Dwarf shrub vegetation of rock ledges and clefts in the Pamir Alai Mountains (Middle Asia: Tajikistan)

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Abstract – The paper presents the results of phytosociological researches on rocky slope vegetation in Tajikistan with the aim to establish a comprehensive syntaxonomical classification system. Field studies were conducted in 2010–2014 in Pamir Alai ranges and Pamirian plateau. Nearly 500 relevés documenting rock and scree vegetation were made according to the Braun-Blanquet method. Numerical analyses of selected 58 relevés representing dwarf shrub vegetation on rock ledges made it possible to distinguish: Ephedro glaucae-Spiraeion baldschuanicae and Ephedrion regeliano-fedtschenkoi alliances, as well as Spiraeetum baldschuanicae, Rhamnetum coriaceae, Pentaphylloidetum parvifoliae and Pentaphylloidetum dryadanthoidis associations, community of Ephedra glauca and community of Rhamnus minuta. The classification of vegetation of dwarf shrubs on rock walls occurring in the Pamir Alai Mts is proposed. Because of the species composition, physiognomy and microhabitat conditions, the plant communities were included into Artemisio santolinifoliae-Berberidetea sibiricae class Ermakov et al. 2006. The main factors determining the species composition of the classified associations seem to be the elevation above sea level. The newly described syntaxa are largely defined by species restricted to very narrow ranges in Middle Asia.

Keywords: alpine vegetation, Campanuletalia incanescentis, chasmophytes, saxicolous communities, syntaxonomy

Introduction

Rocks and screes with their niche diversity create habitats for many specialized plant species (Favarger 1972, Kazakis et al. 2006, Nowak et al. 2011). Rock faces can serve as dry islands, while the crevices, fissures or deep clefts are better supplied with water. Rocky niches can also considerably differ from each other in amount of soil, which is usually not very fertile. The extreme habitat differentiation and uniqueness of petrophytic flora is reflected in the great variety of plant communities developing on rocky walls.

Many phytosociological studies on rupicolous vegetation have been recently conducted in mountainous areas of Europe (e.g., Valachovič et al. 1997, Sanda et al. 2008, Chytrý 2009, Tzovet et al. 2009), especially in the Mediterranean region (e.g., Carmona et al. 1997, Deil 1998, Parolly 1998, Onipchenko 2002, Ermolaeva 2007, Deil et al. 2008, Terzi and D’Amico 2008) as well as arid zones of Asia (e.g. Ermakov et al. 2006, Deil 2014). Despite the considerable areas of mountain ranges and their great diversity in terms of altitudinal amplitude, rock types and climatic conditions, the rock and scree communities in Asia have not yet been studied in detail. The mountain ranges in Tajikistan, especially those with the highest amounts of precipitation (i.e. the Hissar Mts and Alichur Mts), constitute a refuge for a considerable number of stenochoric plant species sensitive to climate change (Kazakis et al. 2006, Baettig et al. 2007, Fay and Patel 2008). The chasmophytic flora of Tajikistan comprises many taxa geographically restricted to this country or to Middle Asia (e.g. Scutellaria megalodonta, S. shugnanica, S. zaprjagaevii, Achorophragma darvazicum, Dionisia involucrata, Viola majchurenensis, Asperula fedtschenkoi, Andrachne fedtschenkoi, Callipeltis cucullaris, Trichodesma incanum, Hypericum scabrum, Silene brahuica and many others). Within the project of the phytosociological survey of Tajik vegetation (e.g. Nowak and Nobis 2012, 2013, Nowak et al. 2013a, 2013b) research on chasmophytic vegetation started in 2009. Although a number of papers focused
on typical rock vegetation (Asplenietae trichomanis) have been presented in recent years, still little is known regarding the scree and talus vegetation or the transitional microhabitats of much eroded rocks or stable scree (Nowak et al. 2014a, 2014b, 2014c). The problem of classification of dwarf-shrub dominated plots on rocky slopes and rock ledges in Middle Asia needs to be investigated and the relation of these phytocoenoses to both Asplenietae trichomanis and Artemisio santolinifoliae-Berberidetea sibiricae class finally settled. The paper is a part of our survey on rock vegetation in Tajikistan with the final intention of building up the syn-taxonomical system of all types of rupicolous environments within the country. Particularly it aims at completing the knowledge of the diversity of rock and scree vegetation in Tajikistan as well as presenting the last successional stage of saxicolous communities here – the dwarf shrub communities which should be considered as a pedoclimax vegetation for this kind of habitat.

Material and methods

Study area

Tajikistan covers an area of ca. 143000 km² and is located between 36°40’–41°05’E and 67°31’–75°14’N in Middle Asia (Fig. 1). According to recent studies about 4550 vascular plant species occur in Tajikistan with ca. 30% generally accepted as endemics (Nowak et al. 2011). This number is still incomplete, as new investigations regularly add new species to the flora of Tajikistan (e.g. Nobis 2013, Nobis et al. 2014a, 2014b, 2014c). An alpine landscape of high mountains dominates the country. More than 50% of the country’s area is located above 3000 m. As typical for the Mediterranean type of climate, the area has generally high solar radiation, as well as a low percentage of cloud cover, high-amplitude annual temperatures, low humidity and precipitation (with the exception of the spring period, when there is a considerable amount of rainfall, Fig. 2). In the south-western regions of Tajikistan, the average June temperatures rise to 30 °C. In the temperate zone and alpine elevations the average temperatures in mid-summer are between 9.7 °C and 13.5 °C. Annual precipitation ranges in Tajikistan from ca. 70 mm (in the mountainous deserts of eastern Pamir and south-western lowlands of the country) to ca. 600 mm (on the southern slopes of the Hissar Range). The limit of perpetual snow is at an altitude of 3500–3600 m in the western Pamir Alai Mts, rising to about 5800 m a.s.l. in the highest elevations of eastern Pamir (Latipova 1968, Narzikulov and Stanjukovich 1968).

The study was situated in different mountain ranges. They include: the Zeravshan Mts, Hissar Mts, Hazratishokh Mts, Darvaz Mts, Rushan Mts, Vanch Mts, Turkestan Mts, Peter I Mts, Yazgulem Mts, Karateginian Mts, Alichur Mts, Shugnan Mts and the Sarikol Mts. All of them belong to the Pamir Alai mountain system (Fig. 3).

Studies on the geology of Tajikistan are still scarce and a bit outdated (e.g. Nedzvedskiy 1968). The middle and
higher parts of the Hissar Mts are largely composed of extrusive rocks, mainly granite, granitoid and syenite (e.g. Varzob valley). Some igneous outcrops also occur in the Darvaz Mts, Kuraminian Mts and in the western Pamir ranges. In the Zeravshan and Turkestan Mts, Cambrian and Silurian sediments predominate. The rocks here are generally limestone (micrite limestone, bituminous limestone, marly limestone and dolomitic coral limestone), marble, dolomite, dolomitic shale, clay shale, phyllitic schist and argillaceous slate. Also, several metamorphic rocks are present within the study area. The most common are migmatitic gneiss, conglomerates and metamorphic mudstones. In eastern Pamir, carboniferous sediments dominate, mainly granite, granodiorite and diorite.

The rupicolous vegetation of Tajikistan is for now classified into 32 associations, 2 alliances and one order (Nowak et al. 2014a, 2014b, 2014c). For rock communities of the alpine zone developing on solid rock faces, crevices and ledges the phytocoenoses are characterized by high constancy and abundance of petrophytic taxa with an Irano-Turanian distributional range. The most frequent species contributing to the phytocoenoses are Campanula inacensens, C. lehmanniana, Poa relaxa, Artemisia ruetica and Sergia regeli. Due to significant differences in habitat conditions (e.g. inclination, insolation, crevice size, soil amount) and species composition, two main groups of plant communities within Asperulo-albiflorae-Poion relaxae were distinguished. The first group includes communities inhabiting fine fissures and tiny crevices on rock faces (representing the Campanulion lehmanniaceae subassociation) and the second group comprises communities developing on larger clefts and small ledges with considerable amounts of soil (representing Pentaneminion albetoregeliae subassociation). For the montane and colline zone, the Caricion koshevnikovii alliance defining the phytocoenoses dominated by acidophilous species like Scutellaria hissarica, S. schugunica, S. zapryazhevi, S. baldshuanica, Tylosperma lignosa and Dionysia involucrata was proposed (Nowak et al. 2014c). The scree and talus vegetation still needs further investigations. The first insights into the vegetation of colluvial cones and sampling of ca. 300 relevés were obtained in 2014 by the team of authors. However the research is still at the beginning stage and the data set will have to be completed and thoroughly analyzed.

**Data and analyses**

The research was conducted in 2010–2014. We sampled vegetation plots on mountain cliffs, slopes and terrace walls. The studied vegetation patches were located between 890 and 4280 m a.s.l. The vegetation plot size was delimited in such a way as to represent the full floristic composition of the phytocoenoses. It varied from 3 to 5 m² depending on plant density and the homogeneity of vegetation cover. The sampling procedure covers all altitudinal zones, variety of bedrocks, inclinations and exposures. For each vegetation plot all vascular plants and cryptogams were recorded. Epilithic lichens have not been considered, as non-specific and insignificant in defining the associations. Plant species were recorded according to the Braun-Blanquet method as the most relevant in the analysis of vegetation variability (Braun-Blanquet 1964). The 7-degree cover-abundance scale was transformed into percentage cover in the Juice program: r = 0.1%; + = 1.0%; 1 = 2.5%; 2 = 15.0%; 3 = 37.5%; 4 = 62.5%; 5 = 87.5% (Tichý 2002). The rock type was determined by analyzing the lithology, pore geometry, mineralogical components, texture, permeability, hardness and pH by a professional geologist (see acknowledgments). The phytocoenoses were developed on different types of rock substrate, with a range of pH reaction between 6.2 and 8.8. Hydrogen ion concentrations were measured in aqueous rock solution using the ELMETRON CP-105 pH meter. During field surveys, 488 phytosociological documents representing the Asperulo-Poion (Nobis et al. 2013, Nowak et al. 2014a, 2014b) and Caricion koshevnikovii (Nowak et al. 2014c) as well as fern associations on rock crefts and crevices and the association of Dionysietum involucratae (Nowak et al. 2014) were taken. Additionally ca. 300 relevés were sampled in scree and talus vegetation to find out the relation of the plots to the main vegetation classes (Asplenietea rupestrina and Artemisio santolinifoliae-Berberidetae sibiricae Ermakov et al. 2006) which should eventually include the samples investigated.

All the relevés were stored in a database using the JUICE program (Tichý 2002). A modified TWINSPAN analysis was conducted (Rolleček et al. 2009) to get the initial idea of the data structure and resolution. We applied the pseudo-species cut levels of 0%, 2%, 5% and 10%. The sampled data showed a unimodal response, allowing us to use a detrended correspondence analysis (DCA) with the floricostal data set (no down-weighting of rare species) to check the floricistic-sociological classification and to show the relationships between the groups. For the ordination, CANOCO for Windows 4.5 was used (Ter Braak and Šmilauer 2002). Af-
ter grouping the samples, 58 relevés were identified as suitable for the description of dwarf shrub vegetation on rock ledges.

Vegetation classification follows the sorted table approach of Braun-Blanquet (1964). In the analytic tables (Tab. 1, On-line Suppl. Tab. 1), species constancies are given in class I–V (Dierschke 1994). In a case in which a particular species was noted in fewer than 8 relevés, the absolute number of species occurrences was specified in the tables (communities of Ephedra glauca and Rhamnus minuta).

 Newly presented syntaxa, described as order, alliance or associations were proposed according to the International Code of Phytosociological Nomenclature (Weber et al. 2000). While distinguishing and ranking the association the works of Nowak et al. (2014a, 2014b, 2014c) were taken into account. The association concept follows Willner (2006).

Plant material collected during field studies is deposited in the Herbarium of the Middle Asia Mountains, housed in OPUN (Opole University, Poland) and KRA (Jagiellonian University, Poland). Species nomenclature follows Czerep-

### Tab. 1. Plant communities of the *Ephedrion regeliano-fedtschenkoi* in Pamir Alai Mts in Tajikistan, in 2013. Locations of samples (according to the numbers of relevés): 1, 3, 7 – to the south from Karasu (37°57′43″, 73°54′21″); 2, 4 – to the south-west from Murgab (37°55′41″, 73°52′02″); 5, 8 – Chatyr-Tash (38°06′32″, 73°53′08″); 6, 9 – Chatyr-Tash (37°50′00″, 73°34′13″); 10, 11 – to the Davaz Pass (38°37′47″, 70°43′01″).

<table>
<thead>
<tr>
<th>Relevé number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
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<td>24/8</td>
<td>24/8</td>
<td>24/8</td>
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<td>pH</td>
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<td>8.4</td>
<td>7.8</td>
<td>8.4</td>
<td>8</td>
<td>7.6</td>
<td>7.7</td>
<td>8</td>
<td>8.4</td>
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<td>NW</td>
<td>SE</td>
<td>NW</td>
<td>SE</td>
<td>SE</td>
<td>SE</td>
<td>SE</td>
<td>W</td>
<td>W</td>
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<td>65</td>
<td>65</td>
<td>55</td>
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<td>55</td>
<td>50</td>
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<td>60</td>
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<td>4217</td>
<td>3811</td>
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<td>3909</td>
<td>3811</td>
<td>4275</td>
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<tr>
<td>Cover of shrub layer (%)</td>
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<td>35</td>
<td>35</td>
<td>55</td>
<td>35</td>
<td>35</td>
<td>30</td>
<td>20</td>
<td>45</td>
<td>30</td>
</tr>
<tr>
<td>Cover of herb layer (%)</td>
<td>10</td>
<td>15</td>
<td>10</td>
<td>10</td>
<td>5</td>
<td>2</td>
<td>10</td>
<td>3</td>
<td>2</td>
<td>15</td>
<td>25</td>
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<tr>
<td>Relevé area (m²)</td>
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<td>3</td>
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<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
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<td>3</td>
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<tr>
<td>Number of species</td>
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<td>8</td>
<td>11</td>
<td>7</td>
<td>5</td>
<td>6</td>
<td>8</td>
<td>8</td>
<td>7</td>
<td>7</td>
<td>10</td>
</tr>
</tbody>
</table>

#### Diagnostic species

**Ass. Pentaphylloidetum dryandanthoidis**

*Pentaphylloides dryandanthoides* b 4 3 3 3 4 3 3 3 2 . . V –

**Community of Rhamnus minuta**

*Rhamnus minuta* b . . . . . . . . . . . . . . . . 3 2 – 2

**All. Ephedron regeliano-fedtschenkoi**

*Ephedra fedtschenkoi* b + 1 1 + . + . + . + IV 1

**O. Ephedretalia gerardianae et Cl. Asplenietea trichomanis**

*Melisissus pamiricus* + + 1 1 1 . . + + + . IV –

*Poa relaxa* . . + 1 + + + + + + . + IV 1

*Paragilegia anemonoides* 1 1 + . + + + + + + . IV –

*Artemisia ratjofia* . 1 + + . . + + + + . IV –

*Onosma dichroanthat* . + . + + + + + + . IV –

*Potentilla malacotricha* 1 1 + + . . + . . . . III –

*Allium tianschanicum* + . + . + + + + + . . II –

*Asperula strizhoviae* . . . . . . . . . . . . . . . . 1 2 – 2

*Psychrogeton leucophyllus* . . . . . . . . . . . . . . . . + + – 2

**Sporadic species:** *Campanula incanescens* 11; *Eritrichium subjacquemonti* 9.

**Others**

*Roegneria czimganica* + + + + + . + . . . IV –

*Draba lanceolata* . . . . . . . . . . . . . . . . 1 + – 2

*Pseudosedum fedtschenkoanum* . . . . . . . . . . + 1 – 2

*Rosularia lutea* . . . . . . . . . . + . . . . II –

*Oxytropis chiliophylla* . . . . . . . . . . + . . . . II –

*Youngia diversifolia* . . . . . . . . . . + . . . . II –

*Stipa glareosa* . . . . . . . . . . + + . . . . II –

**Sporadic species:** *Androsaceae lehmanniana* 1; *Cerasus verrucosa* b 11; *Ephedra* sp. b 11(1); *Tulipa turkestanica* 10.

<table>
<thead>
<tr>
<th>Community</th>
<th>Soil</th>
<th>Rock type</th>
<th>Insol.</th>
<th>Exposition</th>
<th>Altitude</th>
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</thead>
<tbody>
<tr>
<td>Spiraeetum baldschuanicae</td>
<td>M</td>
<td>A</td>
<td>H/M</td>
<td>W</td>
<td>L</td>
</tr>
<tr>
<td>Rhamnetum coriaceae</td>
<td>M</td>
<td>C</td>
<td>H</td>
<td>SE</td>
<td>M</td>
</tr>
<tr>
<td>Pentaphylloidetum parvifolia</td>
<td>L</td>
<td>A</td>
<td>H</td>
<td>N,NW</td>
<td>M/H</td>
</tr>
<tr>
<td>Pentaphylloidetum dryadanthoidis</td>
<td>L</td>
<td>A</td>
<td>H</td>
<td>SE</td>
<td>H</td>
</tr>
</tbody>
</table>

anov (1995) with exception of Ephedra fedtschenkoi the name of which has been adapted after International Plant Names Index (www.ipni.org).

Results

General floristic features and habitat characteristics

The number of taxa recorded in all relevés totals 133, ranging from 3 to 18 species in particular plots (mean ca. 8). More than 59 taxa exceed 5% constancy. Those with the highest constancy are: Spiraea baldschuanica (18 occurrences), Artemisia rutilolia (17), Poa relaxa (17), Campanula incanae (15), Rhamnus coriacea, Stipa caucasica (13), Bromus tectorum, Carex koshevnkovi, Pentaphylloides parvifolia (12) and Callipeltis cucullaris (11). Most of the contributing species are typical chasmophytes adapted to extremely rocky habitats and almost exclusively restricted to eroded rocks. However, there are also a number of taxa with wide ecological amplitude known from other vegetation types. In some studied plots we found e.g. Bromus tectorum, Poa bulbosa, Phleum graecum, Conringia planisiliqua and Bromus oxyodon as species frequently sampled earlier in segetal and disturbed habitats of urbanized areas in Tajikistan. The group of plants that inhabits mainly scree was also numerous in the data set. The most frequent were: Silene brahuiuca, Centaurea squarrosa, Veronica rubrifolia, Aulacospernum roseum, Atraphaxis pyrifolia. Some of the species, e.g. Impatiens parvifolia or Leptorhabdos parviflora, are related to the forest communities. Others have come over from the neighboring rock swards (e.g. Sedum ewersii, Rosularia lutea) or xerothermophilous swards (e.g. Haplophyllum latifolium, Isolirion tatarica). Typically for rock crevice vegetation, moss species also contribute to the sampled plots, however with very low frequency. The most common were Bryum argenteum, B. caespiticum and Grimmia pulvinata.

Detrended correspondence analysis

DCA run for the entire data set clearly segregates relevés representing associations described for the first time: Spiraeetum baldschuanicae, Rhamnetum coriaceae, Pentaphylloidetum parvifoliae and Pentaphylloidetum dryadan-thoidis (Fig. 4). Also well-distinct are samples representing two new alliances: Ephedro glaucae-Spiraeion baldschuanicae (left-bottom part of the diagram) occurring in the western Pamir Alai ranges and Ephedro regelianio-fedtschenkoi (upper-right part of the graph) confined to the uppermost elevations of eastern Pamir. This is due to essential differences in the floristic composition and structure of individual phytocoenoses that accompany considerably different climatic conditions in those two areas. It seems that the vertical gradient of the graph is related to altitude with plots of Rhamnus minuta community and Pentaphylloidetum dryadanthoidis in the upper part and samples of Rhamnetum coriaceae and Spiraeetum baldschuanicae in the bottom part. From left to right the environmental variable which controls the gradient is not so evident. To some extent the floristic differentiation could be related to climate continentality and associated humidity which affect greater share of species originated in Central Asia and Tibetan Plateau. Within the group of western Pamir Alai plots are those described as Ephedra glauca community, showing the close relation to the Spiraeetum baldschuanicae and Pentaphylloidetum parvifoliae.
The communities plots occur between (1200)–1500–2500(–3000) m a.s.l. The phytocoenoses of Ephedro glaucae-Spiraeion baldschuanicae consist on average of moderate number of taxa per plot. Apart from the taxa diagnostic for the alliance, the group of high-abundance species includes: Artemisia rutifolia, Poa relaxa, Campanula incanescens, Rhamnus coriacea, Stipa caucasica, Pentaphylloides parvifolia, Callipeltis cucullaris, Asperula albiflora and Clypeola jonthlaspi. The alliance is intrinsically heterogeneous. There are distinct communities found on slopes and walls with high precipitation and those with lower amount of rainfall. The Hissar and Babatag ranges are inhabited mainly by Spiraeetum baldschuanicae while the more arid mountains like Zeravshan serve as habitat for Rhamnetum coriaceae and Pentaphylloidetum parvifoliae.

1. *Spiraeetum baldschuanicae* ass. nova

Typus relevé: On-line Suppl. Tab. 1, rel. 2, holotypus hoc loco

Diagnostic species: *Spiraea baldschuanica*

The phytocoenoses of *Spiraeetum baldschuanicae* have been found in several stations in the Hissar Mts, mainly on the eastern and southern slopes of the Varzob, Takob, Khondara, Maychura, Sorbo and Sarday-Myena river valleys. *Spiraea baldschuanica* is an endemic species of the western Pamir Alai Mts distributed in the south-western sections of Hissar range at an altitude of 1100–2300 m a.s.l. (Ovchinnikov 1975). The altitudinal distribution of the association is compliant with this amplitude. The samples were taken in the colline zone at the altitudes of 1000 to 1950 m a.s.l. (mean approx. 1500; Fig. 5, On-line Suppl.)

![Fig. 5. Species richness, plot diversity, cover values of herb layer, altitudinal distribution, cliff inclinations and pH of the researched communities: Spiraeetum baldschuanicae (Sb), Rhamnetum coriaceae (Rc), Pentaphylloidetum parvifoliae (Pp), Pentaphylloidetum dryadanoidis (Pd) and communities of Ephedra glauca (Ceg) and Rhamnus minuta (CRm). Whiskers present minimum and maximum observations within fences, block indicates first and third quartile, circles the minimum and maximum value. Outliers are shown as asterisks.](image-url)
Tab. 1). The association inhabits granite and granodiorite rocks (mean pH 6.6), heavily eroded and generally loose. Its plots were found mainly on western and southern expositions with inclinations of mean value approx. 75°. They are characterised by a moderate abundance of vegetation cover which corresponds to the amount of rain and soil deposit on rock ledges. The total cover of the herb layer generally was between 25 and 100% with a mean value of more than 50% (On-line Suppl. Tab. 1, Fig. 5). The phytocoenosis is characterised by a moderate number of species as copious vegetation is concerned, having in one relevé from 4 to 15 taxa (mean value approx. 8). Mosses contribute quite significantly to the association in comparison to other communities from the alliance. The most abundant were *Bryum caespiticium* and *Schistidium apocarpum*. Among the vascular plants the highest values of constancy and abundance were found in: *Carex koshevnikovii*, *Poa bulbosa*, *P. relaxa*, *Campanula incanescens* and *Bromus tectorum*.

2. Rhamnetum coriaceae ass. nova

Typus relevé: On-line Suppl. Tab. 1, rel. 19, holotypus hoc loco

Diagnostic species: *Rhamnus coriacea*

*Rhamnus coriacea* is an endemic species to Middle Asia, distributed in western Pamir Alai and western Tian-Shan. In Tajikistan it occurs mainly in the Zeravshan, Turkestan and southern part of Darvasian mountain ranges at the altitude of 1300–2600 m a.s.l. (Ovchinnikov 1981). During our research the association defined by *Rhamnus coriacea* was found in a few locations of the Iskander-Daria River Valley in the Zeravshan Mts. The phytocoenoses were found almost exclusively on limestone, rarely on dolomite shales (pH 7.4–8.0). The association prefers slope rocks with south-eastern sunny expositions and inclinations of 20°–70° with a mean of approx. 60°. The phytocoenosis develops on moderate elevations within the lower alpine belt. Mean elevation value for research plots was approximately 1750 m a.s.l. *Rhamnetum coriaceae* is an association with moderate plant cover value per plot. The observed variation of this feature was 27%–67% with a mean of 46% (Fig. 5, On-line Suppl. Tab. 1). The species number per plot reaches one of the highest values between the dwarf shrub communities. From 7 to 17 species were noted in a single relevé. On average 9 species were observed in a sample. Mosses were not observed on eroded slopes within the patches. The most abundant and constant vascular plant species within the phytocoenoses of *Rhamnetum coriaceae* are: *Stipa caucasica*, *Artemisia rutifolia*, *Centaurea squarrosa*, *Ephedra glauca* and *Silene brahuiica*.

3. Pentaphylloidetum parvifoliae ass. nova

Typus relevé: On-line Suppl. Tab. 1, rel. 40, holotypus hoc loco

Diagnostic species: *Pentaphylloides parvifolia*

*Pentaphylloides parvifolia* is a chasmophytic species with wide geographical range, known from Middle Asia, the Altai Mts, Siberia, Mongolia and Western China (Ovchinnikov 1975). In Tajikistan the species occurs along the main Zeravshan ridge at elevations of approximately 1600 to 3000 m a.s.l., reaching here the southern limits of its natural range. During the research, populations of *Pentaphylloides parvifolia* were observed in western and central sections of Zeravshan Range in Pastrud-Daria, Iskander-Daria, Veshan and Zeravshan river valleys. The phytocoenosis was found exclusively on limestone and marble rocks of solid structure with coarse crevices and ledges (pH 7.5–8.4). The phytocoenosis develops on relatively high elevations in the alpine zone with a cool microclimate. The observed altitudinal range of the community was between 1850 to 3000 m a.s.l. (mean approx. 2250 m). The association develops on sloping rock ledges and terraces with the inclination value ranging from 55° to 80° (mean approximately 60°, Fig. 5). *Pentaphylloidetum parvifoliae* was generally found on shady, northern and north-western slopes. The mean value of total herb cover was relatively high and exceeds 45%, ranging from 45 to 70% (Fig. 5). Mosses do not contribute to the association. Apart from the diagnostic species, the most abundant and constant species of vascular plants were: *Callipeltis cuscularis*, *Campanula incanescens*, *Veronica capillipes* and *V. rubrifolia*.

4. Community of Ephedra glauca

On-line Suppl. Tab. 1, relevés 44–47.

*Ephedra glauca* has the optimum of its occurrence in high, alpine elevations and in arid areas, e.g. in Zeravshan and Turkestan ranges. The collected sample contains a few relevés representing dwarf shrub vegetation with domination of *Ephedra glauca*. All of the relevés were taken in the central part of the Zeravshan Mts (1600–2200 m a.s.l.). Despite the fact that it seems to us that this species can not be used as diagnostic for any association, we decide to depict these plots and show them on the diagram. Further survey is needed to check whether it should be regarded only as diagnostic for the alliance or it can also serve as a species defining its own association with central position within the alliance.

Alliance: *Ephedrion regeliano-fedtschenkoi* ass. nova hoc loco

Holotypus: *Pentaphylloidetum dryadanthoidis* hoc loco

Diagnostic species: *Ephedra regeliana*, *E. fedtschenkoi*, *E. gerardiana*.

Distribution and ecology: The plots of the *Ephedrion regeliano-fedtschenkoi* were recorded almost exclusively in the highest elevations of eastern Pamir (in the eastern part of Tajikistan). Few samples representing the community with *Rhamnus minuta* were also recorded in the central part of the Darvaz Range. It is possible that the patches representing *Ephedrion regeliano-fedtschenkoi* occur also in arid plateau of eastern Pamir, in western Pamirian ranges (e.g. Vanch, Rushan and Shugnan Mts) as well as in more humid Darvazian Range. The plots were sampled at altitudes of 3150–4275 m a.s.l. The phytocoenoses of *Ephedron regeliano-fedtschenkoi* had low numbers of taxa per plot, approximately 8 on average (Fig. 5). Apart from the taxa diagnostic for the alliance, the group of species with highest abundance and frequency includes: *Pentaphylloides dryadanthoides*, *Artemisia rutifolia*, *Melissitus panmicrus*, *Poa relaxa*, *Poa bulbosa*, *Poa scelerata*, *Artemisia anemonoides* and *Roegneria cizmanica*. Defined by the distributional ranges of both *Ephedra* species, the alliance could be delimited to the Pamir, Tian-Shan, Karakorum and western Himalayan ranges. It includes plant communities adapted to the harshest conditions in the arid, nival zone of the central Asian mountains.
5. Pentaphylloidetum dryadanthoidis ass. nova

Typus relevé: Tab. 1, rel. 1, holotypus hoc loco

Diagnostic species: *Pentaphylloides dryadanthoides*

*Pentaphylloides dryadanthoides* distribution is confined to the highest elevations in the Pamirian plateau and in the surrounding mountains, in Tajikistan and western China (Ovchinnikov 1975). The species was found in several sites in central part of eastern Pamir, in Murgab and Alichur river valleys, in Muzkol and Psharskyi ranges. The phytosociological research confirmed that the species builds its own association developing on relatively firm and solid limestone rocks (pH 7.6–8.8). The association prefers elevations in high alpine and nival zones (Fig. 5), within the altitudinal range between 3800 and 4275 m a.s.l. (mean approximately 4000 m). The phytocoenosis develops on rocks with small or medium-sized crevices, on sloping walls, rock faces or on rock tops. The noted inclination values varied significantly between 50° and 65° (Fig. 5). *Pentaphylloides dryadanthoides* prefers generally south-eastern, fully insolated expositions (Fig. 6). In the sample plots, between 6 and 11 taxa were noted (mean approx. 8), so as majority of the ru-

picolous vegetation, the association should be classified as moderately rich in species. As well as by scarcity of species, the association is characterized by the moderate value of total cover of vascular plants in the plots. It could reach up to 70% with the mean value of approximately 45 % (Fig. 5). No moss species were found within the recorded patches. The group of species with the highest constancy includes: *Artemisia rutifolia*, *Ephedra fedtschenkoi*, *Melissitus pammicrus*, *Onosma dichroantha*, *Paraquilegia anemonoides* and *Roegneria czimganica*.

6. Community of *Rhamnus minuta*

Tab. 1, relevés 10–11.

*Rhamnus minuta* is a rare species in Tajikistan with its range restricted to a few mountain ranges in the Eastern Tajikistanian and Pamirian geobotanical regions. The species is known also from Kashgaria in western China. Habitat preferences of *Rhamnus minuta*, especially its altitudinal amplitude and bedrock type suggest that the community should be included in *Ephedron regeliano-fedtschenkoi*. This was clearly confirmed by the results of the numerical ordination (Fig. 4). Plots of the community were found on
few limestone outcrops near the Khaburabot Pass at the altitude of approximately 3150 m a.s.l. They develop on solid limestone rocks with western expositions and moderate inclinations (ca. 65°). Within the recorded vegetation plots a considerable contribution of rock swards taxa were noted, among others Pseudosedum fedtschenkoanum and Rosularia lutea. Unfortunately, the survey in other regions of the Rhamnus minuta range did not confirm its presence nowadays. So, at this stage of the research we have decided to present the phytocoenosis as a community.

Synopsis of syntaxa

Based on this study, we propose the following classification of vegetation of dwarf shrubs on rock walls in the Pamir Alai Mts in Tajikistan:

Class: Artemisio santolinifolii-Berberidetea sibiricae Ermakov et al. 2006

Order: Hyperico scabri-Lactucetalia orientalis nom. prov. (for explanation see Discussion)

Alliance: Ephedro glaucae-Spiraeion baldschuaniaca
A. Nowak, S. Nowak, M. Nobis et A. Nobis all. nova
1. Spiracium baldschuaniaca A. Nowak, S. Nowak, M. Nobis et A. Nobis ass. nova
2. Rhamnetetum coriaceae A. Nowak, S. Nowak, M. Nobis et A. Nobis ass. nova
3. Pentaphylloidetum parvifoliae A. Nowak, S. Nowak, M. Nobis et A. Nobis ass. nova
4. Community of Ephedra glauca

Order: Ephedretalia gerardiana nom. prov. (for explanation see Discussion)

Alliance: Ephedro regeliano-fedtschenkoi A. Nowak, S. Nowak, M. Nobis et A. Nobis all. nova
5. Pentaphylloidetum dryadanthoidis A. Nowak, S. Nowak, M. Nobis et A. Nobis ass. nova
6. Community of Rhamnus minuta

Discussion

Position of the described association in relation to other types of rupicolous vegetation in Tajikistan and Central Asia

Comparing the microhabitat and climatic conditions of Pamir Alai (Middle Asia) to other areas in Eurasia, the most similar must occur in Central Asia. In particular, the eastern Pamir plateau, Turkestan, Zeravshan and the Peter I range seem to be closely related in terms of precipitation, average temperatures and continentality. Only the southern slopes of the Hissar range are remarkably more humid, amounts of precipitation and its distribution throughout a year being Mediterranean rather than continental. Although some authors stressed that the Tajikistan is influenced by a Mediterranean-type bioclimate, it is rather an oro-Mediterranean subtype overlain by extreme and harsh alpine conditions (Rivas-Martínez et al. 2011). Of course there are considerable differences in diurnal temperature oscillations if we compare the valley bottoms and alpine or nival elevations.

That is why in our opinion, the climatic conditions of the research area could be compared with the Central Asiatic. Another important issue when analyzing the classification of the studied vegetation is the environmental characteristic of the plots inhabited by dwarf-shrub vegetation. The researched phytocoenoses occupy the transitional habitats between typical Asplenietea trichomanis rock faces with crevices and fissures and scree habitats with mobile gravel deposits. This type of microhabitat could be defined as considerably eroded rocks or relatively well stabilized scree. A reflection of this can be seen in the species composition of plant communities with many plants typical for scree vegetation and many coming over from neighboring typical rock habitats. A thorough analysis of the floristic structure of plant communities convinced us to include the rupicolous dwarf shrub vegetation of Pamir Alai into Artemisio santolinifolii-Berberidetea sibiricae. This class was proposed for the taluses and scree of the Western Sayan Mts and the Alai range (Ermakov et al. 2006). As in Central Asia, in Tajikistan too many typical scree species contribute to the researched plots: Callipeltis cuccullaris, Stipa cascasca, Silene bahuica, Clypeola jonthlaspi, Veronica rubrifolia, Galium spurium, Aulacocpermum roseum and others. Also the shrubbery physiognomy, lack of moss layer, very scarce soil content on the sites and the gentle inclination of slopes are fairly similar to those in Alai and Sayan ranges. However, because of the transitional character and the vicinity of rock walls, typical Asplenietea species also contribute to the plant communities. Plots representing Ephedro glaucae-Spiraeion baldschuaniaca are characterized by a considerable share of diagnostic species of the Campanuletalia incanescensis, mainly Campanula incanescens, Poa relaxa and Carex koshevnikovii.

Despite the habitat and structural similarities, there are some important differences in species composition of the researched vegetation if compared to phytocoenoses from southern Siberia. Only a few species were found in common with one that had a considerable abundance and frequency – Artemisia rutifolia. That is why we propose to include the plant communities of dwarf shrubs in Pamir Alai Mts into a new order within the Artemisio santolinifolii-Berberidetea sibiricae. Provisionally we suggest Hyperico scabri-Lactucetalia orientalis with Hypericum scabrum, Lactuca (Scariola) orientalis, Callipeltis cuccullaris as diagnostic taxa. All of them are distributed in Middle Asia, northern Pakistan, northern Afghanistan, Iran and some parts of Near East. As we know from our preliminary studies in Tajikistan, this type of vegetation occurs in semi-arid mountainous areas in colline and alpine belts in western sections of the Pamir Alai ranges. The considerable share of petrophytic species of Iruno-Turanian distributional type is typical for this kind of vegetation (Nowak et al. 2014c). Despite some similarities in species composition (i.e. the presence of Asperula alibiflora and Poa relaxa), the physiognomy as well as habitat requirements of the communities from the Ephedro glaucae-Spiraeion baldschuaniaca are clearly different from those of the associations from the Caricion koshevnikovii and Asperulo-Poion relaxae alliances. The phytocoenoses of Ephedro glaucae-Spiraeion baldschuan-
The Pamir Alai rupeicolous vegetation is highly diverse in terms of endemism, habitat preferences and physiognomy of phytocoenoses. To date, more than 30 plant associations have been defined (Nobis et al. 2013, Nowak et al. 2014a, 2014b, 2014c). This is due to extreme diversity of ecological niches caused by differences in altitudinal amplitude, bedrock type, exposition, inclination, crevice type, amount of soil and water supply within the biotope. The species also respond to geographical barriers responsible for increasing endemism rate and separateness of the floristic structure. It is commonly known from other mountainous areas that highly elevated mountain ridges fasten the speciation and make the rupeicolous flora distinct (Favarger 1972, Médaïl and Verlaque 1997). The DCA based on floristic composition of sampled plots revealed some considerable differences within the dwarf shrub vegetation in the Pamir Alai Mts (Fig. 4). The main discrimination factor seems to be longitudinal gradient which is related to altitude, precipitation and temperature. In eastern Pamir, the climatic conditions are harsh (arid and cold), so the distinctiveness of the flora is clearly marked in comparison to other regions of Middle Asia. This holds true also in the group of unique species which are almost all confined to those geobotanical subregions (Nowak et al. 2011). These climatic conditions are responsible for the considerable difference between the plots from the western Pamir Alai Mts and the eastern ranges, although the range of Peter I and central and northern sections of the Darvaz Mts could be regarded somehow as transitional area (Fig. 3). The species composition is significantly different in samples from those two areas, with Allium tianschanicum, Asperula strizhoviae, Pentaphyllloides dryadanthoides, Ephedra feldschbenkoi, Melissitus pamicuris, Oxytropis chilophylla, Potentilla malacotricha, Rhamnus minuta, Roegneria cizmganaica, Stipa glareosa and Youngia diversifolia occurring exclusively in eastern part of the surveyed area. The evident difference between Spiraeaum baldshuanae and Rhamnetum coriacea could be explained by the bedrock type. Spiraea baldshuanae prefers acidophilous rocks while Rhamnus occurs only on limestones (Tab. 2).

The plots sampled in shrubby vegetation in Tajikistan clearly differ from the corresponding rock vegetation communities known from distant ranges in southern Europe or southern Asia (Dimopoulou et al. 1997, Hein et al. 1998, Parolly 1998, Ermlaeva 2007). Only shrubby Ephedretum gerardianaem described from Nepal can be compared with...
communities recorded in eastern Pamir (Kojima 1990). However, apart from a few widely distributed taxa like *Convolvulus arvensis*, *Chenopodium botrys* or *Ch. ficifolium*, in the patches of these communities almost no species from our study area were noted. This separateness might be attributed again to the unique habitat conditions in rupicolous environments and the related floristic uniqueness. In result the plant communities are also distinct and the beta diversity of mountainous areas increases (Valachović et al. 1997, Deil et al. 2008, Deil 2014). The newly described plant associations are largely defined by species restricted to very narrow ranges (e.g. *Spiraea baldshuanica* known only from W Tajikistan, *Anaphallis darvazica* distributed in the southern part of the country, *Atraphaxis seravshania* known exclusively from Zeravshan Mts, *Dionysia involucrata* occurring in western section of Hissar range or *Onosma atrocyanea* scattered only in western Pamir Alai). This type of stenochory of phytotypic plant species and communities is also observed in many other mountainous areas, especially in those with Mediterranean-type climates, such as the Bokkoya Mts in Northern Morocco (Deil 1994, Deil and Hammoumi 1997), in Gibraltar (Galán de Mera et al. 2000), in Crete and mainland Greece (Dimopoulos et al. 1997), in Bulgaria (Mucina et al. 1990), in the Caucasus and the mountains of Central Asia (Agakhanjanz and Breekle 2002, Ermolaeva 2007), in the Taurus Mts in Turkey (Hein et al. 1998, Parolly 1998) or in Galicia in Spain (Ortiz and Rodríguez-Oubiña 1993).

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