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Research

Floristic diversity and vegetation of communities associated with two endemic *Dianthus* species in the montane steppes of northeastern Iran

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The study aimed to analyze vegetation data using a phytosociological method and to identify species composition and relationships between vegetation and environmental data in communities that include two threatened species (*Dianthus pseudocrinitus* Behrooz. & Joharchi and *D. polylepis* Bien. ex Boiss.) endemic to the montane steppes of Khorassan-Kopet Dagh floristic province in northeastern Iran. We sampled 75 vegetation plots in 15 sites where the endemic *Dianthus* species occur. In order to evaluate community characterization of the species, we investigated floristic composition, life-form spectrum and the phytogeography of the study sites. In all, 370 plant species were recorded, belonging to 184 genera in 45 families. Floristic analysis revealed that Hemicryptophytes are the dominant life-form in these habitats, and Iran-Turanian floristic elements contributed 74.5% of the total number of species. Classification analysis based on TWINSPAN showed a clear separation of the study sites based on *Dianthus* taxa, which was confirmed by detrended correspondence analysis (DCA). The results reflected the highly diverse flora at all *Dianthus* sites. Species composition and the distribution of vegetation groups were influenced by some environmental factors. Habitats for both species could be managed by a community ecological approach; our study provided a better knowledge of these communities' ecological and floristic composition to enhance effective management and conservation of the threatened species.

Keywords: biogeography, conservation, endemism, environmental factors, floristic analysis, Khorassan-Kopet Dagh

Introduction

Montane steppes are a geographic feature and vegetation type that support high diversity and endemism (Munson and Sher 2015, Noroozi et al. 2018). Montane ecosystems often include endemic species, because many species are isolated by surrounding

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lowland vegetation communities (Beniston 2003). The geographic isolation and limited geographic ranges, however, place montane species at greater extinction risk than species in lowland ecosystems (Grabherr et al. 1994). Mountainous regions globally are affected by environmental changes, such as climate change, land-use change and human activities that may affect the vegetation in both quantity and quality. Endemic species in these regions can be more vulnerable to environmental changes than other species (Sanz-Elorza et al. 2003, Egan and Price 2017). Hence, assessing the communities and habitats, and influences of ecological factors in particular for rare, endemic and endangered species, can be considered important to development of integrated conservation strategies (Loarie et al. 2009). Many studies have been developed to investigate aspects of the ecology and conservation of endemic species, involving floristic studies, community characterization and vegetation classification, and their relationships with ecological factors (Kruckeberg and Rabinowitz 1985). Community characteristics and ecological conditions that favor the presence and abundance of endemic species are essential elements in conservation management plans (Caperta et al. 2014, Hobohm 2014).

Dianthus L. is a plant genus that often occurs in montane ecosystems. It has been the focus of several studies as a function of its many endemic and endangered species (Gargano et al. 2009, 2011, Cogoni et al. 2012). In recent decades, the natural habitats of many *Dianthus* species have been altered severely by anthropogenic activities, leading to rapid loss of habitats for many species in the genus. These consequences pose a serious threat of extinction, such that some *Dianthus* species are listed in the IUCN Red List (Bilz et al. 2011).

Dianthus polylepis Bien. ex Boiss. and *D. pseudocrinitus* Behrooz. & Joharchi are two species endemic to the Khorassan-Kopet Dagh floristic province (KK) in northeastern Iran and adjacent parts of southern Turkmenistan (Memariani et al. 2016b). These species are significant elements in montane steppes of KK, growing generally in rocky outcrops, partly on degraded and non-fertile soils. The montane areas of KK have high biodiversity due to complex topography, high habitat heterogeneity and long vegetation history, providing a suitable physiographic context for a complex regional flora in the Irano-Turanian region (Memariani 2020). In detail, *D. polylepis* includes two subspecies: *D. polylepis* subsp. *polylepis* and *D. polylepis* subsp. *binaludensis* (Rech.f.) Vaezi & Behrooz. that are morphologically differentiated in a few traits, suggesting local morphological divergence (Farsi et al. 2013). *D. polylepis* subsp. *binaludensis* is limited to the Binalood Mountains, which are characterized by successions of sedimentary, metamorphic and igneous rocks (Sheikholeslami and Kouhpeyma 2012), whereas *D. polylepis* subsp. *polylepis* is distributed more broadly in other Khorassan-Kopet Dagh mountains on limestone (Nowrouzi et al. 2007). According to IUCN Red List categories and criteria, *D. polylepis* subsp. *polylepis* and *D. polylepis* subsp. *binaludensis* are considered to be least concern (LC) and vulnerable (VU), respectively (Memariani et al. 2016b). Although *D. polylepis* subsp. *polylepis* is considered as least concern in view of its relatively broad distribution range, it may be qualified for a threatened category in the future, like *D. polylepis* subsp. *binaludensis*, because both occur on rocky and barren slopes with relatively unstable surfaces. These habitats are presently affected by intense anthropogenic activities, including road construction and livestock grazing; in addition, climate change may restrict distributional potential in both subspecies (Behroozian et al. 2020a).

Dianthus pseudocrinitus represents another endemic species in the KK floristic province that is known from a few populations in a narrow distribution range. It is considered critically endangered (CR) (Vaezi et al. 2014, Memariani et al. 2016b). This species occurs on calcareous mountains in central and western parts of the KK area, at elevations of 1600–2300 m. The species' habitat is severely affected by destructive anthropogenic activities. In addition, *D. pseudocrinitus* occurs at the margins of and in agricultural areas, particularly in abandoned farmlands (Behroozian et al. 2020b). As such, these species are particularly vulnerable to effects of environmental change.

This study aims to identify the floristic, chorological and vegetation diversity of the communities inhabited by two endemic *Dianthus* species in northeastern Iran and to propose a classification for the plant communities of these species. It also describes relationships between vegetation and environmental data to understand better the ecological features of their habitats. Hence, better knowledge of the ecological and floristic composition of these communities would greatly enhance the effective management and conservation for these species.

Material and methods

Study area and sites

The study area is located in northeastern Iran and adjacent southwestern Turkmenistan (34°20′–39°13′N, 55°05′–61°20′E). It belongs to the Khorassan-Kopet Dagh floristic province (KK) in the Irano-Turanian region. The most prominent mountains are Aladagh (peak 2763 m a.s.l.), Salook (2956 m a.s.l.), Misino (2475 m a.s.l.), Hezar-Masjed (3106 m a.s.l.), Binalood (3301 m a.s.l.) and Kashmar-Torbat (2940 m a.s.l.) ranges (Fig. 1). The area is an ideal place to study flora and vegetation, given that it is a transition zone, connecting different provinces of the Irano-Turanian region and the Hyrcanian montane forests of the Euro-Siberian region (Memariani et al. 2016a). The mean annual precipitation is 175–300 mm in the plains and foothills and 300–380 mm in montane regions. The highest mean monthly air temperatures occur from June to August, with the maximum temperature rarely exceeding 45°C. The lowest mean monthly temperatures, from December to February, can reach −25°C in the high mountains (Djamali et al. 2011). This area has a complex topography, high habitat heterogeneity and long vegetation history, providing a suitable physiographic context for the development of a complex regional flora. It also involves several vegetation types in natural and semi-natural

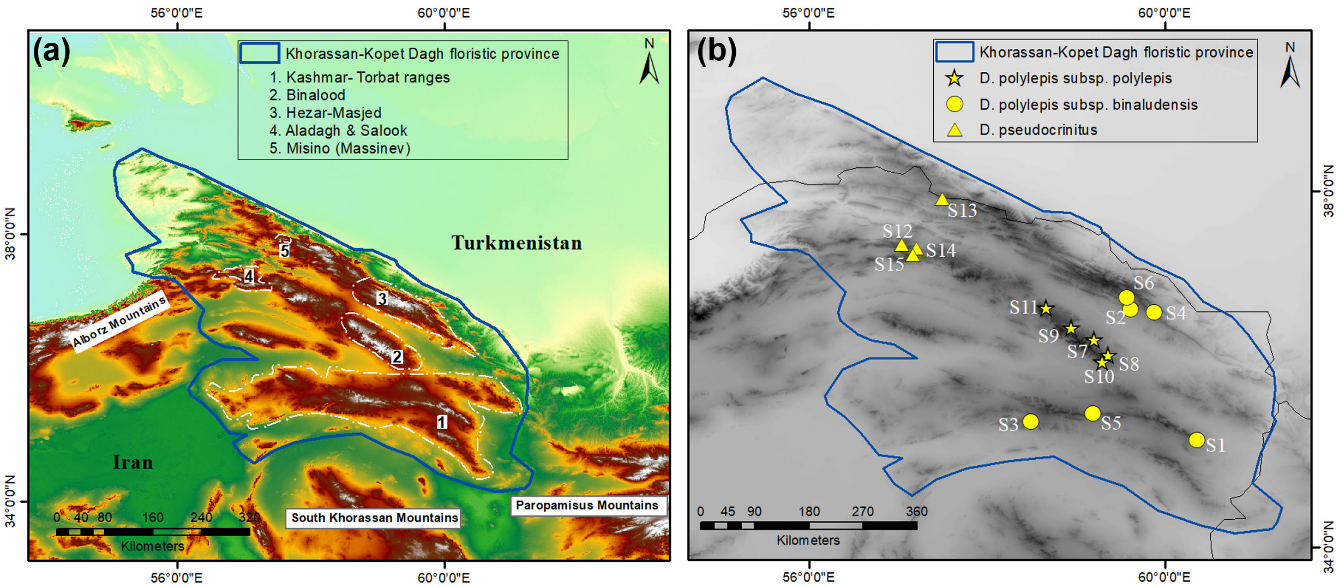

Figure 1. Maps of the study area in Khorassan-Kopet Dagh floristic province (KK). (a) Locations of the mountain systems in KK where sampling was carried out. (b) Sampling sites; stars (*Dianthus polylepis* subsp. *polylepis* sites): S1. Bezd, S2. Kardeh Dam, S3. Kuhsorkh, S4. Khowr, S5. Khomari Pass, S6. Balghur; Circles (*D. polylepis* subsp. *binaludensis* sites): S7. Zoshk, S8. Moghan, S9. Dahane Jaji, S10. Dizbad, S11. Baharkish; Triangles (*Dianthus pseudocrinitus* sites): S12. Rein, S13. Misino, S14. Biu Pass, S15. Rakhtian; prepared with ArcGIS 10.3 (<www.esri.com>) (taken from previous published paper by Behroozian et al. 2020a).

environments, which include scattered montane forests, widespread *Juniperus* woodlands, wild *Pistacia vera* woodlands, open shrublands and scrub, diverse mountain steppe communities, cliff vegetation, semi-desert steppes and halophytic formations, as well as aquatic, ruderal and weed communities (Memariani et al. 2016a, Memariani 2020).

Sites were selected based on geographic distances and contrasting homogeneous ecological conditions where the endemic *Dianthus* species occur. Six sites were selected throughout the different mountains in the study area within the distribution of *D. polylepis* subsp. *polylepis*. Five sites were selected in the distribution of *D. polylepis* subsp. *binaludensis*, within its limited range in the Binalood Mountains. *D. pseudocrinitus* is a rare species, so only four sites could be sampled. In total, 15 sites were sampled in montane steppe areas (1475–2245 m a.s.l.) across the study area (Fig. 1, Supporting information).

Floristic sampling

In all, 75 releves were established and sampled in the study area in Spring 2016–2017. In each 25-m^2 quadrat, canopy cover was estimated visually as a percentage of ground area, and the Braun-Blanquet cover-abundance scale was obtained following the Zürich-Montpellier approach (Barkmann et al. 1964). All species occurring within the releves were collected and identified using the relevant Floras (Rechinger 1963–2015, Assadi et al. 1988–2019). We followed the POWO (2022) for the taxonomy and nomenclature of the plants in the final checklist (Supporting information). The specimens were deposited in the Central Herbarium of Ferdowsi Univ. of Mashhad (FUMH). The vegetation data were stored in the TURBOVEG database (Hennekens and Schaminée 2001) and exported into JUICE 7 (Tichý 2002).

Data analysis

The floristic list was prepared alphabetically following APG IV (2016) to classify vascular plants (Supporting information). The chorotype of each taxon was determined on the basis of the distribution of each species using the different Floras (Rechinger 1963–2015, Assadi et al. 1988–2019). Terminology for phytogeographic units (Irano-Turanian, Mediterranean, Euro-Siberian and Sahara-Sindian) followed Léonard (1988, 1991). We followed Akhani (1998) and Memariani et al. (2016a) to determine subdivisions of the Irano-Turanian region. Description and classification of life-forms followed Raunkiaer (1934), and threat categories were from Jalili and Jamzad (1999) and Memariani et al. (2016b).

Classification and ordination techniques were used to analyze the vegetation. Species recorded in only one releve were removed from analysis to avoid distortion. The classification analysis of the vegetation data was performed using TWINSPAN (Hill 1979), with nine pseudospecies cut levels (0, 1, 2.5, 5, 12.5, 25, 50, 75, 100). After sorting vegetation with TWINSPAN, diagnostic species were determined on the basis of the fidelity concept using the phi coefficient in the JUICE ver. 7.0 program (Tichý 2002). The threshold phi value for the indicator species was set at 0.25, with a 5% significance level for Fisher's exact test. Detrended correspondence analysis (DCA) was used to ordinate plots in two-dimensional space. DCA analysis was performed in R ver. 3.5.0, using the VEGAN package (Oksanen et al. 2012).

To better describe ecological conditions in the communities and their relationships with vegetation, we rearranged the canonical correspondence analysis (CCA) graph performed by Behroozian et al. (2020b) based on the classification groups.

Results

Floristic characteristics of the sites

In all, 370 species were recorded at the study sites, belonging to 184 genera in 45 families (Supporting information). Angiosperms included Dicots (303 species, 152 genera and 35 families) followed by Monocots (65 species, 31 genera and 9 families). The richest families were Asteraceae (27 genera/52 species), Poaceae (21/43), Fabaceae (8/43), Brassicaceae (16/31), Lamiaceae (14/28) and Apiaceae (14/22). *Astragalus* (26 species), *Cousinia* (11), *Alyssum* (11) and *Bromus* (7) were the best genera represented at the sites. For each *Dianthus* community, slightly more species (204) corresponding to habitats of *D. polylepis* subsp. *polylepis*; these numbers were 197 and 193 for *D. polylepis* subsp. *binaludensis* and *D. pseudocrinitus*, respectively (Table 1, Supporting information). Across the life-form spectrum, hemicryptophytes were dominant in the habitats of the three taxa, followed by theropytes, chamaephytes, geophytes and phanerophytes (Fig. 2).

Based on the phytogeographic results for habitats of each taxon, Iran-Turanian elements had the greatest contribution, followed by tri-regional and bi-regional elements respectively. The lowest contribution was from widespread elements (i.e. pluri-regional, sub-cosmopolitan and cosmopolitan species) in all habitats (Fig. 3). The main subdivisions of Irano-Turanian elements were widespread IT, central IT, IT elements endemic to KK floristic province and central-eastern IT (Fig. 4). Endemic species comprised 15.0, 11.3 and 12.6% of the total for *D. polylepis* subsp. *polylepis*, *D. polylepis* subsp. *binaludensis* and *D. pseudocrinitus*, respectively, whereas sub-endemic species were 8.0, 9.8 and 9.0% for the three *Dianthus* taxa (Fig. 5).

Classification and ordination of the vegetation

In the end, 258 species were included in the analyses, after removing species records that occurred in one releve only. Sites were classified at the sixth level into seven vegetation groups labeled 1–7 using the two-way indicator species analysis (TWINSPAN) algorithm (Fig. 6, Table 2). In total, 57 diagnostic species were identified for all sites of seven groups using the phi coefficient of association. A simplified, frequency-fidelity synoptic table of seven vegetation groups was obtained based on 75 resampled releves. The diagnostic species were characterized for each group (Table 2). According to dendrograms at the first level, the first two groups were completely separated from other groups, given their distinct vegetation and environmental conditions. Both groups were characterized by some diagnostic species that occurred only in the sites of these groups, including *Stachys turcomanica* Trautv., *Dianthus pseudocrinitus* and *Erysimum ischnostylum* Freyn & Sint., with fidelity percentages of 83.2, 73.4 and 61.6%, respectively. In more detail, the Misino site, in the first group, was differentiated from the second group, including Rein, Rakhtian and Biu Pass. This site is located in the central Kopet Dagh Mountains, distant from the other three sites. It has the richest vegetation among the seven groups, with the highest average number of species per releve (33 species). The first diagnostic species with the highest fidelity (93.5%) and frequency (100%) was *Androsace maxima* L., followed by *Acer monspessulanum* L. subsp. *turcomanicum* (Pojark.) Rech.f., *Hypericum scabrum* L., *Teucrium polium* L. and *Convolvulus pseudocantabrica* Schrenk ex C.A.Mey., with similar fidelity (81.6%) and frequency (80%). The second group consisted of three sites (Rein, Rakhtian, Biu Pass), 15 releves and an average of 32 species per releve. These sites were located in the western Kopet Dagh Mountains, which present different environmental conditions. The sites were at elevations of 1665–1895 m a.s.l., higher than the first group. *Phlomis cancellata* Bunge was the only diagnostic species (fidelity 60%, frequency 80%).

Groups 3, 4 and 5 (six sites) corresponded to the habitats of *D. polylepis* subsp. *polylepis*. The third group (Balghour and Khomari) was differentiated completely from other sites of this subspecies in terms of species composition. These sites were at higher elevations than the other sites, indicating colder conditions as well as different vegetation. Hence, this group included the most diagnostic species (32 species) among all of the groups. It was specifically separated from groups 4 and 5 by the diagnostic species *Cousinia elata* Boiss.

Table 1. Enumeration of the taxonomic groups in the flora of the habitats associated with the endemic *Dianthus* taxa in Khorassan-Kopet Dagh.

Habitats	Phylum	Subphylum	Family	Genus	Species	The richest genera
D. polylepis subsp. *polylepis*	Angiosperms	Dicots	29	99	162	*Astragalus* (15), *Alyssum* (7), *Cousinia* (6), *Bromus* (6), *Allium* (5), *Silene* (4), *Rochelia* (4), *Euphorbia* (4), *Gagea* (4), *Galium* (4), *Acantholimon* (4)
		Monocots	7	23	41	
	Gymnosperms	–	1	1	1	
D. polylepis subsp. *binaludensis*	Angiosperms	Dicots	26	93	160	*Astragalus* (17), *Alyssum* (8), *Bromus* (6), *Veronica* (5), *Cousinia* (4)
		Monocots	8	19	36	
	Gymnosperms	–	1	1	1	
D. pseudocrinitus	Angiosperms	Dicots	30	95	160	*Astragalus* (8), *Euphorbia* (6), *Alyssum* (5), *Bromus* (4), *Onobrychis* (4), *Cousinia* (4)
		Monocots	3	17	32	
	Gymnosperms	–	1	1	1	

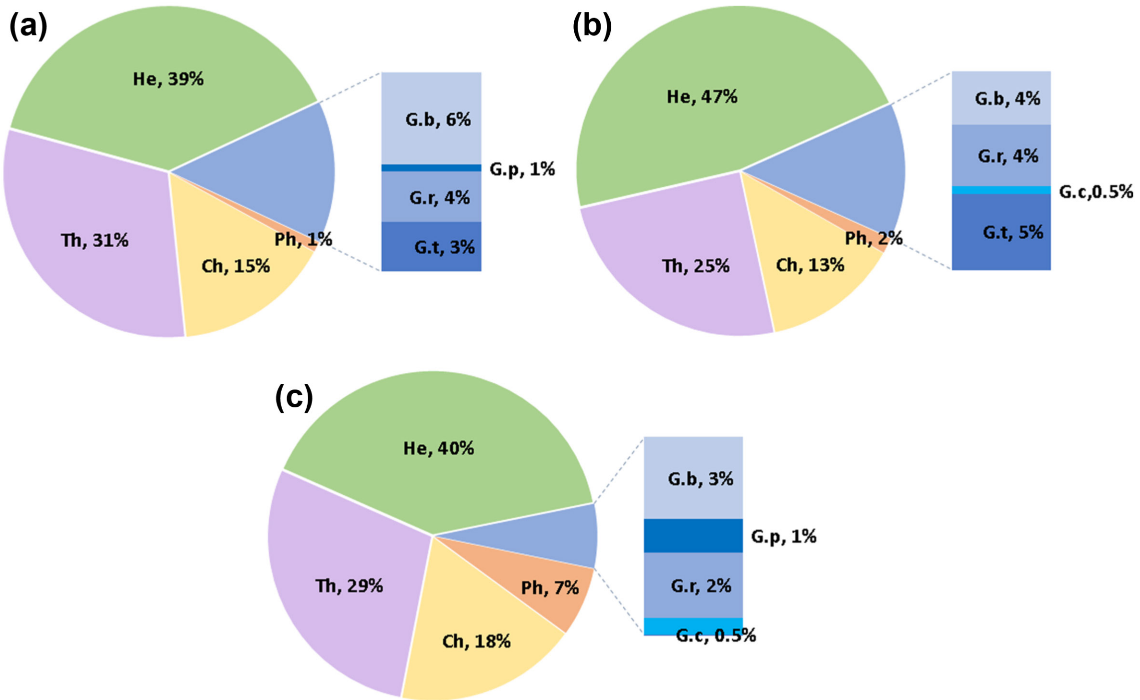

Figure 2. The life-form spectrum of the flora of the study sites. (a) *Dianthus polylepis* subsp. *polylepis*, (b) *D. polylepis* subsp. *binaludensis* and (c) *D. pseudocrinitus* habitats. Ch: chamaephytes, G.b: bulbous geophytes, G.c: cormous geophytes, G.t: tuberous geophytes, G.r: rhizomatous geophytes, G.p: parasitic geophytes, He: hemicryptophytes, Ph: phanerophytes and Th: therophytes.

& Buhse, *Euphorbia bohsei* Boiss. and *Silene crispans* Litv. This group had 29 species per releve on average. *D. polylepis* subsp. *polylepis* (fidelity 68.9%, frequency 100%) was the first diagnostic species, followed by *Stipa hohenackeriana* Trin. & Rupr. (59.4%, 60%) and *Eryngium bungei* Boiss. (56.9%, 100.0%).

According to the dendrogram, groups four (Kuhsorkh and Bezd) and five (Kardeh Dam and Khowre-Kalat) were nearest to one another. Group four had the least diversity in vegetation among all groups, with 20 species per releve on average over 8 releves. Kuhsorkh and Bezd are in the southernmost parts of the distribution of *D. polylepis* subsp. *polylepis*, at elevations of 1487–1660 m, in the southern mountains of the Khorassan Kopet Dagh. *Eryngium bungei* Boiss. (90.5%, 100.0%) and *Hymenocrater platystegius* Rech.f. (77.5%, 88.0%) were the first diagnostic species. Group five included Kardeh Dam and Khowre-Kalat, in the Hezar-Masjed Mountains, at elevations of 1650–1805 m. These sites have higher numbers of species average per releve, compared to other sites of *D. polylepis* subsp. *polylepis*. Diagnostic species included *Phlomis cancellata*, *Cousinia eryngioides* Boiss., *Bromus kopetdaghensis* Drobov and *Iris fosteriana* Aitch. & Baker, with similar fidelity and frequency (5.7%, 50.0%).

All sites of group 6 and 7 were in the Binalood Mountains, at higher elevations than other groups (1800–2260 m a.s.l.). The releves did not separate geographically, so the releves of Baharkish, as well as some releves from Moghan (4 releves), Dahane Jaji (4) and Dizbad (3), were placed in group 6, whereas all releves of Zoshk and all remaining ones were in group 7. These results indicated relatively similar species combination across all sites in the Binalood Mountains. Group 6 was differentiated by high elevations (Baharkish 2260 m a.s.l.) and higher species diversity (average of 31 species per releve) than group 7. The largest value of fidelity (100%) belonged to *D. polylepis* subsp. *binaludensis*, which occurred only in groups 6 and 7. Compared with other groups, several diagnostic species occurred only in these groups, which indicated distinct species composition in the Binalood Mountains. Diagnostic species in group 6 with the highest fidelity included *Cousinia freynii* Bornm. (72.5%), *Astragalus verus* Olivier (67.4%) and *Artemisia kopetdaghensis* Krasch., Popov & Lincz. ex Poljakov (60.9%). On the other hand, group 7 (11 releves) had 27 species per releve on average, at elevations of 1770–2000 m a.s.l. *Galium spurium* L. and *Polygonum paronychioides* C.A.Mey., with similar fidelity and frequency (68.3%, 64.0%), were the first diagnostic species in this group (Fig. 6, Table 2).

The detrended correspondence analysis (DCA) was used to relate the species values to the plots studied. The seven TWINSPAN groups were well separated along the first DCA axes, with eigenvalues of 0.458 and 0.308, respectively (Fig. 7). Higher eigenvalues of the first DCA axis indicated that it captured more of the variation in species composition among sites. The sites of *D. pseudocrinitus* (group 1 and 2) were completely separated from other groups, distributed at the positive end of the first axis of DCA, while other groups occupied the negative end. Group 3 was specifically separated from group 4 and 5 (related to *D. ploylepis* subsp. *polylepis*)

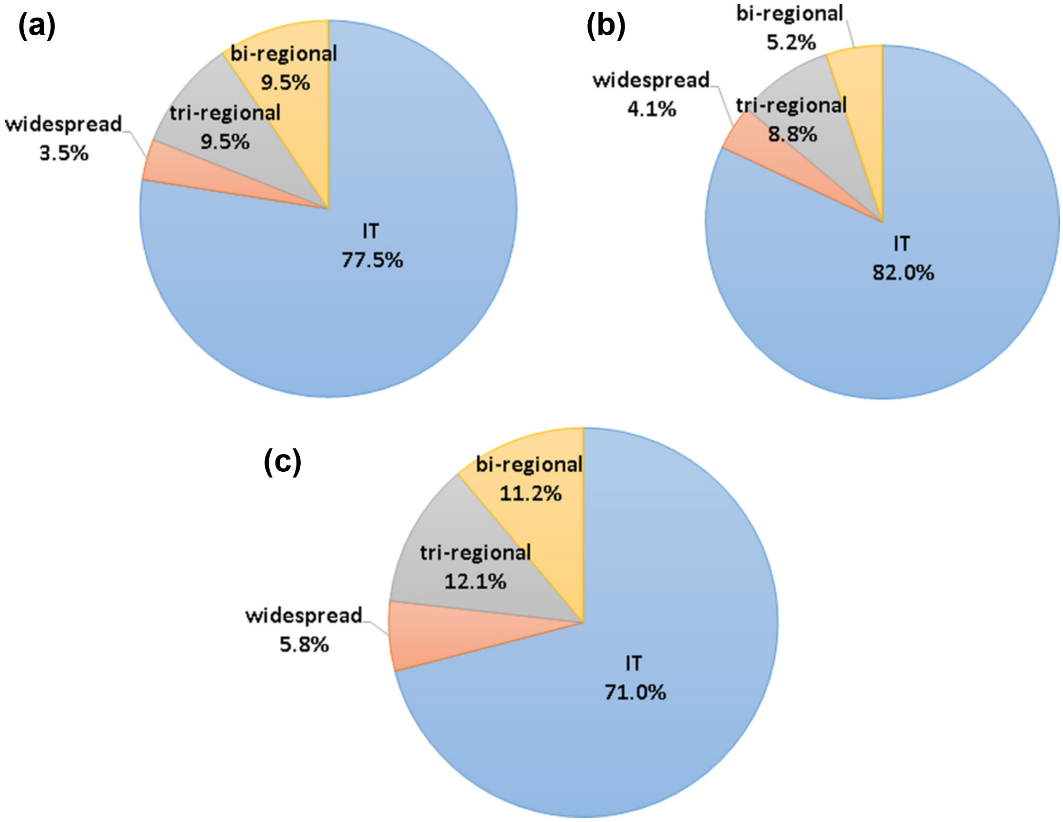

Figure 3. The proportion of the phytogeographic groups in the floras of the study sites. (a) *Dianthus polylepis* subsp. *Polylepis*, (b) *D. polylepis* subsp. *binaludensis* and (c) *D. pseudocrinitus* habitats. Tri-regional (include: IT-ES-M, IT-ES-SS and IT-M-SS), Bi-regional (include: IT-ES, IT-M, IT-SS and ES-M), IT: Irano-Turanian, ES: Euro-Siberian, M: Mediterranean, SS: Sahara-Sindian, COS: Cosmopolitan, SCO: Sub-cosmopolitan and PL: Pluri-regional.

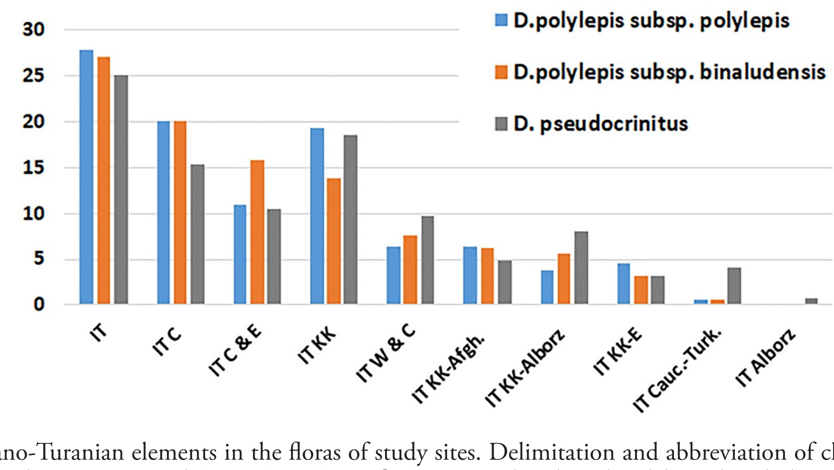

Figure 4. Numbers of Irano-Turanian elements in the floras of study sites. Delimitation and abbreviation of chorological subdivisions are based on Akhani (1998) and Memariani et al. (2016a): IT (or IT^{Omni}): species distributed widely in the whole Irano-Turanian region or with a wide range that cannot be categorized within the subdivisions defined in this work; IT^{KK}: montane areas in northeastern Iran and Kopet Dagh range in southern Turkmenistan; $IT^{KK\text{-}Afgh.}$: mountainous areas in northeastern Iran and Kopet Dagh range in S Turkmenistan and also north and northwest Afghanistan; IT^{W}: preliminarily defined as the Anatolian and western Iranian montane and sub-montane flora; IT^{C}: species whose distribution is confined to the montane and sub-montane areas and the steppes in central Iran (southern slopes of the Alborz Range, eastern slopes of the Zagros Range), mountains in northeast Iran and south Turkmenistan, and most of the west and central parts of Afghanistan; IT^{E}: species occurring mainly in the middle and central Asia but with disjunct occurrences in Khorassan-Kopet Dagh; IT^{Alborz}: species exclusively distributed in the montane steppes along the Alborz range; $IT^{Cauc.\text{-}Turk.}$: species occurring from Caucasia, through Alborz to KK mountains in Turkmenistan. Some distribution patterns may include two chorological subdivisions such as $IT^{C\,\&\,E}$, $IT^{W\,\&\,C}$, $IT^{KK\text{-}Alborz}$ and $IT^{KK\text{-}E}$.

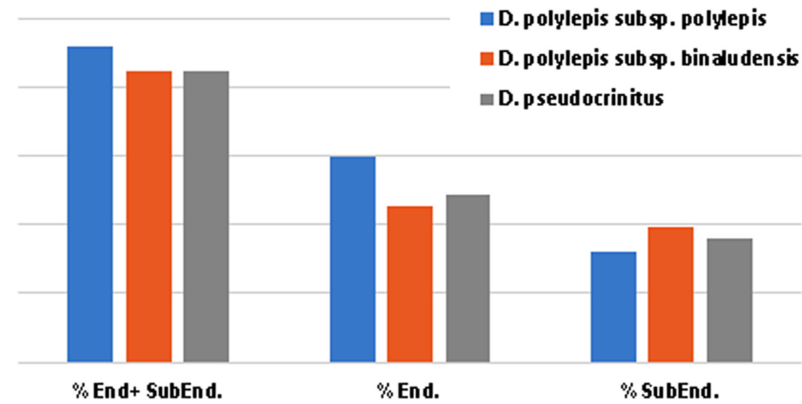

Figure 5. Percentage of the endemic and sub-endemic species for the studied *Dianthus* habitats in Khorassan-Kopet Dagh floristic province.

whereas group 6 and 7 (*D. polylepis* subsp. *binaludensis*) were distributed close together along the first axes of DCA.

According to CCA graphs, some soil, topography and bioclimatic variables displayed significant effects on the species composition of seven groups (Fig. 8). Of the environmental variables, total N, organic matter and lime had positive correlations with the first two groups for *D. pseudocrinitus*, while topographic and soil factors had greater impacts on plant species identity at other five groups for two subspecies of *D. polylepis*.

Discussion

Floristic composition of *Dianthus* habitats

The *Dianthus* taxa that were the focus of this study occur in montane steppes, at elevations of 1500–2300 m a.s.l. These regions include thorn-cushion communities and grassy montane steppes, or combinations, based on elevation, humidity, soil type and degree of disturbance. Floras are rich in these areas, with endemic plants including species in genera *Astragalus*, *Cousinia*, *Allium*, *Acantholimon*, *Acanthophyllum* and *Euphorbia* (Zohary 1973, Takhtajan 1986, Léonard 1991). Generally, *Artemisia kopetdaghensis*, *Astragalus verus*, *Acantholimon avenaceum* Bunge, *Acanthophyllum glandulosum* Buhse ex Boiss. and *Onobrychis cornuta* (L.) Desv. (thorn-cushion formations) and *Stipa arabica* Trin. & Rupr., *Festuca valesiaca* Gaudin, *Elymus hispidus* (Opiz) Melderis and *Poa bulbosa* L. (graminoid formations) were the dominant species in the vegetation of the study sites. Memariani et al. (2016a) confirmed that most thorn-cushion communities in KK are composed of *Acantholimon*, *Acanthophyllum* and *Astragalus* species as well as *Onobrychis cornuta*. *Astragalus* was the best-represented genus in the study area, including the most species in all habitats of the three *Dianthus* taxa. It is considered

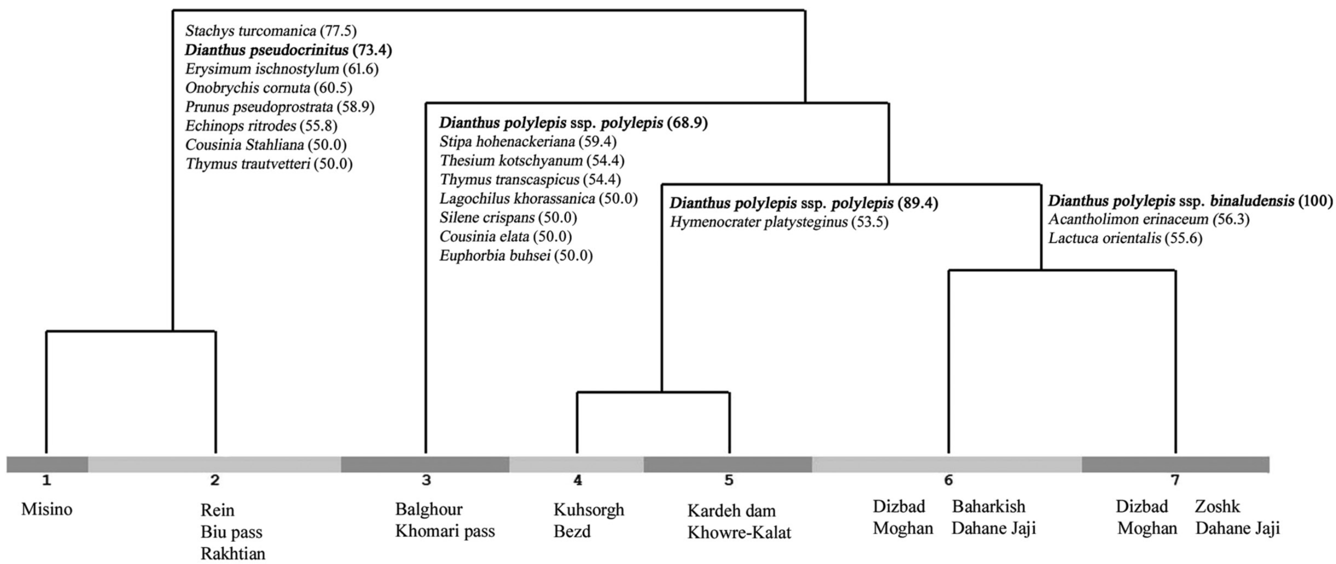

Figure 6. The dendrogram of TWINSPAN classification of 15 study sites in seven vegetation groups (1–7), together with their indicator species resulted from classification of the 75 sample releves.

Table 2. Frequency-fidelity table of seven vegetation groups obtained by TWINSPAN classification. Frequencies of species are presented as percentages with phi values multiplied by 100 shown in superscript. Diagnostic species (phi values higher than 0.25) for each groups are shaded.

Group number	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
No. of sites	1	3	2	2	2	3	2
No. of quadrates	5	15	10	8	10	16	11
Average of species number in quadrates per group	33	32	29	20	30	31	27
Altitude range (m)	1647–1711	1677–1936	1809–1893	1487–1660	1650–1805	1936–2260	1770–2000
Androsace maxima	$100^{93.5}$	7–		13–			
Acer monspessulanum ssp. *turcomanicum*	$80^{81.6}$				10–	25–	36–
Hypericum scabrum	$80^{81.6}$						
Teucrium polium	$80^{81.6}$		30–		20–		
Convolvulus pseudocantabrica	$80^{81.6}$						
Euphorbia kopetdaghi	$60^{65.5}$						
Stipa caucasica	$60^{65.5}$					19–	
Astragalus jolderensis	$60^{65.5}$					13–	
Ziziphora clinopodioides	$60^{65.5}$		20–			25–	9–
Astragalus raddei	$60^{56.6}$	7–	10–				
Minuartia meyeri	$60^{56.6}$	7–		13–	40–		9–
Phlomis cancellata	20–	$80^{60.0}$			50–	50–	18–
Dianthus polylepis subsp. *polylepis*			$100^{68.9}$	80–	90–		
Stipa hohenackeriana	20–	13–	$60^{59.4}$		10–	6–	
Eryngium bungei		20–	$100^{56.9}$	100–	10–	69–	27–
Thesium kotschyanum		13–	$50^{54.4}$		10–		
Thymus transcaspicus		27–	$50^{54.4}$		10–		
Lagochilus khorassanicus		7–	$40^{50.0}$				
Silene crispans			$40^{50.0}$				
Cousinia elata			$40^{50.0}$				
Euphorbia buhsei			$40^{50.0}$				
Lappula micricarpa	40–	60–	$80^{49.2}$		20–	38–	55–
Prunus turcomanica		7–	$50^{45.1}$		13–		9–
Jurinea sintenisii			$40^{42.8}$		10–	6–	
Prangos latiloba			$40^{42.8}$	13–	10–		
Brassica elongata			$30^{42.0}$				
Nepeta glomerulosa			$30^{42.0}$				
Scutellaria litwinowii			$30^{42.0}$				
Helichrysum oocephalum	20–		$40^{39.4}$		10–	6–	9–
Bromus tectorum		13–	$60^{38.4}$	25–	20–	19–	27–
Jurinea stenocalathia			$30^{37.8}$			6–	
Echinops ritrodes	60–	60–	$30^{37.8}$			6–	
Euphorbia bungei	20–	7–	$40^{36.2}$			19–	9–
Teucrium polium			$30^{33.8}$				
Oxytropis kuchanensis			$30^{33.8}$			13–	
Cousinia chaetocephala			$30^{33.8}$		20–		
Buffonia sintenisii			$20^{33.3}$				
Onobrychis cornuta	40–	67–	$20^{33.3}$				
Paracaryum crista-galli			$20^{33.3}$				
Sclerorhachis platyrachis		7–	$20^{33.3}$				
Astragalus culminatus			$20^{33.3}$				
Tulipa undulatifolia var. micheliana	20–		$20^{33.3}$				
Koelpinia linearis		13–	$20^{33.3}$				
Eryngium bungei				$100^{90.5}$			
Hymenocrater platystegius				$88^{77.5}$	10–		
Polygonum paronychioides		7–	50–	$63^{67.4}$			64–
Galium spurium				$63^{54.6}$			
Phlomis cancellata					$50^{57.7}$		
Cousinia eryngioides					$50^{57.7}$		
Bromus kopetdaghensis	40–	7–	10–		$50^{57.7}$	25–	
Iris fosteriana			40–		$50^{57.7}$	25–	
Scandix stellata		40–	10–	25–	$80^{55.1}$	25–	82–
Cousinia freynii			50–	63–	20–	$81^{72.5}$	9–
Astragalus verus	20–	33–	20–	50–	60–	$63^{67.4}$	

(Continued)

Table 2. Continued.

Group number	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
Artemisia kopetdaghensis	80–	53–	20–	50–	50–	$88^{60.9}$	27–
Acantholimon avenaceum			20–	20–	50–	$38^{48.0}$	
Eremurus spectabilis					25–	$38^{48.0}$	
Vicia subvillosa					30–	$63^{45.2}$	18–
Taraxacum sonchoides		7–		13–		$50^{44.8}$	9–
Eryngium bungei					27–	$69^{41.5}$	
Galium spurium		27–		63–	10–		$64^{68.3}$
Polygonum paronychioides							$64^{68.3}$
Sanguisorba minor		20–			10–		$55^{61.2}$
Scandix stellata						25–	$82^{57.0}$

as an indicator species of the Irano-Turanian region, with 804 species in Iran (Maassoumi 1986–2005). The largest families were Asteraceae (26 species) and Poaceae (27 species) for the sites of *D. polylepis* (both subspecies) and *D. pseudocrinitus*, respectively. The majority of species in all sites displayed life-form as hemicryptophyte (43%) which indicates cold, semi-arid conditions. Then, therophytes comprised 27% of species, expressing the adaptability of the species to arid habitats by completing the annual life cycle, following by chamaephytes (15%), including the thorn-cushion species. Cryptophytes (Geophytes) with different underground vegetative organs (bulb, corm, tuber, rhizome, root parasits) contained 11% of species, which this result indicates a relatively low soil moisture in communities (Kamrani et al. 2011). Since Irano-Turanian elements make up the core flora of KK, 75% of the flora of all habitats consisted of Iran-Turanian elements. According to Memariani et al. (2016b), endemic species of KK are concentrated in the central Kopet Dagh Mountains; hence, most endemic species occurred in the sites of *D. polylepis* subsp. *polylepis*, located in the Hezar-Masjed mountain range.

Vegetation characteristics of the communities associated with *Dianthus* taxa

Classification analysis showed a clear separation of the study sites based on *Dianthus* taxa, which was confirmed by DCA analysis. These sites had a rich flora thanks to specific climatic conditions, with a high range of precipitation values.

In the first two groups, although the structure of communities was similar at all sites of *D. pseudocrinitus*, they showed different species combinations. Spiny-plant and grazing-resistant species such as *Artemisia kopetdaghensis* and *Klasea*

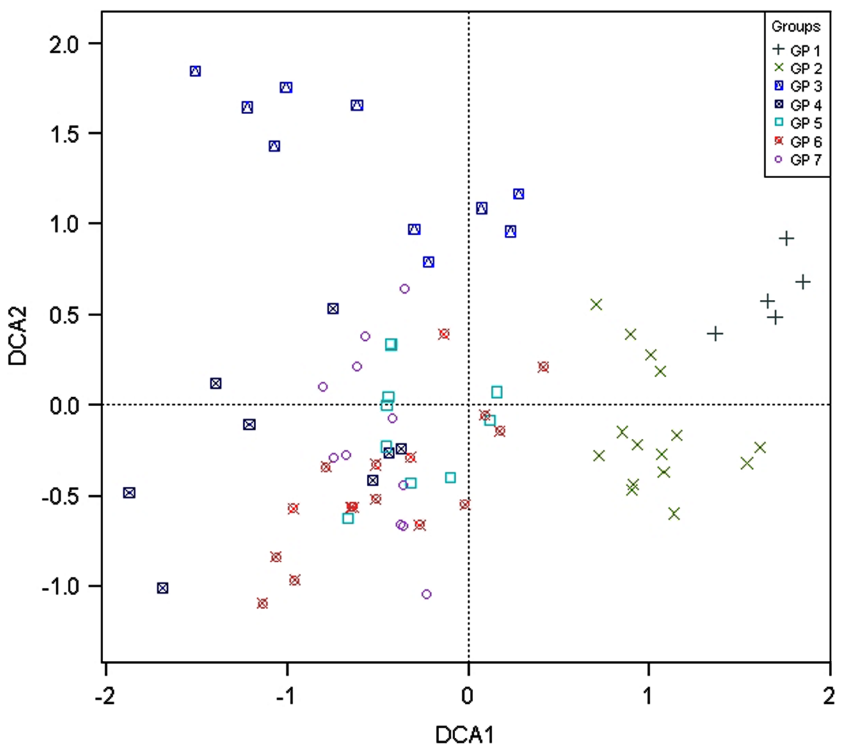

Figure 7. DCA ordination of 75 sample plots on axes 1 and 2 for the seven study groups based on species composition. *Dianthus pseudocrinitus* sites (GP1–2), *Dianthus polylepis* subsp. *polylepis* sites (GP3–5) and *D. polylepis* subsp. *binaludensis* sites (GP6–7).

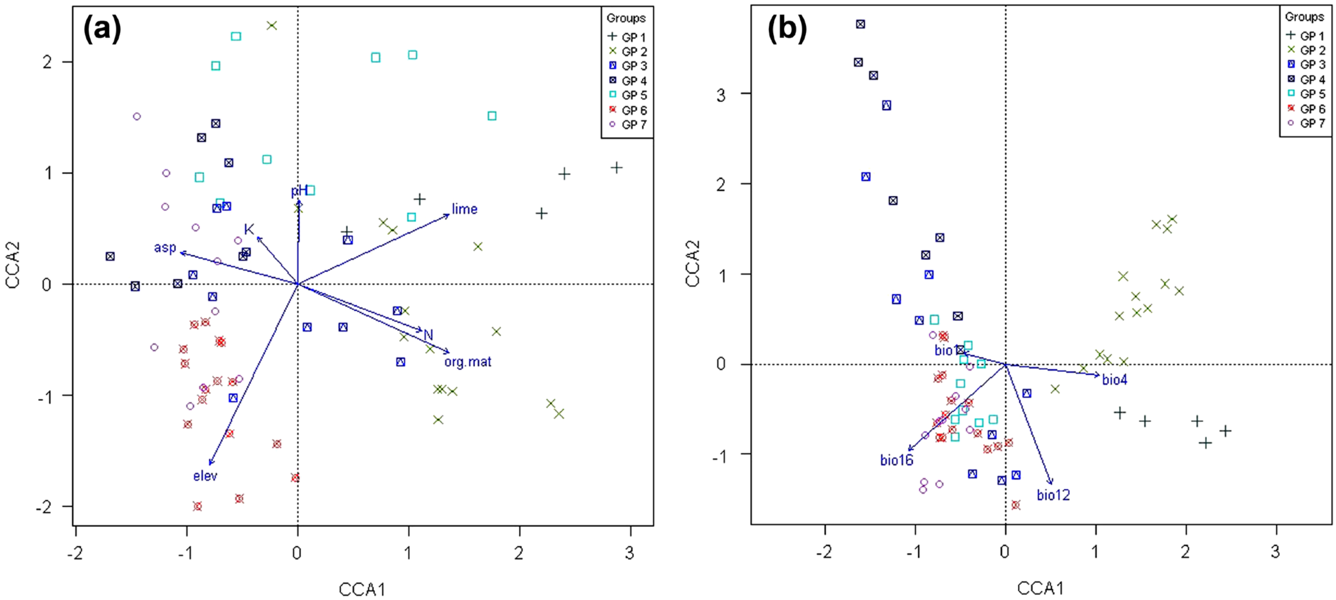

Figure 8. CCA ordination of the first two axes showing the distribution of the 75 plots for the seven study groups. (a) Soil variables (K: potassium; N: total nitrogen; org. mat: organic matter; lime: calcium carbonate) and topography (elev: elevation; asp: aspect), (b) bioclimatic variables (bio1: annual mean temperature; bio4: temperature seasonality; bio12: annual precipitation; bio16: precipitation of wettest quarter). Modified from Behroozian et al. (2020b).

leptoclada (Bornm. & Sint.) L.Martins indicated high grazing in these sites. The distribution of vegetation within groups was mainly controlled by three soil factors including organic matter, N, $CaCO_3$ and two bioclimatic variables of the variability of temperature and annual precipitation (Fig. 8). On the other hand, anthropogenic activities such as overgrazing are more effective factors in these sites that reduce the photosynthetic plant biomass and increase the availability of N in the soil for plant recovery (Sankaran and Augustine 2004). Manninen et al. (2016) pointed out that disturbance and N fertilization increase the abundance of fast-growing graminoids and lead to a new stable composition in plant communities. Organic matter content as an important soil fertility factor also affects vegetation growth and development, so that decomposition of plant residues increases the organic matter content in the soil and enriches the vegetation diversity (Traut 2005, Zhang et al. 2010). Furthermore, the sites are affected by the variability of temperature and the annual precipitation which was closely related to vegetation cover (Rustad et al. 2001, Dieleman et al. 2012, Sistla et al. 2013).

The sites of *D. polylepis* ssp. *polylepis* in group 3, 4 and 5 were distributed throughout the KK area. These sites are influenced by Irano-Turanian desert-continental climate, and experiences a longer dry season, lasting at least eight months (Memariani et al. 2016b). Grazing-resistant species such as *Euphorbia microsciadia* Boiss., *Acantholimon avenaceum*, *Acanthophyllum glandulosum* and *Cousinia* species displayed the full-stressed conditions at the sites. In the CCA results (Fig. 8), soil factors (e.g. N, organic matter, lime and pH), topography (slope and elevation) and low annual temperature and low precipitation were correlated with these sites which demonstrate severe disturbance. Indeed, these sites are located close to villages and roadsides, with overgrazing and high anthropogenic activities. The studies indicated that the soil is evolved by five factors affecting soil formation, including topography, climate, time and living organisms. Topography and climate, the main environmental factors, can control the processes of soil formation in the same geological formation and the specific time intervals between these factors. Hence, topography influences soil characteristics and plant yields by affecting the processes of soil formation (Wang et al. 2001).

All sites of *D. polylepis* subsp. *binaludensis* (group 6 and 7) are in the Binalood Mountains. The Binalood massif developed from a distinct formation geologically (Hubber 1976); hence, these mountains are considered among the important centers of plant endemism in the KK floristic province (Memariani et al. 2016b). Our floristic studies indicated several diagnostic species occurring only at these sites, supporting an exclusive species composition in the Binalood Mountains. The CCA results revealed that topographic factors (e.g. elevation and aspect) and climatic variables (e.g. precipitation of the wettest quarter) are correlated with these groups (Fig. 8). The elevational range has an important effect on the distribution and patterns of vegetation in mountain areas (Titshall et al. 2000). The dominant environmental stresses in the Binalood Mountains are low temperature, dry wind, solar radiation and snow cover reflecting higher elevations than the other mountains in this study. Consequently, the dominant life-forms in the Binalood Mountains are low-growing shrubs, perennial herbs and geophytes. The aspect of slopes affects the vegetation growth significantly at these sites. Jin and Sader (2005) pointed out that the vegetation coverage on the sunny side in the semi-arid mountain area is less well developed than that on the shady side owing to differences in solar radiation and higher land surface temperatures; hence, a better vegetation growth occurs over a larger elevation range on slopes facing north and northeast.

On the other hand, the studies show that the communities with high numbers of hemicryptophytes, geophytes and therophytes are affected by local disturbance regimes, climate factors as well as topographic conditions such as slope and aspect (Vazquez and Givnish 1998, Irl et al. 2020). According to life-form spectra in this study (Fig. 2), hemicryptophytes, geophytes and therophytes comprise the most percentage of life-forms among species for communities of three taxa; hence, it seems that these communities are affected by stressful environmental conditions and conservation programs should be considered for species habitats in the study area.

Conclusions

This study represented a first attempt at classifying and describing plant communities in the habitats of two endemic *Dianthus* species in northeastern Iran. The results reflected a highly diverse flora in all *Dianthus* habitats that we studied. It also indicated the floristic composition and ecology of the communities in their natural habitats of both *Dianthus* species, and revealed that their conservation is affected by severe environments such as low temperature, strong wind, intense solar radiation and human activities. The occurrence of spiny plants and grazing-resistant species showed a relatively high disturbance history in some sites. The natural vegetation of seven groups was strongly correlated with some soil, topography and climatic factors. The results of this study demonstrate that these factors can influence the distribution and abundance of plant species, and can be taken into account in plans to assure the future of plant conservation in montane regions. Our results suggest that the disturbed communities with high values of total nitrogen availability and organic matter of soil (e.g. *D. pseudocrinitus* communities) should be considered for conservation management, such that *D. pseudocrinitus* can be applied as a good indicator to identify the destroyed habitats and conservation status of the studied communities.

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Author contributions

Maryam Behroozian: Data curation (equal); Formal analysis (equal); Investigation (equal); Writing – original draft (equal). **Hamid Ejtehadi**: Conceptualization (equal); Funding acquisition (equal); Project administration (equal); Supervision (equal); Validation (equal); Writing – review and editing (equal). **Farshid Memariani**: Conceptualization (equal); Funding acquisition (equal); Project administration (equal); Resources (equal); Supervision (equal); Validation (equal); Writing – review and editing (equal). **Mohammad Reza Jouharchi**: Data curation (equal); Investigation (equal); Resources (equal); Writing – review and editing (equal). **Mansour Mesdaghi**: Formal analysis (equal); Writing – review and editing (equal).

Data availability statement

Data are available from the Figshare Digital Repository: <https://doi.org/10.6084/m9.figshare.20745973> (Behroozian et al. 2022).

Supporting information

The Supporting information associated with this article is available with the online version.

References

[APG IV] Angiosperm Phylogeny Group 2016. An update of the classification for the Angiosperm Phylogeny Group for the orders and families of flowering plants. – APG IV Bot. J. Linn. Soc. 181: 1–20.
Akhani, H. 1998. Plant biodiversity of Golestan National Park, Iran. – Stapfia 53: 1–411.
Assadi, M. et al. 1988–2019. Flora of Iran, vol. 1–147. – Research Inst. of Forests and Rangelands Publications.
Barkmann, J. J. et al. 1964. Kritische bemerkungen und vorschläge zur quantitativen vegetationsanalyse. – Acta Bot. Neerl. 13: 394–419.
Behroozian, M. et al. 2020a. Climate change influences on the potential distribution of *Dianthus polylepis* Bien. ex Boiss. (Caryophyllaceae), an endemic species in the Irano-Turanian region. – PLoS One 15: e0237527.
Behroozian, M. et al. 2020b. Are endemic species necessarily ecological specialists? Functional variability and niche differentiation of two threatened *Dianthus* species in the montane steppes of northeastern Iran. – Sci. Rep. 10: 11774.
Behroozian, M. et al. 2022. Data from: Floristic diversity and vegetation of communities associated with two endemic *Dianthus* species in the montane steppes of northeastern Iran. – Figshare Digital Repository, <https://doi.org/10.6084/m9.figshare.20745973>.
Beniston, M. 2003. Climatic change in mountain regions: a review of possible impacts. – Clim. Change 59: 5–31.
Bilz, M. et al. 2011. European Red List of vascular plants. – Publications Office of the European Union.
Caperta, A. D. et al. 2014. Habitat specificity of a threatened and endemic, cliff-dwelling halophyte. – AoB 6: plu032.
Cogoni, D. et al. 2012. From seed to seedling, a critical transitional stage for the Mediterranean psammophilous species *Dianthus morisianus* (Caryophyllaceae). – Plant Biosyst. 146: 910–917.
Dieleman, W. J. et al. 2012. Simple additive effects are rare: a quantitative review of plant biomass and soil process responses

to combined manipulations of CO_2 and temperature. – Global Change Biol. 18: 2681–2693.
Djamali, M. et al. 2011. Application of the global bioclimatic classification to Iran: implications for understanding the modern vegetation and biogeography. – J. Mediterr. Ecol. 37: 91–114.
Egan, P. A. and Price, M. 2017. Mountain ecosystem services and climate change. A global overview of potential threats and strategies for adaptation. – UNESCO.
Farsi, M. et al. 2013. The evolution of *Dianthus polylepis* complex (Caryophyllaceae) inferred from morphological and nuclear DNA sequence data: one or two species? – Plant Syst. Evol. 299: 1419–1431.
Gargano, D. et al. 2009. Do inefficient selfing and inbreeding depression challenge the persistence of the rare *Dianthus guliae* Janka (Caryophyllaceae)? Influence of reproductive traits on a plant's proneness to extinction. – Plant Species Biol. 24: 69–76.
Gargano, D. et al. 2011. Fitness drivers in the threatened *Dianthus guliae* Janka (Caryophyllaceae): disentangling effect of growth context, maternal influence and inbreeding depression. – Plant Biol. 13: 96–103.
Grabherr, G. et al. 1994. Climate effects on mountain plants. – Nature 369: 448.
Hennekens, S. M. and Schaminée, J. H. J. 2001. TURBOVEG, a comprehensive data base management system for vegetation data. – J. Veg. Sci. 12: 589–591.
Hill, M. O. 1979. TWINSPAN – a FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. – Cornell Univ.
Hobohm, C. (ed.) 2014. Endemism in vascular plants. – Springer.
Hubber, H. C. 1976. Geological map of Iran, 1:1 000 000 scale (sheet no. 3). – Geological Map of North-East Iran, Exploration and Production, NIOC.
Irl, S. D. H. et al. 2020. Climate controls plant life-form patterns on a high-elevation oceanic island. – J. Biogeogr. 47: 2261–2273.
Jalili, A. and Jamzad, Z. 1999. Red data book of Iran. – Research Inst. of Forests and Rangelands Publications.
Jin, S. and Sader, S. A. 2005. MODIS time-series imagery for forest disturbance and quantification of patch effects. – Remote Sens. Environ. 99: 462–470.
Kamrani, A. et al. 2011. Relationships between environmental variables and vegetation across mountain wetland sites, N. Iran. – Biologia 66: 76–87.
Kruckeberg, A. R. and Rabinowitz, D. 1985. Biological aspects of endemism in higher plants. – Annu. Rev. Ecol. Evol. Syst. 16: 447–479.
Léonard, J. 1988. Contribution a l'étude de la flore et de la végétation des desert d'Iran, Fascicule 8. Étude des Aries de distribution, Les phytochories, Les chorotypes (Contribution to the study of the flora and vegetation of the Iranian desert, vol. 8: Study of distribution areas, phytochoria, chorotypes). – Jardin Botanique National de Belgique.
Léonard, J. 1991. Contribution a l'étude de la flore et de la végétation des desert d'Iran, Fasicule 10. Étude de la vegetation: Analyse phytosociologique et phytochorologique des groupments végétaux (Contribution to the study of the flora and vegetation of the Iranian desert, vol. 10: study of vegetation: phytosociological and phytochorological analysis of plant groups). – Jardin Botanique National de Belgique.
Loarie, S. R. et al. 2009. The velocity of climate change. – Nature 462: 7276.
Maassoumi, A. A. 1986–2005. The genus *Astragalus* L. in Iran, Vol. 1–5. – Research Inst. of Forests and Rangelands Publications.
Manninen, S. et al. 2016. Nitrogen deposition does not enhance *Sphagnum* decomposition. – Sci. Total Environ. 571: 314–322.
Memariani, F. 2020. Khorassan-Kopet Dagh mountains. – In: Noroozi, J. (ed.), Plant biogeography and vegetation of high mountains of central and south-west Asia. Springer, pp. 93–116.
Memariani, F. et al. 2016a. 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.
Memariani, F. et al. 2016b. Endemic plants of Khorassan-Kopet Dagh floristic province in Irano-Turanian region: diversity, distribution patterns and conservation status. – Phytotaxa 249: 31–117.
Munson, S. M. and Sher, A. A. 2015. Long-term shifts in the phenology of rare and endemic Rocky Mountain plants. – Am. J. Bot. 102: 268–276.
Noroozi, J. et al. 2018. Hotspots within a global biodiversity hotspot areas of endemism are associated with high mountain ranges. – Sci. Rep. 8: 10345.
Nowrouzi, G. et al. 2007. Crustal velocity structure in Iranian Kopeh-Dagh, from analysis of P-waveform receiver functions. – J. Sustain. Energy Environ. 8: 187–194.
Oksanen, J. et al. 2012. vegan: community ecology package. – R package ver. 2.0.3, <http://CRAN.R-project.org/package=vegan>.
POWO 2022. Plants of the World Online. – R. Bot. Gard. Kew; <www.plantsoftheworldonline.org/>, accessed 10 January 2022.
Raunkiaer, C. 1934. The life form of plants and statistical plant geography. – Clarendon Press.
Rechinger, K. H. (ed.) 1963–2015. Flora Iranica, vol. 1–181. – Akademische Druck-und Verlagsanstalt.
Rustad, L. E. et al. 2001. A meta-analysis of the response of soil respiration, net nitrogen mineralization and aboveground plant growth to experimental ecosystem warming. – Oecologia 126: 543–562.
Sankaran, M. and Augustine, D. J. 2004. Large herbivores suppress decomposer abundance in a semiarid grazing ecosystem. – Ecology 85: 1052–1061.
Sanz-Elorza, M. et al. 2003. Changes in the high-mountain vegetation of the Central Iberian Peninsula as a probable sign of global warming. – Ann. Bot. 92: 273–280.
Sheikholeslami, M. R. and Kouhpeyma, M. 2012. Structural analysis and tectonic evolution of the eastern Binalud Mountains, NE Iran. – J. Geodyn. 61: 23–46.
Sistla, A. S. et al. 2013. Long-term warming restructures Arctic tundra without changing net soil carbon storage. – Nature 497: 615–619.
Takhtajan, A. 1986. Floristic regions of the world. Translated from Russian. – Univ. of California Press.
Tichý, L. 2002. JUICE, software for vegetation classification. – J. Veg. Sci. 13: 451–453.
Titshall, L. W. et al. 2000. Effect of long-term exclusion of fire and herbivory on the soils and vegetation of sour grassland. – Afr. J. Range Forage Sci. 17: 70–80.
Traut, B. H. 2005. The role of coastal ecotones: a case study of the salt marsh/upland transition zone in California. – J. Ecol. 93: 279–290.
Vaezi, J. et al. 2014. *Dianthus pseudocrinitus* (Caryophyllaceae), a new species from northeast of Iran identified by morphological and molecular data. – Phytotaxa 156: 59–73.

Vazquez, J. A. and Givnish, T. J. 1998. Altitudinal gradients in tropical forest composition, structure and diversity in the Sierra de Manantlan. – J. Ecol. 86: 999–1020.
Wang, J. et al. 2001. Soil nutrients in relation to land use and landscape position in the semi-arid small catchment on the loess plateau in China. – Arid Environ. 48: 537–550.
Zhang, A. et al. 2010. Effect of biochar amendment on yield and methane and nitrous oxide emissions from a rice paddy from Tai Lake Plain, China. – Agric. Ecosyst. Environ. 139: 469–475.
Zohary, M. 1973. Geobotanical foundations of the Middle East, 2 vols. – Gustav Fischer Verlag.