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Effect of slope aspect on vegetation characteristics in mountain rangelands of Tajikistan: considerations for future ecological management and restoration[§]

Mounir Louhaichi^{1,2*} , Rajabov Toshpulot³ , Hloniphani Peter Moyo⁴  and Azaiez Ouled Belgacem⁵ 

¹ International Center for Agricultural Research in the Dry Areas (ICARDA), Tunis, Tunisia

² Department of Animal and Range Science, Oregon State University, Corvallis, Oregon, United States

³ Samarkand State University, Samarkand, Uzbekistan

⁴ International Center for Agricultural Research in the Dry Areas (ICARDA), Amman, Jordan

⁵ Food and Agriculture Organization of the United Nations, Ministry of Environment, Water and Agriculture (MoEWA), Riyadh, Kingdom of Saudi Arabia

*Correspondence: M.Louhaichi@cgiar.org

Tajikistan's rangelands are mostly mountainous and consist of summer and winter pastures. Vegetation structure and composition in these diverse landscapes are generally influenced by environmental factors. The objective of this study was to assess the effects of aspect on vegetation characteristics of two mountainous pastures (summer and winter) over two seasons (autumn and spring) in Tajikistan. A three-way ANOVA was conducted using GLM procedures to test the main effects and interactions of these factors on vegetation attributes. The biomass production (kg DM ha⁻¹) was significantly greater on the north-facing aspects for both summer and winter pastures in spring (483.4, 326.1) and autumn (57.2, 143.9), compared with south-facing aspects (57.2, 143.9 in spring and 18.5, 48.2 in autumn, respectively). Plant cover and plant density were also greater on north than south-facing slopes for summer and winter pastures in spring and autumn. Aspect significantly affected species diversity, botanic composition, and plant life forms of both pastures mainly for grasses and geophytes. There were greater vegetation responses on north than south-facing slopes, implying that aspect is important when designing mountain rangeland restoration. Given this complexity, land managers should thoroughly assess the conditions of the target site before defining restoration objectives and interventions.

Keywords: landscape patterns, plant cover, plant density, species diversity, sustainable production

Introduction

The structure and production of an ecosystem's plant community is the result of interacting processes (Kremen 2005; Hudson et al. 2014). These include both abiotic and biotic processes, such as disturbances through herbivory and climate change (Wallace 2007; Ouled Belgacem and Louhaichi 2013; Islam et al. 2018). Intense herbivory, as the dominant land-use practice in arid and semiarid rangelands, influences the distribution and abundance of certain plant species and also alters the ability of an ecosystem to cope with stress, such as low soil moisture and nutrient levels (Gong et al. 2015; Zubair et al. 2018; Louhaichi et al. 2019). Therefore, it would be vital to evaluate the relationship between vegetation and the environment in order to provide effective rangeland management interventions and maintain sustainable production levels to reduce the degradation of ecosystem goods and services (Watson and Novelty 2004; Suding and Hobbs 2009).

In general, rangelands are characterised by uneven rough topography combined with low and/or erratic precipitation. Particularly, mountainous rangelands are

affected by topography and aspect (Gong et al. 2016; Liu 2017). In the northern hemisphere, south-facing slopes of mountainous rangelands receive a greater amount of radiation than north-facing slopes (Kutiel and Lavee 1999). These differences in solar radiation affect ecologically critical factors of microclimate, including near-surface temperature, photosynthetically active and ultraviolet wavelengths, evaporative demand and soil moisture content (Bale et al. 1998; Lozano-García et al. 2016), which in turn drive differences in vegetation structure, production and composition (Klemmedson and Wienhold 1992; Olivero and Hix 1998). Vegetation composition differs between north- and south-facing aspects (Kutiel and Lavee 1999; Ghimire et al. 2010; Kerven et al. 2011). These differences commonly reflect broader-scale patterns associated with latitudinal and altitudinal gradients in microsite environments (Badano et al. 2005). For example, the lower solar radiation in north-facing slopes results in lower evapotranspiration rates and lower daily maximum temperatures (Begum et al. 2010). Such evidence indicates that spatial variability of aspect

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plays a critical role in influencing vegetation patterns and ecosystem processes in many mountainous environments. Consequently, the sustainable utilisation, management and conservation of mountain rangelands are important for maintaining their unique biological diversity and productivity (Begum et al. 2010).

In Tajikistan, only 7% of the country (approximately 960 000 ha) is arable, and the rest is either mountainous (exceeding 3 000 m asl) or desert. The climatic conditions vary by region and altitude, from hot dry plains to high glacial mountains. Agricultural production is dominated by cattle breeding and horticulture that primarily occur in mountainous landscapes (Djanibekov et al. 2016). The rapid growth of cattle breeding, particularly in the steppes, has played an increasingly important economic role, and it has changed lifestyle of the pastoral population (Lioubimtseva et al. 2005). The majority of rural households raise livestock in the steppes (Kerven et al. 2011). Mountainous rangelands, as in Tajikistan, are represented by highly contrasting vegetation over short distances within a small geographic range. This biophysical condition is usually neglected when grazing is applied in those rangelands. As a consequence, mountainous rangelands in Tajikistan are very often degraded due the combined effects of harsh environment, heterogeneous topography and overgrazing (Louhaichi et al. 2013; Mirzabaev 2016). This seriously affects the species composition and diversity and consequently the productivity and the resilience of these ecosystems. In the current study, we investigated the effects of aspect on vegetation characteristics in the high-altitude grazing lands of Tajikistan. We hypothesised that habitat conditions, especially aspect, would affect vegetation attributes response (vegetation diversity, cover, plant life forms and biomass production) in semiarid mountainous rangelands of Tajikistan.

Materials and methods

Site description

The study was conducted in the Kurama Ranges of the West Tian-Shan Mountains in North Tajikistan (Figure 1). The study area is located in the Matchin and Gafurov districts of Sughd Province. The climate is moderately warm, with short warm winters and long hot dry summers, average annual temperature ranges from 15.6 to 20 °C and average annual rainfall ranges from 230 to 350 mm (Kurbanov 2017). The soils of the Kurama mountain range are very diverse, represented by rocky landscapes. They are mostly light brown, with subtypes light brown carbonate, whereas light sierozems are found only on the foothills (Kurbanov 2017; Turakulov et al. 2021). Agricultural production has expanded owing to an increase in the human population and this has contributed to widespread land degradation (Djanibekov et al. 2016). The major types of land degradation prevalent in the region include soil erosion in the mountainous areas and degradation of high altitude and rangelands vegetation resulting from chronic grazing (Dukhovny and Ziganshina 2011; Louhaichi et al. 2013). The dominant species of overstory vegetation in the study sites are *Artemisia persica* Boiss., *Prangos pabularia* Lindl., *Ferula ovina* (Boiss.) Boiss and *Rosa kokanica* (Regel) Regel ex Juz. in high-elevation mountains, whereas *Artemisia persica* Boiss. and *Stroganowia paniculata* Regel & Schmalh. are widely distributed in low-elevation mountain rangelands.

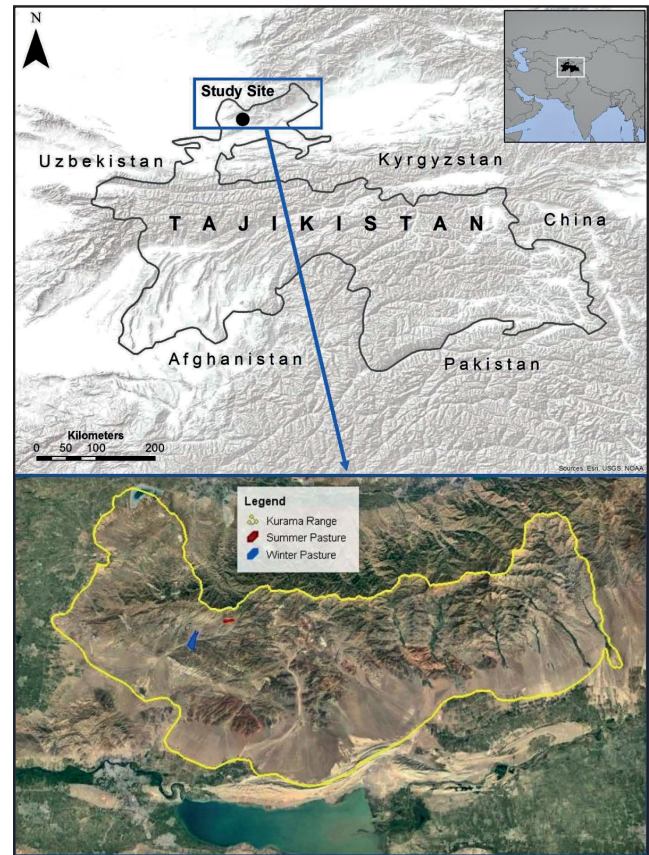


Figure 1: Study area showing the location of summer and winter pastures in the Kurama Ranges, Tajikistan

Study design

In the Kurama Ranges, north- versus south-facing aspects were selected in two mountains facing each other to monitor the interaction of aspect and season of grazing on the growth of vegetation. The summer grazing season begins from early June and ends in October, whereas the spring grazing season lasts from November to May. Small ruminants are the dominant livestock type with an average herd size of approximately 300 head. The summer pastures are characterised by higher elevation and cover an area of approximately 1 km². During the autumn grazing season, the total area is utilised by 2–3 flocks, but this number may decrease during the winter season because of the harsh cold conditions. On the other hand, the winter pastures cover a larger area of approximately 2 km² and their elevation is lower than the summer pastures. However, because they are closer to the settlements, there are more herds grazing during spring (5–7 flocks).

Sampling methodology and measurements

Two V-shaped valleys with north- and south-facing aspects were selected for summer (40°37'10.34" N, 69°45'21.43" E; 1 478 m asl) and winter pastures (40°32'53.23" N, 69°41'11.44" E; 1 063 m asl) (Figure 1). In winter pasture, the selected valley dimensions were 2 km length (the starting point at the bottom of the valley to the top point), 200–250 m width, whereas in summer pasture the

dimensions of the selected valley were shorter (1 km) and wider (300–350 m). In each pasture type, three monitoring locations were set up in two contrasting aspects at the same altitude in each valley. For all slopes, vegetation sampling was carried out at the approximate midpoint of the slopes during the two peak biomass accumulation periods at the end of spring (May) and autumn (November) during 2015 and 2016 to assess the vegetation characteristic changes after grazing and resting periods in both pastures in relation to the aspects. In this study site, the comparison between north- and south-facing slopes presented an opportunity to compare the effects of different landscape types on vegetation growth within the same vicinity. Plots were excluded if covered by >60% rock or exposed soil or if a well-established trail passed through. Species composition and density were described using three randomly placed quadrats (10 m × 2 m) in the mid slope of each aspect in both valleys. Plant density was estimated by counting the number of individuals of each species within each quadrat. The effect of aspect was evaluated in relation to the life form of individual species, as described by Raunkiaer's life forms, which is a classification of plants, based on the position of perennating buds in relation to the soil surface (Raunkiaer 1936). To determine plant canopy cover, the same quadrats (10 m × 2 m) as for density was used, where individual plant crowns of each species within the quadrat frame were measured. Biomass production of annuals was estimated by clipping the grazeable materials within three 1 m × 1 m frame quadrats, randomly distributed on both slopes of each aspect in both valleys. For perennial overstory vegetation within every size category (big, medium and small plants), one representative plant was selected, clipped and weighed for determination of biomass production. In order to determine the percentage dry matter (%DM), samples of both perennial and annual plants were oven dried at 85 °C for 24 h. Biomass production was then calculated, based on plant densities and converted to kg DM ha⁻¹.

The values of species densities per m² recorded in the quadrats were used to calculate the Simpson's diversity index, which takes into account both species richness and evenness using the following formula (Onaindia et al. 2004).

$$D = 1 - \sum \frac{n_i(n_i - 1)}{N(N - 1)}$$

where, n_i = number of individuals or amount of each species (i.e. the number of individuals of the i th species) and N = total number of individuals for the site.

For computing species compositional similarity, the north- and south-facing aspects for both the winter and summer pastures were compared using the Sørensen similarity index (Vellend 2001).

Data handling and analyses

During the two seasons and in each pasture type for both north and south facing aspects there were no true replicates because all sampling sites within each aspect were situated on the same location. Therefore, the samples taken inside the quadrats on each site were considered as replicates for the among-sites comparison, and they were pseudoreplications of the comparison between the

two aspects as well (Hurlbert 1984). Three-way analysis of variance (ANOVA) was applied to the data using Generalised Linear Modelling (GLM procedure). Main effects and interactions between the aspects, seasons and pasture types were tested on three vegetation variables: biomass production, percentage plant cover and density. Kolmogorov-Smirnov and Levene's tests were performed to evaluate adherence of residuals to the normality assumption and homogeneity of variances. The plant density data were normal, but biomass production and plant cover percentage variables were not, and hence log transformed, Q–Q plots were performed to test the normality of both variables before and after the log transformation to make sure they became normal after transformation. All statistical analyses were performed with SAS v. 9.2 software (SAS Institute, Cary NC, USA). Dunnett's T3 test was used for comparison of means at $p < 0.05$.

Results

Effects of season and aspect on plant cover

The ANOVA of total plant cover showed significant differences ($F_{(1,40)} = 21.78$, $p < 0.0001$) between north- and south-facing slopes. Regardless of sampling season, higher plant cover was recorded on the north- compared with south-facing slopes for both summer and winter pastures (53.9 ± 5.9 and $34.4 \pm 7.7\%$; 18.0 ± 0.8 and $16.3 \pm 3.3\%$ in autumn and 53.9 ± 7.1 and $34.4 \pm 8.7\%$; 12 ± 1.9 and $13 \pm 0.2\%$ in spring, respectively) (Figure 2).

In spring, the dominant species (species with highest plant cover percentage) in the summer pasture in overstory vegetation were *Artemisia persica* Boiss., *Ferula ovina* (Boiss.) Boiss., *Prangos pabularia* Lindl and *Eremurus regelii* Vved. Whereas understory vegetation was mainly dominated by *Poa bulbosa* L., the four species are native to central Asia and vary in height: 0.5 m for *A. persica* and *P. pabularia*, 1 m for *F. ovina*, and 1.8 m for *E. regelii*. The common characteristic of these species is their adaptation to a wide range of soils from light sandy to heavy clay soils and from acid to neutral alkaline soils. Although *A. persica*, *P. pabularia* and *E. regelii* are well known traditionally for their medicinal uses, both *P. pabularia* and *F. ovina* are palatable and consumed by ruminants (Amooaghaie 2009; Banday et al. 2012). The dominant species in winter pasture were *Artemisia persica* Boiss. and *Stroganowia paniculata* Regel & Schmalh that belong to Asteraceae and Brassicaceae, respectively. In autumn, *Artemisia* sp. was dominant in both summer and winter pastures.

Effects of season and aspect on plant density

The ANOVA showed that, in both seasonal pastures, there was a significant difference in plant density ($F_{(1,40)} = 15.62$, $p < 0.05$) in relation to aspect. In winter pastures, the north-facing slopes had significantly higher plant density than south-facing slopes ($F_{(1,40)} = 5.21$, $p < 0.05$) during both seasons: 36.333 ± 5.326 and 31.667 ± 4.475 plants ha⁻¹ for the north and south aspects in spring, respectively, and correspondingly 32.667 ± 1.833 and 12.833 ± 4.206 plants ha⁻¹ in autumn. However, during autumn less difference in density values were observed in the summer pasture (Figure 3).

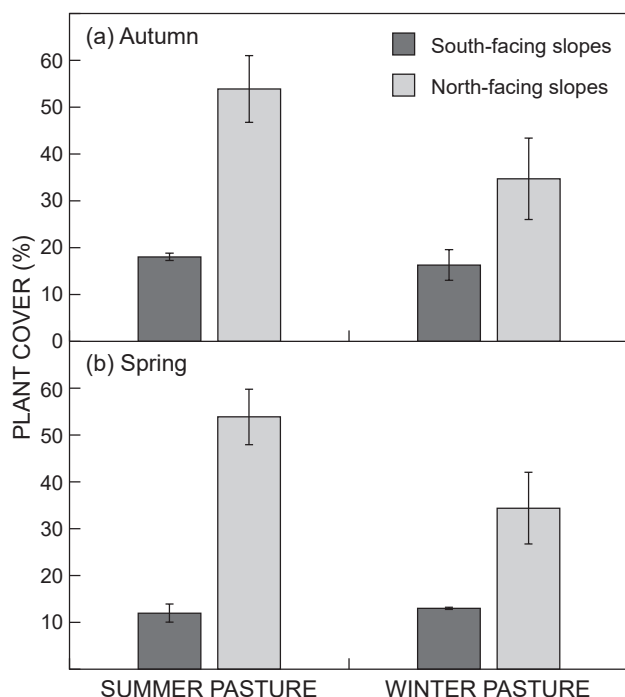


Figure 2: Effect of aspect on plant cover (%) in the mountainous slopes of Tajikistan

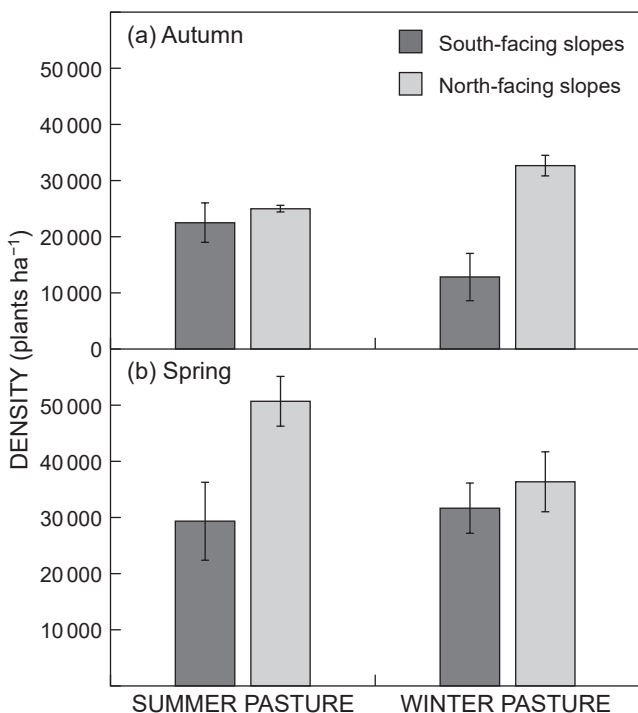


Figure 3: Effects of aspect on plant density in the mountainous slopes of Tajikistan. Mean $\pm$ standard error

Effects of season and aspect on biomass production

Biomass production was significantly higher ($F_{(1,40)} = 21.78$, $p < 0.05$) on north-facing aspects for both the summer ($483.4 \pm$

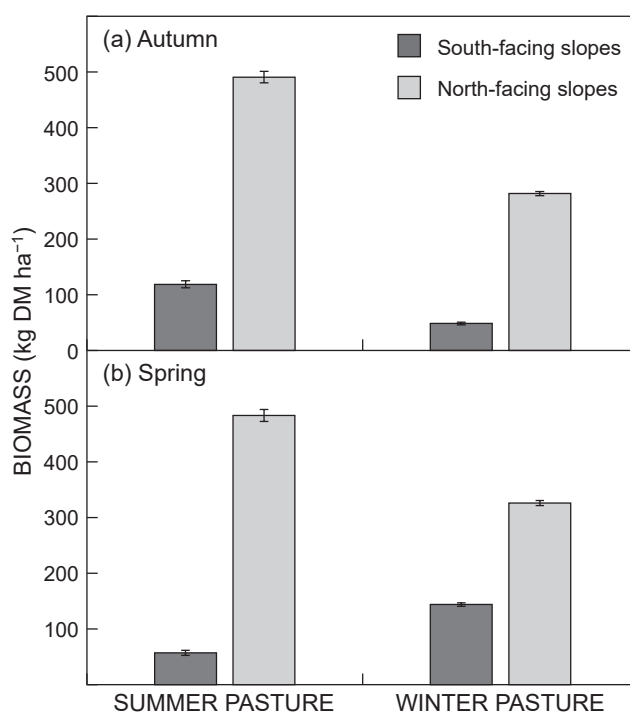


Figure 4: Effect of slope aspect on the seasonal variation of biomass production for mountainous rangelands of Tajikistan. Mean $\pm$ standard error

10.72 kg DM ha⁻¹) and winter (326.1 ± 4.52 kg DM ha⁻¹) pastures in spring, compared with south-facing aspects (Figure 4). A similar pattern was also recorded in autumn, with north-facing aspects in summer (490.6 ± 10.35 kg DM ha⁻¹) and winter pastures (281.5 ± 3.78 kg DM ha⁻¹) having higher biomass production (Figure 4).

Effects of season and aspect on plant families and life forms

Species richness was higher in summer than in winter pasture, particularly on north-facing slopes. In spring, north-facing slopes were usually represented by a diverse community of desirable annual and perennial plants, but south-facing slopes consisted of homogenous vegetation dominated by undesirable annual species, such as *Taeniatherum crinitum* (Schreb.) Nevski. (Table 1). In autumn, the difference in species composition was much less obvious between different aspects because annual species senesced at the end of autumn. As annual plants become dormant in autumn, south-facing slopes will have low vegetation cover and reduced biomass. In fact, perennial plants, such as *Artemisia* spp., were scarce in the vegetation composition.

Species richness was expressed as the number of species represented at each site during the field sampling. In general, species richness was higher in summer than in winter pastures (32 and 19 species, respectively), particularly on north-facing slopes (20 species). In spring, the north-facing slopes in summer pastures were usually represented by a diverse species composition rich in desirable annuals, such as *Bromus danthoniae* Trin., *Bromus tectorum* L., *Minuartia meyeri* (Boiss.) Bornm., *Veronica campylopoda* Boiss.,

Table 1: Abundance of plant species in relation to slope aspect in the summer and winter pastures

North-facing aspect		South-facing aspect	
Summer pasture			
<i>Artemisia persica</i> Boiss.	cop ₃	<i>Taeniatherum crinitum</i> (Schreb.) Nevski.	soc
<i>Prangos pabularia</i> Lindl.	cop ₂	<i>Eremurus olgae</i> Regel.	cop ₂
<i>Ferula ovina</i> (Boiss.) Boiss.	cop ₁	<i>Artemisia</i> sp.	sp
<i>Rosa kokanica</i> (Regel) Regel ex Juz.	cop ₁	<i>Amygdalus spinosissima</i> Bunge.	sp
<i>Cousinia egregia</i> Juz.	sp	<i>Cerasus erythrocarpa</i> Nevski.	sp
<i>Phlomis regelii</i> Popov	sp	<i>Rosa kokanica</i> (Regel) Regel ex Juz.	sp
<i>Ziziphora clinopodioides</i> Lam.	sp		
<i>Eremurus regelii</i> Vved.	sol		
<i>Poa bulbosa</i> L.	cop ₂		
<i>Carex pachystylis</i> J. Gay	cop ₂		
Winter pasture			
<i>Artemisia persica</i> Boiss.	cop ₃	<i>Taeniatherum crinitum</i> (Schreb.) Nevski.	cop ₃
<i>Stroganowia paniculata</i> Regel & Schmalh.	cop ₁	<i>Eremurus olgae</i> Regel.	cop ₁
<i>Crambe kotschyana</i> Boiss.	sol	<i>Artemisia</i> sp.	sp
<i>Poa bulbosa</i> L.	cop ₂	<i>Capparis herbacea</i> Willd.	sp
<i>Carex pachystylis</i> J. Gay.	cop ₂	<i>Nepeta</i> sp.	sp
		<i>Eremurus turkestanicus</i> Regel.	sol
		<i>Cerasus erythrocarpa</i> Nevski.	sol

Note: soc, plants of high sociability; cop₃, very abundant; cop₂, abundant; cop₁, quite abundant; sp, diffusely; sol, isolated; un, a single sample

Ziziphora tenuior L., *Taeniatherum crinitum* (Schreb.) Nevski. and *Holosteum* sp., and perennial plants mainly *Prangos pabularia* Lindl., *Ferula ovina* (Boiss.) Boiss., *Rosa kokanica* (Regel) Regel ex Juz., *Cousinia egregia* Juz., *Phlomis regelii* Popov., *Poa bulbosa* L., *Ziziphora clinopodioides* Lam., *Eremurus regelii* Vved. and *Carex pachystylis* J. Gay. Conversely, the south-facing slopes consisted of homogenous vegetation dominated by undesirable annual species, such as *Taeniatherum crinitum* (Schreb.) Nevski. In autumn, the difference in species composition was less between different aspects. Both aspects were dominated by perennials because annual species had already senesced (*Artemisia* sp. and *Rosa kokanica* (Regel) Regel ex Juz.).

Yet, in winter pasture, during the spring season the species richness of south facing aspects was higher than the north facing (7 and 6, respectively). The recorded species in spring were: *Taeniatherum crinitum* (Schreb.) Nevski., *Eremurus olgae* Regel., *Artemisia* sp., *Capparis herbacea* Willd., *Nepeta* sp., *Eremurus turkestanicus* Regel., *Cerasus erythrocarpa* Nevski., *Artemisia persica* Boiss., *Stroganowia paniculata* Regel & Schmalh., *Crambe kotschyana* Boiss., and *Poa bulbosa* L. In autumn mainly perennial species were recorded, such as *Artemisia persica* Boiss., *Stroganowia paniculata* Regel & Schmalh., *Carex pachystylis* J. Gay. and *Eremurus olgae* Regel. However, the number of species observed in north facing aspect was higher (5 species), compared with the north facing aspect (four species).

Dominant species and their abundances differed between north- and south-facing aspects (Table 1), shaped primarily by topographic effects associated with livestock grazing. The majority of species on north-facing slopes were palatable, whereas south-facing aspects were completely dominated by unpalatable species.

Members of nine different botanical families were recorded (Figure 5). The Asteraceae and Poaceae were the most widely represented families because they were recorded

in all sites despite their relatively low contributions to canopy cover. They were followed by Asphodelaceae and Rosaceae. However, species belonging to other families, such as Capparaceae, were rare and recorded in only one location. The difference in botanical composition of north vs. south-facing aspects was one of the distinct characteristics of the vegetation structure. This difference was more apparent on the north-facing slope of the summer pasture, where a higher number of botanical families was observed, compared with the south aspect and both aspects of the winter pasture. Some species, mainly from the Apiaceae and Lamiaceae, were present only in the north aspect of the summer pasture. In contrast, species belonging to Brassicaceae and Capparaceae were only found in winter pasture and more specifically on the north- and south-facing slopes, respectively. Grasses (Poaceae) were more abundant on the south- than the north-facing slopes for both grazing seasons (summer and winter) (Table 2).

The effect of aspect on representation of Raunkiaer's life forms revealed geophytes as the most abundant in all sites, especially on north-facing slopes of both seasonal grazing pastures (summer and winter), where their contribution to canopy cover ranged within 70 to 80% (Table 3). These were followed with a lower contribution from Hemicryptophytes, composed mainly of grasses, in both grazing seasons and for both aspects. Chamaephytes were mostly represented by *Artemisia persica* and had a high contribution to the canopy cover of the south-facing slopes for summer pasture. Therophytes were recorded only on the south-facing slopes of both pastures and had very low contributions.

Effects of season and aspect on vegetation diversity indices

In both summer and winter pastures, Simpson's diversity index was 34% and 29% greater on north- than south-facing slopes for both summer and winter pastures, respectively

Table 2: Contribution (%) of plant families in flora of north- and south-facing slopes in the summer and winter rangelands of mountainous slopes of Tajikistan

Plant family	Summer pasture		Winter pasture	
	North aspect	South aspect	North aspect	South aspect
Apiaceae	20	0	0	0
Asphodelaceae	10	17	0	33
Asteraceae	20	17	20	17
Brassicaceae	0	0	40	0
Capparaceae	0	0	0	17
Caryophyllaceae	10	0	20	0
Lamiaceae	20	0	0	0
Poaceae	10	16	20	17
Rosaceae	10	50	0	16

Table 3: Plant life forms and their relative contributions (%) in flora of north- and south-facing slopes in the summer and winter rangelands of mountainous slopes of Tajikistan

Plant life form	Summer pasture		Winter pasture	
	North aspect	South aspect	North aspect	South aspect
Chamaephyte	10	50	0	17
Geophyte	70	17	80	50
Hemicryptophyte	20	17	20	17
Therophyte	0	16	0	16

(Table 4). In winter, similar diversity indices were recorded on the north aspects of both seasonal pastures and were significantly ($F_{(1,12)} = 4.62$, $p < 0.05$) higher than those for the south-facing slopes of the summer and winter pastures.

Sorenson's index indicated that the botanical composition of summer and winter pastures of the same aspect were similar to a degree, whereas that of north- and south-facing slopes were almost completely different. In all cases, there were no or very low similarities in terms of species composition between the north- and south-facing slopes regardless of grazing season. However, although there were relatively low to moderate similarity scores (0.40–0.66), there were some similarities between the same aspects (i.e. north–north and south–south comparisons) for summer and winter pastures (Table 5).

Discussion

Tajikistan is considered to be one of the most vulnerable countries to climate change (Fay and Patel 2008). The predictions show an increase in mean annual temperature by 0.2–0.4 °C by 2030 and large variations in rainfall in terms of intensity and geographical distribution. Summers are expected to be wetter, whereas winters are expected to be drier, which could lead to more floods and recurrent drought. This will reduce the rangeland productivity and will eventually lower carrying capacity. It was also reported that climate over Asian montane rangelands is changing faster than the global average, posing serious threats to the future of the region's livestock-based economies and cultures (Kohli et al. 2021). The current study investigated the effects of aspect on the vegetation characteristics of two seasonal mountainous pastures (summer and winter). The plant cover, plant density, species diversity and biomass production were higher for north- than south-facing slopes.

Table 4: Mean ($\pm$ standard error) for Simpson's index of diversity of north- and south-facing slopes of the Kurama Ranges in Tajikistan

	Spring		Autumn	
	Summer pasture	Winter pasture	Summer pasture	Winter pasture
North	0.83 (0.28)	0.65 (0.52)	0.77 (0.66)	0.78 (0.51)
South	0.62 (0.41)	0.48 (0.39)	0.64 (0.47)	0.59 (0.42)

Table 5: Similarity between north- and south-facing slopes of the Kurama Ranges in Tajikistan, measured by the Sørensen index SP, summer pasture; WP, winter pasture; N, north aspect; S, south aspect

	SP_N	SP_S	WP_N	WP_S
SP_N	1	0.125	0.40	0
SP_S		1	0	0.667
WP_N			1	0
WP_S				1

The results of this study revealed less plant cover, lower plant density and far lower biomass production were recorded during both spring and autumn for south-compared with north-facing slopes. The south-facing slopes received more sunlight, and these conditions were not conducive to vegetation growth, but instead favoured drought-resistant vegetation, as suggested by Auslander et al. (2003). In comparison, north-facing slopes retained moisture and were cold and humid, accordingly supporting moisture loving plants (Gutiérrez-Jurado et al. 2013). It was suggested that there are various climatic and soil characteristics, which individually or collectively act to increase plant responses in north- compared with south-facing slopes (Griffiths et al. 2009; Lozano-García

et al. 2016). For instance, on mountainous rangelands, soil moisture availability has been suggested to be the primary limiting resource in shaping species composition and growth (Badano et al. 2005). In addition, soil moisture content is remarkably lower on south- than on north-facing slopes in the northern hemisphere, resulting from south-facing slopes receiving as much as six times more solar radiation than north-facing slopes (Gong et al. 2008).

The biomass production is consistent with those of Louhaichi et al. (2013) for a similar mountainous rangeland in Tajikistan, where significantly higher biomass production was found for north- compared with south-oriented slopes at two different sites. Our values were also close to those found by Gintzburger et al. (2003) in Tajikistan under similar environmental conditions, for which the average productivity of pastures did not exceed 400 kg DM ha⁻¹. The authors ascribed the limited economic use of these pastures to the poor vegetation cover and limited seasonal grazing. The results from this study on the effects of aspect on vegetation characteristics are similar to other findings by Griffiths et al. (2009), Lozano-García et al. (2016) and Bale et al. (1998), who also found greater vegetation production on north- compared with south-facing slopes.

In terms of species richness, the influence of aspect was evident on plant diversity, life forms and families of both pastures mainly for geophytes and *Poaceae* (grasses). These significant effects can be explained by the differences in moisture and temperature (Neuner et al. 1999; Gong et al. 2008; Farzam and Ejtehadi 2017) that enhance or limit the emergence and establishment of new seedlings and consequently affect plant density. This is also likely the reason for the abundance of geophyte species in the northern-facing aspect and greater presence of *Poaceae* on south-facing slopes. Additionally, the abundance of more drought-tolerant species including the chamaephyte *Artemisia persica* and other forbs on the southern aspect, confirms their tolerance to the higher temperature, greater light intensity and lower moisture availability, compared with the north-facing slopes (Small and McCarthy 2002). These findings are in support of the understanding that species on north-facing slopes are less drought tolerant (Bennie et al. 2006).

Several authors found a strong influence of seasonal grazing on vegetation (Shen et al. 2011; Wu et al. 2014; Porensky et al. 2018). However, this was not the case in the current study, because plant responses to grazing in the winter pasture were comparable to the summer pasture although the north-facing slopes had higher plant cover, plant density and biomass production. This is mainly because the stocking rate decreases during autumn grazing seasons because most of the flocks go back to the summer pastures. To this effect, the existing ecological gradients in soil moisture, near-surface air and soil temperature between north- and south-facing slopes, already highlighted in this study, will be increased by climate change and will be a critical driver for the response of species distributions.

The question frequently asked by rangeland managers is whether vegetation cover attributes vary in relation to the topographical heterogeneity, including the aspect, of mountainous rangelands when submitted to similar animal stocking densities. Findings from this study contribute toward

designing sustainable restoration practices for mountain rangelands. It is expected that vegetation will recover quicker when environmental conditions are optimum, generating abundant biomass production that would allow the grazing season to be extended.

Conclusion

In the mountainous rangelands of Tajikistan, the north-facing slopes showed higher vegetation growth characteristics compared with the south-facing slopes. Our results demonstrated that aspect had obvious effects on species richness, plant density and biomass production.

Although the selected study sites were relatively comparable, additional studies considering additional biophysical factors, such as soil properties and grazing pressure, are desirable for a better understanding of the effect of aspect on the spatial and temporal heterogeneity and distribution of moisture and nutrients resources and consequently the response of vegetation attributes, including species diversity and plant growth forms.

Despite these limitations, findings from this study are still important in contributing toward designing site-specific restoration options of mountain rangelands. For south-facing slopes, because of low resource availability and poor quality of soil properties, we suggest the implementation of short-duration rotational grazing systems with low stocking rates on these slopes to minimise overgrazing. On the other hand, because the north-facing slopes have greater resource availability, the expectation is that vegetation will respond quicker in terms of species composition and biomass production, compared with the south-facing slopes, which would allow for animals to spend relatively longer grazing periods.

Finally, overlooking the effect of aspect when considering mountainous rangelands restoration could result in unsuccessful results. Given their complexity, land managers should carefully assess the site-specific conditions prior to identifying restoration targets so that selected interventions address the underlying root cause of low success (Monaco et al. 2012).

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ORCID

Mounir Louhaichi: <https://orcid.org/0000-0002-4543-7631>

Rajabov Toshpulot: <https://orcid.org/0000-0003-2859-5694>

Hlonipani Peter Moyo: <https://orcid.org/0000-0002-5938-2117>

Azaiez Ouled Belgacem: <https://orcid.org/0000-0002-5946-7540>

References

- Amooaghaie R. 2009. The effect mechanism of moist-chilling and GA3 on seed germination and subsequent seedling growth of *Ferula ovina* Boiss. *The Open Plant Science Journal* 3: 22–28. <https://doi.org/10.2174/1874294700903010022>.

- Auslander M, Nevo E, Inbar M. 2003. The effects of slope orientation on plant growth, developmental instability and susceptibility to herbivores. *Journal of Arid Environments* 55: 405–416. [https://doi.org/10.1016/S0140-1963\(02\)00281-1](https://doi.org/10.1016/S0140-1963(02)00281-1).
- Badano EI, Cavieres LA, Molina-Montenegro MA, Quiroz C. 2005. Slope aspect influences plant association patterns in the Mediterranean matorral of central Chile. *Journal of Arid Environments* 62: 93–108. <https://doi.org/10.1016/j.jaridenv.2004.10.012>.
- Bale C, Williams J, Charley J. 1998. The impact of aspect on forest structure and floristics in some Eastern Australian sites. *Forest Ecology and Management* 110: 363–377. [https://doi.org/10.1016/S0378-1127\(98\)00300-4](https://doi.org/10.1016/S0378-1127(98)00300-4).
- Banday JA, Mir FA, Qurishi MA, Koul S, Razdan TK. 2012. Isolation, structural, spectral, and thermal studies of imperatorin micro-crystals from *Prangos pabularia*. *Journal of Thermal Analysis and Calorimetry* 112: 1165–1170. <https://doi.org/10.1007/s10973-012-2683-x>.
- Begum F, Bajracharya RM, Sharma S, Sitaula BK. 2010. Influence of slope aspect on soil physico-chemical and biological properties in the mid hills of central Nepal. *International Journal of Sustainable Development and World Ecology* 17: 438–443. <https://doi.org/10.1080/13504509.2010.499034>.
- Bennie J, Hill MO, Baxter R, Huntley B. 2006. Influence of slope and aspect on long-term vegetation change in British chalk grasslands. *Journal of Ecology* 94: 355–368. <https://doi.org/10.1111/j.1365-2745.2006.01104.x>.
- Djanibekov U, Dzhakypbekova K, Chamberlain J, Weyerhaeuser H, Zomer RJ, Villamor GB, Xu J. 2015. Agroforestry for landscape restoration and livelihood development in Central Asia. ICRAF Working Paper 186. Kunming: World Agroforestry Centre East and Central Asia. https://www.srs.fs.usda.gov/pubs/misc/misc_2015_chamberlain_001.pdf. [Accessed 13 July 2021].
- Dukhovny VA, Ziganshina D. 2011. Ways to improve water governance. *Irrigation and Drainage* 60: 569–578. <https://doi.org/10.1002/ird.604>.
- Farzam M, Ejtehadi H. 2017. Effects of drought and slope aspect on canopy facilitation in a mountainous rangeland. *Journal of Plant Ecology* 10: 626–633.
- Fay M, Patel H. 2008. A simple index of vulnerability to climate change, World Bank report. Washington DC, USA.
- Ghimire B, Mainali KP, Lekhak HD, Chaudhary RP, Ghimeray AK. 2011. Regeneration of *Pinus wallichiana* AB Jackson in a trans-Himalayan dry valley of north-central Nepal. *Himalayan Journal of Sciences* 6: 19–26. <https://doi.org/10.3126/hjs.v6i8.1798>.
- Gintzburger G, Toderich K.N, Mardonov B K, Mahmudov MM. 2003. *Rangelands of the arid and semi-arid zones in Uzbekistan*. Paris: V. Howe and CIRAD Editing and Publication Service.
- Gong X, Brueck H, Giese K, Zhang L, Sattelmacher B, Lin S. 2008. Slope aspect has effects on productivity and species composition of hilly grassland in the Xilin River Basin, Inner Mongolia, China. *Journal of Arid Environments* 72: 483–493. <https://doi.org/10.1016/j.jaridenv.2007.07.001>.
- Gong XY, Fanselow N, Dittert K, Taube F, Lin S. 2015. Response of primary production and biomass allocation to nitrogen and water supplementation along a grazing intensity gradient in semiarid grassland. *European Journal of Agronomy* 63: 27–35. <https://doi.org/10.1016/j.eja.2014.11.004>.
- Gong XY, Giese M, Dittert K, Lin S, Taube F. 2016. Topographic influences on shoot litter and root decomposition in semiarid hilly grasslands. *Geoderma* 282: 112–119. <https://doi.org/10.1016/j.geoderma.2016.07.017>.
- Griffiths RP, Madritch MD, Swanson AK. 2009. The effects of topography on forest soil characteristics in the Oregon Cascade Mountains (USA): Implications for the effects of climate change on soil properties. *Forest Ecology and Management* 257: 1–7. <https://doi.org/10.1016/j.foreco.2008.08.010>.
- Gutiérrez-Jurado HA, Vivoni ER, Cikoski C, Harrison JBJ, Bras RL, Istanbuloglu E. 2013. On the observed ecohydrologic dynamics of a semiarid basin with aspect-delimited ecosystems. *Water Resources Research* 49: 8263–8284. <https://doi.org/10.1002/2013WR014364>.
- Hudson LN, Newbold T, Contu S, Hill SLL, Lysenko I, de Palma A, Phillips HRP, Senior RA, Bennett DJ, Booth H, et al. 2014. The PREDICTS database: a global database of how local terrestrial biodiversity responds to human impacts. *Ecology and Evolution* 4: 4701–4735. <https://doi.org/10.1002/ece3.1303>.
- Hurlbert SH. 1984. Pseudoreplication and the design of ecological field experiments. *Ecological Monographs* 54: 187–211. <https://doi.org/10.2307/1942661>.
- Islam M, Razzaq A, Gul S, Ahmad S, Muhammad T, Hassan S, Rischkowsky B, Ibrahim MNM, Louhaichi M. 2018. Impact of grazing on soil, vegetation and ewe production performances in a semi-arid rangeland. *Journal of Mountain Science* 15: 685–694. <https://doi.org/10.1007/s11629-017-4702-7>.
- Kerven C, Steimann B, Ashley L, Dear C, Rahim I. 2011. Pastoralism and farming in central Asia's mountains: a research review. MSRC Background Paper No. 1. http://www.ucentralasia.org/downloads/pastoralism_and_farming_in_central_asia_mountains. [Accessed 13 July 2021].
- Klemmedson JO, Wienhold BJ. 1992. Aspect and species influences on nitrogen and phosphorus accumulation in Arizona chaparral soil-plant systems. *Arid Land Research and Management* 6: 105–116.
- Kohli M, Mijiddorj T, Suryawanshi K, Mishra C, Boldgiv B, Sankaran M. 2021. Grazing and climate change have site-dependent interactive effects on vegetation in Asian montane rangelands. *Journal of Applied Ecology* 58: 539–549. <https://doi.org/10.1111/1365-2664.13781>.
- Kremen C. 2005. Managing ecosystem services: what do we need to know about their ecology? *Ecology Letters* 8: 468–479. <https://doi.org/10.1111/j.1461-0248.2005.00751.x>.
- Kutiel P, Lavee H. 1999. Effect of slope aspect on soil and vegetation properties along an aridity transect. *Israel Journal of Plant Sciences* 47: 169–178. <https://doi.org/10.1080/07929978.1999.10676770>.
- Kurbonov AR. 2017. Umbelliferae of Northern Tajikistan (Kurama range, Mogoltau, Syrdarya valley). PhD thesis, Tajik National University, Tajikistan.
- Lioubimtseva E, Cole R, Adams J, Kapustin G. 2005. Impacts of climate and land-cover changes in arid lands of Central Asia. *Journal of Arid Environments* 62: 285–308. <https://doi.org/10.1016/j.jaridenv.2004.11.005>.
- Liu B. 2017. Vertical patterns in plant diversity and their relations with environmental factors on the southern slope of the Tianshan Mountains (middle section) in Xinjiang (China). *Journal of Mountain Science* 14: 742–757. <https://doi.org/10.1007/s11629-016-4110-4>.
- Louhaichi M, Nubekov A, Madaminov A, Barbara R. 2013. The influence of geo-morphological landscape patterns on vegetation characteristics in Tajikistan grasslands. In: *Revitalising Grasslands to Sustain our Communities: Proceedings, 22nd International Grassland Congress, 15–19 September 2013, Sydney, Australia, 2013*. New South Wales Department of Primary Industry. pp 860–862.
- Louhaichi M, Ouled Belgacem A, Hassan S, Petersen LS. 2019. Effects of climate change and grazing pressure on shrub communities of West Asian rangelands. *International Journal of Climate Change Strategies and Management* 11: 660–671. <https://doi.org/10.1108/IJCCSM-02-2018-0017>.
- Lozano-García B, Parras-Alcántara L, Brevik EC. 2016. Impact of topographic aspect and vegetation (native and reforested areas) on soil organic carbon and nitrogen budgets in Mediterranean natural areas. *The Science of the Total Environment* 544: 963–970. <https://doi.org/10.1016/j.scitotenv.2015.12.022>.

- Mirzabaev A, Ahmed M, Werner J, Pender J, Louhaichi M. 2016. Rangelands of central Asia: challenges and opportunities. *Journal of Arid Land* 8: 93–108. <https://doi.org/10.1007/s40333-015-0057-5>.
- Monaco TA, Jones TA, Thurow TL. 2012. Identifying rangeland restoration targets: an appraisal of challenges and opportunities. *Rangeland Ecology and Management* 65: 599–605. <https://doi.org/10.2111/REM-D-12-00012.1>.
- Neuner G, Ambach D, Aichner K. 1999. Impact of snow cover on photoinhibition and winter dessication in evergreen *Rhododendron ferrugineum* leaves during subalpine winter. *Tree Physiology* 19: 725–32. <https://doi.org/10.1093/treephys/19.11.725>.
- Olivero AM, Hix DM. 1998. Influence of aspect and stand age on ground flora of southeastern Ohio forest ecosystems. *Plant Ecology* 139: 177–187. <https://doi.org/10.1023/A:1009758501201>.
- Onaindia M, Dominguez I, Albizu I, Garbisu C, Amezcaga I. 2004. Vegetation diversity and vertical structure as indicators of forest disturbance. *Forest Ecology and Management* 195: 341–354. <https://doi.org/10.1016/j.foreco.2004.02.059>.
- Ouled Belgacem A, Louhaichi M. 2013. The vulnerability of native rangeland plant species to global climate change in the West Asia and North African regions. *Climatic Change* 119: 451–463. <https://doi.org/10.1007/s10584-013-0701-z>.
- Porensky LM, Perryman BL, Williamson MA, Madsen MD, Leger EA. 2018. Combining active restoration and targeted grazing to establish native plants and reduce fuel loads in invaded ecosystems. *Ecology and Evolution* 8: 12533–12546. <https://doi.org/10.1002/ece3.4642>.
- Raunkiaer C. 1936. The Life Form of Plants and Statistical Plant Geography. Collected Papers. Oxford: Clarendon Press.
- Shen MG, Tang YH, Chen J, Zhu, XL, Zheng, YH. 2011. Influences of temperature and precipitation before the growing season on spring phenology in grasslands of the central and eastern Qinghai-Tibetan Plateau. *Agricultural and Forest Meteorology* 151: 1711–1722. <https://doi.org/10.1016/j.agrformet.2011.07.003>.
- Small CJ, McCarthy BC. 2002. Spatial and temporal variability of herbaceous vegetation in an eastern deciduous forest. *Plant Ecology* 164: 37–48. <https://doi.org/10.1023/A:1021209528643>.
- Suding KN, Hobbs RJ. 2009. Threshold models in restoration and conservation: a developing framework. *Trends in Ecology & Evolution* 24: 271–279. <https://doi.org/10.1016/j.tree.2008.11.012>.
- Turakulov I, Safarov N, Tojiboev K, Segizboev M, Suyunkulov H, Park M, Na N, Usmonov M, Chang KS, Oh SH, Jang C. 2021. The flora of the Western Tien Shan: Tajikistan part. *Journal of Asia-Pacific Biodiversity* 14: 221–227. <https://doi.org/10.1016/j.japb.2021.02.005>.
- Vellend M. 2001. Do commonly used indices of β -diversity measure species turnover? *Journal of Vegetation Science* 12: 545–552. <https://doi.org/10.2307/3237006>.
- Wallace KJ. 2007. Classification of ecosystem services: problems and solutions. *Biological Conservation* 139: 235–246. <https://doi.org/10.1016/j.biocon.2007.07.015>.
- Watson I, Novelly P. 2004. Making the biodiversity monitoring system sustainable: design issues for large-scale monitoring systems. *Austral Ecology* 29: 16–30. <https://doi.org/10.1111/j.1442-9993.2004.01350.x>.
- Wu J, Shen Z, Shi P, Zhou Y, Zhang X. 2014. Effects of grazing exclusion on plant functional group diversity of Alpine Grasslands along a precipitation gradient on the Northern Tibetan Plateau. *Arctic, Antarctic, and Alpine Research* 46: 419–429. <https://doi.org/10.1657/1938-4246-46.2.419>.
- Zubair M, Saleem A, Baig MA, Islam M, Razzaq A, Gul S, Ahmad S, Moyo HP, Hassan S, Rischkowsky B, Ibrahim MNM, Louhaichi M. 2018. The influence of protection from grazing on Cholistan Desert vegetation Pakistan. *Rangelands* 40: 136–145. <https://doi.org/10.1016/j.rala.2018.05.005>.