	70	47	–	29	–	–	–	–	–	–	–	–	–
Plantago media	–	–	7	10	9	10	13	–	–	–	–	–	–	–	–	–
Poa bulbosa	–	–	–	–	14	10	–	–	–	–	–	–	–	–	–	–
Salvia nutans	–	–	14	23	26	5	–	–	–	–	–	–	–	–	–	–
Cytisus austriacus	–	–	31	3	55	83	8	–	–	–	–	9	–	–	–	–
Festuca pseudovina	–	14	–	–	51	66	–	–	–	–	–	36	–	–	–	–
Poa angustifolia	–	57	64	70	85	95	79	92	59	7	30	18	–	–	–	–
Centaurea scabiosa	13	–	5	–	15	32	8	–	–	–	–	–	–	–	–	–
Agrimonia eupatoria	13	43	48	20	62	78	100	8	–	–	–	36	–	71	–	–
Rosa rubiginosa	–	–	2	13	2	7	13	–	–	14	–	–	–	–	–	–
Galium humifusum	–	43	19	–	11	7	75	–	–	–	–	9	–	–	–	–
Galium verum	–	–	–	–	2	5	42	–	–	–	–	–	–	–	–	–
Schedonorus arundinaceus	25	–	–	–	2	2	42	–	–	–	–	–	–	–	–	–
Ballota nigra	–	–	–	–	–	–	38	–	–	14	–	9	–	–	–	–
Origanum vulgare	–	–	5	–	9	46	50	15	6	–	–	27	–	–	–	–
Knautia arvensis	–	–	–	–	–	2	29	8	–	–	–	18	–	–	–	–
Taraxacum serotinum	–	–	5	7	6	–	8	–	–	–	–	–	–	–	–	–
Bromopsis inermis	–	–	10	–	9	5	4	8	6	7	–	–	–	–	–	–
Cichorium intybus	–	–	29	–	9	17	46	–	–	–	–	–	–	–	–	–
Medicago falcata	–	–	69	77	38	–	46	–	–	–	–	–	–	–	–	–
Phleum pratense	–	43	–	–	4	–	8	–	–	–	–	–	–	–	–	–
Echium vulgare	–	–	12	7	9	5	17	–	–	–	–	–	–	–	–	–
Carex hirta	63	43	–	–	–	–	–	–	–	–	–	–	–	29	–	–
Scrophularia nodosa	38	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Solidago canadensis	38	–	–	–	–	–	–	8	–	–	–	–	–	–	–	–
Leonurus quinquelobatus	63	–	–	–	–	2	–	–	6	7	10	–	–	–	–	–
Cirsium vulgare	100	43	–	–	–	12	33	8	29	7	–	9	–	71	–	–
Poa pratensis	25	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Potentilla reptans	25	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Heracleum s. sibiricum	38	–	–	–	–	–	8	–	–	–	–	9	–	–	–	–
Taraxacum campylodes	38	–	–	–	–	–	–	15	24	–	–	–	–	–	–	–
Arctium lappa	25	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Aethusa cynapium	–	43	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Astragalus cicer	–	43	–	–	6	–	8	–	–	–	–	–	–	–	–	–
Marrubium peregrinum	–	57	–	3	11	10	8	–	–	–	–	–	–	–	–	–
Asclepias syriaca	–	100	14	–	2	5	46	8	29	–	50	36	–	–	–	–
Verbascum lychnitis	–	–	48	67	32	17	–	69	6	–	–	18	–	–	–	–
Hieracium virosum	–	–	5	–	–	–	–	62	12	–	–	–	–	–	–	–
Melica transsilvanica	–	–	–	3	4	7	–	100	41	–	–	–	–	–	–	–
Vicia cracca	–	–	–	3	–	–	–	69	6	–	–	–	–	–	–	–
Euphorbia esula	–	–	–	7	–	2	–	46	6	7	–	–	–	–	–	–
Campanula rapunculoides	–	–	–	–	–	–	–	23	–	–	–	–	–	–	–	–
Hieracium umbellatum	–	–	–	–	–	–	–	46	6	–	–	–	–	–	–	–
Carduus acanthoides	–	–	–	3	6	10	33	54	24	–	–	–	–	–	–	–
Hypericum perforatum	–	–	24	13	34	27	17	69	18	–	–	9	–	–	–	–
Medicago lupulina	–	–	19	3	–	–	–	38	6	–	–	–	–	–	–	–
Nonea pulla	–	–	7	13	–	–	–	38	–	–	–	–	–	–	–	–
Erigeron annuus	–	–	26	7	2	5	33	77	71	21	–	18	–	–	–	–
Potentilla anserina	–	–	40	–	4	–	21	46	12	–	–	–	–	–	–	–
Lathyrus tuberosus	–	43	7	3	9	12	17	54	47	–	–	–	–	–	–	–
Campanula sibirica	–	–	–	–	–	–	–	23	6	–	–	–	–	–	–	–
Tragopogon podolicus	–	–	–	–	–	–	–	23	18	–	–	–	–	–	–	–
Poa compressa	–	–	17	20	23	7	21	31	12	–	–	–	–	–	–	–
Anisantha sterilis	–	–	–	–	–	–	–	46	82	79	30	–	–	–	–	–
Medicago sativa	–	–	7	–	–	–	–	15	29	–	–	–	–	–	–	–
Convolvulus arvensis	–	–	31	7	4	10	50	31	47	–	–	–	–	–	–	–
Artemisia vulgaris	–	–	–	–	–	–	8	15	18	–	–	–	–	–	–	–
Artemisia absinthium	13	–	–	–	2	10	29	54	18	–	–	9	–	–	–	–
Carduus crispus	–	–	–	–	–	–	–	23	6	–	–	–	–	–	–	–
Elytrigia repens	100	100	38	30	55	78	88	92	100	57	30	45	–	29	100	–
Tanacetum vulgare	100	57	–	–	–	10	21	–	–	–	–	–	–	–	–	–
Urtica dioica	63	–	–	–	–	–	17	–	–	–	30	18	–	–	–	–
Viola odorata	–	–	–	–	–	–	–	–	24	93	50	82	–	–	–	–
Galium aparine	38	–	–	3	–	–	–	38	82	100	–	27	–	71	–	–
Alliaria petiolata	–	–	–	–	–	–	–	8	29	43	30	–	–	–	–	–
Myosotis sparsiflora	–	–	–	–	–	–	–	–	–	14	–	–	–	–	–	–
Stellaria media	–	–	–	–	–	–	–	8	47	93	60	9	–	–	–	–
Limonium platyphyllum	–	–	2	–	–	–	–	–	–	14	–	–	–	–	–	–
Chelidonium majus	–	–	–	–	–	–	–	8	29	93	100	45	–	–	–	–
Geum urbanum	–	–	–	–	–	–	–	8	29	36	50	82	–	–	–	–
Chaerophyllum temulum	–	–	–	–	–	–	–	–	–	–	–	18	–	–	–	–
Quercus robur	–	–	–	–	–	12	4	–	12	14	70	64	–	–	–	–
Caragana arborescens	–	–	–	–	–	–	4	–	–	–	50	–	–	–	–	–
Morus alba	–	–	–	–	–	–	–	–	–	–	90	–	–	–	–	–
Sambucus nigra	–	–	–	–	–	–	–	–	–	–	50	18	–	–	–	–
Pyrus communis	–	–	2	–	2	7	4	–	–	–	30	18	–	–	–	–

Species	Association*															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
The number of *releve*	8	7	42	30	47	41	24	13	17	14	10	11	6	7	6	6
Acer negundo	25	–	–	–	–	2	21	–	18	7	20	100	–	–	–	–
Crataegus rhipidophylla	–	–	–	–	–	2	4	–	–	–	50	55	–	–	–	–
Erigeron canadensis	–	–	–	–	–	–	13	–	–	–	–	18	–	–	–	–
Prunus spinosa	–	–	2	3	2	20	8	–	–	–	–	36	–	–	–	–
Amorpha fruticosa	–	–	–	–	4	5	–	–	–	–	–	64	–	–	–	–
Aristolochia clematitis	–	–	–	–	–	2	–	–	–	7	–	45	–	–	–	–
Fraxinus pennsylvanica	–	–	–	–	–	2	13	–	–	–	–	45	–	–	–	–
Schedonorus giganteus	–	–	–	–	–	–	–	–	–	–	–	45	–	–	–	–
Torilis japonica	–	–	–	–	–	–	–	–	–	–	–	55	–	–	–	–
Anthriscus sylvestris	–	–	–	–	–	–	–	–	–	–	–	27	–	–	–	–
Euonymus europaeus	–	–	–	–	–	–	–	–	–	–	–	27	–	–	–	–
Lonicera tatarica	–	–	–	–	–	–	4	–	–	–	–	27	–	–	–	–
Acer pseudoplatanus	–	–	–	–	–	–	–	–	–	–	–	18	–	–	–	–
Elymus caninus	–	–	–	–	–	–	–	–	–	–	–	18	–	–	–	–
Ligustrum vulgare	–	–	–	–	–	–	–	–	–	–	–	18	–	–	–	–
Lysimachia vulgaris	–	–	–	–	–	–	–	–	–	–	–	18	–	–	–	–
Salix alba	–	–	–	–	–	–	–	–	–	–	–	18	–	–	–	–
Ulmus minor	–	–	7	17	4	–	–	–	–	–	–	27	–	–	–	–
Pastinaca sativa	–	–	–	–	–	–	–	8	–	–	–	18	–	–	–	–
Robinia pseudoacacia	–	–	–	–	4	–	–	8	6	7	60	27	–	–	–	–
Cotinus coggygria	–	–	–	–	–	–	–	23	12	14	–	–	–	–	–	–
Ambrosia artemisiifolia	–	–	7	–	–	–	25	8	12	–	–	–	100	–	–	–
Rumex obtusifolius	–	43	–	–	–	–	–	–	–	–	–	–	100	–	–	–
Typha latifolia	–	–	–	–	–	–	–	–	–	–	–	–	100	–	–	–
Humulus lupulus	–	43	–	–	–	–	–	–	–	14	–	9	–	71	–	–
Geranium palustre	63	–	–	–	2	–	–	–	–	–	–	–	–	100	–	50
Inula helenium	–	–	–	–	–	–	–	–	–	–	–	–	–	71	–	–
Sonchus palustris	38	–	–	–	–	–	–	–	–	–	–	–	–	100	–	–
Cornus sanguinea	–	–	–	–	–	–	–	–	–	–	–	18	–	71	–	–
Calamagrostis epigeios	38	–	40	23	11	51	–	31	–	7	–	9	–	71	–	–
Malus domestica	–	–	7	–	–	–	–	–	–	–	–	–	–	29	–	–
Cirsium arvense	–	43	–	–	–	–	–	–	–	–	–	–	–	–	100	–
Glyceria maxima	–	–	–	–	–	–	–	–	–	–	–	–	–	29	100	–
Bolboschoenus maritimus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	100	–
Glyceria fluitans	–	–	–	–	–	–	–	–	–	–	–	–	–	–	100	–
Juncus inflexus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	100	100
Ranunculus repens	–	–	–	–	–	–	–	–	–	–	–	–	–	–	100	–
Rumex crispus	–	–	–	–	–	2	–	–	–	–	–	–	–	–	100	–
Schoenoplectus lacustris	–	–	–	–	–	–	–	–	–	–	–	–	–	–	100	–
Typha angustifolia	–	–	–	–	–	–	–	–	–	–	–	–	–	–	100	–
Equisetum ramosissimum	–	–	–	–	–	5	13	–	–	–	–	64	100	100	100	–
Agrostis gigantea	–	–	–	–	–	–	17	–	–	–	–	–	–	–	–	100
Epilobium hirsutum	63	–	–	–	–	–	–	–	–	–	–	–	–	29	–	100
Alisma plantago-aquatica	–	–	–	–	–	–	–	–	–	–	–	–	–	–	100	100
Lemna minor	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	100
Phragmites australis	–	–	–	–	–	–	–	–	–	–	–	–	100	100	100	–
Sium latifolium	25	–	–	–	–	–	8	–	–	–	–	18	–	100	–	100
Berula erecta	–	–	–	–	–	–	–	–	–	–	–	27	–	–	–	50
Lycopus europaeus	–	–	–	–	–	–	–	–	–	–	–	27	–	–	–	50
Lysimachia nummularia	–	–	–	–	–	–	–	–	–	–	–	45	–	–	–	50

Notes: other species (numbers of associations where the species was found are in parentheses): *Chenopodium album* (7, 12), *Sisymbrium loeselii* (7, 8, 9), *Melilotus officinalis* (3, 5), *Cynoglossum officinale* (6, 7, 9, 11, 12), *Lotus ucrainicus* (3, 5, 7), *Chondrilla latifolia* (3, 8), *Reseda lutea* (6, 8), *Leonurus cardiac* (11, 12), *Trifolium arvense* (3, 5, 8), *Lactuca serriola* (3, 4, 5, 6, 7, 8, 9, 12), *Elytrigia intermedia* (6), *Chondrilla juncea* (3), *Verbascum nigrum* (6, 7), *Trifolium ambiguum* (3), *Tragopogon dubius* (3, 4, 5, 8, 9), *Dactylis glomerata* (8, 10), *Lithospermum officinale* (9), *Malva thuringiaca* (1, 3, 5, 6, 7), *Artemisia vulgaris* (7, 8, 9), *Poa compressa* (3, 4, 5, 6, 7, 8, 9), *Stipa pulcherrima* (3, 4), *Equisetum pratense* (12), *Clinopodium vulgare* (7), *Onopordum acanthium* (7), *Vicia tetrasperma* (12), *Vicia grandiflora* (8), *Silene latifolia* (8), *Sonchus oleraceus* (8), *Cyclachaena xanthiifolia* (7), *Lathyrus sylvestris* (7), *Rumex confertus* (7), *Berteroa incana* (8), *Melica altissima* (10), *Lactuca quercina* (10), *Asparagus officinalis* (5, 6, 7), *Ranunculus acris* (6), *Verbascum marschallianum* (1, 3, 4, 5, 6, 7), *Allium paczoskianum* (3), *Erodium cicutarium* (3), *Ranunculus illyricus* (3), *Veronica dillenii* (3), *Carex acutiformis* (5, 12), *Ulmus pumila* (8, 9), *Carex spicata* (1, 4, 5, 6, 7, 9, 10), *Linum hirsutum* (4), *Clinopodium acinos* (3, 4), *Cephalaria uralensis* (5), *Sonchus arvensis* (9), *Anisantha tectorum* (3, 4), *Carex praecox* (3, 7), *Nigella arvensis* (4), *Poa nemoralis* (9, 11), *Viola arvensis* (6, 12), *Phlomis tuberosa* (7, 12), *Isatis tinctoria* (4, 7, 8), *Galium mollugo* (7), *Valeriana officinalis* (7), *Sisymbrium polymorphum* (4, 8), *Hypericum elegans* (5, 7, 12), *Trifolium repens* (3), *Sisymbrium altissimum* (4), *Dianthus campestris* (3), *Arenaria serpyllifolia* (3, 4), *Hieracium robustum* (3), *Carex melanostachya* (2, 3, 5, 6, 7, 12), *Salvia verticillata* (5), *Gleditsia triacanthos* (3, 5), *Xeranthemum annuum* (4, 5), *Fallopia convolvulus* (6, 9, 12), *Viola ambigua* (3, 4, 5, 12), *Silaum silaus* (8, 9), *Thlaspi perfoliatum* (8, 9), *Onobrychis viciifolia* (3, 8), *Asperula montana* (3, 4), *Erysimum diffusum* (3, 4), *Polygala comosa* (3, 4), *Vicia hirsuta* (3, 4), *Prunus armeniaca* (5, 7, 8), *Acer tataricum* (6, 9, 12), *Trifolium pratense* (3, 9), *Xanthoselinum alsaticum* (6, 7), *Seseli tortuosum* (3, 9), *Thalictrum minus* (6, 7, 10), *Scabiosa ochroleuca* (3, 5, 8, 12), *Hylotelephium ruprechtii* (6, 8, 12), *Cuscuta approximata* (3), *Salvia austriaca* (3), *Phlomis herbaventi* (5, 6), *Astragalus danicus* (3), *Thesium ramosum* (3), *Salvia aethiopis* (3), *Consolida regalis* (4, 5, 8), *Taraxacum serotinum* (3, 4, 5, 7), *Linaria vulgaris* (4, 6, 7), *Astragalus glycyphyllos* (5), *Odontites luteus* (5), *Prunus fruticosa* (5); * 1 – E5.1 Anthropogenic herb stands (Association *Arctietum lappae* Felföldy 1942); 2 – E5.1 Anthropogenic herb stands (Association *Asclepiadetum syriacae* Láníková in Chytrý 2009); 3 – E1.2D3 Pontic Eastern steppes (*Salvio nemorosae-Festucetum valesiacae* Korotchenko et Didukh 1997); 4 – E1.2D3 Pontic Eastern steppes (*Stipo lessingianae-Salvietum nutantis* Vynokurov 2014); 5 – E1.2D2 Sarmatic steppes (*Festuco valesiacae-Stipetum capillatae* Sill 1931); 6 – E2.251 Ponto-Pannonic mesophile hay meadows (*Festuco valesiacae-Poetum angustifoliae* Mirkin in Denisova et al. 1986); 7 – E2.251 Ponto-Pannonic mesophile hay meadows (*Poëtum angustifoliae* Shelyag-Sosonko et al. 1986); 8 – E1.D Unmanaged xeric grassland (*Melico transsilvanicae-Agropyretum* Th. Mull. in Gors 1966); 9 – E1.D Unmanaged xeric grassland (*Convolvulo arvensis-Agropyretum repentis* Felföldy 1943); 10 – I1.5 Bare tilled, fallow or recently abandoned arable land (*Myosotido sparsiflorae-Alliarietum petiolatae* Gutte 1973); 11 – G1.C Highly artificial broadleaved deciduous forestry plantations (*Chelidonio-Robinietum* Jurko 1963); 12 – G1.C Highly artificial broadleaved deciduous forestry plantations (*Chelidonio-Aceretum negundi* L. Ishbirdina et A. Ishbirdin 1991); 13 – D5.1 Reedbeds normally without freestanding water (*Typhetum latifoliae* Soo 1927); 14 – C3.2 Water-fringing reedbeds and tall helophytes other than canes (*Phragmitetum australis* Savič 1926); 15 – D5.2 Beds of large sedges (*Typhetum angustifoliae* Pignatti 1953); 16 – C3.1 Species-rich helophyte beds (*Butomo-Alismatetum plantaginis-aquaticae* Slavnic 1948).

The dominant species were *Achillea millefolium* L. (projective cover 1–7%), *Calamagrostis epigeios* (L.) Roth (3–35%), *Elytrigia repens* (L.) Nevski (1–75%), *Euphorbia stepposa* Zoz. ex Prokh. (1–15%), *Festuca valesiaca* Schleich. ex Gaudin (1–35%), *Galatella villosa* (L.) Rchb. f. (1–25%), *Koeleria cristata* (L.) Pers. (1–25%), *Medicago falcata* L. (1–20%), *Poa angustifolia* L. (2–25%), and *Salvia nemorosa* L. (1–8%). There were 4 species of the genus *Astragalus* (*A. dasyanthus*, *A. glycyphyllos*, *A. onobrychis*, *A. ponticus*). The association contains species listed in the Red Data Book of Ukraine: *Stipa pulcherrima* K. Koch, *Astragalus ponticus* Pall., *A. dasyanthus* Pall., and *Stipa lessingiana* Trin. & Rupr. The association occurs on the slopes of the gully in the middle part at an altitude of 106.9 ± 16.6 m (range 74.2 to 146.0 meters). The associations prefer habitats with high levels of insolation and are found under conditions of solar radiation reaching the surface of 1.5 ± 0.1 MWh/m^2 (in the range from 1.2 to 1.7 MWh/m^2). The topographic index of humidity in the locations where this association was found was 7.3 ± 1.5 (in the range from 5.4 to 12.0). The erosion index was 6.6 ± 5.8 (range 0.003 to 25.1). The naturalness index of this association was 2.6 ± 0.9 (in the range of 0.5 to 5.6). The index of hemeroby of this association was 40.3 ± 9.6% (in the range from 22.7% to 62.5%).

The association *Stipo lessingianae-Salvietum nutantis* Vynokurov 2014 included 86 plant species. The total projective cover varied from 57 to 100%. On average, 20.2 ± 3.9 species were found on the survey plot (ranging from 12 to 34 species). The Shannon diversity of the communities was 3.6 ± 0.4 bits/species (ranging from 2.3 to 4.3 bits/species). The dominant species were *Euphorbia stepposa* Zoz. ex Prokh. (projective covere 1–5%), *Calamagrostis epigeios* (L.) Roth (3–35%), *Elytrigia repens* (L.) Nevski (1–75%), *Euphorbia stepposa* Zoz. ex Prokh. (1–15%), *Artemisia austriaca* Jacq. (1–7%), *Poa angustifolia* L. (1–25%), *Securigera varia* (L.) Lassen) (2–10%), *Bromopsis riparia* (Rehm.) Holub (1–20%), *Medicago falcata* L. (1–10%), *Cleistogenes serotina* subsp. *bulgarica* (Bornm.) Tutin (2–12%), *Festuca valesiaca* Schleich. ex Gaudin (2–30%), *Koeleria cristata* (L.) Pers. (3–35%), and *Stipa capillata* L. (1–40%). There were 3 species of the genus *Astragalus* (*A. dasyanthus*, *A. onobrychis*, *A. ponticus*). The association contains species listed in the Red Data Book of Ukraine: *Stipa pulcherrima* K. Koch, *Astragalus ponticus* Pall., *Astragalus dasyanthus* Pall., and *Stipa lessingiana* Trin. & Rupr. and the Red List of Dnipropetrovsk oblast: *Rosa rubiginosa* L. The association occurs on the slopes of the gully in the middle part at an altitude of 108.2 ± 10.8 m (range from 83.9 to 122.2 meters). The associations prefer habitats with high levels of insolation and occur under conditions of solar radiation reaching the surface of 1.6 ± 0.1 MWh/m^2 (in the range from 1.3 to 1.7 MWh/m^2).

Class *Molinio-Arrhenatheretea* Tx. 1937
Order *Galietalia veri* Mirkin et Naumova 1986
Union *Agrostion vinealis* Sipaylova et al. 1985
Association *Festuco valesiacae-Poetum angustifoliae* Mirkin in Denisova et al. 1986
Association *Poëtum angustifoliae* Shelyag-Sosonko et al. 1986

The class *Molinio-Arrhenatheretea* Tx. 1937 includes the vegetation of steppe, true and wet meadows with the exception of wet meadows. The association *Festuco valesiacae-Poetum angustifoliae* Mirkin in Denisova et al. 1986 contained 87 plant species. The total projective cover varied from 66% to 100%. On average, 13.1 ± 2.4 species were found on the survey plot (in the range from 9 to 17 species). The Shannon diversity of the communities was 2.8 ± 0.5 bits/species (ranging from 1.3 to 3.5 bits/species). The dominant species were *Festuca pseudovina* Hack. ex Wiesb. (2–40%), *Poa angustifolia* L. (1–30%), *Agrimonia eupatoria* L. (projective cover 1–15%), *Calamagrostis epigeios* (L.) Roth (3–80%), *Cytisus austriacus* L. (1–30%), *Elytrigia repens* (L.) Nevski (2–45%), and *Salvia nemorosa* L. (1–7%). The association contains species listed in the Red Data Book of Ukraine: *Stipa capillata* L., *Astragalus ponticus* Pall., and *Verbascum nigrum* L. and in the Red List of Dnipropetrovsk oblast: *Rosa rubiginosa* L. The association occurs on gully slopes in the lower part of the slope at an altitude of 134.8 ± 17.4 m (range 80.6 to 154.5 meters). The association prefers habitats with moderate insolation and occurs under conditions of solar radiation reaching the surface of 1.5 ± 0.1 MWh/m^2 (in the range from 1.3 to 1.6 MWh/m^2). The topographic wetness index in the locations where this association was found was 7.7 ± 2.9 (in the range from 4.8 to 20.4). The erosion index had a value of 7.6 ± 6.8 (range 0.009 to 33.3). The index of naturalness of this association was 2.0 ± 1.1 (in the range of –0.3 to 4.2). The index of hemeroby of this association was 54.4 ± 8.0% (ranged from 36.5% to 69.5%).

The association *Poëtum angustifoliae* Shelyag-Sosonko et al. 1986 included 90 plant species. On average, 17.7 ± 28.1 species were found on the survey plot (in the range from 11 to 30 species). The total projective cover varied from 78% to 100%. The Shannon diversity of the communities was 3.1 ± 0.2 bits/species (ranging from 2.3 to 4.2 bits/species). The dominant species were *Agrimonia eupatoria* L. (2–25%), *Origanum vulgare* L. (1–20%), *Elytrigia repens* (L.) Nevski (10–65%), *Galium humifusum* M. Bieb. (1–10%), *Poa angustifolia* L. (2–50%), *Achillea millefolium* L. (1–15%), *Salvia nemorosa* L. (1–20%), and *Festuca valesiaca* Schleich. ex Gaudin (2–50%). The association contains a species listed in the Red Data Book of Ukraine (*Astragalus ponticus* Pall.) and species included in the Red Data Book of Dnipropetrovsk oblast (*Rosa rubiginosa* L., *Valeriana officinalis* L., *Verbascum nigrum* L.). The association occurs in the lower thirds of the slope and in the thalweg at a relatively close groundwater level. The communities of this association were found in habitats located at an altitude of 103.8 ± 414.6 m (in the range from 84.5 to 148.6 meters). The associations occur in habitats with low insolation and are found under conditions of solar radiation reaching the surface of 1.41 ± 0.02 MWh/m^2 (in the range from 1.19 to 1.64 MWh/m^2). The topographic wetness index in the locations where this association was found was moderate and was 7.5 ± 3.1 (in the range from 5.5 to 11.9). The erosion index was 5.2 ± 14.6 (ranging from 0.009 to 11.9). The index of naturalness of this association was 0.71 ± 0.56 (in the range of –0.52 to 2.50). The index of hemeroby of this association was 62.1 ± 78.1% (ranged from 36.0% to 73.9%).

Class *Artemisietea vulgaris* Lohmeyer et al. in Tx. 1950
Order *Onopordetalia acanthii* Br.-Bl. et Tx. ex Klika et Hadač 1944
Union *Arction lappae* Tx. 1937
Association *Arctietum lappae* Felföldy 1942
Union *Dauco-Melilotion* Görs ex Rostański et Gutte 1971
Association *Asclepiadetum syriacae* Láníková in Chytrý 2009
Oder *Agropyretalia intermedio-repentis* T. Müller et Görs 1969
Union *Convolvulo arvensis-Agropyrion repentis* Görs 1967
Association *Melico transsilvanicae-Agropyretum* Th. Mull. in Gors 1966
Association *Convolvulo arvensis-Agropyretum repentis* Felföldy 1943

The class *Artemisietea vulgaris* Lohmeyer et al. in Tx. includes ruderal communities of tall biennial and perennial plants common in nitrified ecotopes with different moisture and light regimes. The *Arctietum lappae* Felföldy 1942 association included 28 plant species. The total projective cover ranged from 82% to 100%. On average, 11.3 ± 8.8 species were found on the survey plot (in the range from 7 to 14 species). The Shannon diversity of the communities was 2.9 ± 0.1 bits/species (ranging from 2.5 to 3.2 bits/species). The dominant species were *Elytrigia repens* (L.) Nevski (projective coverage 7–20%), *Calamagrostis epigeios* (L.) Roth (10–20%), *Cirsium vulgare* (Savi) Ten. (1–15%), *Tanacetum vulgare* L. (1–20%), *Festuca pseudovina* Hack. ex Wiesb. (2–40%), and *Geranium palustre* L. (5–10%). The association contains species included in the Red List of Dnipropetrovsk oblast (*Geranium palustre* L.). The association occurs in the upper part of the gully in the area of greatest contact with the surrounding agricultural land and in the lower part of the gully in the immediate vicinity of the road. This explains the considerable variation in elevation level where the communities of this association were found to be 122.9 ± 974.9 m (in the range from 85.0 to 151.9 meters). The associations prefer habitats with low levels of insolation and are found under conditions of solar radiation reaching the surface of 1.39 ± 0.01 MWh/m^2 (in the range from 1.23 to 1.53 MWh/m^2). The topographic wetness index in the locations where this association was found was 6.0 ± 1.6 (in the range from 4.7 to 8.6). The erosion index was 3.2 ± 18.0 (range 0.45 to 13.2). The index of naturalness of this association was 1.1 ± 4.4 (in the range –1.1 to 4.3). The index of hemeroby of this association was 66.2 ± 44.7% (in the range from 56.7% to 71.3%).

The *Asclepiadetum syriacae* Láníková community belongs to the union *Dauco-Melilotion* Görs ex Rostański et Gutte 1971 class *Artemisietea vulgaris* Lohmeyer et al. ex von Rochow (1951), i.e. ruderal and weedy vegetation. The association *Asclepiadetum syriacae* Láníková in Chytrý 2009 included 19 plant species. The total projective cover ranged from 86% to 100%. On average, 9.3 ± 1.1 species were found on the survey plot (in the range of 7 to 10 species). The Shannon diversity of the communities was 1.8 ± 0.2 bits/species (ranging from 0.8 to 2.2 bits/species). The dominant species were *Asclepias syriaca* L. (projective cover 20–80%), *Elytrigia repens* (L.) Nevski (2–50%), and *Poa angustifolia* L. (2–10%). No Red List species are found in the association. The association occurs in different locations within the gully system in the area of disturbance caused by human activity. These can be locations near an agricultural field, on a slope in close proximity to artificial tree plantations, or in the lower part of the slope, also in the area of probable human activity. This explains the considerable variation in elevation level where the communities of this association were found to be 132.3 ± 83.3 m (in the range from 123.3 to 150.4 meters). The associations are found in habitats with a wide range of insolation and occur under conditions of solar radiation reaching the surface of 1.46 ± 0.01 MWh/m^2 (in the range from 1.31 to 1.56 MWh/m^2). The topographic moisture index in the locations where this association was found was relatively high and amounted to 10.5 ± 4.9 (in the range from 7.3 to 13.0). The erosion index was 3.0 ± 12.8 (in the range from 0.001 to 7.5). The index of naturalness of this association was –0.8 ± 0.2 (in the range –1.3 to –0.2). The index of hemeroby of this association was 77.8 ± 13.7% (in the range from 73.4% to 81.6%).

The association *Melico transsilvanicae-Agropyretum* Th. Mull. in Gors 1966 included 72 plant species. On average, 18.5 ± 38.9 species were found on the survey plot (in the range from 10 to 29 species). The total projective cover varied from 56% to 94%. The Shannon diversity of the communities was 2.9 ± 0.2 bits/species (varied from 2.4 to 3.7 bits/species). The dominant species were *Elytrigia repens* (L.) Nevski (2–50%), *Erigeron annuus* (L.) Desf. (1–30%), *Poa angustifolia* L. (5–50%), and *Melica transsilvanica* Schur (1–10%). No Red List species occur in the association. The association occurs in the upper thirds of the slope on fallow land and in areas in direct contact with artificial wood plantations. The communities of this association were found in habitats located at an altitude of 126.4 ± 58.7 m (in the range from 118.2 to 144.7 meters). The associations occur in habitats with a high level of insolation and are found under conditions of solar radiation reaching the surface of 1.50 ± 0.01 MWh/m^2 (from 1.32 to 1.61 MWh/m^2). The topographic wetness index in the locations where this association was found was relatively low and amounted to 6.8 ± 2.9 (in the range from 5.1 to 11.9). The erosion index was 5.3 ± 16.1 (in the range from 0.7 to 11.9). The index of naturalness of this association was 0.03 ± 0.84 (in the range –1.2 to 2.3). The index of hemeroby of this association was 69.6 ± 41.3% (in the range from 59.4% to 79.8%).

The association *Convolvulo arvensis-Agropyretum repentis* Felföldy 1943 included 58 plant species. On average, 12.2 ± 22.3 species were found on the survey plot (ranging from 5 to 24 species). The total projective cover varied from 49% to 100%. The Shannon diversity of the communities was 2.5 ± 0.3 bits/species (varied from 1.7 to 3.3 bits/species). The dominant species were *Elytrigia repens* (L.) Nevski (1–50%), *Stellaria media* (L.) Vill (5–20%), *Anisantha sterilis* (L.) Nevski (1–30%), *Galium aparine* L. (5–60), *Poa angustifolia* L. (2–25%), and *Melica transsilvanica* Schur (1–5%). No Red List species are found in the association. The association occurs on the upper thirds of the slope on fallow land and in areas in direct contact with artificial forestry plantations. Communities of this association were found in habitats located at an altitude of 128.1 ± 121.0 m (in the range from 105.0 to 144.9 meters). The associations occur in habitats with moderate insolation and are found under conditions of solar radiation reaching the surface of 1.44 ± 0.01 MWh/m^2 (in the range from 1.35 to 1.58 MWh/m^2). The topographic wetness index in the locations where this association was found was relatively low and was 6.1 ± 1.6 (in the range from 4.9 to 10.0). The erosion index was 2.6 ± 5.6 (in the range from 0.03 to 7.7). The index of naturalness of this association was –0.31 ± 0.25 (in the range of –1.4 to 0.36). The index of hemeroby of this association was 77.9 ± 27.7% (in the range from 67.4% to 86.3%).

Class *Galio-Urticetea* Passarge ex Kopecký 1969

Order *Galio-Alliarietalia* Oberd. in Görs et T. Müller 1969

Union *Geo urbani-Alliarion officinalis* Lohmeyer et Oberd. in Görs et T. Müller 1969

Association *Myosotido sparsiflorae-Alliarietum petiolatae* Gutte 1973

The class *Galio-Urticetea* Passarge ex Kopecký 1969 includes vegetation of semi-natural communities formed by highly and moderately herbivorous species on nitrogen-enriched marginal habitats: edges of mesophytic forests and along linear watercourses in temperate Europe. The peculiarity of the class communities is that they are a "buffer" between forest, shrub, coastal and aquatic communities and ruderal communities, and are also centers of expansion of invasive species. The association *Myosotidos parsiflorae-Alliarietum petiolatae* Gutte included 32 plant species. On average, 8.4 ± 7.6 species were found on the survey plot (ranging from 5 to 14 species). The total projective cover ranged from 53% to 93%. The Shannon diversity of the communities was 1.9 ± 0.3 bits/species (varied from 1.0 to 2.7 bits/species). The dominant species were *Anisantha sterilis* (L.) Nevski (1–60%), *Chelidonium majus* L. (1–35%), *Galium aparine* L. (5–70%), *Stellaria media* (L.) Vill (1–20), and *Viola odorata* L. (1–15%). The association contains a species included in the Red List of Dnipropetrovsk oblast (*Rosa rubiginosa* L.). The association occurs in the upper thirds of the slope on fallow land and in areas in direct contact with artificial tree plantations. The communities of this association were found in habitats located at an altitude of 126.8 ± 152.8 m (in the range from 99.6 to 147.0 meters). The associations occur in habitats with moderate insolation and are found under conditions of solar radiation reaching the surface of 1.44 ± 0.01 MWh/m^2 (in the range from 1.36 to 1.59 MWh/m^2). The topographic wetness index in the locations where this association was found was moderate and equaled 7.1 ± 4.6 (in the range from 4.5 to 10.8). The erosion index was 4.3 ± 10.2 (in the range from 0.15 to 10.7). The index of naturalness of this association was 0.36 ± 0.28 (in the range of –0.47 to 1.23). The index of hemeroby of this association was 79.1 ± 4.8% (in the range from 74.5% to 83.5%).

Class *Robinietea* Jurko ex Hadač et Sofron 1980

Oder *Chelidonio-Robinietalia pseudoacaciae* Jurko ex Hadač et Sofron 1980

Union *Chelidonio-Acerion negundi* L. Ishbirdina et A. Ishbirdin 1991

Association *Chelidonio-Aceretum negundi* L. Ishbirdina et A. Ishbirdin 1991

Union *Chelidonio majoris-Robinion pseudoacaciae* Hadač et Sofron ex Vitková in Chytrỳ 2013

Association *Chelidonio-Robinietum* Jurko 1963

The class *Robinietea* Jurko ex Hadač et Sofron 1980 includes communities of artificial tree and shrub plantations. The association *Chelidonio-Robinietum* Jurko 1963 included 22 plant species. On average, 9.3 ± 5.6 species were found on the survey plot (ranging from 6 to 12 species). The total projective cover varied from 40% to 85%. The Shannon diversity of the communities was 2.4 ± 0.2 bits/species (ranging from 1.8 to 3.0 bits/species). The dominant species in the herbage were *Chelidonium majus* L.(1–60%), *Geum urbanum* L. (2–60%), *Stellaria media* (L.) Vill (1–5%), *Asclepias syriaca* L. (1–60%), and in the stand was *Robinia pseudoacacia* L. (15–35% crown closure), *Morus alba* L.(5–15%), and *Quercus robur* L. (30–60%), and *Sambucus nigra* L. (1–10% crown closure) was represented in the shrub layer. No Red List species were found in the association. The association occurs in the upper thirds of the slope in the area of contact with the surrounding agricultural fields. The communities of this association were found in habitats located at an altitude of 122.2 ± 20.5 m (range from 116.7 to 130.6 meters). The associations occur in habitats with below-moderate insolation and are found under conditions of solar radiation reaching the surface of 1.40 ± 0.01 MWh/m^2 (in the range from 1.30 to 1.48 MWh/m^2). The topographic wetness index in the locations where this association was found was low and equaled 6.5 ± 1.7 (in the range from 4.8 to 8.6). The erosion index was 2.6 ± 4.9 (in the range from 0.22 to 6.6). The index of naturalness of this association was 1.16 ± 0.25 (in the range of 0.53 to 2.10). The index of hemerobia of this association was 72.4 ± 5.9% (in the range from 68.8% to 75.2%).

The association *Chelidonio-Aceretum negundi* L. Ishbirdina et A. Ishbirdin 1991 included 74 plant species. On average, 18.1 ± 11.7 species were found on the survey plot (in the range from 13 to 23 species). The total projective cover varied from 55% to 100%. The Shannon diversity of the communities was 3.4 ± 0.3 bits/species (ranging from 2.6 to 3.9 bits/

species). The dominant species in the herbage were *Chelidonium majus* L. (1–5%), *Elytrigia repens* (L.) Nevski (3–55%), *Equisetum ramosissimum* Desf. (1–5%), *Geum urbanum* L. (1–15%), *Asclepias syriaca* L. (25–70%), and in the stand were *Acer negundo* L. (crown closure 5–20%), *Robinia pseudoacacia* L. (5–10%), *Fraxinus pennsylvanica* Marshall (7–15%), *Quercus robur* L. (5–30%), in the shrub layer *Amorpha fruticosa* L. (crown closure 5–15%), *Crataegus rhipidophylla* Gand. (5–20%), *Sambucus nigra* L. (1–5%) were represented. A species included in the Red List of Dnipropetrovsk oblast (*Berula erecta* (Huds.) Coville) was found in the association. The association occurs on the lower thirds of the slope. The association occurs in the lower thirds of the slope. This association is usually separated from the surrounding agricultural fields by the *Chelidonio-Robinietum* association. The *Chelidonio-Aceretum negundi* association occurred in habitats located at an altitude of 102.0 ± 48.9 m (range 95.4 to 113.9 meters). The associations occur in habitats with low insolation and are found under conditions of solar radiation reaching the surface of 1.37 ± 0.01 MWh/m^2 (in the range from 1.24 to 1.42 MWh/m^2). The topographic wetness index in the locations where this association was found was high and amounted to 9.0 ± 10.4 (in the range from 5.5 to 14.9). The erosion index was 8.6 ± 102.8 (range 0.02 to 28.8). The index of naturalness of this association was 0.97 ± 1.79 (in the range – 1.13 to 2.58). The index of hemeroby of this association was 67.8 ± 43.8% (ranged from 59.8% to 78.2%).

Class *Phragmito-Magnocaricetea* Klika in Klika et Novák 1941
  Order *Phragmitetalia* Koch 1926
    Union *Phragmition communis* Koch 1926
      Association *Phragmitetum australis* Savič 1926
      Association *Typhetum latifoliae* Soo 1927
      Association *Typhetum angustifoliae* Pignatti 1953
    Union *Eleocharito palustris-Sagittarion sagittifoliae* Passarge 1964
  Order *Oenanthetalia aquaticae* Hejný ex Balátová-Tuláčková et al. 1993
      Association *Butomo-Alismatetum plantaginis-aquaticae* Slavnic 1948

The class *Phragmito-Magnocaricetea* Klika in Klika et Novák 1941 comprises communities of wet, marshy and boggy meadows, bogs on soddy, peaty, muddy and meadow-boggy soils, as well as air-water communities on silty-sandy, muddy and silty-peaty bottom sediments. They are characteristic of periodically flooded ecotopes in river floodplains, along the shores of lakes, ponds, reclamation canals, and areas of groundwater upwelling. They are resistant to water level fluctuations during the growing season. The association *Typhetum latifoliae* Soo 1927 included 5 plant species. On average, 5 species were found on the survey plot. The total projective cover ranged from 50% to 65%. The Shannon diversity of the communities was 1.4 ± 0.1 bits/species (ranged from 0.9 to 1.6 bits/species). The dominant species in the herbage were *Typha latifolia* L. (30–45%), and *Phragmites australis* (Cav.) Trin. ex Steud. (5–15%). The projective cover of *Ambrosia artemisiifolia* L. (1–3%), *Rumex obtusifolius* L. (1–5%), and *Equisetum ramosissimum* Desf. (1–7%) was much lower. No Red List species were found in the association. The association occurs in the thalweg in the upper parts of the gully, so the elevation level where the communities of this association are found is relatively high. The communities of this association were found in habitats located at an altitude of 124.5 ± 6.1 m (in the range from 120.0 to 127.2 meters). The associations occur in habitats with moderate insolation and are found under conditions of solar radiation reaching the surface of 1.43 ± 0.01 MWh/m^2 (in the range from 1.34 to 1.56 MWh/m^2). The topographic wetness index in the locations where this association was found was low and amounted to 14.1 ± 17.5 (in the range from 10.7 to 21.7). The erosion index was 2.1 ± 3.6 (in the range from 0.18 to 4.3). The index of naturalness of this association was 1.15 ± 0.04 (in the range of 0.85 to 1.36). The index of hemeroby of this association was 27.8 ± 6.2% (in the range from 24.8% to 30.2%).

The association *Phragmitetum australis* Savič 1926 included 17 plant species. On average, 11.4 ± 0.9 species were found on the survey plot (in the range from 10 to 12 species). The total projective cover ranged from 90% to 100%. The Shannon diversity of the communities was 2.9 ± 0.1 bits/species (ranging from 2.5 to 3.2 bits/species). The dominant species in the herbage were *Phragmites australis* (Cav.) Trin. ex Steud. (20–35%), *Geranium palustre* L. (10–25%), and *Inula helenium* L. (10–20%). The projective cover of *Cirsium vulgare* (Savi) Ten (3–5%), *Galium aparine* L. (3–7%), and *Equisetum ramosissimum* Desf. (3–20%) was much lower. The association contained species included in the Red List of Dnipropetrovsk oblast (*Geranium palustre* L. and *Inula helenium* L.). The association occurs in the thalweg in the lower and middle parts of the gully, so the elevation level where the communities of this association are found is relatively low. The communities of this association were found in habitats located at an altitude of 81.5 ± 47.6 m (range from 74.9 to 91.7 meters). The associations occur in habitats with moderate levels of insolation and are found under conditions of solar radiation reaching the surface of 1.44 ± 0.01 MWh/m^2 (range from 1.29 to 1.59 MWh/m^2). The topographic wetness index in the locations where this association was found was low and amounted to 12.8 ± 1.8 (in the range from 11.6 to 15.6). The erosion index was 3.7 ± 11.0 (in the range from 0.01 to 9.4). The index of naturalness of this association was 3.81 ± 0.29 (in the range of 3.05 to 4.42). The index of hemeroby of this association was 44.0 ± 35.0% (in the range from 36.2% to 53.1%).

The association *Typhetum angustifoliae* Pignatti 1953 included 13 plant species. On average, 13 species were found on the survey plot. The total projective cover ranged from 90% to 100%. The Shannon diversity of the communities was 3.0 ± 0.1 bits/species (ranged from 2.9 to 3.1 bits/species). The dominant species in the herbage were *Phragmites australis* (Cav.) Trin. ex Steud. (20–30%), *Typha angustifolia* L. (5–15%), *Glyceria fluitans* (L.) R. Br. (10–25%), and *Glyceria maxima* (C. Hartm.) Holmb (15–25%). No Red List species were found in the association. The association occurred in the thalweg in the middle part of the gully, so the elevation level where the communities of this association are found is relatively low. Communities of this association occurred in habitats located at an altitude of 84.3 ± 2.2 m (range from 82.1 to 85.9 meters). The associations occur in habitats with moderate insolation and are found under conditions of solar radiation reaching the surface of 1.49 ± 0.01 MWh/m^2 (in the range from 1.41 to 1.53 MWh/m^2). The topographic wetness index in the locations where this association was found was low and amounted to 13.9 ± 11.5 (in the range from 11.1 to 18.7). The erosion index was 1.4 ± 8.8 (in the range from 0.01 to 7.5). The index of naturalness of this association was 2.20 ± 0.05 (in the range from 1.77 to 2.43). The index of hemeroby of this association was 41.3 ± 2.9% (in the range from 38.8% to 43.5%).

The association *Butomo-Alismatetum plantaginis-aquaticae* Slavnic 1948 included 10 plant species. On average, 8 species were found on the survey plot. The total projective cover varied from 70 to 100%. The Shannon diversity of the communities was 2.3 ± 0.1 bits/species (ranged from 1.8 to 2.4 bits/species). The dominant species in the herbaceous stand were *Epilobium hirsutum* L. (20–35%), *Sium latifolium* L. (1–15%), *Juncus inflexus* L. (10–25%), and *Berula erecta* (Huds.) Coville (3–10%). The available areas with a water surface were covered by *Lemna minor* L. (25–35% of water surface cover). The association contained a species included in the Red List of Dnipropetrovsk oblast (*Geranium palustre* L.). The association was found in the thalweg in the upper part of the gully, so the elevation level where the communities of this association are found is relatively high. The communities of this association were found in habitats located at an altitude of 134.6 ± 7.3 m (in the range from 132.3 to 139.4 meters). The associations occur in habitats with moderate levels of insolation and are found under conditions of solar radiation reaching the surface of 1.43 ± 0.01 MWh/m^2 (in the range from 1.39 to 1.52 MWh/m^2). The topographic wetness index in the locations where this association was found was low and amounted to 13.2 ± 6.8 (in the range from 11.5 to 18.5). The erosion index was 2.2 ± 27.2 (range 0.01 to 12.8). The index of naturalness of this association was 2.87 ± 0.15 (in the range from 2.33 to 3.27). The index of hemeroby of this association was 58.4 ± 12.1% (in the range from 54.2% to 63.8%).

The importance of geomorphological factors in shaping vegetation cover. The geomorphological predictors allowed for a classification of vegetation types with an accuracy of 23.8% to 100.0% (Fig. 3). The topographic wetness index was the most important for classification, with a score of 100 (0 = least important, 100 = most important). Altitude and insolation were also important for classification (94 and 95 respectively). Erosion index was the least important for vegetation classification (55 points). The topographic wetness index provided an accurate identification of wetland vegetation of the *Phragmito-Magnocaricetea* class. Naturally, this type of vegetation preferred biotopes with the highest level of soil moisture. High insolation accurately labeled the locations where *Festuco-Brometea* steppe vegetation was most likely to be found. Some of the artificial tree plantations that occurred in the thalweg of the gully can be clearly identified by the high level of the topographic wetness index. Another grouping of artificial tree plantations is located on relatively high relief areas and should be differentiated from *Galio-Urticetea* communities, which prefer locations with higher light levels, and from *Molinio-Arrhenatheretea*, which prefer locations with a higher risk of erosion. The most arid locations are preferred by *Agropyretalia intermedio-repentis* vegetation. Steppe and meadow vegetation located at altitudes less than 116 meters also differ in their preferred height. Steppe vegetation is usually located at a level higher than 95 meters. Natural steppe and meadow vegetation at elevations below 116 meters differs from semi-natural *Galio-Urticetea* vegetation in that the latter usually prefers more well lit locations.

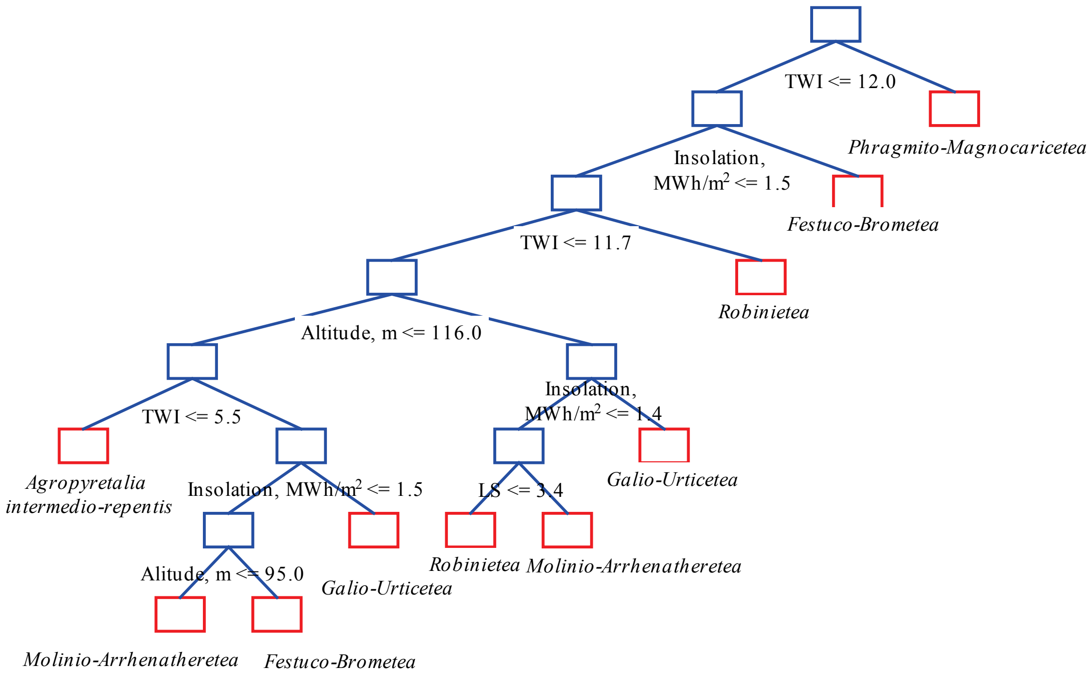

Fig. 3. Classification tree for assessing the role of geomorphic predictors in structuring the vegetation cover of a gully: each dichotomy has a condition next to it: a choice less than the condition indicates a branch of the tree on the left, and a choice on the right indicates a choice on the left; method of choosing a partitioning rule: C and RT (classification and regression trees) based on QUEST (quick, unbiased, efficient statistical trees) algorithms; classification accuracy: *Festuco-Brometea* is 72.9%, *Molinio-Arrhenatheretea* is 30.8%, *Phragmito-Magnocaricetea* is 96.0%, *Onopordetalia acanthi* is 80.0%, *Robinietea* is 23.8%, *Agropyretalia intermedio-repentis* is 76.7%, *Galio-Urticetea* is 100.0%

Steppe communities are misclassified as meadow in 15.3% of cases, and meadow is misclassified as steppe in 18.5% of cases. Artificial tree plantations are misclassified as steppe in 42.9% of cases and 14.3% are misclassified as *Agropyretalia intermedio-repentis*. In its turn, *Agropyretalia intermedio-repentis* is misclassified as *Festuco-Brometea* in 6.7% of cases, as *Molinio-Arrhenatheretea* or *Onopordetalia acanthii* in 3.3% of cases, and as *Galio-Urticetea* in 10.0% of cases. The *Onopordetalia acanthii* community was misclassified as *Festuco-Brometea*, *Molinio-Arrhenatheretea* and *Galio-Urticetea* in 6.7% of cases, respectively.

Discussion

Gullies in the steppe zone represent a wide variety of plant habitats from the driest to the most humid locations. The variation in moisture conditions is redistributed under the influence of terrain, which also determines the intensity of erosion conditions, resulting in the redistribution of matter. Erosion processes affect the depth of the soil layer, which directly determines the conditions for plant life (Mohseni & Hosseinzadeh, 2022). The relief is an important factor that affects the spatial distribution of plant communities (Kövér et al., 2015). That is why quantitative indicators of relief provide information that can explain the spatial variability of vegetation cover and its sensitivity to anthropogenic impact. Our results indicate that the plant communities in the gully are a combination of natural and semi-natural communities that are in varying degrees of anthropogenic transformation. Some communities have retained their original state and are the closest to the state of naturalness (Lovynska et al., 2023). These communities are the result of long-term succession dynamics of plant communities and are to some extent in equilibrium with environmental conditions. Some communities are completely artificial. Their location and species composition of the main species that form them are determined by humans. This category includes artificial tree plantations. There are semi-natural communities that are stages of naturalization of artificial communities or the result of anthropogenic degradation of natural complexes. Artificial and semi-natural communities occupy locations to which natural predecessors were previously adapted. Therefore, the relief preferences of plant communities of different origins may coincide.

The results obtained indicate that such geomorphological predictors as relief height, topographic moisture index, erosion index, and solar radiation distributed over the relief are to some extent independent of each other, which means that they carry specific information about environmental conditions. Almost all of them depend on the slope of the relief, which means that this indicator as an integral variable depends on various features of the relief shape and does not have the differential ability to distinguish between the mechanisms of influence caused by the relief. The relief redistributes solar energy, water, and migration of substances along the surface. All these processes depend on the slope of the terrain. Therefore, to understand the mechanisms of influence on vegetation cover, it is informative to use relief derivatives, which are markers of moisture, erosion, or energy supply. In the descriptions of plant communities, we used more detailed information about variables derived from the digital elevation model instead of only information about the slope or slope exposure.

The association *Festuco valesiacae-Stipetum capillatae* Sill 1931 includes communities that are well represented within the steppe zone and occupy large areas. These communities are formed in different parts of slopes of different exposure and steepness (from 5–7° to 50–55°). The communities of this association represent the stage of restoration of sod-grass steppe after the cessation of excessive grazing. A characteristic feature of the community is a well-formed vegetation cover (total projective cover of 70% to 100%), high soddenness of 10–15% and precipitation (up to 3 cm). The floristic richness of the communities depends on the degree of cenosis recovery after removal of anthropogenic impact and ranges from 25 to 50 species per 100 m^2 (Korotchenko et al., 2009). Our data confirm the above information in terms of vegetation density and species richness. The communities of the *Salvio nemorosae-Festucetum valesiacae* Korotchenko et Didukh 1997 are also well distributed in the steppe zone and occupy large areas confined to the upper and middle parts of gentle and steep (up to 50–55°) slopes of different exposure (Fig. 4). Our results are consistent with the information that communities of this association are formed on soils with little erosion under the influence of moderate grazing (Korotchenko et al., 2009). The erosion index of the locations where the *Salvio nemorosae-Festucetum valesiacae* association was found did not differ from that of the *Festuco valesiacae-Stipetum capillatae* and was lower than that of the *Stipo lessingianae-Salvietum nutantis*. The phytoindication assessment also confirms that the communities of this association are formed in humid habitat conditions and have more xeromesophytic herbaceous species in their floristic composition (Korotchenko et al., 2009). The *Festuco valesiacae-Stipetum capillatae* Sill 1931 associations are formed mainly in the middle, sometimes upper or lower parts of steep (up to 45°) slopes, mainly in the eastern, northeastern, and rarely in the northern and southeastern exposures (Korotchenko et al., 2009), which is also confirmed by our studies. In addition, we found that among all the studied associations of the *Festuco-Brometea* class, the *Festuco valesiacae-Stipetum capillatae* association prefers the most eroded slopes. The projective grass cover depends on the strength of the anthropogenic factor. Areas that are constantly grazed have a sparse grass stand (projective covere of up to 65%) and a depleted floristic composition of coenoses. Areas that are periodically subjected to moderate grazing have a well-formed, homogeneous grass stand (projected coverage of 90–100%) and a rich floristic composition of coenoses (up to 40 species per 100 m^2). The study (Korotchenko et al., 2009), found that two species listed in the Red Data Book of Ukraine (*Astragalus dasyanthus* and *Stipa lessingiana*) occur in the communities of this association. Our results significantly expand the list of species listed in the Red Data Book of Ukraine that grow within the *Stipo lessingianae-Salvietum nutantis* association. In addition to the previously known species, we have also established the presence of *Stipa pulcherrima* and *Astragalus ponticus* in the association.

According to Shyriaieva (2022), the *Festuco valesiacae-Poetum angustifoliae* Mirkin in Denisova et al. 1986 association Mirkin in Denisova et al. 1986 covers meadow communities on elevated floodplain areas and lower parts of floodplain slopes, often under shade by trees or shrubs. This result is also confirmed by our research. The *Festuco valesiacae-Poetum angustifoliae* association occurs in the lower part of the gully slope in close proximity to shrub communities. The association is characterized by a typical combination of xeric-mesophytic and hygro-mesophytic herbs. The dominant species are mainly rhizome cereals. The cenosis is sensitive to the mode of use. Under grazing conditions, they easily turn into weedy xeromesophytic pastures. In the absence of mowing or moderate grazing, they are rapidly overgrown with woody and shrubby vegetation (Shyriaieva, 2022). The association *Poëtum angustifoliae* Shelyag-Sosonko et al. 1986 is usually found on upper or middle parts of gentle slopes of medium-high ridges and flat-upland, well-drained areas of floodplains. Outside of floodplains, they occur on the slopes of river valleys and gully and ravine systems (Dubina et al., 2019). Our research suggests that *Poëtum angustifoliae* associations occur in the lower third of the gully slope in the immediate vicinity of the thalweg, where groundwater is most likely to be at a depth of 1.2–2.0 m or more.

The class *Artemisietea vulgaris* Lohmeyer et al. in Tx. ex Von Rochow 1951 includes communities of tall herbaceous, mainly biennial and perennial ruderal species in anthropogenic and semi-natural ecotopes. As a typical synanthropic community, its coenoses are characterized by a large proportion of adventive species (Yeremenko, 2017). The union *Onopordetalia acanthii* Br.-Bl. et Tx. ex Klika et Hadač 1944 is represented by the association *Arctietum lappae* Felföldy 1942. Archaeophytes are more abundant in the coenoses. The *Onopordetalia acanthi* union includes communities formed mainly by biennials, which are common in areas with moderately moist to dry conditions. The communities are commonly found along riverbanks and roadsides (Yeremenko, 2017). The association *Arctietum lappae* was found in the immediate vicinity of the road and in the upper part of the gully in the area close to agricultural fields. All locations were at a short distance from a water body in the thalweg of the gully. In our study, as well as in the work of Yeremenko (2017), associations were found more often on degraded chernozems with varying degrees of mechanical disturbance. The communities dominated by *Asclepias syriaca* L. form the *Asclepiadetum syriacae* Láníková in Chytrý 2009 associations. They are connected with a variety of transformed sites in a wide range of conditions from the plateau areas near agricultural lands to the lower third of slopes near the thalweg. Anthropogenic disturbance is a condition for the spread of this association. Our results are in line with the data according to which *A. syriaca* forms monospecies thickets, which are usually confined to roadsides, wastelands, abandoned gardens and abandoned lawns. The total projective cover of the identified plant communities ranges from 90% to 100%. The leading role in the adaptation of *A. syriaca* to various environmental conditions is played by the high edaphic plasticity of the species, which allows it to penetrate various habitats of degraded ruderal and segetal complexes (Dvirna, 2018).

The order *Agropyretalia intermedio-repentis* T. Müller et Görs 1969 comprises communities formed mainly by cereals in secondary disturbed ecotopes confined to dry, compacted soils. Within the study area, it is represented by the *Convolvulo arvensis-Agropyrion repentis* Görs 1967. The union unites ruderal communities on transformed ordinary chernozems with crushed stone admixture. Cenophytes are quite common in the community. The community is an intermediate stage of succession of ruderal vegetation. Cenoses are quite common along roads, on wastelands, and in urban areas (Yeremenko, 2017). The association *Melico transsilvanicae-Agropyretum* Th. Mull. in Gors 1966 usually occurs on disturbed gravelly substrates within the steppe zone (Dubina et al., 2019). In the study area, the association occurs in areas significantly disturbed by soil erosion due to plowing on fallow land. They are also found in the zone of spontaneous growth of artificial tree plantations on fallow land. The usual habitat for the association is the area bordering agricultural land. According to the phytoindication assessment, the content of soluble salts in the soil solution of the locations where the *Melico transsilvanicae-Agropyretum* association was not found was the lowest among all the studied associations. It can be assumed that adaptation to existence in depleted soils allows the association to spread in disturbed and gravelly substrates. Also, the microclimatic conditions of this association are marked by the highest continentality and the lowest cryoclimate indices, which can be interpreted as a greater contrast of microclimatic regimes compared to all others. Obviously, changing conditions are formed in ecosystems with disturbed soil cover and dynamic vegetation. The association *Melico transsilvanicae-Agropyretum* is among the associations with the lowest level of naturalness and, accordingly, a very high level of hemeroby.

The phytoindication analysis conducted for the flora of Ukraine based on the gradient of soil water regime showed that *Artemisietea vulgaris* consists mainly of submesophytic communities. More demanding to the soil moisture level are the coenoses of the *Arction lappae* union, which ecologically borders on semi-natural nitrophiliccoenoses of the *Galio-Urticetea* class. The widest range of ecological amplitude along this gradient is characteristic of *Convolvulo arvensis-Agropyrion repentis* (Dubyna et al., 2023). The class *Galio-Urticetea* encompasses semi-natural communities formed by highly and moderately herbivorous species on nitrogen-enriched edge habitats: mesophytic forest edges and along linear watercourses in temperate Europe (Dubina et al., 2019). Our data indicate that the class *Galio-Urticetea* occupies an intermediate position in terms of moisture level between the orders of the class *Artemisietea vulgaris*. The class *Galio-Urticetea* is more humid than the order *Agropyretalia intermedio-repentis*, but less humid than the order *Onopordetalia acanthii*. In turn, the communities of the Galio-Urticetea class are usually located on more eroded soils, but less contrasting in terms of moisture than the communities of the *Artemisietea vulgaris* class. The class *Galio-Urticetea* is represented by the association *Myosotido spariflorae-Alliarietum petiolatae* Gutte 1973, which is commonly found in nitrified forest edges and glades (Dubina et al., 2019). Within the study area, this association occurs on the edges of artificial tree plantations. According to phytoindication estimates, the content of nitrogen compounds in the soil where the *Myosotido spariflorae-Alliarietum petiolatae* association is found is quite high.

a *b*

Fig. 4. The communities of the *Salvio nemorosae-Festucetum valesiacae* Korotchenko et Didukh 1997occupy locations confined to the upper and middle parts of gentle and steep slopes of the southern exposure where species of the genus *Astragalus* (*A. dasyanthus*, *A. glycyphyllos*, *A. onobrychis*, *A. ponticus*): *a* – in the absence of mowing or moderate grazing, the association *Festucovalesiacae-Poetum angustifoliae* Mirkin in Denisova et al. 1986 is rapidly overgrown by shrubs of *Prunus spinosa* L. (*b*)

The class *Robinietea* includes communities of spontaneous urban woody vegetation and various artificial plantations (Dubina et al., 2019). The artificial tree plantations are located in locations characterized by a high level of erosion risks (Kunakh et al., 2023). In general, their creation was aimed specifically at protecting against erosion, which can explain this feature. The level of contrast of moisture conditions for artificial tree plantations is the lowest and the same as that of *Galio-Urticetea* communities located on the edges of artificial plantations. Also, the *Robinietea* are distinguished by a low level of soil solution mineralization and carbonate content. This feature can be explained by the intensification of soil leaching under the influence of woody vegetation. The nitrogen content in artificial tree plantations was the highest among all the studied associations. The *Robinia* trees benefit from nitrogen fixation associated with symbiotic rhizobia in root nodules. The estimated rates of symbiotic nitrogen fixation range from 23 to 300 kg/ha year. Nitrogen is made available to other plants mainly through the rapid decomposition of nitrogen-rich leaves (Cierjacks et al., 2013). In the study area, the *Robinietea* is represented by two associations: *Chelidonio-Robinietum* and *Chelidonio-Aceretum negundi*. The *Chelidonio-Robinietum* association is genetically related to the broadleaf forests, on the site of which they were probably formed. They differ from other communities of the *Robinietea* class by the greater participation of non-moral species (*Geum urbanum*, *Glechoma hederacea*, *Acer platanoides*) (Davydov, 2020). In the study area, the associations are found in the upper and middle thirds of the gully slopes, so their genetic connection with gully forests cannot be ruled out. This hypothesis is supported by the fact that the diagnostic species of the association include species that are typical inhabitants of gully forests, such as *Quercus robur*, *Sambucus nigra*, and *Pyrus communis*. The *Chelidonio-Aceretum negundi* associations tend to be found in the lower thirds of the gully and its thalweg.

The class *Phragmito-Magnocaricetea* Klika in Klika et Novák 1941 includes communities of wet, marshy and boggy meadows, bogs on soddy, glazed, silty and meadow-boggy soils, as well as air-water communities on silty-sandy, muddy and silty-peaty bottom sediments. They are characteristic of periodically flooded ecotopes in river floodplains, along the shores of lakes, ponds, reclamation canals, and areas of groundwater upwelling. They are resistant to water level fluctuations during the growing season (Dubina et al., 2019). In the study area, they are found in the thalweg of gullies. The association *Typhetum latifoliae* is usually found in coastal shallow eutrophic freshwater closed or low-flowing water bodies with muddy, muddy-peaty bottom sediments, weak surface and significant water level fluctuations during the growing season, 20–60 (80) cm thick, neutral or slightly acidic reaction of the environment. The study area is located in the upper part of a gully in an artificial reservoir formed by a dam in a thalweg. According to the topographic moisture index, this association is in the most moisture-supplied conditions. This is probably why the level of contrast of conditions among all associations of the *Phragmito-Magnocaricetea* class was the lowest. The carbonate content in the soils where *Typhetum latifoliae* was found was the highest among all *Phragmito-Magnocaricetea* associations.

The communities of the *Phragmitetum australis* Savič 1926 association are located in the lower part of the gully. These communities occupy the lowest elevations in the relief, but among all the associations of the *Phragmito-Magnocaricetea* class, the topographic moisture index values were the lowest. In turn, their nitrogen content and aeration level were the highest. The association *Typhetum angustifoliae* Pignatti 1953 is located in the area above the road, which crosses the gully and thus creates a dam, which causes localized water accumulation. This area is characterized by the lowest erosion risks. This results in stagnation of water and accumulation of salts in the soil, as indicated by the increased soluble salt content in the soil solution. The *Butomo-Alismatetum plantaginis-aquaticae* Slavnic 1948 association is located in the upper part of the gully, where a pond is probably also of anthropogenic origin. This association is the most hygrophilous, and, naturally, with the lowest level of aeration, among all the communities in the gully. The *Butomo-Alismatetum plantaginis-aquaticae* association is also characterized by the highest level of hemeroby.

Conclusion

Gullies are a focus of biodiversity in the steppe zone of Ukraine, due to the high diversity of landforms in this type of landscape. Relief heterogeneity provides both changing ecological regimes that are favorable for plant species with different ecological characteristics and shielding of plant communities from anthropogenic impact. Relief redistributes water flows and affects soil moisture regimes. Relief affects the risk of erosion processes, which determines the thickness of the soil cover and the contrast of environmental regimes. The function of relief as a factor in the redistribution of solar energy is important, as it affects the amount of energy available for photosynthesis, the rate of evaporation of water from the soil surface, the dynamics of freezing and thawing of groundwater, which also affects the development of erosion phenomena. The derivatives of the digital elevation model, namely the topographic moisture index, erosion index, and the amount of solar radiation distributed by the terrain, are important predictors that help explain the spatial variability of vegetation cover within the steppe gully. The anthropogenic impact within the gully is the result of agricultural activities, creation of artificial tree plantations, transportation impacts, recreation, grazing and haying. The topography determines the accessibility of various forms of anthropogenic impact or shields some areas from it. The amount of solar radiation is the most important predictor that explains the spatial variability of *Festuco-Brometea* steppe vegetation communities. The topographic index of humidity allows us to clearly explain the spatial distribution of wetland communities of *Phragmito-Magnocaricetea*. Semi-natural and artificial communities *Onopordetalia acanthii*, *Robinietea*, *Agropyretalia intermedio-repentis* and *Galio-Urticetea* compete for the spatial niche of *Molinio-Arrhenatheretea* meadow communities, which indicates a significant anthropogenic impact on meadow ecosystems. Artificial woody plantations of *Robinietea* are ecologically heterogeneous and their geomorphological determination is low. Whereas semi-natural communities of *Galio-Urticetea* and *Onopordetalia acanthii* are strongly determined by geomorphological factors.

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