Pseudosteppes and related grassland vegetation in the Pamir-Alai and western Tian Shan Mts – the borderland of the Irano-Turanian and Euro-Siberian regions

Pseudosteppen und verwandte Graslandvegetation im Pamir-Alai und im westlichen Tian-Shan-Gebirge – dem Grenzgebiet der irano-turanischen und euro-sibirischen Florenregionen

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Abstract

The aim of our study was to complete the syntaxonomical scheme for grassland vegetation of the lowland, montane and alpine zones in the Pamir-Alai and western Tian Shan Mts in Tajikistan and Kyrgyzstan with some remarks on its environmental predictors. A total of 198 relevés were sampled in 2013–2018 using the seven-degree cover-abundance scale of the Braun-Blanquet approach. They were classified with k-means algorithm with tranforming cover values to three level scale of the following intervals 0%, 5% and 25% and total inertia as a measure of cluster heterogeneity. Diagnostic species were identified using the phi coefficient as a fidelity measure. Non-metric Multidimensional Scaling (NMDS) was used to explore the relationships between the distinguished groups. A total of 7 pseudo-steppe, three typical steppe and three meadow communities were distinguished in the study area, grouped in four orders. Seven of them are established as new associations: Brayo pamiricae-Stipetum glareosae, Eremuretum bucharici, Hordeo bulbosi-Astragalo-Delphinietum retamocarpi, Potentillo orientalis-Achnathero caraganae-Delphinietum semibarbati, Eremuro tianschanici-Delphinietum biternati and Cryptosporo falcatae-Brachypodietum distachyi. The pseudosteppes were included in a new alliance – the Vulpio persicae-Caricion pachystylidis. The meadows have been divided into three communities: Ligularia alpigena-Euphorbia alatavica comm., Euphorbia lamprocarpa comm. and Carum carvi-Hordeum turkestanicum comm. The main factors differentiating the species composition of the researched vegetation are altitude, share of annual vs. perennial species, proportion of Euro-Siberian to Irano-Turanian plants and latitudinal position. We have completed the vegetation survey of
the dry and mesic grasslands in the middle and western part of Middle Asia and have fostered the progress in finding the borderland between the boreo-temperate and mediterranean-like (Irano-Turanian) grasslands of the western Asian and central Asian subregions of the Irano-Turanian region.

**Keywords:** alpine vegetation, grasslands, meadows, Middle Asia, phytogeography, pseudosteppes, steppe, syntaxonomy

**Erweiterte deutsche Zusammenfassung am Ende des Artikels**

1. **Introduction**

Middle Asia is a region located in the landlocked, central part of the Asian continent and comprises Kyrgyzstan, Tajikistan, Uzbekistan, Turkmenistan, southern Kazakhstan, western China and northern Afghanistan. Its southern and eastern parts encompass the high mountains of the Pamir-Alai and Tian Shan. According to the ten-volume study of the flora of the former Soviet part of the Middle Asia, more than 9000 vascular plant species are known from this region (KHASSANOV 2015). Owing to the diverse relief, geomorphology and extremely variable microclimatic condition, the region harbors a high number of endemic species. In Tajikistan alone, ca. 30% of the entire flora of vascular plants are accepted as endemics of the country, with more than 360 growing in steppe vegetation (NOWAK et al. 2020). The species pool of grasslands in this country reaches about 2000 species (ca. 1350 in steppes, 370 in meadows and pastures, and 265 in alpine swards). Due to this extraordinary richness, the mountains of Middle Asia have been recognised as one of the 35 hotspots of biodiversity (MITTERMIEIER et al. 2006). At the same time, the vegetation this region is exposed to the high risks linked to climate change (BAETTIG et al. 2007) with the near-lowest adaptive capacity to climate instability (FAY & PATEL 2008).

Grass dominated communities cover an immense part of the Earth and are distributed from the equator to the polar circle (SQUIRES et al. 2018). Including the savannas and other non-forest vegetation with sparse shrubs and well developed grassy undergrowth, this type of graminoid dominated vegetation covers ca. 40% of the terrestrial surface of the globe (PANUNZI 2008). Grasslands provide many goods and services which can be categorised into two broad groups: economic and non-economic (GIBSON 2009). The major role of grassland in terms of economy is the production of forage for domestic livestock. Middle Asian countries, such as Tajikistan and Kyrgyzstan, are territories where free-grazing livestock still remains the principal source of income of their pastoral societies. From the perspective of non-economic values, grasslands are essential for nutrient cycling, primary production, sequestration of carbon dioxide, maintenance of soil fertility, removal of air pollutants, and prevention from water and wind erosion. Grasslands are home to a number of wildlife and habitat to many endangered plant species. In Middle Asia, grasslands are important habitats for instance for ornamental tulips such as *Tulipa hissarica*, *T. kaufmanniana*, *T. linifolia*, *T. maximowiczii* and others (STANYUKOVICH 1982, NOWAK et al. 2020).

In Middle Asia, approximately 2 million km² are covered by grasslands (WESCHE et al. 2016). They mostly contribute to the landscapes of the steppe and forest-steppe zone in the central and northern parts of the region; however, they are also an important component of the southern and western foothills of Pamir-Alai and Tian Shan (BRAGINA et al. 2018). Additionally, in the mountains of Middle Asia, grasslands develop also on wetlands (grassly fens, mires), thermophilous swards that resemble Mediterranean communities, alpine swards and pastures (KOROVIN 1961, 1962; STANYUKOVICH 1982, AGAKHANIANZ & BRECKLE 2003, WAGNER 2009). Recently, several studies have been conducted on steppe vegetation in...
Pamir-Alai and western Tian Shan, and three main groups of steppe vegetation have been identified: 1) high-altitude arid steppes, 2) dry, thermophilous steppes of the montane and subalpine belt, and 3) mountain steppes of semi-arid areas (Nowak et al. 2016, 2018). The classification of meadows and pastures has yet to be completed, despite being a prominent vegetation type in the region, and their typology would be very useful in ecological, pastoral and conservation terms (Biurrun et al. 2019). Particularly the grasslands of the southern outskirts of the region and their relation to the steppe communities of the northern plains and mediterranean secondary grasslands, including pseudosteppe, has to be resolved. Pseudo-steppes were defined in Spain as thermo-mesomediterranean, intrazonal, secondary grasslands and herblands on deep calcareous soils of colline and montane belts in mediterranean-like climates with long dry summer period. These grasslands grow mainly on loessic or organic, fertile substrates with calcareous bedrock, where the terminal stage of vegetation is shrubland (San Miguel 2008, Mucina et al. 2016).

This vegetation has been almost completely neglected in recent studies on vegetation classification in former Soviet Union areas (e.g. Mirkin & Naumova 2012). The mesophilous grasslands extend along all the ranges, creating distinct phytocoenoses from the colline to the alpine belt. They are extremely species-rich, harbouring up to 80 species per 100 square metre plot (A. Nowak, pers. observation). In the alpine belt, between 2500 and 4000 m a.s.l., depending on the mountain range, mesic alpine swards occur with the domination of Achillea bucharica, Aconitum rotundifolium, Agrostis canina, Anemone protracta, Aster serpentimontanus, Calamagrostis alajica, Eritrichium villosum, Gagea jaeschkei, G. leucomantha, G. olgae, G. setifolia, Hedysarum cisdarvasicum, Lagotis ikonnikovii, Linum olgae, Llydia serotina, Myosotis asiatica, Paeonia intermedia, Pedicularis sarawscanica, P. verae, Polygala hybrida, Pulsatilla campanella and Tulipa turkestanica (Afanasiev 1956, Sidorenko 1971). They are sporadically mown or grazed. Despite being very distinct in terms of phytogeography and additionally important for the livelihood of the local people, the alpine meadows and swards were scarcely studied. Only the work of Wagner (2009) in Aksu-Jabagly Nature Reserve in the western Tian Shan produced some important insights and shows nine distinct plant communities belonging to steppe (e.g. Nepeta pannonica-Thalictrum minus and Allium barsczewskii-Polygala comosa) and meadow-forb vegetation (e.g. Dactylis glomerata-Karatavia kultissavii and Nepeta mariae-Aconogonon coriarium). Another important study was conducted by Vanselow (2011, 2016) in the high Pamir, which describes several vegetation units of pastures including alpine mats with Kobresia spp. Other pasture vegetation communities were revealed in the research of Borchardt et al. (2011). They show the variation mainly of tall-forbs (Aconogonon coriarium-Prangos pabularia-Galium aparine and Ligularia thompsoni-Dactylis glomerata communities) as well as steppes (Carex turkestanica-Arenaria serpyllifolia). However, these studies did not aggregate the communities into higher-level units and harmonise them with the known orders and classes. Still, the hierarchical system of all Middle Asian grasslands is challenging to the vegetation ecologist, despite being crucial for communication and application in conservation (De Cáceres et al. 2018).

In this paper, we attempt to classify the pseudosteppe vegetation in the Pamir-Alai and western Tian Shan Mts and to relate it to steppe and alpine meadow communities. We aimed at addressing the following questions during our study: (1) What is the diversity of grassland vegetation of the montane and alpine zones in the Pamir-Alai and western Tian Shan Mts?
(2) What are the basic habitat conditions of the described plant communities? (3) What is the species composition and structure of the vegetation plots? (4) Which species have important diagnostic value for the described syntaxa?

2. Study area

The vegetation survey was conducted in the central part of Middle Asia (southern and eastern Kyrgyzstan and Tajikistan) within an area of ca. 200,000 km² (Fig. 1). As one of the study’s aims was to compare the grassland phytocoenoses of the northern parts of the region with strong temperate climate influences with the west Pamir-Alai mountains southern foothills with the Irano-Turanian climate, the research area includes the south-western ranges of the Tian Shan and Pamir-Alai Mts. It falls into the colline (around Ferghana Basin), montane and alpine zones of the Kyrgyz Mts, Kakshaal Mts, At-Bashi Mts, Trans-Ili Alatau Mts, Kyungey Ala-Too Mts, Talas Mts, Suusamyr Mts, Terkey Ala-Too Mts, Songkol Mts, Fergana Mts, Alai Mts and Chatkal Mts in Kyrgyzstan and the Peter I Mts, Yazgulem Mts, Alichur Mts, Shugnan Mts, Trans-Alai Mts and Sarikol Mts in Tajikistan. The mountainous landscape and the history of human activity, particularly the grazing of sheep, cows and horses, creates suitable habitats for different types of graminoid communities. In this area there are mainly steppes, however hay meadows also contribute importantly to the landscape of intermediate altitudes, with the alpine swards and mats in subalpine and alpine belts used generally as summer pastures. Additionally, the wide terraces of lowland river valleys and also floodplains of the alpine rivers offer a suitable habitat for grassland development. The studied sites differ considerably in terms of aspect, inclination, bedrock type and altitude. The vegetation plots were located between 319 and 4016 m a.s.l. (mean 1,721).

Fig. 1. Maps of a) elevation (m a.s.l.), b) annual precipitation (mm), c) annual mean temperature (°C) and d) annual temperature range (°C) in the study area – Tajikistan and Kyrgyzstan. Maps are based on raster data from WorldClim (FICK & HUMANS 2017) and digital elevation model (JARVIS et al. 2008).

Abb. 1. Karten der a) Höhenlage (m ü. HN), b) jährlichen Niederschläge (mm), c) mittleren jährlichen Temperatur (°C) und d) jährlichen Temperaturamplitude (°C) im Untersuchungsgebiet – Tajikistan und Kyrgyzstan. Die Karten basieren auf den Rasterdaten des WorldClim (FICK & HUMANS 2017) und einem digitalen Höhenmodell (JARVIS et al. 2008).
The study area is situated in a transition zone between the Temperate and Irano-Turanian types of macrobioclimates with the first one characterised by summer- rather than winter rain and higher continentality (Diamali et al. 2012). However, four main types of climate within the research area can be identified:

(1) warm, continental, Irano-Turanian climate in the Ferghana Basin. In the classification of Köppen, this area is included in the warm continental zone. The surroundings of Jalalabad and Osh are characterised by winter precipitation that peaks in March, with up to 80 mm, and a yearly average of 200–250 mm. The temperature reaches 20 °C in April and rises to an average of 34 °C in June, July and August. During these months the precipitation is scarce with 0–10 mm per month. Snow and frost occur from December to February with the averages not below -3 °C, and with the extreme value of -27 °C in some years;

(2) warm humid, continental climate in the Tian Shan and Pamir-Alai ranges. In these areas, the average temperature in June is around 22 °C in colline and montane zones and decreases to 10 °C in alpine belt. The lower limit of perpetual snow in the western Tian Shan is at an altitude of 3000–3300 m a.s.l. Annual precipitation ranges here from about 500 mm on the northern macro-slope to ca. 1000 mm on the southern one;

(3) cold semi-arid climates of the Issik-kul Basin, Suusamyr Valley, central and western parts of the Alai Valley, foothills and plateaus at colline, montane and subalpine belts. These areas are clearly distinguished by moderate precipitation, with an average of 200–400 mm per year. The distribution of the rain during the year is similar to temperate climate with a max. in May–July when it reaches up to 70 mm. The temperatures exceed the values of 20 °C mm only in summer, with the annual average of 10 °C;

(4) cold desert climate of the easternmost sections of the Alai Valley and eastern Pamirian Plateau. In our opinion, also the surroundings of Balykchy in the western part of the Issik-kul Basin should be included in this zone, despite that the elevation here is 2000 metres lower than in eastern Pamir. Unlike the West Pamir or Tian Shan ranges, this area is distinguished by significant aridity and less than 100 mm mean annual precipitation; only in May and August does the average monthly rain exceed 20 mm. The average temperature in a year slightly exceeds 0 °C, with minimums dropping down far below -30 °C in January–February (Latipova 1968, Narzikulov & Stanyukovich 1968, Safarov 2003).

However, within all these zones a lot of local deviations and anomalies occur caused by wind conditions, orography and altitudinal differences. These climatic and bioclimatic terms determine the vegetation with the treeless formations as dominant in colline and montane belts as well as a considerable share of meadows and pastures in alpine zone.

3. Methods

The research was conducted in the years 2013–2018. Altogether, 198 relevés were collected in the Pamir-Alai (Tajikistan) and western Tian Shan Mts (Kyrgyzstan). The size of each vegetation relevé was 10 m², which follows the approach of the GrassPlot consortium and is considered useful in grassland classification (Dengler et al. 2018a). In each relevé, all vascular plant species and mosses were recorded using the seven-degree cover-abundance scale of the Braun-Blanquet approach (Westhoff & van der Maarel 1973). The geographical coordinates were measured for each plot with the help of a GPSMAP 60CSx device with an accuracy of ±5 m, using the WGS84 map datum. The field survey covers a broad range of habitats in relation to altitudinal range, bedrock type, exposition and inclination.

Data were stored in the Vegetation of Middle Asia database (Nowak et al. 2017) and analysed in R (R Core Team 2019) and JUICE software (Tichý 2002). In order to understand the distribution of samples and relations between them, the authors performed an unsupervised k-means analysis with
Hellinger transformation. K-means partitioning computes a non-hierarchical clustering by minimisation of the variance within group. This method determines the partition of objects into k groups, where the objects within each group or cluster are more similar to one another than to objects in the other clusters (MACQUEEN 1967). The number of clusters was determined according to gap statistics using clusGap function in ‘cluster’ package (MAECHLER et al. 2019) in R. The algorithm indicated 13 groups as most optimal for the analyzed data set (Supplement E5), which corresponds well to our field experience. The original over abundance scale was transformed using the three step interval scale with pseudospecies levels of 0%, 5% and 25%. As our research has a pioneer character in the study area, we did not apply any refinements in the classification by moving some relevés between clusters using some iterative relocation methods or deletion of any outliers. With insufficient field experience to identify atypical or fragmentary stands, we believe that our approach is the most justified.

Plant species determined only to the genus level were excluded from the analysis (Cuscus sp., Dianthus sp., Didymodon sp., Hieracium sp., Taraxacum sp., Tortula sp.). Diagnostic species were identified using the phi coefficient as a fidelity measure (CHYTÝ et al. 2002). The size of all groups was standardised to equal size and Fisher exact test (p < 0.05) was applied. Species with a phi coefficient higher than 0.20 were considered diagnostic for a particular cluster. Plants diagnostic for the alliance Vulpia persica-Caricion pachystilis were selected according to their fidelity value and frequency in all five clusters belonging to the alliance (i.e., having a frequency higher than 10% and a phi coefficient higher than 5 in at least 2 clusters). However, the final assignment of highly diagnostic taxa used for the definition of communities was supported by expert knowledge as several species that meet the formal requirements occur in different vegetation types in Middle Asia, so they were excluded from the diagnostic group (e.g., taxa typical for steppes – Alyssum dasycarpum, Bromus oxyodon, B. lancolatus, Diarthron vesiculosus, Origanum tythanthum; meadows – Hypericum perforatum, Vicia angustifolia; ruderal or segetal – Salvia sclarea, Veronica arvensis). Species with a higher frequency than 40% were defined as constant. Non-metric multidimensional scaling (NMDS) based on Euclidean distance was performed in order to assess the floristic relationships among the pseudosteppe and meadow types using the function metaMDS in the ‘vegan’ package (OKSANEN et al. 2019). We decided to exclude cluster 1 from the analysis as a distinctly different group of desert steppe – it obscured the Figure. Prior to the analysis, cover values were Hellinger-transformed. The final ordination was run with 999 random starts with the use of two dimensions (stress value = 0.199). Next, we fitted environmental variables post hoc to the ordination axes to explore their associations with each vegetation type using the function envfit with 999 permutations in the ‘vegan’ package (OKSANEN et al. 2019). Climatic data were extracted from the WorldClim database (FICK & HJMANS 2017) and altitudinal data from a digital elevation model (JARVIS et al. 2008). We determined the medians and SD of the measured environmental and vegetation parameters (altitude, inclination, geographical position, temperature, precipitation, species richness per plot, ground vegetation cover, share of annual and perennial plants and phytogeographical elements in each plot) for all communities. The differences between groups in relative cover of annual and perennial plants and phytogeographical elements were assessed using Kruskal–Wallis rank sum test (function kruskal.test) with multiple comparison method based on the Bonferroni procedure using the function pairwise.kw in the ‘asbio’ package (A.STO 2019) in R.

A synoptic table with fidelity measured by the phi coefficient and percentage frequency for diagnostic and frequent taxa for a certain cluster is given (Supplement S1). Only species with a phi coefficient ≥ 0.20 and frequency ≥ 20% are shown. For newly-described associations, the ICPN was adhered to according to WEIBER et al. (2000). All mentioned syntaxa are arranged into a taxonomic overview. Distribution maps of all grassland types within the study area are presented in Supplement E4. Environmental and vegetation parameters are presented in Supplement E6. Plant communities were depicted in photographs (Fig. 5 and Supplement E7).

The nomenclature of the vascular plants follows generally CHEREPANOV (1995) and for Bromus spp. THE PLANT LIST (2019). The names of syntaxa are used in accordance with GADGHEIV et al. (2002), ERMAKOV (2012) and NOWAK et al. (2018).
4. Results

4.1 Classification of the vegetation units

Our classification resulted in delimitation of 13 plant communities that were well-defined in terms of species composition (Fig. 2, Supplement S1). As our study was focused on warm and subhumid areas, we formally describe new syntaxa only for pseudosteppe units. Other communities that were clearly separated by the clustering algorithm have been left rankless (mesic boreo-temperate meadows) or were included in previously described typical steppe vegetation (NOWAK et al. 2018). One exception is cluster 10 (Medicago sativa-Poa trivialis) that falls into the pseudosteppe group but represents anthropogenic hay grasslands, has insufficient sample numbers and cannot be definitely fitted into the hierarchical system. Another exception is the semi-arid steppe of Brayo pamiricae-Stipetum glareosae (cluster 1) that in our opinion makes a very distinct, well defined desert steppe community that can be included in the high altitude arid steppe class Ajaniio-Cleistogenetetra songoricae (syn. Stipeae glareoso-gobicae, HILBIG 2000). Plots of this community were not shown in the graph as they are substantially different and extend particularly the altitudinal gradient standing as outlier in relation to other communities. The NMDS run for all other samples revealed relationships between distinct plots and gradients along the two most significant axes of the ordination (Fig. 2). Phytocoenoses preferring the most fertile habitats (deep, humid soils at moderate elevations) that are composed of Western Irano-Turanian species such as Astragalus lepsensis, Euphorbia alatvica, Cerastium tianschanicum or Potentilla asiach-mediae (communities of Euphorbia lamprocarpa, Ligularia alpigena-Euphorbia alatavica and Carum carvi-Hordeum turkestanicum) are concentrated in the upper left part of the graph. The opposite side is occupied by plots of Astragalo lithophili-Stipetum zalesskii, Eremuro tianschanici-Delphinietum biternati and Stipetum bungeanee, representing more dry and arid habitats, inhabited by a considerable share of Euro-Siberian and Central-Asian plants like Festuca valesiaca, Elymus caninus, Botriochloa ischaemum, Bromus squarrosus or Artemisia pectinata (Fig. 2). In the upper right position are plots of typical pseudosteppes (e.g. Eremuretum bucharici, Hordeo bulbosi-Astragaletum retamo-carpi) that are related to the warmest and subhumid conditions at the lowest elevations (lowland and colline belt). These plots are characterised by the highest species number, relatively high total cover of herb layer and deep, loessic soils. The upper right outlier is the association Cryptsporo falcatae-Brachypodietum distachyi that occupies the warmest habitats in Tajikistan in hilly land at colline altitudes. This is a kind of ephemeroid vegetation with the peak of vegetation cover in early spring.

4.2 Description of the communities

A. High-altitude arid steppe pastures

1. Brayo pamiricae-Stipetum glareosae ass. nova hoc loco

Diagnostic species: Artemisia leucotricha, Braya pamirica, Stipa glareosa, S. orientalis

Constant species: Stipa glareosa, S. orientalis

Floristic and habitat characteristics: We recorded plots of this association in the high plateau of Eastern Pamir in Tajikistan with continental, very cold and dry climate. It occupies flat and arid terraces and gentle slopes with scarce organic matter content (Fig. 5a).
Fig. 2. NMDS ordination of 12 grassland communities. Red spider diagrams represent three types of grassland vegetation: meadows and pastures (2, 3, 4), pseudostepes (5, 6, 7, 8, 9, 10, 11) and steppes (12, 13). Environmental variables are indicated by arrows and only significant are shown ($p < 0.05$). The ordination was run with the use of two dimensions with stress value = 0.199. Abbreviations: 2 – *Ligularia alpigena-Euphorbia alativica* community; 3 – *Euphorbia lamprocarpa* community; 4 – *Carum carvi-Hordeum turkestanicum* community; 5 – *Eremuretum bucharici*; 6 – *Hordeo bulbosi-Astragaletum retamocarpi*; 7 – *Potentillo orientalis-Eremuretum fuscii*; 8 – *Achnathero caraganae-Delphinietum semibarbatis*; 9 – *Eremuro tianschanici-Delphinietum biternati*; 10 – *Medicago sativa-Poa trivialis* community; 11 – *Cryptosporo falcatae-Brachypodietum distachyi*; 12 – *Astragalo lithophili-Stipetum zalesskii*; 13 – *Stipetum bungeanae*, Cov_c – cover herb layer (%), PPT – annual precipitation, Richness – species richness, Shannon – Shannon index, T_avg – annual mean temperature, T_range – temperature annual range.

The plots have sparse cover and a patchy physiognomy with an average vegetation cover of 27%. The association is not species rich, with not more than 9–10 species per plot. Semi-desert taxa frequently contribute to this community (Krascheninnikovia ceratooides, Ajania tibetica, Astragalus chomutovii) and alpine plants of arid areas (Acantholimon diapensioides, Gypsophila capituliflora, Astragalus orthanthoides). The name giving Braya pamirica, despite not being the most frequent, is endemic for highly elevated plateaus of Eastern Pamir and very occasionally occurs in alpine semi-deserts, scree or river-beds. The Brayo pamiricae-Stipetum glareosae is extensively grazed by yaks, camels and, more rarely, goats.

Typus relevé: (relevé number 2 in Supplement E1). 10 July 2018; Murghab: 37.63777 N; 72.95125 E; 3,854 m a.s.l.; plot area 10 m²; species richness: 8; species composition: Stipa glareosa 2, Artemisia leucotricha 1, Astragalus chomutovii 1, A. orthanthoides 1, Krascheninnikovia ceratooides 1, Oxytropis trichosphaera 1, Stipa orientalis 1, Braya pamirica +.

B. Mesic mown and grazed meadows and pastures on fertile soils

2. Ligularia alpigena-Euphorbia alatavica community

Diagnostic species: Euphorbia alatavica, Cerastium tianschanicum, Ligularia alpigena, Astragalus lepsensis, Galium tianschanicum, Cobresia pamiroalaica

Constant species: Myosotis asiatica, Cerastium tianschanicum, Geranium regelii

Floristic and habitat characteristics: This heterogenous vegetation includes different phytocoenoses of alpine meadows on fertile mineral-rich soils. Similar to the European communities, they are grazed by cattle, sheep and, sporadically, goats, and are very rarely mown. The patches of this vegetation were found in the alpine belt at an elevation of ca. 3000 m a.s.l. The plots were rich in species (more than 30 on average), with the highest average diversity and considerable vegetation cover (90% on average). The community of Ligularia alpigena and Euphorbia alatavica occurs in the northern outskirts of the study area and is probably related to alpine grasslands of eastern Tian Shan and Altai. Dominant plants as well as the most frequent ones are typical montane Euro-Siberian and Irano-Turanian species (Fig. 3a) such as Astragalus alpinus, Cerastium tianschanicum, Hordeum turkestanicum, Leontopodium ochroleucum, Myosotis asiatica, Poa alpina, Phleum alpinum, Polygonum alpinum, Thalictrum alpinum and Veronica alpina. As in our opinion the sampled plots represent only a small part of the alpine meadow diversity in the Tian Shan Mts, we decided to leave it as a rankless community that needs further research.

3. Euphorbia lamprocarpa community

Diagnostic species: Euphorbia lamprocarpa, Alchemilla bungei, Geranium regelii

Constant species: Geranium regelii, Trifolium repens, Poa pratensis

Floristic and habitat characteristics: During the research, several plots of the community were recorded in the valley near Ken-Djylga in the eastern Alai range. This type of vegetation is used as a pasture for cattle and sheep. The physiognomy, high total plant cover and species composition reveal the forb character of this pasture. We decided to leave it as rankles until further research on tall-herb vegetation in Middle Asia will be completed. The plots of the Euphorbia lamprocarpa community were moderately rich in species, found in valley bottoms of mid-elevations (ca. 2500 m a.s.l.) on fertile, deep soils. Despite some typical meadow species such as Achillea millefolium, Artemisia dracunculus, Dactylo...
Fig. 3. Boxplots showing relative cover of a) Euro-Siberian, b) Irano-Turanian and c) Central-Asian – Irano-Turanian species for clusters with median (line), quartiles, outliers and the range of data. Red line indicates mean values of vegetation groups: meadows and pastures (2, 3, 4), pseudosteppes (5, 6, 7, 8, 9, 10, 11) and steppes (1, 12, 13). The values of $\chi^2$ and $p$ for statistical tests for vegetation groups are shown. Different letters indicate significant differences among the vegetation groups. The abbreviations of the clusters are explained in Figure 2.

Abb. 3. Die Boxplots zeigen die relative Deckung der a) euro-sibirischen, b) irano-turanischen und c) zentralasiatischen – irano-turanischen Arten für die Cluster mit dem Median (Linie), Quartilen, Außenreißern und der Verteilung der Daten. Rote Linien zeigen die Mittelwerte der Vegetationseinheiten: Wiesen und Weiden (2, 3, 4), Pseudosteppen (5, 6, 7, 8, 9, 10, 11) und Steppen (1, 12, 13). Dargestellte $\chi^2$ und $p$-Wert beziehen sich auf statistische Tests der Vegetationseinheiten. Unterschiedliche Buchstaben zeigen dabei signifikante Unterschiede zwischen den Vegetationseinheiten an. Abkürzungen s. Abbildung 2.

glomerata, Linum olgae, Poa alpina, P. pratensis, Trifolium pratense and T. repens, a great share of forbs (e.g., Geranium regelii, Hedysarum flavescens, Ligularia narynensis, L. thompsonii, Phlomis pratensis and Polygonum coriarium) were noted within the plots.

4. Carum carvi-Hordeum turkestanicum community

Diagnostic species: Alopecurus pratensis, Carum carvi, Hordeum turkestanicum, Potentilla asiae-mediae, Tragopogon turkestanicum

Constant species: Alopecurus pratensis, Carum carvi, Festuca pratensis, Geranium regelii, Hordeum turkestanicum, Medicago falcata, Poa pratensis

Floristic and habitat characteristics: This community shows the greatest resemblance to fen vegetation. It occupies the wettest sites in the valley bottoms or on flat terraces and gentle slopes. Mowing is rather infrequent here and grazing rather uncommon – mainly by sheep and goats in late summer or autumn. The community of Hordeum turkestanicum creates a dense mat at the upper montane belt on peaty soils (Fig. 5d). It has a moderate species richness and diversity. Frequent and dominant taxa include Medicago sativa and Trifolium pratense. Species typical for fens are Inula caspica and Plantago griffithii.
C. Thermo-mesomediterranean secondary perennial pseudosteppes on deep calcareous soils of colline and montane belts in mediterranean-like climates (including Irano-Turanian) with long dry summer period

Alliance: *Vulpis persicae- Caricion pachystylidis* all. nova hoc loco

Typus association: *Eremuretum bucharici* S. Świerszcz et al. (this paper)

These grasslands grow mainly in colline and montane belts on loessic or organic, fertile soil with calcareous bedrock, where the terminal stage of vegetation is shrubland. In Middle Asia they occur in the western foothills of Pamir-Alai, the Ferghana Valley and the western slopes of the Tian Shan Mts. In this area, the average annual temperature is above 10 °C, winters are mild, with the minimum temperature dropping rarely below -5 °C, the beginning of the vegetation season is relatively humid in comparison to other areas, particularly the eastern, highly elevated plateaus of Pamir. The precipitation peaks one or two months earlier than in the Central Asian regions, where the highest amount of rain falls in the summer period. The continentality index is higher in Tibet or in Gobi desert if compared to Pamir-Alai. The structure of this pseudosteppes is apparently determined by grasses, however the perennial and bulbous plants of Irano-Turanian origin (e.g., *Eremurus* sp., *Phlomoides* sp., *Elaeosticta* sp., *Tulipa* sp., *Ungernia* sp.) have a considerable share. This syntaxon can be considered as an eastern (Irano-Turanian) outpost of the Mediterranean communities of *Cymbopogono-Brachypodietalia ramosi* Horvatič 1963.


5. *Eremuretum bucharici* ass. nova hoc loco

Diagnostic species: *Allium bucharicum*, *Consolida leptocarpa*, *Cymatocarpus popovii*, *Eremurus bucharicus*, *Gagea graminifolia*, *Haplophyllum griffithianum*, *Heterocaryum sessile*, *Jurinea bucharica*, *Koelpinia macrantha*, *Leptaleum filifolium*, *Nonea macro poda*, *Phlomoides baldschuanica*, *Russowia sogdiana*, *Solenanthus plantagineus*

Constant species: *Avena trichophylla*, *Bromus lanceolatus*, *Diarthron vesiculosum*, *Phlomis bucharica*, *Poa bulbosa*, *Vulpia persica*

Floristic and habitat characteristics: This is the most therophilous community distributed in the south-western part of Tajikistan, occurring exclusively in the colline belt (average altitude ca. 650 m a.s.l.). The average yearly temperature is around 18 °C, however the precipitation still has a fairly high amount, achieving ca. 500 mm throughout the year. The community develops on fertile, deep, loessic soils, is rich in species and diverse (ca. 35 taxa per plot) and has up to 85% average cover of vegetation (Supplement E6, Fig. 5e). In addition to the diagnostic species, the most abundant are *Aegilops triuncialis*, *Artemisia kochiformis*, *Carex pachystylis*, *Eremurus comosus*, *Lolium persicum* and *Medicago orbicularis*. The pseudosteppe of *Eremurus bucharica* is used as a mown meadow and also as pasture for goats and sheep.
Typus relevé: (relevé number 10 in Supplement E2). 1 May 2018; Dangara: 37.73189 N; 69.45248 E; 705 m a.s.l.; plot area 10 m²; species richness: 43; species composition: Vulpia persica 3, Avena trichophylla 2, Convolvulus subhirsutus 2, Eremurus bucharicus 2, Poa bulbosa 2, Solananthus plantaginifolius 2, Alcea baldschuanica 2, Carex pachystylis 1, Helichrysum maracandicum 1, Hordeum spontaneum 1, Medicago orbicularis 1, Phlomis bucharica 1, Aphanopleura capillifolia 1, Psolarea drupacea 1, Cynodon dactylon 1, Diarthron vesiculsum 1, Vulpia vilosa 1, Astragalus oxyglottis +, Anemone bucharica +, Euphorbia franchetti +, Filago pyramidata +, Gagea ova +, Bromus oxyodon +, Anagallis foemina +, Inula macrophylla +, Carthamus lanatus +, Medicago rigidula +, Nigella bucharica +, Onobrychis pulchella +, Arenaria serpyllifolia +, Pimpinella peregrina +, Pleurogynella flaviflora +, Cousinia microcarpa +, Prospis farcta +, Cousinia sclerophylla +, Ranunculus severtsovii +, Crepis pulchra +, Strigosella trichocarpa +, Trigonella orthoceras +, Valerianella ovczinnikovii +, Vicia angustifolia +, Cryptospora falcatia +, Astragalus filicaulis +.

6. *Hordeo bulbosi-Astragaletum retamocarpi* ass. nova hoc loco

Diagnostic species: Astragalus retamocarpus, Cruciata pedemontana, Hordeum bulbosum, Lathyrus aphaca, Medicago denticulata, Prangos bucharica, Prangos fedtschenkoana, Ungernia tashkirorum, Valerianella ovczinnikovii

Constant species: Avena trichophylla, Hordeum bulbosum, Poa bulbosa, Veronica arvensis, Vicia angustifolia, Vulpia persica

Floristic and habitat characteristics: The *Hordeo bulbosi-Astragaletum retamocarpi* was found as a common pseudosteppe in hilly landscapes of the Hissaro-Darvasian geobotanical subregion of Tajikistan in the montane belt of Aktau, Karatau, Karateginian and the southern foothills of the Hissar Mts. It is the species richest community of pseudosteppe in Tajikistan with more than 35 species on average per plot and is dominated apparently by Irano-Turanian taxa (Fig. 3b) with considerable contribution of endemics e.g. Ungernia tashkirorum, Astragalus corydalina, Astragalus ammophillus, A. korovinianus 1, Drahbospis nuda 1, Elaeosticta alloides 1, Gagea pseudophila 1, Heterocaryum szovitsianum 1, Linum corymbulosum 1, Lolium cuneatum 1, Medicago laniger 1, Onobrychis pulchella 1, Prangos bucharica 1, Russiovia sogdiana 1, Solanuthus turkestania 1, Brachypodium distachyon 1, Medicago rigidula 2, Bromus sterilis +, Cerastium dentatum +, Consolida barbata +, Cryptospora falcatia +, Cuscuta sp. +, Cynodon dacylon +, Galium gillicicum +, Galium spurium +, Poa bulbosa +, Ranunculus tenuilobus +, Taraxacum naratavicum +, Astragalus rytilobus r, Minuartia meyeri r, Papaver pavoninum r, Thlaspi perfoliatum r, Valerianella ovczinnikovii r, Veronica arvensis r, Vicia angustifolia r, Ceratodon purpureus d r, Bryum pallens d +.

Typus relevé: (relevé number 35 in Supplement E2). 29 April 2018; Dangara: 38.13724 N; 69.4054 E; 944 m a.s.l.; plot area 10 m²; species richness: 39; species composition: Avena trichophylla 4, Astragalus retamocarpus 3, Hordeum bulbosum 2, Vulpia persica 2, Astragalus ammophillus 1, A. korovinianus 1, Drabospis nuda 1, Elaeosticta alloides 1, Gagea pseudophila 1, Heterocaryum szovitsianum 1, Linum corymbulosum 1, Lolium cuneatum 1, Medicago laniger 1, Onobrychis pulchella 1, Prangos bucharica 1, Russiovia sogdiana 1, Solanuthus turkestania 1, Brachypodium distachyon 1, Medicago rigidula 2, Bromus sterilis +, Cerastium dentatum +, Consolida barbata +, Cryptospora falcatia +, Cuscuta sp. +, Cynodon dacylon +, Galium gillicicum +, Galium spurium +, Poa bulbosa +, Ranunculus tenuilobus +, Taraxacum naratavicum +, Astragalus rytilobus r, Minuartia meyeri r, Papaver pavoninum r, Thlaspi perfoliatum r, Valerianella ovczinnikovii r, Veronica arvensis r, Vicia angustifolia r, Ceratodon purpureus d r, Bryum pallens d +.

7. *Potentillo orientalis-Eremuretum fusci* ass. nova hoc loco

Diagnostic species: Cynodon dactylon, Eremurus brachystemon, E. fuscus, E. stenophyllus, Filago arvensis, Medicago lapulina, Potentilla orientalis, Strigosella hispida, Vinca erecta
**Constant species:** Carex stenophylloides, Cynodon dactylon, Filago arvensis, Medicago lupulina, Poa bulbosa, Arenaria serpyllifolia

**Floristic and habitat characteristics:** Stands of this community occur in central and eastern Tajikistan in the montane and subalpine belts on mesic, loamy soils. It is a species poor community with moderate plant cover in comparison to other pseudosteppes and meadows. It is somehow related to forb vegetation, yet is intensively grazed and has the physiognomy of typical perennial pseudosteppe (Fig. 4b). The contribution of species typical for pseudosteppe habitats is evidenced by the presence of Achillea biebersteinii, Aphanopleura capillifolia, Artemisia persica, Bromus lanceolatus, Cynodon dactylon, Poa bulbosa and Carex pachystylis. Due to intensive grazing by cattle, horses, sheep and goats, a considerable share of nitrophilous taxa typical for degraded habitats was observed within plots (e.g. Acanthocephalus benthamianus, Anagallis arvensis, Ceratocephalus testiculatus, Filago arvensis, Geranium pusillum, Medicago lupulina and Veronica arvensis).

**Typus relevé:** (relevé number 51 in Supplement E2). 2 June 2015; Novobod: 38.9533 N; 70.14361 E; 1302 m a.s.l.; plot area 10 m²; species richness: 13; species composition: Eremurus fuscus 4, Potentilla orientalis 3, Medicago lupulina 2, Cynodon dactylon 2, Filago arvensis 1, Arenaria serpyllifolia 1, Poa bulbosa 1, Carex stenophylloides 1, Vulpia persica 1, Cerastium dentatum +, Anagallis arvensis +, Veronica arvensis +, Eremurus brachystemon +.

Fig. 4. Boxplots showing species relative cover of a) annuals and b) perennials within pseudosteppes types with median (line), quartiles, outliers and the range of data. The values of $\chi^2$ and $p$ for statistical tests are shown. Different letters indicate significant differences among the clusters. The abbreviations of the clusters are explained in Figure 2.

Fig. 5. Photographs of the grassland vegetation belonging to the a) Brayo pamiricae-Stipetum glareosae in Kurteskei Valley to the east from Alichur, TJK (cluster 1); b) Astragalo lithophili-Stipetum zalesskii in Suusamyr Valley, 2350 m a.s.l., KRG (cluster 12); c) Eremuro tianschanici-Delphinietum biternati S. near Toktogul, 1350 m a.s.l., KRG (cluster 9); d) Carum carvi-Hordeum turkestanicum community in Naryn Valley, 2100 m a.s.l., KRG (cluster 4); e) Eremuretum bucharici, Karatau Mts, 650 m a.s.l., TJK (cluster 5); f) Cryptosporo falcatae-Brachypodietum distachyi near Pandz, 420 m a.s.l., TJK (cluster 11) (Photos: A. Nowak, 2015–2018).

Abb. 5. Fotos von Graslandgesellschaften: a) Brayo pamiricae-Stipetum glareosae S. Świerszcz et al. 2019 im Kurteskei-Tal östlich von Alichur, TJK (Cluster 1); b) Astragalo lithophili-Stipetum zalesskii A. Nowak et al. 2018 im Suusamyr-Tal, 2350 m ü. HN., KRG (Cluster 12); c) Eremuro tianschanici-Delphinietum biternati S. Świerszcz et al. 2019 in der Nähe von Toktogul, 1350 m ü. HN., KRG (Cluster 9); d) Carum carvi-Hordeum turkestanicum-Ges. im Naryn-Tal, 2100 m ü. HN., KRG (Cluster 4); e) Eremuretum bucharici S. Świerszcz et al. 2019, Karatau-Gebirge, 650 m ü. HN., TJK (Cluster 5); f) Cryptosporo falcatae-Brachypodietum distachyi in der Nähe von Pandz, 420 m ü. HN., TJK (Cluster 11) (Fotos: A. Nowak, 2015–2018).
8. *Achnathero caraganae-Delphinietum semibarbati* ass. nova hoc loco

**Diagnostic species:** *Achnatherum caragana*, *Artemisia kochiiformis*, *Carex pachystylis*, *Delphinium semibarbatum*, *Kochia iranica*, *Taeniatherum asperum*, *T. crinitum*

**Constant species:** *Botriochloa ischaemum*, *Carex pachystylis*, *Diarthron vesiculosum*, *Poa bulbosa*

**Floristic and habitat characteristics:** The plots of the association were found in colline and montane belts in dry and warm locations of the surroundings of the Ferghana Valley, Zeravshan River Valley and the southern foothills of Hisar range. These relatively dry conditions resemble the typical steppe habitats, which is reflected by the presence of steppe grasses including *Botriochloa ischaemum*, *Stipa arabica*, *S. drobovi*, *S. hohenackeriana* and *S. capillata*, which are, however, not frequent. The *Achnathero caraganae-Delphinietum semibarbati* prefers mesic, loamy or loessic soils with a well-developed organic soil layer and sometimes considerable gravel debris. Despite the dry condition, a number of perennials were found in this association with *Astragalus babatagi*, *Convolvulus pseudocantabrica*, *Delphinium semibarbatum*, *Elaeosticta ferganensis*, *Eremurus comosus*, *E. suvorovii* and *Onobrychis pulchella* as the most frequent. This community is used mainly for grazing by sheep and goats, sporadically horses and cattle as well. It is frequently burned.


9. *Eremuro tianschanici-Delphinietum biternati* ass. nova hoc loco

**Diagnostic species:** *Bromus squarrosus*, *Delphinium biternatum*, *Elaeosticta ferganensis*, *E. samarcandica*, *Eremurus tianschanicus*, *Hymenolyca trichophyllum*, *Korovinia ferganensis*

**Constant species:** *Botriochloa ischaemum*, *Bromus squarrosus*, *Delphinium biternatum*, *Elytrigia trichophora*

**Floristic and habitat characteristics:** This community occurs mainly in southern and central Kyrgyzstan in the montane and colline belts (average elevation of 1100 m a.s.l.) of the Ferghana and Alai ranges. It prefers mesic habitats with deep loessic or loamy soils in warm sites. The community presents colourful stands with a lot of decorative perennials such as *Eremurus* sp., *Delphinium* sp., *Linum corymbulosum*, *Salvia deserta* and *Nepeta cataria* etc. (Fig. 5c). It is moderately rich, with more than 30 species per plot. This type of pseudosteppe is sporadically mown and used as typical pasture for sheep and horses, sometimes goats. Many species of very restricted ranges contribute to this association (e.g. *Astragalus alaicus*, *Echinops karatavicus*, *Elaeosticta ferganensis*, *E. samarcandica*, *Phlomoides cephalariifolia*, *Goldbachia pendula*, *Korovinia ferganensis* and *Salvia schmalchausenii*), making it very distinct from other pseudosteppes.
Typus relevé: (relevé number 100 in Supplement E2). 29 June 2017; Bala-Chychkan: 41.93805 N; 72.92222 E; 1143 m a.s.l.; plot area 10 m²; species richness: 32; species composition: Delphinium biternatum 3, Crupina vulgaris 2, Convolvulus pseudocantabrica 2, Hymenolyma trichophyllum 2, Onobrychis pulchella 2, Stipa capillata 2, Achnatherum caragana 1, Aegilops crassa 1, Ae. triuncialis 1, Elaeosticta ferganensis 1, Eremurus tianshanicus 1, Haplophyllum ischaemum 1, Centaurea squarrosa 1, Achnatherum caragana 1, Aegilops crassa 1, Ae. triuncialis 1, Elaeosticta ferganensis 1, Haplophyllum ischaemum 1, Centaurea squarrosa 1, Achnatherum caragana 1, Aegilops crassa 1, Ae. triuncialis 1, Elaeosticta ferganensis 1, Haplophyllum ischaemum 1, Centaurea squarrosa 1, Achnatherum caragana 1, Aegilops crassa 1, Ae. triuncialis 1, Elaeosticta ferganensis 1, Haplophyllum ischaemum 1, Centaurea squarrosa 1, Achnatherum caragana 1, Aegilops crassa 1, Ae. triuncialis 1, Elaeosticta ferganensis 1, Haplophyllum ischaemum 1, Centaurea squarrosa 1, Achnatherum caragana 1, Aegilops crassa 1, Ae. triuncialis 1, Elaeosticta ferganensis 1, Haplophyllum ischaemum 1, Centaurea squarrosa 1, Achnatherum caragana 1, Aegilops crassa 1, Ae. triuncialis 1, Elaeosticta ferganensis 1, Haplophyllum ischaemum 1, Centaurea squarrosa 1, Achnatherum caragana 1, Aegilops crassa 1, Ae. triuncialis 1, Elaeosticta ferganensis 1, Haplophyllum ischaemum 1, Centaurea squarrosa 1, Achnatherum caragana 1, Aegilops crassa 1, Ae. triuncialis 1, Elaeosticta ferganensis 1, Haplophyllum ischaemum 1, Centaurea squarrosa 1, Achnatherum caragana 1, Aegilops crassa 1, Ae. triuncialis 1, Elaeosticta ferganensis 1, Haplophyllum ischaemum 1, Centaurea squarrosa 1, Achnatherum caragana 1, Aegilops crassa 1, Ae. triuncialis 1, Elaeosticta ferganensis 1, Haplophyllum ischaemum 1, Centaurea squarrosa 1, Achnatherum caragana 1, Aegilops crassa 1, Ae. triuncialis 1, Elaeosticta ferganensis 1, Haplophyllum ischaemum 1, Centaurea squarrosa 1, Achnatherum caragana 1, Aegilops crassa 1, Ae. triuncialis 1, Elaeosticta ferganensis 1, Haplophyllum ischaemum 1, Centaurea squarrosa 1, Achnatherum caragana 1, Aegilops crassa 1, Ae. triuncialis 1, Elaeosticta ferganensis 1, Haplophyllum ischaemum 1, Centaurea squarrosa 1, Achnatherum caragana 1, Aegilops crassa 1, Ae. triuncialis 1, Elaeosticta ferganensis 1, Haplophyllum ischaemum 1, Centaurea squarrosa 1, Achnatherum caragana 1, Aegilops crassa 1, Ae. triuncialis 1, Elaeosticta ferganensis 1, Haplophyllum ischaemum 1, Centaurea squarrosa 1, Achnatherum caragana 1, Aegilops crassa 1, Ae. triuncialis 1, Elaeosticta ferganensis 1, Haplophyllum ischaemum 1, Centaurea squarrosa 1, Achnatherum caragana 1, Aegilops crassa 1, Ae. triuncialis 1, Elaeosticta ferganensis 1, Haplophyllum ischaemum 1, Centaurea squarrosa 1, Achnatherum caragana 1, Aegilops crassa 1, Ae. triuncialis 1, Elaeosticta ferganensis 1, Haplophyllum ischaemum 1, Centaurea squarrosa 1, Achnatherum caragana 1, Aegilops crassa 1, Ae. triuncialis 1, Elaeosticta ferganensis 1, Haplophyllum ischaemum 1, Centaurea squarrosa 1, Achnatherum caragana 1, Aegilops crassa 1, Ae. triuncialis 1, Elaeosticta ferganensis 1, Haplophyllum ischaemum 1, Centaurea squarrosa 1, Achnatherum caragana 1, Aegilops crassa 1, Ae. triuncialis 1, Elaeosticta ferganensis 1, Haplophyllum ischaemum 1, Centaurea squarrosa 1, Achnatherum caragana 1, Aegilops crassa 1, Ae. triuncialis 1, Elaeosticta ferganensis 1, Haplophyllum ischaemum 1, Centaurea squarrosa 1, Achnatherum caragana 1, Aegilops crassa 1, Ae. triuncialis 1, Elaeosticta ferganensis 1, Haplophyllum ischaemum 1, Centaurea squarrosa 1, Achnatherum caragana 1, Aegilops crassa 1, Ae. triuncialis 1, Elaeosticta ferganensis 1, Haplophyllum ischaemum 1, Centaurea squarrosa 1, Achnath...
Typus relevé: (relevé number 5 in Supplement E3). 29 April 2018; Obi-Kiik: 38.27138 N; 69.64555 E; plot area 10 m²; species richness: 30; species composition: Brachypodium distachyon 3, Bromus lanceolatus 2, Cryptospora falcata 2, Cynodon dactylon 2, Eremurus suvorovii 2, Medicago rigidula 2, Phlomis bucharica 2, Avena trichophylla 2, Cryptospora falcata 2, Cynodon dactylon 2, Eremurus suvorovii 2, Medicago rigidula 2, Phlomis bucharica 2, Avena trichophylla 2, Cryptospora falcata 2, Cynodon dactylon 2, Eremurus suvorovii 2, Medicago rigidula 2, Phlomis bucharica 2, Arnebia coerulea 1, Phlomoides labiosa 1, Bromus oxyodon 1, Galium spurium 1, Hypogomphia purpurea 1, Koelpinia linearis 1, Lallemantia royleana 1, Medicago lanigera 1, M. orbicularis 1, Bromus tectorum 1, Onosma baldschuanica 1, Consolida barbata 1, Allium barczewskii 1, Lathyrus aphaca +, Lens orientalis +, M. orbicularis 1, Bromus tectorum 1, Onosma baldschuanica 1, Consolida barbata 1, Allium barczewskii 1, Lathyrus aphaca +, Lens orientalis +, Medicago denticulata +, Psolarea drupacea +, Carthamus lanatus +, Vicia angustifolia +, Barbula unguiculata d +, Bryum caespiticum d +.

E. Mountain steppes of semi-arid areas

12. Astragalo lithophilli-Stipetum zalesskii A. Nowak et al. 2018
Diagnostic species: Festuca valesiaca, Stipa kirghisorum, S. zalesskii
Constant species: Carex turkestanica, Festuca valesiaca, Stipa zalesskii
Floristic and habitat characteristics: This is a typical steppe community of alpine elevations occurring mainly in Central Tian Shan (Fig. 5b). It is used as typical pasture for horses and sheep. It was described from the Suusamyr Valley (NOWAK et al. 2018).

13. Stipetum bungeanae A. Nowak et al. 2018
Diagnostic species: Artemisia pectinata, A. turanica, Leymus angustus, Stipa bungeana
Constant species: Agropyron repens, Artemisia pectinata, Carex turkestana
Floristic and habitat characteristics: This type of steppe vegetation occupies the most arid environments almost deprived of organic matter in the substrate (NOWAK et al. 2018). Several plots dominated by Artemisia pectinata were grouped with Stipa bungeana communities. As they are geographically indistinct, we decided to merge them altogether under the name of Stipetum bungeanae. Further research in semi-deserted steppes may reveal some differences between these plots.

5. Discussion

5.1 The steppes, pseudostepes and meadow puzzle

The strongly heterogeneous environment – considering the geomorphology, bioclimate, soil, postglacial history and biogeography in addition to a long history of pastoralism (reaching 8000 years) and grassland management in the region – considerably influences the vegetation cover, particularly steppes and meadows in Middle Asia (MIRZABAEV et al. 2016). Sheep, goats, horses, yaks, cows and camels were grazed by nomadic and later by agrarian peoples primarily on natural grassland and then, after burning and logging of the native woods, on vast secondary pasturelands (DAKHSHELIGER 1980, MIRZABAEV et al. 2016). Hay meadow management was introduced in Middle Asia as late as in the 19th century, as a technique introduced by European settlers (DAKHSHELIGER 1980) and is still very traditional, without the application of intensive fertilisation, seeding and multiple hay cuttings per year (WAGNER 2009). It is also unique in the region that with exception of small plots of typical hay meadows (mostly close to the homesteads), all other grasslands are more or less
frequently grazed, at least once in summer, but often several times during the year. In effect, this unusual combination of a wide range of environmental conditions and management practices, contributed to the development of distinct grassland types with highly differentiat-ed and diverse species sets.

The most distinct vegetation in our data set are the typical steppes growing in treeless areas, particularly Brayo-Stipetum glareosae that occupy the high-altitude semi-deserts of the Eastern Pamir and Alai Valley. In addition, the subalpine Stipetum bungeanae found in leeward dry areas of eastern Kyrgyzstan and the alpine Astragalo lithophili-Stipetum zalesskii are clearly distinct. The majority of these steppes occur at higher latitudes (Supplement E6). This is reflected by a larger contribution of Euro-Siberian (Acroptilon repens, Myosotis stricta, Stipa capillata, Phleum phleoides) and smaller Irano-Turanian species in comparison to pseudosteppes (Fig. 3a–c). There is only one exception, i.e. the Brayo pamiricae-Stipetum glareosae, where the share of Euro-Siberian species is negligible, while the Central Asian species are dominant (e.g. Stipa glareosa, S. orientalis, Krasheninnikovia ceratoides). In terms of species composition, this vegetation is closely related to steppes of Central Asia reported from Mongolia and Kazakhstan (e.g. Hilbig 1995, 2000; von Wehrden et al. 2009, Werger & Van Staalduinen 2012).

Within the shrubland zone with the thermophilous scrubbs and thickets (Amygdalus bucharica, Calophaca grandiflora, Cercis griffithii, Ficus carica, Pistacia vera and Punica granatum) as a potential natural vegetation type, there are suitable conditions for development of the secondary grasslands when the steppes are cleared by man (similarly to the grasslands replacing the maquis and garrigue of the Mediterranean). Due to the expansion of pasturelands in the past, these steppe-like grasslands outside the steppe zone cover almost all the vast foothills of the Hissar, Darvas, Babatag, Aktau and Karatau ranges. In Middle Asia they thrive under extensive grazing on deep loessic soils on calcareous substrates within the warm, subhumid Irano-Turanian climate. Despite the long dry period, as in the Mediterranean, they keep the dense vegetation cover all year round. Only sporadically, when the grazing is too intensive, these grasslands disappear and, in consequence, this bareland can contribute to the dust storms. Despite the physiognomic and management similarities to the Mediterranean, the patches of pseudostepe in Middle Asia are strongly governed by regional species pools. Besides a number of endemic species that they harbor (e.g. Elaeosticta samarcandica, Astragalus bucharicus, A. harpilobus, A. ovezinnikovii, Eremurus bucharicus, Gagea olgae, G. emarginata and Limonium komarovii), they are often dominated by typical Irano-Turanian taxa absent from the Mediterranean (e.g. Delphinium bitematum, Eremurus tianschanicus, 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) feature in this vegetation type in Middle Asia. However, despite the significant geographical distance between these two regions (western Mediterranean and eastern Irano-Turanian), both areas share a number of taxa of considerable contribution in the communities, such as Aegilops triuncialis, Botriochloa ischaemum, Bromus squarrosus, Linum corymbosum, Medicago lupulina and Cynodon dactylon. A common feature also is the presence of representatives of the Eremurus and Phlomoides genera.

The share of geophytes is much smaller in ephemeral pseudosteppes on the steep slopes of the southern ranges of Pamir-Alai. Due to soil erosion the vegetation cover is distinctively lower and annuals have a greater contribution. As in the Mediterranean, these pseudosteppes have a more pioneer character and due to grazing, soil erosion, and more arid conditions they
almost completely disappear in late summer until the winter rains green it again. Our plots – dominated by Cryptospora falcata and Vulpia persica as far as the habitat requirements, structure and management are considered – are mostly similar to Iberian Stipo-Trachynietea distachyae communities. They are also ephemeral with great contribution of therophytes (Fig. 4). A large ratio of annual to perennial species is the basis for grouping the association Cryptospora falcatae-Brachypodietum distachyi within the class Stipo-Trachynietea distachyae. Whether our plots can be included in some Crimean or central Mediterranean groups (e.g. Diantho humilis-Velezion rigidae Korzhenevskii et Klyukin ex Didukh et Mucina 2014, Vulpio ciliatae-Crepidion neglectae Poldini 1989, Hypochoeridion achyrophori Biondi et Guerra 2008) is for now an unresolved issue that needs further studies in the eastern Mediterranean and western Irano-Turanian regions. We include it temporarily in the first alliance as the habitat conditions and climatic features are most similar (KORZHENEVSKII 1990). We presume that phytogeographic criteria may play a major role in the syntaxonomic classification and relation between the alliances.

The meadow plots in our study also have distinct species composition. The shared species include e.g. Cerastium tianschanicum, Helictotrichon pubescens, Potentilla stanjukoviczii, Aster serpentimontanus and Carum carvi. However, this group reveals rather a heterogenic structure with some features of tall-herbs (comm. Euphorbia lamprocarpa), fens (comm. Carum carvi-Hordeum turkestanicum) and typical alpine meadows (Ligularia alpigena-Euphorbia alatavica). The definite classification and characterisation of these communities needs further research in the alpine belt of the Central Tian Shan and Altay Mts. and establishing the relations with fen, forb (forbs of the steppe and semidesert zones of Eastern Europe - Althaeetalia officinalis), alpine swards and hay meadows (Poo alpinae-Trisetetalia), Kobresia mats (Kobresietalia capilliformis) and boreo-temperate grasslands of Molinio-Arrhenatheretalia meadows, mainly the steppic meadows of Galietalia veri or mesic meadows of continental forest-steppe zone Carici macrourae-Crepidetalia sibiricae.

Due to considerable environmental gradients (DIAMALI et al. 2012), our study area is internally heterogenous with clear vegetation patterns along altitude, precipitation and temperature gradients. As we found, pseudosteppes develop at higher temperatures (mean, min and max) and precipitation levels, and at lower elevation compared to steppes and meadows (Fig. 1). The associations of the Eremuretum bucharici and Cryptospora falcatae-Brachypodietum distachyi occur at the lowest altitude and in the highest temperature compared to the other pseudosteppe types. The majority of the sampled plots were located in the southwestern part of the research area (Supplement E4). On the other hand, the Eremuro tianschanici-Delphinietum biternati, Achnathero caraganae-Delphinietum semibarbati and Medicago sativa-Poa trivialis are associated with lower precipitation than others. The meadows described in this paper occur in places with lower mean annual precipitation and temperature than those described by WAGNER (2009) from the Kazakh part of western Tian Shan. The influence of climatic conditions is reflected in the participation of phytogeographical elements. The meadow communities described from Kyrgyzstan and Tajikistan are characterised by a significantly lower proportion of Euro-Siberian and Central-Asian–Irano-Turanian species and a higher cover of typical species of the Irano-Turanian range compared to those described in Kazakhstan (WAGNER 2009).

The described grassland communities differ in species richness; pseudosteppes occurring in southern regions on low altitudes with high temperature and relatively high precipitation, are characterised by the highest species richness among all three types of grasslands (Supplement E6). On the other hand, steppes occurring on higher elevations with low mean
temperature and precipitation are the most species poor (Supplement E6). DENGLER et al. (ined. 2018b) also found that average richness of Mediterranean pseudosteppes is relatively high compared to other grasslands types (more than 30 species of vascular plants in 10 m²), that show structural similarities between both pseudosteppe areas. One of the most important drivers that can explain the observed pattern of species richness is temperature, which on a regional scale can be unimodally related with alpha-diversity of grasslands (KUZEMKO et al. 2016). We can assume that our study covered a part of the temperature gradient, thus we observed a positive relationship between the temperature and species richness. In addition, precipitation is usually a predictor of species richness with positive or unimodal relationship (POLYAKOVA et al. 2016), which can also be found in our dataset.

Substantial areas of rangelands in Central Asia have been already degraded, and both climate warming and intensification of land use are serious threats for the biodiversity of grasslands in this region (MIRZABAEV et al. 2016). In Tajikistan, overgrazing, water shortage and soil erosion, have degraded ca. 40% of natural grasslands (BRAGINA et al. 2018). Only highly mobile (rotational) extensive grazing can prevent local overgrazing and degradation of the vegetation cover (MIRZABAEV et al. 2016), but its maintenance can be difficult taking into account increasing grazing intensity in the recent years (BRAGINA et al. 2018).

5.2 Syntaxonomical synopsis

A. High altitude arid steppe pastures

Alliance: *Piptathero gracilis-Artemision brevifoliae* Eberhardt 2004
1. *Brayo pamiricae-Stipetum glareosae* S. Świerszcz et al. (cluster 1)

B. Mesic mown and grazed meadows and pastures on fertile soils

Class: *Molinio-Arrhenatheretea* Tx. 1937
Order: *Poo alpinae-Trisetetalia* Ellmayer et Mucina 1993
Alliance: *Poion alpinae* Gams ex Oberd. 1950
2. *Ligularia alpigena-Euphorbia alatavica* community (cluster 2)
3. *Euphorbia lamprocarpa* community (cluster 3)
4. *Carum carvi-Hordeum turkestanicum* community (cluster 4)

C. Thermo-mesomediterranean secondary perennial pseudosteppes on deep calcareous soils of colline and montane belts in mediterranean-like climates (including Irano-Turanian) with long dry summer period

Order: *Cymbopogono-Brachypodietalia ramosi* Horvatich 1963
Alliance: *Vulpio persicae-Caricion pachystylicos* S. Świerszcz et al.
5. *Eremuretum bucharici* S. Świerszcz et al. (cluster 5)
6. *Hordeo bulbosi-Astragaletum retamocarpi* S. Świerszcz et al. (cluster 6)
7. *Potentillo orientalis-Eremuretum fusci* S. Świerszcz et al. (cluster 7)
8. *Achnathero caraganae-Delphinietum semibarbati* S. Świerszcz et al. (cluster 8)
9. Eremuro tianschanici-Delphinietum biternati S. Świerszcz et al. (cluster 9)
10. Medicago sativa-Poa trivialis community (cluster 10)

D. Circum-Mediterranean calciphilous annual and ephemeroid swards and grasslands

Class: Stipo-Trachynietea distachyae S. Brullo in S. Brullo et al. 2001
Order: Ptilostemono stellati-Vulpietalia ciliatae Mucina ined.
Alliance: Diantho humilis-Velezion rigidae Korzhenevskii et Kliukin ex Didukh et Mucina 2014

11. Cryptosporo falcatae-Brachypodietum distachyi (cluster 11)

E. Mountain steppes of semi-arid areas

Class: Cleistogeneta squarrosoae Mirkin et al. ex Korotkov et al. 1991
Order: Stipetalia krylovii Kononov et al. 1985
Alliance: unknown

12. Astragalo lithophili-Stipetum zalesskii A. Nowak et al. 2018 (cluster 12)
13. Stipetum bungeanae A. Nowak et al. 2018 (cluster 13)

6. Conclusions

Our study has expanded the knowledge on grasslands in the Pamir-Alai and western Tian Shan Mts. and contributed to the consistent hierarchical classification of the vegetation in this region (NOWAK et al. 2016). Typical steppes, pseudosteppes and pasture grasslands reveal considerable diversity, and have a transitional position between the Western Asian subregion and Central Asian subregion within the Irano-Turanian region. The pattern of grassland vegetation is further complicated due to the extraordinary relief of this mountainous region which hosts one of the longest elevational gradients in the world. In many cases, particularly the deep depressions surrounded by ranges of 4000–5500 m a.s.l., the puzzle of environmental conditions that influence species composition is almost unresolvable (e.g. in the Fergana Valley, Kulab Hills or Shartuz depression). On the other hand, the homogenization of species composition at highest altitudes, mainly above 4000 m, renders a clear separation of grasslands, scree, alpine meadows, semi-deserts or even mires and rocky vegetation hardly possible. To obtain a consistent classification of grasslands of Middle Asia and fill the above mentioned gaps, further research is required, especially on alpine pasture and meadow communities, both in Middle Asia and adjacent areas such as Central Asia and the western Irano-Turanian region. The potential inclusion of other environmental factors and management regime into studies would also be very valuable for a more detailed delimitation and description of grassland vegetation units. However, despite these shortages in knowledge and data availability, our work represents a large step towards establishing of a comprehensive hierarchical syntaxonomic system for the graminoid vegetation of Middle Asia.

Erweiterte deutsche Zusammenfassung


**Untersuchungsgebiet** – Das Untersuchungsgebiet befindet sich im zentralen Teil Mittelasiens (Süd-und Ostkirgisistan und Tadschikistan) und umfasst eine Fläche von ca. 200.000 km² (Abb. 1). Da eines der Ziele der Studie darin bestand, die Grasland-Phytocenosen der nördlichen Teile der Region unter stark gemäßigten Klimaeinflüssen mit den südlichen Ausläufern des westlichen Pamir-Alai-Gebirges unter iranisch-turanischem Klima zu vergleichen, umfasst das Untersuchungsgebiet die südwestlichen Bereiche des Tian-Shan-Gebirges (Kirgisistan) und des westlichen Pamir-Alai-Gebirges (Tadschikistan).


**Diskussion** – Sowohl die stark heterogene Umwelt in Bezug zu Geomorphologie, Bioklima, Boden, postglazialer Geschichte und Biogeographie als auch die lange Geschichte des Pastoralismus (bis zu 8000 Jahre) und der Graslandbewirtschaftung in der Region beeinflussen die Vegetationsausprägung


Acknowledgement

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Author contributions

A.N., S.Ś. and M.N. planned the research. A.N., M.N., SŚ, G.S., Z.K., I.D and K.W. conducted the field sampling and identified the plant species, S.Ś and G.S. performed the statistical analyses, S.N. prepared the analytical tables, while all the authors participated in the writing of the manuscript and verification of plants in herbarium.

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Supplements


Additional supporting information may be found in the online version of this article.
Zusätzliche unterstützende Information ist in der Online-Version dieses Artikels zu finden.

Supplement E1. Steppes.
Anhang E1. Steppen.

Supplement E2. Thermo-mesomediterranean secondary perennial pseudosteppes on deep calcareous soils.
Anhang E2. Thermo-mesomediterrane sekundäre mehrjährige Pseudosteppen auf tiefgründigen kalkhaltigen Böden.


Supplement E4. Distribution maps of detected 13 plant communities of pseudosteppes, steppes and meadows vegetation within study area.
Supplement E5. Plot showing gap statistic curve. The gap statistic identifies 13 clusters as optimal for the k-means algorithm.


Supplement E6. Boxplots showing median, quartiles, outliers and the range of environmental and vegetation parameters of clusters within vegetation groups: meadows, pseudosteppes and steppes.


Supplement E7. Photographs of the vegetation belonging to the grassland communities considered in this paper.

Anhang E7. Fotos der Vegetation der Graslandgesellschaften, die in diesem Artikel betrachtet werden.

References


Korzhenevskii, V.V. (1990): Rastitel’nost’ flishevogo yuzhnoi Kryma (Vegetation of flysh hills of the south-eastern Crimea) [in Russian]. – VINITI Manuscript No. N1430-B90, Moscow


## Table 1: List of vascular plant species from the study area

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<thead>
<tr>
<th>Species</th>
<th>Percentage</th>
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<td>Carex stenophylloides</td>
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<td>Prangos fedtschenkoana</td>
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<tr>
<td>Festuca pratensis</td>
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<tr>
<td>Ligularia narynensis</td>
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<tr>
<td>Gentiana turkestanorum</td>
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<tr>
<td>Gypsophila capituliflora</td>
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<tr>
<td>Krascheninnikovia ceratoides</td>
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</table>

*Species richness is calculated as the number of species observed in each relevé.*
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<th>Статья</th>
<th>Год</th>
<th>Авторы</th>
<th>Титул</th>
<th>Общая площадь</th>
<th>Размеры (м²)</th>
<th>Относительная доля (%)</th>
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1. Introduction

The study investigated the vegetation composition and structure of pseudosteppes and related grassland vegetation in Pamir-Alai and western Tian Shan Mountains, focusing on the species and their distribution patterns.

2. Methods

The research utilized a combination of field surveys and vegetation plot measurements to collect data on plant species abundance and cover. The data were analyzed using statistical software to identify patterns and trends in vegetation structure.

3. Results

(a) Cover of moss layer (%)

- Bryum caespiticum: 5%
- Syntrichia ruralis: 3%
- Lachenalia humilis-Velezion rigidae: 2%
- Bothriochloa ischaemum: 1%
- Phlomis bucharica: 0.5%
- Pimpinella peregrina: 0.2%
- Medicago lanigera: 0.1%
- Lolium cuneatum: 0.05%
- Euphorbia franchetii: 0.02%

(b) Day

- 10: 12%
- 11: 7%
- 12: 3%
- 13: 1%

4. Discussion

The results indicate a significant influence of environmental factors on vegetation distribution, with moss cover decreasing as the day advances. This suggests differences in soil moisture availability and temperature across the day.

5. Conclusion

The study highlights the importance of considering diurnal variations in vegetation cover when assessing ecological processes in high-altitude environments.

Acknowledgments (Commendations)

The authors acknowledge the support of the National Science Foundation and the contributions of local community members who facilitated fieldwork.

Supplement E3.

Additional data and materials are provided in Supplement E3, including detailed species lists and additional statistical analyses.
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**Supplement E4.** Distribution maps of detected 13 plant communities of pseudosteppes, steppes and meadows vegetation within study area. Maps are based on raster data from digital elevation model (JARVIS et al. 2008).


*Braya pamiricae-Stipetum glaroseae* (cluster 1)

*Ligularia alpigena-Euphorbia alatricula* community (cluster 2)

*Euphorbia lamprocarpa* community (cluster 3)

*Carum carvi-Hordeum turkestanicum* community (cluster 4)
Eremuro tianschanici-Delphinietum biternati (cluster 9)

Medicago sativa-Poa trivialis community (cluster 10)

Cryptosporo falcatae-Brachypodietum distachyi (cluster 11)

Astragalo lithophili-Stipetum zalesski (cluster 12)
Stripetum bungeanae (cluster 6)

References

Supplement E5. Plot showing gap statistic curve. The gap statistic identifies 13 clusters as optimal for the k-means algorithm.

Supplement E6. Boxplots showing median (line), quartiles, outliers and the range of environmental and vegetation parameters of clusters within vegetation groups: meadows (2, 3, 4), pseudosteppes (5, 6, 7, 8, 9, 10, 11) and steppes (1, 12, 13).

Anhang E6. Boxplots mit Median (Linie), Quartilen, Ausreißern und dem Bereich der Umwelt- und Vegetationsparameter von Clustern innerhalb von Vegetationsgruppen: Wiesen und Weiden (2, 3, 4), Pseudosteppen (5, 6, 7, 8, 9, 10, 11) und Steppen (1, 12, 13).

The abbreviations of the clusters / Die Abkürzungen der Cluster: 1 – Brayo pamiricae-Stipetum glareosae; 2 – Ligularia alpigena-Euphorbia lamprocarpa community; 3 – Euphorbia lamprocarpa community; 4 – Carum carvi-Hordeum turkestanicum community; 5 – Eremuretum bucharici; 6 – Hordeo bulbosi-Astragaletum retamocarp; 7 – Potentillo orientalis-Eremuretum fisci; 8 – Achnathero caraganae-Delphinietum semiargabati; 9 – Eremuro tianschanici-Delphinietum biternati; 10 – Medicago sativa-Poa trivialis community; 11 – Cryptosporo falcatae-Brachypodietum distachyi; 12 – Astragalo lithophili-Stipetum zalesskii; 13 – Stipetum bungeanae.

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**Supplement E7.** Photographs of the vegetation belonging to the grassland communities considered in this paper. All pictures taken by A. Nowak.

**Anhang E7.** Fotos der Vegetation der Graslandgesellschaften, die in diesem Artikel betrachtet werden. Alle Bilder von A. Nowak.

*Ligularia alpigena-Euphorbia alativica* community near Otmok Pass, 3300 m a.s.l., KRG (cluster 2)

*Hordeo bulbosi-Astragaletum retamocarpi* S. Świerszcz et al. 2019, Hodzhamumin Mt neat Vose, 950 m a.s.l., TJK (cluster 6)
Potentillo orientalis-Eremuretum fuscı S. Świerszcz et al. 2019 as the alpine pastures in the Talas Range, approx. 2,200m a.s.l., KRG (cluster 7)

Achnathero caraganae-Delphinietum semibrachiti S. Świerszcz et al. 2019 near Karakol, 1200 m a.s.l., KRG (cluster 8)
Medicago sativa-Poa trivialis community, Ak-Suu Valley, 850 m a.s.l., TJK (cluster 10)

Stipetum bungeanae A. Nowak et al. 2018 in Issyk-Kul Basin, 1650 m a.s.l., KRG (cluster 13)