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RESEARCH PAPER

Conspectus of the vegetation types of Tajikistan and adjacent areas with special focus on phytosociological classes

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Abstract

Vegetation classification is a tool for organizing the patterns and diversity of plant communities. It is used in nature conservation, and helps to understand the role of vegetation in the biosphere. Given the rapidly diminishing opportunity to understand the vegetation diversity of Tajikistan located in the Middle Asian region, phytosociological surveys using the floristic-ecological approach and the Braun-Blanquet cover-abundance scale were undertaken in 2006. After 18 years of research, with a total of 55 research expeditions to Tajikistan, Kyrgyzstan, and Uzbekistan, it is time to summarise and make a first attempt to establish a comprehensive classification system for the entire vegetation of Tajikistan and the surrounding areas. As a first step, the Vegetation of Middle Asia (VMA) database with records from three countries: Tajikistan (4,130 relevés), Kyrgyzstan (1,681 relevés) and Uzbekistan (13 relevés) was created. The internal comparison of all the plots and the analysis of the similarities with the vegetation of Iran, Russia, Afghanistan, Mongolia, Pakistan, and China make it possible to present the comprehensive list of plant communities organized in 45 classes, 47 orders, 83 alliances, 297 associations, and 237 rankless units. In addition to those described in our previous works, we propose also several new sytaxa: *Eremogono griffithii-Nepetetea podostachyos*, *Artemisio persicae-Stipetea drobovii*, *Festucetea alaico-krylovianae*, *Carici koshewnikowii-Asperuletea oppositifoliae*, *Trichodesmo incani-Pachypterygietea brevipes*, *Aceretalia turkestanici*, *Juniperetalia seravschanicae*, *Crataegetalia ponticae*, *Populetalia pruinoso-euphraticae*, *Salici capusii- Hippophaeetalia rhamnoidis*, *Carici stenophylloidis-Stipetalia drobovii*, *Eritrichion pamirico-subjacquemontii*, *Stipetum kazachstanicae*, *Caricetum pamirensis*, and *Bolboschoenetum affinis*. This systematic compilation of data, based on our fieldwork and literature data, is not definitive, and certainly the rich and diverse vegetation of Middle Asia requires further studies incorporating also modern LIDAR and satellite techniques.

Keywords
Kyrgyzstan; Middle Asia; phytogeography; syntaxonomy; Tajikistan; Uzbekistan; vegetation classification; vegetation survey

1. Introduction

Vegetation is one of the most fundamental elements of the biosphere – a basic life-supporting environment for the majority of organisms. It provides the driving force for the ecosystem services that sustain life on our planet and regulate geomorphological, hydrological, and climatic processes (Mucina et al., 2016). Vegetation is a home of species, and therefore, in order to effectively protect life and biodiversity on Earth, not to exclude human populations, for particular vegetation type, we need to recognize its distribution range, diversity, distinctiveness, stability, and degree of degradation. The field of knowledge that allows us to answer these questions is, among others, vegetation classification (Chytrý et al., 2019; de Cáceres et al., 2015). Vegetation typology answers various practical and academic questions and is commonly used not only for conservation purposes but also in many basic studies, including those that deal with global warming (Oehri et al., 2022).

Vegetation classification is central to basic scientific research as a tool for recognizing and interpreting patterns and diversity of plant communities. Conducting or publishing any ecological research without reference to the type of vegetation in which the work was carried out is very similar to depositing a specimen in a museum without providing a label. Early efforts at vegetation classification were largely driven by a desire to understand the natural diversity of vegetation and the environmental factors that shape it. Already in the early 19th century, Alexander von Humboldt insisted that the study of plants should be stratified according to their natural zonation. Humboldt's ecology gave rise to various schools or traditions of phytosociology (formalized by the Polish botanist Józef Paczoski in 1896) based on physiognomy, floristics, and/or environmental relationships (A. Nowak & S. Nowak, 2022).

Classification of plant communities using the so-called phytocoenological relevés, i.e., lists of plant species with data on their quantitative representation prepared for small terrain patches, has in Central Europe a long tradition dating back to the first decades of the 20th century (Moravec, 1994). The basic methodological principles of phytocoenology were formulated by the Swiss plant ecologist Braun-Blanquet (1921, 1928). Braun-Blanquet's methods spread rapidly across Europe and currently is commonly applied on all continents (de Cáceres et al., 2015). At the same time, the foundations of other schools of vegetation classification were emerging, including the Russian one, which was based on groups of dominant species. This methodological approach prevailed throughout the former USSR, including Middle Asia (Aleksandrova, 1978).

In the last decades, the classification of vegetation was further developed and refined with the use of numerical methods, which quickly became standard analytical tools in vegetation ecology (de Cáceres et al., 2015). The Working Group for Ecoinformatics of IAVS facilitates access to big data by establishing standards for data exchange providing tools for data identification, access, integration, storage, and analysis. The numerical approach has dominated the classification and ordination procedures in multidimensional space and responds to the need for a common language, standardization, and formalization of classification procedures (Mucina, 1997). This structuring of the method, enabling efficient analysis of vast amount of vegetation samples from the field, helped to convince administrative bodies to use phytosociology in habitat definition and identification in the European Union. Habitat typology based on the vegetation classification method has been implemented since the 1990s. In 1992 the European Communities adopted the Habitats Directive (92/43/EEC), which became the basic legislative document for the implementation of nature conservation in the European Union and the creation of a system of Natura 2000 protected areas. For habitat identification and quality assessment, the phytosociological method is probably the most appropriate, as it is based on detailed analyses of the species composition of the vegetation, which knowledge is crucial for biodiversity conservation purposes.

Unfortunately, in many regions outside Europe, nature and biodiversity conservation suffer from a lack of consistent, harmonized knowledge on vegetation (Dengler et al., 2008). Despite some achievements in this regard in Russia (e.g. Mirkin & Naumova, 2011), South America (Galán-de-Mera et al., 2020; Galán de Mera & Orellana, 2006; Peyre et al., 2022), Mexico (Rzedowski, 1978), Africa (Alvarez et al., 2021; Brown et al., 2013; Mucina & Rutherford, 2006; Natta et al., 2003), Australia (e.g. Bridgewater, 1982; Pignatti & Pignatti, 1997) and finally Asia (Dvorskỳ et al., 2011; Fujiwara, 1996; Guo et al., 2018; Hartmann, 1968, 1995, 1997; Hukusima et al., 2013; Miehe et al., 2011; Miyawaki, 1980–1989; Peer, 2000), there are still many regions that have poorly recognized hierarchical vegetation classification systems. One of them is Middle Asia.

Most of Middle Asia was included in the former Soviet Union, and its vegetation was so far described according to the Russian school of phytosociology, with dominant species as one of the most important classification criterion (Shennikov, 1964; Sukachev, 1929). The limited communication between scientists from former Soviet republics and research centers of Europe resulted in the relative scarcity and lack of dissemination of vegetation studies devoted to Middle Asia. In particular, nearly two decades after the collapse of the Soviet Union have been characterized by the stagnation of geobotanical research in Tajikistan, which might be linked to the civil war, the destabilization of the country, and the underfunding of research. However, recently, there has been a gradually increasing interest in vegetation as an object of scientific research (e.g., Safarov, 2018).

A geobotanical survey aimed at a detailed description of Tajik vegetation with the use of the cover-abundance scale of Braun-Blanquet (1964) was initiated in the year 2006 by a team of researchers from the University of Opole and Jagiellonian University in Kraków. Segetal and littoral phytocoenoses were described as first (e.g. A. Nowak et al., 2014b, 2015; S. Nowak & A. Nowak, 2013; S. Nowak et al., 2013a, 2013b). Then the study of aquatic and petrophytic vegetation with the first insights into forest communities was conducted (e.g., Nobis et al., 2013; A. Nowak & Nobis, 2012, 2013; A. Nowak et al., 2014a, 2014b, 2014c, 2016c). Recent phytosociological studies in Tajikistan and Kyrgyzstan focus on fen, mire, steppes and forb steppes, halophytic vegetation, alpine grasslands, chionophilous vegetation, open woodlands, shrublands and deciduous forest plant communities (A. Nowak et al., 2016a, 2016b, 2017a, 2020b, 2022a, 2022b, 2023; S. Nowak et al., 2023; Swacha et al., 2023; Świerszcz et al., 2023, 2021). Additionally, phytosociological research on epiphytic moss communities was conducted in Kyrgyzstan (A. Nowak et al., 2016d). Besides data collected by Polish botanists, important vegetation information has been reported from the region by other contributors from Germany (Vanselow, 2016; GIVD ID: AS-KG-001; GIVD ID: AS-TJ-001).

After a total of 55 research expeditions conducted in the last 18 years to Tajikistan, Kyrgyzstan, and Uzbekistan, it is time to make a summary and a first attempt at establishing a comprehensive classification system for the whole vegetation of Tajikistan and surrounding areas.

2. Material and methods

2.1. Geographic extent and methods of the survey and the dataset compilation

Phytosociological studies were carried out mainly in Tajikistan, evenly across the country. To stabilize the system, surveys were also conducted in the eastern part of Uzbekistan (mainly the Hissar Mountains and SW Tian Shan) and throughout almost whole Kyrgyzstan. At the current state, the Vegetation of Middle Asia database includes relevés from three countries: Tajikistan (n = 4,130), Kyrgyzstan (n = 1,681), and Uzbekistan (n = 13). Plots are distributed across the main mountain ranges of the region, with the highest density in the western Pamir Alai Mountains.

Tajikistan is highly elevated, mountainous country, thus during the research we have focused on several ranges, including Pamir Alai: the Zeravshan Mts., Hissar Mts., Hazratishokh Mts., Darvaz Mts., Turkestan Mts., Karateginian Mts., Babatag Mts., Aktau Mts., Sarsarak Mts., Vakhsh Mts. and Karatau Mts. Some studies were also conducted in the Tian Shan: the Kuraminian and Mogoltau Mts. We concentrate our survey efforts in the Pamirs, including the Eastern Pamir Plateau. We collected relevés in the Rushan Mts., Vanch Mts., Peter I Mts., Yazgulem Mts., Alichur Mts., Shugnan Mts., Trans-Alai Mts. and Sarikol Mts. In 2009, we began the phytosociological studies in Uzbekistan and Kyrgyzstan. In Uzbekistan, we collected only a limited number of relevés (13) in the ruderal and aquatic habitats of Tashkent and Samarkand. In Kyrgyzstan, our projects covered almost the whole country. To date, we have investigated the Kyrgyz Mts., Kakshaal Mts., Trans-Ili Alatau Mts., Kyungey Ala-Too Mts., Talas Mts., Suusamyr Mts., Terksey Ala-Too Mts., Songkol Mts., Fergana Mts., Alay Mts. and Chatkal Mts. In this database, we exclusively present original field data with no supplementation from other literature sources.

Tajikistan and adjacent areas are located in Middle Asia. Recent studies on the bioclimate of SW and Central Asia suggest that Middle Asia should be classified within the Irano-Turanian bioclimatic zone. It differs from the Central Asian climate due to lower and uneven precipitation (peaking in spring), a drier summer season, and reduced continentality (Djamali et al., 2012).

There is no consistent species checklist available for the whole of Middle Asia. A checklist of vascular plant species was recently prepared for Kyrgyzstan only (Lazkov & Sultanova, 2014), whereas, in the case of Tajikistan, part of the flora was included in the Illustrated Flora of Tajikistan (A. Nowak et al., 2020a) as well as in the Red List of vascular plants of Tajikistan (A. Nowak et al., 2020b), however, all these entries cover only part of the flora of Central Asia. For this reason, we used the Plants of the World Online (POWO, 2023), with some necessary amendments due to recent descriptions of new taxa (e.g., Lazkov, 2008; Nobis, 2013; Nobis et al., 2013, 2017). In the case of problematic genera, we additionally used Cherepanov list (Cherepanov, 1995), The World Flora Online (WFO, 2023), or other sources like e.g., Nobis et al. (2020) for *Stipa* spp. The bryophyte nomenclature follows Ignatov et al. (2006) and Ros et al. (2013). In all documented vegetation plots included in the VMA database 3,037 vascular plant species (representing 863 genera and 182 families) were found. The database is stored and managed in TURBOVEG (Hennekens & Schaminée, 2001) as the most suitable and comprehensive software for the preservation of phytosociological information and communication with other databases. The plant material collected during field studies is deposited in the Herbarium of Middle Asia Mountains, hosted in OPUN (University of Opole, Poland) and KRA (Jagiellonian University, Poland).

We used standard plot sizes of 10 m^2 for grasslands, salt marshes, segetal vegetation, aquatic and littoral vegetation, tall forbs and screes; 100 m^2 for scrub; 200 m^2 for shrublands and openwoods; and 400 m^2 for woods. Because of the great variability of chasmophytic habitats in Middle Asia, the rock vegetation was sampled using 0.4 to 3 m^2 plots depending on crack or ledge size and share of dwarf shrubs. In all surveys, vascular plant species and bryophytes were recorded using the seven-grade Braun-Blanquet cover-abundance scale (Westhoff & van der Maarel, 1973). Geographical coordinates were measured using a GPSMAP 60CSx device with an accuracy of ±5 m and a WGS84 reference frame. All data stored in the VMA database registered in the Global Index of Vegetation-Plot Databases (GIVD) under the code AS-00-003 (A. Nowak et al., 2017b).

All classifications carried out, irrespective of the method subsequently used, were initially subject to transformation. The Braun-Blanquet cover-abundance scale was transformed into percentage values as follows: r (0.1%), + (2%), 1 (3%), 2, (13%), 3 (38%), 4 (63%) and 5 (88%). Then, depending on the characteristics of the data, the interpretability of the results and the history of the survey of the particular vegetation type, different methods were implemented for clustering of the dataset, including mainly hierarchical unsupervised or semi-supervised classification. Among others, we used modified TWINSPAN analysis with down-weighting of rare species and the use of chord distance as a measure of cluster heterogeneity (Hill, 1979; Roleček et al., 2009). For pseudosteppe, fen, mire, and spring vegetation classification, we performed an unsupervised or semi-supervised k-means analysis with Hellinger transformation of species percentage cover values (see Naqinezhad et al., 2021; Świerszcz et al., 2020). For alpine grasslands, we applied the agglomerative hierarchical Ward's method (Jongman et al., 1997; Podani, 2000) in the PC-ORD program ver. 7.08 (McCune & Mefford, 2011) employing the Euclidean distance measure.

In almost all original definitions of vegetation types, the diagnostic, constant, and dominant species were presented. Diagnostic species were determined using the phi coefficient as a fidelity measure (Chytrý & Tichý, 2003) following their statistical validation by the Fisher exact test ($p < 0.01$). In each work, the shortened and full synoptic tables with the constancy of all diagnostic species were presented.

With the release of successive editions of the International Code of Phytosociological Nomenclature (ICPN; Theurillat et al., 2021; Weber et al., 2000), as well as progressive changes in publishing policy, many of the syntaxon names entered into the system required correction and validation. These difficulties related to the effective publication of newly established syntaxa, which often were *nomen ineditum* (if the paper was entirely published online before 2021) or *nomen nudum* (if the typus relevés were distributed only as online appendices before 2021) or due to a simple mistake in the conjugation of the Latin names of syntaxa. In each case of inconsistencies with the ICPN, the validation was provided according to the newest version of the ICPN (Theurillat et al., 2021).

2.2. Verbal diagnosis of the syntaxa

The verbal diagnoses were provided as brief text for accepted syntaxa, a sort of condensed surrogate of a definition of the unit. These diagnoses include: (1) the physiognomy of the vegetation classified within the given unit (e.g., forest, open woods, grassland, shrubland, aquatic vegetation, etc.), sometimes with an indication of dominant plant species (e.g., pistachio open wood) or growth form (e.g., forb steppe); (2) their unifying ecological context (e.g., mesic, nutrient-poor soils, segetal, pseudosteppes); and (3) their distribution (e.g., Irano-Turanian, Pamiro-Alaian, Central Asian, etc.).

2.3. Ordering and grouping of the classes

To distinguish and define vegetation classes, we applied the Cocktail method (Bruelheide, 1997). Although this method is particularly useful for regions with a long tradition of vegetation surveys, we think that at class rank it is also suitable for Tajikistan after almost 20 years of research. The Cocktail method is a supervised classification method that uses formal rules to match relevés to predefined vegetation units and utilizes the explicit definition of a given vegetation unit corresponding to the concept of that unit (Bruelheide, 1997, 2000). We proposed formal definitions of vegetation classes as an expert system (ES) for automatic allocation of relevés to syntaxon (see Noble, 1987). When elaborating the ES, species recognized only at the genus level were deleted from the dataset. Species records from multiple layers were merged and classified into four categories: (***i***) tree layer – includes trees recorded in a tree layer, (***ii***) shrub layer – includes shrubs and trees recorded in the shrub layer, (***iii***) herb layer – includes both vascular plants recorded in the herb layer and seedlings or juveniles of woody species, and (***iv***) moss-lichen layer – included non-vascular plants and lichens. We excluded from the dataset moss vegetation samples (with only bryophytes and without vascular plants), so there are a total of 2,790 vascular plant species and 5,350 relevés in the system. Formal definitions of classes were created using discriminating species groups (Landucci et al., 2015; Tichý et al., 2019), which are a list of species that characterize a vegetation class. The ES uses the ratios between the sum of the square-root covers of the species in the discriminating species group over another group. The discriminating species groups (Appendix 1) contain an a priori defined list of diagnostic species for a given class, statistically expressed by the *phi* coefficient (Chytrý et al., 2002) or based on our expert knowledge and our previous publications, significantly increased the classification success. Additionally, we created two discriminating species groups: shrub layer species and tree layer species. The formal definition of a given class consisted of discriminating groups combined by logical operators AND, OR, and NOT (Bruelheide, 1997).

We assigned all relevés in the data set to vegetation classes using the ES introduced above, and then described them using the lists of diagnostic species (Appendix 1). As a measure of fidelity, we used the phi coefficient (Chytrý et al., 2002). Each species with phi $\geq$ 0.20 was considered diagnostic. The significance of species occurrence patterns was tested by Fisher's exact test after the virtual standardization of groups to equal size (Tichý & Chytrý, 2006). Diagnostic species were determined by analyzing the hierarchically equivalent syntaxa.

3. Results

3.1. Conspectus of vegetation units

The vegetation plots recorded in Tajikistan and adjacent areas represent 45 classes, 47 orders, 83 alliances, 297 associations, and 237 rankless plant communities (Appendix 2). The synopsis mainly covers plant communities found in Tajikistan (about 60%) and Kyrgyzstan (about 35%). The remaining units were included due to their occurrence in close proximity, mainly in the Irano-Turanian or Western Himalayan region. These include: forest communities from the Altai (Mongolia and Kazakhstan) included in the class *Populetea laurifolio-suaveolentis* Hilbig 2000, juniper cryophilous scrubs representing alliance *Juniperion semiglobosae* Eberhardt 2004 recorded in the Hunza region in northern Pakistan, krummholz vegetation of the Karakorum alliance *Salicion karelinii* Eberhardt 2004, *Pistacia khinjuk* open woods from eastern Iran belonging to typical Irano-Turanian vegetation dominated by pistachio trees (class *Pistacietea verae* Nowak et al. 2024) and steppes dominated by *Stipa richteriana* known from lowlands and colline belts of Kazakhstan.

By including in the analysis all vegetation types documented by almost 6,000 relevés, it was possible to identify and define five new phytosociological classes. These are: *Eremogono griffithii-Nepetetea podostachyos* for Irano-Turanian subalpine forb steppes, *Artemisio persicae-Stipetea drobovii* for dry, thermophilous steppes of montane and subalpine belt of Middle Asia, *Festucetea alaico-krylovianae* for mesic grasslands of the alpine belt of the Middle and Central Asia, *Carici koshewnikowii-Asperuletea oppositifoliae* for chasmophytic vegetation of montane and alpine rock faces of Middle and Central Asia, and *Trichodesmo incani-Pachypterygietea brevipes* for scree vegetation of montane and subalpine belts of Irano-Turanian region. Additionally, we redefined the position and diagnostic taxa sets for open wood vegetation of *Pistacietea verae* Nowak et al. 2024 and hypersaline grasslands in the semi-desert and desert zones on solonchak soils from *Climacopteretea crassae* Akhani ex S. Świerszcz et al. 2021. Together with *Ephedretea intermedio-equisetinae* which is currently proposed as provisional, these eight vegetation types form the foundation of the distinction of the Irano-Turanian region in terms of plant community's high richness and uniqueness.

Additionally, six new orders were defined: mesic broad-leaved forests *Aceretalia turkestanici*, thermophilous Zeravshan juniper open woods of Turkestanian province *Juniperetalia seravschanicae*, scrub vegetation of xeric and nutrient-poor habitats (so-called Rozaria) *Crataegetalia ponticae*, riparian galley open woods of alluvial habitats in Irano-Turanian region *Populetalia pruinoso-euphraticae*, buckthorn and willow scrub vegetation on river bars in Middle Asia *Salici capusii- Hippophaeetalia rhamnoidis* and thermophilous steppes of montane and subalpine belts *Carici stenophylloidis-Stipetalia drobovii* (see Appendix 2). One alliance was validated after checking the relationships to other chasmophytic plant communities of the semi-arid Eastern Pamir alliance *Eritrichion pamirico-subjacquemontii* (Appendix 2).

Moreover, we present five new associations. These are: *Stipetum kazachstanicae* being a mesic steppe of the colline and montane belts of the central and eastern Tian Shan, *Asperulo oppositifoliae-Achnatheretum jacquemontii* – a chasmophytic vegetation found recently on limestone rocks of the eastern Pamir-Alai near Achikalma, *Bolboschoenetum affinis* –littoral reed vegetation on subhalophytic habitats in Central Asia and *Caricetum pamiricae* – a littoral, high alpine reed in the cold, mountain lakes and ponds.

Still, mainly due to too little data or the marginal position of the vegetation type in relation to the compact center of its range, several vegetation units remain provisional. The provisional units include: vegetation classes (e.g., *Ephedretea intermedio-equisetinae*) as well as orders (e.g., *Ephedretalia intermediae* including subalpine chasmophytic vegetation of cold and arid habitats in Central Asia), alliances (e.g., *Myricarion bracteato-squamosae* and *Chamaenerion latifolii* typical for river bars, *Bassio prostratae-Artemision ferganensis* referring to lowland desert steppes, *Cirsion incani* containing segetal vegetation) or associations (e.g. *Ranunculetum natantis* including aquatic vegetation of shallow alpine lakes and pools in the Eastern Pamir). Additionally, recently, two associations (*Salici pycnostachyae-Hippophaeetum rhamnoidis* and *Calamagrostio pseudophragmites-Hippophaeetum rhamnoidis*) were described by other researchers from Hunza Valley in Karakorum (Eberhardt, 2004) and we uphold this assignment.

Still, more than two hundred plant communities remain with no rank (237). This concerns mainly ruderal, semi-desert and scrub communities where our recognition is poor.

3.2. Expert system

The Middle Asian Expert System (MA-ES) was developed for the Middle Asian vegetation database as a part of the JUICE software (Tichý, 2002). It can be used to determine the affinity of vegetation plots to 39 vegetation classes described for this region. The list of diagnostic species comprises 1,110 taxa. Automated classification is based on the occurrence of diagnostic species of vegetation classes in the plots and, in some cases (also open woods, cryophilous steppes, semi-deserts), on differences in vegetation structure reflected by total plant cover. The manual for the MA-ES is provided in Appendix 1. It does not include five classes (*Sisymbrietea, Polygono arenastri-Poëtea annuae, Alno glutinosae-Populetea albae, Pegano harmalae-Salsoletea vermiculatae, Vaccinio-Piceetea*) for which we do not have detailed field data but know about their representation in Middle Asia based on literature or our field observation. The two unidentified vegetation groups, including tragacanthic, wind-swept vegetation of the alpine and subnival belts of the Irano-Turanian region and krummholz vegetation in the subalpine belt of Central Asia and Himalayas are also omitted. The MA-ES assigned ~97% of the plots in the dataset. Ca. 88% of the plots were classified according to the original classification based on previous studies. The lowest percentage of plots classified by the MA-ES compared to the original classification was recorded for: *Tamaricetea arceuthoidis* class (40% of the plots originally classified), *Eremogono griffithii-Nepetetea podostachyos* class (71% of the plots) and *Artemisio persicae-Stipetea drobovii* class (64% of the plots). The highest percentage of plots (more than 95%) compared to the original classification was recorded for classes: *Carpino-Fagetea sylvaticae, Populetea laurifolio-suaveolentis, Junipero-Pinetea sylvestris, Juniperetea pseudosabinae, Pistacietea verae, Carici rupestris-Kobresietea bellardii, Haloxyletea ammodendri, Haloxylo-Salsoletea tomentosae, Climacopteretea crassae, Adiantetea capilli-veneris, Papaveretea rhoeadis, Oryzetea sativae, Artemisietea vulgaris, Bidentetea tripartitae* and *Pegano harmalae-Salsoletea vermiculatae*.

3.3. New syntaxa described in this paper

In this paper, following the rules of the International Code of Phytosociological Nomenclature given in its 4th edition (Theurillat et al., 2021), we provide protologues for five classes, seven orders, one alliance, and six associations.

Eremogono griffithii-Nepetetea podostachyos **A. Nowak, S. Świerszcz, G. Swacha, S. Nowak et M. Nobis 2024 cl. nov.**

This class is described based on a novel syntaxonomic concept reflecting the unique ecology of subalpine grasslands with a considerable share of dicots and graminoids in the Irano-Turanian region. This type of vegetation occurs throughout the Pamir-Alai, western and southern Tian Shan, western Hindukush, and Kopet-Dagh Mts. It is encountered on stony slopes with relatively fertile soil. This forb steppe vegetation frequently develops in areas after clear-cuts of juniper open woods and is most often used extensively as pastures.

Here we describe this class in a formal way and designate *Nepetetalia podostachyos* A. Nowak, S. Świerszcz, M. Nobis, G. Swacha et S. Nowak 2023 as the holotypus of the class and list the following species as diagnostic of the new class: *Calamagrostis anthoxanthoides*, *Cousinia franchetii*, *Delphinium oreophilum*, *Eremogone griffithii*, *Gentiana olivieri*, *Geranium regelii*, *Geum kokanicum*, *Leymus alaicus*, *Ligularia thomsonii*, *Nepeta podostachys*, *Pedicularis krylovii*, *Poa bucharica*, *P. fragilis*, *P. zaprjagajevii*, *Potentilla grisea*, *Rhodiola heterodonta*, *Semenovia dasycarpa*.

Artemisio persicae-Stipetea drobovii **A. Nowak, S. Świerszcz, S. Nowak, A. Nobis et M. Nobis 2024 cl. nov.**

This class includes thermophilous steppes developing on summer dry, often stony slopes in montane and subalpine belts of Middle Asian mountains. In Tajikistan, this type of vegetation is common in the Zeravshan, Turkestan, Kuraminian, Karateginian, and Peter I ranges. Besides, it also occurs on the driest slopes of the Hissar, Hazratishoh, and Darvaz Mts. However, because the distribution ranges of the diagnostic species of the class are typically Irano-Turanian, this vegetation is suspected to occur in the vast areas of western Irano-Turanian geobotanical region. Plots of this vegetation were sampled on different altitude levels (from foothills to the upper montane belt). In Tajikistan, they were noted mainly at an elevation of 1,300–2,500 m a.s.l. This steppe type is moderately rich in species when compared to other types of steppe vegetation, having, on average, ca. 20 species per plot.

Here within, we describe this new class in a formal way and designate *Carici stenophylloidis-Stipetalia drobovii* Nowak et al. 2024 (this paper) as the holotypus of the class and list the following species as diagnostic of the new class: *Piptatherum songaricum*, *Stipa drobovii*, *S. lipskyi*, *S. arabica*, *S. jagnobica*, *S. margelanica*, *S. macroglossa*, *S. turkestanica*, *Artemisia persica*, *A. tenuisecta*, *A. baldshuanica*, *Otostegia olgae*, *O. fedtschenkoana*.

Festucetea alaico-krylovianae A. Nowak, S. Świerszcz, G. Swacha, S. Nowak et M. Nobis 2024 cl. nov.

This vegetation is structurally and ecologically considered a vicariant of European alpine and subalpine calcicolous swards of the nemoral mountain ranges of *Elyno-Seslerietea* Br.-Bl. 1948 or, to some extent, *Juncetea trifidi* Hadač in Klika et Hadač 1944 (Mucina et al., 2016). In Middle Asia, there is a noticeable difference in the distribution of this vegetation between Tajikistan, which lies mainly outside the nemoral zone, and Kyrgyzstan with many mountain ranges with a coniferous forest belt. The distinctiveness of alpine grasslands in Kyrgyzstan is well defined by the share of endemic species, like *Aconitum nemorum*, *Alfredia acantholepis*, *Artemisia aschurbaevii*, *Astragalus nivalis*, *Festuca alatavica*, *Hedysarum kirghisorum*, *Oxytropis ochroleuca*, *Phlomoides pratensis*, *Saussurea sordida*, *Seseli valentinae*, and many others. The mesic grasslands of the alpine belt of the Middle and Central Asia in Western and Central Tian Shan are closely related to ranges further north and east, particularly in the Altai and Sayan Mts. They are species-rich and distinct. Plots of the vegetation are relatively intensively grazed by sheep and goats. The compositional relation to hemiboreal regions is reflected by a considerable share of genera like *Trisetum*, *Oxytropis*, *Aconitum*, *Seseli*, *Geranium*, *Bistorta*, *Phlomoides*, *Primula*. This class includes the Altai-Sayan order of alpine swards *Festucetalia krylovii* and Pamir-Alai-western Tian Shan order *Geranio saxatilis-Festucetalia alaicae* (Ermakov & Zibzeev, 2012; Zibzeev & Nedovesova, 2015).

Here within, we describe this class in a formal way and designate *Geranio saxatilis-Festucetalia alaicae* A. Nowak et al. 2024 (this paper) as the holotypus of the class and list the following species as diagnostic of the new class: *Alchemilla tianschanica*, *Astragalus alpinus*, *Bistorta elliptica*, *Cerastium pusillum*, *Erigeron tianschanicus*, *Geranium saxatile*, *Pedicularis korolkowii*, *P. bucharica*, *Potentilla nervosa*, *P. pamiroalaica*, *Primula algida*, *Thalictrum simplex*, *Trisetum spicatum*.

Carici koshewnikowii-Asperuletea oppositifoliae A. Nowak, S. Świerszcz, S. Nowak, A. Nobis et M. Nobis 2024 cl. nov.

The definition of this class is needed due to the high phytogeographical distinctiveness and the remarkably high level of endemism. The share of endemics reaches even 80–100% in plots representing some plant communities distinguished within this class. The chasmophytic vegetation of montane and alpine rock faces of Middle and Central Asia has been one of the least understood vegetation types of the Irano-Turanian region, although also one of the most diverse. This vegetation develops on a variety of rocky substrates, in crevices, fissures, rock ledges, solid faces, cracks, or boulders in all mountain ranges of the Middle and Central Asian region.

Here within, we describe this class in a formal way and designate *Campanuletalia incanescentis* A. Nowak et al. 2014 as the holotypus of the class and list the following species as diagnostic of the new class: *Campanula lehmanniana*, *Asperula oppositifolia*, *Pentanema albertoreglia*, *Sergia regelii*, *Scutellaria megalodonta*, *Campanula albertii*, *Dionysia involucrata*, *Scutellaria schugnanica*, *Achosiphragma pinnatifia*, *Rhinactinidia limoniifolia*, *R. popovii*, *Aquilegia anemonoides*, *Stipa zeravshanica*.

Trichodesmo incani-Pachypterygietea brevipes A. Nowak, S. Świerszcz, S. Nowak, A. Nobis et M. Nobis 2024 cl. nov.

Similar to chasmophytic vegetation of rocky habitats, the communities inhabiting the screes of Middle Asian mountains are also characterized by high endemism. This vegetation is extremely diverse and develops on rock substrates differing in size (cobbles, gravels, pebbles, blocks), humus content in the parent material, elevation, or slope inclination, which is also related to the velocity of sliding down. The mountainous relief of Middle Asia and the distinctiveness of the phytogeography necessitate the description of the scree vegetation of montane and subalpine belts of the Irano-Turanian region as a separate class.

Here within, we describe this class in a formal way and designate *Sileno brahuicae-Lactucetalia orientalis* A. Nowak, S. Świerszcz, S. Nowak, M. Nobis 2021 as the holotypus of the class and list the following species as diagnostic of the new class: *Vicia kokanica*, *Ferula foetidissima*, *F. bucharica*, *Tetratenium olgae*, *Ferula ovina*, *Mediasia macrophylla*, *Ferula koso-polianskyi*, *Angelica ternata*, *Ampelopsis vitiifolii*, *Ferula grigoriewii*, *Bunium badachschanicum*, *Trichodesma incanum*, *Pachypterygium brevipes*, *Lagochilus seravschanicus*, *Glaucium squamigerum*, *Caccinia dubia*, *Eremostachys tadschikistanica*.

Aceretalia turkestanici A. Nowak, S. Świerszcz, S. Nowak, A. Nobis et M. Nobis 2024 ord. nov.

This order includes typical mesic broad-leaved forest vegetation on hills and slopes of a montane belt in Middle Asia. The soils typical for this vegetation are relatively fertile; however, they are rather shallow and lithomorphic, with no strong drainage or moisture deficiency even during summer. There are no permanent or ephemeral inundations; however, in some cases, the groundwater level is fairly high (e.g., *Swido darvasicae-Platanetum orientalis* A. Nowak et al. in A. Nowak et al. 2017). Currently, this type of vegetation, called traditionally in Middle Asia a "black forest" (from Russian chernolese), occupies mainly northern slopes in the Hissar, Darvaz, Hazratishoh, Peter I, Ferghana, Kyrgyz, and Chatkal ranges in Tajikistan and Kyrgyzstan. These mesic forests have not been glaciated during Pleistocene cooling episodes and are, therefore, the refuge of many relict and endemic species such as *Ostrovskia magnifica* and *Swida darwazica*.

Here within, we describe this order in a formal way and designate *Acero turkestanici-Juglandion regiae* A. Nowak, M. Nobis et S. Nowak in A. Nowak et al. 2017 as the holotypus of the order and list the following species as diagnostic of the new order: *Acer regelii*, *A. turkestanica*, *Platanus orientalis*, *Juglans regia*, *Asyneuma attenuata*, *A. baldshuanica*, *Brachypodium sylvaticum*, *Clinopodium integerrimum*, *Malus sieversii*, *Poa nemoralis*, *Aegopodium tadshikorum*, *Impatiens parviflora*.

Juniperetalia seravschanicae **A. Nowak, M. Nobis, S. Nowak, M. Kotowski et S. Świerszcz 2024 ord. nov.**

The thermophilous Zeravshan juniper open woods assigned to this order occur across western parts of Middle Asia (western Tian Shan, Pamir-Alai, western Hindukush, and probably also in Kopet-dagh (Turkmenistan), Baluchistan (Pakistan), Hazarmaysh Mts. (Afghanistan) and Kuyhitang Mts. (Uzbekistan). The altitudinal range of this vegetation centers in the montane belt between 1,500 and 2,700 m a.s.l. The vegetation patches representing the order are found on fairly steep slopes of various aspects. They develop on chestnut-brown soils and are adapted to the winter-rain Mediterranean-like climate of considerable continentality. These open woods are a source of firewood and are extensively grazed, mainly by sheep and goats.

Here within, we describe the new order in a formal way and designate *Juniperion seravschanicae* A. Nowak, M. Nobis, S. Nowak, M. Kotowski, S. Świerszcz 2022 as the holotypus of the order and list the following species as diagnostic of the new order: *Berberis integerrima*, *Campanula glomerata*, *Juniperus polycarpos* var. *seravschanica*, *Oxytropis capusii*, *Thalictrum sultanbadense*, *Pedicularis dolichorhiza*, *P. krylovii*, *Poa fragilis*, *P. nemoraliformis*, *P. trivialis*, *Seseli schrenkianum*, *Silene tachtensis*, *Veronica rubrifolia*, *Geranium regelii*, *Lonicera nummulariifolia*, *Ligularia thompsonii*, *Rosa webbiana*, *R. kokanica*.

Crataegetalia ponticae **A. Nowak, M. Nobis, S. Nowak, M. Kotowski, E. Klichowska, A. Nobis et S. Świerszcz 2024 ord. nov.**

This order includes mesic and occasionally semi-arid shrubby vegetation on steep slopes developing within the upper montane and subalpine belts in Middle Asia (so-called Rosaria). It encompasses the mantle vegetation seral or marginal to broad-leaved forests (mainly *Juglans regia* and *Acer turkestanica* forests) in the nemoral, subhumid zone of the Irano-Turanian region. This shrubland vegetation develops mainly on shallow to moderately deep soils. Sometimes, it occurs on scree slopes with different inclinations. Plant communities included in this order are supposed to occur at elevations between 1,000 and 3,500 m a.s.l., and are mainly composed of species with the Irano-Turanian distributional pattern. They are mostly natural vegetation of mountain slopes but also include the secondary scrublands that developed after clear cuttings of woody vegetation at lower altitudes in the valley of the warmer and more humid areas. They are dominated by representatives of *Crataegus* spp., *Cotoneaster* spp., *Prunus* spp., *Caragana* spp., and *Spiraea* spp. genera.

Here within, we describe the new order in a formal way and designate *Ranunculo tenuilobi-Cotoneasterion hissarici* A. Nowak, M. Nobis, S. Nowak, M. Kotowski, E. Klichowska, A. Nobis, S. Świerszcz 2022 as the holotypus of the order and list the following species as diagnostic of the new order: *Amygdalus bucharica*, *Ranunculus tenuilobus*, *Cotoneaster hissaricus*, *Caragana turkestanica*, *Crataegus pontica*, *Astragalus darwasicus*, *Asyneuma argutum* subsp. *baldshuanica*, *Neopaulia ovczinnikovii*, *Prunus sogdiana*, *Calophaca grandiflora*, *Fraxinus raibocarpa*, *Exochorda korolkowii*, *Berberis heteropoda*, *B. integerrima*.

Populetalia pruinoso-euphraticae **A. Nowak, S. Świerszcz, S. Nowak, A. Nobis et M. Nobis 2024 ord. nov.**

This riparian gallery open woods are composed of *Populus pruinosa* and *P. diversifolia*. The order includes forest or forest-thicket vegetation typical of alluvial plains in the warmest climate zone in the Irano-Turanian region. It groups plant communities like *Populetum pruinosae* that thrive on wet, marshy, and frequently inundated river terraces with significant salinity. They are distributed at elevations between 200 and 450 m a.s.l. with shallow groundwater tables and numerous oxbow lakes, ditches, and marshlands. The range of this vegetation includes southern regions of Middle Asia (S Uzbekistan, Turkmenistan, SW Tajikistan, and N Afghanistan).

Here within, we describe this order in a formal way and designate *Elaeagno angustifoliae-Populion pruinosae* A. Nowak, M. Nobis et S. Nowak in A. Nowak et al. 2017 as the holotypus of the order and list the following species as diagnostic of the new order: *Populus pruinosa*, *P. ephratica*, *Eleagnus angustifolia*, *Erianthus ravennae*, *Cynanchum acutum*, *Elaeagnus angustifolia*, *Erianthus ravennae*, *Glycyrrhiza glabra*, *Limonium raeniformae*, *Tamarix ramosissima*, *T. meyeri*, *T. hispida*, *Zygophyllum oxianum*.

Salici capusii-Hippophaeetalia rhamnoidis **A. Nowak, S. Świerszcz, S. Nowak, A. Nobis et M. Nobis 2024 ord. nov.**

Vegetation representing the order is met in vast river valleys of the Pamir-Alai, as well as the Tian Shan, which abound in broad bars with thick deposits of gravel sediments. It is composed of dense thickets of buckthorn and willows, or *Myricaria* spp., which are subject to frequent inundations. This vegetation has been sampled during our expeditions, however, it was first described from the Karakorum in northern Pakistan by Eberhardt (2004). This type of vegetation is found throughout the Irano-Turanian region at varying altitudes, from submontane to subalpine belt, between 1,000 and 3,000 m a.s.l. Although this vegetation appears to be, to a large extent, different than poplar stands of temperate zones of Central Asia, we decided to place it within the class *Alno glutinosae-Populetea albae*, because of the habitat similarities.

Here within, we describe this order in a formal way and designate *Hippophaeion rhamnoidis* Eberhardt 2004 as the holotypus of the order and list the following species as diagnostic of the new order: *Hippophae rhamnoides*, *Salix blakii*, *S. capusii*, *S. pycnostachya*, *Saccharum spontaneum*, *Calamagrostis pseudophragmites*, *Berberis nummularia*, *Clematis orientalis*, *C. songarica*.

Carici stenophylloidis-Stipetalia drobovii **A. Nowak, S. Świerszcz, S. Nowak, A. Nobis et M. Nobis 2024 ord. nov.**

This order includes thermophilous steppes on summer dry, often gravel slopes in the western Pamir-Alai mountains. It extends into montane and subalpine belts of the Zeravshan, Turkestan, Hissar, Kuraminian, Hazratishoh, Karateginian, and Peter I ranges. However, the distributional range of diagnostic species of this order is typically Irano-Turanian, but it comprises the western Irano-Turanian geobotanical region. This vegetation has been observed at altitudes between 1,300 and 2,700 m.

Here within, we describe this order in a formal way and designate *Poo bulbosae-Artemision persicae* A. Nowak, S. Nowak, A. Nobis, M. Nobis 2016 as the holotypus of the order and list the following species as diagnostic of the new order: *Bromus danthoniae*, *Cousinia mulgediifolia*, *Meniocus liniifolius*, *Poa bulbosa*, *Stipa arabica*, *Trigonella orthoceras*, *Alyssum desertorum*, *Artemisia ferganensis*, *A. persica*, *Carex stenophylloides*, *Festuca valesiaca*, *Centaurea squarrosa*, *Oxytropis capusii*.

Eritrichion pamirico-subjacquemontii **A. Nowak , S. Świerszcz, S. Nowak, V. Plášek, A. Nobis, E. Klichowska et M. Nobis 2024 all. nov.**

This type of high alpine vegetation is distributed across the subarid zone of the Eastern Pamir, but can also be found on the highest, windswept peaks in West Pamir. It is met in areas with extremely continental climate, where temperatures range between −40 and +50. Vegetation of this alliance inhabits rock clefts, larger cracks, and shadowed ledges in Rushan, Yazgulem, Ishkashim, Vakhan, Alichur, Muzkol, and Schugnan ranges. It was recorded mainly in high alpine elevations between (3,200–)3,500–4,700(–5,500) m a.s.l. It is extremely poor in species vegetation, with a very short blooming period taking place in July and August.

Here within, we describe this alliance in a formal way and designate *Crepidifolio tenuifolii-Stipetum tianschanicae* A. Nowak, S. Świerszcz, S. Nowak, V. Plášek, A. Nobis, E. Klichowska, M. Nobis 2022 as the holotypus of the alliance and list the following species as diagnostic of the new order: *Eritrichium pamiricum, E. subjacquemontii, Lonicera humilis, Roegneria schugnana, Rubia tibetica, Androsace villosa var. dasyphylla, Allium tianschanicum, Crepidifolium tenuifolium*.

Stipetum kazachstanicae **M. Nobis, E. Klichowska et A. Nowak 2024 ass. nov.**

Diagnostic species: *Centaurea ruthenica*, *Gypsophila patrini*, *Stipa macroglossa* subsp. *kazachstanica*, *Erysimum diffusum*, *Potentilla recta*

Floristic and habitat characteristics: Patches typical for this association form a mesic steppe within the colline and montane belts of the central and eastern Tian Shan. The community is a typical grassland of Central Asia covering an extensive area in the northern at altitudes between 1,500 and 2,500 m a.s.l. The patches of the association are moderately rich in species. An average of 30 taxa were recorded within a 10 m^2 patch.

Holotypus: Sary-Tologoy, Tyul River Valley, hills on the northern side of the valley, Kyrgyzstan; 10 m^2; 08.07.2015; 42.73111 N, 78.82444 E; 1,915 m a.s.l.; c – 90%, aspect: SE, inclination: 10°; *Stipa macroglossa* subsp. *kazachstanica* 4, *Ziziphora clinopodioides* 2, *Meniocus linifolius* 2, *Astragalus pterocephalus* 2, *Silene brahuica* 1, *Koeleria cristata* 1, *Patrinia intermedia* 1, *Erysimum diffusum* 1, *Artemisia maracandica* 1, *Dracocephalum bipinnatum* 1, *Lappula consanguinea* 1, *Oxytropis tachtensis* 1, *Potentilla recta* 1, *Eremopyrum bonaepartis* 1, *Phlomoides speciosa* 1, *Rosularia paniculata* 1, *Galium pamiro-alaicum* +, *Artemisia scoparia* +, *Chorispora sibirica* +, *Stipa capillata* +, *Artemisia dracunculus* +, *Elaeosticta ferganensis* +, *Hedysarum pavlovii* +, *Jurinea abolinii* +, *Lagochilus platyacanthus* +, *Stipa caucasica* +, *Centaurea ruthenica* +, *Gypsophila patrinii* +, *Melica secunda* +, *Scutellaria przewalskii* +, *Thesium alatavicum* +, *Cuscuta* sp. +, *Diarthron vesiculosum*, +, *Takhtajaniantha pusilla*.

Caricetum pamirensis **A. Nowak et M. Nobis 2024 ass. nov.**

Diagnostic species: *Carex pamirensis*

Floristic and habitat characteristics: Patches typical for this association form coastal rushes clearly dominated by the diagnostic species. The community is a typical alpine rush inhabiting the riparian zone of lakes and ponds of the Eastern Pamir (e.g., around Murghab or Bulunkul) or the Transalayan range (e.g., Tulpar Lake). It is an extremely species-poor vegetation found on the alpine floor at altitudes between 3,000 and 4,000 m a.s.l.

Type relevé: Kara-su to the S from Murghab, Tajikistan; 10 m^2; 16.06.2015; 38.006643 N, 73.933265 E; 3,776 m a.s.l.; c – 65%; *Carex pamirensis* 4, *Stuckenia amblyphylla* +, *Halerpestes sarmentosa* +, *Algae* indet. 1.

Bolboschoenetum affinis **A. Nowak et M. Nobis 2024 ass. nov.**

Diagnostic species: *Bolboschoenus maritimus* subsp. *affinis*

Floristic and habitat characteristics: The association commonly occurs in shallow, temporary pools, irrigation and drainage ditches, occasionally on lake margins, particularly in brackish waters on subsaline habitats across Central Asia. It is distributed rather in lowlands of the Irano-Turanian region, at an altitude up to 1,000 m a.s.l. Patches representing the association develop in muddy clay substrates, and consist of plants reaching heights typical for medium-sized reeds, i.e., up to 0.5 m. In the surveyed plots of this community the diagnostic taxon predominates, reaching an average coverage of 50%. We have noticed patches of this association in several places in central Kyrgyzstan.

Type relevé: Khodzhaata, Kyrgyzstan; 10 m^2; 20.06.2017; 41.672338 N, 72.027867 E; 950 m a.s.l.; c – 65%; *Bolboschoenus maritimus* subsp. *affinis* 3, *Polypogon demissus* 1, *Phragmites australis* +, *Juncus articulatus* 1, *Calamagrostis pseudophragmites* +, *Eleocharis mitracarpa* +, *Cynodon dactylon* +, *Bidens frondosa* +, *Myricaria bracteata* +, *Plantago lanceolata* +, *Saccharum spontaneum* +, *Equisetum ramosissimum* +, *Chenopodium glaucum* +.

4. Discussion

4.1. Justification for the hierarchical classification and establishment of new vegetation classes

Recognizing and understanding vegetation patterns and classifying plant communities have been major challenges for vegetation ecologists since the beginning of geobotanical research. Geobotany is generally considered to be the branch of science that links vegetation and plants to space and time (Frey & Lösch, 2010). Vegetation classification makes it possible to understand how vegetation types function in the environmental gradients and to study drivers (including anthropogenic) of plant communities. The important role of vegetation classification as an applied science is the geobotanical map as the basis for the conservation of vegetation diversity and habitats (A. Nowak & S. Nowak, 2022). Unfortunately, despite the habitat diversity, large areas and different habitats in Middle Asia are poorly recognized in terms of vegetation to date (A. Nowak et al., 2020a). Previous studies, although sometimes quite intensive, have mainly focused on limited area or single vegetation type, such as forests as an example. Only our project, which started in 2006, has achieved a comprehensive survey of most habitat types and areas in the whole of Tajikistan and Kyrgyzstan, as well as some parts of Uzbekistan and Kazakhstan. As a result, we are now able to report on the exceptional richness of rock and scree vegetation or aquatic communities, and to prove the existence of secondary pseudosteppes or to discuss the relationship between shiblyak (mesophilous shrubland) and xerothermophilous scrub or open woodland. In total, we identified 550 vegetation units belonging to 45 classes, 47 orders, and 83 alliances (Appendix 2). It is difficult to compare this richness to any other studied area, but it is certainly impressive for such a relatively small area which we have explored. For example, the total number of basic vegetation units in the Czech Republic and Poland (an area roughly equivalent to Tajikistan and Kyrgyzstan) is about 650. Recently, 233 alliances have been identified in Germany and 1,105 in Europe. But research in Central Europe has a much longer tradition, is more advanced, and is carried out by many more botanists associated with different scientific centers (Chytrý & Tichý, 2018; Matuszkiewicz, 2013; Preislerová et al., 2022; Rennwald, 2002).

One of the main objectives of this work was to identify potential new vegetation types at higher levels of the hierarchical system. To date, it has been difficult to define vegetation with certainty at the class level. Firstly, due to a lack of data, and secondly, because the previously separated analysis included only selected habitat types (e.g., steppes, forests, or alpine meadows). An additional difficulty was that the study area (Tajikistan, Kyrgyzstan) did not cover the whole phytogeographical unit. Surveys in Iran, Kazakhstan, and other areas were necessary to get an idea of the relationships and to study the centers of occurrence of certain vegetation types that have only outposts or marginal locations in our study area (e.g. *Pistacietea* or *Haloxyletea*).

4.2. Irano-Turanian subalpine forb steppes

Most of the vegetation units recognized in Middle Asia have a typical Irano-Turanian geography related to the history of their formation, glaciation, orogeny, and climatic aridification in the Eocene and Miocene (Kamelin, 1973). Undoubtedly, the uniqueness and distinctiveness of the Middle Asian vegetation are also related to human activity. Steppes and secondary pseudosteppes form the most prominent biomes in Middle Asia due to the continental climate, which is characterized by warm, dry summers and severe, very cold winters that do not support tree growth. Environmental conditions with a long pastoral tradition have led to the domination of extensive areas in montane, subalpine, and even alpine belts by this type of vegetation (A. Nowak et al., 2018; Świerszcz et al., 2022; Werger & van Staalduinen, 2012). However, along the border between the montane and alpine belts, often on the former habitat of cleared juniper forests, a type of steppe has developed that is also rich in dicots. It is a so-called forb steppe. This type of steppe develops as a result of long-term grazing and is structurally similar to the so-called meadow steppe (e.g., southern Urals). Forb steppe is included in the class *Festuco-Brometea* and the suballiance *Phlomenion pungentis* Saitov et Mirkin 1991 (Demina, 2014; Yamalov et al., 2014). It is clearly distinct from the other vegetation types and is characteriszd by high endemism, high species richness, very dry habitat (drier than that in case of meadows), and a long growing season (longer than in the case of the steppes). We have found a number of endemic species that occur exclusively or with optimum occurrence in this type of vegetation (e.g. *Allium paulii*, *Astomaea galiocarpa*, *Astragalus irinaea*, *A. macronyx*, *A. pauperiformis*, *Corydalis macrocentra*, *Cousinia macilenta*, *C. tomentella*, *Dianthus pamiralaicus*, *Gagea capusii*, *G. minutissima*, *Iris parvula*, *I. tadshikorum*, *I. zaprjagajevii*, *Silene erubescens*, *Poa bactriana*, *Primula baldshuanica*, *P. lactiflora*). For this reason, we have created a separate class for this vegetation: *Eremogono griffithii-Nepetetea podostachyos*. This vegetation is related to juniper woods but has its ecology, species content and occurs in the subalpine belt of the Irano-Turanian mountains. We have met the patches typical for it at many sites in Pamir-Alai, western Tian Shan and northern Hindu Kush. Our preliminary studies in other regions of Asia and the analysis of the distribution of diagnostic species (e.g., *Eremogone griffithii*, *Nepeta podostachys*, *Morina coulteriana*) indicate that this grass-dominated ecosystems occur throughout the Irano-Turanian area (especially Kopet-Dagh Mts, Altai Mts, Dzhungarian Alatau, Zagroz Mts, Alborz Mts, Southern Hindukush, Koh-i-baba, Paropamisus Mts, East and Central Iranian Mts). This vegetation class needs to be further studied, especially in relation to the rubble vegetation, which represents *Prangetea ulopterae* class, occupies more rubble sites and is dominated by Apiacae representatives. *Eremogono griffithii-Nepetetea podostachyos* also requires a detailed comparison with typical mountain steppe (*Artemisio persicae-Stipetea drobovii*) and alpine meadows (*Festucetea alaico-krylovianae*). It would also be important to compare this vegetation with the so-called "montane steppes" met in the Middle East and Armenia (Ambarlı et al., 2020). This montane steppe is considered to be the natural vegetation of wind-swept slopes located above the tree line to the sub-alpine zone (1,800–3,500 m a.s.l.; Kürschner 1986).

4.3. Thermophilous steppes

Another main type of grasslands in Middle Asia is the mountain steppe on summer-dry, stony slopes in the montane belt (*Artemisio persicae-Stipetea drobovii*). They clearly prefer the Irano-Turanian climate and this region is their center of occurrence. This can be seen clearly on the border between the Pamiro-Alai and the Tian Shan, where they decrease significantly towards the north. These steppes have a relatively low vegetation cover (30–70%), consist of quite low plants (up to 50–70 cm high), and are characterized by a significant share of plants typical of scree habitats. Initially, we considered this vegetation type to belong to the class *Astragalo microcephali-Brometea tomentelli* Quézel 1973. However, in terms of the structure, soil substrate, and, above all, species composition, the steppes of central Turkey should be considered as eastern Mediterranean vegetation. Thermophilous mountain steppes of Central Asia occur mainly in the Pamir-Alai, western Tian Shan, Kopet-dagh, and Hindu

Kush mountains. Further phytosociological surveys in these areas will certainly make it possible to show the diversity of these steppes at the order level. At present, only one order, namely *Carici stenophylloidis-Stipetalia arabicae* has been described for the Pamir-Alai. (A. Nowak et al., 2016d). It is much richer in species (up to 40 species per 10 m^2) than Central Asian grasslands representing *Cleistogenetea squarrosae* class Mirkin et al. ex Korotkov et al. 1991 or high-altitude arid steppes included in *Ajanio-Cleistogenetea songoricae* (Mirkin in Kashapov et al. 1987) Mirkin et al. 1988. They are often characterized by a significant contribution of dwarf shrubs and thorny cushion plants (e.g., *Convolvulus spinifer*, *Otostegia* spp.). Typically Irano-Turanian vegetation, they share a number of species of *Stipa* spp., *Astragalus* spp., *Artemisia* spp., *Alyssum* spp., *Cousinia* spp., *Echinops* spp., *Nepeta* spp., *Phlomis* spp., *Phlomoides* spp., *Salvia* spp., and *Silene* spp. genera (A. Nowak et al., 2016b). As a typical representative of Irano-Turanian vegetation, it has a high degree of endemism. The patches representing this vegetation harbor an average of about 50% endemics (A. Nowak et al., 2016b, 2018).

4.4. Scree vegetation of montane and subalpine belts of the Irano-Turanian region

Adjacent to thermophilous steppes, talus communities develop on steep slopes. Middle Asia is a land of rocks and screes that dominate large areas of barren mountains. The scree habitat is extremely diverse in terms of species composition, reflecting differences in the degree of slope inclination, size of the parent material, the rate of rock and scree movement, aspect, and, of course, altitude. Although this group has been studied since the beginning of our project, further detailed study is required, especially in the northern part of Middle Asia. The class *Trichodesmo incani-Pachypterygietea brevipes* seems to be very diverse and clearly different from the European *Thlaspietea rotundifolii* (Mucina et al., 2016). Due to a lack of sufficient knowledge and reliable comparative data from neighboring areas, we initially included this vegetation in *Artemisio santolinifoliae-Berberidetea sibiricae* class, which was reported by Ermakov et al. (2006) from southern Siberia. However, the current state of research makes it possible to demonstrate the profound distinctiveness of most Middle Asian scree communities in comparison to scree vegetation occurring in the Altai and Sayan Mountains. The latter developed in areas with continental climate, but characterized by significant temperate influences. Furthermore, following Ermakov et al. (2006), we concluded that the Siberian habitats are much more stable and have much more shrubby physiognomy. We suppose that this class includes shrubby vegetation on mobile screes and rock outcrops within Central and Middle Asia. Besides, within *Artemisio santolinifoliae-Berberidetea sibiricae* class, two orders can possibly be distinguished: *Ephedretalia intermediae* nom. prov. (subalpine chasmophytic vegetation of cold and arid habitats in Middle and Central Asia) and *Artemisio santolinifoliae-Berberidetalia sibiricae* Ermakov et al. 2006 (subalpine and upper montane chasmophytic vegetation of warm and arid zones in northern Middle and Central Asia). Other possibilities, such as including this vegetation in *Thlaspietea rotundifolii* distinguished for European vegetation, *Lamio tomentosi-Chaerophylletea humilis* for the Caucasus, or *Heldreichietea* proposed for the Taurus Mts in Turkey, have to be rejected due to significant differences in species composition and phytogeography (Belonovskaya, 2012; Belonovskaya et al., 2014; Parolly, 1998; Quézel, 1973; Valachovič et al., 1997). In Tajikistan, the isolation of the scree habitats is also evident due to the extreme draught, the very harsh microclimate at higher altitudes, the unstable soil, and the frequent rock falls, which are destructive to plants. A number of endemic species, such as *Allium crystallinum*, *Astragalus varzobicus*, *Cousinia butkovii*, *C. corymbosa*, *C. pseudoshisakensis*, *Delphinium ovczinnikovii*, *Ferula equisetacea*, *F. koso-polianskyi*, *Lagochilus kschtutensis* have adapted to these particular conditions. This results in narrow distribution ranges of scree plant communities, especially in the montane and colline belts. As a number of scree plant communities in Middle Asia consist of many Apiaceae representatives (e.g., *Ferula* sp., *Angelica* sp., *Semenovia* sp., *Seseli* sp., *Aulacospermum* sp., *Tetrataenium olgae*, *Mediasia macrophylla*, and others), it will be necessary for the future to establish the relationship between this vegetation and *Prangetea ulopterae* class including relatively dry tall-forbs, which are also frequently reported from scree habitats. The difference that is most often indicated is that *Prangetea ulopterae* communities develop where stones slide over the top soil layer of the slope, whereas typical scree has the entire root zone mobile with little or no soil content. Despite the presence of Apiacae, important components of Middle Asian scree vegetation are also *Rheum*, *Euphorbia*, *Piptatherum*, *Scutellaria*, *Scrophularia*, and *Zygophyllum* representatives.

4.5. Chasmophytic vegetation of montane and alpine rock faces of Middle and Central Asia

Even more diverse than the scree plant communities is the vegetation of the rock wall habitats of Middle Asia. The richness of species and their communities, as well as the degree of distinctiveness, is striking. It is surprising that this extraordinary diversity has been so little studied. Our research presents about 70 chasmophytic associations of fissures, crevices, cracks, or solid rock faces, which we initially included in *Asplenietea trichomanis* class. However, analysis of the species composition, share of endemics, and phytogeographical range suggests that they should be included in a completely new class – *Carici koshewnikowii-Asperuletea oppositifoliae* described above. This class is the chasmophytic vegetation of the Irano-Turanian rocks and should be divided into four alliances: *Asperulo albiflorae-Campanulion lehmannianae* (chasmophytic vegetation of the upper montane and alpine rock faces of Middle Asia), *Caricion koshevnikovii* (vegetation of the crevices of the submontane and colline zone in the Pamir-Alai and Tian Shan Mts.), *Eritrichion pamirico-subjacquemontii* (vegetation of rock ledges and crevices in the high altitude semi-arid zone of the Pamir) and *Hippolytion darvasicae* (rock vegetation of the subhumid zone in the eastern Pamir-Alai and western Pamir; Appendix 2).

4.6. Mesic grasslands of the alpine belt of the Middle and Central Asia

The last of the newly described classes is distinguished for alpine grasslands, strongly influenced by the continental temperate climate. This vegetation was initially observed in the Altai and described at the rank of order (Ermakov &

Zibzeev, 2012; Zibzeev & Nedovesova, 2015). Our research, which covers studies on meadow, steppe, semi-desert, and tall-farb vegetation in montane and alpine belts in the Pamir, Hissaro-Alai, and western Tian Shan Mts., shows a considerable distinction of the alpine grasslands of northern Middle Asia. This vegetation is similar in structure and ecology to the alpine and subalpine calcicolous swards occurring in the nemoral mountain ranges of Europe, specifically the *Elyno-Seslerietea* class Br.-Bl. 1948 or, to some extent, *Juncetea trifidi* class Hadač in Klika et Hadač 1944 (Mucina et al., 2016). The distinctiveness of alpine grasslands, particularly in northern parts of Middle and Central Asia, is well indicated by the share of endemic species like *Aconitum nemorum*, *Alfredia acantholepis*, *Astragalus nivalis*, *Artemisia viridis*, *A. aschurbaevii*, *Festuca alatavica*, *Schmalhausenia nidulans*, *Phlomoides pratensis*, *Oxytropis ochroleuca*, *O. ruebsaamenii*, *Saussurea sordida*, *Seseli valentinae*, *Tulipa dasystemon*, *Hedysarum kirghisorum* and many others. Geographically, the alpine vegetation of Middle Asia, especially in its northern part (Western and Central Tian Shan), is closely linked to areas of mountain glaciation and subsequent reestablishment of vegetation migrating from the south and populating the alpine belt above the upper forest limit. These compositional similarities can be clearly seen at the genus level. including such common taxa as *Trisetum* spp., *Oxytropis* spp., *Aconitum* spp., *Seseli* spp., *Geranium* spp., *Bistorta* spp., *Phlomoides* spp., *Primula* spp., etc. Similarly to other alpine grasslands, communities from *Festucetea alaico-krylovianae* class are intensively grazed by sheep, goats and, yaks. In recent years, grazing intensity has increased dramatically, and in many regions, the alpine graminoid vegetation has been heavily degraded. Having in mind all the floristic, phytogeographical, and ecological characteristics that define the alpine grasslands typical for northern parts of Middle and Central Asia, in our opinion, it should be ranked as the class that comprises Altai-Sayan order *Festucetalia krylovii* (mainly in Central Asia) and Pamir-Alai-western Tian Shan order *Geranio saxatilis-Festucetalia alaicae* (Ermakov & Zibzeev, 2012; Zibzeev & Nedovesova, 2015; Appendix 2).

4.7. Sclerophyllous and thermophilous scrub vegetation of arid habitats on large rock ledges, screes and badlands

Despite the intensive survey, we still have some doubts and refrain from deciding regarding many vegetation types. One is the *Ephedretea intermedio-equisetinae* tentatively proposed and still pending a thorough analysis. This sclerophytic vegetation grows on eroded slopes of arid and semi-arid habitats in mountain ranges in the montane and subalpine belts, inhabiting large rocky shelves, cracks, aprons, cones, and other screes with coarse cobble and pebble deposits. It is also observed in badlands with semi-desert vegetation (e.g., the western part of the Issik-kul basin). Apart from *Ephedra* representatives, this semiarid chasmophytic vegetation also includes other sclerophylous shrubs, like *Atraphaxis* spp., *Spiraea* spp., *Rhamnus* spp., *Prunus verrucosa* or *Sageretia laetevirens*. After surveying xerophytic scrubs in Uzbekistan and Iran, it seems to us that *Ephedra*-dominated vegetation needs to be separated at least at the order level. This is, to some extent, confirmed in the literature, where these communities are often called "ephedrovniki" and presented as a separate vegetation type (e.g. Safarov 2016, Stanyukovich 1982). The structure and ecology of this vegetation are not restricted to Middle Asian semi-arid habitats. Similar xerophytic communities also occur in the semi-deserts of Utah, California and Arizona in North America (e.g., Kearsley et al., 2015). Also, in semi-deserts and the coastal arid vegetation of Chile, the communities with *Ephedra breana* were distinguished (Luebert & Pliscoff, 2022). Detailed research in the area of Kopet-dagh, Zagros, Alborz, western Tian-Shan, and Hindukush, is still needed to check whether the communities dominated by *Ephedra* should be included in a separate class of semi-arid scrublands of Middle Asia or continental and cold-adapted vegetation of *Artemisio santolinifoliae-Berberidetea sibiricae*.

Perhaps also thermophilous secondary grasslands of Irano-Turanian region should be separated from the Mediterranean *Stipo capensis-Trachynietea distachyae*. Despite some obvious similarities (e.g., sharing *Vulpia* spp, *Trachynia distachya*), there is a lot of unique species for both regions (e.g., *Astragalus bucharicus*, *A. corydalinus*, *A. harpilobus*, *A. maverranagri*, *A. ovczinnikovii*, *Elaeosticta samarcandica*, *Eremurus bucharicus*, *Jurinea bucharica*, *Ungernia tadshikorum*). Additionally, they are often dominated by typical Irano-Turanian taxa absent in the Mediterranean region (e.g., *Delphinium biternatum*, *Eremurus tian-schanicus*, *E. suvorovii*, *Elaeosticta ferganensis*, *E. fuscus*, *Gagea vegeta*, *G. pseudophila*, *Carex pachystylis*, *Phlomis bucharica* and *Vulpia persica*). Also, spring geophytes like tulips (e.g., *Tulipa tubergeniana* and *T. dasystemon*) are an important component of this vegetation type (Świerszcz et al., 2020).

4.8. Perspectives on the practical applications

One of the most important imperatives of vegetation classification is to enable appropriate and effective conservation of vegetation diversity. Effective conservation of vegetation harboring the whole biodiversity is only possible with a well-recognized, detailed vegetation classification. This has been proved in Europe, where typological studies of vegetation have been carried out for decades. Up-to-date knowledge of vegetation types, distribution, diagnostic species sets, ecology, and management for a given vegetation type is essential for effective conservation of natural habitats (European Commission, 2013). Unfortunately, only Europe has been comprehensively surveyed, while other continents, particularly Asia and Africa, remain understudied and await comprehensive analyses (Mucina et al., 2016). Middle and Central Asia lies at the crossroads of several important geographical regions and constitutes one of the world's biodiversity hotspots (Mittermeier et al., 2005). At the same time, the region is at high risk of climate change (Baettig et al., 2007) and has the lowest adaptive capacity to climate instability (Fay & Patel, 2008).

Of course, our synthesis is not the end of efforts to create classifications of the Middle Asia vegetation. In particular, the survey of the Hindu Kush in Afghanistan, the Kopet-dagh mountains on the border between Turkmenistan and Iran, and the Zagros mountains on the border between Iran, Iraq, and Turkey should be completed. We hope that in the near future, it will be possible to verify our decisions regarding the vegetation of Tajikistan and Kyrgyzstan and to present the overall diversity of Irano-Turanian vegetation. However, this research needs to be accelerated as it is inevitable that the vegetation of Middle Asia will be transformed or even destroyed due to human activity. An example of a threatened plant communities that is crucial in terms of both ecosystem services and biodiversity hotspots and traditional pastoralism is the pistachio grove. Due to timber plundering, resin exploitation, burning, more frequent natural fires, and intensive grazing, open forests of *Pistacia khinjuk* in the Zagros Mts. are likely to disappear within the next fifty years (Kheshti, 2020; A. Nowak et al., 2022a; Pourreza et al., 2008). Considering the possibility of rapid and irreversible destruction to understand the vegetation diversity of the Irano-Turanian region, hybrid surveys involving different methodological approaches should be undertaken. Remote sensing methods may be helpful here, especially for exploring war zones such as Afghanistan. Airborne LIDAR could be considered a useful tool in the exploration of such areas. Recently, a semi-automatic approach to vegetation mapping with LIDAR, using hierarchical object-based classification together with the Bayesian Information Criterion algorithm and unsupervised classification techniques, has been shown to be an effective method of vegetation mapping and classification (Su et al., 2016; Uyeda et al., 2020).

5. Supplementary material

The following supplementary materials are available for this article:

Appendix 1. Expert system for classification of the phytosociological classes of Tajikistan and adjacent areas.

Appendix 2. Conspectus of the syntaxa of the Middle Asia and adjacent areas dominated by vascular plants.

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