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GRASSLANDS OF ASIA

The *Pistacietea verae*: a new class of open, deciduous woodlands in Middle and Southwestern Asia

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Abstract

Aims: To analyse the syntaxonomy of open, deciduous woodlands at the southern margin of the steppe zone in the colline and montane belts of the Pamir-Alai, western Tian Shan and Iranian Mountains (Irano-Turanian region). **Study area:** Tajikistan (Middle Asia) and Iran (Southwestern Asia). **Methods:** We prepared two datasets: the first dataset contained 110 relevés from Tajikistan and Iran representing pistachio groves, the second one was a comparative dataset of 1,276 relevés of pistachio groves and floristically related woody and grassland phytocoenoses from the Irano-Turanian and Mediterranean regions. These two datasets were classified separately with the modified TWINSPAN algorithm with pseudospecies cut levels 0%, 2%, 10% and 25%, and total inertia as a measure of cluster heterogeneity. Diagnostic species were identified using the phi coefficient as a fidelity measure. A NMDS ordination was used to explore the relationships between the distinguished groups. **Results:** We found that *Pistacia* open woodlands are very distinctive in terms of species composition, including numerous endemics. Our observations in Pamir-Alai, Kopet-Dagh, Zagros, Alborz and other Central and southern mountains of Iran proved that pistachio open woodlands form distinct zonal vegetation of the colline-montane belt. We thus propose a new class *Pistacietea verae*, with the order *Pistacietalia verae* and appropriate type alliance *Pistacion verae*, including two associations: *Pistacietum verae* and *Pistacietum khinjuk*. **Conclusions:** Our research has shown that the *Pistacia* open woodlands are a distinct vegetation typical of the Irano-Turanian region and due to its specific ecology, phytogeography and unique species composition, should be regarded as a vegetation class *Pistacietea verae*. It needs further examination and comparison with similar vegetation in the western Irano-Turanian and Hindu Kush regions. Recognizing the unique pistachio open woodlands as a distinct vegetation class in the Irano-Turanian region is crucial for establishing effective conservation strategies in these understudied yet ecologically significant ecosystems, spanning potentially from the Zagros, Alborz and other Central and southern Mountains of Iran to Tajikistan, Afghanistan, Uzbekistan, and Pakistan.

Taxonomic reference: Plants of the World Online (POWO 2023), with World Flora Online (WFO 2023) for some problematic cases and Nobis et al. (2020) for *Stipa* spp.

Syntaxonomic references: Mucina et al. (2016) for SE European syntaxa, Nowak et al. (2022a, 2022b) for all other syntaxa.

Abbreviations: NMDS = Non-metric multidimensional scaling.

Keywords

grove, Iran, Middle Asia, Pamir Alai Mts, phytosociology, *Pistacietea verae*, Southwestern Asia, syntaxonomy, Tajikistan, vegetation classification, wild orchard

Introduction

The concept of the vegetation class as the most comprehensive syntaxonomic unit was introduced by Braun-Blanquet (1928). A class of vegetation refers to a large and usually widely distributed biogeographical unit (Pignatti et al. 1995; Loidi et al. 2020) and is mainly characterised by a specific set of diagnostic taxa, its ecological uniqueness and a distinct pattern of distribution (i.e. chorology; Pignatti et al. 1995). According to Pignatti et al. (1995), a vegetation class is a syntaxon of the highest rank, occupying a common ecological space, having member associations, and being recognisable by the presence of a set of diagnostic taxa that are chorologically homogeneous. According to the fourth criterion proposed by Pignatti et al. (1995), a class is a unique and repeatable structure that exists due to its unique and well-defined ecology. The vegetation class itself is the expression of the ecological and dynamic diversity occurring within it, but it can also express a certain biogeographical-evolutionary legacy (Loidi 2020).

All or only few of the aforementioned criteria have been applied for delimitation of a vegetation class (see example studies: Akhani and Mucina 2015; Noroozi et al. 2017). However, most frequently, the floristic composition and ecological uniqueness have been independently utilised for the delimitation of the vegetation classes. For example, the *Seslerietea variae* Br.-Bl. 1948 was initially characterised by a set of associations colonizing alpine limestone grasslands (Pignatti et al. 1995) whereas the *Querco-Fagetea* Br.-Bl. et Vlieger 1937 was mainly distinguished due to its floristic composition, particularly the occurrence of taxa such as *Lamium galeobdolon* subsp. *galeobdolon*, *Euonymus europaeus*, *Athyrium filix-femina*, *Dryopteris filix-mas*, *Hieracium murorum*, *Lactuca muralis* or *Poa nemoralis* (Mucina et al. 1993). In addition to floristic composition, ecology and phytogeography, vegetation classes might be easily distinguished by their physiognomy and spatial structure. For example, the division of deciduous woody vegetation into forests (*Querco-Fagetea*) and shrubland (*Crataego-Prunetea*) is widely accepted. The latter class is considered as a successional phase towards mature deciduous stands in mesic habitats and is predominantly a result of human activities. However, one should also take into account the floristic composition, ecological characterisation and phytogeographical distinction along with vegetation structure and physiognomy of the vegetation (Pignatti et al. 1995). All these features are often related to the natural history and phylogeny of vegetation in a particular phytogeographical unit. For example, both pistachio open woodlands and juniper stands have common roots in the so-called *proto-šhiblyak* (Kamelin 1967).

The so-called wild orchards, groves and open woodlands were relatively poorly known in Middle Asia. This is mainly due to the fact that they were considered as secondary vegetation replacing forests and thus often ignored in synthetic vegetation studies (see Zapryagaeva 1976). This vegetation constitutes a complex ecosystem of woody and herbaceous plants and is often included into forest-steppe vegetation, which is considered to be shaped by "two worlds" that are very distinct in terms of structure, ecology and function (Erdős et al. 2018). Additionally, there is no unequivocal approach among the Russian and Tajik authors how to treat the so-called *šhiblyak*, i.e. shrubland dominated by such taxa as *Acer* spp., *Crataegus* spp., *Cercis griffithii*, *Celtis* spp., *Ziziphus jujuba*, *Pistacia* spp., *Caragana* spp., *Lonicera* spp., *Zygophyllum* spp., *Prunus* spp. (subg. *Amygdalus*), *Atraphaxis* spp. and *Punica granatum*. Previously, this vegetation was classified into mesophilous forest vegetation (e.g. Ovchinnikov 1957) or into xerophytic open woodlands (redkolesa; e.g. Safarov 2018). It was also considered as part of cold-deciduous open xeromorphic scrub (sensu Frey and Probst 1986; Carle and Frey 1977), which was originally termed "Pistazien-Mandel-Ahorn-Trockenwald" by Bobek (1951). This vegetation type is located in the lower montane and colline belts with a lower precipitation of ca. 200–400 mm/yr compared to the upper montane belt (with ca. 1,500–2,000 mm/yr; Assadi 1986; Safarov 2018; Nowak et al. 2022a). Our recent phytosociological studies have shown that the woody vegetation of Tajikistan should be divided into thermophilous open woodlands (pistachio stands), mesophilous shrubland (*šhiblyak* as a seral vegetation to mesic broad-leaved forests or a thermophilous shrubland on edaphically extreme habitats), juniper stands (with two very different types) and xeric shrubland that develop on initial soils (Nowak et al. 2022b, 2022a; Świerszcz et al. 2022). *Pistacia* woodlands are distributed in the Irano-Turanian and Eastern Mediterranean phytogeographical regions (e.g. Zohary 1973). Middle Asia is considered the centre of pistachio distribution and speciation, including the deciduous species *P. vera*, *P. khinjuk* and *P. eurycarpa*. Based on recent molecular studies, the genus *Pistacia* has evolved in Middle Asia due to the aridification of the climate after the retreat of the Paratethys in the Miocene (Li et al. 2020). They are distributed mainly in colline and montane belts between 500 and 2,000 m a.s.l. Other species of the genus *Pistacia* present in the region are *P. atlantica*, *P. terebinthus*, *P. palaestina*, *P. chinensis*, *P. eurycarpa* and *P. lentiscus* (Bozorgi et al. 2013; Xie et al. 2014; Kozhoridze et al. 2015). However, *P. vera* and *P. khinjuk* are considered as the oldest and most widespread taxa that form zonal open woodlands in the Irano-Turanian region (Zohary 1973). Additionally, in Southeast Caucasus, the similar arid open woodlands of *P. atlantica* were mentioned (Lachashvili et al. 2020).

Given the exceptional composition and distribution in the landscape of pistachio open woodlands in Tajikistan and other areas of the Irano-Turanian region, and obtaining data from the different vegetation units closely related with these woodlands, we decided to check whether pistachio open woodlands are a distinct vegetation type at the class level. We address the following questions: (i) What is the floristic distinction and the biological content of pistachio open woodlands in Irano-Turanian region? (ii) What are the ecological and chorological characteristics of pistachio open woodlands? (iii) How are the distinguished syntaxa related to other similar vegetation types known from Asia and Europe?

Study area

In the current study, the sampling was mainly conducted in the Pamir-Alai in Tajikistan and Zagros Mts in Iran. These are long ranges, mainly stretching from east to west with a number of summits exceeding 4,000 m a.s.l. In the Pamir-Alai the highest summit is Somonii Peak (7,495 m a.s.l.), in Zagros Mts is Zard Kuh (4,548 m a.s.l.).

The eastern outskirts of the study area (in Tajikistan; 36.6743–41.0391°N, 67.3393–75.1250°E) are characterised by spring rather than winter rains and high continentality (Djamali et al. 2012). In southwestern Tajikistan the sub-humid climate predominates. The average temperature in June is around 28 °C in the colline belt, and 13 °C in the alpine belt. The annual precipitation ranges here from about 600 mm in the lowlands to ca. 1,700 mm on the southern slopes of the upper montane belt (Latipova 1968; Narzikulov and Stanyukovich 1968). However, due to differences in altitude, orography and wind conditions, there are significant local deviations from the general bioclimatic patterns. Towards the east, winter temperature minima are more extreme and continentality increases compared to neighbouring Mediterranean and Saharo-Sindian regions (Djamali et al. 2012).

In the western part of the study area, in Iran, Armenia, Azerbaijan and inland Turkey, winter precipitation is lower and summer precipitation slightly higher, reflecting similarity to the Mediterranean climatic pattern. In the area of pistachio grove sampling (Zagros Mts, 29.1062–45.9406°N, 35.1067–52.6405°E), the annual precipitation ranges from 300 mm in the colline belt to 850 mm in the montane belt, with average temperatures ranging from about 30 °C to 15 °C, respectively (Djamali et al. 2012).

In comparison with Euro-Siberian and Mediterranean regions (*sensu* Zohary 1973), both areas of the study area are characterised by distinctive features of the Irano-Turanian climatic region, i.e. relatively low annual precipitation, predominant late winter-spring rainfall, prolonged summer drought, extreme seasonal and diurnal temperature variations, bi-seasonal plant dormancy (in southernmost regions) and extremely low humidity (Djamali et al. 2012).

The uniqueness of the Irano-Turanian region is linked to its extraordinary richness of plants, many of which are endemic. For example, the vascular plant flora consists of more than 8,000 species in Iran (Jalili and Jamzad 1999; Noroozi et al. 2019), 4,300 in Tajikistan (Nowak et al. 2020), 4,300 in Uzbekistan (Sennikov et al. 2016) and 4,000 in Kyrgyzstan (Lazkov and Sultanova 2014). The present characteristics of the woody vegetation have been influenced by the centuries-old use of wood as a building material and energy source, and by pastoralism, especially the grazing of sheep, goats, cows and horses. In addition, in most part of Middle and Southwest Asia there was no glaciation during the Pleistocene, allowing the Tertiary flora to persist (Safarov 2003).

Methods

Data sampling

The first (main) dataset included 110 relevés of pistachio open woodlands and xeric scrubs from Tajikistan and Iran (Figure 1). This dataset was used for floristic and phytogeographical analysis of the pistachio open woodlands. The potential class range was delimited according to the distribution of wild *Pistacia vera* occurrences and the literature with pistachio open woodlands reports, sometimes as *Pistacieta* vegetation (e.g. Kamakhina 1994; Popov 1994; Barazani et al. 2003; Kozhoridze et al. 2015; Tojibaev et al. 2017; Breckle and Rafiqpoor 2020; Lachashvili et al. 2020). Plant material collected during the field studies is preserved at OPUN (Opole University, Poland) and KRA (Jagiellonian University, Poland).

The second dataset consisted of 1,276 relevés including the first dataset, but augmented with a wide range of woody and grassland phytocoenoses growing in the study area and neighbouring regions to determine the relationships of pistachio open woodlands with neighbouring vegetation. For this purpose, we selected vegetation types that show spatial (*Pino-Juniperetea*, *Juniperetea pseudosabinae*, *Carpino-Fagetea*, *Prangetea ulopterae*), ecological (*Quercetea ilicis*, *Quercetea pubescentis*, *Crataego-Prunetea*) or dynamic (*Stipo-Trachynietea distachyae*) relationships with open woodlands of pistachio in the Irano-Turanian or Mediterranean regions. The data set included 110 relevés of pistachio open woodlands and xeric scrubs from Tajikistan (Nowak et al. 2022b) and Iran (A. Naqinezhad unpubl.), 352 of *Carpino-Fagetea* forests from Tajikistan (Nowak et al. 2017a) and Iran, 119 of *Pino-Juniperetea* and *Juniperetea pseudosabinae* stands from Tajikistan (Nowak et al. 2022a), 231 of *Quercetea ilicis* and *Quercetea pubescentis* forests from Italy and Greece (Tsiourlis et al. 2007; Gianguzzi and Bazan 2019), 146 of *Crataego-Prunetea* shrubland from Tajikistan (*šhiblyak*; Nowak et al. 2022b; Świerszcz et al. 2022), 156 of *Prangetea ulopterae* tall-forb communities from Tajikistan (Nowak et al. 2020) and 180 of *Stipo-Trachynietea distachyae* pseudosteppes from Tajikistan (Świerszcz et al. 2020).

Depending on the physiognomy of vegetation, the plot sizes varied from 10 m² in grassland communities to 100 m² in open woodlands and 400 m² in forests in such way to enable providing homogeneity in terms of structure,

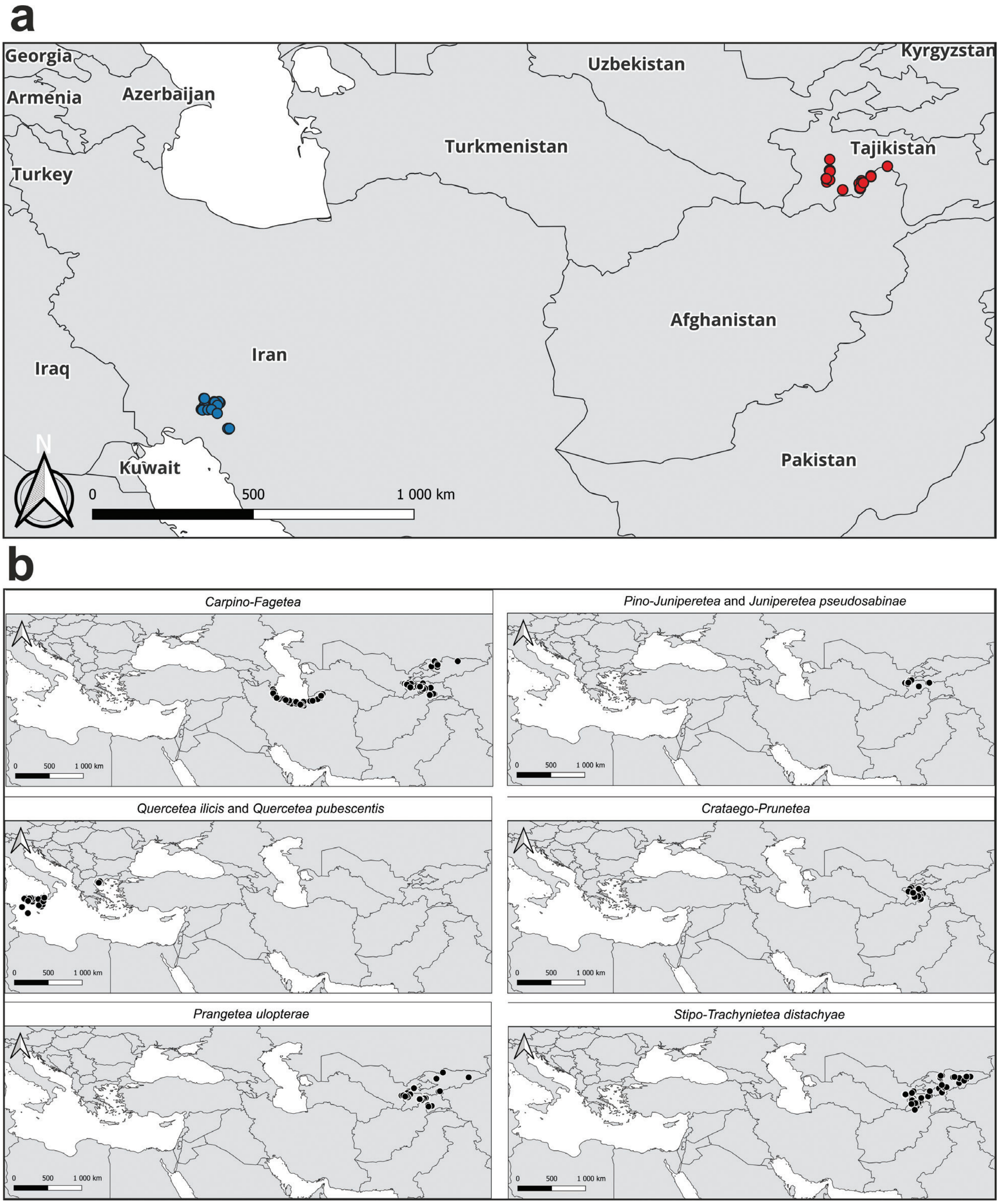

Figure 1. (a) Map showing the distribution of vegetation plots from dataset of pistachio open woodlands (110 relevés) with blue circles represent the *Pistacietum khinjuk*, red circles the *Pistacietum verae*. (b) Map showing distribution of the plots from the second comparative dataset (1,276 relevés) including woody and grassland phytocoenoses with close relationship with analysed vegetation in the Irano-Turanian or Mediterranean regions: *Carpino-Fagetea* forests (352 relevés), *Pino-Juniperetea* and *Juniperetea pseudosabinae* stands (119 relevés), *Quercetea ilicis* and *Quercetea pubescentis* forests from (321 relevés), *Crataego-Prunetea* shrubland (146 relevés), *Prangetea ulopterae* tall-forb communities (156 relevés) and *Stipo-Trachynietea distachyae* pseudosteppes (180 relevés).

species composition and habitat conditions of the phytocoenosis following the Braun-Blanquet approach (Chytrý and Otýpková 2003). For each vegetation plot, all species of vascular plants were recorded with the use of 7-degree cover-abundance scale (r, +, 1, 2, 3, 4, 5; Braun-Blanquet 1928). Species were recorded in five layers of the wood or scrub stands: t1 – higher tree layer (> 7 m), t2 – middle tree layer (3–7 m), t3 – lower tree layer (< 3 m), s1 – shrub layer, hl – herb layer. 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 ± 3 m and the WGS-84 geographic system.

Data analyses

The relevés from Tajikistan were stored in TURBOVEG format (Hennekens and Schaminée 2001) in the Vegetation of Middle Asia Database (GIVD ID AS-00-003; Nowak et al. 2017b). The two datasets were analysed separately in the JUICE software (Tichý 2002). A modified TWINSPAN analysis (Roleček et al. 2009) was performed on the pistachio open woodlands relevé group (90 relevés from Tajikistan and 20 from Iran) in order to classify them with the use of cutoff levels of 0%, 2%, 10% 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 at the association to order level were identified using the phi coefficient as a fidelity measure (Tichý and Chytrý 2006). The size of all groups was standardised to equal size, and the Fisher's exact test ($p < 0.05$) was applied in order to exclude species with non-significant occurrence optimum in a particular cluster. Species with a phi coefficient ≥ 0.20 and frequency ≥ 20% were considered diagnostic for the *P. vera* stands (excluding species with a wide ecological amplitude or diagnostic for other syntaxonomic units, based on expert judgement), while for a very distinct community of *P. khinjuk* we applied phi ≥ 0.60 and frequency ≥ 45%. Diagnostic species for the class *Pistacietea verae* were identified based on the analysis of the entire dataset used in these studies for all types of naturally occurring woody and grassland phytocoenoses and pistachio open woodlands. For determining a diagnostic value for the class *Pistacietea verae*, we considered species with phi ≥ 0.20, standardised to equal group size. We excluded taxa with wide geographical distribution and ruderal species (e.g. *Anagallis foemina* or *Vicia sativa* subsp. *nigra*) from the diagnostic species group, selected on the base of expert knowledge.

Plot sizes in the available data sources varied greatly from 10 to 400 m^2 between syntaxa and also regions, but this was unavoidable at this current stage as these were the only available data. We acknowledge that plot sizes that vary so greatly will have a significant impact on species constancies and thus phi values when syntaxa sampled with different mean plot sizes are compared (Dengler et al. 2009). Effectively, the frequencies and thus phi values in syntaxa sampled with larger plot sizes are systematically overestimated compared to the frequency and phi-values of syntaxa sample with smaller plot sizes. Since there is no easy way to correct for this bias, we present the raw outcomes, but invite the readers to carefully consult the row with the mean plot sizes to estimate which of the given diagnostic species might be artefacts due to the variation in plot sizes.

A shortened synoptic table of pistachio open woodlands vegetation in Middle and Southwestern Asia with the fidelity and relative percentage frequency of all diagnostic species and other species with frequency > 30% was compiled (Table 1) and the full synoptic table is available in the Suppl. material 1. A synoptic table of the entire dataset used to compare pistachio open woodlands with related vegetation types of forest, shrubland and grassland phytocoenoses is shown in Suppl. material 2. An analytical table of the *Pistacietea verae* is available in Suppl. material 3. New syntaxa are proposed according to the ICPN (Theurillat et al. 2021). In addition, in Table 2, we present species recorded in pistachio open woodlands endemic to Tajikistan, identified based on our field data and the description of the ecology of plants in the Flora of Tajikistan (Ovchinnikov 1957, 1963, 1968, 1975, 1978, 1981; Chukavina 1984; Kochkareva 1986; Kinzikaeva 1988; Rasulova 1991).

To visualize the vegetation grouping and to highlight the relationships between relevés and species, non-metric multidimensional scaling (NMDS) was performed after downweighting of rare species. It was computed using the 'vegan' package version 2.5.4 (Oksanen et al. 2019) in R version 4.2.2 (R Core Team 2022). Species cover data were log-transformed ($\ln(x + 1)$) without down-weighting of rare taxa. Differences in climatic factors (mean annual temperature, temperature annual range, mean temperature of warmest and coldest quarter, sum of annual precipitation, precipitation of warmest and coldest quarter) and richness of phytogeographical elements (Mediterranean, Irano-Turanian, Central Asian and Eurosiberian) between the most similar groups were assessed 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 version 4.2.2 (R Core Team 2022). Climatic data were extracted from the CHELSA database, version 2.1 (http://chelsa-climate.org; Karger et al. 2017). The floristic elements were defined on the basis of the species ranges presented in POWO (https://powo.science.kew.org/) and GBIF (https://www.gbif.org/), and according to the phytogeographical divisions of Djamali et al. (2012).

Results

The uniqueness of floristic composition of pistachio open woodlands

The total number of taxa recorded in the dataset from *Pistacia* woodlands in Tajikistan and Iran (110 relevés) was 616. Within this dataset, the most diagnostic taxa

Table 1. Shortened synoptic table of pistachio open woodlands vegetation in Middle and Southwestern Asia belonging to the class *Pistacietea verae* (*Pistacietum verae* and *Pistacietum khinjuk*). The phi values × 100 (in superscript) are only shown when positive. Main values are species frequencies (in percent). Other species with a frequency higher than 30% in the full dataset are also shown. Abbreviations in layer column: t1 – higher tree layer, t2 – middle tree layer, t3 – lower tree layer, sl – shrub layer, hl – herb layer. A full synoptic table is presented in Suppl. material 1.

		Pistacietum verae		***Pistacietum khinjuk***	
Number of relevés		90		20	
Mean plot size (m^2)		100		200	
	Layer	Freq.	phi	Freq.	phi
Ass. *Pistacietum verae*					
Pistacia vera	t2	77	85	0	·
Aegilops triuncialis	hl	70	73	0	·
Bromus popovii	hl	52	67	0	·
Anagallis arvensis subsp. *foemina*	hl	60	62	0	·
Vulpia myuros	hl	42	57	0	·
Prunus verrucosa	sl	40	53	0	·
Brachypodium distachyon	hl	40	53	0	·
Taeniatherum caput-medusae	hl	29	34	0	·
Phlomoides hissarica	hl	26	46	0	·
Eremurus roseolus	hl	23	46	0	·
Ferula tadshikorum	hl	23	43	0	·
Artemisia baldshuanica	hl	22	41	0	·
Asparagus bucharicus	hl	21	39	0	·
Galagania tenuisecta	hl	21	35	0	·
Cousinia grigoriewii	hl	20	33	0	·
Acer pentapomicum	sl	20	26	0	·
Medicago rigidula	hl	31	28	25	20
Avena sterilis subsp. *ludoviciana*	hl	61	58	0	·
Inula orientalis	hl	52	50	0	·
Vicia sativa subsp. *nigra*	hl	44	38	0	·
Amygdalus bucharica	sl	38	43	0	·
Ass. *Pistacietum khinjuk*					
Pistacia eurycarpa	t3	0	·	70	82
Pistacia khinjuk	t3	0	·	60	76
Achillea nobilis subsp. *neilreichii*	hl	0	·	55	72
Arum rupicola	hl	0	·	50	69
Lepidium chalepense	hl	0	·	45	65
Nepeta macrosiphon	hl	0	·	45	65
Centaurea intricata	hl	0	·	45	65
Pyrus glabra	t3	0	·	45	65
Cirsium syriacus	hl	0	·	45	65
Calendula arvensis	hl	0	·	45	65
Other species (sorted alphabetically)					
Anchusa strigosa	hl	0	·	35	57
Arenaria serpyllifolia	hl	49	36	0	·
Asperugo procumbens	hl	1	·	35	49
Asperula glomerata subsp. *eriantha*	hl	0	·	40	61
Astragalus brachycalyx	hl	0	·	40	61
Avena barbata	hl	0	·	40	61
Bellevalia glauca	hl	0	·	35	57
Bromus fasciculatus	hl	0	·	35	57
Bromus oxyodon	hl	46	34	0	·
Bromus tomentellus	hl	0	·	35	56
Bunium paucifolium	hl	0	·	40	61
Centaurea virgata subsp. *squarrosa*	hl	1	·	40	38
Chaerophyllum macropodum	hl	0	·	40	61
Chrozophora tinctoria	hl	0	·	35	57
Cousinia bachtiarica	hl	0	·	40	61
Crepis pulchra	hl	80	54	0	·
Dianthus orientalis	hl	0	·	35	57
Elaeosticta hirtula	hl	50	36	0	·
Eryngium billardieri	hl	0	·	40	61
Euphorbia franchetii	hl	39	35	0	·
Fraxinus ornus	t2	0	·	45	59
Galium aparine	hl	50	24	20	·
Galium spurium	hl	46	27	0	·
Grammosciadium scabridum	hl	0	·	35	57
Helichrysum oligocephalum	hl	0	·	35	57
Hordeum bulbosum	hl	67	46	35	17
Lactuca orientalis	hl	1	·	35	50
Lepyrodiclis stellarioides	hl	31	46	0	·
Linum corymbulosum	hl	32	35	0	·
Lolium temulentum	hl	40	51	0	·
Mentha longifolia var. *asiatica*	hl	0	·	35	39
Nonea persica	hl	0	·	35	57
Notobasis syriaca	hl	0	·	20	43
Parietaria lusitanica subsp. *serbica*	hl	42	48	0	·
Phleum phleoides	hl	39	37	0	·
Phlomis olivieri	hl	0	·	40	61
Phlomis persica	hl	0	·	40	61
Plantago lanceolata	hl	33	14	30	·
Poa bulbosa	hl	43	10	35	·
Rostraria cristata	hl	0	·	35	57
Rumex dentatus subsp. *halacsyi*	hl	0	·	40	60
Salvia persepolitana	hl	0	·	35	57
Salvia syriaca	hl	0	·	40	61
Salvia virgata	hl	0	·	35	55
Sanguisorba minor	hl	0	·	40	59
Scandix pecten-veneris	hl	31	24	35	29
Sonchus asper subsp. *glaucescens*	hl	0	·	35	57
Stachys pilifera	hl	0	·	40	61
Teucrium orientale	hl	0	·	40	61
Torilis leptophylla	hl	7	3	35	51
Veronica arvensis	hl	12	4	40	38

for *Pistacia khinjuk* stands were as follows: *Pistacia eurycarpa*, *Pistacia khinjuk*, *Achillea nobilis* subsp. *neilreichii*, *Arum rupicola*, *Nepeta macrosiphon*, *Notobasis syriaca*, *Centaurea intricata*, *Calendula arvensis*, *Pyrus glabra*, *Lepidium chalepense*. In the group of *Pistacia vera* open woodlands in Tajikistan, the ten species with highest scores of fidelity were: *Pistacia vera*, *Crepis pulchra*, *Anagallis arvensis* subsp. *foemina*, *Brachypodium distachyon*, *Aegilops triuncialis*, *Vulpia myuros*, *Lolium temulentum*, *Vicia sativa* subsp. *nigra*, *Euphorbia franchetii*, *Hordeum bulbosum*. It is worth noting that within the sampled plots some endemic and threatened species occurred, and many of them have the optimum of distribution in pistachio open woodlands (Table 2).

The ecological distinction against other woody or herbaceous vegetation in Middle Asia

Seven main groups determined by using TWINSPAN are shown in the NMDS ordination plot (Figure 2). Although pistachio open woodlands showed much internal heterogeneity in our collection (data from Pamir-Alai and Zagros), they formed a rather distinct group. As expected, the most closely related vegetation type were the pseudosteppes (secondary thermophilous grassland). Open woodlands with *Pistacia vera* had also a close relationship with *šhiblyak* (Figure 2).

The differences in climatic conditions and the habitats of the vegetation types that were most similar to the pis-

Table 2. Endemic species for Tajikistan recorded in pistachio open woodlands. As species endemic to pistachio open woodlands we consider all taxa that were found during our surveys in this certain vegetation type and have endemic status within Tajikistan (not considering their relative frequency against other habitats in which they occur). Endemic species with optimum of distribution in pistachio open woodlands are these that have the highest frequencies in pistachio open woodlands, based on our data set of 5,824 relevés from Middle Asia.

	Endemic species names
Endemic species of pistachio open woodlands	*Allium gypsaceum*, *A. gypsodictyum*, *Amygdalus bucharica*, *Artemisia baldshuanica*, *A. kochiiformis*, *Arum korolkowii*, *Asparagus bucharicus*, *Astragalus ammophilus*, *A. chionanthus*, *A. hissaricus*, *A. nobilis*, *A. retamocarpus*, *A. trachycarpus*, *A. viridiflorus*, *Bunium hissaricum*, *Calophaca grandiflora*, *Cotoneaster hissaricus*, *Cousinia sclerophylla*, *Cuscuta bucharica*, *Dianthus darvazicus*, *Dianthus baldshuanicus*, *Elaeosticta bucharica*, *E. conica*, *E. tschimganica*, *Eremurus bucharicus*, *Eremurus comosus*, *E. olgae*, *E. roseolus*, *E. suworowii*, *Ferula clematidifolia*, *F. decurrens*, *F. tadshikorum*, *Fessia puschkinioides*, *Fritillaria bucharica*, *Gagea paedophila*, *Hypogomphia bucharica*, *Jurinea bucharica*, *Klasea chartacea*, *Korshinskia olgae*, *Ladyginia bucharica*, *Medicago lanigera*, *Nigella bucharica*, *Onosma baldshuanica*, *Paulita ovczinnikovii*, *Phlomoides tadshikistanica*, *Polygonum ovczinnikovii*, *Potentilla kulabensis*, *Primula baldshuanica*, *Ranunculus sewerzowii*, *Rhamnus dolichophylla*, *Rosa huntica*, *R. ovczinnikovii*, *Semenovia bucharica*, *Solenanthus plantaginifolius*, *Taraxacum nuratavicum*, *Tulipa tubergeniana*, *Ungernia tadshicorum*, *Valerianella ovczinnikovii*, *V. vvedenskyi*
Endemic species with optimum of distribution in pistachio open woodlands	*Ajuga turkestanica*, *Allium rosenbachianum*, *Anemone bucharica*, *Artemisia prasina*, *Astragalus babatagi*, *A. brachycalyx*, *A. bucharicus*, *A. corydalinus*, *A. darwasicus*, *A. discessiflorus*, *A. quisqualis*, *A. susianus*, *A. vegetior*, *A. xanthomeloides*, *Asyneuma argutum* subsp. *baldshuanicum*, *Cousinia bachtiarica*, *C. grigoriewii*, *Euphorbia sogdiana*, *Fallopia baldschuanica*, *Galium nupercreatum*, *Iris bucharica*, *I. lineata*, *Onobrychis baldshuanica*, *Oxytropis linczevskii*, *O. tenuirostris*, *Phlomoides baldschuanica*, *Prangos fedtschenkoi*, *Tulipa subquinquefolia*

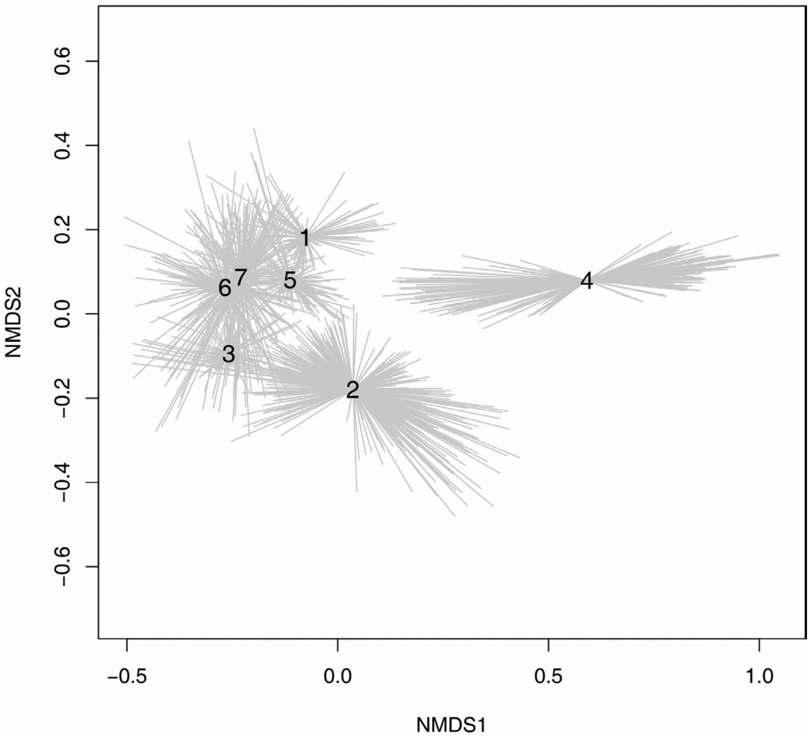

Figure 2. NMDS ordination of 1,276 plots presenting the relationships between pistachio open woodlands all types of naturally occurring woody and related grassland phytocoenoses analysed in this study. Abbreviations: 1 – *Pistacietea verae* (110 relevés, Tajikistan and Iran), 2 – *Carpino-Fagetea* (352 relevés, Tajikistan), 3 – *Pino-Juniperetea* and *Juniperetea pseudosabinae* (119 relevés, Tajikistan), 4 – *Quercetea ilicis* and *Quercetea pubescentis* (213 relevés, Mediterranean Basin), 5 – *Crataego-Prunetea* (146 relevés, Tajikistan), 6 – *Prangetea ulopterae* (156 relevés, Tajikistan) and 7 – *Stipo-Trachynietea distachyae* (180 relevés, Tajikistan).

tachio open woodlands are presented in Figure 3. Interestingly, with exceptions such as the precipitation of the coldest quarter, these conditions were significantly different. The pistachio groves differed mostly in their mean temperature of the coldest quarter and their mean annual temperature (significantly higher than *šhiblyak* and juniper stands). Pistachio groves also had the least precipitation in the warmest quarter.

The vegetation of the pistachio groves showed the highest richness of the Irano-Turanian elements (Figure 4). The richness of Mediterranean species was also quite high (the highest among other Middle Asian vegetation types. Surprisingly, also the proportion of Euro-Siberian elements was indeed the highest amongst the compared vegetation types (although the richness was relatively low: only about 5; Figure 4).

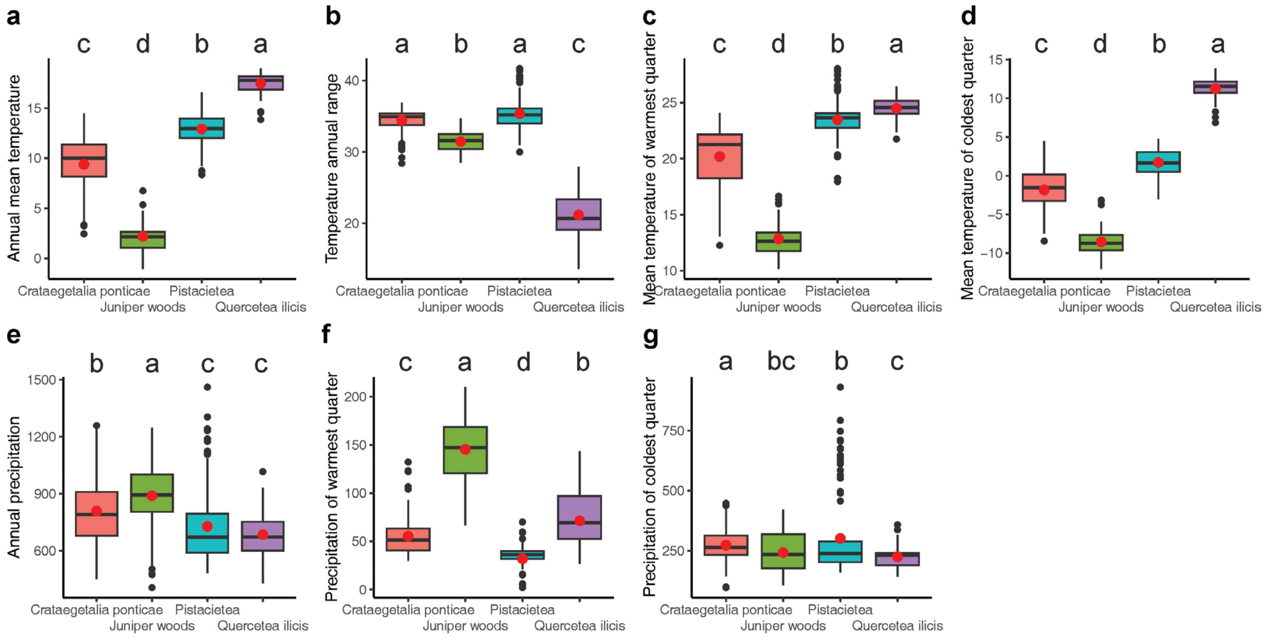

Figure 3. Boxplots showing median (line), mean (red dot), quartiles, outliers and the range of (a) annual mean temperature, (b) temperature annual range, (c) mean temperature of the warmest quarter, (d) mean temperature of the coldest quarter, (e) sum of annual precipitation, (f) precipitation of the warmest quarter and (g) precipitation of the coldest quarter for (from left to right) *šhiblyak* (*Crataego-Prunetea*, Tajikistan), Juniper woods (*Pino-Juniperetea* and *Juniperetea pseudosabinae*, Tajikistan), pistacio open woodlands (*Pistacietea verae*, Tajikistan and Iran) and Mediterranean scrubs (*Quercetea ilicis*, Mediterranean Basin). Different letters indicate significant differences among the groups after the Kruskal–Wallis rank sum test with $p < 0.05$.

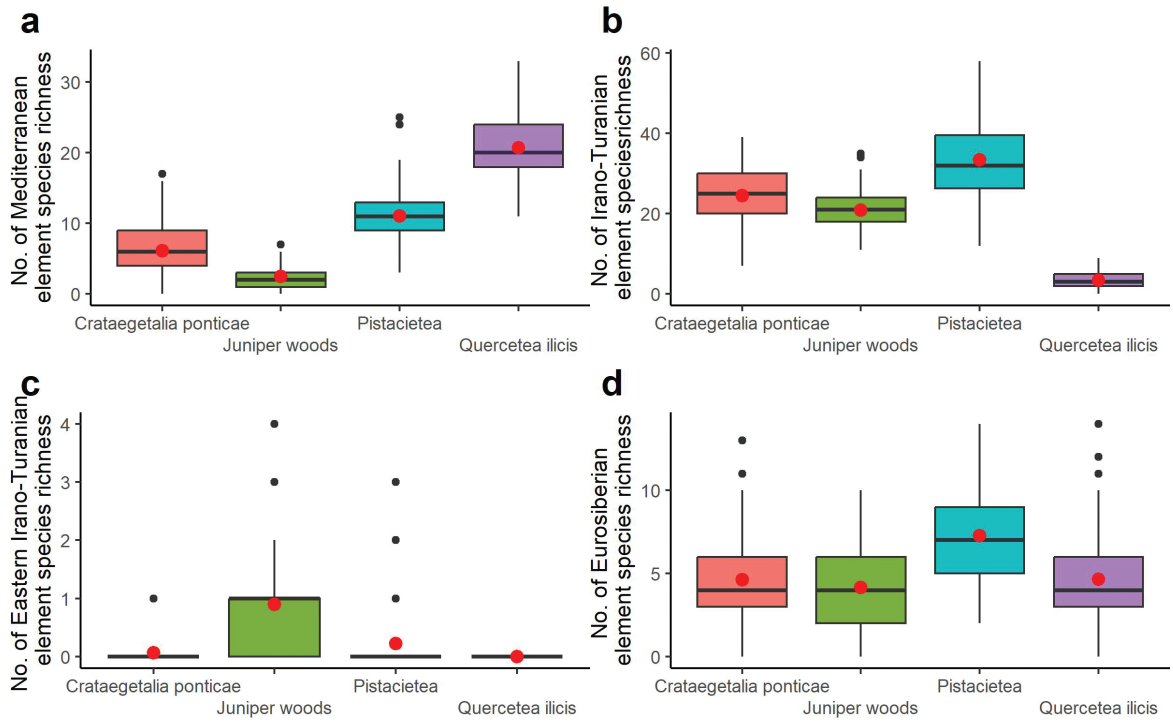

Figure 4. Boxplots showing median (line), mean (red dot), quartiles, outliers and the range of species richness of (a) Mediterranean, (b) Irano-Turanian, (c) Central Asian and (d) Eurosiberian elements for (from left to right) *šhiblyak* (*Crataego-Prunetea*, Tajikistan), Juniper woods (*Pino-Juniperetea* and *Juniperetea pseudosabinae*, Tajikistan), pistacio open woodlands (*Pistacietea verae*, Tajikistan and Iran) and Mediterranean scrubs (*Quercetea ilicis*, Mediterranean Basin). Different letters indicate significant differences among the groups after the Kruskal–Wallis rank sum test with $p < 0.05$.

Proposed syntaxonomic scheme of pistachio open woodlands

Based on the analyses, we propose the following classification for the Irano-Turanian open woodlands in warm, subtropical, semi-arid to sub-humid climate:

Class: *Pistacietea verae* A. Nowak et al. 2024
- Order: *Pistacietalia verae* A. Nowak et al. 2024
  - Alliance: *Pistacion verae* A. Nowak et al. 2022
    - A. Eastern group with *Pistacia vera*
      - Association: *Pistacietum verae* A. Nowak et al. 2022
        - Subassociation *Pistacietum verae typicum* A. Nowak et al. 2022
        - Subassociation: *Pistacietum verae cercidetosum griffithii* A. Nowak et al. 2022
    - B. Western group with *Pistacia khinjuk*
      - Association: *Pistacietum khinjuk* A. Nowak et al. 2024

I. *Pistacietea verae* A. Nowak et al. 2024 cl. nov. hoc loco

Holotypus: ***Pistacietalia verae* A. Nowak et al. 2024 (see below)**

General remarks: This vegetation class includes open woodlands with *Pistacia vera* giving them the characteristic appearance of sparse stands with small umbrella-crowned trees or shrubs. This physiognomy resembles savanna-like vegetation, similar to the *Olea europaea* or *Sideroxylon spinosum* open woodlands in the Mediterranean. The canopy density depends on the intensity of grazing and browsing, and the harvesting of the trees by local populations. This vegetation class is well developed in the eastern part of the Irano-Turanian region, where the genus *Pistacia* originated. The shrub layer is poorly developed and the undergrowth is dominated by herbaceous species, often associated with pseudosteppes. Denser forb grasslands develop as a kind of mantle around trees or groups of trees.

Diagnostic species: *Asparagus bucharicus*, *Asperula glomerata* subsp. *eriantha*, *Astragalus brachycalyx*, *A. chionanthus*, *A. kabadianus*, *A. mirabilis*, *A. murinus*, *A. ovinus*, *Avena barbata*, *A. sterilis* subsp. *ludoviciana*, *Bellevalia glauca*, *Brachypodium distachyon*, *Bromus fasciculatus*, *B. oxyodon*, *B. racemosus*, *B. tomentellus*, *Bunium paucifolium*, *Celtis occidentalis*, *Centaurea intricata*, *Cercis griffithii*, *Chaerophyllum macropodum*, *Chrozophora tinctoria*, *Cirsium syriacus*, *Colchicum persicum*, *Consolida stocksiana*, *Convolvulus stachydifolius*, *Cousinia bachtiarica*, *C. grigoriewii*, *C. microcarpa*, *C. multiloba*, *Crambe cordifolia* subsp. *kotschyana*, *Crataegus ambigua*, *C. songarica*, *Dianthus orientalis*, *Ephedra foliata*, *Eremurus roseolus*, *Eryngium billardieri*, *E. caeruleum*, *Euphorbia franchetii*, *Ferula tadshikorum*, *Filago pyramidata*, *Galagania tenuisecta*, *Galium nupercreatum*, *Helichrysum oligocephalum*, *Hordeum bulbosum*, *H. spontaneum*, *Inula orientalis*, *Lallemantia royleana*, *Lathyrus aphaca*, *Lepidium chalepense*, *Linum corymbulosum*, *Malva bucharica*, *Medicago rigidula*, *Nepeta macrosiphon*, *Nigella bucharica*, *Nonea persica*, *Onosma microcarpum*, *Peltaria angustifolia*, *Phleum paniculatum*, *Phlomis olivieri*, *P. persica*, *Phlomoides hissarica*, *Pistacia eurycarpa*, *P. khinjuk*, *P. vera*, *Pseudosedum bucharicum*, *Pyrus glabra*, *Quercus brantii*, *Ranunculus elymaiticus*, *Rostraria cristata*, *Salvia persepolitana*, *S. syriaca*, *S. virgata*, *Scandix iberica*, *S. pecten-veneris*, *Solenanthus plantaginifolius*, *Sonchus asper* subsp. *glaucescens*, *Stachys pilifera*, *Taeniatherum caput-medusae*, *Tanacetum polycephalum*, *Teucrium orientale*, *T. polium*, *Trigonella verae*, *Valerianella coronata*, *Velezia rigida*, *Vulpia myuros*

Geographical range: Eastern Irano-Turanian phytogeographical region (Iran, southern Azerbajan, Afghanistan, Uzbekistan, Turkmenistan, Kyrgyzstan and Tajikistan), particularly the colline and lower montane belts of the Alborz, Zagros, Kopet-Dagh, Pamir-Alai, Tian Shan and Hindu Kush Mts.

Habitat characteristics: It is a typical open woodland vegetation that forms a zonal belt in colline and lower montane elevations of mountain ranges. It develops mainly on fertile to moderately fertile habitats in a semi-arid to subhumid climatic zones. As in the case of other woody vegetation in the region, the abundance and frequency of its undergrowth is strongly influenced by grazing and other types of land use.

***Pistacietalia verae* A. Nowak et al. 2024 ord. nov. hoc loco**

Holotypus: ***Pistacion verae* A. Nowak et al. 2022b (p. 60)**

General remarks: Wild pistachio open woodlands in Tajikistan form a distinct zonal type of vegetation that clearly stands out in the landscape. No occurrence of juniper was recorded in the plots of the community. In many parts of the southwestern part of the country, it has extensive stands, mostly used as fruit plantations or grazing land. *Pistacia vera* woodlands are a distinct vegetation type on the Kopet-Dagh Mts. These are isolated and remnant xerophilous stands of the wild pistachio as subtropical semi-savanna, occurring between altitudes 800 and 1,200 m a.s.l. from the western to eastern Kopet-Dagh Mts (Atashgahi et al. 2022). Due to the low precipitation and high maximum temperature, the understory layer is mainly covered by winter and early-spring ephemeroids, including grasses such as *Poa bulbosa* and the sedge *Carex pachystylis* (Memariani et al. 2016).

Diagnostic species: *Acer pentapomicum*, *Aegilops triuncialis*, *Amygdalus bucharica*, *Artemisia baldshuanica*, *Asparagus bucharicus*, *Avena sterilis* subsp. *ludoviciana*, *Brachypodium distachyon*, *Bromus popovii*, *Cousinia grigoriewii*, *Eremurus roseolus*, *Ferula tadshikorum*, *Galagania tenuisecta*, *Inula orientalis*, *Medicago rigidula*, *Phlomoides hissarica*, *Pistacia vera*, *Prunus verrucosa*, *Taeniatherum caput-medusae*, *Vulpia myuros*.

Geographical range: This order of wild pistachio open woodlands is distributed within the native range of *Pistacia vera*. It mainly includes the colline and montane belt of Eastern Hindu Kush, western Pamir-Alai, western Tian Shan and Kopet-Dagh. The Kopet-Dagh mountain range, northeastern Iran, is the westernmost distribution range of wild pistachio (Atashgahi et al. 2022). It grows between 400 and 2,000 m a.s.l. In Tajikistan, *Pistacia vera* was reported from foothills of Mogol-Tau, Zeravshan, Hissar, Sarsarak, Sangloh, Ak-Tau, Babatag, Darvaz and Hazratishoh Mts (Ovchinnikov 1981).

Habitat characteristics: *Pistacia vera* open woodlands in Pamir Alai are the zonal vegetation inhabiting semi-arid to sub-humid climates with hot summers and mild winters. It shows seasonal changes with intense flowering in early spring and withering of the plants during the hot summer. It thrives on quite fertile loess soils (sometimes also on large rock ledges and slopes on ranker soils), on gentle to moderately steep slopes (Figure 5a). Open groves of *Pistacia vera* are used as pastures for sheep, cows and goats, and are often converted to pistachio plantations. In comparison to other vegetation, pistachio groves are subjected to frequent fires.

A. Eastern group dominated by *Pistacia vera*

See description in Nowak et al. (2022b).

B. Western group dominated by *Pistacia khinjuk*

Pistacietum khinjuk A. Nowak et al. 2024 ass. nov. hoc loco

Holotypus: 2000; 31.04861°N, 50.11139°E; 2216 m a.s.l.; aspect W; slope 9°; plot area 200 m^2; cover tree layer 65%, cover shrub layer 15%, cover herb layer 75%.

Middle tree layer: *Fraxinus ornus* 2, *Morus alba* 1;

Lower tree layer: *Pistacia khinjuk* 3, *Crataegus ambigua* 2, *Crataegus songarica* 2, *Pyrus glabra* 2, *Pistacia eurycarpa* 1, *Cyperus rotundus* +;

Shrub layer: *Vitex pseudonegundo* 2, *Prosopis farcta* +;

Herb layer: *Leiotulus porphyrodiscus* 2, *Parietaria judaica* 2, *Pimpinella affinis* 2, *Achillea nobilis* subsp. *neilreichii* 1, *Allium scabriscapum* 1, *Arum rupicola* 1, *Asperula glomerata* subsp. *eriantha* 1, *Astragalus siliquosus* 1, *Bunium paucifolium* 1, *Carduus pycnocephalus* subsp. *marmoratus* 1, *Chrozophora tinctoria* 1, *Cousinia multiloba* 1, *Crepis sancta* 1, *Echinops cyanocephalus* 1, *Echinops kermanshahanicus* 1, *Erigeron canadensis* 1, *Nonea lutea* 1, *Nonea persica* 1, *Onosma nervosa* 1, *Phlomis olivieri* 1, *Silene conoidea* 1, *Sonchus asper* subsp. *glaucescens* 1, *Tanacetum polycephalum* 1, *Anagallis arvensis* +, *Astragalus susianus* +, *Avena barbata* +, *Avena fatua* +, *Bromus danthoniae* +, *Cirsium syriacus* +, *Convolvulus betonicifolius* +, *Coriandrum sativum* +, *Dionysia bryoides* +, *Echinochloa oryzoides* +, *Grammosciadium scabridum* +, *Haussknechtia elymaitica* +, *Helichrysum oligocephalum* +, *Hordeum spontaneum* +, *Marrubium cuneatum* +, *Mentha longifolia* var. *asiatica* +, *Onosma rostellatum* +, *Plantago lanceolata* +, *Salvia syriaca* +, *Silybum marianum* +, *Smyrnium cordifolium* +, *Trifolium scabrum* +. [relevé number in Suppl. material 3: 105]

Diagnostic species: *Achillea nobilis* subsp. *neilreichii*, *Arum rupicola*, *Centaurea intricata*, *Cirsium syriacus*, *Lepidium chalepense*, *Nepeta macrosiphon*, *Pistacia eurycarpa*, *Pistacia khinjuk*, *Pyrus glabra*.

Geographical range: This association is distributed within the native range of *Pistacia khinjuk* and *P. atlantica*. It mainly includes the colline and montane belt of Zagros, Alborz, central and southern mountains of Iran. Forest-steppes of pistachio-almond occur in lower altitudes of Zagros Mts and other central Iranian ranges down to 750 m a.s.l. However, this vegetation grows between 1,300 and 1,800 m a.s.l. in Alborz and rarely up 3,000 m a.s.l., with a dominance of either *Pistacia atlantica* or *Prunus eburnea* (syn. *Amygdalus scoparius*) (Ravanbakhsh et al. 2013, 2016; Ravanbakhsh and Moshki 2016).

Habitat characteristics: Stands of *Pistacia khinjuk* in Iran form a zonal vegetation inhabiting areas with semi-arid to sub-humid climates (Figure 5b). In general, the *Pistacia-Prunus* (*Amygdalus*) shrubland forms a vegetation belt around the Zagros oak woodland, this belt being broader in the eastern Zagros foothills facing the Central Iranian Plateau (Djamali et al. 2009). Pistachio woodland is better adapted to drier habitats and can withstand the long summer drought. The oak woodland,

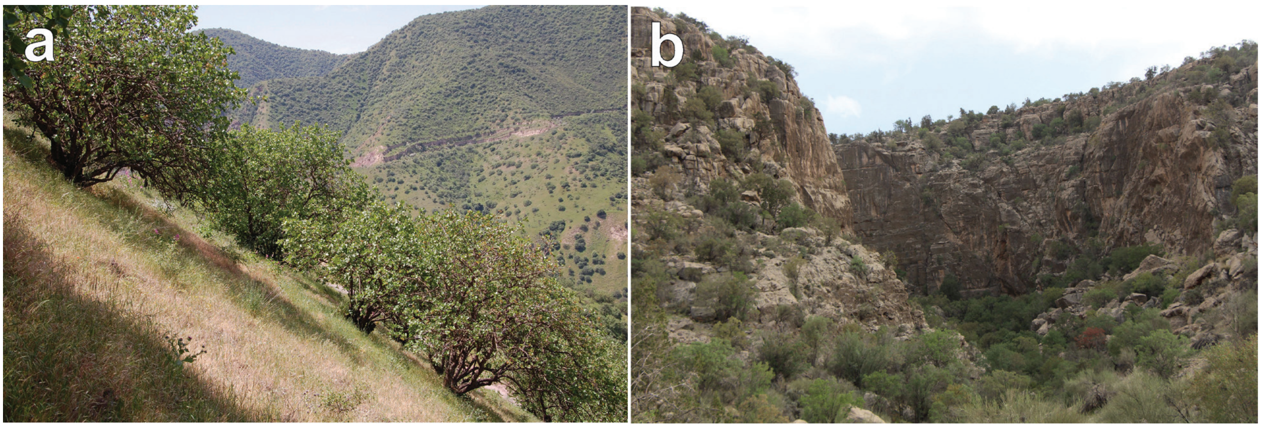

Figure 5. Photographs of pistachio open woodlands: (a) *Pistacietum verae* near Norak, Tajikistan (Photo: S. Świerszcz) and (b) *Pistacietum khinjuk* near Ramhormoz, Iran (Photo: A. Naqinezhad).

however, requires a shorter dry period during the summer and more rain in the spring. The lower limit of the shrubland is determined by the amount of precipitation received (300–350 mm/year).

Remarks: This vegetation type is also called as cold-deciduous open xeromorphic pistachio-almond scrub vegetation (*Pistacia-Amygdalus* steppic woodlands/shrubland) in many mountain ranges of west, south, north and central Iran. They occur between lowland *Artemisia sieberi* semi-desert steppes and thorn-cushion formations of the upper mountains. They once densely covered the many foothills and lower slopes of Iranian steppic mountains and now are remnants that are severely degraded due to anthropogenic effects and fire-cutting management (Djamali et al. 2008, 2009). At the current stage of research, we do not have enough data to accurately build a hierarchical system of this type of vegetation in eastern part of Middle and Southwestern Asia.]

Discussion

How should pistachio open woodlands be treated syntaxonomically?

From the phytosociological point of view, the vegetation type at the highest rank, i.e. class, should be defined by a set of diagnostic taxa (Pignatti et al. 1995). Although at this stage of research, with rather scarce data from the entire potential range of pistachio groves, this set is not complete nor perfect, the high distinctiveness of this class from its neighbouring woody and shrub vegetation types is evident (Figure 2). In particular, the species composition of the pistachio patches differs from the vegetation of the *Quercetea ilicis*, which is typically Mediterranian and occurs far to the west and is characterised by the dominance of oaks (*Quercus rotundifolia*, *Q. pyrenaica*, *Q. ilex*, *Q. pubescens* subsp. *pubescens*, *Q. ithaburensis* subsp. *macrolepis*, *Q. suber*, *Q. coccifera*, *Q. infectoria*), pines (*Pinus halepensis*, *P. pinaster*) or olive (*Olea europaea*). Only in eastern Hindu Kush or western Zagros there are some stands with some oak species such as *Q. brantii*, *Q. libani*, *Q. baloot* or *Q. floribunda* (Erdős et al. 2018; Sagheb-Talebi et al. 2014). Additionally, in *Quercetea ilicis* stands there is a number of herb species that has a typical Mediterranean distribution like, e.g., *Acanthus mollis* subsp. *mollis*, *Asparagus acutifolius*, *Calicotome infesta*, *Cistus salvifolius*, *Cyclamen repandum* subsp. *repandum*, *Daphne gnidium*, *Dioscorea communis*, *Ruta chalepensis*, *Smyrnium olusatrum*. Similarly, the floristic composition of the pistachio groves is totally different than the shrubland vegetation of *Crataegetalia ponticae* in Middle Asia. In these more fertile habitats that are related with broad-leaved forests we can find a number of diagnostic species like *Acer platanoides* subsp. *turkestanica*, *Astragalus darwasicus*, *Brachypodium sylvaticum*, *Caragana turkestanica*, *Corydalis darwasica*, *C. nudicaulis*, *Cotoneaster hissaricus*, *Crataegus pseudoheterophylla*, *Ferula gigantea*, *Malus sieversii*, *Neopaulia ovczinnikovii*, *Potentilla kulabensis*, *Prunus sogdiana*, *Rosa achburensis*, *Vinca erecta* and many others (Świerszcz et al. 2022). Again, the set of diagnostic species as well as the overall composition of thermophilous pistachio open woodlands are largely different. The same is true for the juniper groves that, despite the similar open structure and origin relating to aridification of Central Asia in the Miocene and Pliocene, share almost no common species (no occurence of *Berberis integerrima*, *Juniperus polycarpos* var. *seravschanica*, *Juniperus pseudosabina*, *Juniperus semiglobosa*, *Libanotis schrenkiana*, *Lonicera stenantha*, *Oxytropis capusii*, *O. ovczinnikovii*, *Poa urssulensis*, *Polygonatum roseum* among diagnostic and dominant; Nowak et al. 2022a).

The high floristic distinctiveness of pistachio groves is also due to the high degree of endemism of both vegetation types and their phytogeographical area. The group of endemic taxa which has an ecological optimum in pistachio open woodlands includes, among others: *Ajuga turkestanica*, *Astragalus quisqualis*, *Cousinia grigoriewii*, *Euphorbia sogdiana*, *Fallopia baldschuanica*, *Onobrychis baldshuanica*, *Oxytropis linczevskii*, *Oxytropis tenuirostris*, *Phlomoides baldschuanica* or *Tulipa subquinquefolia* (Table 1). These species are mostly thermophilous and shade-tolerant plants that grow around pistachio trees or groups of pistachio trees forming a specific mantle. It is worth noting that if we had been able to collect more data from the entire *Pistacia vera* and *P. khinjuk* range, there would probably be many more such national or regional endemics. The vast majority of species that build pistachio open woodlands have an Irano-Turanian distribution. Certainly, further research in Turkmenistan, Afghanistan and eastern Iran should confirm this pattern, as this phytogeographical region has its own distinct natural history and bioclimate (Djamali et al. 2009, 2012).

It is also worth noting that the overall richness of this vegetation is impressive, in 110 relevés we found 616 species of vascular plants. This number is high compared to mesic shrubs (120 plots of 100 m^2 mean size, 566 species), pseudosteppes (200 plots of 10 m^2 mean size, 770 species), steppes (eastern Middle Asia: 274 plots, 503 species and western: 148 plots of 20 m^2 mean size, 384 species), deciduous forests 201 plots of of 200 m^2 mean size, 545 species) and even tall-forb communities (244 plots of 10 m^2 mean size, 810 species) studied so far in Middle Asia (Nowak et al. 2017a, 2018, 2020, 2022b). Of course, an important group characterising pistachio open woodlands are the species of the herbaceous undergrowth that is often dominated by plants typical of pseudosteppes. Their considerable proportion and high frequency in our plots is due to the dynamic relationship between pistachio stands and surrounding grasslands and the effect of the ecotonal nature (transitional character), the removal of open woodlands and intensive grazing. A similar relationship and overlap of diagnostic species groups is found in seral or marginal vegetation like *Crataego-Prunetea* and *Carpino-Fagetea*, *Trifolio-Geranietea* and *Crataego-Prunetea* or *Paliuretalia* and *Quercetea pubescentis* (see Mucina et al. 2016; Chytrý 2013).

Taking the above arguments into account, in our opinion pistachio groves have a distinct species composition in comparison to neighbouring vegetation types, including a set of diagnostic, dominant and frequent taxa of typical Irano-Turanian distribution. This also indicates the potential extent of this vegetation and shows that its rank should be related to wide phytogeographical unit, that means the floristic region as suggested by Pignatti et al. (1995). In our opinion, the extent of the proposed class is sufficient and, in addition, quite uniform with respect to the phytogeographical division. This is because it covers almost all mountain ranges of the Irano-Turanian region. A wide range of this vegetation type, as well as the high rate of endemism of the floras of the mountains of the Irano-Turanian region, will result in a high variety of associations.

Relationship with other vegetation types in the Irano-Turanian and Mediterranean area

At the initial stages of phytosociological research of the Irano-Turanian region, pistachio open woodlands were included in the class *Junipero-Pistacietea* (Zohary 1973). Apart from the fact that this class was described invalidly (Art. 2b, see Mucina et al. 2016), it seems that current knowledge does not justify including both types – juniper and pistachio groves – into one class of vegetation. In the mountains of Pamir-Alai and Tian Shan (in Uzbekistan, Tajikistan and Kyrgyzstan), they are clearly climatically separated in the landscape and form two distinct elevational belts of vegetation (see Figure 3). The juniper stands grow in upper montane to lower subalpine belts and only occasionally overlap with the pistachio woodlands (some plots of *J. seravshanica* in the Khodzhamumin and Babatag Mts). In our data from Tajikistan, juniper was not found in pistachio woodlands and we noticed only two occurrences of juniper in *šhiblyak* shrubland (*Calophaca grandiflora* stands). Even in the original species lists and descriptions provided by Zohary (1973), there were no plots that contained both junipers and pistachios with significant cover. Juniper stands and pistachio woodlands were also distinct and separated in the description of vegetation in north-eastern Iran (Memariani et al. 2016), probably also due to different climatic conditions (particularly precipitation and mean temperature in the warmest qurter) as it was found in the area of Tajikistan (Figure 3; Nowak et al. 2022a). In Turkmenistan, in the Badghyz region, two large open pistachio woodlands of Kushka and Pulikhatum have been described as distinct zonal vegetation dominated solely by *P. vera* with some admixture of *Ficus carica* and *F. afghanica* (Popov 1994). The same zonation with separate pistachio and juniper vegegation is reported from Iori plateau in eastern Georgia (Lachashvili et al. 2020) and Hindu Kush Mts (Freitag 1971). Only towards the southern, more arid and warm territories of Hindu Kush, Zagros and Kopet-dagh, pistachia form mixed stands with *Cercis griffithii*. It can be one of the main canopy species or form a pure stands of a more shrubby physiognomy.

We have checked also the similar vegetation in Eastern Mediterranean and Southwestern Asia – the Kurdo-Zagrosian forest-steppe. All of the known vegetation types, including sclerophilous oak stands of the thermo- to supramediterranean belts of Southwestern Asia (*Quercetea brantii* Zohary 1973) and several vegetation types from the *Quercetea ilicis* (sclerophilous oak and conifer forests and associated macchia in the thermo- to supramediterranean belts of the Eastern Mediterranean – *Quercetalia calliprini*, thermo-mesomediterranean pine forests of the Central and Eastern Mediterranean – *Pinetalia halepensis*, mesomediterranean evergreen endemic golden oak forests of Cyprus – *Quercion alnifoliae*, thermo-mesomediterranean low-grown matorral, macchia and garrigue of the Mediterranean Basin - *Pistacio lentisci-Rhamnetalia alaterni*, thermomediterranean calcicolous macchia of the Liguro-Tyrrhenian Seaboards with evergreen *Olea europaea*, *Ceratonia siliqua* and *Pistacia lentiscus* stands with a closed tree canopy in the drought-prone lowlands and foothills of the Mediterranean and Macaronesia – *Oleo-Ceratonion siliquae*, Mesomediterranean sclerophyllous garrigue of the Eastern Mediterranean – *Pistacio terebinthi-Rhamnion alaterni*, evergreen calcicolous mesic kermes oak forests of the Eastern Mediterranean - *Arbuto andrachnes-Quercion cocciferae*, thermo-mesomediterranean evergreen oak forests on deep soils of the Iberian Peninsula and North Africa - *Oleo sylvestris-Quercion rotundifoliae*) vary considerably in terms of the ecology, seasonality, physiognomy, floristic composition, range, evolution of the main species that make up the communities.

Structure, ecology and origin of pistachio open wooldlands

For anyone visiting countries such as Iran, Turkmenistan, Uzbekistan, Tajikistan, Kyrgyzstan or Afghanistan, the vegetation of open woodlands with pistachio trees proves to be one of the most distinctive vegetation types and landscape features. It forms a distinct zone in the colline and montane belts of most ranges throughout the warm and sub-humid areas in Middle Asia and the entire Irano-Turanian region. For years, it has been the subject of research by botanists who coined the term *redkolese* (from Russian for sparse forest), or just grove, open arid forest, open woodland, wild orchard, or open scrubs (e.g. Frey and Probst 1986; Zohary 1973; Popov 1974, 1994; Kamelin and Rodin 1989; Memariani et al. 2016; Nowak et al. 2022a) or Pistacieta arid open woodlands (see Lachashvili et al. 2020). Other scientists have created some confusion by considering these ecosystems to be a type of thermophilous mesic continental shrubland called *šhiblyak* (e.g. Ovchinnikov 1948; Popov 1994; Safarov 2018). We have discussed in detail this misleading classification in our recent work (Nowak et al. 2022b), and considered pistachio open woodlands, a savanna-like vegetation in Middle Asia, as well settled. In addition to its spatial distinction in the landscape and specific "floristic content", the vegetation with *Pistacia vera* dominance is characterised by a number of other features that allow it to be considered a distinct type at the highest rank according to the widely accepted criteria (Pignatti et al. 1995; Loidi 2020).

One of these features is the open structure of the stands due to grazing and browsing, and also the climatic and edaphic conditions. Recent intensification of grazing and logging have led to a loss of the canopy compactness, rising light intensity and the encroachment of heliophilous plants from the surrounding pseudosteppes as well as many ruderal plants. The southern parts of Middle Asia have been used as grazing lands for centuries by the ancient Indus Valley civilisation (Shortugai) or the local Bactrian Kingdom people (Lawler 2007; Chew and Sarabia 2016; Sinha et al. 2019). This situation is very analogous to vegetation in Mediterranean countries such as olive or argan groves in Morocco, Italy or Greece. It is not easy to determine what the natural density of the pistachio canopy was in pre-historic times, when goats and sheep were not grazing. The wild herbivores that naturally occur in the pistachio open woodlands were mainly *Saiga tatarica* (saiga), *Gazella subgutturosa* (dzheyran), *G. bennettii* (chinkara), *Ovis vignei* (urial) and *Equus hemionus* (kulan). During the long history of megafauna extirpation by humans across Southwestern and Middle Asia the populations of these animals have drastically decreased and most of them are currently considered as critically endangered or extinct in some countries (e.g. Abdusalyamov 1988). After the first global human-driven megafauna extinctions in the Quaternary period (approx. 50,000 to 10,000 years ago; Barnosky 2008; Smith et al. 2018), the large herbivores of Middle Asia were gradually replaced by herds of domesticated goats, sheep, donkeys and cows. To what extent the current state reflects the situation before the introduction of intensive livestock grazing in Asia is difficult to say. What is undeniable, however, is that at the southern limit of the range of woody vegetation, in areas where herds of herbivorous megafauna and accompanying predators such as *Panthera leo* subsp. *leo* (Persian lions), *Panthera tigris* subsp. *tigris* (Caspian tigers) and *Hyaena hyaena* (stripped hyenas) lived in the wild, there was a belt of open vegetation dominated by pistachio. The herbivore pressure is still preserved today and is evident in the high proportion of herbs in the undergrowth and the characteristic ‚savanna' physiognomy of the umbrella-like canopy of pistachio crowns. It is worth mentioning that such a loose structure of this vegetation is also evident on the larger rock ledges (e.g. in southern Hazratishoh range), which are not accessible to grazing animals, but only to wild urials.

An important distinguishing feature of the vegetation at class level is its well-defined ecology (Pignatti et al. 1995; Loidi 2020). In entire Middle Asia, the pistachio open woodlands reveal strong seasonal variation of plant cover. In early spring the colourful geophyte aspect is apparent while during the hot summer the herbaceous layer easily wither to the bareland. The closely related thermophilopus *Juniperus seravschanica* open woods, which evolved also from *proto-šhiblyak* (Kamelin 1967), have apparently different seasonality, precipitation and temperature requirements related to elevation and subalpine vegetation. Additionally, *Pistacia* groves during hot summers are exposed to frequent fires. Young seedlings are resistant to it and due to the high nutrient content in large seeds, can rapidly develop deep roots which secure the young trees' survival in the first, most critical year of their life (Popov 1994). Wild fires are observed frequently in Khatlon province, both in plantations and wild pistachio woodlands, resulting in a very scarce shrub layer and a preference for fire-avoiding or resistant species - such as geophytes - in the undergrowth.

Today, the wide native distribution of *P. vera* and *P. khinjuk* is well characterised, and Middle Asia is believed to be a primary center of origin and diversity of these species. This opinion is supported by many botanists, among others Popov (1929), Morozov (1929), Vavilov (1931), Whitehouse (1957), Zohary (1996). *Pistacia vera* is also considered the most economically important species of the genus (FAOSTAT 2023), whereas *P. atlantica* and *P. khinjuk* that grow in Southwestern Asia (Rechinger 1969; Khatamsaz 1988; Behboodi 2003) did not receive commercial acceptance and have not been extensively cultivated. However, their nuts are used mainly as traditional food or for their medicinal properties (Bozorgi et al. 2013).

The phylogenetic data show that *P. vera* and *P. khinjuk* are the oldest (Kozhoridze et al. 2015) and genetically closely related representatives of the genus (Zarei and Erfani-Moghadam 2021). Palaeobotanical data indicate that before the Pleistocene, *P. vera* was one out of four species of this genus that inhabited Middle Asia (Popov 1994; Zlotin 1994). Loidi (2020), in his discussion of vegetation class delimitation, emphasises the importance of the common evolution of species and vegetation that creates a given type of high rank vegetation. The ancestral vegetation that gave rise to the pistachio groves was most likely the Mesozoic flora of warm and subtropical climates called Tethys Flora. In the early Palaeogene (from the Palaeocene to Eocene; 66 to 33.9 M years ago) this flora was probably close to the known Eocene flora of Badghyz (Kurbanov 1994; Hurka et al. 2019). This palaeoflora was dominated by e.g. *Rhus turkomanica*, species of *Prunus*, *Pistacia*, evergreen species of *Quercus* and some *Lauraceae* taxa (Korovin 1934; Kurbanov 1994). It is possible that this vegetation gave rise to the xerophylic tree and shrub communities of *proto-šhiblyak* during the Tertiary period (66 to 2.6 M years ago; Kamelin 1970, 1973), which was composed of sclerophyllous and thermophilous shrubs and small trees (Kurbanov 1994). Contemporary *šhiblyak* vegetation still includes Tertiary taxa like *Ziziphus jujuba*, *Rhus coriaria*, *Celtis caucasica*, *Cercis griffithii*, *Punica granatum* and *Ficus carica*. However, it lacks oak species that were common in Palaeogen (*Quercus ilex*, *Q. balloot* and *Q. castaneifolia*). Aridisation of climate and steppe formations in Miocene and Pliocene caused the xerophytisation of *proto-šhiblyak*. This ancient zonal vegetation type could be regarded as a shrinking relict refuge of a number of paleoendemic taxa. Examples are, e.g., *Prunus bucharica*, *Calophaca grandiflora*, *Cephalorhizum micranthum*, *Eversmannia sogdiana*, *Lipskya insignis*, *Mediasia macrophylla* or *Oedibasis tamerlanii*. As a consequence of aridisation, the withdrawal of the para-Tethys sea and climate oscillation during the Pleistocene, *proto-šhiblyak* has formed a variety of vegetation formations from pistachio open woodlands in the lowest and warmest areas, through the deciduous forests of *Juglans regia* occupying the valleys in the mid-latitudes, to the juniper woods inhabiting subalpine belt. It is worth noting that important compositional elements of woodlands like *Prunus*, *Pyrus* and *Malus* evolved during this aridification. In mid-Miocene (ca. 14 M years ago), *Rosaceae* also diversified, most likely in response to increasingly less humid climate (Töpel et al. 2012). Also in the Late Miocene the divergence time of *Calophaca* took place in Middle Asia (Zhang et al. 2015). The community of the latter species occupies large areas in central Tajikistan and occupies an intermediate position between pistachio open woodlands and typical *šhiblyak* (Nowak et al. 2022b).

Ethnobotanical evidence showing the extent of pistachio open woodlands in Middle Asia

The name for pistachio originated from Middle Asian languages. In Uzbek and Tajik, it is *pista*, in Kazakh *psta*, in Turkmen *pisse*, and in Kyrgyz *miste* (Khalmatov et al. 1984). Evidence of these formerly extensive open woodlands can be found in the many pistachio related names of villages, small streams, waterfalls, and gorges (Khanazarov et al. 2009). Pistachio groves are culturally significant to Tajik (and neighbouring) people not only for their fruit production or livestock grazing, but also for their fruit trees cultivation tradition and scenic value of their homeland. It is very common for pistachio trees to be planted in home gardens. Also, many places derive their names from the local name for pistachios. Often these names occur in areas that are now 100% occupied by pseudosteppe vegetation, with only single trees growing next to buildings, e.g. Pistimazor near Vahdad, ca. 700 m a.s.l., Pistimazor near Kulob, ca. 600 m a.s.l. These two names also show the connection between pistachios and religion: “Mazor” or “Mazar” means mausoleum of holy people and is surrounded by religious worship. The name *Pistimazor* can therefore be translated as “sacred place under the pistachio”. Other names related to pistachio come from the Ferghana Basin and western Pamir Alai: Gulpista (means flower of pistachio, Tajikistan), Pista Mazor, Pistamazar (Pstamazar), Pista Quduq, Pystalik (Pistalik; Uzbekistan), Jeke-Miste (Kyrgyzstan). There are even pistachio mountains Pistalitau in Uzbekistan (Alibekov and Alibekov 2007). Probably also Psa Mandeh and Pstigrom in Afghanistan are based on the pistachio name.

Conclusions and outlook

In this paper we propose to recognise the *Pistacietea verae* as a distinct and new vegetation class. It was compared with similar vegetation of the eastern Mediterranean and Irano-Turanian vegetation of shrublands, mesic and Mediterranean woodlands, juniper open woods, tall-forb communities and pseudosteppes. Taking into account species composition, rate of endemism, phytogeography, ecology and seasonal dynamics, range and use before the development of pastoral civilisation and today, this research suggests that the new vegetation class is a distinct vegetation type stretching across the entire region. Further research in the Hindu Kush, Kopet-Dagh, Zagroz Mts and south-eastern Caucasus (Iori plateau in Georgia and Turian-Chay State Reserve in Azerbajan) will certainly yield interesting data on the internal diversity of this vegetation. Based on our data, we could only describe one association from the western part of the range - *Pistacietum khinjuk*. This open woodland with *Pistacia* spp. dominance is a heterogeneous vegetation with its distribution center in the Irano-Turanian phytogeographical region. Previously it had been described as an arid open woodland, thicket, thin forest, grove, savanna or savanna-like steppe woodland, open arid forest or wild orchard (Zohary 1973; Kayimov et al. 2001; Kaya et al. 2010; Fayvush and Aleksanyan 2016; Gianguzzi and Bazan 2019; Ambarlı et al. 2020; Lachashvili et al. 2020). Unfortunately, strong negative impacts by humans through intensive grazing, logging and burning, on pistachio woodlands together with the lack of effective conservation measures and forest management are causing a gradual decline in the range of this species-rich vegetation, which harbours many rare, endemic and relict taxa.

Data availability

The datasets of the current study are available from the corresponding author on reasonable request.

Author contributions

ANo conceived the idea of the vegetation class, ANo, SŚ, ANa and MN planned the research, conducted the field sampling and identified the plant species. ANo and SŚ performed statistical analyses, while all the authors participated in the writing of the manuscript and verification of plants in herbarium.

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Supplementary material

Supplementary material 1
Synoptic table of pistachio open woodlands vegetation in Middle and Southwestern Asia belonging to the class *Pistacietea verae* (*.xlsx)
Link: https://doi.org/10.3897/VCS.104841.suppl1

Supplementary material 2
Synoptic table of the full dataset used for comparing the pistachio open woodlands with related vegetation types of naturally occurring woody and grassland phytocoenoses in Middle and Southwestern Asia (*.xlsx)
Link: https://doi.org/10.3897/VCS.104841.suppl2

Supplementary material 3
Analytical table of class *Pistacietea verae* (*.xlsx)
Link: https://doi.org/10.3897/VCS.104841.suppl3