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Source: Mountain Research and Development, 40(1)

Published By: International Mountain Society

URL: https://doi.org/10.1659/MRD-JOURNAL-D-18-00089.1

Mountain Research and Development (MRD)
An international, peer-reviewed open access journal
published by the International Mountain Society (IMS)
www.mrd-journal.org

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Floristic Diversity and Distribution Patterns Along an Elevational Gradient in the Northern Part of the Ardabil Province Rangelands, Iran

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This study evaluated the distribution pattern, species diversity index (richness, diversity, and evenness), importance value index (IVI), and family importance value (FIV) of all vascular plant species and various plant community life-form spectra along the Moghan Plain–Sabalan Mountain rangelands, Ardabil province, Iran. Sampling was conducted in 11 elevation classes at 300-m elevation intervals (100–3300 masl). In each elevation interval, 30 quadrats (1 × 1 m) were laid to collect vegetation data. Different vegetation attributes (density, frequency, and canopy cover) were measured for each quadrat. Regression analyses were employed to explore the interrelation of elevation with diversity, species richness, evenness, and IVI. In total, 251 species (143 genera, 38 families) were recorded across the study area. Poaceae, Fabaceae, and Asteraceae were most dominant families according to the FIV. According to the IVI, Poa bulbosa, Festuca ovina, Medicago minima, *and* Artemisia austriaca *were the dominant species along the elevation gradient. Total diversity and species richness showed a normal distribution along the elevation gradient. Overall, hemicryptophytes and therophytes were the dominant life forms, while chamaephytes and geophytes were less frequent forms. The life-form patterns changed along elevation gradients. While the diversity and species richness values of therophytes and chamaephytes showed a decreasing trend, hemicryptophytes increased with increasing elevation. Diversity, species richness, and evenness of geophytes were not significantly different across the elevation gradient. Class I (highly palatable) and class II (mostly palatable) species declined as the elevation increased and then increased, while class III (hardly or unpalatable) species showed a reverse trend. The difference in the abundance and distribution of species in elevation classes could be related to resource availability, overlap of habitats, habitat patchiness, land area, degree of human influence, or biotic disturbances.*

Keywords: *diversity index; elevation gradient; grazing pressure; importance value index; species composition.*

Peer-reviewed: *September 2019* ***Accepted:*** *May 2020*

Introduction

The Moghan Plain–Sabalan Mountain rangelands (MPSMRs) in Ardabil province, Iran, supply livestock forage and play an essential role in food provision, groundwater enrichment, clean water production, wildlife, tourism, recreation, medicinal plant provision, beekeeping, and climate change mitigation (Ghorbani et al 2014, 2017, 2018; Nazari Anbaran et al 2016; Ghafari et al 2017, 2018). According to the literature, 396 plant taxa have been identified in the area. Of these, 25 plant taxa are endemic to Iran (Ghafari et al 2017, 2018). Because of the variety of plant species and the climate, beekeeping is a good source of food in this area (330,000 kg/y honey products; Sharifi et al 2017). The MPSMRs are also rich in medicinal and commercially valuable plants, which require sustainable management to promote health, income, and employment (Ghorbani et al 2017). In recent decades, with the increasing population, low level of development, and high dependence of local communities on rangelands for their primary livelihood needs, as well as increasing livestock numbers as living standards have improved, the MPSMRs have been overused. Excessive and irregular grazing, destruction by livestock, disregard for seasonal unsuitability for grazing, conversion of rangelands, and road construction are the main causes of degradation in the MPSMRs (Ghafari et al 2017, 2018). In the early 1980s, the rangelands covered 58.2% of the land area; however, by 2015, its coverage had been reduced to 53.9% (Kakehmami et al 2017). Understanding the capabilities and limitations of rangelands is essential for appropriate management at the regional level. The rapid change in elevation, even over short distances, makes the MPSMRs an ideal place for studying the vegetation dynamics associated with biotic and abiotic factors that vary with elevation (Körner et al 2011).

Few studies conducted in the MPSMRs (Ghorbani et al 2014, 2017; Nazari Anbaran et al 2016; Ghafari et al 2017,

2018) have focused on vegetation structure and species richness. However, understanding diversity patterns is essential for developing best approaches to diversity conservation as well as the sustainable utilization and management of plant resources. Hence, the aim of this study was to analyze floristic composition, diversity, and structure along the elevation gradient of the MPSMRs. This is expected to provide baseline data along with an analysis that can be used to develop diversity conservation strategies and sustainable rangeland management plans for the study area. This study attempted to answer the following questions: (1) Do species composition, ecological importance, and structural components of vegetation vary significantly along the elevation gradient? (2) What is the relation between elevation and species richness? (3) Do the diversity index and ecological importance along the elevation gradient differ, and if so, how?

Rangeland history and biophysical specificities of the area

The Ardabil province rangelands are located at the confluence of the 3 climatic areas: the Siberian from the north, the Mediterranean from the west, and the wet from the Caspian Sea. This, together with the Sabalan and Khoroslou mountains and hills (slopes 5% to more than 100%), affects climate and plant diversity in the region (Sharifi et al 2017). Various types of rangelands, such as summer rangelands (Sabalan, Baghru, and Buzghush mountains rangelands), spring and autumn rangelands (low mountainous areas, such as Kalantar-Khoroslou, to hilly areas, such as Gharesou river landscapes, also known as the Arshagh rangelands) and winter rangelands (Moghan Plain rangelands) are part of Ardabil province.

The second largest nomad tribe, the Shahsavan, belong to Ardabil province (Hosseinzadeh et al 2017a). The nomadic livestock husbandry system is one of the most important and oldest livestock husbandry systems in Iran. It strongly depends on natural rangelands. For centuries, the Moghan Plain has served as a grazing area for nomadic tribes, with agriculture being of secondary importance. Shahsavan nomads move their livestock to make the best use of available forage and water in a seasonal cycle on their allotted spring, summer, autumn, and winter rangelands (Hosseinzadeh et al 2017b). Shahsavan nomads use the Moghan rangelands for about 6 months of the year (Arjmand Karkazloo 2016).

The climate is favorable for agriculture and animal husbandry. Traditional and semi-industrial animal husbandry are practiced in villages (paddocks) and are dependent on rangeland forage and agricultural residues. In Ardabil province, 1600 pastoralist households (11,000 people) and their livestock (about 3,400,000 animal units/sheep) contribute at least $57 million per year (milk, meat, dairy, and other by-products) to the province's economy (Sharifi et al 2017). Sheep are the dominant livestock (95%), followed by goats (3%) and cows (2%) (Nazari Anbaran et al 2016; Ghafari et al 2018).

Recently, more extensive irrigated farmlands and agroindustrial schemes have been introduced in the winter rangelands of the Moghan Plain, which, together with the expansion of farming, has further reduced the rangelands and increased the settlement rate among nomads, causing drastic social and economic changes in their way of life (Arjmand Karkazloo 2016). In spring (April to late June) and autumn (mid-September to end of November) the herds feed on the heavily grazed transition routes between winter and summer rangelands. In recent years, spring and autumn rangelands have been cultivated in residential areas, irrigated, dry-farmed, and used for horticulture. The small remaining area is rangeland (Ghafari et al 2018). While overall the rangelands of Ardabil province are now becoming better understood, little is known about its spring and autumn rangelands. At the end of April, as the snow recedes and rangeland becomes available, the nomads move to their summer Sabalan Mountain rangelands at higher elevations. Summer rangelands have prolonged snow cover in winter and comparatively high annual precipitation (400–700 mm). They mark the upper limit of agriculture and permanent human settlement. The harsh climate (extremely low temperature and strong winds), rugged terrain, and geological and hydrological conditions make the Sabalan Mountain rangelands particularly vulnerable to unsound practices of natural resource management and environmental degradation. Erosion rates are higher and the loss of fertility due to nutrient leaching is more pronounced than elsewhere. Because of the prevailing low temperatures, plant growth and soil formation are slower, and vegetation cover is significantly less abundant than in lowland areas (Sharifi et al 2017).

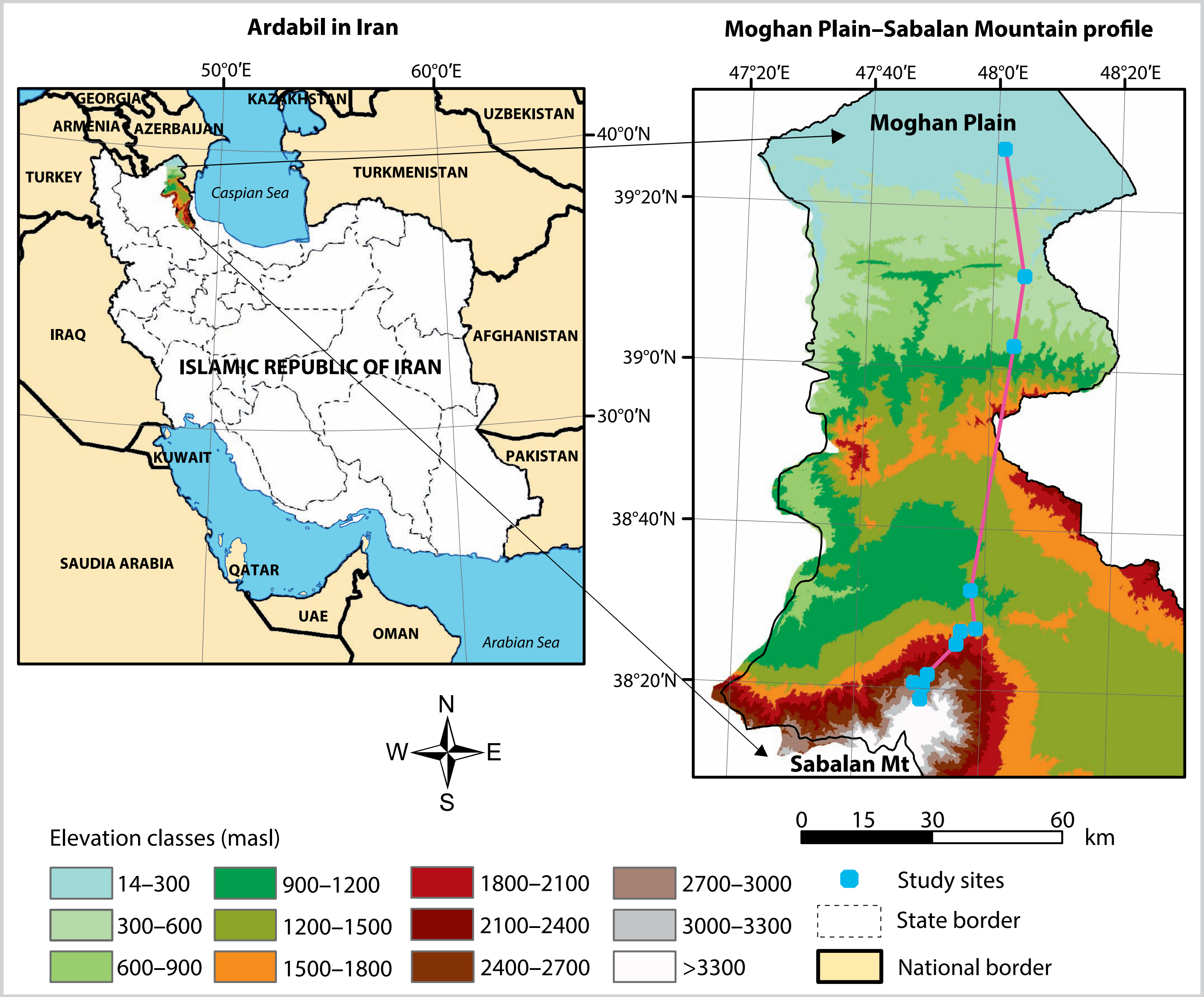
Study sites

The study was carried out in the area stretching from the Moghan Plains to Sabalan Mountain in Ardabil province, Iran, located at 47°45′ to 48°23′E and 38°18′ to 39°27′N (Figure 1). Data collection sites have the following characteristics: (1) stratified at approximately 300 m elevation intervals; (2) located in the natural rangelands (depending on road accessibility corridors selected); and (3) a minimum distance of 300 m from the road, agricultural lands, and residential and other institutional compounds to avoid edge effects. According to the criteria used in selecting sites, the study sites were in the elevational range of 100–3300 masl (anthropogenic ecosystems, such as agricultural lands and residential and industrial areas, dominate elevations below 100 masl, and there are no access roads to sites above 3300 masl). For this study, we categorized the elevation zone between 100 and 3300 masl into 3 elevation categories: low elevation (100–900 masl), mid-elevation (900–2100 masl), and high elevation (2100–3300 masl). The climate at higher elevations is cold semiarid, with cold winters and temperate summers; however, lower elevations have a temperate semiarid climate and most of the precipitation is during winter. Higher elevations are covered with snow and ice for 3–4 months of the year (Tavosi and Delara 2011). More details about the study sites are presented in Table 1.

Methodology

The selected rangelands were sampled from April 2015 to July 2016. Within each of the elevation classes, three 100-m transects were set at 50-m intervals parallel to each other and perpendicular to the main slope. Along each transect, 10 quadrats (1×1 m^2) (at 10-m intervals) were set for systematic random sampling. Since diversity and species richness are

FIGURE 1 Geographical location of the area under study (Moghan Plain–Sabalan Mountain rangelands).



quadrat size and abundance dependent (Magurran 2004), the same quadrat size was used for both. Vegetation attributes (density, canopy cover, and frequency), along with spatial coordinates (latitude, longitude, and elevation) using a global positioning system, were recorded for each quadrat.

Species were identified using literature such as Assadi et al (1988–2012), Davis (1965–1988), Ghahreman (1979–2003), Komarov (1934–1954), and Rechinger (1963–2010). The name of taxon authors was verified using IPNI (International Plant Names Index; 2018) and The Plant List (2018). The life forms were identified using Raunkiær classification (Raunkiaer 1934). Species were sorted into palatability classes: highly palatable (class I)—forage plants, most preferred by domestic livestock; mostly palatable (class II)—plants averagely preferred by livestock; hardly or unpalatable (class III)—plants least preferred or not grazed by livestock at any stage; and harmful and possibly toxic (Hussain and Durrani 2009). The palatability classes for each species were determined using literature such as FRWO (1982) and Ghafari et al (2017).

A complete picture of the ecological importance of each species in the community was obtained by calculating the importance value index (IVI) and the family importance value (FIV). To determine the IVI, the percentage values of relative density, relative dominance, and relative frequency were added together (Curtis and McIntosh 1950). The IVI was calculated for each species in each of the 11 elevation classes to determine the vegetation structure. The plant species with the highest importance value at each site were considered to be dominant species, and the plant species with the lowest importance value at each site were considered rare (Curtis and McIntosh 1950).

The FIV for botanical families was calculated by summing the IVI for different species of the same family (Mori et al 1983). IVI and FIV were calculated using the equations in Table 2.

The vegetation was analyzed for species diversity, richness, and evenness to reduce the complexity of data (Whittaker 1953). Species diversity (Shannon and Weaver 1963), richness (Menhinick 1964), and evenness (Pielou 1969) were determined using the equations in Table 2.

TABLE 1 Environmental characteristics of 11 elevation classes along elevation gradient of Moghan Plain–Sabalan Mountain rangelands.

Elevation (masl)	Longitude	Latitude	Slope (%)	Average annual precipitation (mm)	Average annual temperature (°C)
Low					
100–300	48°01′07″	39°27′20″	3	270	14
300–600	48°04′53″	39°11′38″	22	279	13
600–900	48°03′31″	39°02′51″	31	298	12
Mid					
900–1200	47°57′54″	38°32′22″	24	323	11
1200–1500	47°58′52″	38°27′38″	35	340	10
1500–1800	47°56′30″	38°27′17″	14	355	9
1800–2100	47°55′55″	38°25′41″	34	366	8
High					
2100–2400	47°51′19″	38°21′45″	31	385	7
2400–2700	47°49′13″	38°21′47″	39	398	6
2700–3000	47°49′16″	38°20′43″	33	404	6
3000–3300	47°50′25″	38°18′44″	19	425	5

Species diversity indices (species diversity, richness, and evenness) for the 4 life forms (hemicryptophyte, therophyte, chamaephyte, and geophyte) were obtained using Past 3.1 software (Øyvind Hammer, Natural History Museum, University of Oslo, Oslo, Norway, 2013). Regression models were fitted to assess the interrelations between elevation and the 3 diversity indices (diversity, richness, and evenness) and IVI of total plant and variety life form. For each model, the usual statistics such as R^2 and partial coefficients were obtained. Regression analyses were performed using Minitab 17 (Minitab Inc. State College, PA, USA, 2013).

Results

Floristic composition, family dominance, and their distribution

Overall, 251 species of 143 genera belonging to 38 families were recorded along the elevation gradient on the MPSMRs (*Supplemental material*, Table S1; https://doi.org/10.1659/MRD-JOURNAL-D-18-00089.1.S1). The highest species richness

TABLE 2 Equations for importance value index (IVI), family importance value (FIV), species diversity, species richness, and evenness.

Diversity indices	Equation	Reference	Comments
IVI	$\text{Frequency} = \frac{\text{Total number of quadrats in which the species occurred}}{\text{Total number of quadrats studied}}$	Misra (1968); Curtis and McIntosh (1950)	
	$\text{Relative frequency}(\%) = \frac{\text{Frequency of a spesies}}{\text{Frequency of all species}} \times 100$		
	$\text{Density} = \frac{\text{Total number of individuals of a species}}{\text{Total number of quadrats studied}}$		
	$\text{Relative density}(\%) = \frac{\text{Number of individuals of a species}}{\text{Number of individuals of all species}} \times 100$		
	$\text{Cover} = \frac{\text{Total of coverage of a species}}{\text{Total of coverage of quadrats in which the species occurred}}$		
	$\text{Relative dominance} = \frac{\text{Coverage of a species}}{\text{Coverage of all species}} \times 100$		
	$\text{IVI} = \text{Relative frequency} + \text{Relative density} + \text{Relative dominance}$		
FIV	$\text{FIV} = \frac{\text{Total number of all individuals a family}}{\text{Total number of all individuals in each site}} \times 100$	Mori et al (1983)	
Species diversity	$H' = \sum_{i=1}^{S} \frac{n_i}{N} \ln \frac{n_i}{N}$	Shannon and Weaver (1963)	S = total number of species, N = total number of individuals of all species, n_i = number of individuals of species i, N_i = number of individuals of most important species, H' = Shannon–Wiener diversity index and $H_{\max}$ = maximum possible diversity
Species richness	$SR = S/\sqrt{N}$	Menhinick (1964)	
Evenness	$E = H'/H_{\max}$	Pielou (1969)	

TABLE 3 Number of species, genera, families, life forms, and palatability classes [a] along elevation gradient of the Moghan Plain–Sabalan Mountain rangelands.

Parameter	masl											Total
	100–300	300–600	600–900	900–1200	1200–1500	1500–1800	1800–2100	2100–2400	2400–2700	2700–3000	3000–3300	
Number of species	28	38	35	64	72	65	74	39	42	41	29	251
Genera	24	35	33	53	57	58	62	33	35	37	27	143
Families	13	19	17	21	18	20	24	18	22	18	16	38
Hemicryptophytes	11	9	12	18	22	22	37	18	26	26	18	105
Therophytes	15	23	15	35	42	37	25	9	2	6	5	101
Geophytes	1	2	7	5	3	2	7	6	10	4	5	29
Chamaephytes	1	1	1	6	5	4	5	6	4	5	1	16
Class I	7	9	6	9	13	11	11	3	7	9	5	44
Class II	7	9	7	15	19	14	16	9	11	8	6	55
Class III	14	20	22	40	40	40	47	27	24	24	18	152

[a] Palatability classes: highly palatable (class I)—forage plants, most preferred by domestic livestock; mostly palatable (class II)—plants averagely preferred by livestock; hardly or unpalatable (class III)—plants least preferred or not grazed by livestock at any stage; and harmful and possibly toxic.

was observed for the families Asteraceae, Poaceae, and Fabaceae. The dominant genera in the sampling sites were *Astragalus* (11 species) and *Allium*, *Trigonella*, and *Veronica* (6 species each). The number of species varied significantly along the elevation gradient, with the highest value, 74, being recorded at the mid-elevation sites (1800–2100 masl), and the lowest value, 28, being recorded at the low-elevation sites (100–300 masl) (Table 3). Five families (Asteraceae, Caryophyllaceae, Fabaceae, Poaceae, and Scrophulariaceae) showed great potential to adapt across a wide elevational range (*Supplemental material*, Table S1; https://doi.org/10.1659/MRD-JOURNAL-D-18-00089.1.S1).

Among families, Poaceae, followed by Fabaceae, Asteraceae, Caryophyllaceae, and Brassicaceae, had the highest FIV. Malvaceae, Apocynaceae, Violaceae, Berberidaceae, and Dipsacaceae were recorded with the lowest FIV in the study area (Table 4).

Trifolium subterraneum had the highest IVI value in a single elevation class, reaching 124.95 at 600–900 masl (*Supplemental material*, Table S1; https://doi.org/10.1659/MRD-JOURNAL-D-18-00089.1.S1). *Poa bulbosa* was distributed across the widest range of elevation classes and reached the highest total IVI value (184.66), followed by *Festuca ovina*, *Medicago minima*, and *Artemisia austriaca*. The lowest IVI values across the entire study area were for *Erodium hoefftianum*, *Cirsium* sp, *Malva nicaeensis*, *Astragalus stevenianus*, and *Linaria simplex*.

Of the 251 species that were recorded, 44 species were class I, 55 species were class II, and 152 species were class III (Table 3). In class III, *Artemisia austriaca*, *Colpodium parviflorum*, and *Bromus tectorum* had the highest overall IVI values (108.35, 72.06, and 68.47, respectively), making them the most dominant unpalatable species. *Agrostis canina*, *Sanguisorba minor*, *Geranium pusillum*, *Astragalus stevenianus*, and *Erodium hoefftianum* were recorded as preferred plants (low IVI; *Supplemental material*, Table S1; https://doi.org/10.1659/MRD-JOURNAL-D-18-00089.1.S1). The IVI of species class I declined with increasing elevation and then increased, while species class III showed the reverse trend (Figure 2).

Diversity index

Analyses of the diversity of species showed that diversity indices were significantly different across the elevation gradient (Figure 3). Diversity and species richness showed similar trends. They increased significantly with increasing elevation and then declined (Figure 4). There was no significant difference in species evenness along the elevation gradient (Figure 5).

The dominant species of hemicryptophytes with high IVI values were *Festuca ovina* and *Colpodium parviflorum*. *Silene* sp and *Astragalus stevenianus* were less abundant hemicryptophytes, with the lowest IVI in the study sites (Figure 6; *Supplemental material*, Table S1; https://doi.org/10.1659/MRD-JOURNAL-D-18-00089.1.S1). A statistically significant second-order polynomial interrelation between species richness, evenness, and IVI with elevation was found, but the interrelation between diversity and elevation was not significant. Species richness and evenness were normally distributed along the elevation gradient, while IVI increased with increasing elevation and showed J-shaped interrelations with elevation. The diversity of hemicryptophytes increased with elevation but was not significantly different across the elevation gradient (Figures 3–5).

The most abundant therophytes of the study area were *Trifolium subterraneum* and *Medicago minima*, with high IVI. The rarest therophytes recorded with minimum IVI were *Linaria simplex* and *Malva nicaeensis* (Figure 6; *Supplemental material*, Table S1; https://doi.org/10.1659/MRD-JOURNAL-D-18-00089.1.S1). The overall pattern of therophyte IVI shows an inverse interrelation with increasing elevation. A statistically significant second-order polynomial interrelation between diversity, species richness, and evenness with elevation was found for therophytes. Diversity and species richness were normally distributed along the elevation gradient (Figures 3–5).

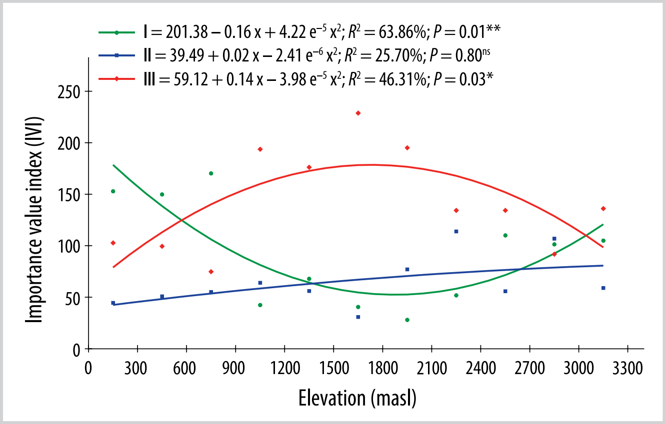
The dominant species of chamaephytes with the highest IVI values were *Artemisia austriaca* and *Thymus kotschyanus*, whereas *Helichrysum oligocephalum* and *Noaea mucronata* were

TABLE 4 Family importance values along the elevation gradient.[a)]

Plant families	masl										
	100–300	300–600	600–900	900–1200	1200–1500	1500–1800	1800–2100	2100–2400	2400–2700	2700–3000	3000–3300
Alliaceae	–	0.75	2.03	1.72	–	–	–	1.64	0.87	–	1.39
Apiaceae	42.97	14.41	33.12	6.87	13.51	4.14	9.39	–	0.26	3.52	0.83
Apocynaceae	–	–	0.53	–	–	–	–	–	–	–	–
Asteraceae	96.05	77.46	34.70	103.04	47.11	30.94	19.43	6.47	12.02	22.67	30.59
Berberidaceae	–	0.33	–	–	–	–	–	–	–	–	–
Boraginaceae	–	–	–	1.54	–	2.77	7.03	7.19	2.39	–	–
Brassicaceae	–	1.56	3.76	4.61	11.57	9.08	25.68	10.16	27.19	7.26	31.56
Campanulaceae	–	–	–	–	–	–	1.54	–	2.39	2.64	4.05
Caryophyllaceae	6.23	7.70	1.80	37.18	40.74	48.53	21.10	1.96	0.88	17.77	2.52
Chenopodiaceae	–	–	–	9.28	0.35	–	–	–	–	–	1.06
Cistaceae	–	1.94	–	21.94	14.15	1.27	–	–	–	–	–
Colchicaceae	–	–	–	–	–	–	0.79	–	18.17	2.15	15.12
Convolvulaceae	–	–	–	–	–	1.19	1.04	–	–	–	–
Crassulaceae	–	3.29	–	1.36	0.67	–	–	–	–	–	–
Cyperaceae	–	–	–	–	–	–	–	2.17	13.63	–	2.30
Dipsacaceae	–	–	–	0.35	–	–	–	–	–	–	–
Ephedraceae	–	–	–	3.42	–	–	–	–	–	–	–
Euphorbiaceae	1.19	1.17	–	–	–	0.23	2.51	13.96	0.41	–	–
Fabaceae	61.97	106.73	128.24	41.37	64.99	53.23	40.27	44.43	59.10	38.28	37.05
Geraniaceae	0.47	19.79	8.70	10.80	6.53	2.14	–	–	–	–	–
Hyacinthaceae	–	–	1.54	0.65	2.33	–	0.85	12.95	3.09	–	–
Illecebraceae	–	9.80	14.74	–	–	0.34	1.79	–	–	–	–
Iridaceae	–	–	–	–	0.37	–	–	2.41	–	–	–
Lamiaceae	2.64	1.58	1.95	0.70	24.59	30.14	31.96	11.17	9.66	2.38	–
Liliaceae	–	3.79	1.03	–	–	–	0.21	–	3.99	3.74	–
Malvaceae	0.80	–	–	–	–	0.17	–	–		–	–
Plantaginaceae	21.16	5.11	–	–	–	0.50	0.48	–	2.34	2.45	2.91
Plumbaginaceae	–	–	–	0.72	9.61	11.51	2.28	4.04	0.62	0.21	–
Poaceae	64.36	37.86	45.81	50.07	49.79	92.29	100.07	148.17	99.16	153.75	146.97
Polygonaceae	–	–	–	–	–	–	0.22	4.40	0.64	9.35	–
Primulaceae	–	–	–	0.28	0.90	0.86	1.19	–	–	–	–
Ranunculaceae	0.39	0.64	10.11	2.79	–	–	–	4.37	21.96	6.21	5.88
Rosaceae	–	–	–	–	2.42	–	4.78	8.02	7.87	11.15	4.55
Rubiaceae	0.52	5.76	0.70	0.98	7.43	5.36	8.37	–	–	3.95	–
Santalaceae	–	–	–	–	–	–	–	1.52	–	–	–
Scrophulariaceae	1.26	0.32	8.40	0.33	2.94	4.82	18.17	14.98	13.08	10.36	12.29
Valerianaceae	–	–	2.82	–	–	0.51	0.43	–	0.27	2.16	0.92
Violaceae	–	–	–	–	–	–	0.44	–	–	–	–

[a)] – indicates not present.

FIGURE 2 Variation in IVI by palatability class along the elevation gradient of the Moghan Plain–Sabalan Mountain rangelands. Palatability classes: highly palatable (class I)—forage plants, most preferred by domestic livestock; mostly palatable (class II)—plants averagely preferred by livestock; hardly or unpalatable (class III)—plants least preferred or not grazed by livestock at any stage; and harmful and possibly toxic. ns indicates no significant difference.*Significant difference at $P < 0.05$. **Significant difference at $P < 0.01$.



considered rare (Figure 6; *Supplemental material*, Table S1; https://doi.org/10.1659/MRD-JOURNAL-D-18-00089.1.S1). The diversity and species richness of chamaephytes were normally distributed along the elevation gradient, while evenness and IVI showed U-shaped interrelations with elevation (Figures 3–5).

The dominant species of geophytes were *Poa bulbosa* and *Colchicum trigynum*, while the rare geophytes were *Allium affine* and *Bongardia chrysogonum*, which had the lowest IVI in the region (Figure 6; *Supplemental material*, Table S1; https://doi.org/10.1659/MRD-JOURNAL-D-18-00089.1.S1). Species richness and evenness decreased with elevation, while diversity and IVI increased with increasing elevation; however, neither of these indicators was significantly different across the elevation gradient (Figures 3–5).

FIGURE 3 Variation in species diversity by life form along the elevation gradient of the Moghan Plain–Sabalan Mountain rangelands. Life forms: He indicates hemicryptophyte; Th, therophyte; Ge, geophyte; Ch, chamaephyte. ns indicates no significant difference. *Significant difference at $P < 0.05$. **Significant difference at $P < 0.01$.

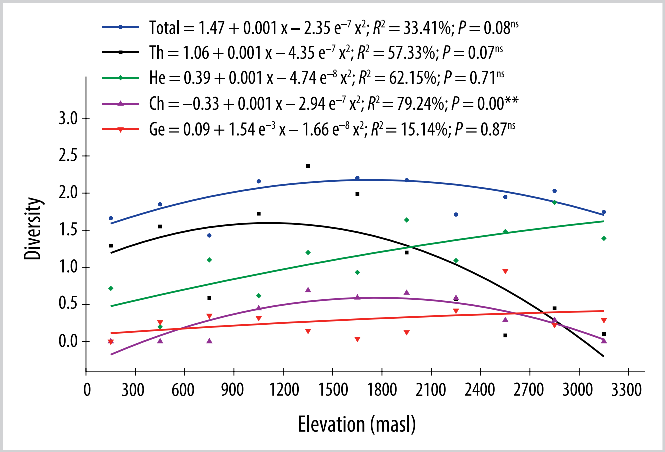
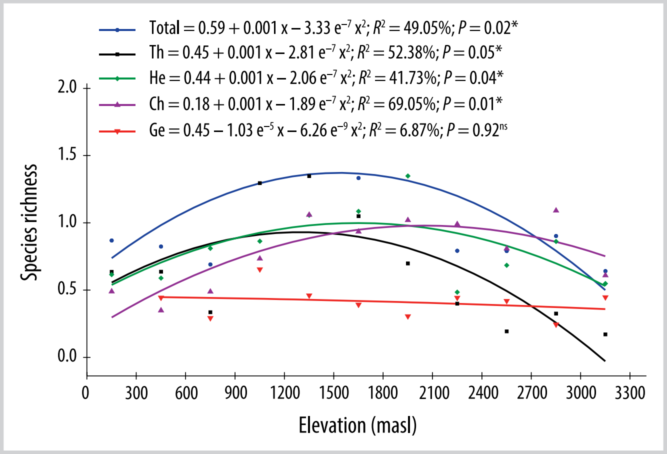


FIGURE 4 Variation in species richness by life form along the elevation gradient of the Moghan Plain–Sabalan Mountain rangelands. Life forms: He indicates hemicryptophyte; Th, therophyte; Ge, geophyte; Ch, chamaephyte. ns indicates no significant difference. *Significant difference at $P < 0.05$. **Significant difference at $P < 0.01$.



Discussion

Interrelation between species composition and elevation gradient

The most species-rich families were Asteraceae, Poaceae, and Fabaceae. The dominance of these families is due to their high compatibility with the semiarid climate conditions (Ghafari et al 2018). Several studies (eg Teimoorzadeh et al 2015; Nazari Anbaran et al 2016; Ghafari et al 2017; Taheri Niari et al 2018) have also reported similar results in other habitats of Ardabil province. The high FIV values of Poaceae, Fabaceae, Asteraceae, and Caryophyllaceae might be due to their widespread dispersal mechanism (Muhammad et al 2016). Asteraceae, Caryophyllaceae, Fabaceae, Poaceae, and Scrophulariaceae have been able to adapt to different environmental conditions and resource limitations (Kargar Chigani et al 2017; Noroozi et al 2018), which results in their dominance in all selected sites. However, members of other families were restricted to a particular elevation, suggesting

FIGURE 5 Variation in species evenness by life form along the elevation gradient of the Moghan Plain–Sabalan Mountain rangelands. Life forms: He indicates hemicryptophyte; Th, therophyte; Ge, geophyte; Ch, chamaephyte. ns indicates no significant difference. *Significant difference at $P < 0.05$. **Significant difference at $P < 0.01$.

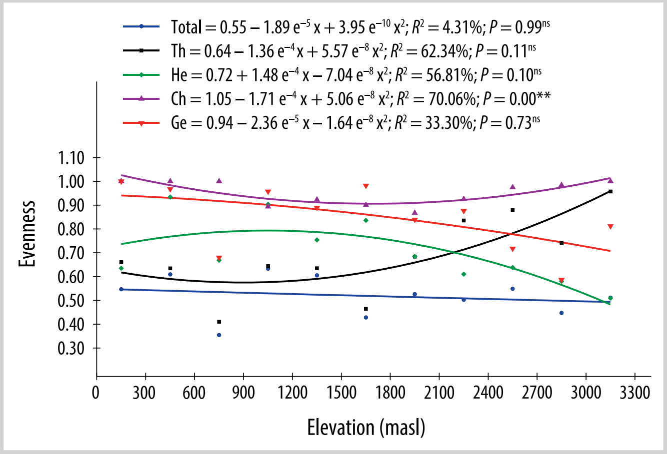
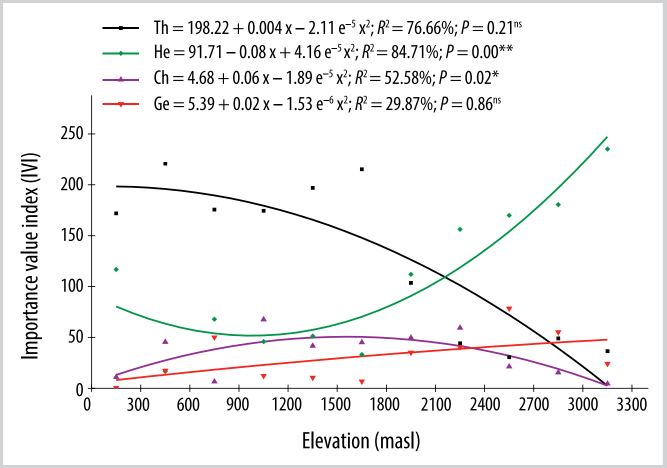


FIGURE 6 Variation in IVI by life form along the elevation gradient of the Moghan Plain–Sabalan Mountain rangelands. Life forms: He indicates hemicryptophyte; Th, therophyte; Ge, geophyte; Ch, chamaephyte. ns indicates no significant difference. *Significant difference at $P < 0.05$. **Significant difference at $P < 0.01$.



that specific physiographic and elevation conditions support different species. Asteraceae was the most species-rich family, showing high compatibility with the difficult conditions (shallow soil depth, steep slopes, and high solar radiation) in cold arid and semiarid climates (Ghafari et al 2017; Taheri Niari et al 2018).

Some species were mainly distributed at lower elevations, such as *Pimpinella kotschyana*, *Lepidium draba*, *Phlomis herba-venti*, and *Senecio glaucus*, whereas *Ficaria kochii*, *Agrostis canina*, and *Lolium rigidum* were recorded at the higher elevations. Plant species composition gradually changed as a function of variation in environmental factors; therefore, species distribution and composition differ across elevation classes along an ecological gradient (Rahman et al 2016). The species distribution showed that no single species has a wide distribution along the whole elevational range. *Poa bulbosa* (300–3000 masl) and *Festuca ovina* (900–3300 masl) were the only species that had a wide range of compatibility over the study area. The occurrence of these species across the elevation gradient suggests their wider ecological amplitude and tolerance to biotic pressures, in addition to their good reproductive capacity (Gairola et al 2011).

The IVI of species differed along the elevation, which indicates the relative importance of each species in the spectrum of elevation classes (Pandey 2015). Among the species with a high IVI, *Poa bulbosa*, *Festuca ovina*, *Medicago minima*, *Artemisia austriaca*, and *Bromus tectorum* spanned the widest elevational range. This indicates that they are the most compatible with available resources. Some species showed no distinctive distribution patterns along the gradient; some were distributed over a restricted elevational range, whereas others showed wider elevational ranges. The number of rare species in this study confirms the commonly cited concept that most of the species in plant communities are rare, rather than dominant (Magurran 2004). The rarity of species may be due to (1) strong density dependence (population growth rates are regulated by the density of a population); (2) uneven distribution of a resource, which leads to occupation by species at various locations resulting in variation in abundance and distribution; (3) natural or anthropogenic disturbances; and (4) competition effects (Scherrer and Körner 2011; Kacholi 2014; Körner et al 2017).

Interrelation of diversity, species richness, and evenness with elevation gradient

Species richness and diversity significantly increased with increasing elevation to 1200–1500 masl but then start to decline to 3300 masl. The increase in diversity value and species richness at mid-elevations could be because of (1) appropriate environmental conditions, such as low thermal and water stress and high humidity; (2) overlapping habitats; (3) the wide range (larger area) and proportionally more habitat area availability; and (4) potential high productivity (Ren et al 2012).

Due to the optimal combination of resources, more species coexist in the mid-elevation ranges (Ahmad Dar and Sundarapandian 2016); thus, more species were found in this elevation range. A positive impact of increased precipitation combined with the negative impact of decreased temperature produces a complex double gradient resulting in an optimum climate at the mid-elevation that favors diversity and species richness. While the limitations of low precipitation at low elevations or low temperature at high elevations would lead to different low-diversity ecosystems, dominated respectively by species adapted to limited precipitation or low temperatures (Sanchez et al 2013; Moradi et al 2017; Körner and Paulsen 2017).

Overlapping habitats and resources in mid-elevation areas could be partially responsible for the high diversity and species richness at this elevation range, which may indicate the existence of a transitional region for plants located at the mid-elevation (Senbeta et al 2014). Thus, in the mid-elevation a mix of high-elevation and low-elevation species give greater species richness than at higher or lower elevations (Ghafari et al 2018). The maximum diversity at mid-elevations might be attributed to the intermediate disturbance hypothesis. which suggests that the highest diversity will occur at levels of intermediate disturbance (Connell 1978; Mohamed Neji et al 2018). Most residential areas and agricultural lands are at low elevations, where there is a heavy disturbance. At higher elevations, degradation involves seasonal grazing and tourism activities; thus, disturbance is less than at low and mid-elevations. The reasoning is that diversity and species richness should be increased at median levels of disturbance (mid-elevation) because at high-disturbance levels (low elevation) most species will go locally extinct, and only the most resistant species will survive, whereas, at low levels of disturbance (high elevation), competitive exclusion increases and excludes other species (Zhang et al 2013). At the median disturbance, diversity increases because of disturbance-tolerant species and because highly competitive species coexist (Lee and Chun 2016).

Usually, with an increase of elevation, the total habitat decreases (McCain and Grytnes 2010; Noroozi and Körner 2018). Hence, the wider area in the lower elevations would provide a larger area for species distribution (Lomolino 2001). Though the area was larger at the lower elevation gradient, because of high temperature, low humidity, high human population density, changes in land use, road construction, overgrazing, and conversion of rangelands for agricultural purposes, only a few plant species are favored, with correspondingly decreased diversity and species richness (Nogués-Bravo et al 2008; Noroozi et al 2018).

The effect of fewer surfaces with increasing isolation results in a decreasing number of species at higher elevations (Lomolino 2001). In addition, the reduction in diversity and species richness at higher elevations could be related to ecophysiological constraints and harsh climatic conditions (extremely low temperature and strong winds; increase in snow cover and solar radiation), nutrient availability, water holding capacity, short growing seasons, geographical obstacles, and low ecosystem productivity (Mahdavi et al 2013; Sanchez et al 2013; Körner and Paulsen 2017). These restrict the physiological development of species to adapt and survive (Namgail et al 2012). The degree of disturbance decreased as elevation increased because tourism density and agriculture activities decreased with increased elevations (Sharifi et al 2017). However, heavy snowfall in winter, high grazing intensity in early spring and summer, and uncontrolled collection of medicinal and fodder plants has decreased species diversity (Sharifi et al 2017). With increasing elevation, people are increasingly dependent on rangelands because access to goods and services decreases (Thapa et al 2016). Sources of income and occupations other than livestock husbandry in the MPSMRs are rare, and, because of this, the number of livestock per unit area held by each household has increased (Sharifi et al 2017).

The evenness index showed no significant difference along the elevation gradient. Although the total evenness of all plants showed some fluctuation, there was no clear peak. According to Huang et al (1997), variations in the evenness of plant communities could be independent of the environmental gradient.

Hemicryptophytes were dominant (the highest IVI) at higher elevations. The change in dominance of life forms with elevation is probably due to the greater frequency of some species along the elevation gradient. For instance, the abundance of *Festuca ovina*, *Colpodium parviflorum*, *Alopecurus vaginatus*, *Trifolium medium*, and *Poa pratensis* resulted in a large number of hemicryptophytes at 2100–3300 masl elevation. Mota et al (2017) and Moradi and Attar (2019) found that hemicryptophytes are the most dominant life forms at high elevations. The lower disturbance at higher elevations favors hemicryptophytes. Thus, elevation and human activities play an important role in determining the diversity, life-form, and biological distribution spectrum of a habitat (Ren et al 2012).

The high proportion of therophytes in the investigated area reflects the cold winters and dry summers (Aghaei et al 2013). The spread of therophytes in the study area, especially unpalatable weeds, is likely a response to overgrazing (Balpinar et al 2018; Gamoun et al 2018). The preponderance of therophytes at mid-elevations might be the result of agricultural activities, overgrazing, and human activities (Ahmadi et al 2013). The dominance of therophytes at lower elevation can be partly explained by low soil moisture. At the lower elevation, although temperatures and growing season length are suitable, soil moisture is low (Barone et al 2008). Regardless of the type of ecosystem, overgrazing, especially at low elevations, led to the predominance of invasive and weed therophytes, indicating degradation (Carey et al 2017; Ghafari et al 2017; Wronski et al 2017; Lake and Minteer 2018; Shapero et al 2018).

The higher percentage of chamaephytes in the mid-elevation may be related to the impact of human activities (Balpinar et al 2018). Chamaephytes affect other species associated with stress tolerance and a strong competitive-response ability (Arila and Gupta 2016). Additionally, most chamaephytes are relatively resistant to livestock grazing (Terradas 1991) because of protective or defensive organs (such as spines, hairs, thorns, bitter taste, and unpleasant odor) and unpalatability. The species that provide the greatest protection to the buds are compact cushion plants, such as *Acantholimon*, *Astragalus*, and *Onobrychis* (Balpinar et al 2018; Moradi and Attar 2019). The higher elevation is characterized by higher solar radiation, which is unfavorable for the development of chamaephytes (Traquillini 1979).

The low proportion of geophytes in the region indicates that they are not adapted to the climatic conditions. The dominance of geophytes at higher elevations results from the high average annual rainfall, lengthy wet period during the growing season, and long duration of snow cover (Naqinezhad and Esmailpoor 2017). According to Meço et al (2018), geophytes are mostly associated with cold winters.

Plant palatability variation with elevation gradient

IVI species class I declined as the elevation increased (1800–2100 masl) and then increased, while species class III showed a reverse trend. At lower elevations, the rangeland conversion to agricultural land decreases rural livestock grazing intensity. Most of the rangeland is grazed by nomads' livestock. In addition, at low elevations, fodder crops, such as *Medicago*, *Trifolium*, and *Onobrychis*, are planted as livestock forage. Moreover, post-harvest crop residues are given to ranchers during the dry season for hay feeding, which provides part of the livestock needs in these areas. Therefore, in these regions, the presence of plants with good and medium palatability is higher than class III plants. In other words, although the diversity and species richness are low, rangeland degradation is medium at low elevation.

Optimal humidity conditions at mid-elevations and the high productivity in these habitats resulted in an optimal combination of resource availability (Hua 2004). Because of human population density, excessive grazing (rural and nomads' livestock), and conversion of rangelands for agricultural purposes, there is more degradation at mid-elevations. Although diversity and species richness increased, the presence of class III unpalatable plants was greater than the presence of plants with good and medium palatability at the mid-elevation. This is consistent with other studies that found that heavier grazing intensity was associated with higher species richness (Espinoza et al 2017). Moreover, many plants were found to be highly preferred, whereas some plants were avoided by the grazing livestock, leading these species to be widespread. This leads to the dominance of many unpalatable species, such as *Astragalus microcephalus*, *Bromus arvensis*, *Bromus tectorum*, *Taeniatherum caput-medusae*, and *Artemisia austriaca* as well as the disappearance of many other species that are less well adapted to unfavorable conditions and intense biotic influences. According to Renne and Tracy (2007), unpalatable plants increased in sites under grazing pressure. The major palatable species in the mid-elevation are *Astragalus stevenianus*, *Astragalus pinetorum*, *Sanguisorba minor*, *Trifolium repens*, and *Trigonella arcuata*, which are scarcely present at mid-elevations. Because they are highly palatable, these species have been greatly affected by grazing pressure. Most of the rare species present at mid-elevations were palatable and faced the excessive pressure of grazing. The grazing caused substitution of palatable plants by unpalatable plants, affecting abundance, dominance, plant frequency, and thus overall plant species composition (Espinoza et al 2017).

At higher elevations, the dominance of palatable species might be due to low human population density, lack of cultivation and agricultural activities, and limited seasonal grazing due to the shortened growing period (mid-May to mid-September). This rangeland is also only grazed by nomads' livestock. Nogués-Bravo et al (2008) explained that the higher elevations probably harbor large numbers of species because anthropogenic activities and destruction decrease with increased elevation.

Conclusion

Results showed that species diversity in plant communities of the region was considerable. Species richness and diversity peaked at mid-elevations along the elevational gradient. However, relative richness and diversity of species within different life-form groups varied differently along the gradient. The IVI of species differed along the elevation, indicating the relative importance of each species in a spectrum of elevation classes. The results showed that the analysis of plants using diversity indicators did not provide sufficient information on the actual condition of the rangeland plants. We believe the present approach should be encouraged in future studies for better understanding the structural status of rangelands using both species diversity and ecological importance indices of plants. By considering the results of this study, a proper conservation strategy, multipurpose use, and comprehensive regional planning could be developed to promote the sustainable use of MPSMRs.

ACKNOWLEDGMENTS

This research was funded by the Grant and Research Program of the University of Mohaghegh Ardabili. Samaneh Mohammadi Moghadam, Zahra Abdolalizade, and Ruhollah Dabiri assisted with the field work.

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Supplemental material

TABLE S1 Importance value index (IVI) along elevation gradient in the Moghan Plain–Sabalan Mountain rangelands.

Found at: https://doi.org/10.1659/MRD-JOURNAL-D-18-00089.1.S1