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Syntaxonomical and ecological diversity of the class *Polygono-Poetea annuae* in Bulgaria

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Abstract – Class *Polygono-Poetea annuae* Rivas-Mart. 1975 includes therophyte-rich vegetation on trampled habitats. The study presents the first analysis of the syntaxonomy of this class and its ecology in Bulgaria. One hundred seventy-five relevés from this class were collected and stored in the Balkan Vegetation Database during 2017–2020. Numerical classification (hierarchical divisive) and ordination were performed by JUICE and CANOCO software packages. Diagnostic species were determined by calculating the Phi-coefficient. Four associations, *Sclerochloo durae-Polygonetum arenastri, Polygonetum arenastri, Lolio-Polygonetum arenastri* and *Poëtum annuae,* were recognized. Their floristic composition has been shaped mainly by climatic and soil conditions. *Sclerochloo durae-Polygonetum arenastri* association has been found at lower altitudes, occurring in fully lighted habitats with high radiation, whereas *Poëtum annuae* has been found at higher altitudes in wetter and cooler areas. On the other hand, stands of *Polygonetum arenastri* have been found on nutrient-rich soils, whereas communities of *Lolio-Polygonetum arenastri* were distributed in warmer and nutrient-poor areas. The *Polygono-Poetea annuae* class is still poorly studied in Bulgaria and much more information from all regions of the country needs to be collected and analyzed.

Key words: Braun-Blanquet approach, *Polygono arenastri-Poetalia annuae*, *Saginion procumbentis*, trampled vegetation

Introduction

The class *Polygono-Poetea annuae* Rivas-Mart. 1975 includes disturbed vegetation of trampled habitats, formed mostly by annual plants with a ruderal or stress-tolerant life strategy (Láníková 2009). This vegetation is typical of anthropogenically influenced surfaces (roads, parks, parking lots, agricultural roads, playgrounds, etc.). Conditions are unfavorable and include mechanical pressure, leading to vegetation disruption. Soils are weakly aerated and highly compacted and sites have been sealed which leads to there being limited space for plants to grow. Drainage is also poor and plants that adapt and form these phytocoenoses are R and RS strategists (Grime 2001).

The syntaxonomical diversity of this vegetation has not been studied in Bulgaria due to a lack of rare plants, as well as plants with high conservation importance. Anthropogenic pressure in the last 60-80 years led to an increase in the size of areas with communities of the *Polygono-Poetea annuae* class. The class has been studied in different European countries: the Czech Republic (Láníková 2009), Slovakia (Jarolímek et al. 1997, Redneková and Mičieta 2017), Romania (Coldea 2012, Sanda et al. 2008), Slovenia (Čarni 2005), Austria (Mucina 1993), Albania (Dring et al. 2002), Slovenia (Šilc 2009, Šilc and Košir 2006), Croatia (Škvorc et al. 2017), North Macedonia (Čarni et al. 2002), etc. Accord-

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ing to Mucina et al. (2016) the class includes one order (*Polygono arenastri-Poetalia annuae* Tx. in Géhu et al. 1972 corr. Rivas-Mart. et al. 1991) and three alliances (*Polygono-Coronopodion* Sissingh 1969, *Polycarpion tetraphylli* Rivas-Mart. 1975 and *Saginion procumbentis* Tx. et Ohba in Géhu et al. 1972).

Synanthropic vegetation in Bulgaria (incl. classes of *Stellarietea mediae* s.l., *Artemisietea vulgaris*, *Epilobietea angustifolii*, *Galio-Urticetea*, *Bidentetea tripartitae* and *Oryzetea sativae*) has also been poorly studied. Data concerning this vegetation were presented in the publications of Kolev (1976), Mucina and Kolbek (1989), Dimitrov (2004), Dimitrov et al. (2005), Tzonev (2009), and Gussev et al. (2020). The syntaxonomical diversity includes 6 classes, 11 orders, 16 alliances, 33 associations, five plant communities (cf. Tzonev et al. 2009), and the prevailing number of syntaxa was described only from a single relevé. Moreover, some vegetation plots e.g. published by Kolev (1976) had a size of only 1 m^2, which is not recommended from the current perspective (see Chytrý and Otýpková 2003) and might not include the complete floristic composition since they are characterized by lower species richness than exhibited by recent data.

The aim of this study is to investigate the distribution, ecology and syntaxonomical diversity of the class of *Polygono-Poetea annuae* in Bulgaria.

Materials and methods

Study area

The *Polygono-Poetea annuae* class Rivas-Mart. et al. 1975 is found within areas diverse from the point of view of physical geography, e.g. lowlands, valleys, hills, plateaus, low and high mountains in Bulgaria. The most prominent lowland and valley features include the large areas of the Danube Valley and the Thracian Valley as well as the smaller ones of Sofia, Burgas and Kostenets-Dolna Banya Valleys. They fall mainly within the hypsometric zone between 0 m and 500-600 m a.s.l. The hilly and plateau relief includes the features of the Dobrudzha, Frangensko, Shumensko and Ludogorsko Plateaus, as well as the Haskovski and Chirpan Highlands, ranging from 300 m to 600 m a.s.l. Low mountainous territories include the areas of the Forebalkan, the mountains of Mala Planina, Chepan, Viskyar, Lyulin and Ihtimanska Sredna Gora that fall mainly within the hypsometric zone between 600 m and 1200-1300 m a.s.l. The highest mountains in the research area are the Balkan Range, Vitosha and Rila being three of the four highest mountains in the country.

The climate is temperate with large territories in the zone with transitional climates and areas with sub-Mediterranean features along the Black Sea coast. The water resources include some of the largest rivers in the country: the Iskar, Maritsa, Yantra and Ogosta along with their tributaries, accompanied by some shorter but still important river arteries, such as the Rositsa and Nishava.

Soil types are diverse as well, including *Chernozems*, *Cambisols*, *Vertisols*, *Luvisols*, *Fluvisols* and *Leptosols*.

Field sampling and data analysis

In Bulgaria 175 vegetation plots (relevés) presenting trampled vegetation, were sampled during the 2017-2020 period following the Braun-Blanquet approach (Westhoff and van der Maarel 1973). The plot size was 10-25 m^2, as recommended for synanthropic communities (Chytrý and Otýpková 2003). All relevés were stored in the Balkan Vegetation Database (Vassilev et al. 2020, currently including 18406 relevés) and analyzed with JUICE 7.0 (Tichý 2002) software.

Altitude, slope inclination and location were determined by a Garmin eTrex Vista device and the aspect of the slope with a compass for each relevé. Soil depth was estimated in three degrees: (1) shallow (<10 cm depth), (2) moderately deep (10-20 cm) and (3) deep (>20 cm).

Classification of relevés was carried out with JUICE 7.0 software (Tichý 2002). Modified TWINSPAN (Roleček et al. 2009) was applied for clustering the total number of sampled relevés and for the analysis of associations' heterogeneity. The diagnostic species were identified according to the Phi-coefficient (Chytrý et al. 2002). Only statistically significant values of Phi-coefficients, evaluated with Fisher's exact test ($P < 0.05$), have been given in the synoptic table. All clusters have been standardized to equal sizes. The threshold value for a species that is considered as diagnostic was set at a Phi-coefficient ≥ 0.3 (multiplied by 100). Species with Phi-coefficient ≥ 0.5 have been considered highly diagnostic. The species in the synoptic table have been ordered according to a decrease in the fidelity value. The diagnostic role of the species has also been considered according to available literature sources. The text presents diagnostic species that are the result of current analysis, whereas the tables also include those given as diagnostic in the literature. Two values have been presented for each species in the synoptic table: "Fidelity" – expressed by the Phi-coefficient and "Frequency" expressed as a percentage. Species with coverage above 50% in at least 20% of the relevés in any cluster have been considered as dominant, whereas constant species were those having at least 50% presence in a cluster. Differences in the ecological preferences of the four plant associations have been assessed using the Mann-Whitney and Kruskal-Wallis tests.

Detrended correspondence analysis (DCA) has been used as an indirect ordination technique using the CANOCO 4.5 software package (ter Braak and Šmilauer 2002) to reveal the major environmental gradients shaping the floristic composition. Square root transformation and downweighting of rare species have been applied. The habitat's ecological conditions has been assessed using the "Ellenberg Indicator Values" (Ellenberg et al. 1992) passively projected onto the ordination space. The significance of correlation of mean EIVs with scores of samples along ordination axes has been calculated using the modified permutation test elaborated by Zelený (Zelený and Schaffers 2012) and implemented in the stand-alone application MoPeT (available at: https://davidzeleny.net/wiki/doku.php/eiv:software).

The nomenclature of vascular plants is following Delipavlov and Cheshmedzhiev (2003) and has subsequently been standardized according to the Euro+Med PlantBase (2006-2020). The floristic elements have been interpreted according to Assyov and Petrova (2012). The species' life forms have been determined according to the classification of Raunkiær (1934). The nomenclature of the high rank syntaxa has been harmonized with Mucina et al. (2016). All species determined to genus level have been deleted. In addition, bryophytes and lichens have been removed from the species composition because they still are not determined for all relevés. We have also merged the following species into aggregates: *Achillea millefolium* agg. (*Achillea millefolium*, *A. distans*, *A. collina*, *A. setacea*), *Cerastium fontanum* agg. (*Cerastium fontanum*, *C. fontanum* subsp. *vulgare*), *Juniperus communis* agg. (*Juniperus communis*, *J. communis* subsp. *nana*), *Tragopogon pratensis* agg. (*Tragopogon pratensis*, *T. pratensis* subsp. *orientalis*), *Trifolium repens* agg. (*Trifolium repens*, *T. repens* var. *orbelicum*), *Verbascum longifolium* agg. (*Verbascum longifolium*, *V. longifolium* subsp. *pannosum*), *Vicia villosa* agg. (*V. villosa*, *V. villosa* subsp. *varia*) and *Polygonum aviculare* agg. (*Polygonum aviculare*, *P. rurivagum*).

Results

The 175 relevés have been classified into 4 associations, as a result of the analyses conducted and all of them have been defined floristically and ecologically (Tables 1, 2, Figs. 2, 3). The proposed syntaxonomical scheme is as follows:

Polygono-Poetea annuae Rivas-Mart. 1975
- *Polygono arenastri-Poetalia annuae* Tx. in Géhu et al. 1972 corr. Rivas-Mart. et al. 1991
  - *Polygono-Coronopodion* Sissingh 1969
    - *Sclerochloo durae-Polygonetum arenastri* Soó ex Bodrogközy 1966 corr. Borhidi 2003
    - *Polygonetum arenastri* Gams 1927 corr. Lanikova in Chytry 2009
    - *Lolio-Polygonetum arenastri* Br.-Bl. 1930 em. Lohmeyer 1975
  - *Saginion procumbentis* Tx. et Ohba in Géhu et al. 1972
    - *Poëtum annuae* Gams 1927

***Sclerochloo durae-Polygonetum arenastri* Soó ex Bodrogközy 1966 corr. Borhidi 2003** (Tab. 1, On-line Suppl. Tab. 1)

Diagnostic species: *Sclerochloa dura*

Constant species: *Polygonum aviculare* agg. (94%), *Lolium perenne* (70%)

Dominant species: *Polygonum aviculare* agg. (40%), *Sclerochloa dura* (32%)

Distribution and ecology: This association is widely distributed in Bulgaria (Fig. 1) and has been identified between 100 and 570 m a.s.l., in the Sofia lowland (Sofia city, Elin Pelin, Gorna Malina, Kostinbrod, Bozhurishte municipalities), the Thracian plain (Chirpan, Brezovo, Sadovo, Bratya Daskalovi, Rakovski municipalities), Mt Sredna

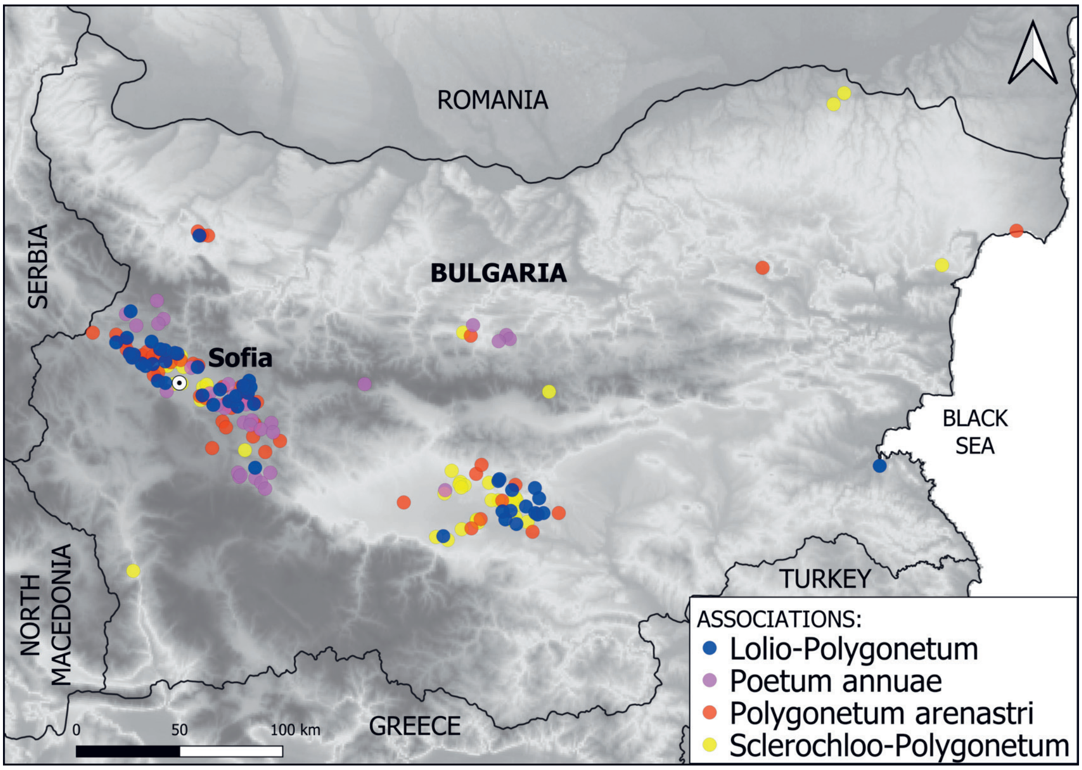

Fig. 1. Map of the study area. Sampled locations of the vegetation indicated in relation to association level.

Tab. 1. Shortened synoptic table of the class *Polygono-Poetea annuae* in Bulgaria. Light grey shade – diagnostic species with Phi > 30; Dark grey shade – diagnostic species with Phi > 50. Life forms abbreviations: B – Biannual, H – hemicryptophyte, T – Therophyte, T-B – Therophyte-Biannual. Florisric elements abbreviations: Adv – Adventive, Eur-As – Euro-Asiatic, Eur-Bal – Euro-Balkanic, Eur-Sib – Euro-Siberian, Eur-Med – Euro-Mediterranean, Kos – Cosmopolitian; SPont – South Pontic.

Life forms	Floristic elements	Number of relevés	*Sclerochloo-Polygonetum* 47 Phi	% friquency	*Polygonetum arenastri* 46 Phi	% friquency	*Poëtum annuae* 34 Phi	% friquency	*Lolio-Polygonetum* 48 Phi	% friquency
Diagnostic species of *Sclerochloo-Polygonetum arenastri*										
H	Eur-As	*Sclerochloa dura*[1]	66.1	83	---	9	---	9	---	21
H	Eur-As	*Lolium perenne*[2]	---	70	---	72	---	91	25.9	100
B	Eur-Sib	*Cynodon dactylon*	---	45	---	28	---	44	---	38
H	Eur-Med	*Lepidium draba*	18.4	11	---	0	---	0	---	6
Diagnostic species of *Polygonetum arenastri*										
T	Kos	*Polygonum aviculare* agg.[3]	---	94	19.7	100	---	79	---	85
Diagnostic species of *Poëtum annuae*										
H	Kos	*Ochlopoa annua*[3]	---	34	---	15	53.5	85	---	25
H	Eur-Sib	*Trifolium repens* agg.[4]	---	6	---	7	61.8	71	---	15
B	Boreal	*Plantago major*[3]	---	2	---	4	55.4	53	---	8
Diagnostic species of *Lolio-Polygonetum*										
T	Eur-Sib	*Capsella bursa-pastoris*[5]	49.6	89	---	35	---	41	---	21
Diagnostic species of all. *Sagion procumbentis*										
T-B	Eur-As	*Herniaria glabra*	---	0	---	0	21.2	6	---	0
T-B	subBoreal	*Spergularia rubra*	---	0	---	0	40.3	21	---	0
Diagnostic species of all. *Polygono-Coronopodion*										
H	Kos	*Verbena officinalis*	---	2	---	4	27.5	21	---	4
T	Eur-Med	*Descurainia sophia*	---	2	---	2	---	0	---	0
T	subBoreal	*Erodium cicutarium*	---	2	---	2	---	9	---	10
T-B	Eur-Med	*Geranium pusillum*	---	0	---	0	---	0	---	2
Diagnostic species of ord. *Polygono arenastri-Potalia annuae* & cl. *Polygono-Poetea annuae*										
T-B	Eur-As	*Lepidium ruderale*	---	2	---	0	---	0	---	0
Other species with Phi >30										
T	Adv	*Chenopodium album*	---	4	54.2	50	---	9	---	0
T	Eur-As	*Fallopia convolvulus*	---	4	30.6	17	---	0	---	0
H	Eur-Sib	*Alopecurus myosuroides*	45.9	43	---	4	---	3	---	8
H	Eur-As	*Anisantha sterilis*	30.1	26	---	0	---	6	---	8
T-B	Eur-As	*Torilis japonica*	---	0	---	0	30.2	12	---	0
T	Eur-Med	*Bromus hordeaceus*	---	2	---	0	33.1	24	---	6
H	Eur-Bal	*Agrostis capillaris*	---	0	---	0	33.8	15	---	0
T	Eur-Med	*Dactylis glomerata*	---	4	---	9	36.7	41	---	15
T	subBoreal	*Vulpia myuros*	---	0	---	2	40.3	24	---	0
H	SPont	*Potentilla argentea*	---	0	---	0	43.3	35	---	10
H	Eur-As	*Achillea millefolium* agg.	---	4	---	11	48.6	65	---	29
T	Kos	*Convolvulus arvensis*	---	36	---	52	---	50	30.6	81

[1] Species diagnostic also for *Polygonetum arenastri*, ord. *Polygono arenastri-Potalia annuae* & cl. *Polygono-Poetea annuae*; [2] Species diagnostic also for *Polygonetum arenastri*, *Lolio-Polygonetum*, all. *Sagion procumbentis*, ord. *Polygono arenastri-Potalia annuae* & cl. *Polygono-Poetea annuae*; [3] Species diagnostic also for *Lolio-Polygonetum*, alliance *Sagion procumbentis*, ord. *Polygono arenastri-Potalia annuae* & cl. *Polygono-Poetea anuue*; [4] Species diagnostic also for *Poëtum annuae*, ord. *Polygono arenastri-Potalia annuae* & cl. *Polygono-Poetea annuae*; [5] Species diagnostic also for ord. *Polygono arenastri-Potalia annuae* & cl. *Polygono-Poetea annua.*

Gora (Ihtiman municipality), the valley of the Struma river (Strumyani municipality), the Danube plain (Silistra municipality) and the northern Black Sea coast (Aksakovo municipality). These communities developed in the spring-early summer period. This association is distributed in the warmer regions of Central Europe (Láníková 2009). It is also widespread in Romania (Coldea 2012, Sanda et al. 2008), North Macedonia (Čarni et al. 2002).

We identified this association in the lower parts of the country, characterized by extensive sunlight exposure, along agricultural roads, park alleys, near buildings, parking lots and other anthropogenically influenced areas and intensively trampled sites and some abandoned agricultural lands. However, it was of rare occurrence. Terrains were flat or with a slope of up to 5°. Soil depth was diverse – from shallow to moderately deep. Intensive solar radiation during the summer months leads to prolonged droughts. Areas with gley soils periodically hold water, especially in periods with heavy precipitation. This association was typical for areas with high anthropogenic pressures.

Synmorphology: The communities of the association had low species richness (the species number varied from four to 29, with an average of 10 species). They had a predominantly semi-open horizontal structure with a coverage of 50 to 100% (84% on average). A 95-100% coverage was typical of the less trampled sites. The dominant species was *Polygonum aviculare* agg., while *Sclerochloa dura* was subdominant. *Lolium perenne* also occurred as a subdominant in some vegetation plots. Ruderal species, such as *Aegilops cylindrica*, *Anisantha sterilis*, *Matricaria chamomilla*, *Cichorium intybus*, *Hordeum murinum*, *Lactuca serriola*, etc. were frequent in the species composition. When anthropogenic pressure was low or missing, *Lolium perenne* and *Ochlopoa annua* increased their coverage. In those cases, the cover of *Polygonum aviculare* agg. was also larger. Mosses were either absent or had a coverage as low as 2-3%.

In the floristic composition, therophytes prevailed (51.5%), followed by hemicryptophytes (26.3%), therophyte-biannuals (11.1%) and biannuals (10%). Euro-Asiatic (26.3%), Euro-Mediterranean (16.2%), Euro-Siberian (10%), Cosmopolitan (10%) and sub-Mediterranean (8.1%) floristic elements prevailed in the species composition.

Syntaxonomical notes: The variability of the floristic composition of *Sclerochloo durae-Polygonetum arenastri* is quite high (e.g. Sanda et al. 2008) and presents 12 subassociations in Romania. According to Coldea (2012), there are two subassociations: *typicum* and *chamomilletosum* Morariu 1943. In this article, the small number of relevés did not allow us to make an overall evaluation of the community diversity at subassociation level. The communities of the association *Sclerochloo durae-Polygonetum arenastri* frequently formed mosaics in disturbed habitats with the *Polygonetum arenasti* association and more rarely with the *Lolio-Polygonetum arenastri* association.

***Polygonetum arenastri* Gams 1927 corr. Lanikova in Chytry 2009** (Tab. 1, On-line Suppl. Tab. 1)

Diagnostic species: missing from the current analysis

Constant species: *Polygonum aviculare* agg. (100%), *Lolium perenne* (72%), *Convolvulus arvensis* (52%)

Dominant species: *Polygonum aviculare* agg. (80%)

Distribution and ecology: This vegetation type appeared mainly in anthropogenic areas characterized by the highest anthropogenic pressure rates in terms of time and intensity, within the *Polygono-Poetea annuae* class in the studied area. We found this association in the following territories (Fig. 1): Sofia Valley (the municipalities of Sofia, Bozhurishte, Elin Pelin, Gorna Malina, Slivnitsa and Dragoman), Western Sredna Gora Mountain (Ihtiman

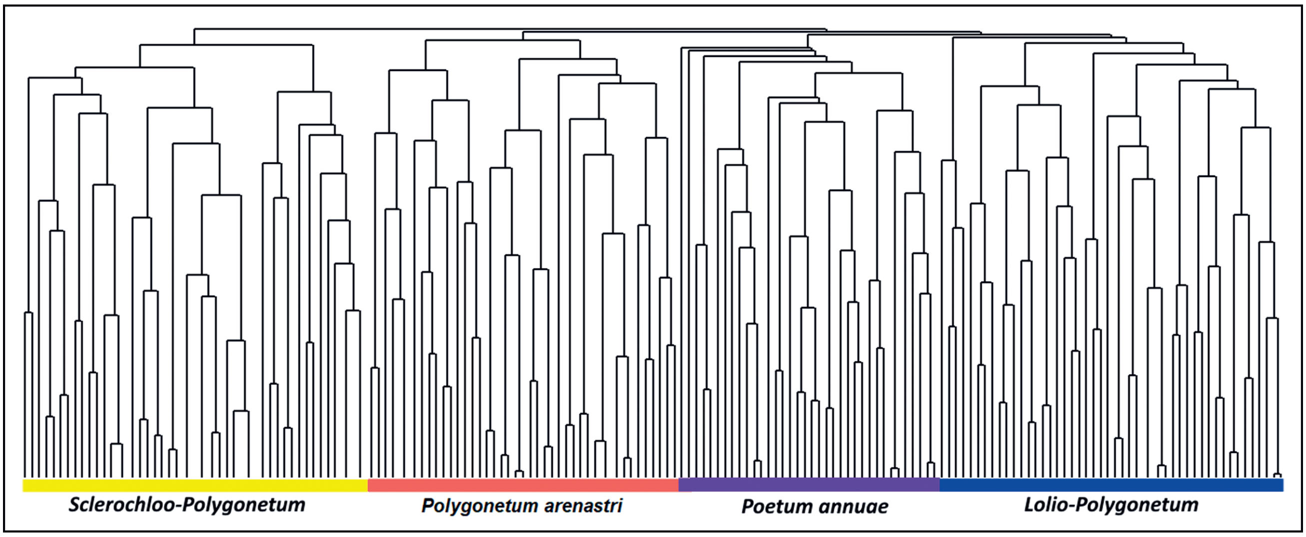

Fig. 2. Classification dendrogram of the analyzed data set with cluster interpretation. According to Modified TWINSPAN classification, four well-distinguished associations of *Polygono-Poetea annuae* class are identified. Associations established indicated on the X-axis. Cluster similarity expressed on the Y-axis.

Municipality), Thracian Valley (the municipalities of Chirpan, Bratya Daskalovi, Sadovo and Maritsa), Danube Valley (Krivodol Municipality), Central Forebalkan (Gabrovo Municipality) and the northern Black Sea coast (Kavarna Municipality).

This association occupied territories near roads, pathways, parks, alleys and parking lots. Terrains were flat to slightly inclined (3-5^0). Soils were shallow to moderately deep, frequently clayey. The vegetation was disturbed in some of the plots due to anthropogenic pressure, leading to the formation of tracks. Bedrock types differed.

Synmorphology: The species composition of the association was poor. The number of species varied from four to 27 (the average count was 10). The dominating species was *Polygonum aviculare* agg. with a cover from 20-25% to 75-85%. Due to intensive trampling and mechanical disturbances, the tufts of *Polygonum aviculare* were rooted out which had led to differences in the cover. Other common species were *Lolium perenne, Cynodon dactylon, Cichorium intybus,* and *Convolvulus arvensis*.

In the life form spectrum, the therophytes prevailed (50.4%), followed by hemicryptophytes (32.5%), therophyte-biannuals (7.7%) and biannuals (6.8%). Euro-Asiatic (20.5%), Euro-Mediterranean and Cosmopolitian (12%), sub-Mediterranean (9.4%), European (7.7%) and Euro-Siberian, Boreal and subBoreal (6%) floristic elements prevailed in the species composition.

The species composition included the diagnostic species of the classes *Sisymbrietea* (e.g. *Amaranthus hybridus*, *Convolvulus arvensis*, *Xanthium strumarium,* etc.), *Papaveretea rhoeadis* (e.g. *Matricaria chamomilla*, *Anagallis arvenis*, *Cirsium arvense*, *Apera spica-venti*, *Stellaria media*, etc.) and *Artemisietea vulgaris* (e.g. *Centaurea solstitialis*, *Daucus carota*, *Cichorium intybus*, *Elytrigia repens*, etc.).

Syntaxonomical notes: The communities within *Polygonetum arenastri* are ecologically and floristically close to those of *Lolio-Polygonetum arenastri*. Subdominants in the association of *Lolio-Polygonetum arenastri* are *Polygonum aviculare* agg. and *Lolium perenne*. Moreover, the anthropogenic pressure within its communities was weaker, which led to the presence of more favorable conditions for the development of *Lolium perenne*. Coldea (2012) classifies the association *Polygonetum arenasti* Gams 1927 as a syn. of *Matricario-Polygonetum arenatsri* T. Műller in Oberd. 1971. For the *Matricario-Polygonetum arenastri* association, the edificators were *Matricaria discoidea* and *Polygonum arenastrum* [*Polygonum arenastrum* included in the *P. aviculare* agg, cf. Láníková (2009)]. *Matricaria discoidea* was absent in stands in Bulgaria. The current study adopts the conception of Láníková (2009), who considers the association *Matricario-Polygonetum arenastri* T. Müller in Oberd. 1971 as synonymous to the association *Polygonetum arenastri* Gams 1927 corr. Láníková in Chytrý 2009.

According to Láníková (2009), the association includes three variants: with *Chenopodium album*, *Lepidium ruderale* and *Matricaria discoidea*. The latter three not yet identified in Bulgaria.

***Lolio-Polygonetum arenastri* Br.-Bl. 1930 em. Lohmeyer 1975** (Tab. 1, On-line Suppl. Tab. 1)

Diagnostic species: missing from the current analysis

Constant species: *Lolium perenne* (100%), *Polygonum aviculare* agg. (85%), *Cichorium intybis* (77%), *Plantago lanceolata* (65%)

Dominant species: *Lolium perenne* (77%)

Distribution and ecology: We found this association in valleys and semi-mountainous areas in the country (Fig. 1) – Mt Western Balkan. (Godech Municipality), Mt Sredna Gora (the municipalities of Elin Pelin, Gorna Malina and Kostenets), Sofia Valley (the municipalities of Sofia, Bozhurishte, Slivnitsa, Kostinbrod and Elin Pelin), Thracian Valley (the municipalities of Chirpan, Sadovo and Bratya Daskalovi) and the Southern Black Sea coast (Burgas Municipality).

The association's communities were common on trampled sites, but this disturbance was of a lower intensity. They occupied fields and urbanized areas, sometimes together with the association *Lolio perennis-Cynosuretum cristati* Tüxen 1937. Terrains were flat to gently sloped (up to 5^0). Soils were averagely deep, characterized by prolonged droughts during the summer. Bedrock types were diverse.

Synmorphology: The communities of this association had a slightly higher number of species than *Polygonetum arenastri* and *Sclerochloo durae-Polygonetum arenastri*. The average species number was 12. The narrow contact of this association with the neighboring phytocoenoses of *Stellarietea mediae*, *Molinio-Arrhenatheretea* and *Artemisietea vulgaris* classes had led to presence of some species typical for these classes.

The dominant species was *Lolium perenne* and subdominant was *Polygonum aviculare* agg. The species composition included taxa resistant to trampling, such as *Convolvulus arvensis, Plantago lanceolata, Cynodon dactylon* and *Cichorium intybus*. The total cover varied between 65 and 100% (with an average of 90%).

Therophytes prevailed (50%), followed by hemicryptophytes (27.7%), therophyte-biannuals (12.3%) and biannuals (9.2%). Euro-Asiatic (20.6%), Euro-Mediterranean and sub-Mediterranean (12.2%), Cosmopolitian (10.7%), Euro-Siberian and Boreal (5.3%) floristic elements dominated in the species composition.

Syntaxonomical notes: The association has been well-studied syntaxonomically in Romania (Coldea 2012), Austria (Mucina 1993) and Poland (Salachna 2020).

Some authors classify these communities in the class *Plantaginetea majoris* R. Tx. et Preising in R. Tx. 1950 (Chifu and Irimia 2014, Sanda et al. 2008), while others assign them to the class *Molinio-Arrhenatheretea* (Pott 1995) through order *Plantaginetalia majoris* R. Tx. et Preising in R. Tx. 1950 (Chifu and Irimia 2014). Although there are some similarities with other secondary grasslands dominated by *Lolium perenne* and classified in class *Molinio-Arrhenatheretea*, there are significant differences in the floristic composition (richer in *Gramineae* and *Fabaceae* species). Rivas-Martinez (1975) classifies all therophyte vegetation on nutrient-rich soils in the *Polygono-Poetea annuae* class, an opinion widely accepted today (Mucina et al. 2016). The pronounced ruderal and synanthropic character, the floristic composition rich in therophyte dwarf herb species as well as the distribution areas were strong arguments for classification of the investigated communities in the class *Polygono-Poetea annuae* Rivas-Martinez 1975.

Poëtum annuae **Gams 1927** (Tab. 1, On-line Suppl. Tab. 1)

Diagnostic species: *Ochlopoa annua, Trifolium repens* agg., *Plantago major*

Constant species: *Lolium perenne* (91%), *Polygonum aviculare* agg. (79%), *Cichorium intybus* (68%), *Plantago lanceolata* (65%)

Dominant species: *Polygonum aviculare* agg. (44%), *Lolium perenne* (29%)

Distribution and ecology: We found this association in mesophilous and meso-xerophilous habitats mostly in semi-mountainous areas and rarely in lowlands (Fig. 1). The localities were in the Western Balkan Range (Godech, Svoge and Dragoman municipalities), Central Balkan Range (the area of the Central Balkan National Park), Central Forebalkan (Gabrovo and Sevlievo municipalities), Western Sredna Gora Mountain (Ihtiman, Kostenets, Dolna Banya, Samokov, Elin Pelin and Gorna Malina municipalities), Thracian Valley (Rakovski municipality) and in the Sofia Valley (Sofia-town municipality). Terrains were flat with slopes of up to 8-10°. Soils were moderately deep, mostly gleyic. The association was typical for trampled forest pathways, the shorelines of different water bodies and anthropogenic features, such as parking lots, playgrounds, parks, etc. Trampling was a very common feature for this association.

Synmorphology: Moderately rich in species community, which had semi-open to closed horizontal structure with a total coverage of 70-100%. Species of a higher coverage and abundance were *Ochlopoa annua, Lolium perenne, Trifolium repens, Plantago major*. Annual plants such as *Ochlopoa annua, Polygonum aviculare, Matricaria chamomilla, Vulpia myurus*, etc., often participated in the species composition. The cover of *Lolium perenne, Trifolium repens* and *Plantago major* extends during the summer, when they reach their optimum. *Trifolium repens* and *Plantago major* are hemicryptophytes that form rosettes and become the dominant species during the summer in some of the vegetation plots. *Poëtum annuae* was characterized by the richest species composition (average number of 16 species in a plot), compared to the other three associations. Some mesic species, such as *Dactylis glomerata, Achillea millefolium* agg., *Plantago major, Trifolium repens* and *Agrostis capillaris* were also typical for this association.

The therophytes (41.4%) prevailed, following by hemicryptophytes (40.7%), biannuals (7.6%) and therophyte-biannuals (6.2%). Euro-Asiatic (20%), Euro-Mediterranean (15%), Cosmopolitian (11%), Euro-Siberian (10%) and sub-Mediterranean (9%) floristic elements dominated in the species composition.

Syntaxonomical notes: This association is common for different parts of Europe – the Czech Republic (Láníková 2009), Slovakia (Kovář and Lepš 1986, Jarolímek et al. 1997, Redneková and Mičieta 2017), Slovenia (Čarni 2005), Romania (Coldea 2012). Jarolímek et al. (1997) discuss two subassociations – *Poëtum annuae typicum* Felföldy 1942 and *Poëtum annuae matricarietosum discoideae* Jarolímek et al. 1997. The communities of *Poa annua* in Bulgaria were floristically and ecologically closer to those of the typical subassociation.

Lolio-Plantaginetum Beger 1930 *poetosum annuae* Krippelová 1972 is also well known in syntaxonomical literature (Jarolímek et al. 1997). Mucina (1993) classifies the phytocoenoses of *Poa annua* as a plant community type in Austria. Both syntaxa have similar species composition and ecology to *Poëtum annuae*.

Vegetation – environment relationships

The studied associations were distinguished well in the ordination space (Fig. 3, Tab. 2). Eigenvalues obtained: 1st axis – 0.408; 2nd axis – 0.214. Gradient length along 1st axis – 3.13; 2nd axis – 2.38. Correlation of Ellenberg Indicator values (EIV) with axes: Light (1st axis: -0.1592 n.s.; 2nd axis: 0.1100 n.s.); Temperature (1st axis: 0.2462 n.s.; 2nd axis: 0.3425*); Continentality (1st axis: -0.5321*; 2nd axis: 0.0931

Tab. 2. Ecological preferences (EIV) of the four associations classified in the *Polygono-Poetea* class in Bulgaria (means and standard deviation). Significant differences ($\alpha = 0.05$) among groups (clusters) according to Mann-Whitney post-hoc test highlighted with different font. The *p*-values are derived from the non-parametric Kruskal-Wallis test.

	Sclerochloo-Polygonetum	*Polygonetum arenastri*	*Poëtum annuae*	*Lolio-Polygonetum*	*P-value*
Light	7.58 ± 0.28^{a}	7.34 ± 0.26^{b}	7.40 ± 0.27^{b}	7.46 ± 0.28^{ab}	< 0.01
Temperature	6.34 ± 0.18^{a}	6.14 ± 0.28^{b}	6.15 ± 0.23^{b}	6.22 ± 0.15^{b}	< 0.001
Continentality	4.90 ± 0.96^{a}	4.28 ± 0.78^{b}	4.05 ± 0.42^{b}	4.24 ± 0.52^{b}	< 0.001
Moisture	4.32 ± 0.19^{a}	4.37 ± 0.32^{a}	4.31 ± 0.37^{a}	4.26 ± 0.26^{a}	n.s.
Reaction	7.25 ± 1.12^{a}	6.96 ± 1.16^{b}	6.62 ± 0.66^{c}	7.05 ± 0.44^{b}	< 0.001
Nutrients	5.55 ± 0.39^{a}	5.87 ± 0.55^{b}	5.12 ± 0.81^{a}	5.37 ± 0.56^{a}	< 0.001

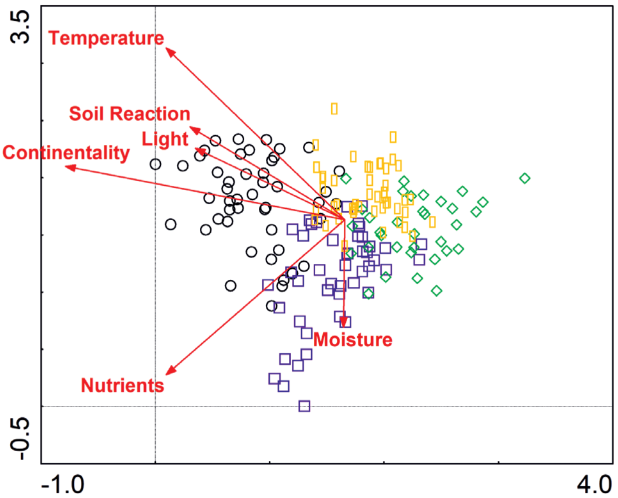

Fig. 3. Ordination diagram of the analyzed data set along the first two axes. Variables (EIV) passively projected onto the ordination space. Vegetation units expressed by figures of different shapes: circles – *Sclerochloo durae-Polygonetum arenastri*, squares – *Polygonetum arenastri*, diamonds – *Lolio-Polygonetum arenastri*, rectangles – *Poëtum annuae*.

n.s.); Moisture (1st axis: -0.1021 n.s.; 2nd axis: -0.2868 n.s.); Reaction (1st axis: -0.1244 n.s.; 2nd axis: 0.3069*); Nutrients (1st axis: -0.2114546 n.s.; 2nd axis: -0.2735 n.s.). *P*-values derived from the Zelený's modified permutation test (* < 0.05, n.s. – non-significant).

The first axis related to the continentality and microhabitat temperature conditions. *Sclerochloo durae-Polygonetum arenastri* occupied lower altitudes, occurring in fully lighted habitats with high solar radiation. In contrast, the communities of *Poëtum annuae* occupied higher altitudes, in wetter, cooler and shady areas. The variability expressed by the second axis represented the temperature and nutrient conditions. The stands of *Polygonetum arenastri* occupied nutrient-rich soils, whereas communities of *Lolio-Polygonetum arenastri* preferred warmer and nutrient poor areas. *Polygonetum arenastri* formed stands close to arable fields, parks and generally in areas periodically fertilized over the past 20 years. In addition, they grow on gleyic soils, which hold water, especially in periods with heavy precipitation within the studied stands. Generally, this leads to increased humidity. On the other hand, in the communities of *Lolio-Polygonetum arenastri* anthropogenic pressure and soil types were quite diverse.

Discussion

This is the first syntaxonomical study in Bulgaria focusing on the class *Polygono-Poetea annuae*, despite its wide distribution in the country. The four associations represent different types of trampled vegetation depending on the anthropogenic pressure and local ecological conditions such as moisture and nutrients. This pressure decreases from the *Polygonetum arenastri* towards the *Sclerochloo durae-Polygonetum arenastri* and *Lolio-Polygonetum arenastri* associations and it is the weakest within *Poëtum annuae*. According to Čarni and Mucina (1998), the major factors enhancing the variability of trampled vegetation include local floristic pools (mass effect) and the enrichment of trampled habitats by encroaching alien plant species.

These associations in Bulgaria are ecologically and floristically similar to their stands in other parts of Central and Southeastern Europe (Mucina 1993, Jarolímek et al. 1997, Čarni 2005, Šilc and Košir 2006, Láníková 2009, Coldea 2012, Redneková and Mičieta 2017). The mesic *Sclerochloo-Polygonetum arenastri* association occurs in North Macedonia (Čarni et al. 2002) while *Poëtum annuae* is found in North Macedonia and Slovenia as well (Čarni et al. 2002, Šilc and Košir 2006). Dring et al. (2002) reports the plant community type *Poa annua-Plantago major* for Albania. The established low species richness of trampled vegetation in Bulgaria (average species number ranges between 10 and 16) supports the results of Šilc et al. (2012) and Láníková (2009). Trampling and vertical pressure on soil substrate decrease soil aeration, limit the plants' access to soil, water and nutrients and may prevent the germination of many plant seeds (Čarni and Mucina 1998). Generally, the species composition consists of widespread species resistant to trampling such as *Polygonum aviculare* agg., *Plantago major*, *Cynodon dactylon*, *Sclerochloa dura*, *Ochlopoa annua*, *Lolium perenne*. The same tendency was observed by Čarni and Mucina (1998) and Láníková (2009). Some of these species are also widespread in and characteristic for other habitats and vegetation types, e.g. *Cynodon dactylon* is characteristic for dry grasslands of *Festuco-Brometea* and *Helianthemetea guttati* classes, but *Lolium perenne* is common for the mesic grasslands of the *Molinio-Arrhenatheretea* class.

So far, our study has revealed the syntaxonomical diversity of trampled vegetation in a limited area of Bulgaria (mainly in the central and western parts of the country), where the climate is temperate. On the other hand, available and analyzed data from regions with sub-Mediterranean climate are still limited. The syntaxonomical and ecological diversities of the four associations established in Bulgaria have not yet been studied in detail, including the level below association. For example, Láníková (2009) comments on three variants of the *Polygonetum arenastri* association while Sanda et al. (2008) present 12 subassociations for the *Sclerochloo durae-Polygonetum arenastri* association.

There are some other associations, belonging to the *Polygono-Poetea annuae* class that we expect to find in South Bulgaria: *Poo annuae-Coronopodetum squamati* Gutte 1966, *Eragrostio minoris-Polygonetum arenastri* Oberdorfer 1954 corr. Mucina in Mucina et al. 1993, *Sagino procumbentis-Bryetum argentei* Diemont et al. 1940, *Rumici acetosellae-Spergularietum rubrae* Hülbusch 1973, *Herniarietum glabrae* (Hohenester 1960) Hejný et Jehlík 1975 and *Lolio perennis-Matricarietum discoideae* Tüxen 1937. Potential territories with sub-Mediterranean climate are the Thracian plain, the Black Sea coastline, the valleys of the Mesta and Struma rivers, the Eastern Rhodope

Mountains and the Eastern Balkan Range. Some of the expected phytocoenoses may exist in the urban areas but have actually not yet been sampled.

We suggest there should be further regional and local studies of the vegetation of this class. We expect the background will come as data from regional and national databases (the Balkan Vegetation Database, the Romanian Grassland Database, etc.), as well as information from the European Vegetation Archive (Chytrý et al. 2016).

Conclusion

This is the first study focusing on the syntaxonomy and ecology of trampled vegetation in Bulgaria. In all, one class (*Polygono-Poetea annuae*), one order (*Polygono arenastri-Poetalia annuae*), two alliances (*Polygono-Coronopodion, Saginion procumbentis*) and four associations (*Sclerochloo durae-Polygonetum arenastri, Polygonetum arenastri, Lolio-Polygonetum arenastri* and *Poëtum annuae*) have been published for the first time for Bulgaria. The species richness and floristic composition of the associations established come as a result of the environmental conditions and the intensity of anthropogenic pressure. The communities of *Poëtum annuae* have the highest species richness. *Sclerochloo durae-Polygonetum arenastri* occupied lower altitudes, warmer and drier areas, while *Poëtum annuae* occurred in wetter and cooler areas mainly in semi-mountainous regions. The stands of *Polygonetum arenastri* occupied nutrient-rich soils, while the communities of *Lolio-Polygonetum arenastri* preferred warmer and nutrient-poor areas. The intensity of anthropogenic pressure has a peak in the communities of *Polygonetum arenastri* and decreases within the stands of the *Lolio-Polygonetum arenastri* and *Poëtum annuae*.

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