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ECOLOGICAL FEATURES OF FORMATION OF LANDFILL VEGETATION IN LVIV REGION (UKRAINE)

Purpose. Determination of the ecological features of the process of formation of vegetation cover on landfills in Lviv region by analysing the floristic composition of ecotopes of different stages of restoration succession.

Methodology. Phytoindication of ecological parameters based on ecological data of landfill vegetation; Data Mining methods; multidimensional coordination of plants based on Principle Component Analysis; statistical processing of ecotope data.

Findings. The phytoindicative assessment of habitat conditions of 5 ecological and coenotic groups and 16 subgroups of plant species from different ecotopes of landfills in Lviv region was carried out by six parameters: L – illumination, T – thermal regime, K – continentality, F – moisture regime, R – acidity, N – nitrogen content, points. The main regularity of ecotope formation at landfills in Lviv Region is the following structure of relationships between environmental parameters: with an increase in soil humidity, nitrogen content and soil pH, the indicators of illumination, temperature and continental climate decrease. The ecological equivalent of the increase in anthropogenic load in the conditions of landfill ecotopes is the increase in illumination, thermal regime, climate continentality, and nitrogen content. The ecological and coenotic space of the vegetation cover of landfills in Lviv region can be represented as a quadrangle, in the centre of which there are ruderal communities of the Chenopodietea class, communities of nitrified meadows on the banks of water bodies of the Agrostietea stoloniferae class and meadow communities of the Molinio-Arrhenatheretea class, and in the corners 1) communities of aquatic class Lemnetea, marsh class Phragmitetea and ruderal vegetation on waterlogged substrates of class Bidentetea; 2) communities of non-moral forest vegetation of class Quereo-Fagetea; 3) steppe communities of class Festuco-Brometea; 4) ruderal vegetation of class Artemisietea.

Originality. The ecological and coenotic space of landfills in Lviv region was assessed on the basis of the arrangement of vascular plants along the axes of complex ecological gradients. The results show that ruderal and meadow species occupying the central part of the territory are the most resistant to landfill conditions. The most vulnerable are steppe and hydrophilic vegetation located on the periphery of the general vegetation space of the landfill.

Practical value. Knowing the ecological parameters of flora species, it is possible to determine their position in the ecological and coenotic space of the landfill vegetation cover and predict their stability and dynamics.

Keywords: *landfill, ecotope, ecological and coenotic groups, multidimensional vegetation ordination*

Introduction. Despite the population decline, there is a tendency towards a steady increase in the volume of municipal solid waste (MSW) collection and disposal in Ukraine. According to the Ministry of Regional Development of Ukraine, in 2015, about 48 million m^3 or about 10 million tonnes of solid waste were generated [1].

The predominant method of waste management is its disposal in specially designated places. In particular, household waste is disposed of at 6,000 landfills and dumpsites with a total area of over 9,000 hectares. The imperfect system of solid waste management in settlements, especially in the domestic sector, leads to the formation of about 28,000 unauthorised landfills covering an area of more than 1,000 hectares annually. Out of 593 landfills that require reclamation, only 37 have actually been reclaimed [1].

The operation of landfills is accompanied by the release of toxic substances into the environment – heavy metals, decomposition and combustion products. In this regard, phytomelioration methods for the restoration of contaminated areas are becoming increasingly important. Studies of plant communities at landfills will allow for the introduction and formation of optimal protective plantations in the future [2, 3].

Literature review. A significant number of scientific papers have been devoted to exploring the negative impact of landfills and dumpsites on the environment [4, 5].

Unsolved aspects of the problem. However, a small share of research is devoted to vegetation cover on the territories taken up by waste, the area of which is constantly growing [6, 7]. This issue requires additional attention and research, especially for the effective implementation of phytomelioration measures [8, 9]. After all, phytomelioration is a promising and safe way to decommission landfills.

Purpose. The study area covers the lowlands and foothills of Lviv region (western Ukraine), which is characterised by a temperate continental climate. The average temperature in January is –3––5, in July – +17–18 °C. The average rainfall is 750–1,000 mm. The most widespread sod-podzolic and grey forest and grey podzolic soils are characterised by a low level of natural fertility.

The ecological structure and level of synanthropisation of the vegetation cover of solid waste landfills were analysed based on the literature and our own field studies conducted in

2006–2020 [10, 11]. The objects of research are the Lviv solid waste landfill (currently undergoing reclamation) and 24 landfills in Lviv region. The object of the study is the general patterns of landfill vegetation formation under the negative impact of environmental pollution by solid household waste.

Research methodology description. The ecological patterns of landfill vegetation formation in Lviv Region were studied using data mining methods [12, 13]. First, the data were analysed to identify patterns between variables (tacit knowledge) that can be applied to new data sets and to predict processes and phenomena (data mining) [12, 13]. The study was conducted in three stages: studying the structure of the relative location of species in a multidimensional space, signs of environmental parameters, mathematical modelling of the structure and verification of the mathematical model.

The main geobotanical information is information on the environmental parameters of 135 species of vascular plants representing various ecotopes of landfills, based on six parameters: *L* – illumination; *T* – thermal regime; *K* – continentality; *F* – humidity regime; *R* – acidity; *N* – nitrogen content, points [14, 15].

Establishing systematic relationships between the environmental parameters of vascular plants enabled the implementation of mathematical modelling [13, 14]. In the multidimensional feature space, each species is represented as a point with coordinates representing the values of environmental regime parameters. Based on the distances between the points, it is possible to determine the similarity of species by a set of environmental parameters. Then, the axes of maximum variation were identified, their number was determined, and the contribution of each environmental parameter to the variation was assessed using principal component analysis [12, 13]. The mathematical model was verified on the basis of a comparative assessment of the position of species on the axes of maximum variation (multidimensional ordination) with the results of geobotanical studies and data from the literature [4, 6].

The degree of anthropogenic impact on the formation of landfill vegetation cover was characterised based on indicators of hemerobia, urbanity, and ruderality [16, 17]. Hemerobia is the ability of a species to exist and spread in anthropogenically altered habitats [18, 19]. Urbanity characterises the sensitivity of species to urbanisation processes and their tendency to occur in cities. Ruderality reflects the intensity of the life strategy of exporters – true ruderal plants adapted to life in conditions of disturbance, species of early stages of succession [16].

Results. Landfill ecotopes are characterised by heating of the substrate, waste combustion, and the harmful effects of gases released during intensive waste decomposition. Leachate is formed as a result of atmospheric precipitation seeping through the waste and accumulating at the foot of the landfills. Due to the systematic layering of waste and the inflow of new portions of waste, vegetation is constantly being destroyed. In this regard, the vegetation cover of landfills is characterised by great heterogeneity and mosaicism. The formation of vegetation cover is greatly influenced by agricultural land and forest plantations located next to landfills.

Depending on the duration of the vegetation formation, there are three stages of regeneration succession: pioneer, intermediate and renatural. The pioneer stage is represented by *Chenopodium album L., Convolvulus arvensis L., Tussilago farfara L., Matricaria perforata Merat, Stenactis annua Nees. Calamagrostis epigeios (L.) Roth, Dactylis glomerata L., Artemisia vulgaris L., Elytrigia repens (L.) Nevski, Sambucus nigra L.* form the basis of the communities at the renatural stage [1].

Ecological and phytocoenological analysis is a method for understanding the patterns of formation, functioning and prediction of vegetation dynamics. The main characteristic of this analysis is the classification of plant species according to their affiliation with a particular classification unit of plant communities [14, 15]. Based on our own research and analysis of the literature [6, 9], we identified 5 ecological and cenotic groups (groups of vegetation classes) and 16 subgroups (vegetation classes) of plant species in the vegetation cover of landfills in Lviv region (Table 1). The largest number of species is typical for synanthropic (3.3. Chenopodietea, 3.5. Artemisietea), meadow (5.4. Molinio-Arrhenatheretea) and nemorose forest (8.4. Quereo-Fagetea) vegetation.

Analysis of the ecological and coenotic composition of the vegetation communities of landfills in Lviv region was aimed at determining the location of ecological and coenotic groups of species on the gradients of environmental factors. The ecological behaviour of species with respect to the six main factors was determined on a nine-point scale, where 1 means the lowest and 9 – the highest degree of influence of this factor. Only the soil humidity parameter has 12 gradations [13].

The ecological scale of illumination reflects the relative value of this ecological factor in a particular habitat compared to open space. Almost all vascular plants, including shade-loving ones, develop better in full or partial daylight, providing that the air humidity remains sufficient. The structure of landfill vegetation is dominated by light-loving species (ecological parameter L = 7–8 points), which account for 60.0 % of the total number of plants. Actually, light-loving plants (ecological parameter of illumination L = 8–9 points), which are able to tolerate strong lighting for a long time, are most typical of the ecological and phytocoenotic subgroup 3.5. Artemisietea. These are, in particular, species of *Arctium lappa, Oenothera biennis L., Carduus acanthoides, Artemisia absinthium L., Cirsium vulgare*. Shade-tolerant species are more common on the slopes of the northern exposure and at the foot of slopes where the suspension of substrate mixing has favoured the spread of woody plants. Shade-tolerant species are most characteristic of the ecological and phytocoenotic subgroup of broadleaved forests of class 8.4. Quereo-Fagetea. The average value of the illumination regime parameter of the landfill habitats is $L = 6.98 \pm 0.12$ points, which is typical for light-loving species (Table 2).

The ecological temperature scale T reflects the gradation of species in relation to the heat factor – from the nival and alpine mountain belt to the warm plains [14]. The structure of the landfill vegetation cover is dominated by species with values of the ecological parameter T = 6 points, which account for 43.7 % of their total number. These are, in particular, *Anthemis tinctoria L., Arctium lappa, Artemisia absinthium, A. vulgaris, Bidens cernua, B. tripartita, Chelidonium majus, Daucus carota, Elytrigia repens, Galium aparine L., Hippophae rhamnoides L., Lycopus europaeus, Polygonum hydropiper* and others. Heat-loving species are represented exclusively by ruderal plants of ecological and phytocoenotic group 3. Disturbed and secondary vegetation, mainly of class 3.5. Artemisietea: *Impatiens glandulifera Royle, Oenothera biennis, Chenopodium urbicum L., Helianthus tuberosus L.* The average value of the thermal regime parameter of the landfill habitats is $T = 5.84 \pm 0.06$ points, which is typical for foothills and foothill plains. At the level of ecological and coenotic groups of plants, the thermal regime of landfills in Lviv region is characterised by a relatively narrow range of parameter values (T = 5.50–6.25 points). The difference between the ecological and phytocoenotic groups by the thermal regime parameter is not significant (Table 2).

The influence of large areas of land on atmospheric processes is determined by the continental climate [14]. It depends on a number of factors, including the annual amplitude of air and the lack of relative humidity. The phytocoenotic structure of landfills is dominated by species with values of the ecological parameter K = 3–5 points (54.7 % of the total) and indifferent species with a wide range of tolerance (29.6 %). The average value of the continentality parameter of landfill habitats is $K = 4.33 \pm 0.12$, which is typical for sub-oceanic and intermediate, from slightly oceanic to slightly subcontinental climate. The difference between the ecological and phytocoenotic groups by the climate continentality parameter is not significant (Table 2). Thus, for the ecological-phytocoenotic

Table 1

The system of ecological and cenotic groups of vegetation cover species of landfills in Lviv region

Ecological and cenotic group (group of vegetation classes, vegetation class)	Typical flora representatives
1. Water, swamp and moor vegetation	
1.1. Lemnetea. Community of unrooted plants floating freely on the surface or in the water column	*Hydrocharis morsus-ranae* L., *Lemna minor* L. – 2 species
1.5. Phragmitetea. Wet, marshy and boggy meadows and coastal and aquatic communities	*Carex acuta* L., *Lycopus europaeus* L., *Phalaroides arundinacea* (L.) Rausch., *Phragmites australis* (Cav.) Trin. ex Steud., *Schoenoplectus lacustris* (L.) Palla, *Typha latifolia* L. – 7 species
3. Disturbed and secondary vegetation	
3.2. Bidentetea. Pioneer ruderal communities on waterlogged, partially nitrified substrates near water bodies, farms and along watercourses	*Bidens cernua* L., *Bidens tripartita* L., *Polygonum hydropiper* L. – 4 species
3.3. Chenopodietea. Community dominated by ruderal annual plants of restorative sustainable succession on disturbed ecotopes	*Chenopodium album*, *Diplotaxis muralis* (L.) DC., *Galinsoga ciliata* (Rafin.) Blake, *Polygonum persicaria* L., *Setaria viridis* (L.) Beauv., *Setaria glauca* (L.) Beauv., *Sonchus oleraceus* L. – 12 species
3.4. Secalietea. Agrophytocoenoses of cereals and row crops	*Papaver rhoeas* L. – 1 species
3.5. Artemisietea. Ruderal communities of tall biennial and perennial species	*Arctium lappa* L., *Artemisia vulgaris*, *Carduus acanthoides* L., *Chelidonium majus* L., *Cirsium vulgare* (Savi) Ten., *Daucus carota* L., *Epilobium hirsutum* L., *Stenactis annua*, *Leonurus cardiaca* L., *Solidago canadensis* L., *Tanacetum vulgare* L., *Urtica dioica* L. – 25 species
3.6. Agropyretea. Ruderal and semi-ruderal hemicryptophyte communities on dry anthropogenic or natural ecotopes with compacted soils	*Elytrigia repens*, *Convolvulus arvensis* – 3 species
3.7. Plantaginetea. Community of low-growing synanthropic species resistant to trampling and grazing on compacted substrates, partially nitrified, mostly open habitats	*Plantago major* L. – 1 species
3.8. Agrostietea stoloniferae. Nitrified meadow communities on the banks of water bodies	*Althaea officinalis* L., *Potentilla anserina* L., *Rumex conglomeratus* Murr., *Trifolium hybridum* L. – 4 species
Ecological and cenotic group (group of vegetation classes, vegetation class)	Typical flora representatives
5. Anthropo-zoogenous heath, grasslands and pastures	
5.3. Festuco-Brometea. Steppe communities	*Carlina vulgaris* L., *Euphorbia cyparissias* L., *Galium verum* L., *Stachys recta* L., *Koeleria cristata* (L.) Pers. – 5 species
5.4. Molinio-Arrhenatheretea. Meadow communities (excluding wet meadows)	*Achillea submillefolium* Klok. et Krytzka, *Alopecurus pratensis* L, *Leucanthemum vulgare* Lam., *Lolium perenne* L., *Phleum pratense* L., *Poa pratensis* L., *Trifolium pratense* L. – 12 species
Ecological and cenotic group (group of vegetation classes, vegetation class)	Typical flora representatives
6. Forest edge heath and forb vegetation	
6.1. Trifolio-Geranietea. Broadleaf forest, mixed forest and shrubland communities	*Lathyrus sylvestris* L. – 1 species
6.2. Epilobietea angustifolii. Groupings of felling and forest fires	*Chamaerion angustifolium* (L.) Holub, *Salix caprea* L. – 3 species
8. Broadleaved forests and woodlands	
8.1. Salicetea purpureae. Tree and shrub communities in river floodplains	*Populus nigra* L., *Salix purpurea* L. – 2 species
8.2. Alnetea glutinosae. Community of eutrophic forest and shrub bogs	*Alnus glutinosa* (L.) Gaertn., *Frangula alnus* Mill. – 2 species
8.4. Quereo-Fagetea. Broadleaf forest communities on nutrient-rich soils	*Acer platanoides* L., *Alnus incana* (L.) Moench, *Aquilegia vulgaris* L., *Carex pilosa* Scop., *Equisetum telmateia* Ehrh., *Fraxinus excelsior* L., *Impatiens parviflora* DC., *Malus sylvestris* (L.) Mill. – 16 species

subgroup 3.5. Artemisietea, the K parameter varies from 2 to 7 points, for the characteristic species of broadleaf forests of class 8.4. Quereo-Fagetea parameter K has the same amplitude of values.

The soil humidity scale F describes the distribution of species on the gradient of soil humidity or groundwater level from dry rocks to marshes and water bodies [14]. The humidity of the soil substrate of landfills largely depends on the relief conditions and slope exposure. The high water permeability of the substrate with a high content of construction residues plays an important role. Areas with waterlogged soils are formed at the foot of slopes. The structure of the landfill vegetation cover is dominated by species with ecological parameter values of $F = 4–6$ points, which account for 54.1 % of the total, and indifferent species with a wide range of tolerance (20.0 %). Maximum values of $F = 10–11$ points are typical for species of ecological and phytocoenotic subgroups 1.1. Lemnetea and 1.5. Phragmitetea. The minimum values of soil moisture are typical for steppe species of class 5.3. Festuco-Brometea (*Stachys recta, Euphorbia cyparissias, Koeleria cristata, Carlina vulgaris*) and ruderal plants of class 3.3. Chenopodietea (*Diplotaxis muralis, Chenopodium album, Sonchus oleraceus, Setaria glauca*

Table 2

Environmental parameters of mine waste heaps habitats

Ecological and cenotic group (group of vegetation classes, vegetation class)	Average values of environmental parameters of habitats, points								
	L	*T*	*K*	*F*	*R*	*N*	*Hem*	*Urb*	*Rud*
1. Water, swamp and moor vegetation	7.44	5.56	4.53	9.78	6.88	6.11	3.13	1.83	0.00
1.1. Lemnetea	7.00	5.50	3.50	11.00	6.94	6.00	–	1.50	–
1.5. Phragmitetea	7.57	5.57	4.82	9.43	6.86	6.14	3.13	2.00	0.00
3. Disturbed and secondary vegetation	7.31	6.02	4.42	5.43	6.94	6.96	4.25	2.87	3.24
3.2. Bidentetea	7.25	6.00	4.44	8.50	6.44	8.25	4.00	2.00	5.00
3.3. Chenopodietea	6.91	6.07	3.74	4.61	6.56	6.61	5.23	2.82	5.76
3.4. Secalietea	6.00	6.00	3.00	5.00	7.00	6.00	5.00	2.00	5.00
3.5. Artemisietea	7.52	5.95	4.57	5.38	7.16	7.40	3.92	3.20	2.33
3.6. Agropyretea	7.33	6.00	5.46	4.23	6.63	5.76	4.00	2.67	1.67
3.7. Plantaginetea	8.00	5.82	4.39	5.00	6.88	6.00	3.00	3.00	3.33
3.8. Agrostietea stoloniferae	7.00	6.25	4.60	6.50	7.19	6.00	3.50	1.75	0.83
5. Anthropo-zoogenous heath, grasslands and pastures	7.10	5.68	4.28	4.67	6.85	4.81	3.24	2.26	1.58
5.3. Festuco-Brometea	7.20	5.76	4.48	3.40	7.58	2.60	2.75	1.75	3.33
5.4. Molinio-Arrhenatheretea	7.08	5.62	4.01	5.22	6.52	5.91	3.42	2.42	0.83
6. Forest edge heath and forb vegetation	7.60	5.86	4.00	4.80	6.40	6.40	3.80	2.20	0.00
6.1. Trifolio-Geranietea	7.00	6.00	4.00	4.00	8.00	2.00	3.50	2.00	0.00
6.2. Epilobietea angustifolii	7.75	5.82	4.00	5.00	6.00	7.50	3.88	2.25	0.00
8. Broadleaved forests and woodlands	5.81	5.71	4.29	5.96	6.98	5.87	3.12	2.19	0.24
8.1. Salicetea purpureae	6.50	5.50	5.00	6.84	7.50	6.65	3.00	1.00	0.00
8.2. Alnetea glutinosae	5.50	5.50	4.00	8.50	5.00	6.29	2.50	2.00	0.00
8.4. Quereo-Fagetea	5.69	5.74	4.31	5.40	7.22	5.59	3.22	2.31	0.31
Mean	6.98	5.84	4.33	5.75	6.90	6.30	3.74	2.50	1.99
Std. Dev.	1.17	0.59	1.18	1.89	0.83	1.74	0.83	0.85	2.54

and others). The average value of soil moisture availability in landfill habitats is $F = 5.75 \pm 0.18$ points, which is typical for fresh and damp soils.

The soil acidity scale *R* describes the dependence of species distribution on the gradient from extremely acidic to alkaline (rich in carbonates or calcium) soils [14]. The availability of nutrients to plants depends on the acidity of the soil. In very acidic soils, iron and aluminum are converted into forms that are easily taken up by plants, and an increase in their concentration can have a toxic effect. The structure of the landfill vegetation cover is dominated by species with an ecological parameter $R = 7–8$ (slightly acidic and slightly alkaline soils), which account for 42.2 % of the total, as well as indifferent species with a wide range of tolerance (43.0 %). The average value of the soil acidity parameter of landfill habitats is $R = 6.65 \pm 0.12$ points, which is typical for neutral soils (from slightly acidic to slightly alkaline). Acidic and moderately acidic soils ($R = 4–5$ points) are characterised by *Calamagrostis arundinacea (L.) Roth, Frangula alnus, Chamaerion angustifolium, Galinsoga parviflora Cav., Leontodon autumnalis L., Polygonum hydropiper.* Weakly alkaline and alkaline soils ($R = 8–9$ points) are most often represented by steppe species of ecological and cenotic subgroup 5.3. Festuco-Brometea (*Stachys recta, Koeleria cristata*) and ruderal plants of subgroups 3.3. Chenopodietea (*Diplotaxis muralis, Sonchus oleraceus*) and 3.5. Artemisietea (*Carduus acanthoides, Arctium tomentosum Mill., Leonurus cardiaca, Epilobium hirsutum*).

The soil N availability scale reflects the gradation of mineral nitrogen (NH_4^+ and NO_3^-) [14]. Landfill ecotopes in Lviv region have a significant difference in soil nitrogen content (Table 2), ranging from very nitrogen-poor soils ($N = 2–3$ points) in steppe vegetation ecotopes of class 5.3. Festuco-Brometea (indicators *Koeleria cristata, Stachys recta, Carlina vulgaris, Euphorbia cyparissias*) to nitrogen-rich soils ($N = 8–9$ points) in the ecotopes of ruderal vegetation of class 3.5. Artemisietea (indicators *Arctium tomentosum, Arctium lappa, Urtica dioica, Carduus crispus L., Armoracia rusticana Gaertn. et Scherb., Leonurus cardiaca*). The structure of the landfill vegetation cover is dominated by species with values of the ecological parameter $N = 7–8$ points, which account for 42.2 % of their total number, as well as indifferent species with a wide range of tolerance (22.2 %). The average value of the nitrogen content parameter of landfill habitats is $N = 6.30 \pm 0.17$ points, which is typical for the range from moderately nitrogen-rich to nitrogen-rich soils.

Hemerobia or hemerobicity is a term that reflects the degree of tolerance of species to anthropogenic factors [16]. Hemerobia is assessed quantitatively by the intensity and duration of anthropogenic impacts that a species can withstand. According to the classification by D. Yalas and G. Sukopp [15, 20], there are:

- agemerobes (a) – almost no anthropogenic impact – 1 point;
- oligohermerobes (o) – weak anthropogenic impact – 2 points;
- mesohemerobes (m) – moderate impact – 3 points;
- eugemerobes – species resistant to anthropogenic impact, prefer anthropogenically modified habitats:
- β-eugemerobes (b) – moderately strong impact – 4 points;
- α-eugerms (c) – strong influence – 5 points;
- polyhemerobes (p) – very strong influence – 6 points;
- metaheterobes (t) – extremely strong impact – 7 points.

Indicators of a low degree of hemerobia are species of ecological and cenotic group 8. Broadleaved forests and woodlands (*Carex pilosa, Frangula alnus, Malus sylvestris, Swida sanguinea (L.) Opiz*), steppe vegetation of subgroup 5.3. Festuco-Brometea (*Stachys recta, Galium verum, Carlina vulgaris, Euphorbia cyparissias*) and subgroup 1.5. Phragmitetea (*Lycopus europaeus, Phragmites australis, Typha latifolia*). A high degree of hemerobia is indicated by the presence of ruderal species of ecological and coenotic subgroups 3.3. Chenopodietea (*Diplotaxis muralis, Galinsoga ciliata, Setaria viridis, Sonchus oleraceus*) and 3.5. Artemisietea (*Chenopodium urbicum, Oenothera biennis, Melilotus officinalis (L.) Pall., Cirsium vulgare)*. The structure of the floristic composition of landfills is dominated by species with hemerobia index values *Hem* = = 2–4 points, which account for 38.5 % of their total number. The average value of the hemerobia index of landfill vegetation species is *Hem* = *N* = 3.78 ± 0.08 points, which is typical for β-eugemerobes.

The Urbanity parameter characterises the distribution of vascular plants in relation to urbanised areas based on a five-point scale. Urban-phobic plants (*Urb* = 1 point) are found only outside of settlements, and urban-philic plants (*Urb* = = 5 points) are found exclusively within them. For the vegetation cover of landfills, low values of Urbanity are characterised by species belonging to different ecological and phytocoenotic groups – from aquatic to forest: *Hydrocharis morsus-ranae, Althaea officinalis, Stachys recta, Carum carvi L., Rumex conglomeratus, Carex pilosa, Calamagrostis arundinacea (L.)*. Urban plants most often belong to the ecological and phytocoenotic subgroup 3.5. Artemisietea: *Chenopodium urbicum, Tanacetum vulgare, Leonurus cardiaca, Conium maculatum L., Chelidonium majus, Artemisia vulgaris*. The average value of the Urbanity index of landfill vegetation species is *Urb* = 2.50 ± 0.09 points, which is typical for the category of urban-neutral species.

Ruderal plants play an important role in the formation of landfill vegetation cover, as they are not particularly resistant to stressful conditions and are not competitive, but can quickly take over the territory between stronger plants. This type of life strategy is characterised by the Ruderality index. The highest values of Ruderality are characterised by species of ecological and coenotic subgroup 3.3. Chenopodietea (*Thlaspi arvense L., Setaria glauca, Polygonum persicaria, Sonchus arvensis, Galinsoga parviflora, Galinsoga ciliata, Setaria viridis*). Due to the long period of operation of the landfills, the structure of the vegetation cover is dominated by species of competitive life strategy (C-strategists), for which the Ruderality index is zero. Their share is 46.7 % of the total. These are mostly species belonging to subgroups 1.5. Phragmitetea (*Lycopus europaeus, Typha latifolia, Phragmites australis*), 6.2. Epilobietea angustifolii (*Salix caprea, Chamaerion angustifolium, Verbascum thapsus L.*), 8.4. Quereo-Fagetea (*Carex pilosa, Equisetum telmateia, Swida sanguinea, Fraxinus excelsior*). The average value of the Ruderality index of landfill vegetation species is *Rud* = 1.99 ± 0.26 points. Based on the analysis of variance, it can be concluded that the differential ability of the Ruderality index at the level of ecological and phytocoenotic subgroups (Fisher's criterion $F = 6.93$) is less than the hemerobia index ($F = 12.19$), but greater than the Urbanity parameter (Fisher's criterion $F = 3.87$).

The assessment of the dependence between the environmental parameters of vascular plants of landfill sites (Table 3) indicates that there is no significant relationship between the variables. The correlation coefficients are low, but for the parameter soil moisture *F* – nitrogen N content, this indicator exceeds 0.3. In most cases, the relationship between the variables is curvilinear (Fig. 1). If we analyse the significant deviations of the points from the regression curve, we can see that there is no ordered structure in the location of species in the multidimensional space of environmental parameters. In this regard, two-dimensional scatter plots do not reveal a clear pattern that can be used to explain the distribution of vascular plants at landfills in Lviv Region.

Our next research is aimed at mathematical modelling of the structure of species arrangement in the hyperspace of features. Given that it is impossible to visually recognise the structure in a multidimensional space, we applied multidimensional ordination methods [12, 13]. Considering that the ecological parameters of vascular plants in landfills are partially interrelated, the observed data can be explained by a small number of new variables that can be obtained using a linear combination of the original data but not directly measured [12, 13]. Thus, the dimensionality of the observation field can be reduced. Graphically, the calculation procedure moves the origin to the data centre, rotates the axes, and compresses the horizontal axis to work in the direction of maximum variance of the dataset (Fig. 2).

Based on the correlation matrix, the results of the principal components analysis are as follows

$$Factor_1 = -0.27 \cdot L - 0.27 \cdot T - 0.31 \cdot K + 0.57 \cdot F - 0.38 \cdot R + 0.54 \cdot N, \quad \lambda_1 = 1.56;$$

$$Factor_2 = -0.56 \cdot L + 0.45 \cdot T - 0.43 \cdot K - 0.24 \cdot F - 0.38 \cdot R - 0.32 \cdot N, \quad \lambda_2 = 1.06;$$

Table 3

Relationship between environmental parameters of vascular plants of landfill sites and complex environmental gradients

	L	*T*	*K*	*F*	*R*	*N*	*Hem*	*Urb*	*Rud*
L	1.00	0.03	0.09	–0.13	0.10	0.00	0.14	0.15	0.05
T	0.03	1.00	0.03	–0.14	0.01	–0.08	0.31	0.24	0.25
K	0.09	0.03	1.00	–0.09	0.11	–0.09	0.04	0.08	–0.09
F	–0.13	–0.14	–0.09	1.00	–0.11	0.33	–0.25	–0.22	–0.20
R	0.10	0.01	0.11	–0.11	1.00	–0.16	–0.01	0.08	–0.09
N	0.00	–0.08	–0.09	0.33	–0.16	1.00	0.18	0.23	–0.04
Hem	0.14	0.31	0.04	–0.25	–0.01	0.18	1.00	0.54	0.58
Urb	0.15	0.24	0.08	–0.22	0.08	0.23	0.54	1.00	0.27
Ruder	0.05	0.25	–0.09	–0.20	–0.09	–0.04	0.58	0.27	1.00
Factor1	–0.33	–0.33	–0.39	0.71	–0.48	0.67	–0.13	–0.13	–0.11
Factor2	–0.57	0.46	–0.44	–0.25	–0.39	–0.33	0.04	–0.06	0.20
Factor3	–0.55	–0.64	–0.01	0.04	0.36	–0.38	–0.37	–0.31	–0.22
Factor4	0.43	–0.27	–0.77	–0.20	0.11	–0.07	–0.03	–0.03	0.05

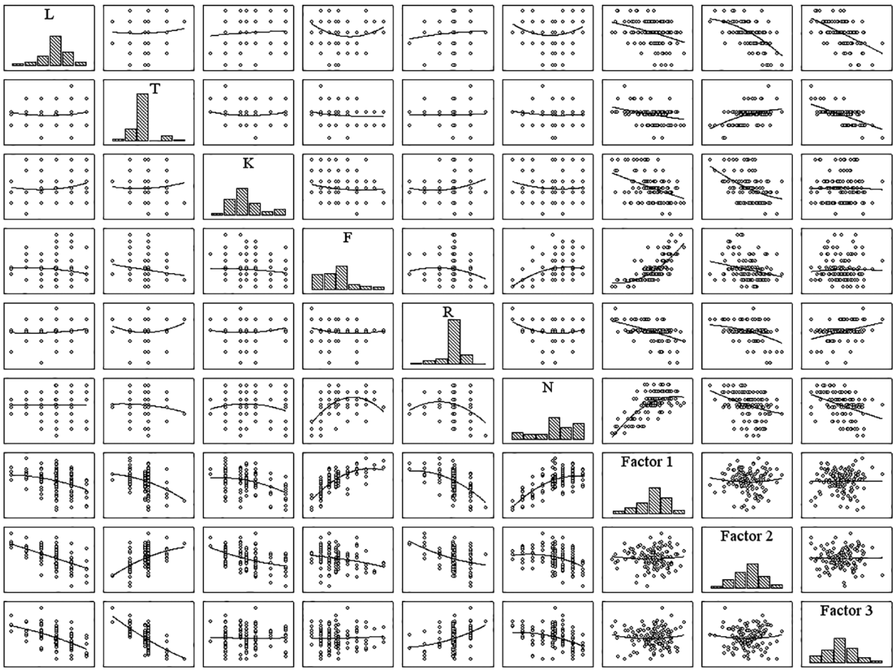

Fig. 1. Ecological and coenotic space of the vegetation cover of landfills in Lviv region:

L – illumination; T – thermal regime; K – continentality; F– moisture regime; R – acidity; N – nitrogen content, points; Factor1–3 –complex environmental gradients

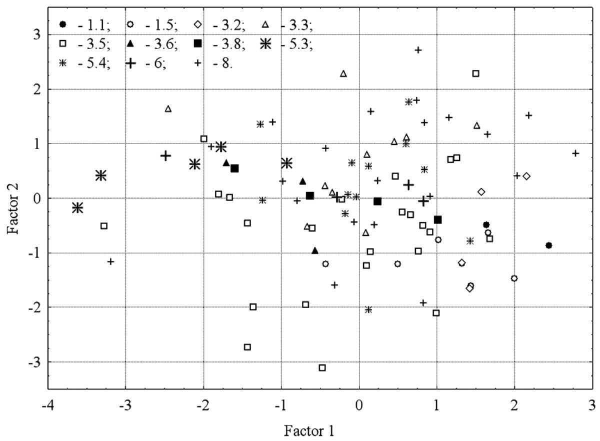

Fig. 2. The ecological and coenotic space of the vegetation cover of landfills in Lviv region:

1. Water, swamp and moor vegetation: 1.1. Lemnetea, 1.5. Phragmitetea; 3. Disturbed and secondary vegetation: 3.2. Bidentetea, 3.3. Chenopodietea, 3.5. Artemisietea, 3.6. Agropyretea, 3.8. Agrostietea stoloniferae; 5. Anthropo-zoogenous heath, grasslands and pastures: 5.3. Festuco-Brometea, 5.4. Molinio-Arrhenatheretea; 6. Forest edge heath and forb vegetation; 8. Broadleaved forests and woodlands; Factor1–2 – complex environmental gradients

$$Factor_3 = -0.55 \cdot L - 0.64 \cdot T - 0.01 \cdot K + 0.04 \cdot F + 0.36 \cdot R - 0.38 \cdot N, \quad \lambda_3 = 0.98;$$

$$Factor_4 = 0.45 \cdot L - 0.28 \cdot T - 0.81 \cdot K - 0.21 \cdot F + 0.12 \cdot R - 0.08 \cdot N, \quad \lambda_4 = 0.91,$$

where $Factor_i$ is component coordinates, complex environmental gradients; *L, T, K, F, R, N* – standardised values of ecological parameters of herbaceous species (illumination, thermal regime, continental climate, soil moisture, soil acidity, mineral nitrogen content) λ_i – eigenvalues of vectors.

The first principal component $Factor_1$ explains 26.0 % of the total variance. The highest values of the $Factor_1$ function are characterised by vascular plants of eutrophic bog communities 8.2. Alnetea glutinosae (*Alnus glutinosa, Frangula alnus*), aquatic and marsh vegetation of ecological and cenotic subgroups 1.1. Lemnetea (*Hydrocharis morsus-ranae, Lemna minor*), 1.5. Phragmitetea (*Phragmites australis, Schoenoplectus lacustris, Typha latifolia*), ruderal vegetation on waterlogged substrates 3.2. Bidentetea (*Polygonum hydropiper, Bidens cernua, Bidens tripartita*) (Fig. 2). The minimum values of the first principal component are typical for steppe plants 5.3. Festuco-Brometea (*Koeleria cristata, Stachys recta, Euphorbia cyparissias*). The values of the first principal component depend primarily on soil moisture (correlation coefficient $r = 0.71$), nitrogen content ($r = 0.67$) and soil pH ($r = -0.48$), and also on illumination ($r = -0.33$), temperature ($r = -0.33$) and continental climate ($r = -0.39$) (Table 3). In our opinion, the first axis of maximum vegetation variation reflects the main pattern of landfill ecotopes formation – the influence of relief conditions on the redistribution of environmental factors, since moisture-loving species are most often distributed in waterlogged areas at the foot of landfills, and drought-resistant steppe species – on the upper parts of slopes. The spread of moisture-loving species can also be caused by the emergence of small wetland complexes formed due to surface subsidence or disorderly excavation of the substrate.

The second principal component, $Factor_2$, additionally explains 17.6 per cent of the total variance in the data. The value of the $Factor_2$ function mainly depends on the factors of illumination ($r = -0.57$), temperature ($r = -0.46$) and continental climate ($r = -0.44$), less on soil pH ($r = -0.39$), soil moisture ($r = -0.25$) and nitrogen content ($r = -0.33$) (Table 3). The minimum values of the second principal component are shown by the ruderal plants of the ecological and phytocoenotic subgroup 3.5. Artemisietea (*Arctium tomentosum, Carduus acanthoides, Epilobium hirsutum, Artemisia absinthium, Leonurus cardiaca*). The maximum values of $Factor_2$ function are characterised by vascular plants of ecological and phytocoenotic subgroup 8.4. Quereo-Fagetea (*Carex pilosa, Acer platanoides, Impatiens parviflora, Aquilegia vulgaris, Equisetum telmateia*) (Fig. 2).

The two key components account for only 43.6 % of the total variance, so for many analytical purposes, the use of 2D projections of geobotanical data is not sufficient (Fig. 2). The position of vascular plants on the third axis of maximum variation (Table 4) additionally explains 16.3 % of the total variance. The third principal component reflects a decrease in the parameters of illumination ($r = -0.55$), thermal regime ($r = -0.64$) and nitrogen content ($r = -0.38$), and an increase in soil acidity ($r = 0.36$) (Table 3). The minimum values of the third principal component are characterised by ruderal plants of ecological and phytocoenotic subgroups 3.3. Chenopodietea and 3.5. Artemisietea, and the maximum values are characterised by forest species of subgroup 8.4. Quereo-Fagetea and steppe species of subgroup 5.3. Festuco-Brometea (Table 4). The third axis of maximum variation in landfill vegetation reflects a decrease in the intensity of anthropogenic load: a decrease in the hemerobia index ($r = -0.37$), urbanity ($r = -0.31$) and ruderality ($r = -0.22$) (Table 3).

Vascular plants of Lviv region landfills grow in a certain ecological and coenotic space, which can be roughly estimated based on the ordination of species on the axes of complex environmental gradients (Fig. 2) and coordination of ecological and coenotic groups and subgroups (Table 4). The centre of this space is occupied by the ruderal communities 3.3. Chenopodietea, a community of nitrified meadows on the banks of water bodies 3.8. Agrostietea stoloniferae and meadow communities 5.4. Molinio-Arrhenatheretea, which show maximum resistance at landfills. The most sensitive to the disturbing impact are the phytocoenoses located on the periphery of the ecological and coenotic space: steppe communities 5.3. Festuco-Brometea, aquatic communities 1.1. Lemnetea, coastal and aquatic communities 1.5. Phragmitetea and potential bog communities 8.2. Alnetea glutinosae.

Table 4

Results of coordination of ecological and cenotic groups and subgroups of plants of landfills in Lviv region

Ecological and coenotic group, plant subgroup	Position on the axes of maximum vegetation variation			
	Factor 1	*Factor 2*	*Factor 3*	*Factor 4*
1. Water, swamp and moor vegetation	1.29	–1.05	0.18	–0.27
1.1. Lemnetea	2.04	–0.68	0.56	0.14
1.5. Phragmitetea	1.07	–1.16	0.07	–0.38
3. Disturbed and secondary vegetation	–0.09	–0.15	–0.54	0.04
3.2. Bidentetea	1.62	–0.58	–0.95	–0.51
3.3. Chenopodietea	–0.04	0.70	–0.50	0.37
3.4. Secalietea	0.14	1.23	0.40	0.57
3.5. Artemisietea	–0.13	–0.56	–0.56	0.07
3.6. Agropyretea	–1.00	–0.00	–0.43	–0.50
3.7. Plantaginetea	–0.58	–0.38	–0.48	0.53
3.8. Agrostietea stoloniferae	–0.24	0.03	–0.29	–0.38
5. Anthropo-zoogenous heath, grasslands and pastures	–0.74	0.31	0.39	0.39
5.3. Festuco-Brometea	–2.35	0.49	1.06	0.62
5.4. Molinio-Arrhenatheretea	0.07	0.23	0.08	0.43
6. Forest edge heath and forb vegetation	–0.10	0.19	–0.64	0.55
6.1. Trifolio-Geranietea	–2.49	0.78	1.24	0.77
6.2. Epilobietea angustifolii	0.50	0.04	–1.10	0.49
8. Broadleaved forests and woodlands	0.27	0.53	0.86	–0.35
8.1. Salicetea purpureae	0.30	–0.78	0.83	–0.52
8.2. Alnetea glutinosae	2.49	1.17	0.29	–0.82
8.4. Quereo-Fagetea	–0.12	0.62	1.05	–0.32
Mean	0.00	0.00	0.00	0.00
Std. Dev.	1.32	1.11	1.06	0.99

Multivariate statistical analysis can be used to determine the similarity of not only ecological and phytocoenotic groups of vascular plants, but also the environmental factors themselves. As a result of the cluster analysis of geobotanical information, we obtained the following classification of environmental factors according to their influence on the formation of landfill vegetation:

1. Natural environmental factors:

1.1. Soil humidity and nitrogen content (reflecting the main pattern of vegetation formation at the renatural stage of the regenerative succession).

1.2. Illumination, soil acidity, thermal regime and continental climate.

2. Anthropogenic and coenotic factors (reflecting the peculiarities of vegetation cover formation at the pioneer stage of regenerative succession):

2.1. Hemerobia and urbanity.

2.2. Ruderality.

Conclusions. A complex combination of environmental factors causes a great variety of habitat conditions for the vegetation cover of landfills in Lviv region. The combined effect of soil humidity and mineral nitrogen content determines the main pattern of vegetation formation at landfills, in particular, the influence of relief conditions on the redistribution of these environmental factors. The anthropogenic impact is reflected in the ecological phytocoenotic series: forest vegetation communities of the Quereo-Fagetea class and steppe phytocoenoses of the Festuco-Brometea class → ruderal vegetation communities of the Chenopodietea and Artemisietea classes. The ecological equivalent of an increase in anthropogenic load in the conditions of landfill ecotopes is an increase in illumination, thermal regime and continental climate parameters, and nitrogen content. The index of hemerobia is characterised by better differentiating properties of the intensity of anthropogenic impact compared to the indicators of urbanity and ruderality.

The ecological and coenotic space of the vegetation cover of landfills in Lviv region can be represented as a quadrangle, where the centre is the ruderal community of the class Chenopodietea, the community of nitrified meadows on the banks of water bodies of the class Agrostietea stoloniferae and the meadow community of the class Molinio-Arrhenatheretea, and the corners are 1. aquatic Lemnetea, marsh Phragmitetea and ruderal vegetation communities on waterlogged substrates of Bidentetea; 2. non-morphic forest vegetation communities of Quereo-Fagetea; 3. steppe communities of Festuco-Brometea; 4. ruderal vegetation communities of Artemisietea.

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Екологічні особливості формування рослинного покриву сміттєзвалищ Львівської області (Україна)

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Мета. Встановити екологічні особливості процесу формування рослинного покриву сміттєзвалищ Львівської області за допомогою аналізу флористичного складу екотопів різних стадій відновлювальної сукцесії.

Методика. Фітоіндикація екологічних параметрів на основі екологічних даних рослинності сміттвавалищ; методи добування даних (Data Mining methods); багатовимірне координування рослин на основі аналізу головних компонент (Principle Component Analysis); статистична обробка даних екотопів.

Результати. Проведена фітоіндикаційна оцінка умов місцезростання 5 еколого-ценотичних груп та 16 підгруп видів рослин з різноманітних екотопів сміттєзвалищ Львівської області відповідно до шести параметрів: *L* – освітленість, *T* – термічний режим, *K* – континентальність, *F* – режим зволоженості, *R* – кислотність, *N* – вміст азоту, бали. Основна закономірність формування екотопів сміттєзвалищ Львівської області полягає в такій структурі взаємозв'язків між екологічними параметрами: зі збільшенням вологості ґрунту, вмісту азоту та pH ґрунту зменшуються показники освітленості, температурного режиму й континентальності клімату. Екологічним еквівалентом зростання антропогенного навантаження в умовах екотопів сміттєзвалищ слугують зростання освітленості, параметрів термічного режиму й континентальності клімату, вмісту азоту. Еколого-ценотичний простір рослинного покриву сміттєзвалищ Львівської області можна представити у вигляді чотирикутника, у центрі якого розташовані рудеральні угруповання класу Chenopodietea, угруповання нітрифікованих лук на берегах водойм класу Agrostietea stoloniferae і лучні угруповання класу Molinio-Arrhenatheretea, а в кутах: 1) угруповання водної класу Lemnetea, болотної класу Phragmitetea і рудеральної рослинності на перезволожених субстратах класу Bidentetea; 2) угруповання неморальнолісової рослинності класу Quereo-Fagetea; 3) степові угруповання класу Festuco-Brometea; 4) рудеральна рослинність класу класу Artemisietea.

Наукова новизна. Еколого-ценотичний простір сміттєзвалища у Львівській області оцінено на основі впорядкування судинних рослин на осях складних екологічних градієнтів. За результатами найбільшу стійкість в умовах полігону виявляють рудеральні й лучні види, що займають центральну частину простору. Найбільш уразливими є степова та гідрофільна рослинність, що розташована на периферії загального рослинного простору сміттєзвалища.

Практична значимість. Знаючи екологічні параметри видів флори, можна визначити їх положення в еколого-ценотичному просторі рослинного покриву сміттєзвалищ і прогнозувати їх стійкість і динаміку.

Ключові слова: *сміттєзвалище, екотоп, еколого-ценотичні групи, багатовимірна ординація рослинності*

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