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Phytosociological survey of juniper wood vegetation in Tajikistan (Middle Asia)

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Abstract

The paper presents the first syntaxonomic classification for juniper wood communities in Tajikistan with some remarks on their environmental gradients. A total of 119 relevés were sampled between 2015 and 2021 using the seven-degree Braun-Blanquet cover-abundance scale. They were classified by a modified TWINSPAN method. Diagnostic species were identified using *phi* coefficient as a fidelity measure. Detrended Correspondence Analysis (DCA) was used to determine relationships between samples, vegetation units and major gradients in species composition. Plant communities have been divided into two main groups. The first one is a west Irano-Turanian wood of *Juniperus polycarpos* var. *seravschanica* of the Pamir-Alai mountane belt. It occurs in two variants depending mainly on the aspect and precipitation. The second juniper wood type in Tajikistan is a stand of *Juniperus pseudosabina*. It prefers the northern slopes and north-eastern ranges of the Pamir-Alai and slightly lower elevations. Both juniper wood types are highly distinct in terms of species composition, especially in the moss layer, and have therefore been assigned to different classes: *Pino-Juniperetea* (*Juniperetum seravschanicae*) and *Juniperetea pseudosabinae* (*Carici turkestanicae-Juniperetum pseudosabinae*). The main factors determining the species composition of the studied associations are latitude, growing season precipitation, annual range of air temperature and precipitation of coldest quarter. Our study has shown that there are two very distinct vegetation types of the juniper wood groves in Tajikistan, which reflect the main phytogeographical division between the provinces of Turkestan and Central Asia.

Keywords: *Juniperetalia seravschanicae*, Pamir-Alai Mts., *Pino-Juniperetea*, syntaxonomy, vegetation classification

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Introduction

Tajikistan is a mountainous country with an extremely diverse landscape, climate and habitat conditions. It is located in the central part of the Middle Asia on the borderland of large phytogeographical units (Central Asian, Turkestanian and Western Himalayan). In its western part, the vegetation is controlled by the subhumid Irano-Turanian or humid alpine climate and consists of typical Irano-Turanian species. The montane belt of these ranges offer suitable conditions for juniper wood vegetation, which tolerates summer droughts and high climate continentality (Nowak et al., 2020a).

The juniper woods are one of the most important and widespread type of forest in Tajikistan, being apparently distinct from mesophilous broad-leaved forests (chernolese), river carrs (belolese), termophilous open woods and scrubs (šhiblyak and pistachio groves) and subtropical tugai gallery forests (Nowak & Nobis, 2013; Nowak et al., 2015, 2022; Nowak et al., 2017a; Świerszcz et al., 2022). According to Zapryagaeva (1976), the dendroflora of Tajikistan counts 268 species. Our analyses show that the native dendroflora of Tajikistan counts 102 tree species and 211 shrub species. Our analyses show that the forest habitats of Tajikistan are inhabited by ca. 800 native plant species and its dendroflora counts 102 tree and 211 shrub species. Juniper forests harbour 382 species, including 281 endemic and 171 subendemic taxa (Nowak et al., 2020b).

The natural lower treeline, which is visible in the south-western Pamir-Alai, is about 500-700 m and is marked by a line of open pistachio woods. However, due to centuries of pastoralism and deforestation caused by mismanagement of timber resources, it is now at an altitude of 1,200–1,500 m a.s.l. in most of the western Tajikistan (Zapryagaeva, 1976). The upper forest limit is at an altitude of about 3,200–3,400 m a.s.l. (rarely 3,700 m a.s.l.) and is bounded by a line of open juniper woods and azonal forests composed of various birch species. Further east, in southeastern Tibet, it is elevated much higher, to about 4,900 m a.s.l., and marked by juniper stands (Miehe et al., 2007).

One of the most important synthetic studies on the forests of Tajikistan is the work of Zapryagaeva (1976). The author divides juniper woods into two main types that are controlled by climate, i.e. thermophilous (with *J. polycarpos* var. *seravschanica* [= *J. seravschanica*]) and cryophilous (with *J. pseudosabina* [=*J. turkestanica*] and *J. semiglobosa*). Thermophilous juniper woods were reported from altitude of (1,300)1,700–2,200(2,700) m a.s.l. in Pamir-Alai with an average precipitation of 600 mm/year and average annual temperature of 14 °C. This type of juniper stand occurs on chestnut-brown soils in areas with a typically continental climate, where during the vegetation season the daily amplitude can reach more than 40 °C and at higher altitudes frost occur even in mid-summer. In winter, the temperature often drops to −25 °C. Zapryagaeva ambiguously describes the dynamic relationship of thermophilus juniper woods with other vegetation, suggesting a close relationship with mesophilous broad-leaved forests or thermophilous woodlands with *Pistacia vera* or *Crataegus* spp. and *Prunus* spp. This type of thermophilous juniper groves is known to have a wide range reaching the Atlas Mountains in North Africa, the entire Mediterrenian region and the Zagros, Alborz, Kopet-dagh, Kugitang and Hindukush Mountains in the east (e.g. Zohary, 1973; Kamelin, 1979; Fet, 1994; Popov, 1994; Tsiourlis et al., 2007; Douaihy et al., 2013; Memariani et al., 2016b; Mucina et al., 2016). However, it is worth noting that Middle Asian thermophilous juniper stands are distinguished by the absence of *Quercus* and *Arbutus* species.

Following Zapryagaeva (1976), the second type of juniper stands in Tajikistan occupies wetter and colder habitats in the upper montane belt at 2,200–3,400 m a.s.l., and consists mainly of *Juniperus pseudosabina* and *J. semiglobosa*. It is called "microtherm" – cryophilous juniper forest. This zone is characterized by a high degree of continentalism and temperature differences between winter and summer reaching up to 65 °C, long-lasting snow cover (up to 8 months) and deep freezing of the soil profile (up to 130 cm). They occur in a mosaic of cryophilous steppes, alpine tall-forbs and grassland. Significant species co-occurring in these woods are *Sorbus tianschanica*, *Betula tianshanica*, *Berberis integerrima*, *Lonicera simulatrix* and *Astragalus tibetanus*. These woods reaching the upper subalpine belt in Middle Asia, are undoubtedly similar to the juniper forests of Tibet and the Himalayas in terms of climatic conditions, mainly built by *J. convallium* (=*J. mekongensis*), *J. indica*, *J. przewalskii*, *J. recurva* and *J. tibetica* (e.g. Ghimire et al., 2008; Miehe et al., 2008; Tambe & Rawat, 2010).

Unlike Zapryagaeva (1976), Safarov (2018) and Zakirov (1984) distinguished many more juniper forest types depending on the proportion of plant species recruited from neighbouring vegetation types. These divisions follow the work of Kamelin (1979) and Ovchinnikov (1957), who classified juniper woods into three main types depending on the humidity of the climate and the phytogeographical origin of the main floristic components of the communities (Middle Asian, ancient Mediterranean and Eastern Mediterranean). Safarov (2018) points out that juniper forests in Tajikistan cover approx. 50% of the total forested area and occur mainly in the mountains of Zeravshan, Turkestan, Alaian, Darvazian, Hissar, Peter the First, Sarsarak, Vakhsh and Hazratishoh. He includes in the group of cryophilous juniper forests

two main types within *Peucedrymion holarcticum* – a taiga-like group of sparse coniferous forests built by species such as *Larix* spp., *Pinus* spp., *Picea* spp. This group also includes forests of *Picea schrenkiana* and *Abies semenovii*, found just north of the Pamir-Alai, in Kyrgyzstan. The cryophilous juniper stands are presented in contrast to birch and poplar forests, which are also found in the taiga zone, and in Middle Asia most often form azonal riparian forests along mountain streams, reaching up to 3,800 m above sea level. (Nowak et al., 2017a). The main formation is a stand of *Juniperus pseudosabina* growing between 2,900 and 3,500 m a.s.l. Despite the main diagnostic tree, the most frequent contributors are *Thalictrum minus*, *Phleum phleoides*, *Asyneuma argutum*, *Ephedra equisetina*, *Delphinium oreophillum*, *Dracocephalum bipinnatum*, *Roegneria ugamica*, *Oxytropis lehmanni*, *Geranium regelii*. In the upper limit of this vegetation, *Juniperus sibirica* (=*J. communis* var. *saxatilis* Pall.) also plays an important role, especially in central Tajikistan (Obighingou valley, Rasht and Tavildara districts). The main subgroups were distinguished according to the proportion of tall-forb (*Ligularia alpigena* and *Codonopsis clematidifolia*) and grassland species share (*Festuca sulcata, F. valesiaca*. *Elymus alaicus*).

In the second group, which is called *Arceuthodrymion mediterraneum*, Safarov (2018) lists a number of thermophilous juniper wood types that occupy the montane belt from 600–800 to 3,000 m a.s.l. Typical components of these communities are *Artemisia baldshuanica*, *Rosa kokanica*, *R. maracandica*, *Lonicera nummulariifolia*, *Crataegus pontica*, *Pyrus korshinskyi*, *Agropyrum trichophorum*, *Poa bulbosa*, *Carex pachystylis*, *Artemisia tenuisecta*, *Acer turkestanicum*, *A. regelii*, *Cotoneaster hissaricus*. This species composition indicates a close relationship of thermophilous juniper forests with mesophilous scrub (šhiblyak) and open pistachio woods (Nowak et al., 2022; Świerszcz et al., 2022).

Recent research on juniper woods of Tajikistan was conducted by Konnov (1973). He shares the position of earlier researchers on the division of juniper forests. As the northernmost refuge of *J. seravschanica* woods, he indicates the Sary-Chelek region in the Khatkal range in Kyrgyzstan. He points out that *J. semiglobosa* is more common in the thermophilous type of juniper woods and forms its own stands in Central Tian Shan, Kyrgyzstan. In contrast, he distinguished stands of *J. schugnanica* in the Western Pamirs, which is now synonymised with *J. semiglobosa*. These stands in the subalpine belt (up to 3,700 m) in the Shugnan, Ishkashim and Shahdarian mountains are dwarf shrubby vegetation with a *J. semiglobosa* cover of about 20–30%.

In the western part of Middle Asia, in the Kopet-dagh Mts., open woodland of *Juniperus turcomanica* (=*Juniperus polycarpos* var. *turcomanica*) have been recorded at 800–2,400 m altitude. This vegetation at the upper limit is accompanied by scrubs of *Juniperus communis* and *J. sabina*, which form carpet-like formations on exposed rocks in subalpine areas, especially on the northern slopes of Aladagh and Ghorkhod Mts. at altitudes of 1,600–2,600 m a.s.l. (Memariani et al., 2016a). These woods have 30–40% cover in the tree layer and extend mainly in territories of southwestern Kopet-dagh, the watershed plateaus between the Sumbar and Arvaz rivers, the Kurydere and Kalymkhoz valleys and within the Syunt Khasardagh reserve. They occupy well-humidified northern slopes at an altitude of about 1,300 to 1,600 m a.s.l. (Fet, 1994). This endemic to Turkmenistan juniper wood type has also been observed at an altitude of 400 m a.s.l., where annual precipitation is about 200 mm and the temperature rises to 48 °C in summer (Popov, 1994). This is very close to the drought line in *Juniperus* forests in southern Tibet, where relict forests of *J. convallium* and *J. tibetica* were formerly common up to 4,800 m a.s.l. (Miehe et al., 2008).

Unfortunately, the area of these forests has been steadily declining and has decreased by 50% between 1930 and 1960 alone. The same applies to forests with *J. seravschanica*, in the Kugitang Mts. on the border with Uzbekistan and Afghanistan. Due to human impact, the lower limit of this juniper stand has shifted from approx. 800 to as high as 1,300 to 1,700 m a.s.l. (Popov, 1994).

Along the southern edge of Middle Asia, two types of juniper vegetation occur in the Afghan Hindukush. The northern with *J. excelsa, J. semiglobosa, J. seravschanica* and the eastern with *J. semiglobosa* and *J. seravschanica* (Freitag, 1971). Additionally, the high-altitude subalpine scrub built by *J. squamata* accompanied by *J. nana, Ribes alpestre* and *R. villosum* is mentioned (Freitag, 1971). Additionally, one of the largest surviving refugium of *J. excelsa* forests has been reported in the Balochistan province of Pakistan. It covers an area of approx. 141,000 hectares between altitudes of 2000–3350 m a.s.l. (Sarangzai et al., 2012).

The aim of this study is to answer the following questions: (i) which juniper wood communities can be distinguished in Tajikistan and how should they be arranged in the syntaxonomic system of Eurasia? (ii) what are the compositional, ecological and chorological characteristics of the distinguished juniper woods? (iii) how the distinguished syntaxa are related to others known from adjacent areas of Asia and Europe?

Material and methods

Study area

The study area covered the northwestern phytogeographic regions of Tajikistan (Fig. 1): Zeravshanian

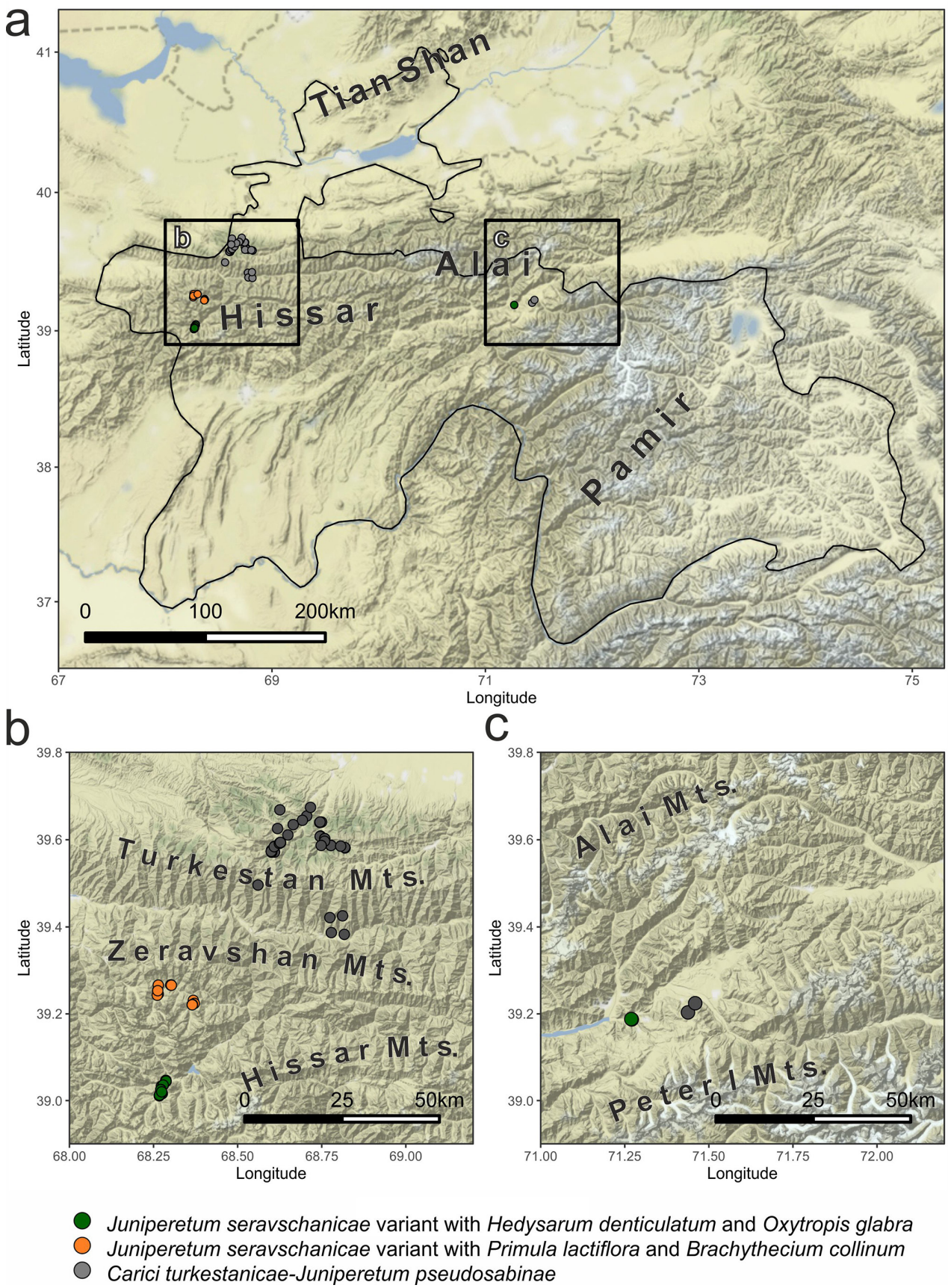

Fig. 1. Map showing study area and distribution of the relevés (a) assigned the particular vegetation associations (n = 110), and more detailed maps of relevés distribution in the Zeravshan and Turkestan Mts. (b), and Peter the First Mts. (c). Note that due to the scale, some points may overlap. The exact locations of the relevés can be found in Table S1

B, Zeravshanian C, Turkestanian A and East Tajikistanian A. The plots in Zeravshanian regions were located along the river valleys of Chapdara, Iskanderkul (west of Lake Iskanderkul), Mura and Nofin (east of Lake Nofin). In the Turkestanian region, research was conducted in the Archazor forest along the Aktengi river valley and the Byurogan river valley, and then further south along the Altykul and the Zaravshan river valley with its two tributaries – Pakhurd and Rarz. In the eastern part of Tajikistan, the relevés were located along the Surkhob river valley. The studied sites were located on hillsides with different aspects, slopes and altitude, and only ranker soil was a stable factor. The vegetation plots were located between 1,803 and 3,100 m a.s.l. The annual precipitacion in studied area varies from 405 to 1,246 mm, and mean annual temperature varies from -1.05 to 6.75 °C.

The Zeravshan region is a typical mountainous area, located between 850 (Zeravshan river valley on the border with Uzbekistan) and 5,489 m a.s.l. (Chimtarga peak). The main mountain subranges within the Zeravshan Mountains are Dukdon, Fann, Zinach, Kugibodrawak and Ljangar. Due to its relief and altitude, the alpine character of the climate strongly influences the area. Along the Zeravshanian and Turkestanian ranges, in the outer Pamir, Cambrian and Silurian sediments dominate. The rocks are generally limestone, dolomite, marble, clay shale, phyllitic shale, dolomite and argillaceous shale. In general, Tajikistan experiences high insolation, as well as low cloud cover, high annual temperature amplitudes, low humidity and precipitation. The most extensive and dense stands of seravshan juniper are found in the Zeravshan, Turkestan, Hissar and Darvaz ranges in the western Pamir-Alai at an altitude of about 1,000–2,500 m a.s.l.

Taxonomic treatment

The taxonomy of the genus *Juniperus* is very complex and, despite decades of research, still vague. For example, *J. seravschanica* as well as *J. turcomanica* are merged with *J. excelsa* subsp. *polycarpos* (Farjon, 1992). Adams (2016), after analysis of nrDNA and cpDNA (petN-psbM, trnS-trnG, trnD-trnT, trnL-trnF), includes *J. seravschanica* in *J. excelsa* var. *seravschanica*. However, the same author previously includes *J. seravschanica* in *J. polycarpos* var. *seravschanica* (Adams, 2001, 2004) and this approach is adopted in the Plant List (The Plant List, 2020). Some authors have synonymised *J. seravschanica* with *J. excelsa* (e.g. Mazur et al., 2004). *Juniperus turkestanica*, after examining its relationship to *J. centrasiatica*, *J. pseudosabina* and *J. indica* was synonymised with *J. pseudosabina* (Adams & Turuspekov, 1998). Due to all these inconsistencies, we decided to follow the Plant List (2020) as the basic source for taxonomic resolution in this study. Therefore, we treat *J. seravschanica* as a variety of *J. polycarpos* whereas *J. turkestanica* as conspecific with *J. pseudosabina*. In this approach, data on *Juniperus seravschanica* Kom., *Juniperus excelsa* subsp. *seravschanica* (Kom.) R. Kam. ex Imch., *Juniperus kulsaica* V.D. Dmitriev, *Juniperus polysperma* V.D. Dmitriev, *Juniperus zaaminica* V.D. Dmitriev and *Sabina seravschanica* (Kom.) Nevski are treated as *Juniperus polycarpos* var. *seravschanica* (Kom.) Kitam. Data on *Sabina pseudosabina* var. *turkestanica* (Kom.) C.Y. Yang and *Juniperus turkestanica* Kom. are treated as synonyms of *J. pseudosabina*.

Data sampling and data analyses

The phytosociological survey was conducted from 2015 to 2021. In total, 119 relevés were collected in all types of naturally occurring juniper forest phytocoenoses growing in the country. Plant material collected during the field studies is preserved at OPUN (Opole University, Poland) and KRA (Jagiellonian University, Poland). The vegetation plot size was delimited to 100 m² in such way to enable providing homogeneity in terms of structure, species composition and habitat conditions of the phytocoenosis following the Braun-Blanquet approach (Dengler et al., 2008), globally used geobotanical method (Nowak & Nowak, 2022). For each vegetation plot all species of vascular plants and tericolous bryophytes were recorded with the use of 7-degree cover-abundance scale (r, +, 1, 2, 3, 4, 5; Braun-Blanquet, 1964). Species were recorded in four layers of the wood or scrub stands: a_2 – lower tree layer, b – shrubs, c – herbs, d – bryophytes. Geographical coordinates, elevation, aspect and slope inclination were recorded for each relevé. Geographical coordinates of plots were obtained using a GPS device with an accuracy of ± 10 m and the WGS-84 grid reference system.

The relevés were stored in TURBOVEG format (Hennekens & Schaminée, 2001) in the Vegetation of Middle Asia Database (GIVD ID AS-00-003; Nowak et al., 2017b). They were analysed in the JUICE software (Tichý, 2002). The Braun-Blanquet scale was transformed by JUICE to percentage values as follows: + = 2%, 1 = 3%, 2 = 13%, 3 = 38%, 4 = 68% and 5 = 88%. A modified TWINSPAN analysis (Roleček et al., 2009) was performed in order to classify the relevés by using cutoff levels of 0%, 2%, 5% and 25%. Total inertia was used as a measure of cluster heterogeneity (Roleček et al., 2009). Plant species determined only to the genus level were omitted before the analysis. Diagnostic species were identified using the *phi* coefficient (Chytrý et al., 2002) and cover ratio (Willner, 2006) as a fidelity measure. The size of all groups was standardised to equal size, and the Fisher's exact test ($p < 0.05$) was applied in

Table 1. Synoptic table of juniper wood vegetation in Tajikistan. The *phi* coefficient values (in superscript) in the table are multiplied by 100. All diagnostic species and other plants of frequency ≥ 20% are shown. Main values are species frequencies (in percentages). Abbreviations in layer column: a2 – lower tree layer, b – shrub layer, c – herb layer. Group No.: 1 – Ass. *Juniperetum seravschanicae* variant with *Hedysarum denticulatum* and *Oxytropis glabra*, 2 – Ass. *Juniperetum seravschanicae* variant with *Primula lactiflora* and *Brachythecium collinum*, 3 – Ass. *Carici turkestanicae-Juniperetum pseudosabinae*

Cluster No.	Layer	3		4		5	
No. of relevés		30		23		57	
Ass. *Juniperetum seravschanicae* and All. *Juniperion seravschanicae*							
Juniperus polycarpos var. *seravschanica*	a2	100	31	100	31	.	–
Juniperus polycarpos var. *seravschanica*	b	100	32	100	32	.	–
Oxytropis glabra	c	50	67	.	–	.	–
Berberis integerrima	b	57	44	26	–	21	–
Pedicularis dolichorrhiza	c	47	44	26	–	4	–
Hedysarum denticulatum	c	17	37	.	–	.	–
Seseli schrenkianum	c	50	32	65	50	.	–
Silene tachtensis	c	40	29	43	34	5	–
Brachythecium collinum	d	.	–	74	83	.	–
Eremogone griffithii	c	30	–	87	73	5	–
Primula lactiflora	c	.	–	57	71	.	–
Poa nemoraliformis	c	50	–	91	60	30	–
Ass. *Carici turkestanicae-Juniperetum pseudosabinae* and All. *Juniperion pseudosabinae*							
Juniperus pseudosabina	a2	.	–	.	–	100	100
Juniperus pseudosabina	b	.	–	.	–	88	92
Juniperus pseudosabina	c	.	–	.	–	100	100
Oxytropis ovczinnikovii	c	.	–	.	–	63	76
Gentianella turkestanorum	c	3	–	9	–	72	74
Cerastium dichotomum subsp. *inflatum*	c	.	–	.	–	49	66
Codonopsis clematidea	c	.	–	.	–	39	58
Erigeron seravschanicus	c	.	–	.	–	39	58
Phleum phleoides	c	.	–	22	–	49	50
Carex turkestanica	c	63	–	9	–	82	49
Helictotrichon hookeri	c	.	–	13	–	39	46
Sanionia uncinata	d	.	–	61	–	96	44
Thalictrum kuhistanicum	c	7	–	.	–	30	43
Hypnum cupressiforme	d	83	–	61	–	96	41
Others							
Allium weschniakowii	c	27	48	.	–	.	–
Artemisia dracunculus	c	10	–	48	23	.	–
Artemisia santolinifolia	c	3	–	30	44	4	–
Astragalus aksuensis	c	.	–	30	51	.	–
Astragalus tibetanus	c	43	–	30	–	54	27
Asyneuma argutum subsp. *argutum*	c	37	–	39	–	47	–
Aulacospermum roseum	c	7	–	30	–	33	28
Berberis integerrima	c	30	–	57	25	39	–
Bryum caespiticium	d	23	17	13	–	.	–
Campanula glomerata	c	23	–	30	–	84	63
Carduus nutans	c	33	49	4	–	.	–
Cicerbita zeravschanica	c	.	–	22	38	4	–
Cotoneaster zeravschanicus	b	37	42	17	–	.	–
Crepis pulchra	c	37	–	35	–	58	29
Cystopteris fragilis	c	.	–	4	–	40	38
Draba nemorosa	c	30	–	74	52	33	–
Draba yunussovii	c	3	–	30	47	.	–
Ephedra intermedia	c	10	–	26	35	2	–
Erigeron petroiketes	c	.	–	.	–	21	42
Erigeron pseudoseravschanicus	c	20	41	.	–	.	–
Euphrasia pectinata	c	20	–	4	–	37	38
Festuca rupicola	b	60	–	30	–	81	44

Cluster No.	Layer	3		4		5	
No. of relevés		30		23		57	
Galium pamiroalaicum	c	27	–	43	–	37	–
Galium spurium	c	30	30	.	–	.	–
Gentiana olivieri	c	23	4	.	–	4	–
Geranium regelii	c	77	–	87	–	93	31
Hedysarum flavescens	c	30	47	.	–	4	–
Hieracium robustum	c	17	–	52	54	4	–
Juniperus polycarpos var. *seravschanica*	c	20	–	35	26	.	–
Juniperus semiglobosa	b	.	–	26	24	9	–
Koeleria pyramidata	c	33	–	43	–	35	–
Lactuca soongorica	c	10	–	26	37	.	–
Ligularia thomsonii	c	97	–	96	–	95	–
Lonicera nummulariifolia	b	87	8	70	–	65	–
Lonicera stenantha	b	17	–	22	–	7	–
Myosotis refracta	c	27	38	9	–	.	–
Myosotis laxa subsp. *caespitosa*	c	3	–	17	–	37	40
Nepeta podostachys	c	33	–	52	25	.	–
Oxytropis capusii	c	13	–	22	29	.	–
Oxytropis lehmanni	c	.	–	22	–	21	22
Pedicularis krylowii	c	27	–	17	–	18	–
Petrorhagia alpina	c	10	–	43	31	23	–
Poa bulbosa	c	40	13	13	–	11	–
Poa fragilis	c	23	–	17	–	74	41
Poa pratensis	c	43	–	30	–	44	–
Poa trivialis	c	33	11	30	–	5	–
Polygonum coriarium	c	37	–	70	32	2	–
Potentilla mollissima	c	23	44	.	–	.	–
Psychrogeton pseuderigeron	c	.	–	43	51	12	–
Ribes meyeri	b	3	–	22	38	.	–
Rosa kokanica	b	50	23	26	–	5	–
Rosa kokanica	c	7	–	13	–	25	28
Rosa webbiana	b	60	43	35	–	23	–
Syntrichia ruraliformis	d	20	41	.	–	.	–
Syntrichia ruralis	d	57	–	83	16	40	–
Taraxacum agg.	c	43	–	22	–	56	24
Thalictrum minus subsp. *maxwellii*	c	30	30	9	–	18	–
Thalictrum sultanabadense	c	3	–	52	34	2	–
Thymus seravschanicus	c	10	–	52	–	68	36
Veronica rubrifolia	c	27	–	26	–	4	–

order to exclude species with non-significant occurrence optimum in a particular cluster. Species with a *phi* coefficient higher than 0.30 and cover ratio higher than 2 were considered diagnostic for a specific cluster, except taxa considered diagnostic for various and different vegetation types in Middle Asia on the basis of our expert knowledge. We define alliances by those species that have a *phi* coefficient ≥ 0.30 in at least two clusters within the alliance. Species with frequency higher than 30% in a particular cluster were defined as constant species. To show compositional differences between distinguished thermophilous open woodlands and scrub units, Detrended Correspondence Analyses (DCA) was computed using the 'vegan' package version 2.5.4 (Oksanen et al., 2019) in R version 4.0.5 (R Core Team, 2020). Species cover data were log-transformed (log(x+1)) with down-weighting of rare taxa. For ecological interpretation of the ordination axes, environmental parameters were plotted onto a DCA ordination diagram as supplementary variables using the *envfit* function of the 'vegan' package. Environmental parameters include altitude, inclination, latitude, longitude, and bioclimatic variables (bio1 – mean annual air temperature, bio7 – annual range of air temperature, bio12 – annual precipitation amount, bio18 – mean monthly precipitation amount of the warmest quarter, bio19 – mean monthly precipitation amount of the coldest quarter and gsp – accumulated precipiation amount on growing season days). We also calculated differences in environmental factors and vegetation variables (cover tree, shrub, herb and moss layer, overall species richness and phytogeographical elements richness) between syntaxonomic

units using the Kruskal–Wallis rank sum test (function *kruskal.test*) with multiple comparison based on Dunn's test using the *dunnTest* function in the 'FSA' package (Ogle et al., 2018) in R. Climatic data were extracted from the CHELSA database version 2.1 (http://chelsa-climate.org; Karger et al., 2017).

A synoptic table with the fidelity and relative percentage frequency of all diagnostic species and other plants of frequency ≥ 20% are shown in Table 1. Analytic table including type relevés and full synoptic table are given in Supplementary material (Table S1 and Table S2 respectively). Newly presented syntaxa are proposed according to the ICPN (Theurillat et al., 2021). All mentioned syntaxa are arranged into a syntaxonomic overview at the end of the description in the Results section. The association concept follows Willner (2006) and the alliance follows Willner (2020). The nomenclature of the vascular plants follows generally Cherepanov (1995) and The Plant List (2020) Version 1.1. (http://www.theplantlist.org/), and bryophytes follows Ignatov et al. (2006).

Results

General floristic and physiognomic features

In our data set for Tajikistan (119 relevés), the juniper woodlands harbour 308 vascular plant species and 13 mosses. In total, 65 species reached constancy above 10% and 52 taxa above 20%. The open structure of juniper stands allows settlements and gaining high frequencies of species typical for neigbouring vegetation like alpine tall-forbs (e.g. *Ligularia thomsonii*, *Geranium regelii*, *Polygonum coriarium*), cryophilous steppes (e.g. *Festuca rupicola*, *Koeleria pyramidata*, *Eremogone griffithii*) or deciduous forests and shrubs (e.g. *Astragalus tibetanus*, *Poa pratensis*). Among the typical woodland taxa, the most frequent were: *Lonicera nummulariifolia* (73%), *Campanula glomerata* (52%), *Juniperus polycarpos* var. *seravschanica* (50.9%), *J. pseudosabina* (20,3%), *Poa fragilis* (47%), *P. nemoraliformis* (44%), *Asyneuma argutum* subsp. *argutum* (44%), *Berberis integerrima* (38%), *Draba nemorosa* (37%) and *Seseli schrenkianum* (25%). Important components of Tajik cryophilous juniper stands are species typical for mires, such as *Gentianella turkestanorum* (37%) or *Codonopsis clematidea* (18.5%). Among trees, *Juniperus polycarpos* var. *seravschanica* (50.4%) and *Juniperus pseudosabina* (48%) were the most frequent. The most constant species in shrub layer were *Lonicera nummulariifolia* (73%), *Juniperus polycarpos* var. *seravschanica* (50.4%), *J. pseudosabina* (42%), *Rosa webbiana* (32.7%), *Berberis integerrima* (29.4%), *R. kokanica* (22.7%), *Cotoneaster zeravschanicus* (12.6%), *L. stenantha* (11.7%) and *J. semiglobosa* (10.1%). Unlike many other vegetation types in the subarid zones of Middle Asia, juniper woods are relatively abundant and rich in moss species (Nowak et al., 2022). The most common bryophyte species were: *Hypnum cupressiforme* (80.6%), *Sanionia uncinata* (62.2%), *Syntrichia ruralis* (55.5%), *Brachythecium collinum* (14.3%) and *Bryum caespiticium* (9.2%).

Numerical classification and DCA ordination

The TWINSPAN classification revealed five clusters (Fig. 2), three of them are interpretable by a set of diagnostic species. On the left side of the diagram, there are two small groups corresponding to plots dominated by the zeravshan juniper. Cluster 1 corresponds to the plots sampled in the Sary-Khosor National Park, which differ in the abundance of tall-forb species. Cluster 2 encompasses a highly grazed plots with a high proportion of pasture and steppe species and low cover in tree and herb layers. These communities were surveyed in the intensively grazed Half-kul Valley. Since clusters 1 and 2 consists only of 4 and 5 relevés respectively, we decided to leave them rankless. Looking further from the left to the right of the figure (Fig. 2), two fairly large groups of the plots with *Juniperus polycarpos* var. *seravschanica* can be distinguished. First (cluster 3) encompasses Zeravshan juniper stands that are located on more isolated, warmer slopes with dominant western, southern and rarely north-eastern exposition. The right one (cluster 4), located in the central part of the graphs, groups stands of *J. polycarpos* var. *seravschanica* which grow mostly on northern and north-western, steep slopes with relatively abundant moss layer. The most homogeneous group corresponds to the *Juniperus pseudosabina* community (cluster 5). Despite the large number of plots with this species, they are clearly distinct and well separated from the other communities at a high level of dissimilarity. It suggests a very diverse species composition and the possibility of distinction at a high level in the hierarchical arrangement.

Vegetation groups defined in the TWINSPAN classification are clearly separated by the two first axes of DCA analysis (Fig. 3). The first axis of the DCA reflects a strong latitudinal, growing season precipitation, annual temperature range and precipitation of the coldest quarter gradients, which differentiates clusters 3–4 and 5. Plots classified to the association *Carici turkestanicae-Juniperetum pseudosabinae* occurs at higher latitudes with more continental climate (higher annual temperature ranges) and are associated with higher precipitation amount in the growing season (Fig. 3 and 4). In contrast, *Juniperetum seravschanicae* were found in localities of lower latitudes and higher precipitation in winter.

The second axis shows the relation to mean annual temperature gradient and the precipitation amount of the warmest quarter differentiating clusters 3 and 4 (variants of *Juniperetum seravschanicae*). Variant with *Hedysarum denticulatum* and *Oxytropis glabra* was found in an area with the higher mean annual temperature, and higher sum of annual precipitation, as well as lower precipitation amount in the warmer quarter, in comparison to the variant with *Primula lactiflora* and *Brachythecium collinum* (Figs 3 and 4).

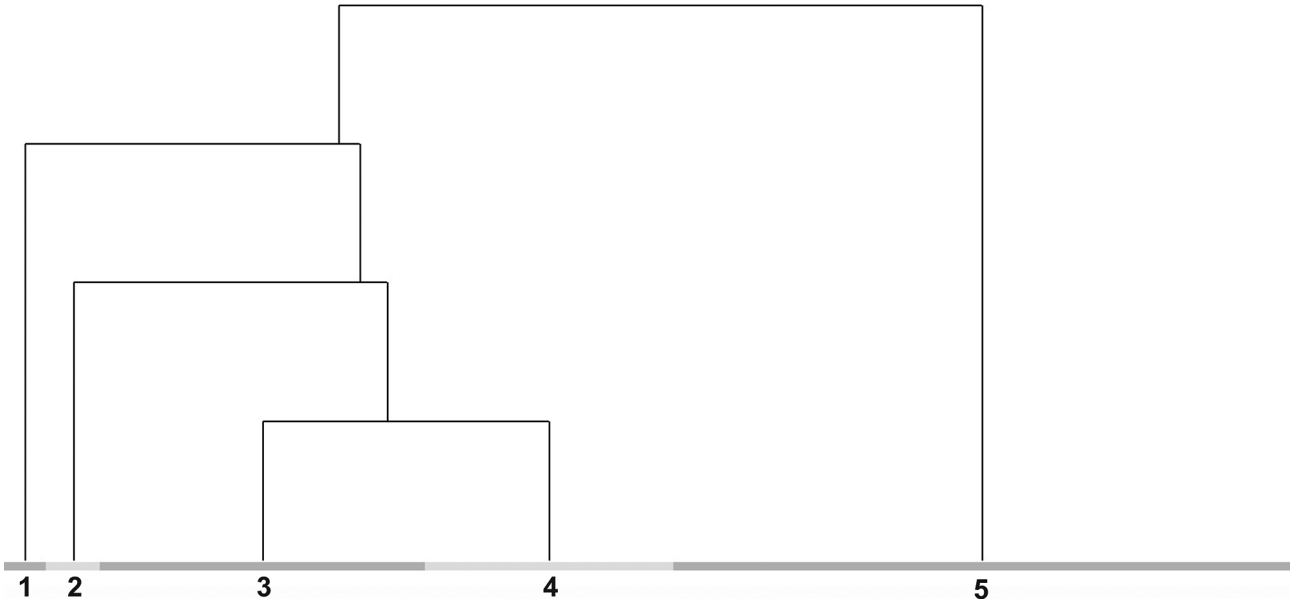

Fig. 2. Dendrogram illustrating the assigment of relevé groups identified by TWINSPAN to particular syntaxonomic units: 1 and 2 – communities left rankless, 3 – Ass. *Juniperetum seravschanicae* variant with *Hedysarum denticulatum* and *Oxytropis glabra*, 4 – Ass. *Juniperetum seravschanicae* variant with *Primula lactiflora* and *Brachythecium collinum*, 5 – Ass. *Carici turkestanicae-Juniperetum pseudosabinae*

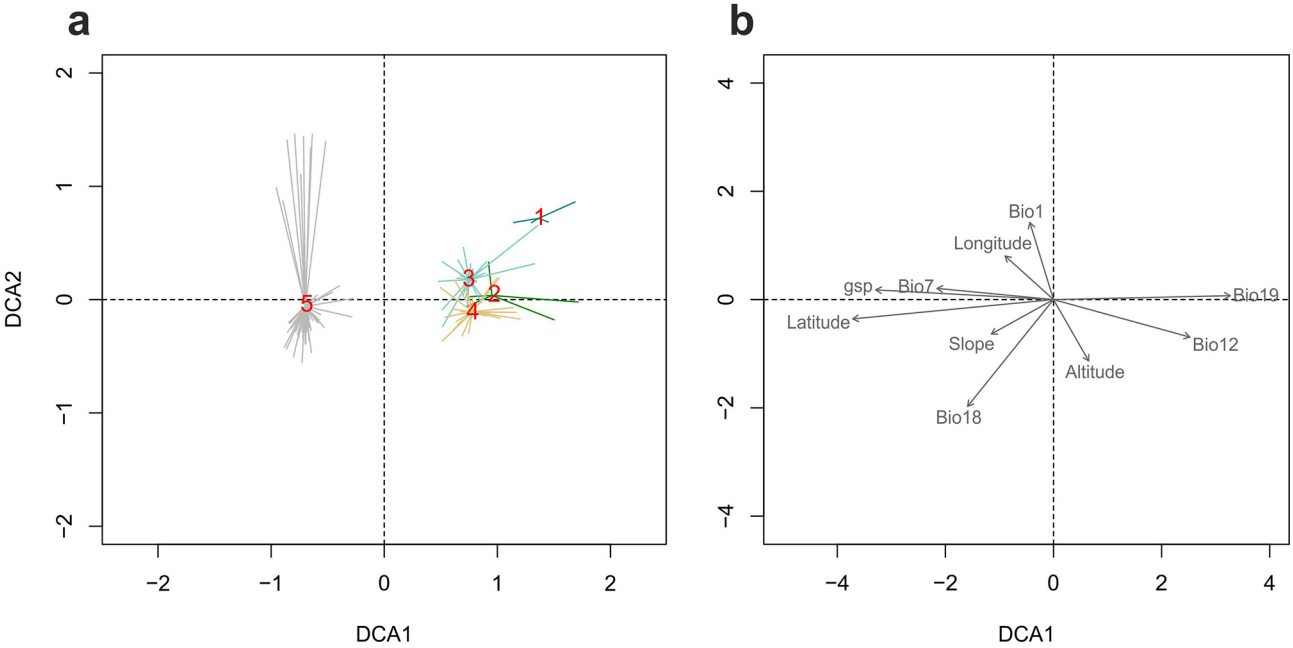

Fig. 3. Detrended Correspondence Analysis diagram of juniper woods vegetation in Tajikistan. (a) Spider plots with vegetation units centroids are plotted. The second diagram (b) shows the same ordination with environmental variables passively plotted onto DCA diagram. The eigenvalues and lengths of gradients were 0.40, 2.66 (Axis 1) and 0.16, 2.02 (Axis 2), respectively. Abbreviations: Bio1 – mean annual air temperature (°C), Bio7 – annual range of air temperature (°C), Bio12 – annual precipitation amoun (mm), Bio18 – mean monthly precipitation amount of the warmest quarter (mm), Bio19 – mean monthly precipitation amount of the coldest quarter (mm), gsp – accumulated precipiation amount on growing season (mm), Slope – inclination of the slope (°)

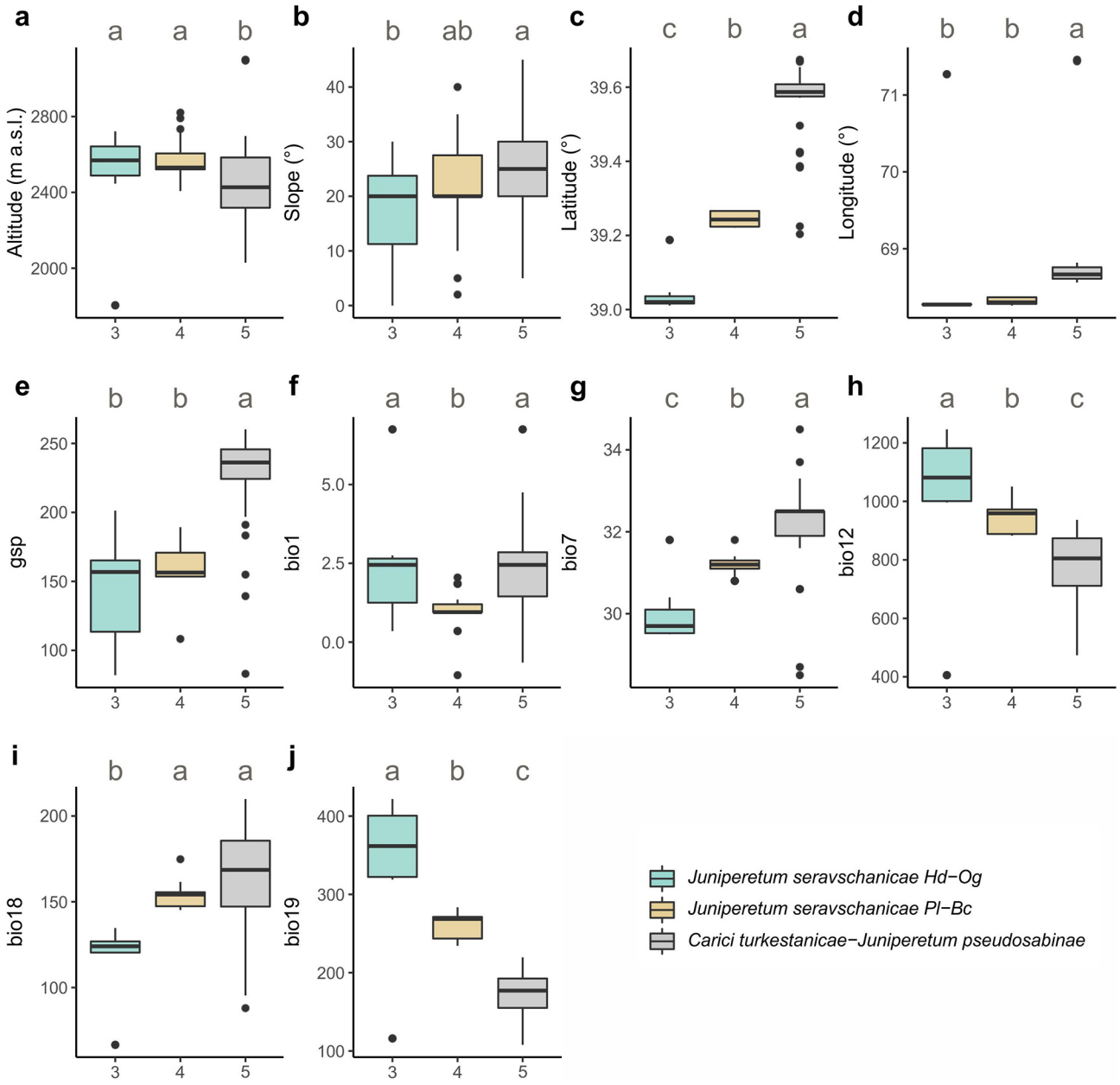

Fig. 4. Boxplots showing median (line), quartiles, outliers and the range of (a) altitude, (b) inclination of the slope, (c) latitude, (d) longitude, (e) accumulated precipiation amount in growing season (mm), (f) mean annual temperature (°C), (g) annual range of air temperature (°C), (h) sum of annual precipitation (mm), (i) mean monthly precipitation amount of the warmest quarter (mm) and (j) mean monthly precipitation amount of the coldest quarter (mm) for particular syntaxonomic units. The letters represent homogeneous groups according to Dunn's post hoc test following a significant Kruskal–Wallis rank sum test ($p < 0.05$), and labels on the x-axis correspond to cluster numbers

Synopsis of syntaxa

Based on the analyses, we propose the following classification for the juniper woods in Tajikistan:

Thermophilous Zeravshan juniper stands in the lower montane belt of Middle Asia

Class: *Pino-Juniperetea* Rivas-Mart. 1965 (?)

Order: *Juniperetalia seravschanicae* nom. prov.

I. Alliance: *Juniperion seravschanicae* Nowak et al. 2022 all. nova hoc loco

I.1 Association: *Juniperetum seravschanicae* Nowak et al. 2022 ass. nova hoc loco

– variant with *Hedysarum denticulatum* and *Oxytropis glabra* (group 1)

– variant with *Primula lactiflora* and *Brachythecium collinum* (group 2)

Cryophilous juniper stands in the upper montane belt of Middle and Central Asia (and probably also Himalayas)

Class: *Juniperetea pseudosabinae* Mirkin et al. 1986

Order: *Juniperetalia pseudosabinae* Mirkin et al. 1986

II. Alliance: *Juniperion pseudosabinae* Mirkin et al. 1986

II.1. Association: *Carici turkestanicae-Juniperetum pseudosabinae* Nowak et al. 2022 ass. nova hoc loco (group 3)

Description of syntaxa of the thermophilous open woodland and scrub vegetation in Tajikistan

Group I. Thermophilous Zeravshan juniper stands in the lower montane belt of Middle Asia

Order: *Juniperetalia seravschanicae* nom. prov.
Nomenclatural type: *Juniperion seravschanicae* all. nov. hoc loco
Diagnostic species: *Berberis integerrima, Campanula glomerata, Juniperus polycarpos* var. *seravschanica, Oxytropis capusii, Nepeta podostachys, Thalictrum sultanbadense, Pedicularis dolichorhiza, P. krylovii, Poa fragilis, P. nemoraliformis, P. trivialis, Seseli schrenkianum, Silene tachtensis, Veronica rubrifolia.*
Constant species: *Asyneuma argutum* subsp. *argutum, Geranium regelii, Lonicera nummulariifolia, Ligularia thompsonii, Poa pratensis, Rosa webbiana, R. kokanica*.
Geographical range: The phytocoenoses assigned to this order occur across western parts of Middle Asia (western Tian Shan, Pamir-Alai, western Hindukush, and probably also in Kopet-dagh (Turkmenistan), Baluchistan (Pakistan), Hazarmaysh Mts. (Afghanistan) and Kuyhitang Mts. (Uzbekistan).
Habitat characteristics: Main vertical range in the montane belt between 1,500 and 2,700 m a.s.l., occasionally descending to lower altitudes, especially towards the south-west. The communities of the new order develop on the slopes of the mountain ranges of intermediate altitude, preferring fairly steep slopes of various aspects. They develop on chestnut-brown soils and are adapted to the winter-rain mediterranean-like climate of considerable continentality. *Juniperetalia seravschanicae* thermophilous juniper woods are used as a source of firewood and are extensively grazed, mainly by sheep and goats.
Remarks: The order includes phytocoenoses dominated by the Zeravshan juniper *Juniperus polycarpos* var. *seravschanica*. It should probably also include other thermophilous juniper phytocoenoses from the entire Irano-Turanian region, at least from the Turkestanian province, such as *Juniperus polycarpos* var. *turcomanica* from the Kopet-dagh Mts. in Turkmenistan and Iran. This vegetation has an open structure with an average tree canopy cover of ca. 50% and is composed mainly by Irano-Turanian species. Since the naming taxon is subjected to different taxonomic treatments, we decided to take as the name of the order its local name, which is well-rooted in the geobotanical literature and accepted in The Plant List as a variety name.

I. Alliance: *Juniperion seravschanicae* all. nov. hoc loco
Nomenclatural type: *Juniperetum seravschanicae* ass. nov. hoc loco
Diagnostic species: at the current stage of the survey the same as for the order.
Constant species: at the current stage of the survey the same as for the order.
Geographical range: The phytocoenoses assigned to the alliance occur across western parts of Middle Asia (western Tian Shan, Pamir-Alai, western Hindukush, and probably also in Kopet-dagh (Turkmenistan), Baluchistan (Pakistan), Hazarmaysh Mts. (Afghanistan) and Kuyhitang Mts. (Uzbekistan). The largest forest complexes of Zeravshan juniper extend in Zeravschan, Hissar, Babatag, Vakhsh, Sarsarak, Hazratishoh, Kuraminian in Tajikistan, Hindukush in Afghanistan and the western Tian Shan ranges in Kyrgyzstan.
Habitat characteristics: Patches of this community occur in the montane belt of the western part of Middle Asia, mainly Tajikistan and Kyrgyzstan. Thermophilous juniper woods grow in Pamir-Alai at altitudes of (1,300)1,700–2,200(2,700) m a.s.l. in areas with an average precipitation of 500–700 mm/year and average annual temperature of about 12–15°C. In winter the temperature often falls well below -25°C. The stands inhabit shallow to moderately deep soils (sometimes also on screes) with a strongly dried topsoil in the hot summer period. This vegetation type develops on slopes of different inclinations and aspect and is not strongly associated with northern exposure, such as *Juniperus pseudosabina* stands. The plant communities included in this alliance consist mainly of species of the Irano-Turanian distributional range.

I.1. *Juniperetum seravschanicae* ass. nov. hoc loco
Diagnostic species: *Berberis integerrima, Brachythecium collinum, Eremogone griffithii, Hedysarum denticulatum, Juniperus polycarpos* var. *seravschanica, Oxytropis glabra, Pedicularis dolichorrhiza, Poa nemoraliformis, Primula lactiflora, Seseli schrenkianum, Silene tachtensis.*
Constant species: *Hypnum cupressiforme, Juniperus polycarpos* var. *seravschanica, Lonicera nummulariifolia; Geranium regelii, Ligularia thomsonii.*
Geographical range: Plots of this community were sampled in Zeravshan Mts., mainly in Pastrud-daria, Imat and Iskander-daria River Valleys (Fonn Mts; Fig. 1). It is the core distributional area of the main diagnostic taxon and its locus classicus.

Floristic composition: The tree and shrub layer is clearly dominated by *Juniperus polycarpos* var. *seravschanica*. Additionally, *Berberis integerrima, Lonicera nummulariifolia, L. stenantha, Cotoneaster seravschanicus, C. oliganthus, Rosa kokanica, R. webbiana, Ribes meyeri* and *Juniperus semiglobosa* also have a significant share in the shrub layer (mean cover 33%; Fig. 5b). The herbaceous layer is quite scarce, reaches 30–80% (mean 51%; Fig. 5c) and consists of 18–43 taxa (mean 28; Fig. 5e), with *Carex turkestanica, Hedysarum denticulatum, Ligularia thomsonii* and *Poa trivialis* being the most abundant (Fig. 7b). Mosses are quite abundant in this wood having from 1 to 30% coverage with the mean of about 8% (Fig. 5d).

Habitat characteristics: The community inhabits relatively dry, often stony slopes in the montane elevations (1,800–2,800 m a.s.l., mean ca. 2,500; Fig. 4a). Plots of the community were sampled within large juniper complexes on slopes with inclination up to 40° and only occasionally on flat land (Fig. 4b, 7a). Aspects were variable with predominantly western and northern exposures (Fig. 6).

Remarks: The TWINSPAN classification showed the existence of two clusters that differ insignificantly with the floristic composition of the plots.

Holotypus: (sequence number in Table S1 – 40) 8 July 2021; 68.36853 °E; 39.22339 °N; 2517m a.s.l.; aspect N; slope 25°; plot area 100 m^2; cover tree layer 60%; cover shrub layer 50%; cover herb layer 30%; cover moss layer 5%; species composition:
Tree layer: *Juniperus polycarpos* var. *seravschanica* 4. Shrub layer: *Juniperus polycarpos* var. *seravschanica* 2, *Lonicera nummulariifolia* 2, *Berberis integerrima* 1, *Sorbus persica* 1, *Ribes meyeri* +, *Rosa webbiana* +. Herb layer: *Geranium regelii* 1, *Ligularia thomsonii* 1, *Polygonum coriarium* 1, *Primula lactiflora* 1, *Artemisia dracunculus* +, *Artemisia santolinifolia* +, *Astragalus aksuensis* +, *Draba nemorosa* +, *Ephedra intermedia* +, *Eremogone griffithii* +, *Leonurus turkestanicus* +, *Pedicularis krylowii* +, *Poa nemoraliformis* +, *Poa trivialis* +, *Ribes meyeri* +,

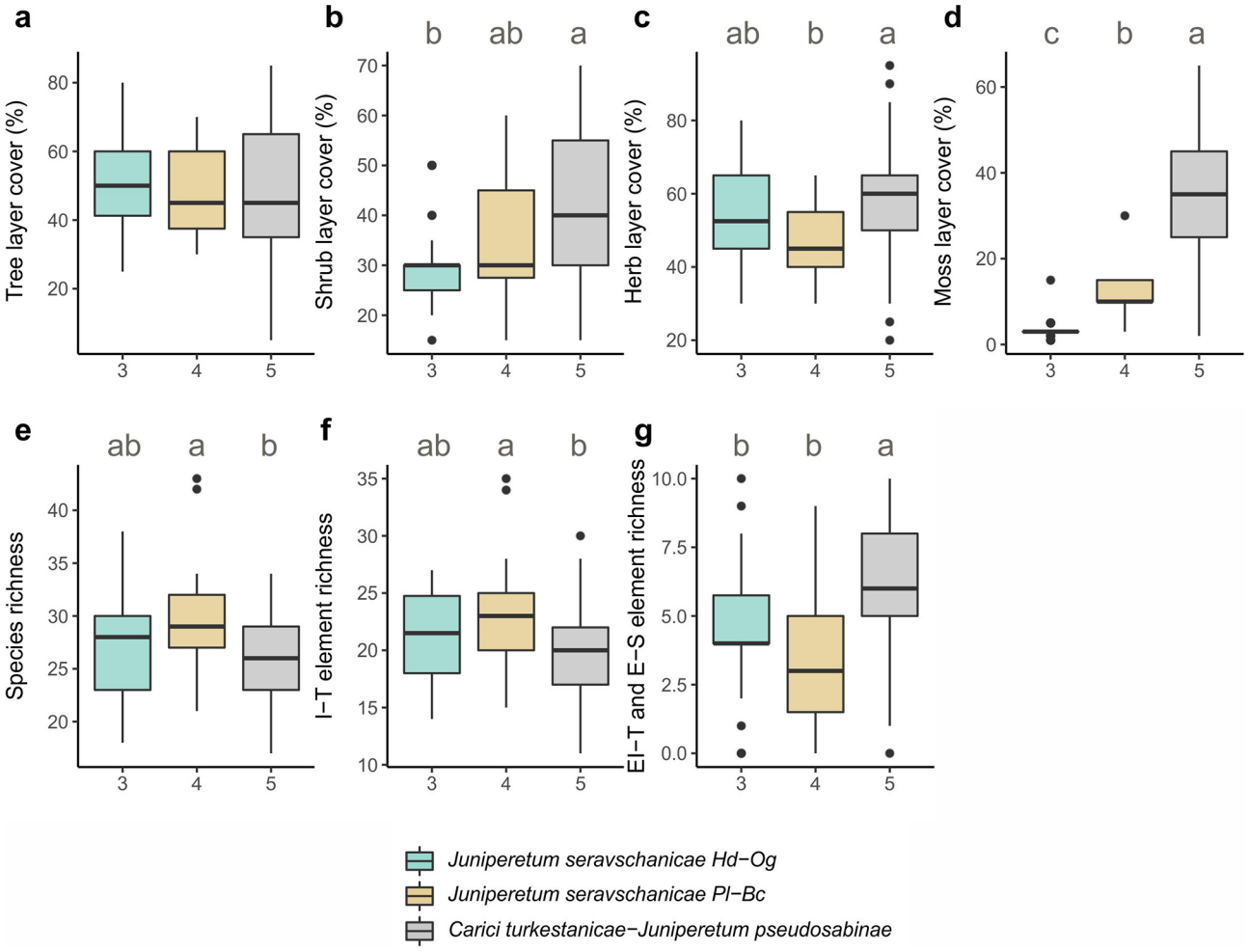

Fig. 5. Boxplots showing median (line), quartiles, outliers and the range of (a) cover of tree layer, (b) cover of shrub layer, (c) cover of herb layer, (d) cover of moss layer, (e) species richness, (f) species richness of Irano-Turanian element and (g) species richness of Eastern Irano-Turanian with Euro-Siberian element for particular syntaxonomic units. The letters represent homogeneous groups according to Dunn's post hoc test following a significant Kruskal–Wallis rank sum test ($p < 0.05$), and labels on the x-axis correspond to cluster numbers

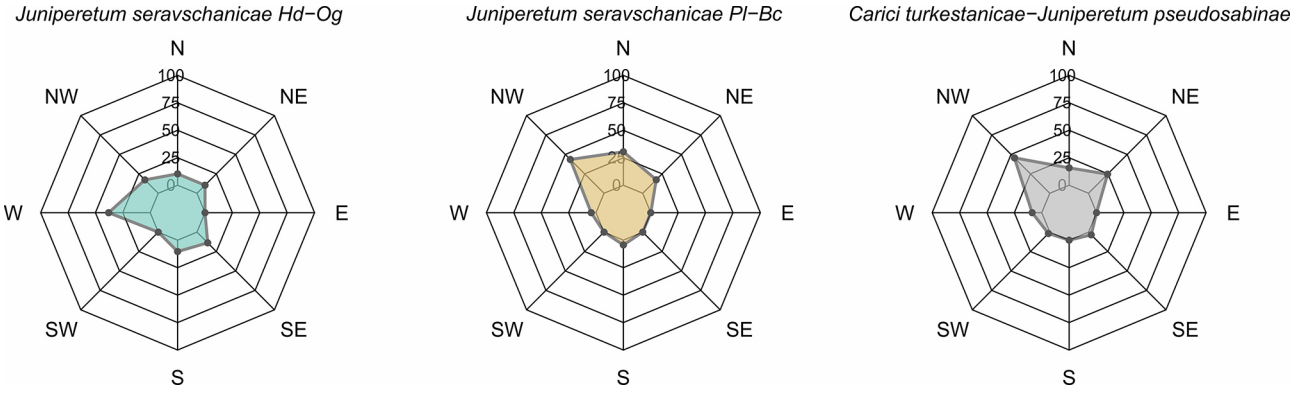

Fig. 6. The exposition preferences of the researched plant communities

Seseli schrenkianum +, *Silene tachtensis* +, *Thalictrum sultanabadense* +. Moss layer: *Hypnum cupressiforme* 1, *Brachythecium collinum* +, *Syntrichia ruralis* +.

– variant with *Hedysarum denticulatum* and *Oxytropis glabra*

This variant is distinguished by slightly higher precipitation (especially in the winter), lower slope inclination (wide glacial valleys) and more diverse aspects, also to the south and west (Figs 4 and 5). The herb layer is a bit more abundant here, in contrast to the poorer moss layer (Fig. 5d). There are a number of species typical for more fertile habitats resistant to grazing, e.g. *Carex turkestanica, Gentiana olivieri, Adonis turkestanica, Carduus nutans, Erigeron pseudoseravschanicus, Potentilla molissima, Thalictrum minus* subsp. *maxwellii* or *Pedicularis krylowii*. Plots of this community were found mainly in the valleys of the Kara-kul and Iskander-daria rivers (Fig. 1).

– variant with *Primula lactiflora* and *Brachythecium collinum*

The variant with *Primula lactiflora* and *Brachythecium collinum* (Fig. 7c) differs from the previous one by significantly more abundant moss layer, which can cover up to 30% of the area (Fig. 5d). Patches of this community develop on steeper slopes which usually have northern exposure (Fig. 6). Grazing is less intensive here and the soil is less fertile. In the undergrowth the plants typical for this variant are *Astragalus aksuensis, Phleum phleoides, Oxytropis lehmannii, Aulacospermum roseum, Ribes meyeri, Cicerbita seravschanica, Psychrogeton pseuderigeron, Artemisia santoliniifolia, Draba junusovii, Oxytropis capusii*.

In the group of thermophilous juniper woods, the TWINSPAN algorithm distinguished two clusters of few plots (nine in total). These are the communities from the Sary-Khosor area with a large share of tall-forb species and from the Half-kul valley with intensive goat and sheep grazing. For these reasons, these plots differ strongly from the other groups and thus we decided to leave it rankless without further consideration.

Cryophilous juniper stands in the upper montane belt of Middle and Central Asia

II. Alliance: *Juniperion pseudosabinae* Mirkin et al. 1986

Diagnostic species: *Carex turkestanica, Cerastium dichotomum* subsp. *inflatum, Codonopsis clematidea, Erigeron seravschanicus, Gentianella turkestanorum, Helictotrichon hookeri, Hypnum cupressiforme, Juniperus pseudosabina, Oxytropis ovczinnikovii, Phleum phleoides, Sanionia uncinata, Thalictrum kuhistanicum*.

Constant species: *Carex turkestanica, Geranium regelii, Hypnum cupressiforme, Juniperus pseudosabina, Ligularia thomsonii, Lonicera nummulariifolia, Sanionia uncinata, Thymus seravschanicus*.

Geographical range: The vegetation of this alliance extends from the northern Pamir-Alai, through a large territory of the western and central Tian Shan, Altai, to the Sayan Mts. In Tajikistan, this *Juniperus pseudosabina* is distributed in the upper montane belt mainly in Turkestan, Peter the First, Kuraminian and Zeravshan Mts. at elevations between 2,000 and 3,600 m a.s.l., but the highest outposts of the community resambles rather subalpine krummholz with patchy shrub vegetation (Fig. 7e).

Floristic composition: The *Juniperion pseudosabinae* forms dense monospecies stands (Fig. 7d) with up to 85% cover of the tree layer (mean ca. 50%; Fig. 5a). The shrub layer is also abundant (mean ca. 40%, Fig. 5b), and the most frequent species are *Lonicera nummulariifolia, L. korolkowii, Rosa webbiana* and *Berberis integerrima*. The plots are clearly dominated by *Juniperus pseudosabina* in the canopy and *Carex turkestanica, Ligularia thomsonii, Poa nemoralis, Ranunculus aureopetalus, Thalictrum kuhistanicum, Thymus seravschanicus, Hypnum cupressiforme, Sanionia uncinata* in herb and moss layers. Plots of this vegetation are moderately rich in species but have fairly abundant moss cover.

Habitat characteristics: The vegetation with the domination of *Juniperus pseudosabina* occurs in moderately warm and cold regions of Tajikistan. It develops in the upper montane to subalpine belts on mainly on northern slopes.

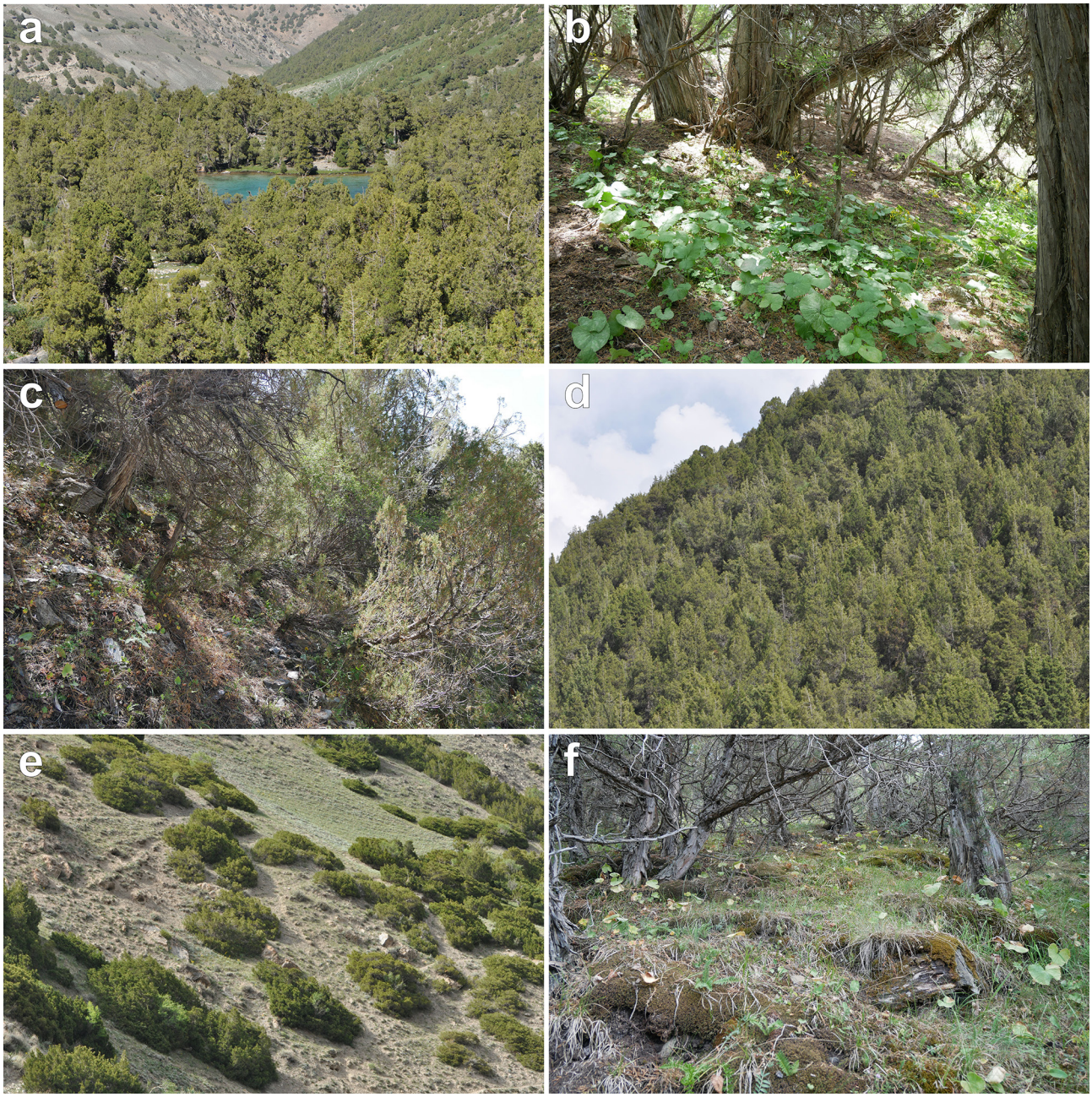

Fig. 7. Photographs of the juniper wood vegetation in Tajikistan: a) *Juniperetum seravschanicae* in the area of Alaudin lakes, b) *Juniperetum seravschanicae* with *Ligularia thompsonii* in the herb layer, Iskander-daria River Valley, c) *Juniperetum seravschanicae* variant with *Primula lactiflora* and *Brachythecium collinum* in Pastrud-daria River Valley, d) stands of the *Carici turkestanicae-Juniperetum pseudosabinae* near Buragen, e) patches of the *Juniperion pseudosabinae* vegetation at upper treeline near Koshtegirmen, f) high bryophytes abundance in the *Carici turkestanicae-Juniperetum pseudosabinae* stands, Buragen (pictures a, d, e were taken by A. Nowak and b, c, f by S. Świerszcz)

II.1. Association: *Carici turkestanicae-Juniperetum pseudosabinae* ass. nov. hoc loco

Diagnostic species: *Carex turkestanica, Cerastium dichotomum* subsp. *inflatum, Codonopsis clematidea, Erigeron seravschanicus, Gentianella turkestanorum, Helictotrichon hookeri, Hypnum cupressiforme, Juniperus pseudosabina, Oxytropis ovczinnikovii, Phleum phleoides, Sanionia uncinata, Thalictrum kuhistanicum*.

Constant species: *Carex turkestanica, Geranium regelii, Hypnum cupressiforme, Juniperus pseudosabina, Ligularia thomsonii, Lonicera nummulariifolia, Sanionia uncinata, Thymus seravschanicus.*

Geographical range: The *Juniperus sabina* vegetation was surveyed mainly in the Ohtangi Valley and in the vicinity of Shahristan Pass in the Turkestan Mountains (Fig. 1). It occupies the upper montane belt between 2,000 and 3,100 m a.s.l. (mean ca. 2,500

m), but few patches of a dwarf form of *J. pseudosabina* have also been found at altitudes of about 3,700 m in the Peter the First Mts.

Floristic composition: The canopy of this wood is clearly dominated by *Juniperus pseudosabina*. Unlike the thermophilous *J. polycarpos* var. *seravschanica* stands in the shrub layer the main diagnostic taxon has a low proportion. This layer is dominated by species such as *Lonicera nummulariifolia, L. korolkowii* and *Rosa webbiana*. The herb layer has a cover of 20–95% (mean 60%; Fig. 5c) and consists of 17–34 species (mean ca. 26; Fig. 5e, 7f). The herb layer occurs with a number of Eastern Irano-Turanian and Euro-Siberian species (Fig. 5g), most commonly *Astragalus tibetanus, Brachypodium sylvaticum, Campanula glomerata, Crepis pulchra, Euphrasia pectinata, Festuca rupicola, Phleum phleoides, Poa pratensis* and *Trifolium repens*. *Juniperetum pseudosabinae* is rich in moss species that form an abundant layer with *Hypnum cupressifoliae, Distichum capillaceum, Sanionia uncinata* and *Syntrychia ruralis*. The moss cover reaches 65%, with the mean of ca. 35% (Fig. 5d).

Habitat characteristics: The tree stands of *Juniperus pseudosabina* are associated with the upper montane belt of the northern ranges in central Tajikistan and occur on brown mountain soils with poorly developed profile. It prefers moderately sloping sites (mean inclination approx. 25°, Fig. 4b) and with exposure from north-east to north-west (Fig. 6).

Remarks: In Middle Asia, there is a gradual transition of dense stands of *J. pseudosabina* into mosaic dwarf shrub communities in the treeline zone is observed. Such plots with ca. 20–40% juniper cover and a rich herb layer composed mainly by cryophilous steppe or alpine tall-forb taxa were observed in various regions of Tajikistan and Kyrgyzstan, e.g. in the Kyrgyz, Peter the First and Talass Mts. Due to the considerable physiognomic distinctiveness and different species composition, these plots were excluded from the study.

Holotypus: (sequence number in Table S1 – 84) 12 July 2021; 68.74634 °E; 39.60838 °N; 2324 m a.s.l.; aspect NW; slope 25°; plot area 100 m^2; cover tree layer 80%; cover shrub layer 20%; cover herb layer 55%; cover moss layer 35%; species composition:
Tree layer: *Juniperus pseudosabina* 5. Shrub layer: *Lonicera nummulariifolia* 2, *Festuca rupicola* +, *Juniperus pseudosabina* +. Herb layer: *Carex turkestanica* 3, *Juniperus pseudosabina* 2, *Rosa kokanica* 2, *Koeleria pyramidata* 1, *Ligularia thomsonii* 1, *Thymus seravschanicus* 1, *Berberis integerrima* +, *Campanula glomerata* +, *Cerastium dichotomum* subsp. *inflatum* +, *Crepis pulchra* +, *Cystopteris fragilis* +, *Erigeron seravschanicus* +, *Gentianella turkestanorum* +, *Geranium regelii* +, *Helictotrichon hookeri* +, *Oxytropis ovczinnikovii* +, *Petrorhagia alpina* +, *Phleum phleoides* +, *Poa fragilis* +, *Taraxacum* agg. +, *Thalictrum kuhistanicum* +, *Viola suavis* +. Moss layer: *Hypnum cupressiforme* 3, *Sanionia uncinata* 2.

Discussion

Comparisons of the Middle Asian juniper woods to the neigbouring areas

Undoubtedly, the thermophilous juniper woods of Tajikistan dominated by *J. polycarpos* var. *seravschanica*, in terms of structure and habitat conditions, are similar to those of Iran, Turkmenistan, Afghanistan and Uzbekistan (Freitag, 1971; Popov, 1994). They probably differ only in their species composition due to the high rate of Pamir-Alai endemism. Despite the scarcity of phytosociological data, we can find fairly similar features of *J. polycarpos* var. *turcomanica* stands in western Kopet-dagh to eastern Khorassan in the Bardu and Bezd mountains in Torbat-e Jam on the Iranian-Turkestanian borderland. They occupy the montane belt at 800–2,400 m a.s.l. and form open woodland (the average tree cover 30–40%) with a rich undergrowth composed of thermophilous, steppe and tall-forb species (Memariani et al., 2016b). However, unlike the Zeravshan juniper stands in Pamir-Alai, they are limited in the upper boundary not by zonal juniper stands (like *J. pseudosabina* woods in Pamir-Alai) but by shrubby, subalpine vegetation with *J. sabina* and *J. communis*. The exposure of the remnant Turkmen junipers also varies and, due to the increased drought in this region, they mainly occupy the northern slopes.

In Afghanistan, a stand of *J. polycarpos* var. *seravschanica* forms the upper tree line in the northern Hindukush at an altitude of about 3,500 m. Due to harsh conditions and severe drought in this region, the higher elevations are treeless. They are the only coniferous stands outside the areas of monsoon influence and due to the highly variable topography, harbour a wide range of undergrowth species (Freitag, 1971). Juniperus open woods form a montane belt from ca. 1,400–2,900 in the west and in the north-east from ca. 3,000–3,100 to about 3500 m a.s.l. Total precipitation here ranges from 500 to as much as 1,200 mm, with winter precipitation in the north and summer monsoon in the south. Juniper stands inhabit skeleton, rendzina soils and form fairly dense stands with up to 60–80% canopy coverage. They share many species with Tajik stands such as *J. polycarpos* var. *seravschanica, J. semiglobosa, Ephedra equisetina, Lonicera nummulariifolia, Amygdalus bucharica, Crataegus songarica, Phlomis cashmeriana, Thalictrum sultanbadense, Koeleria cristata*. A striking feature of this woods is the great share of šhiblyak taxa like *Cercis griffithii, Crataegus turcestanica, Pyrus korshinskyi, Malus turkmenorum, Astragalus cisdarvasicus*. This proves to some extent the validity of the hypothesis of a common origin of the thermophilous juniper woods and xerophytic šhiblyak scrub from a single Tertiary formation, the palaeošhiblyak (Kamelin, 1967). At the

beginning of the Lower Miocene, significant climatic fluctuations and gradual aridization caused the replacement of broad-leaf turgay woods (the so called ancient Mediterranean vegetation) by the more xerophytic palaeošhiblyak. This formation is considered to be the ancestor formation of juniper groves and present-day šhiblyak (Kamelin, 1967; Ovchinnikov, 1967, 1971; Pavlov, 1980).

The Afghan stands of *J. polycarpos* var. *seravschanica* are closely related to the North Pakistani sites of *J. excelsa* subsp. *polycarpos* in Chitral (Nüsser & Dickore, 2002). In our opinion, the taxonomic vagueness of the genus is responsible for the different species assignments and it is likely that this woody vegetation is formed by the same taxon. Despite the physiognomic similarity of this open woodland, a kind of steppe-forest vegetation, there are also floristic similarities, as both vegetation types share a number of species such as *Acanthocephalus benthaminanus*, *Artemisia persica*, *Crataegus songarica*, *Gypsophila floribunda*, *Rosa beggeriana* or *Scabiosa olivieri*.

In Armenia, juniper stands are included in the Mediterranean matorral vegetation. The shrubby formation consists of *Juniperus polycarpos*, *J. foetidissima*, *J. communis*, *J. oxycedrus*, *J. phoenicea*, *J. lycia*, *J. drupacea* and *J. thurifera*. It rather resembles Mediterranean shrubby vegetation with a distinct species composition (Fayvush & Aleksanyan, 2016). However, there is also a stand of *J. excelsa* and *J. foetidissima* in the upper montane and subalpine belts of Armenia, which physionomically is quite similar to typical Irano-Turanian woods in Tajikistan.

Also juniper woods in northern Iran in the Alborz and Hezarmasjed Mts. reveal close similarities to the open stands of Middle Asia. They occur at 1,300–2,100 m altitude and are dominated by *Juniperus excelsa* or *J. polycarpos* and share a number of species, like *Lonicera nummulariifolia*, *Cotoneaster nummularioides*, *C. numulariifolia*, *Berberis integerrima*, *Crataegus pontica* (Kartoolinejad & Moshki, 2014; Ravanbakhsh et al., 2016). Six associations and five subassociations have been defined in Alborz (Ravanbakhsh et al., 2016). However, most of them on scarce samples. These have been assigned to *Junipero-Pistacietea* Zohary 1973.

The Zeravshan juniper stands in Tajikistan also show close relationship to other eastern Mediterranean and Western Irano-Turanian open woods dominated by *Juniperus excelsa*, *J. oxycedrus* or *J. polycarpos* in Turkey, *J. excelsa* in Al-Hajar Mts. in Oman, Lebanon, southern Pakistan, Dagestan (eastern Caucasus; e.g. Fisher & Gardner, 1995; Çolak & Rotherham, 2006; Sarangzai et al., 2012; Douaihy et al., 2013; Sadykova et al., 2018; Ambarlı et al., 2020).

In contrast to the woods of *J. polycarpos* var. *seravschanica*, the Tajik northern forests of *J. pseudosabina* display strong relationship with juniper woods of Central Asia, Tibet and the Himalayas. In the Himalayan range, almost pure juniper stands were found above about 3,500 m a.s.l. in the driest areas. These stands are dominated by *Juniperus recurva* in the eastern Himalayas and by *J. wallichiana* and *J. communis* in the western part of the range. Like in Middle Asia, the shrub and undergrowth layers harbour species of *Caragana* spp. and *Artemisia* spp. In the far northern Altay Mts. (Gobi Altay), *J. sabina* scrubs are recorded at the upper boundary of trees which to some extent resamble the uppermost scrub-like stands of *J. pseudosabina* in higher elevations in Peter the First and western Pamirian Ranges (Vanch, Yazgulem, Rushan; Wesche et al., 2005). The montane scrubland of the southern Mongolian Mts. has been included in the order *Juniperetalia pseudosabinae* (Mirkin et al., 1986) and is probably the northernmost refugium of this vegetation in Central Asia. In Tajikistan, south-western refuges of this vegetation form dense zonal woods in the upper montane belt.

Towards the east, the cryophilous woods change their floristic composition and are mainly built by *Juniperus indica, J. convallium* and *J. tibetica*, which form zonal subalpine scrub or isolated bushy relicts (Ghimire et al., 2008; Miehe et al., 2008; Tambe & Rawat, 2010). Their last remnants in southern Tibet have often been saved only because of their religious significance, but their syntaxonomic status remains unknown. This woods were much more widespread before the deforatation began ca. 600 years ago. Human impact relating to pastoral culture and intensive grazing are causing severe degradation of Tibetan woodlands, which support the transformation into the present degraded pastures (Miehe et al., 2008).

Does altitude, or rather continentality and precipitation gradients really play a major role in the classification of juniper woods in Middle Asia?

Most of the studies on the *Juniperus* woods of Tajikistan to date pointed the altitude as an important determinant of the distributional pattern of juniper forests and thus highlighting the thermophilous-cryophilous division. However, looking more generally and considering the entire Asian juniper-dominated vegetation, it seems that the primary variable is higher annual temperature range (continentality) with its associated strong phytogeographic division between the Turkestan province and the much more cold and continental Central Asian province. This is also reflected in the precipitation pattern with winter (spring) rainfall in Southwest Asia and summer peak rainfall in Central Asia. Such a strong climatic, floristic and environmental gradient is also apparent in many other vegetation types, especially steppes,

semi-deserts and scree vegetation (see Nowak et al., 2016, 2018, 2021) and should perhaps become a reason for the revision of the phytogeographic division of Middle & Central Asia. For this reason, we believe that the division of Tajikistan's juniper forests should take into account this fundamental difference in climatic conditions and may be reflected even at the level of the phytosociological class. Therefore, we classify the thermophilous stands as Mediterranean and Southwest Asian *Pino-Juniperetea*, and cryophilous ones to *Juniperetea pseudosabinae*. Such a division reflects a continentality and precipitation during the growing season rather than an altitudinal gradient, although in Tajikistan these two main vegetation types overlap and form interrelated zones in the montane belt. This is also proved by the composition of typical Irano-Turanian and Eastern Irano-Turanian with Euro-Siberian species in our plots (Fig. 5f and g). The first group clearly dominates in Zeravshan juniper stands and the second in the northern *J. polycarpos* ones. Probably the origin of these two types of woody vegetation in Middle Asia is much different. As mentioned above, south-western (Turkestan) juniper woods are direct descendants of palaeoshiblyak, which evolved from the Tertiary Turgay flora and then underwent xerophytisation after climate aridisation (Kamelin, 1967; Ovchinnikov, 1967, 1971; Pavlov, 1980) while Central Asiatic juniper stands may have a different history (Mao et al., 2010).

Should we classify Zeravshan juniper woods into a class of *Pino-Juniperetea* of Europe and turkestan woods into *Juniperetea pseudosabinae*?

Classifying our plots to the *Pino-Junipereta* Rivas-Martinez 1964 may raise some doubts. This is a vegetation type coined for juniper and pine dominated woods of the western Mediterranean (Brullo et al., 2001). The range of this vegetation has been extended much to the east, where it is represented by the order *Juniperetalia hemisphaericae*, which comprises two new alliances: *Berberidion aetnensis*, restricted to the central Mediterranean area, and *Berberido creticae-Juniperion foetidissimae*, distributed in the eastern Mediterranean (Brullo et al., 2001). However, Mucina et al. (2016) in their fundamental work on the European syntaxa inverted the name into *Junipero-Pinetea* stating that this vegetation type refers to various pine-dominated communities. Pine is absent in Tajikistan and Kyrgyzstan, and towards the south, the first sites of *Pinus wallichiana* and other species only begin in Pakistan and Afghanistan in monsoon-influenced areas. We believe that the stands of *J. polycarpos* var. *seravschanica* should be included in this class. The considerable floristic distinctiveness of Middle and Central Asian juniper woods can be expressed at the level of class and order. On the other hand, the class *Pino-Juniperetea* refers to mountainous habitats in a Mediterranan type climate zone with winter rains and skeletal and calcareous soils. In this respect, it fits very well with Tajik habitats.

For the Middle East region, the juniper open woodlands were classified along with pistachio stands. At a higher rank of phytosociological division, they were included in the *Junipero-Pistacietea* class (Zohary, 1973). Apart from the fact that this class was described incorrectly (Art. 2b, see Mucina et al., 2016), it seems that current knowledge does not justify the inclusion of both types, juniper and pistachio groves, in one vegetation class. In the mountains of Uzbekistan, Tajikistan and Kyrgyzstan, they are clearly distinguished in the landscape as two separate belts of vegetation. The juniper stands grow in the upper montane to lower subalpine belts and only occasionally overlap with pistachio woodlands (some plots of *J. seravshanica* in Hodzhamumin, Babatag and Kugitang Mts.). In our relevés from Tajikistan we have not noticed the occurrence of *Pistacia vera* in juniper woods.

Certainly, further studies throughout Southwest Asia are needed to answer the question to which class the thermophilous juniper woods of Tajikistan belong to, or whether there is a need to establish a separate class for this vegetation in the Irano-Turanian region. These studies should also include an analysis of the origin and distribution of all *Juniperus* sect. *sabina* species (Mao et al., 2010). At the present stage of the study, we are only certain that for western Middle Asia we can coin the order for thermophilous Zeravshan juniper woodlands that encompasses at least the Pamir-Alai, Hindukush and western Tian Shan montane belt.

The fact that the Central Asian juniper woods belong to the class *Juniperetea pseudosabinae* also raises some doubts. This is because of the southernmost, marginal location of this vegetation in Tajikistan in relation to the locus classicus in Altai. The vegetation in Altai on the northern limit has a physiognomy of mosaic dwarf scrub-grassland, while in Tajikistan it forms dense forest stands, especially in the Turkestan range. An additional complication is the fact that the author of the class synonymised it with the *Artemisio santolinifoliae-Berberidetea sibiricae* Ermakov, Chytrý and Valachovič (2006), which was referred to steppe and forest-steppe vegetation (Mirkin & Naumova, 2012), but originally to petrophytic communities (Ermakov et al., 2006). Moreover, they did not list *Juniperus pseudosabina* in the set of diagnostic species. In our opinion, these two vegetation types are fundamentally different and we are convinced that the *Juniperetea pseudosabinae* class should be preserved.

Nevertheless, the final arrangement of this class should take into account the results of further phytosociological studies in southern Tibet and the Himalayas in the communities of *J. recurva*, *J. convallium*, *J. indica* and *J. tibetica*.

Conservation

Following long-term timber exploitation by local communities, woodlands are one of the most threatened ecosystems in Tajikistan (Safarov, 2003). Approximately 90% of them have been legally or illegally logged in recent centuries, resulting in extraordinary deforestation and consequent landslides and soil denudation. Almost all authors describing juniper woods in Middle Asia indicate that their area and quality are rapidly decreasing. And it is important to notice that juniper woodlands in Tajikistan constitute half of the forested area. Their cutting for heating and construction purposes poses a serious threat not only to forest ecosystems of Middle Asia, but also to soil erosion and strong aridization. Secondary vegetation that develops after the tree and shrub layer has been cleared are tall-forb communities (Nowaket al., 2020c), which are often intensively used by grazing. Despite the implementation of some conservation measures and the establishment of the Zeravshan Nature Reserves and Tajik National Park, the process of juniper woods decline is still ongoing. A similar situation is taking place in neighbouring countries. In Kopet-dagh the area of juniper forests is constantly decreasing and only between 1930 and 1960 it decreased by 50%. The same applies to forests with *J. seravshanica*, in Kugitang Mts. on the border with Uzbekistan and Afghanistan. Due to human impact, the lower boundary of this juniper stand has shifted from approx. 800 to as high as 1,300 to 1,700 m a.s.l. (Popov, 1994). Currently, also due to climate change, we face a dramatic endangerement of woody ecosystems in Middle Asia and immediate action is needed to stop this degradation processes.

Author contributions

A.N. planned the research, A.N., S.Ś, M.N. conducted the field sampling, A.N. and S.Ś. wrote the draft of the manuscript, S.Ś. performed the statistical analyses, while all authors contributed to the writing.

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References

Adams RP (2001) Geographic variation in leaf essential oils and RAPDs of *Juniperus polycarpos* K. Koch in Central Asia. Biochemical Systematics and Ecology 29: 609–619. doi:10.1016/S0305-1978(00)00098-3.

Adams RP (2004) *Juniperus deltoides*, a new species, and nomenclatural notes on *J. polycarpos* and *J. turcomanica* (Cupressaceae). Phytologia 86: 47–51.

Adams RP (2016) Two new cases of chloroplast capture in incongruent topologies in the *Juniperus excelsa* complex: *J. excelsa* var. *turcomanica* comb. nov. and *J. excelsa* var. *seravschanica* comb. nov. Phytologia 98: 219–231.

Adams RP & Turuspekov Y (1998) Taxonomic reassessment of some Central Asian and Himalayan scale-leaved taxa of *Juniperus* (Cupressaceae) supported by random amplification of polymorphic DNA. TAXON 47: 75–83. doi:10.2307/1224021.

Ambarlı D, Naqinezhad A & Aleksanyan A (2020) Grasslands and shrublands of the middle east and the Caucasus. Encyclopedia of the World's Biomes 3–5: 714–724.

Braun-Blanquet J (1964) Pflanzensoziologie. Grundzüge der Vegetationskunde. Springer, Wien, Austria.

Brullo S, Giusso Del Galdo G & Guarino R (2001) The orophilous communities of the *Pino-Juniperetea* class in the Central and Eastern Mediterranean area. Feddes Repertorium 112: 261–308. doi: 10.1002/fedr.4921120308.

Cherepanov SK (1995) Plantae Vasculares URSS. Nauka, Leningrad, Russia.

Chytrý M, Tichý L, Holt J & Botta-Dukát Z (2002) Determination of diagnostic species with statistical fidelity measures. Journal of Vegetation Science 13: 79–90. doi:10.1658/1100-9233(2002)013[0079:-DODSWS]2.0.CO;2.

Çolak AH & Rotherham ID (2006) A review of the forest vegetation of Turkey: Its status past and present and its future conservation. Biology and Environment 106: 343–354.

Dengler J, Chytrý M & Ewald J (2008) Phytosociology: Encyclopedia of Ecology (ed. by SE Jørgensen & BD Fath) Elsevier B.V., pp. 2767–2779.

Douaihy CB, Restoux G, Machon N, Bou M, Douaihy CB, Restoux G, Machon N & Dagher-Kharrat MB (2013) Ecological characterization of the *Juniperus excelsa* stands in Lebanon. Ecologia Mediterranea 39: 169–180.

Ermakov N, Chytrý M & Valachovič M (2006) Vegetation of the rock outcrops and screes in the forest-steppe and steppe belts of the Altai and Western Sayan Mts., southern Siberia. Phytocoenologia 36: 509–545. doi: 10.1127/0340-269X/2006/0036-0509.

Farjon A (1992) The Taxonomy of multiseed Junipers (*Juniperus* sect. *Sabina*) in southwest Asia and East Africa (Taxonomic notes on Cupressaceae I). Edinburgh Journal of Botany 49: 251–283. doi:10.1017/S0960428600000524.

Fayvush GM & Aleksanyan AS (2016) Habitats of Armenia. Institute of Botany - National Academy of Sciences of the Republic of Armenia, Yerevan, Armenia.

Fet GN (1994) Vegetation of Southwest Kopetdagh: Biogeography and ecology of Turkmenistan. (ed. by V Fet & KI Atamuradov) Springer, Dordrecht, Germany, pp. 149–172.

Fisher M & Gardner AS (1995) The status and ecology of a *Juniperus excelsa* subsp. *polycarpos* woodland in the northern mountains of Oman. Vegetatio 119: 33–51. doi: 10.1007/BF00047369.

Freitag H (1971) Die natürliche Vegetation Afghanistans. Beiträge zur Flora und Vegetation Afghanistans I. Vegetatio 22: 285–344.

Ghimire BK, Lekhak HD, Chaudhary RP & Vetaas OR (2008) Vegetation analysis along an altitudinal gradient of *Juniperus indica* forest in Southern Manang Valley, Nepal. International Journal of Ecology and Development 9: 20–29.

Hennekens SM & Schaminée JHJ (2001) TURBOVEG, a comprehensive data base management system for vegetation data. Journal of Vegetation Science 12: 589–591. doi:10.2307/3237010.

Ignatov MS, Afonina OM & Ignatova EA (2006) Check-list of mosses of East Europe and North Asia. Arctoa 15: 1–130.

Kamelin RV (1967) About some remarkable anomalies in the flora of Mountainous Middle Asian province. Botanicheskii Zhurnal 52: 447–460.

Kamelin RV (1979) Kukhistanskiy okrug gornoy Sredney Azii (Botaniko-geograficheskiy analiz). Izdatelstvo Nauka, Leningrad, Russia.

Karger DN, Conrad O, Böhner J, Kawohl T, Kreft H, Soria-Auza RW, Zimmermann NE, Linder HP & Kessler M (2017) Climatologies at high resolution for the earth's land surface areas. Scientific Data 4: 170122.

Kartoolinejad D & Moshki A (2014) Changes in *Juniperus polycarpos* community in response to physiographical factors (Hezarmasjed Mountain, Iran). Austrian Journal of Forest Science 131: 215–232.

Konnov AA (1973) Archovye lesa Tadzhikistana. Donish, Dushanbe, Tajikistan.

Mao K, Hao G, Liu J, Adams RP & Milne RI (2010) Diversification and biogeography of *Juniperus* (Cupressaceae): variable diversification rates and multiple intercontinental dispersals. New Phytologist 188: 254–272. doi:10.1111/j.1469-8137.2010.03351.x.

Mazur M, Boratynska K, Marcysiak K, Didukh Y, Romo A, Kosinski P & Boratynski A (2004) Low level of inter-populational differentiation in *Juniperus excelsa* M. Bieb.(Cupressaceae). Dendrobiology 52: 39–46.

Memariani F, Akhani H & Joharchi MR (2016a) Endemic plants of Khorassan-Kopet Dagh floristic province in Irano-Turanian region: diversity, distribution patterns and conservation status. Phytotaxa 249: 31–117. doi:10.11646/phytotaxa.249.1.5.

Memariani F, Zarrinpour V & Akhani H (2016b) A review of plant diversity, vegetation, and phytogeography of the khorassan-kopet dagh floristic province in the irano-turanian region (northeastern Iran–southern Turkmenistan). Phytotaxa 249: 8–30. doi:10.11646/phytotaxa.249.1.4.

Miehe G, Miehe S, Will M, Opgenoorth L, Duo L, Dorgeh T & Liu J (2008) An inventory of forest relicts in the pastures of Southern Tibet (Xizang A.R., China). Plant Ecology 194: 157–177. doi:10.1007/s11258-007-9282-0.

Miehe G, Schlütz F, Miehe S, Opgenoorth L, Cermak J, Samiya R, Jäger EJ & Wesche K (2007) Mountain forest islands and Holocene environmental changes in Central Asia: A case study from the southern Gobi Altay, Mongolia. Palaeogeography, Palaeoclimatology, Palaeoecology 250: 150–166. doi:10.1016/j.palaeo.2007.03.022.

Mirkin BM, Manibazar N, Muchametsina VS, Alimbekova LM & Oniscenko LI (1986)Vtoroye priblizhenie klassifikatsii rastitelnosti poym rek MNR. XIII. Klassy Thero-Salicornietea Br.-Bl. et Tx. 43 em. Tx. 55. i Juniperetea pseudosalinae cl. nova (Second approximation of classification of the Mongolian People's Republic rivers' floodplain vegetation. XIII. Classes Thero-Salicornietea Br.-Bl. et Tx. 43 em. Tx. 55 and Juniperetea pseudosalinae cl. nova).— Manuscript; VINITI, Moskva, 09.07.86, N 2535-B86.

Mirkin BM & Naumova LG (2012) Sovremennoe sostoyanie osnovnykh kontseptsii nauki o rastitel'nosti. Akademia Nauk Respubliki Baskortostan, Gilem, Ufa, Russia.

Mucina L, Bültmann H, Dierßen K, Theurillat J, Raus T, Čarni A, Šumberová K, Willner W, Dengler J, Gavilán García R, Chytrý M, Hájek M, Pietro R, Iakushenko D, Pallas J, Daniëls FJA, Bergmeier E, Santos Guerra A, Ermakov N, Valachovič M, Schaminée JHJ, Lysenko T, Didukh YP, Pignatti S, Rodwell JS, Capelo J, Weber HE, Solomeshch A, Dimopoulos P, Aguiar C, Hennekens SM & Tichý L (2016) Vegetation of Europe: hierarchical floristic classification system of vascular plant, bryophyte, lichen, and algal communities. Applied Vegetation Science 19: 1–264. doi:10.21570/EDGG.Bull.33.28 29.

Nowak A & Nobis M (2013) Distribution, floristic structure and habitat requirements of the ripari-

an forest community *Populetum talassicae* ass. nova in the Central Pamir-Alai Mts (Tajikistan, Middle Asia). Acta Societatis Botanicorum Poloniae 82: 47–55.

Nowak A, Nobis M, Gębala M & Wasik P (2015) *Populetum pamiricae* ass. nova – an endemic forest association to Pamir in Tajikistan (Middle Asia). Open Life Sciences 10: 71–80. doi:10.1515/biol-2015-0009.

Nowak A, Nobis M, Nowak S, Gębala M & Nobis A (2017a) Phytosociology and ecology of deciduous forests in Tajikistan (Middle Asia). Phytocoenologia 47: 67–94. doi:10.1127/phyto/2017/0084.

Nowak A, Nobis M, Nowak S, Kotowski M, Klichowska E, Nobis M & Świerszcz S (2022) Syntaxonomy and ecology of thermophilous deciduous open woodlands and scrub vegetation in Tajikistan (Middle Asia). Dendrobiology 87: 47–68. doi:10.12657/denbio.087.004.

Nowak A, Nobis A, Nowak S & Nobis M (2018) Classification of steppe vegetation in the eastern Pamir Alai and southwestern Tian-Shan Mountains (Tajikistan, Kyrgyzstan). Phytocoenologia 48: 369–391. doi:10.1127/phyto/2018/0237.

Nowak A, Nobis M, Nowak S, Nobis A, Swacha G & Kącki Z (2017b) Vegetation of Middle Asia - The project state of art after ten years of survey and future perspectives. Phytocoenologia 47: 395–400. doi:10.1127/phyto/2017/0208.

Nowak A, Nobis M, Nowak S, Nobis A, Wróbel A, Świerszcz S, Klichowska E, Dembicz I & Kusza G (2020a) Illustrated flora of Tajikistan and adjacent areas (ed. by A Nowak & M Nobis) Polish Academy of Sciences, Botanical Garden Center for Biological Diversity Conservation and Polish Botanical Society, Warsaw-Cracow-Opole.

Nowak A & Nowak S (2022) Geobotany revisited – a glimpse at the blooming and influential discipline with its strong roots in the beauty of Nature and the pragmatic need of its protection. Acta Societatis Botanicorum Poloniae. (In press)

Nowak A, Nowak S, Nobis A & Nobis M (2016) Vegetation of feather grass steppes in the western Pamir Alai Mountains (Tajikistan, Middle Asia). Phytocoenologia 46: 295–315. doi:10.1127/phyto/2016/0145.

Nowak A, Świerszcz S, Nowak S, Hisorev H, Klichowska E, Wróbel A, Nobis A & Nobis M (2020b) Red list of vascular plants of Tajikistan – the core area of the Mountains of Central Asia global biodiversity hotspot. Scientific Reports 10: 6235. doi:10.1038/s41598-020-63333-9.

Nowak A, Świerszcz S, Nowak S & Nobis M (2020c) Classification of tall-forb vegetation in the Pamir-Alai and western Tian Shan Mountains (Tajikistan and Kyrgyzstan, Middle Asia). Vegetation Classification and Survey 1: 191–217. doi:10.3897/VCS/2020/60848.

Nowak A, Świerszcz S, Nowak S & Nobis M (2021) Vegetation diversity of screes and taluses of the Pamir and South-Western Tian Shan in Middle Asia. Folia Geobotanica 56: 43–67. doi:10.1007/s12224-021-09392-w.

Nüsser M & Dickore WB (2002) A tangle in the triangle: Vegetation map of the eastern Hindukush (Chitral, northern Pakistan). Erdkunde 56: 37–59.

Ogle DH, Wheeler P & Dinno A (2018) FSA: Fisheries Stock Analysis. R package version 0.8.22.

Oksanen J, Blanchet FG, Friendly M, Kindt R, Legendre P, McGlinn D, Minchin PR, O'Hara RB, Simpson GL, Solymos P, Henry M, Stevens H, Szoecs E & Wagner H (2019) vegan: Community Ecology Package. R package version 2.5-4.

Ovchinnikov PN (1957) Flora Tadzhikskoi SSR. T. I, Paprotnikoobraznye - Zlaki. Izdatelstvo Akademii Nauk SSSR, Moskva-Leningrad, Russia.

Ovchinnikov PN (1967) Osnovnye cherty rastitelnosti i rajony flory Tajikistana. Flora Tajikskoy SSR, Vol. 1. Izdatelstvo Nauka, Moskva-Leningrad, Russia.

Ovchinnikov PN (1971) Vidovoy sostav rastitelnogo pokrova ushchelya reki Varzob. 1. Vyshe rastenya: Flora i rastitelnost ushchelya reki Varzob (ed. by PN Ovchinnikov) Izdatelstvo Nauka, Leningrad, Russia.

Pavlov VN (1980) Rastitelnyi pokrov zapadogo Tian-Shanya. Izdat. Moskovskovo Univ., Moscow, Russia.

Popov KP (1994) Trees, shrubs and semishrubs in mountains of Turkmenistan: Biogeography and ecology of Turkmenistan (ed. by V Fet & KI Atamuradov) Kluwer Academic Publisher, Dotrecht, Germany, pp. 173–186.

R Core Team (2020) R: A language and environment for statistical computing.

Ravanbakhsh H, Hamzeh'ee B, Etemad V, Marvie Mohadjer MR & Assadi M (2016) Phytosociology of *Juniperus excelsa* M.Bieb. forests in Alborz mountain range in the north of Iran. Plant Biosystems 150: 987–1000. doi:10.1080/11263504.2014.1000420.

Roleček J, Tichý L, Zelený D & Chytrý M (2009) Modified TWINSPAN classification in which the hierarchy respects cluster heterogeneity. Journal of Vegetation Science 20: 596–602. doi:10.1111/j.1654-1103.2009.01062.x.

Sadykova GA, Aliev KU, Neshataeva VY & Amirkhanova NA (2018) Communities of *Juniperus excelsa* subsp. *polycarpos* (Cupressaceae) of High Mountain Daghestan. Botanicheskiĭ Zhurnal 103: 1514–1539. doi:10.1134/S0006813618120025.

Safarov N (2003) National strategy and action plan on conservation and sustainable use of biodiversi-

ty. Governmental Working Group of the Republic of Tajikistan, Dushanbe, Tajikistan.

Safarov NM (2018) Vegetation of the Central Pamir-Alay (floristic composition, phytocenology, zoning issues). Diss. Ph. D. thesis. Federal State Budgetary Institution of Science Botanical Institute named after V.L. Komarov Russian Academy of Sciences, Russia.

Sarangzai AM, Ahmed M, Ahmed A, Tareen L & Jan SU (2012) The ecology and dynamics of *Juniperus excelsa* forest in Balochistan-Pakistan. Pakistan Journal of Botany 44: 1617–1625.

Świerszcz S, Nobis M, Nowak S, Kotowski M, Klichowska E, Nobis A & Nowak A (2022) Syntaxonomy and ecology of mesophilous scrub vegetation in Tajikistan (Middle Asia). Phytocoenologia 51: 177–198. doi:10.1127/phyto/2022/0395.

Tambe S & Rawat GS (2010) The alpine vegetation of the Khangchendzonga landscape, Sikkim Himalaya. Mountain Research and Development 30: 266–274. doi:10.1659/MRD-JOURNAL-D-09-00058.1.

The Plant List. http://www.theplantlist.org/.

Theurillat J-P, Willner W, Fernández-González F, Bültmann H, Čarni A, Gigante D, Mucina L & Weber H (2021) International code of phytosociological nomenclature. 4th ed. Applied Vegetation Science 24: e12491. doi:10.1111/avsc.12491.

Tichý L (2002) JUICE, software for vegetation classification. Journal of Vegetation Science 13: 451–453. doi:10.1111/j.1654-1103.2002.tb02069.x.

Tsiourlis G, Konstantinidis P & Xofis P (2007) Taxonomy and ecology of phryganic communities with *Sarcopoterium spinosum* (L.) Spach of the Aegean (Greece). Israel Journal of Plant Sciences 55: 15–34. doi:10.1560/IJPS.55.1.15.

Wesche K, Miehe S & Miehe G (2005) Plant communities of the Gobi Gurvan Sayhan National Park (South Gobi Aymak, Mongolia). Candollea 60: 149–205.

Willner W (2006) The association concept revisited. Phytocoenologia 36: 67–76. doi:10.1127/0340-269X/2006/0036-0067.

Willner W (2020) What is an alliance? Vegetation Classification and Survey 1: 139–144. doi:10.3897/VCS/2020/56372.

Zakirov KZ (1984) Rastitel'nyy pokrov Uzbekistana i puti yego ratsional'nogo ispol'zovaniya. Tom IV. Izdatelstvo FAN Uzbekskoy SSR, Tashkent, Uzbekistan.

Zapryagaeva WI (1976) Lesnyje resursy Pamiro-Alaja. Nauka, Leningrad, Russia.

Zohary M (1973) Geobotanical foundations of the Middle East. Volumes 1 & 2. Gustav Fischer Verlag, Stuttgart, Germany.