

# IMPACT OF CLIMATE CHANGE ON RUDERAL COMMUNITIES IN THE CONDITIONS OF UKRAINE

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## Abstract

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We elucidated the reaction of ruderal vegetation community to environmental changes. It made it possible to assess the level and nature of the synanthropic vegetation dynamics, fluctuation processes, and also to indicate the scenarios of evolution of ruderal communities throughout the environmental changes, in particular, climate changes. In this study, we used the original methods: synphytoindications and estimation of the climate change impact and the species reaction according to their ecological strategy. Dataset included 1200 phytosociological relevés of different synanthropic habitat types (borders of fields, ruderal areas, and railway tracks). As a result of vegetation analysis, we obtained 16 alliances of ruderal vegetation belonging to the six classes and two natural vegetation derivatives of the *Sedo-Scleranthetea* Br.-Bl. 1955 and *Festuco-Brometea* Br.-Bl. & Tx. 1943. Evaluation of ecological indicator value changes in relation to 1, 2 and 3 °C increase in average annual temperatures allowed to determine how significant is the threat to the existence of ruderal communities. It is particularly noticeable in the thermal regime, and some changes in edaphic properties of soil, especially acidity (pH). Under the conditions of climate changes and ecological indicator value changes, such communities could be easily restored both in the appropriate conditions of the region and outside it, that is, shifting their range. But thanks to this strategy, the emergence of new species and, as a result of this, the formation of completely new vegetation types is possible.

**Key words:** ruderal vegetation, ecological assessment, environmental strategies, climate change forecast.

## Introduction

With the development of human civilization, there is a change in the role of plant species in ecosystems, that is, the replacement of species characteristic of communities by secondary, pioneer apophytes and the introduction of new alien plants. The consequence of this is synanthropization of natural vegetation and the formation of specific completely new ruderal plant communities. Such communities form synanthropic vegetation on the site of destroyed natural ones under constant anthropogenic load. The areas of such communities are increasing; in other words, diversity is increasing. It can be expected that in the future, their role in the structure of the vegetation cover will grow, as they influence the functioning of ecosystems, the nature of the natural processes' evolution. Much attention is paid to the study of the classification of ruderal vegetation and assessment of its reaction to the influence of external factors in Europe (Brandes, 2009; Chytrý, 2009; Lososová et al., 2004; Šilc, 2010; Jarolímek et al., 1997; Passarge, 1996; Rivas-Martinez et al., 2001; Viciani 2020 et al.; Matuszkiewicz, 2001; Borhidi et al., 2012; Tzonev, 2009).

In Ukraine, the first studies of ruderal vegetation began in the 80s of the 20th century. In the compilation by Solomakha

et al. (1992), this vegetation was classified into nine classes. In the process of carrying out further studies on synanthropic vegetation (Gamor, 1987; Kucheryavy et al., 1991; Papucha, 1991; Levon, 1999; Chokha, 2005; Bagrikova, 2005; Epikhin, 2006; Osypenko, 2006; Dubyna et al., 2018; Orlov, Yakushenko, 2005; Soroka, 2008; Bredikhina, 2015; Makhynya, 2015; Pashkevych, 2018; Yeremenko, 2018), the syntaxonomic structure was expanded.

However, in recent years, there have been significant changes in the syntaxonomy of ruderal vegetation in Europe (Mucina, 2016). In 2019, a syntaxonomic work «Prodromus of Vegetation of Ukraine» (Dubyna et al., 2019) was published, which differs in content from the European checklist. Thus, the synanthropic vegetation of annuals and biennials are combined into the class *Stellarietea mediae*, and the classes *Papaveretea rhoeadis* S. Brullo et al. 2001, *Sisymbrietea* Gutte et Hilbig 1975, *Chenopodietea* Br.-Bl. in Br.-Bl. et al. 1952, *Digitario sanguinalis-Eragrostietea minoris* Mucina, Lososová et Šilc in Mucina et al. 2016 are not selected. In our opinion, such discrepancies are related to insufficient study of synanthropic vegetation. The second problem in the identification of syntaxons is the significant continuity between degraded natural vegetation and formed synanthropic

vegetation, which makes it difficult to distinguish syntaxons.

Climatogenic changes in vegetation cover are difficult to distinguish against the background of natural changes and local anthropogenic influences. One of the effective and economical methods of assessing environmental changes is monitoring–modeling–forecasting with the involvement of biological objects, which are sensitive indicators of fluctuations in environmental factors of biosystems. One of the first to respond to the environment changes are species with a high adaptation potential, which are able to expand their range or create a new one – alien species (Burda, 2018). Alien species make up the basis of ruderal vegetation and ensure rapid response of communities to environmental changes.

Our task was to reveal the patterns of ruderal plant communities' differentiation and the correlation between ecological indicator values, as well as to predict how the ecological conditions of vegetation will change when the indicator values change.

## Material and methods

This paper is a result of the field research of ruderal vegetation on the territory of Ukraine during the years 2010–2019. This dataset included 1200 phytosociological relevés of different synanthropic habitat types (borders of fields, ruderal areas, and railway tracks), stored in the phytosociological database format of Turboveg software package (Hennekens, Schaminée 2001). Most of these relevés (about 70%) were made on the standard 10 m<sup>2</sup> plots, or, in several cases, in areas less than 1–2 m<sup>2</sup>. Data processing and classification were carried out using the JUICE software package (Tichý, 2002).

We used three authors' methods, synphytoindications (Didukh, 2011, 2012) and estimation of the climate change impact (Didukh, 2022), in the process of research. The ecological analysis of the communities included an assessment of their leading ecological indicator values based on the methodology of synphytoindication using the ECODID database. Ecological analysis was carried out according to the phytoindication method (Didukh, Pluta, 1994) on the basis of the ecological scales proposed by Didukh (2011). They are characterized by the following dimensions: soil moisture (Hd – 23 grades), variability of damping (fH – 11 grades), soil acidity (Rc – 15 grades), total salinity (Sl – 19 grades), carbonate content (Ca – 13 grades), nitrogen content (Nt – 11 grades), soil aeration (Ae – 15 grades), temperature (Tm – 17 grades), humidity (Om – 23 grades), continentality (Kn – 17 grades), cryoregime (Cr – 15 grades), and lighting (Lc – nine grades). The calculation of ecological indicator values was made using JUICE 7.0 (Tichý, 2002). To visualize the multivariate floristic similarity patterns, we carried out principal component analysis (PCA). In the ordination diagram, environmental factors and vegetation parameters correlated to one of the axes with  $r^2 \geq 0.20$  were displayed as vectors. To compare the ecological indicator values and their interdependence, we built the graphs based on the averaged indexes of 12 ecological values (Didukh's scales) calculated using PAST 4.04. PCA was performed using a data correlation matrix. Syntaxonomy was in accordance with Mucina et al. (2016), indicating the associations of prodrome of the vegetation of Ukraine (2019).

Estimation of ecological indicator value changes in relation to 1, 2 and 3 °C increases in average annual temperatures

was carried out according to the method of Didukh (2022). It is based on the correlation assessment between climatic indicator values (temperature, which depends mostly on changes in annual temperatures) and others. Indicator values of average annual temperatures of the beginning of the 21st century were taken as the initial position (Krakovska et al., 2011; Didukh, Vynokurov, 2021). The next stage was to calculate each ecological indicator value changes according to the average value of modern living conditions.

The plant species names follow by Euro+Med Checklist (2020), mosses species names – by Hodgetts et al. (2020).

## Results and discussion

### Syntaxonomic analysis

Based on the vegetation analysis, we selected 18 clusters representing 16 alliances of ruderal vegetation belonging to the six classes and two natural vegetation derivatives. Here is the list of the selected syntaxons and the number of analyzed relevés:

- Cl. *Sisymbrietea* Gutte et Hilbig 1975
    - All. *Atriplicion* Passarge 1978 (38 relevés)
    - All. *Sisymbriion officinalis* Tüxen et al. ex von Rochow 1951 (110)
  - Cl. *Digitario sanguinalis*–*Eragrostietea minoris* Mucina, Lososová et Šilc in Mucina et al. 2016
    - All. *Eragrostion* Tx. in Oberd. 1954 (123)
    - All. *Spergulo arvensis*–*Erodion cicutariae* J. Tüxen y Passarge 1964 (23)
  - Cl. *Polygono arenastri*–*Poëtea annuae* Rivas-Martínez 1975
    - All. *Polygono arenastri*–*Coronopodion squamati* Sissingh 1969 (85)
    - All. *Saginion procumbentis* Tüxen et Ohba in Géhu et al. 1972 (46)
  - Cl. *Plantaginetea majoris* Tüxen et Preising ex von Rochow 1951
    - All. *Plantagini*–*Prunellion* Eliáš 1980 (55)
    - All. *Potentillion anserinae* Tüxen 1947 (38)
  - Cl. *Artemisietea vulgaris* Lohmeyer et al. in Tüxen ex von Rochow 1951
    - All. *Dauco*–*Melilotion albi* Görs ex Rostański et Gutte 1971 (58)
    - All. *Convolvulo arvensis*–*Elytrigion repentis* Görs 1967 (138)
    - All. *Onopordion acanthii* Br.-Bl. et al. 1936 (47)
  - Cl. *Epilobietea angustifolii* Tüxen et Preising ex von Rochow 1951
    - All. *Senecionion fluviatilis* Tüxen ex Moor 1958 (118)
    - All. *Aegopodion podagrariae* Tüxen 1967 (96)
    - All. *Geo urbani*–*Alliarion officinalis* Lohmeyer et Oberd. in Görs et Müller 1969 (39)
    - All. *Arction lappae* Tüxen 1937 (93)
  - Cl. *Bidentetea* Tüxen et al. ex von Rochow 1951
    - All. *Bidention tripartitae* Nordhagen ex Klika et Hadač 1944 (37)
  - Cl. *Sedo-Scleranthetea* Br.-Bl. 1955
    - ruderalized community all. *Corynephorion canescentis* Klika 1931 (28)
  - Cl. *Festuco-Brometea*
    - ruderalized *Festucion valesiacae* Klika 1931 (28).
- Class *Sisymbrietea* Gutte et Hilbig 1975 is represented by ruderal vegetation communities of winter-annual herbs, estab-

lishing stages of restorative successions. Vegetation of *Atriplicion* Passarge 1978 is formed mainly by tall annual species (*Atriplex patula* L., *Atriplex sagittata* Borkh., *Chenopodium album* agg., *Erigeron canadensis* L., *Lactuca serriola* L., *Sisymbrium loeselii* L., *Sisymbrium officinale* (L.) Scop.) on sandy nutrient-rich soils, on recently disturbed areas with bare soil, forming ephemeral communities on technological substrates (accumulation of sand and building materials, dumps), at the construction sites, on the side of sandy tracks, railways, and around farms in the second half of summer. Alliance *S. officinalis* Tüxen et al. ex von Rochow 1951 includes ruderal, medium-tall, thermophilic, and drought-adapted vegetation of winter-annual herbs, such as *Anisantha sterilis* (L.) Nevski, *A. tectorum* (L.) Nevski, and *Hordeum murinum* L., which are demanding of nutrients and growing on sandy soils. These species rapidly colonize recently disturbed or discovered habitats in anthropogenic areas, settlements, and on roadsides and gain maximum biomass of spring.

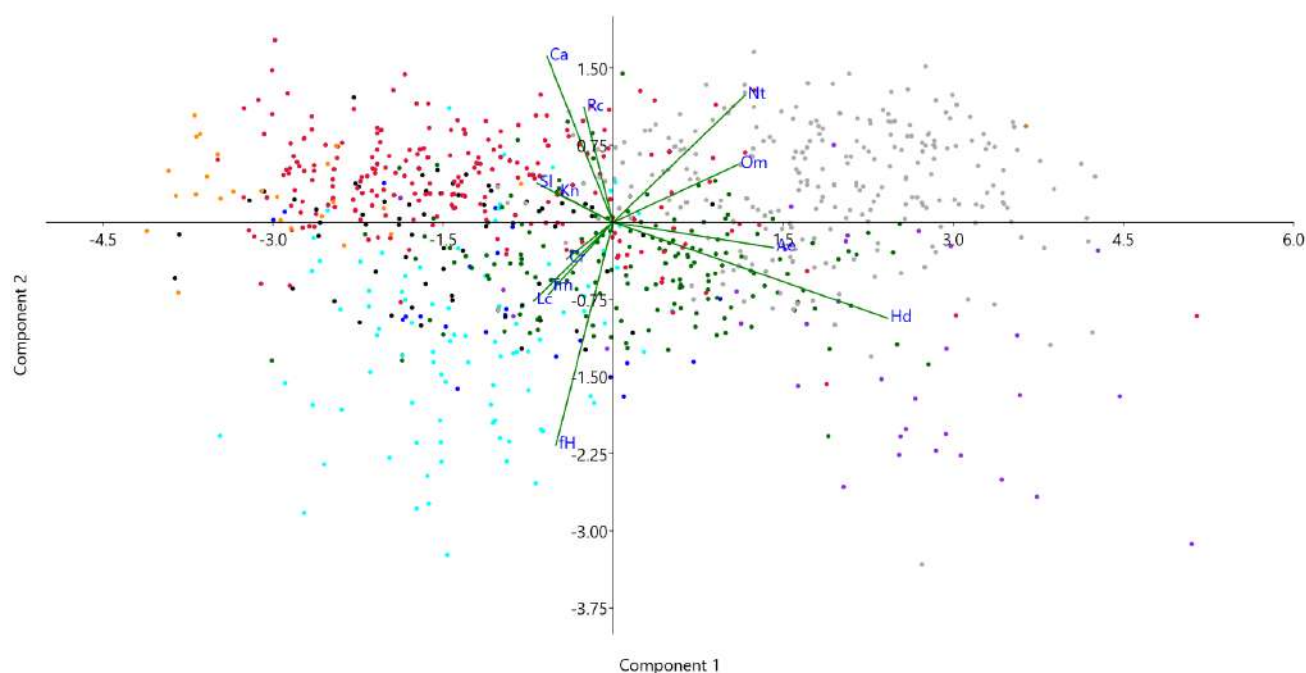
*Digitario sanguinalis-Eragrostietea minoris* Mucina, Lososová et Šilc in Mucina et al. (2016) are thermophilic communities of late-summer annual grasses. Vegetation of *Eragrostion* Tx. in Oberd. 1954 preferring sandy light-textured soils occurs on cultivated areas and non-cultivated disturbed grounds. It is able to survive in conditions of long periods of summer drought and high temperatures, or in temporary habitats on sandy soils in conditions of variable humidity. The floristic composition has a significant presence of C4 plants and neophytes of American origin. The dominant species are *Amaranthus retroflexus* L., *Erigeron canadensis*, *Cynodon dactylon* (L.) Pers., *Digitaria ischaemum* (Schreb.) Muhlb., *D. sanguinalis* (L.) Scop., *Eragrostis minor* Host, *E. pilosa* (L.) P. Beauv., *Portulaca oleracea* agg., *Setaria viridis* (L.) P. Beauv., *S. pumila* (Poir.) Roem. & Schult., and others. Alliance *Spergulo arvensis-Erodion cicutariae* J. Tüxen in Passarge 1964 includes ruderal vegetation with C4 species in the communities *Echinochloa crus-galli* (L.) P. Beauv., *Setaria pumila*, and *Galinsoga parviflora* Cav., which occur on dry sandy, loose soils. It develops mainly in agrocenoses of row crops or vegetable fields, vineyards, and flower beds. These are mostly warmth-demanding annuals plants that germinate in late summer or early autumn.

*Polygono-Poetea annuae* Rivas-Martínez 1975 includes initial communities growing under conditions of insufficient moisture under the intensive influence of trampling. Communities *Polygono-arenastri-Coronopodium squamati* Sissingh 1969 formed on roadsides, footpaths, and edges of sports grounds. The floristic composition of the communities consists of *Polygonum aviculare* agg., *Ochlopoa annua* (L.) H. Scholz, *Lepidium ruderae* L., *Eragrostis minor*, *Sclerochloa dura* (L.) P. Beauv., and *Matricaria discoidea* DC. The vegetation of the alliance *Saginion procumbentis* Tüxen et Ohba in Géhu et al. 1972 is typical for the western regions and northern and central parts of Ukraine. It is formed in conditions of semi-shading on well-moistened poor and acid soils. This is a community of paving fissures in the road surface and compacted soil with a significant level of trampling, mainly found in settlements. Often, communities of disturbed pastures and trampled habitats have in the lower layer *Plantaginetea majoris* Tüxen et Preising ex von Rochow 1951, which are formed by low-growing mosses *Bryum argenteum* Hedw., *Funaria hydrometrica* Hedw., and *Marchantia polymorpha* L., and in the upper layer plants which are characterized by obtaining moisture due to precipitation, such as *Plantago major* L., *Ochlopoa*

*annua*, *Polygonum aviculare* agg., *Portulaca oleracea* agg., and *Sagina procumbens* L. Communities *Plantagini-Prunellion* Eliáš 1980 formed in conditions of moderate moisture under the influence of trampling on forest footpaths, trails, sports grounds, and pastures on light soils. The floristic composition consists mainly of archaeophytes or apophytes: *Juncus compressus* Jacq., *J. tenuis* Willd., *Ochlopoa annua*, *Plantago major*, *Prunella vulgaris* L., and *Trifolium repens* L. Alliance *Potentillion anserinae* Tüxen 1947 represents a community of hemicryptophytes on nitrified pastures with significant influence of waterfowl and anthropogenic impact (swimming, laundry, grazing, fishing) near settlements formed in wetland ecotopes, with moderate trampling. The floristic composition consists of mesophytes *Elytrigia repens* (L.) Nevski, *Rumex crispus* L., *Agrostis stolonifera* L., *Alopecurus geniculatus* L., *Trifolium fragiferum* L., and *Rorippa sylvestris* (L.) Besser.

*Artemisietea vulgaris* Lohmeyer et al. in Tüxen ex von Rochow 1951 is a xerophilous ruderal vegetation with biennial and perennial species. Ruderal and semi-ruderal two-layer communities *Dauco-Melilotion albi* Görs ex Rostański et Gutte 1971 of hemicryptophyte species, with high projective coverage. The communities include adventive species that often form monodominant overgrown *Centaurea diffusa* Lam., *Solidago canadensis* L., *Bunias orientalis* L., *Asclepias syriaca* L., and *Grindelia squarrosa* (Pursh) Dunal along the roads, on pastures, and downed areas. Dynamic communities of alliance are a stage of disturbed semi-natural grassland communities under constant anthropogenic load. Ruderal thermophilous vegetation *Convolvulo arvensis-Elytrigion repentis* Görs 1967 is on dry or periodically drying well-lit areas with a significant proportion of perennial herbs, mainly archaeophytes. These are mainly highly competitive species (*Arrhenatherum elatius* (L.) J. Presl & C. Presl, *Dactylis glomerata* L.); some grasses have a well-developed root system (*Bromus inermis* (Leyss.) Holub, *Elytrigia repens*). Thermophilous and drought-resistant ruderal communities *Onopordion acanthii* Br.-Bl. et al. 1936 consist of biennial and perennial herbs. These are cenoses of different closure, poorly structured, and formed by ruderal hemicryptophytes (*Artemisia absinthium* L., *A. vulgaris* L., *Ballota nigra* L.) and annuals and biennials (*Carduus acanthoides* L., *Echium vulgare* L., *Onopordum acanthium* L., *Grindelia squarrosa*) on slopes, scree, as border strips of wastelands, and agrocenoses. They grow on dry, loamy, clay, sandy, stony soils with a significant content of carbonates and traces of mineralization.

*Epilobietea angustifolii* Tüxen et Preising ex von Rochow 1951 is represented by grass perennial communities of disturbed mesophytic habitats with nitrate-rich soils and restoration of deforestation and burned areas. Tall-grass communities *Senecionion fluviatilis* Tüxen ex Moor 1958 with climbing dicotyledonous mesohygrophytes (*Aristolochia clematitis* L., *Calystegia sepium* (L.) R. Br., *Cuscuta europaea* (L.) R. Br., *Eupatorium cannabinum* L., *Humulus lupulus* L., *Mentha longifolia* (L.) L., *Rubus caesius* L., *Urtica dioica* L.) are in the ruderalized coastal strip of reservoirs and canals. Communities are formed on moderately moist, nitrogen-enriched, loose soils and are typical for mountainous, forest, and forest-steppe regions. Semi-shaded mesophytic communities *Aegopodion podagrariae* Tüxen 1967 with dicotyledonous tall perennial herbs: *A. podagraria* L., *Anthriscus sylvestris* (L.) Hoffm., *Chaerophyllum aromaticum* L., *Heracleum sphondylium* L., *Poa trivialis* L., and *Urtica dioica* L. Communities form



**Fig. 1.** Analysis of the main components (PCA) by ecological indicator values: *Sisymbrietea* (black), ruderalized *Corynephorion canescentis* (blue), *Digitario sanguinalis*–*Eragrostietea minoris* (light blue), *Polygono arenastri*–*Poëtea annuae* and *Plantaginetea majoris* (green), *Artemisi-etea vulgaris* (red), *Epilobietea angustifolii* (gray), *Bidentetea* (violet), and ruderalized *Festucion valesiacae* (orange).

of different closure in mesophilic edges of forests and parks, along shaded walls and abandoned buildings on loose soils enriched with the mineral nitrogen. Communities *Geo urbani-Alliarion officinalis* Lohmeyer et Oberd. in Görs et Müller 1969 consist of tall biennial herbs *Alliaria petiolata* (M. Bieb.) Cavara & Grande, *Chaerophyllum temulum* L., *Chelidonium majus* L., *Galium aparine* L., *Geranium robertianum* L., *Geum urbanum* L., *Lamium album* L., *Torilis japonica* (Houtt.) DC. Communities occupy areas on fresh and moist soils of shaded ruderalized ecotopes of meadows and shaded or semi-shaded nodes and shrubs along roads. Two-layer communities *Arctium lappae* Tüxen 1937 are formed mainly by tall species (*Arctium lappa* L., *Helianthus tuberosus* L., *Lamium purpureum* L., *Leonurus glaucescens* Bunge, *Sambucus ebulus* L., *Urtica dioica*) confined to settlements, road-sides, landfills, dumps, disturbed areas around reservoirs or along walls, and fences in conditions of partial shading. They are formed on open or slightly shaded areas on drained substrates with nitrified and nutrient-rich soils.

Synanthropic communities *Bidention tripartitae* Nordhagen ex Klika et Hadač 1944 are found in weakly disturbed wetlands; they are annuals herbs, mainly from the genus *Bidens* L., *Persicaria* Mill., and *Ranunculus* L. and other hydrophytes, which often have significant invasive potential. Herb's thickets are formed along the coastal strips of rivers, ponds, reservoirs, streams, canals, and bottoms of dry reservoirs on muddy, silty–sandy, slightly turfed soils throughout the country.

Ruderalized community all. *Corynephorion canescentis* Klika 1931 includes open, drought-adapted vegetation occurring on roads and compacted places, as well as pioneer vegetation on carbonate-free, low-nutrient siliceous soils. In the floristic com-

position of the community, in addition to typical ruderal thermophilous therophyte- and geophyte-rich therophytes (*Pilosella officinarum* Vaill., *Veronica dillenii* Crantz, *Scleranthus annuus* L., *Helichrysum arenarium* aggr.), there are many natural species from the nearest biotopes of alluvial sandy floods and pine forest terraces. Vegetation occupied from Northern to Central Ukraine.

Degraded steppe vegetation of *Festucion valesiacae* Klika 1931 is represented by communities of *Festuca* L. and *Poa* L. grasses. The stands of these communities occupy the southern slopes in the southern and central regions. They develop on rich humus soils. If the structure is disturbed due to overgrazing, the influence of transport or other agricultural machinery, it has a secondary character. The floristic composition is dominated by *Bothriochloa ischaemum* (L.) Keng., *Eryngium campestre* L., *Euphorbia cyparissias* L., *Festuca valesiaca* Gaudin, *Medicago falcata* L., *Potentilla incana* G. Gaertn. & et al., and *Salvia nemorosa* L. A significant proportion of alien-invasive species was noted: *Aegilops cylindrica* Host, *Anisantha tectorum*.

### Synphytoindication assessment of ecological indicators of ruderal communities and their reaction to climate change

The next stage was to assess the impact of leading ecological indicator values on the distribution of plant communities and to establish the nature of the correlation between indicator values of external factors based on the synphytoindication method (Didukh, 2011, 2012). As a result of the PCA-analysis of the head components, it was established with a readable differentiation

of syntaxons of ruderal vegetation into equal classes. The main environmental factors that determine the differentiation of syntaxons are lighting, soil moisture, chemical properties of the soil, and temperature (Fig. 1). From left to right, the communities are divided from xerophytes to mesohydrophytes, from light-loving plants that grow on soils with relatively low nutrient content and have a sparse cenotic structure to dense communities, demanding nutritious soils.

The greatest influence on the distribution of syntaxons is by soil moisture and humidity, aeration, and nutrient supply (nitrogen content). They correlate with each other and are close to the PCA-1 axis. The communities *Epilobietea angustifolii* and *Bidentetia* develop in conditions of moist soil and humid air, low aeration, and enrichment of nutrients. The chemical properties of soils have a much smaller influence. Thus, total salt regime, acidity, and carbonate content are correlated with continentality. At this pole are the ruderalized communities *Festucion valesiacae*, *Artemisietea vulgaris*, *Digitario sanguinalis-Eragrostietea minoris*, and *Sisymbrietea*. Intermediate positions are occupied by *Polygono arenastri-Poëtea annuae*, *Plantaginetea majoris*, and ruderalized communities *Corynephorion canescentis*. The third group of factors is the variability of damping, soil moisture, temperature, and lighting, close to the axis PCA-2.

The established patterns of differentiation of plant communities and the nature of the correlation between the ecological indicator values are important for assessing how environmental conditions and communities' positions in the ecological coordinates system may change throughout the country. In particular, it is important to assess these ecological indicator values' changes in relation to the average annual temperature increases by 1, 2, and 3 °C. We made such calculations according to the method of Didukh (2021), which is based on estimation of the correlation between climate indicator values (temperature, which depends mostly on changes in annual temperatures) and others. Thus, for an initial position, indicators of average annual temperatures of the beginning of the 21st century were taken (Krakovska et al. 2011; Didukh, Vynokurov, 2021).

The next stage was to calculate the changes in these indicator values for each factor in accordance with the average value of modern living conditions. When the annual average temperature increases by 1 °C (blue dotted line) (Salinitro et al., 2019; McDonald et al., 2013), most of the ecological indicator values do not exceed the existing amplitude ( $\pm 2\delta$ ), but their amplitude shifts and almost all communities respond to such changes (Hobbs et al., 2009). The largest shift is observed for temperature, soil acidity, total salt regime, and carbonate content and the least shift is for continentality (Fig. 2). The leading influence on temperature (Tm) is recorded only for nine alliances: *Plantagini-Prunellion*, *Potentillion anserinae*, *Convolvulo arvensis-Elytrigion repentis*, *Senecionion fluviatilis*, *Aegopodion podagrariae*, *Arction lappae*, *Bidentetia tripartitae*, and the ruderalized community *Festucion valesiacae*.

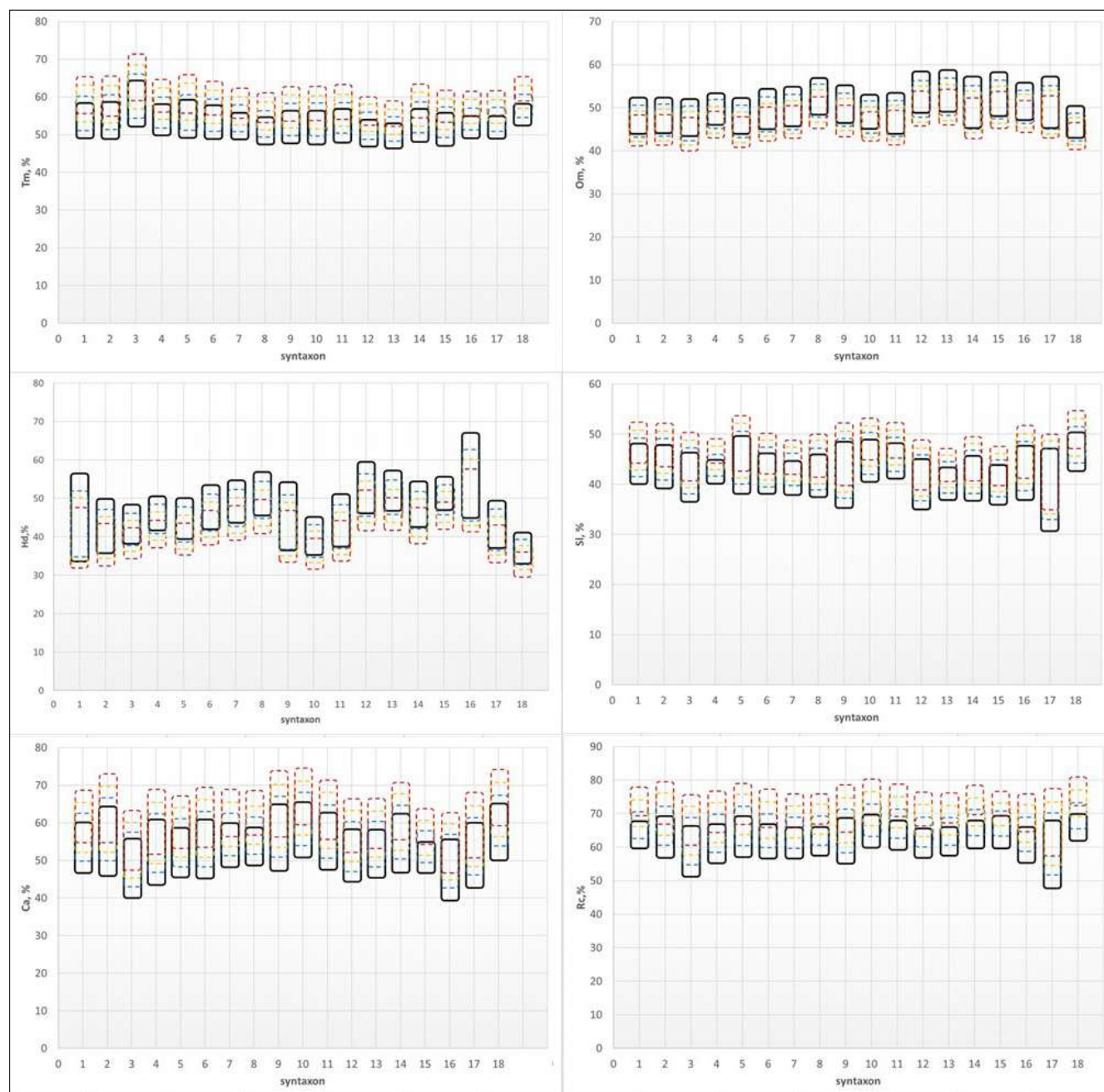
A 2 °C increase in the average annual temperature (yellow dotted line) was noted for most (15) alliances: *Atriplicion*, *Spergulo arvensis-Erodion cicutariae*, *S. officinalis*, *Polygono-Coronopodion*, *Onopordion acanthii*, *Saginion procumbentis*, *Plantagini-Prunellion*, *Potentillion anserinae*, *Convolvulo arvensis-Elytrigion repentis*, *Senecionion fluviatilis*, *Aegopodion podagrariae*, *Geo urbani-Alliarion petiolatae*, *Bidentetia tripartitae*, and ruderalized *Festucion valesiacae*. The average values of soil acidity (Rc)

are already beyond the current amplitude. At the same time, their amplitudes still overlap. This characterizes the threats of habitat change due to the indirect influence of climate on the soil (Fig. 2). Interestingly, the synanthropic vegetation changes in the city observed in 30 years show (Pyšek et al., 2004) an increase in all edaphic indicator values, which could be explained as due to the influence of urbanization.

In addition, a decrease in the total salt regime (Sl) for the alliance of *Spergulo arvensis-Erodion cicutariae* and in the carbonate content (Ca) for the alliances of *Potentillion anserinae* and *Arction lappae* was recorded.

With 3 °C increase in the average annual temperature (red dotted line), these alliances remain at risk of change by the temperature (Tm) values. As for the alliance of steppe vegetation *Festucion valesiacae*, its amplitude no longer overlaps with the original, which means that the conditions change so much that it can no longer exist here, and we interpret it as missing. A similar situation is typical for soil acidity, where eight alliances fall into the category of missing: *Atriplicion*, *Onopordion acanthii*, *Potentillion anserinae*, *Senecionion fluviatilis*, *Aegopodion podagrariae*, *Geo urbani-Alliarion petiolatae*, *Arction lappae*, and *Festucion valesiacae*. At the same time, the number of alliances for which crisis significance, namely, threats to existence, has been fixed is expanding. In terms of Sl, *Atriplicion*, *Onopordion acanthii*, *Plantagini-Prunellion*, *Potentillion anserinae*, *Aegopodion podagrariae*, and *Festucion valesiacae*; and in terms of carbonate, *Atriplicion*, *Polygono-Coronopodion*, *Onopordion acanthii*, *Saginion procumbentis*, *Plantagini-Prunellion*, *Convolvulo arvensis-Elytrigion repentis*, *Senecionion fluviatilis*, *Aegopodion podagrariae*, *Geo urbani-Alliarion petiolatae*, *Festucion valesiacae* are above the crisis values. This means that when the temperature rises, the total salt regime and soil acidity change precisely because of the change in carbonate content ( $\text{Mg}_2\text{CO}_3$ ,  $\text{Ca}_2\text{CO}_3$ ) (Fig. 2), while changes in chloride salinity are less pronounced.

Assessing the response to climate change and the nature of communities' evolution, we can conclude that the alliances of the forest zone *Senecionion fluviatilis* and *Aegopodion podagrariae* are most sensitive to climate change; they are reduced already with 2 °C increase in average annual temperature and may disappear in this area with 3 °C increase in temperature (George et al., 2009). Less sensitive, but in the risk zone, are communities of alliances *Potentillion anserinae*, *Geo urbani-Alliarion petiolatae*, and *Arction lappae*. They are characterized by reduction and disappearance of relevant stations or the possibility of shifting to other regions. Instead, although communities of the alliances *Atriplicion* are vulnerable to Rc changes, they have the ability to preserve areas, and the *Eragrostion*, *Saginion procumbentis*, and *Polygono-Coronopodion* communities may even expand their area and capture other territories. These are species-poor grasslands in which alien species often invade (Padullés et al., 2022). This trend could be explained by the floristic composition of the communities that are formed on the territory of Ukraine and where C4 species predominate. They are able to adapt well to the new edaphic and climatic conditions (soil salinity, a sharp change in moisture, and high temperatures in summer). There are no threats to *Sisymbrium officinalis* and *Onopordion acanthii* communities, and ruderalized *Festucion valesiacae* communities (mainly due to the complex of *Artemisietea vulgaris* species), although endangered, are able to recover in other areas under appropriate conditions due to fluctuating species development.



**Fig. 2.** Synphytoindication assessment of ecological indicator values of ruderal communities (black) and their reaction to 1°C (blue), 2°C (orange), and 3°C (red) increase in average annual temperature: *Atriplicion* (1), *Sisymbrium officinalis* (2), *Eragrostion* (3), *Spergulo arvensis*–*Erodion cicutariae* (4), *Coronopodo*–*Polygonion arenastri* (5), *Saginion procumbentis* (6), *Plantagini*–*Prunellion* (7), *Potentillion anserinae* (8), *Dauco carotae*–*Melilotion* (9), *Convolvulo arvensis*–*Elytrigion repentis* (10), *Onopordion acanthii* (11), *Senecionion fluviatilis* (12), *Aegopodion podagrariae* (13), *Geo urbani*–*Alliarion petiolatae* (14), *Arction lappae* (15), *Bidention* (16), *Corynephorion canescens* (17), and *Festucion* (18).

## Conclusion

Estimation of ecological indicator value changes in relation to 1, 2, and 3 °C increases in average annual temperatures allowed to establish the following:

The change in average annual temperatures by 3 °C is so significant that it threatens the existence of even ruderal communities, most of which are significantly reduced; it causes transfor-

mation of the species composition, and some will disappear in such conditions.

Of the four climatic factors, temperature increase is manifested only the temperature indicator values ( $T_m$ ), which are determined by climatic characteristics such as photosynthetic active radiation (PAR), the duration of the growing season, and rising temperatures during the growing season; in this case, in contrast to natural communities, indicator values of other climatic factors



(Cr, Kn, Om) are not of limiting importance for ruderal communities.

There is an effect of triggering climate change, which is manifested in the fact that with average annual temperatures increasing, the edaphic (chemical) soil properties change. The most important one is soil acidity (pH). In such conditions, some ruderal communities disappear (mesophytic nitrophilous perennial cenoses), some become impoverished or their floristic composition changes with the involvement of a greater number of xerophytes, and communities such as *Atriplicion*, *Eragrostion*, and *Sisymbrium officinalis* develop well. We observe a tendency for formation of new ruderal communities due to the introduction of new alien species resistant to new ecological conditions.

However, as we noted earlier, such threats and even the loss of communities provoke a certain back reaction to the existing live conditions. Such a reaction could be implemented in different directions: reduction of areas or disappearance of relevant habitats, adaptation to new conditions, or displacement of relevant habitats in those regions where appropriate conditions are present or formed. Hence, we are talking about the need to assess the possible dynamics of communities, which, in contrast to the natural ones, are characterized by a high degree of lability.

Thus, under conditions of climatic changes and ecological indicator values' changes, most of the ruderal communities formed under the influence of anthropogenic factors could be easily restored both in the relevant conditions of the region and in similar conditions outside its borders, to shift their areal.

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