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# Classification of the class *Molinio-Arrhenatheretea* in the forest and forest-steppe zones of Ukraine

Anna A. Kuzemko*

## Abstract

**Aims:** This paper reviews the classification of mesic grassland vegetation (phytosociological class *Molinio-Arrhenatheretea*) in Ukraine, and integrates the units recorded into the common European syntaxonomical system of the *Molinio-Arrhenatheretea* class. It also proposes solutions to a number of issues that cause conflict between the classical Central European concept of the *Molinio-Arrhenatheretea* class and its traditional syntaxonomy in the former USSR. **Location:** Forest and forest steppe zones of Ukraine. **Methods:** I analysed 2,105 relevés originally assigned to the *Molinio-Arrhenatheretea* class using the European Expert System and *K*-means clustering. The units were evaluated for quality and internal homogeneity using Sharpness index and Average Whittaker beta-diversity. I determined the diagnostic species of the vegetation units using calculations of their fidelity based on a *phi*-coefficient. The environmental assessment of the units follows the Didukh indicator values. **Results:** I interpreted the resulting vegetation units as alliances of the Braun-Blanquet system (*Agrostion vinealis, Arrhenatherion elatioris, Cynosurion cristati, Deschampsion cespitosae, Molinion caeruleae, Potentillion anserinae* and *Calthion palustris*) based on a complex of diagnostic species. I also analysed the distribution of the communities of the identified alliances in the study area, revealing their ecological features. **Conclusions:** The use of modern phytosociological methods in this study to analyse geobotanical data collected over a long period and a large area covering the whole range of the *Molinio-Arrhenatheretea* class in the country, clarified a number of controversial issues previously related to the lack of coordination between the Central and Eastern European phytosociology.

**Keywords:** *Arrhenatheretalia*; Europe; expert system; *Galietalia veri*; grassland; meadow; *Molinietalia*; syntaxonomy; vegetation database.

**Nomenclature:** Flora Europaea (Tutin et al. 1968–1993) for vascular plants; Mucina et al. (in press) for higher syntaxa.

**Abbreviations:** DCA = Detrended Correspondence Analysis; DIV = Didukh indicator values; EVA = European Vegetation Archive (http://euroveg.org/eva-database); GIVD = Global Index of Vegetation-Plot Databases (http://www.givd.info); ICPN = International Code of Phytosociological Nomenclature; PAM = Partitioning around medoids.

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## Introduction

Mesic grasslands are one of the main types of natural and semi-natural habitats in the forest and forest-steppe zones of Ukraine and Europe. On the one hand, this vegetation type is very diverse, but on the other, a large number of its syntaxa are widespread, often across the whole European continent. The vast majority of these syntaxa are found in Ukraine, which, as shown by recent studies (Jiménez-Alfaro et al. 2014) is the second of the Mediterranean countries in the number of classes and alliances it supports. Due to its importance as pasture and meadow, the state of the vegetation is largely determined by socio-economic factors, in particular, the level of development of animal husbandry and conservation of traditional land use. Therefore, changes in Ukrainian soci-

*Author's address: National Dendrological Park "Sofiyivka", National Academy of Sciences of Ukraine, 12a Kyivska St., Uman', 20300, Ukraine; anya_meadow@i.ua.


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ety over the past decades have significantly affected the structure and functioning of meadow vegetation. As a result, there is a need to inventory the meadow vegetation of Ukraine to record its current state as well as to compare it with meadow vegetation in other European countries. A number of works providing overviews of European grassland syntaxonomy, including meadow vegetation, have been published in recent decades (Mucina et al. 1993; Dierschke 1995; Päzolt & Jansen 2004; Chytrý et al. 2007; Janišová 2007; Rūsiņa 2007; Hegedüšová Vantarová & Škodová 2014, etc.). In Ukraine, such recent approaches to phytosociological research are little known so far, which significantly complicates the integration of information on the plant community diversity of this country in the global and European system.

For a long time, vegetation in Ukraine was studied following the Soviet tradition in geobotany. In the 1980's, the Braun-Blanquet approach was introduced in Ukraine and only the floodplain meadow vegetation of the *Molinio-Arrhenatheretea* Tx. 1937 class was chosen to test this method in the Ukrainian context. This choice was dictated by the frequent presence of several dominant species in meadow communities (so-called poly-dominance), which complicates the use of the Soviet approach for their classification (Mirkin & Shelyag-Sosonko 1979; Shelyag-Sosonko et al. 1989).

It is possible to distinguish three stages in the history of the phytosociological study of mesic grasslands of Ukraine: During the first stage (1980–1983) the floodplain meadows of some rivers of Ukraine were examined with the aim to collect geobotanic data following the Braun-Blanquet methodology. Data from the valleys of the Dnieper and Dniester rivers were then analysed based on the Braun-Blanquet approach in which environmentally specific groups of species were identified. Based on this, the ecological and topological types of vegetation with the ranks of associations, subassociations and variants were obtained in which the associations were combined into conventional units of higher rank. Phytocoenoses were given without complete tables and nomenclatural types (Shelyag-Sosonko et al. 1980, 1981, 1982; Solomakha 1981a, 1981b, 1982; Shelyag-Sosonko & Solomakha 1981; Sipailova & Shelyag-Sosonko 1981; Sypailova & Shelyag-Sosonko 1982a, 1982b). In the second stage (1983–1990), the data were systematized and classification schemes were proposed as a complete hierarchy of syntaxonomical units for each studied region (floodplain of the Dnieper, Dniester, Desna, Vorskla rivers, small rivers of Ukrainian Polesie) (Shelyag-Sosonko et al. 1985, 1986, 1987) and named following the ICPN (Barkmann et al. 1976). This stage is characterized by the description of new syntaxa including the order *Poo-Agrostietalia vinealis* Shelyag et al. 1985, the alliances *Agrostion vinealis* Sypailova et al. 1985 and *Festucion pratensis* Sypailova et al. 1985, and many associations (Sypailova et al. 1985; Shelyag-Sosonko et al. 1985, 1987). At the same time, the lack of information on syntaxonomy of Central Europe was a serious limitation. Thus, some of the European syntaxa were re-described by Ukrainian phytosociologists, which caused a number of syntaxonomical problems that have not yet been resolved. In the third stage (from 1990 to present) regional classification schemes were systematically developed in order to create the full list of syntaxa for different regions and for Ukrainian vegetation in total, including meadows (Sypailova & Shelyag-Sosonko 1996; Shevchyk et al. 1996; Vorobyov et al. 1997; Senchylo et al. 1997, 1998; Bairak 1998; Kuzemko 1999, 2011a, 2011b; Goncharenko 2000a, 2000b, 2003; Fitsailo 2003; Solomakha et al. 2004; Gomlya 2005; Orlov & Yakushenko 2005; Chorney et al. 2005; Klimuk et al. 2006; Gal'chenko 2006; Onyshchenko 2006; Tertyshnyi 2006; Soroka 2008; Tokaryuk et al. 2009; Solomakha & Chornei 2011). At this stage, foreign literature became more widely available and Ukrainian scientists were able to compare syntaxa described in the Ukraine with the European units. However, this positive phenomenon had somewhat negative consequences, because some of the identified units were included in European syntaxa without considering their diagnosis, and often only based on the name-giving taxa.

The accumulation of a large number of relevés and the need for its critical analysis and synthesis induced Ukrainian scientists to produce a four-volume "Vegetation of Ukraine" (Malynovs'kyi & Krichfalushyi 2000; Dubyna 2006; Dubyna et al. 2007; Kuzemko 2009b). This was mainly based on an inductive approach, which meant that the analysis considered relevés from all over Ukraine, which were processed by phytocoenotic table transformation using the FICEN software package (Kosman et al. 1991). The 4th volume of this edition was prepared by the author of this paper and devoted to vegetation of the *Molinio-Arrhenatheretea* class (Kuzemko 2009b). At the same time, the studies of vegetation in Ukraine on the basis of the Braun-Blanquet approach were summarized in the review of Solomakha (2008).

The structure of the *Molinio-Arrhenatheretea* class differs considerably in the monographs of Solomakha (2008) and Kuzemko (2009b), especially in the part that concerns xero-mesophytic meadows, since Solomakha distinguishes two orders which include this type of meadow communities. He defines the *Poo-Agrostietalia vinealis* Shelyag, V. Solomakha et Sipailova 1985 order as xero-mesophilous and meso-xerophilous communities of the elevated areas of central and riverine parts of floodplains in the Ukrainian plains on turf, sod-meadow and chernozem-meadow soils. He defines the *Galietalia veri* Mirk et Naumova 1986 order as communities of fringes and meadows on medium rich soils with moderately variable atmospheric moisture, and floodplain meadows on slightly developed sandy soil that are moistened by precipitation in the Forest-Steppe zone. However, Kuzemko

& Dziuba (2002) consider these two orders to be synonymous and include all "dry" communities of the *Molinio-Arrhenatheretea* class in the *Galietalia veri* (Kuzemko 2009b) order, which they define as xero-mesophilous and meso-xerophylous communities of steppic meadows on turf, sod-meadow and chernozem-meadow sandy and loamy soils. Two alliances *Trifolio-Brizion elatioris* Didukh & Kuzemko 2009 and *Helictotricho-Bistortion officinalis* Didukh & Kuzemko 2009 that are given in this monograph were described from Crimea (Didukh & Kuzemko 2009), while the rest represent the vegetation of the plain part of Ukraine and the Carpathians.

Thus, two recently published classification schemes of the *Molinio-Arrhenatheretea* class in Ukraine significantly differ and are not consistent with the syntaxonomy of the class accepted in other European countries. This indicates a need for further critical revision of the vegetation class using modern research methods.

In this regard, the aims of this paper are:

i) to carry out a syntaxonomical analysis of available data on mesic and wet grasslands of the *Molinio-Arrhenatheretea* class to alliance level using modern numerical phytosociological methods
ii) to analyze the geographical distribution of the units obtained in the forest and forest-steppe zones of Ukraine and to determine the features of their ecological differentiation;
iii) to integrate the units obtained in the common European syntaxonomical system of the *Molinio-Arrhenatheretea* class, and
iv) to resolve a number of critical issues that create contradiction between the classical Central European concept of the *Molinio-Arrhenatheretea* class and its traditional syntaxonomy in the former USSR.

## Study area

The study area covers the forest and forest-steppe zones of the Ukrainian plains. In general, I follow the boundaries of the territory in accordance with the latest version of geobotanical zonation of Ukraine (Didukh & Shelyag-Sosonko 2003) (Fig. 1). Overall, the study area covers about 54% of Ukraine (~326 000 km²).

Much of the territory belongs to the Polissian (maximum 316 m a.s.l.) and Dnieper (236 m) lowlands. The right bank of the Dnieper River is dominated by upland areas, namely the Podolian (471 m), Volyn (361 m) and Dnieper (323 m) uplands (Marinich et al. 1985; Kryzhova & Kulyk 2007), in which different rocks (granite, limestone, chalk, sandstone, etc.) are often exposed on the surface. This causes considerable diversity of steppe and petrophyte grassland vegetation. However, the river valleys in the upland regions are often narrow with very small floodplains, and little space for mesic and wet grasslands. In contrast, lowland regions are characterized by extensive floodplains with high diversity of mesic, damp and wet grasslands.

In the Polissian lowland area, the zonal soils are sod-podzols. In big lowlands with relatively frequently high water tables, the soils are gleying in the lower horizons and the landscape is dominated by bog-podzolic soils. In depressions in continental meadows, sod-gley soils are formed with varying degrees of gleying, depending on the depression depth. The periphery of peatlands usually contains peat-bog soils. The transition from Polissya (forest zone) to forest-steppe is associated with the appearance of carbonate loess sediments that change from non-carbonate glacial deposits. In the forest-steppe, the zonal soils are light grey and grey forest soils as well as typical chernozems. Floodplains have mainly meadow and meadow-marsh soils (Vernander 1986).

The large size of the study area (about 500 km from north to south and more than 1,100 km from west to east) means there is a wide variety of climatic conditions, which obviously have a great influence on the grassland formations, including meadow vegetation. The average annual temperature increases slightly from north to south. It is the lowest in the northeast (6–7°C), and the highest in the southwest (9–10°C). Due to the air circulation patterns, precipitation in Ukraine decreases from the north and northwest towards the south and southeast. In the cold period (November-March), precipitation throughout most of the territory is 175–200 mm. In the warm season (April-October), the spatial distribution of precipitation is similar to the annual distribution (Lipins'kyi et al. 2003). The highest annual rainfall occurs in the western part of the study area (450–475 mm) and the lowest along the boundaries of the forest-steppe and steppe zone (325–350 mm). Thus, during the warm season precipitation gradually decreases in the direction from northwest to southeast. The plain part of Ukraine is located within two climatic regions, with the study area being assigned to the Atlantic-Continental regional climate (Lipins'kyi et al. 2003).

## Methods

### Data preparation

The study is based on the vegetation relevés collected from the literature and from unpublished sources stored in the Ukrainian Grassland Database (GIVD code EU-UA-001) (Kuzemko 2012b), which is also included in the European Vegetation Archive (EVA) (Chytrý et al. 2016).

Only those relevés previously assigned to the *Molinio-Arrhenatheretea* class were selected, resulting in a dataset with 2,105 relevés and 1,047 species. The plot size of the relevés ranged from 16 to 100 m², which is considered acceptable for grassland vegetation. The floristic data were

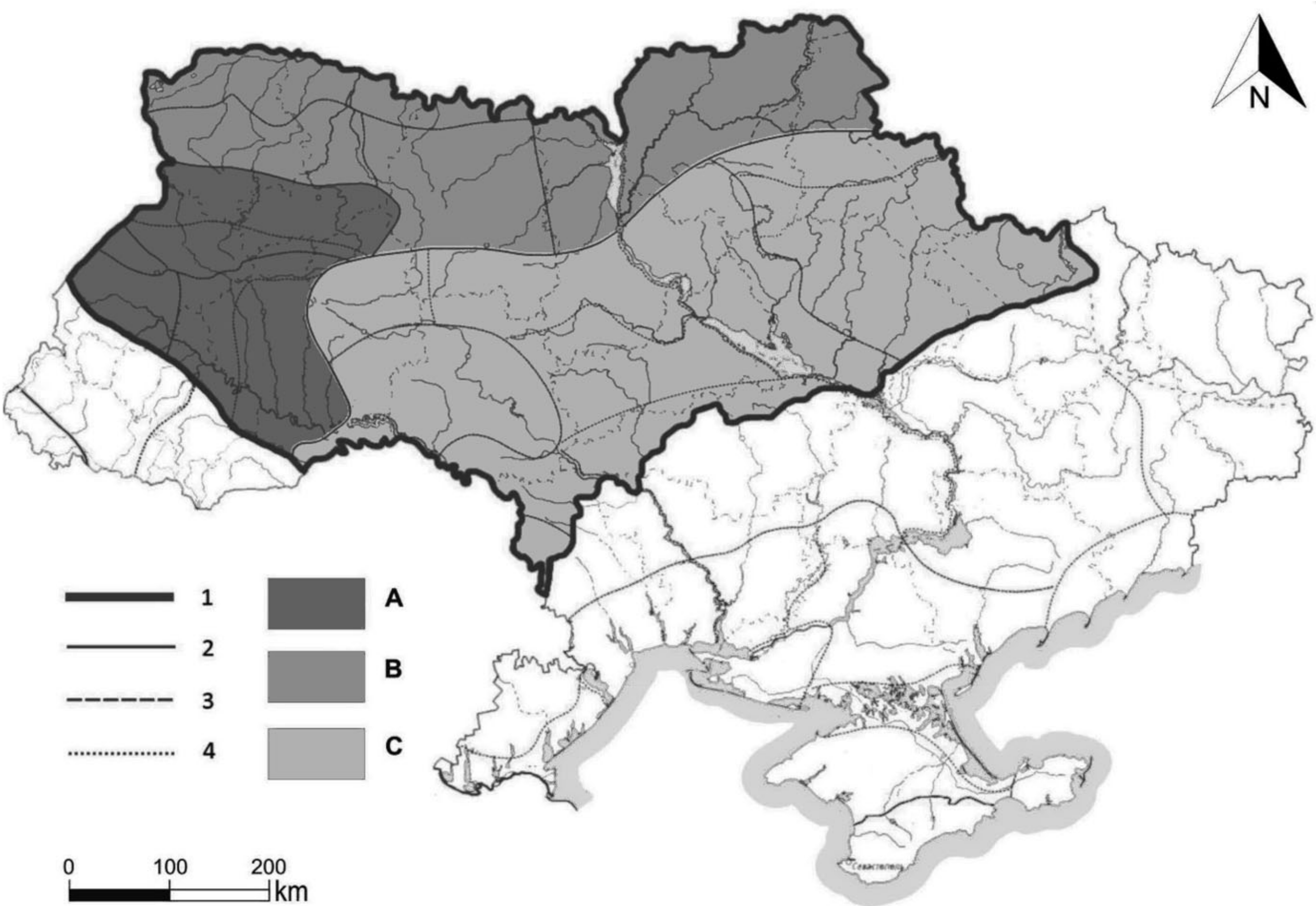


**Fig. 1.** Forest and forest-steppe zones of Ukraine (Didukh & Shelyag-Sosonko 2003). 1-4 the borders of the units of geobotanical zonation of Ukraine – zones (1), provinces (2), subprovinces (3) and districts (4); A-B – European broad-leaves forests zone: Central European province of broad-leaved forest (A), Eastern European province of mixed and broad-leaved forest (B), C – Forest-Steppe zone, Forest-Steppe province of the oak forests, steppe meadow and meadow steppes.

revised and corrected according to Flora Europaea (Tutin et al. 1968–1993). There are some mismatches in nomenclature used in Ukrainian and European taxonomy. In some cases, I used species aggregates as presented in the Supplement S1 in order to avoid introducing error into the identification of vegetation units based on floristic composition.

For more accurate assignment of relevés to the *Molinio-Arrhenatheretea* class, I carried out additional analyses using the European Expert System (Mucina et al., in press) in the JUICE program (Tichý 2002), which allows raw automatic classification of plant community data using some selected target species and thus assigning them to a class of vegetation. During this analysis, 414 relevés were re-assigned to other classes of vegetation. A total number of 1,691 relevés that according to the expert system were correctly classified in the class *Molinio-Arrhenatheretea* class were finally selected. Since not all relevés contained information about cryptogams or tree and shrub layers, all of these species were removed before further analysis in order to obtain a more homogeneous dataset. I also excluded all species identified only to the genus level (except the *Alchemilla* genus). The dataset was stratified following a Heterogeneity-Constrained Resampling (Lengyel et al. 2011) to the relevés from one cell of the geographical grid of 1.25 minutes of longitude × 0.75 minutes of latitude (approximately 1.5 × 1.4 km). The relevés were then sorted in order to maximize beta-diversity (according to the Bray-Curtis Index) in the range from 1 to 5 relevés per stratum. As a result of this stratification 1,197 relevés with 681 species were obtained and used for further analysis.

## Data analysis

All analyses were performed in JUICE 7.0 (Tichý 2002). In particular, I tested divisive methods of clustering: TWINSPAN algorithm (Hill 1979), modified TWINSPAN (Roleček et al. 2009) measuring of heterogeneity with Sørensen, Simpson, Jaccard dissimilarity and Whittaker beta-diversity, and also agglomerative methods based on cluster analysis in PC-ord software (McCune & Mefford 2006). I used different combinations of distance measures and group linkage method, with and without logarithmic transformation of the data, and also cluster algorithms of non-supervised *K*-means (Legendre & Legendre 1998) and PAM (Kaufman & Rousseeuw 1990) with number of starts 10 and number of related plots for definition of starting centroid three or five. To determine the optimal number of clusters I used functions "crispness of classification" (Botta-Dukát et al. 2005) the results of which are presented in Supplement S2.

The units obtained in the analysis have been evaluated for quality using Sharpness index (Chytrý & Tichý 2003) and for internal homogeneity by calculating Average Whittaker beta-diversity. When selecting the optimal method of classification, an advantage was given to the method that provided the receiving units with: 1) higher values of Sharpness index, 2) lower values of Average Whittaker beta-diversity, and 3) lower values of standard deviation for both of these indexes (Supplement S3). However, the final choice of the best method of classification was based on expert knowledge of the author.

Diagnostic species of the vegetation units were determined using calculations of their fidelity based on a *phi*-coefficient (Tichý & Chytrý 2006). Diagnostic species were considered as those with a *phi*-coefficient higher than 0.2, and highly diagnostic species were those with *phi* > 0.4 (bold in the text). When calculating this index I used the following options: 1) calculation of fidelity based on the presence / absence of species; 2) standardization of all relevés to groups of equal size; 3) exclusion of non-essential values of fidelity based on Fisher's exact test at $p < 0.01$.

The identification of the obtained syntaxa was carried out on the basis of analysis of their diagnostic species using the author's own expert assessment and the literature (Päzolt & Jansen 2004; Hájková et al. 2007, 2014; Rūsiņa 2007; Kącki et al. 2013). The most useful sources were those using numerical methods of vegetation classification, an inductive approach and a clear, ecologically grounded concept of syntaxa.

I used the Didukh indicator values (DIV; Didukh 2011) for the environmental assessment of the identified units including 10 factors: soil water regime (Hd), soil acidity (Rc), total salt regime (Sl), carbonate content in soil (Ca), nitrogen content in soil (Nt), thermoregime (Tm), continentality of climate (Kn), humidity of climate (Om), cryo-climate (Cr) and light (Lc). The values of the environmental factors were determined in the program JUICE by using the tool "Indicator values". To identify the patterns of syntaxa arrangement in multidimensional space of environmental factors I used a method of DCA-ordination with R-project, integrated into JUICE with DIV as environmental vectors.

## Results

### Classification

The 414 relevés originally assigned to the *Molinio-Arrhenatheretea* class that were not confirmed by the European Expert System were re-assigned to the classes *Phragmito-Magno-Caricetea* Klika in Klika et Novák 1941 (123 relevés), *Artemisietea vulgaris* Lohmeyer et al. ex von Rochow 1951 (104 relevés), *Festuco-Brometea* Br.-Bl. et Tx. ex Soó 1947 (80 relevés), *Koelerio-Corynephoretea* Klika in Klika et Novák 1941 (79 relevés), *Scheuchzerio-Caricetea fuscae* Tx. 1937 and *Stellarietea mediae* Tx. et al. ex von Rochow 1951 (7 relevés each), *Nardetea strictae* Oberd. 1949 (six relevés), *Galio-Urticetea* Passarge ex Kopecký 1969, *Bidentetea* Tx. et al. ex von Rochow 1951 and *Trifolio-Geranietea sanguinei* T. Müller 1962 (two relevés each), *Polygono-Poetea annuae* Rivas-Mart. 1975 and *Salicetea purpureae* Moor 1958 (one relevé each).

I accept that differentiation at the alliance level reflects the results with the number of clusters from six to 10 that depends on the method chosen. When using the cluster analysis, available in PC-ord, with different distance measures and group linkage methods, the units obtained are characterized by a quite low values of the Sharpness Index and high values of the Whittaker beta-diversity. This indicates that they are less suitable for analysis of the data set compared to other methods (Supplement S3). The best results for sharpness and homogeneity of the units were obtained using the modified TWINSPAN algorithm. However, when using this method the mean values of the Sharpness Index and Whittaker beta-diversity were characterized by very high values of the standard deviation, which is explained by the uneven number of relevés in clusters, which ranged from three to 590. When clustering methods using *K*-means and PAM were used (with number of starts being 10 and number of related plots for definition of starting centroid being five), the results were approximately similar, but with *K*-means clustering the units are characterized by lower figures of Whittaker beta-diversity, i.e. they are internally more homogeneous. Thus, the best results were obtained by the clustering method of *K*-means and seven clusters, which allowed the best interpretation of the results (Table 1).

The resulting vegetation units were interpreted as alliances of the Braun-Blanquet system based on complex of diagnostic species (Supplement S4).

Cluster 1 was identified as the *Agrostion vinealis* alliance. Diagnostic species: *Achillea millefolium* subsp. *millefolium*, *Agrostis vinealis*, *Allium angulosum*, *Bromopsis inermis*, ***Carex praecox***, *Centaurea jacea* subsp. *jacea*, *Cichorium intybus*, *Crepis tectorum*, *Dianthus borbasii* subsp. *borbasii*, *Elytrigia repens* subsp. *repens*, *Eryngium planum*,

**Table 1.** Characteristics of the distinguished vegetation units.

| Cluster N | Syntaxa | Number of relevés | Sharpness Index | Whittaker beta-diversity Index |
|---|---|---|---|---|
| 1 | *Agrostion vinealis* | 158 | 32.40 | 13.78 |
| 2 | *Arrhenatherion elatioris* | 207 | 20.20 | 18.86 |
| 3 | *Cynosurion cristati* | 253 | 11.39 | 16.53 |
| 4 | *Deschampsion cespitosae* | 120 | 29.03 | 10.73 |
| 5 | *Molinion caeruleae* | 91 | 38.79 | 12.38 |
| 6 | *Potentillion anserinae* | 165 | 20.99 | 17.81 |
| 7 | *Calthion palustris* | 203 | 21.60 | 17.06 |

*Euphorbia virgata*, *Festuca valesiaca* subsp. *valesiaca*, *Filipendula vulgaris*, ***Galium verum* subsp. *verum***, ***Koeleria delavignei***, *Lotus corniculatus* subsp. *corniculatus*, ***Poa angustifolia***, ***Potentilla argentea***, *Rumex acetosella* subsp. *acetosella*, *Rumex thyrsiflorus*, ***Stellaria graminea***, *Vicia tetrasperma*.

It includes relevés of communities that are distributed mainly in the northeastern part of Ukraine, on the left bank of the Dnieper River (Fig. 2a). In the right-bank of the Dnieper River (Right-Bank Ukraine) they occur only in the Dnieper basin. This syntaxon includes psamo-xero-mesophilous communities common in riverine part of floodplains. The communities are usually used as pasture although they have low productivity. Dominants in this vegetation are representatives of the steppe and psammophytic communities *Agrostis vinealis, Poa angustifolia* and *Koeleria delavignei*. The complex of diagnostic species is well defined, which is also confirmed by high values of the Sharpness Index (see Table 1) and also includes a significant proportion of representatives of the afore-mentioned types of vegetation. The species with the highest constancy in this alliance are *Plantago lanceolata, Festuca pratensis, Alopecurus pratensis* and *Trifolium pratense*.

Cluster 2 was identified as the alliance *Arrhenatherion elatioris* Luquet 1926.

Diagnostic species: ***Achillea millefolium* subsp. *millefolium***, *Anthoxanthum odoratum*, *Bromus hordeaceus* subsp. *hordeaceus*, *Carex hirta*, *Carum carvi*, *Cerastium fontanum* subsp. *fontanum*, *Dactylis glomerata* subsp. *glomerata*, *Daucus carota* subsp. *carota*, *Erigeron annuus* subsp. *annuus*, *Galium mollugo*, *Medicago lupulina*, *Oenothera rubricaulis*, *Pimpinella saxifraga*, *Plantago lanceolata*, *Trifolium dubium*, *Veronica chamaedrys* subsp. *chamaedrys*.

It includes communities distributed mainly in the northern part of the study area within the forest zone, but in the forest-steppe they are rare (Fig. 2b). The syntaxon includes communities of mesic floodplains and upland meadows, mainly distributed in flat, sometimes depressed areas of riverbed parts of floodplain and slightly elevated areas in the central part of floodplains. This alliance is characterized by the highest internal heterogeneity as the value of Whittaker beta-diversity is greater than that of the other alliances (see Table 1). Dominant species of the communities are typical of mesic grasslands *Festuca rubra, F. pratensis, Poa pratensis*. The same species as well as *Ranunculus acris, and Trifolium pratense* have the highest constancy.

Cluster 3 includes relevés assigned to the *Cynosurion cristati* Tx. 1947 alliance.

Diagnostic species: *Festuca pratensis*, *Leontodon autumnalis*, *Lolium perenne*, *Poa pratensis* subsp. *pratensis*, *Ranunculus acris* subsp. *acris*, *Taraxacum officinale*, *Trifolium pratense* subsp. *pratense*, *Trifolium repens* subsp. *repens*.

Communities of this alliance are quite evenly distributed throughout the study area, while in the north-western regions they are somewhat less common (see Fig. 2c). The alliance includes communities of floodplain, upland or lowland mesic grasslands confined to the plain, rarely slightly raised or depressed areas of the central and terrace part of floodplain. Outside floodplains they occur on the flat-depressed areas of the watershed, in the bottoms of the shallow flowing valleys and other depressions. The vegetation of this alliance is formed only under fairly intensive grazing or combined use. The alliance is characterized by the lowest value of the Sharpness Index (see Table 1). The communities are dominated by *Festuca pratensis*, as well as *Lolium perenne, Poa pratensis* and *Trifolium repens,* which are the main cenosis-forming species in mesic grasslands in Ukraine and have wide ecological amplitudes as well as being typical pasture species resistant to trampling. This complex of diagnostic species is generally consistent with the Central European version, with the exceptions of the name-giving taxon *Cynosurus cristatus* and *Bellis perennis*, because these species are at the southern and eastern limits of their continuous distribution in the study area. The highest constancy in the relevés is reached by *Achillea millefolium, Potentilla anserina, Ranunculus repens*.

a)

*Agrostion vinealis*

b)

*Arrhenatherion elatioris*

c)

*Cynosurion cristati*

d)

*Deschampsion cespitosae*

e)

*Molinion caeruleae*

f)

*Potentillion anserinae*

g)

*Calthion palustris*

**Fig. 2.** Distribution of the alliances of the *Molinio-Arrhenatheretea* class in the forest and forest-steppe zones of Ukraine.

Cluster 4 was identified as the alliance *Deschampsion cespitosae* Horvatić 1930, and was distributed mainly in the north-eastern part of the study area in the forest zone, sometimes in the forest-steppe, but mainly on the Left-Bank part of Ukraine (Fig. 2d).
Diagnostic species: ***Achillea pyrenaica***, *Agrostis canina* subsp. *canina*, *Agrostis gigantea* subsp. *gigantea*, *Allium angulosum*, *Alopecurus pratensis*, ***Beckmannia eruciformis***, ***Carex vulpina***, *Cnidium dubium*, ***Gratiola officinalis***, *Inula britannica*, *Juncus atratus*, *Lysimachia nummularia*, *Lythrum virgatum*, *Myosotis cespitosa*, ***Poa palustris***, *Ranunculus flammula*, *Ranunculus repens*, *Veronica longifolia*.

This alliance includes communities of wet floodplain meadows, which are confined to depressions of different parts of floodplain, often in riverine and central parts, enriched by alluvial deposits. The formation of these communities is determined by flooding intensity, which is typical for floodplains in the lower reaches of large rivers. The land use is mainly hay mowing or mowing and grazing at moderate intensity. The alliance is characterized by a moderately high value of the Sharpness Index and at the same time it has the lowest value of the Whittaker beta-diversity (see Table 1). The communities are dominated by the tall grasses *Alopecurus pratensis, Poa palustris* and *Agrostis gigantea. Potentilla anserina* and *Mentha arvensis* have the highest constancy.

Cluster 5 includes relevés assigned to the *Molinion caeruleae* Koch 1926 alliance.
Diagnostic species: *Salix cinerea*, *Salix rosmarinifolia*; *Anthoxanthum odoratum*, *Briza media*, *Carex davalliana*, *Carex flava* subsp. *flava*, *Carex pallescens*, ***Carex panicea***, *Epipactis palustris*, *Filipendula ulmaria*, *Galium uliginosum*, *Genista tinctoria*, *Gentiana pneumonanthe*, *Holcus lanatus*, *Linum catharticum* subsp. *catharticum*, *Luzula multiflora* subsp. *multiflora*, *Lysimachia vulgaris*, ***Molinia caerulea***, *Parnassia palustris*, *Polygala amarella*, ***Potentilla erecta***, *Sanguisorba officinalis*, *Schoenus ferrugineus*, *Selinum carvifolia*, *Serratula tinctoria* subsp. *tinctoria*, *Stachys officinalis* subsp. *officinalis*, ***Succisa pratensis***, *Trifolium montanum* subsp. *montanum*, *Valeriana simplicifolia*.

Communities of this cluster are distributed mainly in the northern regions of Ukraine within the forest zone, their largest concentration is observed in the west and northeast of the study area (Fig. 3e). The alliance includes communities of floodplain, upland and lowland moderately wet meadows in shallow depressions of the terraced area, with less in the central part of floodplain. In addition these commuinities occur outside floodplains in depressions on the river terraces or watersheds, often in place of partially reclaimed terrace marshes and in flat depressions with low amplitude of moisture fluctuations. They also occur in areas with low to moderate grazing intensity, sometimes disturbed by peat extraction, or in overgrown former peat extraction sites. The land use is mowing and grazing with moderate intensity. The alliance exceeds all other alliances in the value of the Sharpness Index, and yet it has a very low Whittaker beta-diversity value (see Table 1). The dominant species is *Molinia caerulea*, and *Potentilla anserina, Deschampsia cespitosa* and *Ranunculus acris* have the highest constancy values.

Cluster 6 was identified as the alliance *Potentillion anserinae* Tx. 1947, including relevés throughout the study area with an exception of the northwestern regions, and also the south forest-steppe of the Right-Bank of the Dnieper River (Fig. 2f).
Diagnostic species: ***Agrostis stolonifera* subsp. *stolonifera***, *Alopecurus geniculatus*, *Bidens tripartitus* subsp. *tripartitus*, *Eleocharis palustris* subsp. *palustris*, *Glyceria fluitans*, *Mentha arvensis*, *Persicaria maculosa*, *Plantago major* subsp. *major*, *Potentilla anserina* subsp. *anserina*, *Rorippa amphibia*, *Schoenoplectus tabernaemontani*, *Trifolium fragiferum* subsp. *fragiferum*, *Triglochin palustris*.

The alliance combines the vegetation of floodplain and lowland meadows, common in flat and shallow depressions of the terrace part (in floodplains of large and medium rivers) and the central part (floodplains of small rivers). They often occur in the floodplains affected by drainage amelioration. Outside floodplains, the communities are confined to depressed areas of river terraces, watershed depressions, bottoms of ravines and gullies, drained valley marshes. They are formed in place of damp and wet meadows under conditions of intense grazing, which leads to the deterioration of the air and water regime of soil, often accompanied by the formation of characteristic hubble microrelief. The dominant species is *Agrostis stolonifera* which is well adapted to grazing. The grazing tolerant species *Ranunculus repens* and *Trifolium repens* also have highest constancy.

Cluster 7 is represented by communities assigned to the alliance *Calthion palustris* Tx. 1937 and evenly distributed over the study area (Fig. 2g).
Diagnostic species: *Caltha palustris*, *Calystegia sepium*, *Carex acutiformis*, *Cirsium rivulare*, *Equisetum palustre*, *Galium palustre*, *Iris pseudacorus*, *Juncus effusus*, *Juncus inflexus*, *Lythrum salicaria*, *Phalaroides arundinacea*, *Scirpus sylvaticus*, *Symphytum officinale* subsp. *officinale*, *Valeriana officinalis*.

It includes the most humid communities of lowland and floodplain wet and damp meadows of the *Molinio-Arrhenatheretea* class. These communities are confined to eutrophic and meso-eutrophic habitats in shallow flat depressions (slightly flowing or not flowing), along the edges of floodplain ponds and marshes in terraces and central parts of floodplains, as well as outside floodplains in the depressions of river terraces and watersheds, on the margins of terrace marshes. The landuse regime is mowing or combined mowing and grazing, rarely grazing or abandoned. This alliance, like the previous one, has average values of the Sharpness Index and a relatively high internal heterogeneity (see Table 1). The communities are dominated mostly by *Scirpus sylvaticus* and *Carex cespitosa*. The species with the highest constancy are *Ranunculus repens* and *Potentilla anserina*.

The proposed synopsis of the studied class in the present study is the following:

*Molinio-Arrhenatheretea* Tx. 1937
- *Galietalia veri* Mirkin et Naumova 1986 (syn. *Poo-Agrostietalia vinealis* Shelyag-Sosonko et al. 1985 (nom. inval.))
  - *Agrostion vinealis* Sypailova et al. 1985
- *Arrhenatheretalia* Pawłowski et al. 1928
  - *Arrhenatherion elatioris* Luquet 1926 (syn. *Festucion pratensis* Sipailova et al. 1985)
  - *Cynosurion cristati* Tx. 1947
- *Molinietalia* Koch 1926 (incl. *Deschampsietalia caespitosae* Horvatić 1958, *Potentillo-Polygonetalia* Tx. 1947)
  - *Deschampsion cespitosae* Horvatić 1930 (syn. *Alopecurion pratensis* Passarge 1964)
  - *Molinion caeruleae* Koch 1926
  - *Potentillion anserinae* Tx. 1947
  - *Calthion palustris* Tx. 1937 (incl. *Filipendulion ulmariae* Segal 1966, *Veronico longifoliae-Lysimachion vulgaris* (Passarge 1977) Bal.-Tul. 1981)

## Ordination

According to the results of the DCA-ordination (Fig. 3) the first ordination axis correlates strongly with moisture vector, along which the identified alliances are arranged from the driest *Agrostion vinealis* to the wettest *Calthion palustris*. The vector of carbonate content in the soil is also close to the first axis and is directed toward the opposite of moisture vector. Thus, the right part of the ordination diagram contains the xero-mesophilous alliance *Agrostion vinealis* and mesophilous alliances *Arrhenatherion* and *Cynosurion cristati*. The left-hand section contains the alliances of wet meadows *Potentillion anserinae* and *Calthion palustris*, and an intermediate position in the center of the diagram is occupied by the fresh meadow alliances *Deschampsion* and *Molinion*. The second ordination axis is strongly correlated with the vector of soil salt regime and less strongly with the vectors of soil acidity, continentality and thermoregime. According to this distribution, the lower area of the diagram contains the alliances *Potentillion anserinae*, *Cynosurion cristati* and less *Deschampsion*, because their communities undergo intensive, mostly pasture use. The upper area contains the alliances *Molinion*, *Arrhenatherion* and less *Calthion*, which are used less intensively and primarily as hayfields. The *Agrostion vinealis* alliance occupies an intermediate position with its centroid set right on the second ordination axis. Other factors play a smaller role in differentiating the syntaxa. Thus, the vector of nitrogen content in the soil separates the *Potentillion anserinae* alliance, which is linked to the management regime mentioned above. The *Molinion* and *Arrhenatherion* alliances are separated by a factor of cryoregime, the *Molinion* and *Calthion* by a factor of ombroregime due to the distribution of majority of these alliances communities in the north of the study area within the humid zone.

## Discussion

Using the European Expert System resulted in about 20% of the relevés previously assigned to the *Molinio-Arrhenatheretea* class being excluded from the analysis, and assigned to 12 other classes. At the same time, 93% of these relevés were assimilated to just four classes. It is therefore logical that a large number of relevés of wet meadows, previously included mainly to the *Calthion* alliance were classified by the expert system within *Phragmito-Magno-Caricetea* class, since the boundaries between classes are rather blurred. The other three classes, *Artemisietea vulgaris*, *Festuco-Brometea* and *Koelerio-Corynephoretea* included mainly the relevés previously contained within the *Galietalia veri* order. The order originally assigned to the *Trifolion montani* alliance came into *Festuco-Brometea*, those ordered to the *Agrostion vinealis* came in the *Koelerio-Corynephoretea* and transformed communities of both alliances came in the *Artemisietea vulgaris*. This situation once again proved to be a debatable syntaxonomy of the “dry wing” of the *Molinio-Arrhenatheretea* class. This problem has been discussed repeatedly in the literature (Kuzemko & Dziuba 2002; Kuzemko 2009a, 2009b, 2012a; Kuzemko et al. 2014). These communities are almost absent in Europe, with the results that they have no analogues among classical Central European syntaxonomic units. There is also no consensus on the syntaxonomy of such communities among phytocenologists from Eastern Europe. Most researchers include them in the various alliances of the

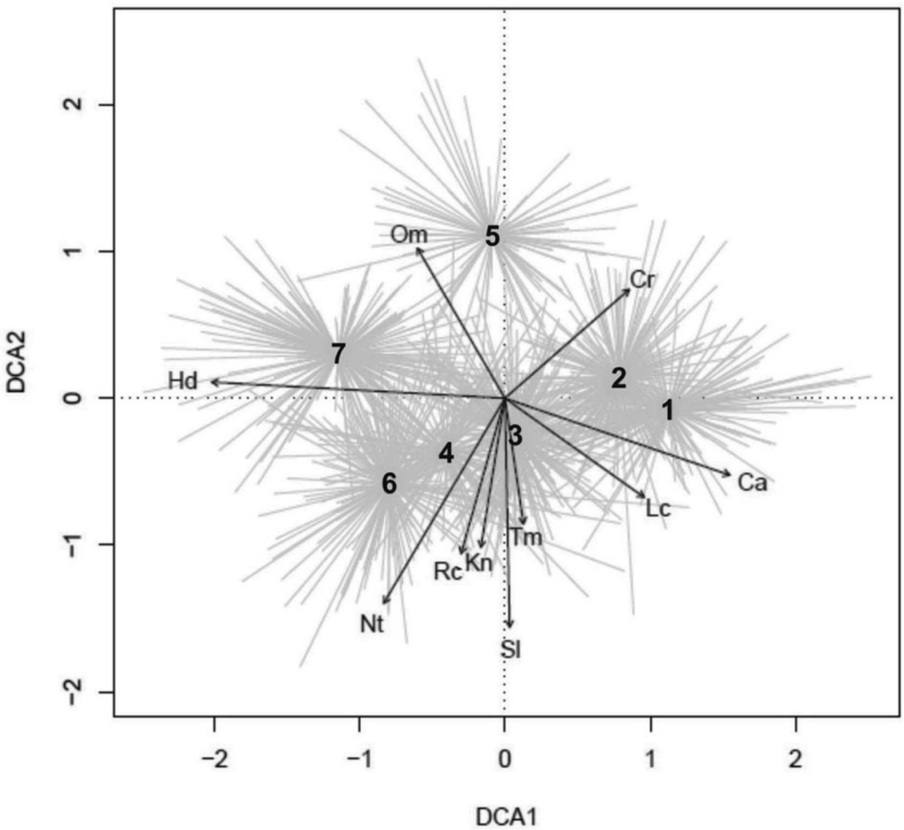


**Fig. 3.** DCA-ordination of the dataset with centroids of particular clusters. Number of the centroids corresponds to the numbers of clusters in the Table 1. Ecological vectors: Hd – soil water regime, Rc – soil acidity, Sl – total salt regime, Ca – carbonate content in soil, Nt – nitrogen content in soil, Tm – thermoregime, Om – humidity of climate (ombroregime), Kn – continentality of climate, Cr – cryoregime and Lc – light; alliances 1 – *Agrostion vinealis*, 2 – *Arrhenatherion elatioris*, 3 – *Cynosurion cristati*, 4 – *Deschampsion caespitosae*, 5 – *Molinion caeruleae*, 6 – *Potentillion anserinae*, 7 – *Calthion palustris*. Eigenvalues: 1st axis (DCA1) 0.4278, 2nd axis (DCA2) 0.2547.

*Galietalia veri* Mirkin et Naumova 1986 order (Kuzemko 2009b; Bulokhov 2001; Ermakov 2012; Yamalov et al. 2012; etc.). Recent publications have suggested distributing these communities between classes *Koelerio-Corynephoretea*, *Festuco-Brometea* and to a lesser extent *Molinio-Arrhenatheretea* and *Trifolio-Geranietea* (Kuzemko et al. 2014). In the present analysis, the use of the European Expert System actually led to some of the relevés previously considered as a part of the the *Galietalia veri* order being excluded from the *Molinio-Arrhenatheretea* class and referred to the three abovementioned classes of dry grasslands. However, many of the relevés still remain in the *Molinio-Arrhenatheretea* class. These relevés form a separate cluster, identified as *Agrostion vinealis* alliance with a distinct diagnostic block of species, as evidenced by the high value of the Sharpness Index (the value of this index for this alliance is second only to that of the *Molinion caeruleae*, which characterizes it as a "good" unit) and no signs of internal differentiation, sufficient for identification within a cluster of several units of the alliance rank, as evidenced by the low Whittaker beta-diversity Index. Thus, the *Agrostion vinealis* occupies an intermediate position between the *Molinio-Arrhenatheretea* class and other classes of dry grasslands. In the present paper, an affiliation of the syntaxa to the *Molinio-Arrhenatheretea* class was confirmed by the analysis using the European Expert System, but nevertheless the alliance was clearly separated by a set of diagnostic species. However, it was somewhat surprising that, based on the results, it was not possible to distinguish another xeromesophilous alliance, *Trifolion montani* Naumova 1986, which was distinguished earlier using other methods (Kuzemko 2009a, 2009b, 2012a). The differentiation of these alliances was not observed in the variants of analysis with larger numbers of clusters with the consequence that they only made the interpretation of the units at the level of alliances more difficult. Obviously, the communities that were previously considered as a part of this alliance, were assigned by the expert systems to the *Festuco-Brometea* class.

Another problem was the differentiation of the "dry wing" of the *Molinio-Arrhenatheretea* class at the level of orders. In the original publication, the *Agrostion vinealis* alliance was included to the *Arrhenatheretalia* order (Sypailova et al. 1985), and later assigned to the newly described order *Poo-Agrostietalia vinealis* (Shelyag-Sosonko et al. 1985). Only one recently published synthesis on the vegetation of Europe (Rodwell et al. 2002) places the *Agrostion vinealis* alliance within the *Poo-Agrostietalia vinealis* order, which in this publication is, however, not included into *Molinio-Arrhenatheretea* class, but into the *Festuco-Brometea* class. Moreover, in that publication it is stated, probably erroneously, that communities of the *Agrostion vinealis* alliance are formed on leached chernozem-like soils, whereas in fact they are confined to light sod and meadow-sod soils. Earlier it was proved that the *Poo-Agrostietalia vinealis* and *Galietalia veri* orders are synonymous (Kuzemko & Dzyuba 2002; Kuzemko 2009b), the first of them is not valid according to the current edition of ICPN (Weber et al. 2000). The assignment of the *Agrostion vinealis* alliance to the *Arrhenatheretalia* order is not appropriate because, unlike typical mesophytic communities that are traditionally assigned to this order, it includes xero-mesophylous communities. In addition, the author adheres to the class concept *Molinio-Arrhenatheretea*, which provides differentiation in the "dry" (*Galietalia veri* order), "mesophytic" (*Arrhenatheretalia* order) and "wet" (*Molinietalia* order) part, and not just on mesophytic and wet parts as in the traditional Central-European syntaxonomy.

The syntaxonomy of mesic meadows is less controversial, but the status of the *Festucion pratensis* alliance and its relationship with the *Arrhenatherion* alliance nevertheless remains unclear. These two alliances have been traditionally considered as vicariants (Sypailova et al. 1985; Kuzemko 2009b; Birzniece et al. 2011). However, the results of the analysis did not show sufficient separation of the alliance. The reason for this can be seen in the features of the original diagnosis of the alliance, which includes species with wide ecological amplitude such as *Festuca pratensis, F. rubra, Poa pratensis, Phleum pratense, Trifolium pratense*. All these species are present in the *Arrhenatheretalia* order communities actually within the entire range from the Iberian Peninsula (Rodriquez-Rojo et al. 2014) to Bashkortostan (Yamalov 2005). The name *Festucion pratensis* obviously needs to be removed in accordance with Article 24 of the ICPN (Weber et al. 2000) and classified as synonym of the *Arrhenatherion elatioris* alliance, since the association *Festucetum pratensis* Soó 1938 that was chosen as nomenclature type of the *Festucion pratensis* alliance (Sypailova et al. 1985) belongs to the *Arrhenatherion elatioris* alliance in the original publication (Soó 1939). When comparing the complex of diagnostic species of this alliance in Ukraine with the diagnostic species of the alliance in Central Europe, particularly Czech Republic (Hájková et al. 2007), Poland (Kącki et al. 2013), Slovakia (Hájková et al. 2014) it is clear that many of the species that are diagnostic for the alliance in Central Europe (*Arrhenatherum elatius, Campanula patula, Leucanthemum vulgare, Knautia arvensis*, etc.), have a relatively high fidelity in this cluster but not enough to consider them as diagnostic in Ukraine. These differences between Ukrainian and Central European communities resulted in the description of the *Festucion pratensis* alliance. However, the present analysis did revealed no differentiation within this vegetation unit that justifies considering these two alliances separately. The cluster that includes relevés assigned to the *Arrhenatherion* alliance has the greatest internal heterogeneity compared with other units (see Table 1), which indicates the need to confirm the results obtained by the analysis using data from wider area. It is notable that most of the relevés of transformed pastures previously identified within the *Festucion pratensis* alliance were included in the present analysis in the *Cynosurion cristati* alliance. This alliance has the lowest number of diagnostic species, and the lowest Sharpness Index among all analyzed alliances of the class. This is understandable when considering the excessive transformation of plant communities due to grazing that leads to a leveling of environmental conditions and loss of specialist species, to be replaced by generalists.

Taking into account the largest number of described alliances, the syntaxonomy of the "wet" part of the *Molinio-Arrhenatheretea* class, is difficult, however, as all of them were described in Central Europe, they are therefore less controversial compared to previous units. Some inconsistency is observed on the status of certain alliances of damp and wet meadows. Hence, for the countries of Central Europe the *Deschampsion* alliance is traditional (Päzolt & Jansen 2004; Hájková et al. 2007, 2014), and its diagnosis almost overlaps with the alliance *Alopecurion pratensis,* which is traditional for East European phytocenology (Bulokhov 2001; Grigor'ev et al. 2002; Kuzemko 2009b; Yamalov et al. 2012 etc.). Most European authors consider the *Alopecurion pratensis* alliance together with *Agrostion albae* Soó 1941, *Cnidion venosi* Bal.-Tul. 1965 and *Veronico longifoliae-Lysimachion vulgaris* (Passarge 1977) Bal.-Tul. 1981 alliances as synonymous with the *Deschampsion* alliance (Botta-Dukát et al. 2005; Hájková et al. 2007). However, this rule has many exceptions, e.g. in the last survey of Polish vegetation (Kącki et al. 2013) such communities are considered in the *Cnidion venosi* alliance. Instead, in the "*Prodromus of higher vegetation units of Russia*" (Ermakov 2012), the syntaxonomical status of the *Deschampsion* alliance is consistent with the Central European status, and the *Alopecurion pratensis* alliance is considered a synonym. Thus, according to the results of the present analysis, these communities from Ukraine should also be included in the *Deschampsion* alliance, especially as this solution has already been established for Central Europe using statistical methods (Botta-Dukát et al. 2005). However, in many sources from Eastern Europe the *Deschampsion* alliance is named, but with a description that is much more consistent with the Central European *Potentillion anserinae* alliance. Despite the fact that the communities of this alliance have not been previously mentioned for the territory of Ukraine, as far as the author knows, there is reason to suggest that these communities of wet meadows with pasture use should be regarded as part of the *Potentillion anserinae* alliance.

One of the most clearly defined alliances of meadow vegetation is *Molinion caeruleae*, which in the present analysis was characterized by the highest Sharpness Index and the highest internal homogeneity. However, this alliance proved also to have the lowest number of relevés. The reason for this could be that a necessary condition for the formation of the communities of the *Molinion* alliance is late mowing of herbage for the collection of litter for animal bedding (Poschlod et al. 2009). However, this practice is now very rare in Ukraine and only found in some western regions. In the rest of the area these communities are rapidly reducing in area due to increasing land use intensity, especially by grazing, or are otherwise abandoned and overgrown with trees and shrubs. Another issue not yet sufficiently investigated in the syntaxonomy of wet meadows, is the feasibility of differentiation of their "wettest" wing. In some sources, especially from Poland, a proportion of such communities with a predominance of tall grasses was assigned to the alliance *Filipendulion ulmariae* Segal 1966 (Matuszkiewicz 2008; Kuzemko 2009b) or in the *Veronico longifoliae-Lysimachion vulgaris* alliance (Kącki et al. 2013). However, the results of the present analysis did not demonstrate such differentiation within this unit, so that the wettest communities of the *Molinio-Arrhenatheretea* class were placed within the *Calthion* alliance (*sensu lato*).

There are also certain disagreements regarding the assignment of alliances of damp and wet meadows to the orders. In most of the analyzed sources, all wet meadows belong to the same order *Molinietalia*. However, some publications separately considerd the *Deschampsietalia* order (Sypailova & Shelyag-Sosonko 1996; Päzolt & Jansen 2004), while others included the *Potentillo-Polygonetalia* Tx. 1947 order (Ermakov 2012; Kącki et al. 2013). As already mentioned, the concept that I adopted, namely that the *Molinio-Arrhenatheretea* class contains three orders that are differentiated by the degree of moisture, does not provide differentiation of orders by management or transformation, which is the main criterion for differentiation at the alliance level.

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Supplement S1: A list of species aggregates.
Supplement S2: A results of the "crispness of classification" analysis.
Supplement S3: A results of the Sharpness Index and Whittaker beta-diversity Index calculation for the results of different methods of cluster analysis and differen number of clusters (mean ± SD).
Supplement S4: Synoptic table.

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