Hacquetia 15/2 • 2016, 21–35 DOI: 10.1515/hacq-2016-0014

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Mountain pastures of Qilian Shan: plant communities, grazing impact and degradation status (Gansu province, NW China)

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Key words: alpine vegetation, altitudinal gradient, Detrended Correspondence Analysis (DCA), Indicator Species Analysis (ISA), overgrazing, pasture degradation, species diversity.

Ključne besede: alpinska vegetacija, višinski gradient, korespondenčna analiza z odstranjenim trendom (DCA), analiza indikatorskih vrst (ISA), pretirana paša, degradacija pašnikov, vrstna pestrost.

Abstract
Environmental degradation of pasture areas in the Qilian Mountains (Gansu province, NW China) has increased in recent years. Soil erosion and loss of biodiversity caused by overgrazing is widespread. Changes in plant cover, however, have not been analysed so far. The aim of this paper is to identify plant communities and to detect grazing-induced changes in vegetation patterns. Quantitative and qualitative relevé data were collected for community classification and to analyse gradual changes in vegetation patterns along altitudinal and grazing gradients. Detrended correspondence analysis (DCA) was used to analyse variation in relationships between vegetation, environmental factors and differential grazing pressure. The results of the DCA showed apparent variation in plant communities along the grazing gradient. Two factors – altitude and exposure – had the strongest impact on plant community distribution. Comparing monitoring data for the most recent nine years, a trend of pasture deterioration, plant community successions and shift in dominant species becomes obvious. In order to increase grassland quality, sustainable pasture management strategies should be implemented.

Izvleček
Degradacija pašnih površin v gorovju Qilian (provinca Gansu, SZ Kitajska) se je v zadnjih letih močno povečala. Erozija tal in izguba biotske pestrosti sta se zaradi pretirane paše zelo razširili. Do sedaj še nismo analizirali sprememb v pokrovnosti rastlin. V članku smo opisali rastlinske združbe in označili spremembe vegetacije zaradi paše. Združbe smo klasificirali na podlagi kvantitativnega in kvalitativnega popisnega gradiva in analizirali postopne spremembe v vegetacijskem vzorcu vzdolž gradienta višine in paše. Vegetacijo smo klasificirali z metodo združevanja. Za analizo variabilnosti odnosov med vegetacijo, okoljskimi dejavniki in različno intenzivnostjo paše smo uporabili korespondenčno analizo z odstranjenim trendom (DCA). Rezultati analize DCA so pokazali očitno raznolikost rastlinskih združb vzdolž gradienta paše. Največji vpliv na razširjenost rastlinskih združb sta imela višina in ekspozicija. S primerjavo podatkov monitoringa zadnjih devetih let smo ugotovili, da se zaradi paše očitno slabša sukcesija rastlinskih združb, prihaja pa tudi do sprememb dominantnih vrst. Za izboljšanje kakovosti travišč bo potrebno uvesti trajnostne načine gospodarjenja.

Received: 28. 11. 2015
Revision received: 18. 04. 2016
Accepted: 21. 04. 2016

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Introduction

The impact of grazing on plant communities has been the focus of a multitude of studies all over the globe. Results showed that effects of grazing vary strongly between regions with different precipitation regimes and types of pasture lands, and depend on the scale and specific site conditions (Vetter 2005, Metera et al. 2010). Direct effects of grazing are associated with a change in canopy height, habit and shoot architecture of plants, whereby short, prostrate and rosette plant forms are less sensitive to grazing (Diaz et al. 2006). In general, grazing favours annual over perennial plants (Diaz et al. 2006), and increases the abundance of low-growing forbs compared to grass and tall forb species (Metera et al. 2010). Generally, the effect of grazing is connected with the disappearance of good forage grasses and an increase in the proportion of invasive species (Zhou et al. 2006).

According to the intermediate disturbance hypothesis (Connell 1978, Kershaw & Mallik 2013), the diversity of grazed plant communities varies along a gradient of grazing pressure. Extensive (or moderate) grazing was shown to be an effective tool to maintain genetic and biotic diversity of grasslands, while species richness is lower under the complete exclusion of livestock as well as under overgrazing (Wu et al. 2009, Metera et al. 2010, Török et al. 2014). Moderate grazing was found to be optimal to retain high plant species diversity (Zhou et al. 2006). Low grazing intensity was recommended to sustain the highest levels of plant functional diversity, while intensive grazing was shown to decrease the proportion of characteristic grassland species (Török et al. 2016).

In the Qilian Mountains (Heihe River Basin, Gansu Province, NW China) overgrazing has been identified as the core environmental problem of the region (Li et al. 2003, Li et al. 2004), corroborating the general view among county officials that overgrazing is threatening forest and rangeland sustainability. Uncertainties regarding rights of access and use of grazing resources hinder the establishment of proper rangeland management (Dingguo 1992, Li et al. 2003). Sheep, goats and yak graze almost everywhere in the forests and adjoining rangelands, which seems to be the prime cause preventing natural regeneration of trees and shrubs. Uncontrolled increases in the number of animals exceeds the carrying capacity of grazing lands. Grazing pressure is extraordinarily high on montane pastures, which are grazed in spring and autumn, when alpine pastures are still or already snow-covered. Pasture lands are insufficient in area, and intensive grazing on spring, autumn, and summer pastures inhibits plant growth and reproduction (Dingguo 1992). Most of the forests and grasslands have been replaced by secondary vegetation, with a considerable percentage of unpalatable, toxic and often thorny or spiny shrub and herb species that have a lower grazing value and rarely form a closed vegetation cover, at least in drier areas.

Only very few preliminary studies on vegetation and its degradation in the Qilian Mountains are available in the literature, most of them in Chinese. A phytosociological study was conducted by Kürschner et al. (2005), giving an overview of vegetation patterns and floristic composition, formed under long-term grazing pressure. Wang (2002) and Wang et al. (2002) studied distribution patterns of vegetation along an elevational gradient and detected peaks in species richness and species diversity at intermediate positions of this gradient. Plant species composition is also reported to vary between north-facing and south-facing slopes (Wang et al. 2002, Wang 2002, Huang et al. 2011). Chang et al. (2004) reported a decline in biodiversity and found that more than 50% of the pasture communities are composed of toxic plant species. In overgrazed conditions, total nitrogen and total phosphorus of the alpine pastures decreased significantly, whereas pH and soil bulk density significantly increased (Sheng et al. 2009). However, there are so far no detailed studies focusing on vegetation-environment relationships and on variation of vegetation patterns with changing site conditions and differential grazing impact.

In order to fill this research gap, the objectives of this study are to clarify hitherto unknown implications of increased grazing intensity for rangelands in the Qilian Mountains. We hypothesize that the habitat quality and biodiversity of grazing lands are declining due to increased use intensity under the conditions of recent socio-economic change in NW China. We focus (1) on the main environmental variables influencing vegetation patterns along the altitudinal gradient, and (2) on the assessment of the pasture quality according to species composition and grazing impact in montane and alpine grasslands of the Qilian Mountains.

Methods

Study area

The Heihe River Basin, 97°24'–102°08' E to 37°44'–42°42' N, is the second largest inland river basin in the arid regions of northwestern China (Zhao et al. 2006). It belongs to the middle part of the Hexi corridor, which is a 40–80 km wide tectonic depression between the Longshou Mountains in Inner Mongolia and the Qilian Mountains along the border of the Tibetan Plateau (Figure 1). The Qilian Mountains are of extraordinary importance as a water source region for the lower reaches of Heihe, Shiyang, and Shule rivers, supplying 4 million people living in the Hexi Corridor. The majority of the water flow is derived from the meltwater of glaciers and snow-covered permafrost areas, which are protected by the continuous spruce forest cover (Guojing et al. 2005).

The annual mean precipitation in the middle section of Qilian Mountains increases with elevation from 250 mm to 700 mm at a mean rate of ca. 3–5% per every 100 m from 2000 to 3700 m.a.s.l. (Wang et al. 2002). Peak rainy season is between June and September (ca. 89% of the total precipitation with 63% between June and August) (Zhao et al. 2009). Lower precipitation values were registered in the low valleys of the Heihe River and the northwestern part, and higher values appeared in the areas with higher altitude and in the southeastern part. The amount of precipitation varies during the growing season with highest precipitation values in July, ranging from 46 mm to 145 mm, and lowest values in May, from 25 mm to 64 mm. Generally, precipitation decreases from east to west and increases from north to south, whereas the temperature shows a reverse pattern in the study area (Zhao et al. 2009). The annual mean temperature decreases with elevation from 6.2°C to –9.6°C (Zhao et al. 2009).

Permafrost soils and seasonally frozen soil horizons are widespread in the middle and high elevations. Mountain gray-brown soil (gray sierozem, mountain chestnut) is the main soil type with pH ranging from 7 to 8, with a relatively shallow soil profile, rough texture (silty loam) and intermediate organic matter content. Other soil types are present along the altitudinal gradient: subalpine-meadow soils and alpine cold desert soils near the summit, and brown-desert soils at lower elevations (Wu 1980, Wang 2002). According to the FAO international classification, the main soil types of the arid mountain areas were haplic Calcisol and calcic Luvisol (Yu et al. 2010, Lider 2013).

The land cover of the region is stratified along the elevational gradient into the following types: desert and semi-desert (1470 to 1900 m.a.s.l.), montane grassland (2200 to 2900 m.a.s.l.), alpine grassland (2900 to 3700 m.a.s.l.), dry shrubland (2350 to 2800 m.a.s.l.), moist alpine shrubland (3100 to 3700 m.a.s.l.), coniferous forest (2450 to 3200 m.a.s.l.); snowland (above 3700 m.a.s.l.) (Wang et al. 2002). Forests cover shady north-facing slopes at intermediate altitudes, whereas south-exposed sunny slopes are occupied by grasslands with sparsely distributed drought-tolerant shrub patches.

Grazing in Qilian Shan follows a transhumance pastoral system (Yuan & Hou 2015) – herders graze sheep, goats and yaks on low montane grasslands near the villages (2400–2600 m.a.s.l.) only in winter time; in spring and autumn they move upwards to high montane and alpine grasslands (below 3000 m.a.s.l.); for summer grazing herders with families migrate to summer camps in distant alpine pastures (above 3000 m.a.s.l.).

This study was conducted in Pailugou Catchment (100°17' E, 38°24' N), which is located in the Xishui Natural Forest, extending from 2600 to 3600 m.a.s.l. This catchment is a representative example of forest and rangeland conditions for the wider area in the middle section of the Qilian Mountains. The area of the catchment is subject to spring and autumn grazing by sheep, goats and yaks.

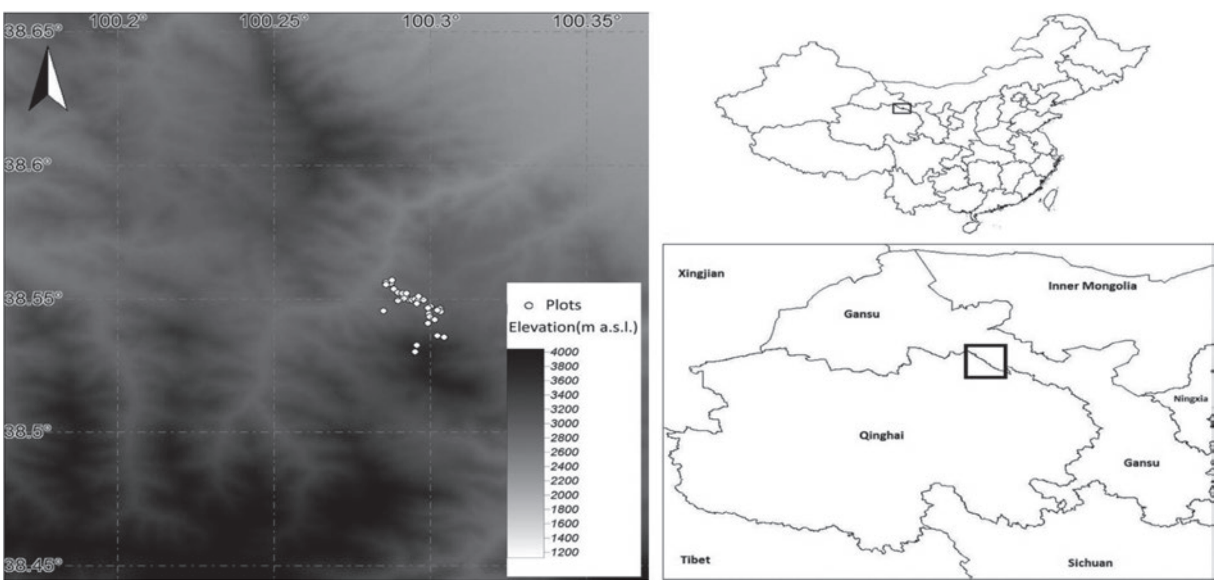

Figure 1: Location of the study area: North-West China, Gansu Province, Qilian Mountains, Pailugou Catchment.
Slika 1: Lokacija preučevanega območja: SZ Kitajska, provinca Gansu, gorovje Qilian, porečje Pailugou.

Sampling design

To sample vegetation data with respect to grazing, covering sites with different habitat type and altitude, 37 sample sites were randomly selected along the elevational gradient (2650–3600 m.a.s.l.) over a range of slope aspects. The sampling was restricted by the topography of the Pailugou catchment, therefore some slope aspects were not reachable or were not present within the catchment. For each sampled plot, latitude, longitude and altitude was obtained using Garmin GPS 60, with accuracy of 4–6 m. Slope angle was measured by inclinometer Suunto MB-6 Nord.

Vegetation sampling was conducted during the summer season 2012, following an adapted relevé method (Braun-Blanquet 1964, Kent 2012). We used a standard relevé size of 10×10 m^2 that exceeded the minimal area as determined according to Mueller-Dombois & Ellenberg (1974). Relevé analysis included the listing of all vascular, bryophyte, and lichen species as well as the assessment of species cover according to the Braun-Blanquet cover-abundance scale (7 classes). In total 37 relevés were completed. Some species were identified *in loco,* while specimens of critical species were collected for the final identification in the herbarium of the Academy of Water Conservation Forest of the Qilian Mountains (AWCFQ) in Zhangye, using the local flora catalogues (Xiande et al. 2001, Anlin & Zongli 2009) as well as online databases (eFloras, Subject Database of China Plant, The Plant List, Plantarium). From each relevé, plot soil samples (3 samples of 100 cm^3) were taken from the uppermost mineral soil horizon (max. 10 cm depth). In order to calculate water content, fresh and dry soil samples were weighed. Dry weight was measured after oven-drying for 5–6 hours at 105°C. Standard laboratory soil analyses included water content (DIN ISO 11465) and organic matter content (DIN ISO 10694), pH (in CaCl2) (DIN ISO 10390:2005) and electric conductivity (DIN ISO 11265) (HFA 2009, ISO 2010). The analyses were made in the soil laboratory in Department of Geography, University of Hamburg.

The grazing impact was estimated by direct visual observation of different qualitative parameters on each plot (cf. Du Toit 2000, cf. Borchardt et al. 2011, cf. Brinkmann et al. 2009). Parameters measured were: evidence of grazing on the plant specimens, dryness and steepness of the slope, erosion evidence, presence of cattle tracks and dung, number and cover of toxic plant species. Each of the plots was assigned to one of three grazing classes: slight (1), moderate (2), intensive (3).

Data analysis

We used PC-ORD v.6 software (McCune & Mefford 2011) for vegetation analyses. The Braun-Blanquet scale was converted according to Wildi (2010) into percentage values; slope aspect degrees (0–360°) were recalculated into two independent variables "eastness" and "northness" after Zar (1999): Eastness = sin ((slope aspect in degrees × Pi)/180); Northness = cos ((aspect in degrees × Pi)/180).

To classify plant communities, Hierarchical Cluster Analysis was performed using Euclidian dissimilarity distance measure and Ward's group linkage method. To check the significance of the differentiated clusters, the Multi-Response Permutation Procedure (MRPP) with Euclidian (Pythagorean) dissimilarity distance measure with natural weighting option was used (McCune & Mefford 2011).

To analyse relationships between variation in vegetation and environmental factors (including differential grazing pressure), Detrended Correspondence Analysis (DCA) was performed with downweighting of rare species (Fmax/5, where Fmax = frequency of the commonest species), rescaling threshold 0.5 and number of segments 26 (Wildi 2010, McCune & Mefford 2011).

To calculate the significance of relationships between environmental variables and ordination axes, Mantel's asymptotic approximation test with Sørensen (Bray-Curtis) distance measure was used (Wildi 2010, McCune & Mefford 2011).

In order to identify indicator species of each group and the value of each species in the whole dataset, Indicator Species Analysis (ISA) was carried out (Dufrêne & Legendre 1997). This method combines the information on the concentration of the species abundance in each group and estimates the faithfulness of the occurrence of species to a particular group, which allows a threshold for Cluster Analysis to be set. To evaluate the statistical significance of indicator values for given species, we used a Monte Carlo test with 999 permutations (McCune & Mefford 2011).

To assess a potential grazing-induced degradation of grasslands in the mountain pasture areas in Qilian Shan, relevés and species records from 2003 and 2012 were compared with respect to percent of palatable / unpalatable species. Species data from 2003 was collected in an investigation of the whole area of Pailugou catchment, conducted by scientists of Academy of Water Resource Conservation Forest of Qilian Mountains (AWRCFQM), Zhangye, Gansu Province. They divided the entire area of the grasslands into the polygons, and recorded in each of them dominant plant species and their coverage within the main grassland associations. Due to substantial differences in aims and performance of sampling design, both data sets, used for comparison, were subject to scalar transformation (Wildi 2010).

To assess rangeland quality, all recorded plant species of the grasslands in Pailugou catchment were analysed with respect to their palatability according to Damiran (2005), Lu et al. (2012) and Quattrocchi (2012). In order to make recommendations for sustainable pasture management, species indicating specific site-environmental conditions were distinguished using the databases eFloras (2008) and Subject Database of China Plant.

The palatability of the plant species changes over the course of the seasons. Damiran (2005) provides palatability measures for the four seasons: 1 – winter (January-March), 2 – spring (April-June), 3 – summer (July-September), 4 – autumn (October-December). Our study area is located in spring-autumn pasture area; therefore, palatability of the forage plants was examined only for spring and autumn by taking a mean of palatability scores for these two seasons.

Results

Classification and distribution patterns of vegetation

The vegetation of the Pailugou catchment was divided into five types, obtained by cluster analyses (Figure 2): *Picea crassifolia* forest (1); *Salix gilashanica-Arctostaphylos alpina* shrubland (2); *Potentilla anserina-Geranium pratense* grassland (3); *Stellera chamaejasme* shrubby grassland (4), *Stipa capillata* mixed grassland (5). The significance of the difference between species composition of distinguished groups was indicated by MRPP (Multi-Response Permutation procedure): T =-10.42, A = 0.08, $p < 0.001$ (T = difference between observed and expected deltas; A = chance-corrected within-group agreement). The following plant communities were differentiated according to dominant species, identified by Indicator Species Analysis (Table 1).

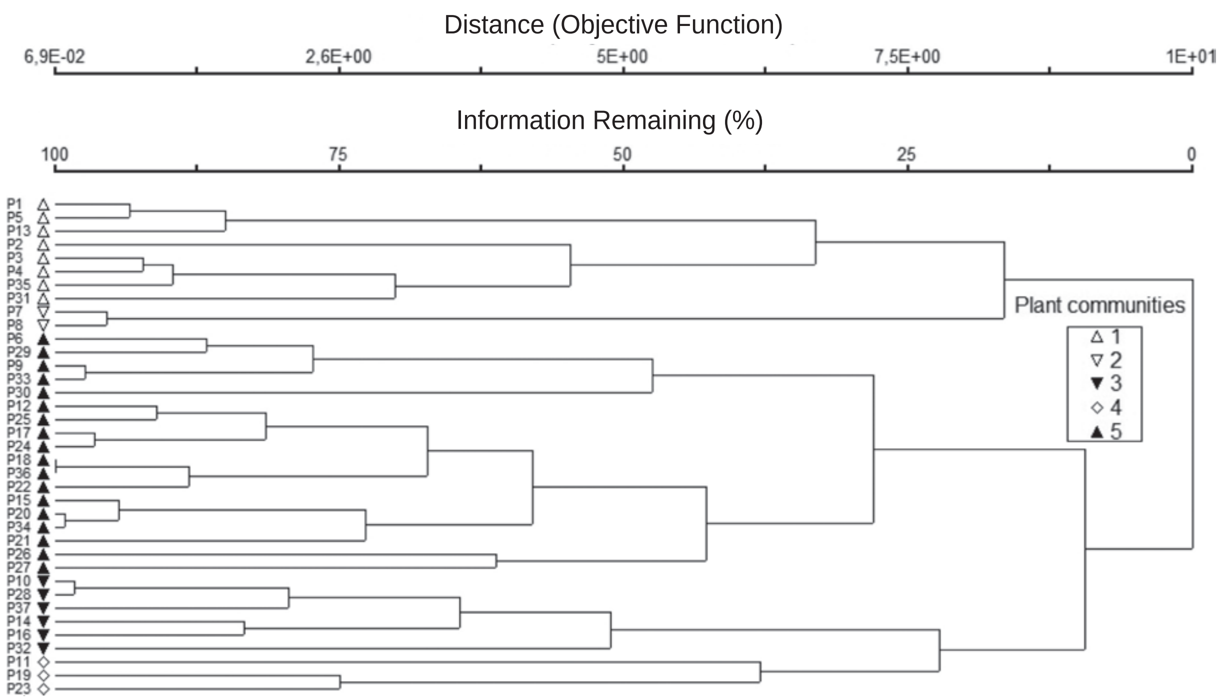

Figure 2: Dendrogram showing different vegetation units along the altitudinal gradient in the Pailugou catchment obtained by Hierarchical Cluster Analyses.

Slika 2: Dendrogram prikazuje različne vegetacijske enote vzdolž višinskega gradienta v porečju Pailugou, ki smo ga dobili z metodo združevanja.

Table 1: Distribution of plant communities in Pailugou Catchment.

Tabela 1: Razširjenost rastlinskih združb v porečju Pailugou.

Plant communities	Altitude	Exposition	Soil types	Description	Numbers of plots
Picea crassifolia forest (1)	2650–3300 m.a.s.l	north-east, north-west facing slopes	Cryosol, Regosol, Cambisol	Spruce forest occurs only on north-facing slopes due to the cooler and more humid topo- and microclimate. The upper boundary of the forest is determined by orography (rocky outcrops) and climatic factors. The age of the majority of spruce trees varies from 80 to 120 years. The trees attain a height of only c. 15 m due to the harsh climatic and unfavorable soil conditions (permafrost). Total forest cover varies from 80 to 100%. Cattle tracks and trampling impact were widespread up to 3000 m.a.s.l	P1, P2,P3, P4, P5, P13, P31, P35
Salix gilashanica -Arctostaphylos alpina shrubland (2)	3400–3600 m.a.s.l	north, north-west facing slopes	Cryosol	Due to the high elevation and orography (rocky outcrops and steep slope up to 45°), it is less accessible and less affected by grazing and trampling. This vegetation unit is characterized by dense shrub thickets with total cover of 70–85%, and most diverse herb communities in the undergrowth (see Tab. 6, Tab. 7).	P7, P8
Potentilla anserina - Geranium pratense grassland (3)	2680–3020 m.a.s.l	north-west/ west- north-east facing slopes	Leptosol, Regosol	Total herb and grass cover reaches 95–100%, with slope inclinations from 5° to 10°. *Potentilla fruticosa* makes up the shrub layer, total shrub cover does not exceeds 30%. This grassland is already occupied by unpalatable *Iris* populations, positively selected by long-term grazing.	P10, P14, P16, P27, P28, P32
Stellera chamaejasme shrubby grassland (4)	2660–3000 m.a.s.l	south-, south-west facing slopes	Leptosol, Regosol	Total herb and grass cover is between 60–80% and shrub cover between 50–80%, with varying slope inclinations from 5° to 30°.	P11, P19, P23
Stipa capillata mixed grassland (5)	2700–2900 m.a.s.l	various slope exposures	Leptosol, Regosol.	Slope steepness varies from 20° to 35°. Shrub cover is highly variable ranging from 2% to 65% with herb cover of 60% to 85%. Herb layer is dominated by poisonous and/or unpalatable species (see Table 6).	P6, P9, P12, P15, P17, P18, P20, P21, P22, P24, P25, P26, P27, P30, P31, P33, P34, P36

Vegetation-environment relationships

Initially, fourteen environmental variables were used in DCA analysis, but those with low Pearson correlation coefficient ($r < 0.3$) were not included into the further analysis. Mantel test showed a significant relation between vegetation and environmental data ($p < 0.001$). Among the variables, altitude, tree cover, shrub cover and "northness" factor were found to be strongly positively correlated with Axis 1 in ordination space, whereas "grazing impact" factor showed strong negative correlation with Axis 1 (Table 2, Figure 3).

The distribution pattern of vegetation types showed a clear dependence on altitude and slope exposure: *Stellera chamaejasme* shrubby grassland (4) community was distributed at lower altitudes, occupying south-east/southwest facing slopes, whereas *Picea crassifolia* forest (1) and *Salix gilashanica - Arctostaphylos alpina* shrubland communities (2) covered north/north-east/north-west-facing slopes at higher elevations. To elaborate the effect of grazing and related environmental factors, grassland communities were analysed separately (Figure 4, Table 3).

Table 2: Pearson's correlation scores from PC-ORD DCA output for the first three axes with the 6 environmental variables and plant cover values (Figure 3).

Tabela 2: Pearsonove korelacijske vrednosti v točkah iz PC-ORD DCA za prve tri osi s šestimi okoljskimi spremenljivkami in pokrovnostjo rastlinskih vrst (Slika 3).

Axis	1	2	3
Pearson's correlation	R	r	r
Altitude	0.648	-0.002	-0.296
Total Cover	0.313	0.191	-0.320
Tree Cover	0.701	0.082	0.529
Shrub Cover	0.474	-0.594	-0.164
Grazing Impact	-0.491	-0.164	0.061
Northness	0.661	0.186	0.031

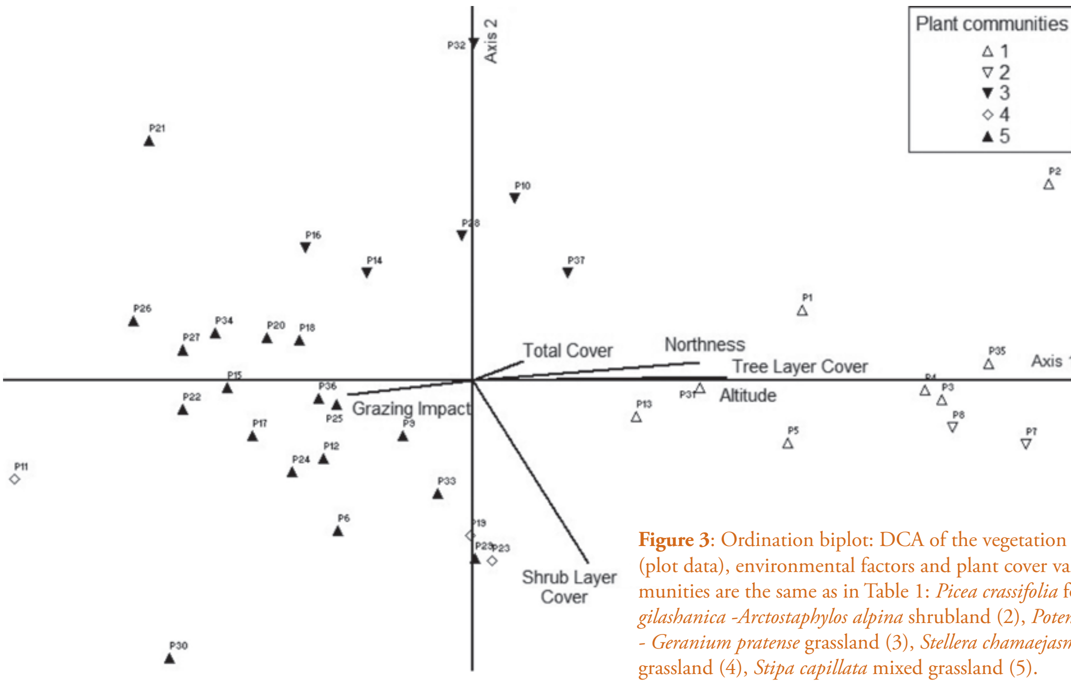

Figure 3: Ordination biplot: DCA of the vegetation distribution (plot data), environmental factors and plant cover values. Plant communities are the same as in Table 1: *Picea crassifolia* forest (1), *Salix gilashanica -Arctostaphylos alpina* shrubland (2), *Potentilla anserina - Geranium pratense* grassland (3), *Stellera chamaejasme* shrubby grassland (4), *Stipa capillata* mixed grassland (5).

Slika 3: Ordinacijski diagram: DCA razširjenosti vegetacije (podatki ploskev), okoljski dejavniki in pokrovnost rastlinskih vrst. Rastlinske združbe so kot v Tabeli 1: gozd *Picea crassifolia* (1), grmišče *Salix gilashanica -Arctostaphylos alpina* (2), travišče *Potentilla anserina - Geranium pratense* (3), grmičasto travišče *Stellera chamaejasme* (4), mešano travišče *Stipa capillata* (5).

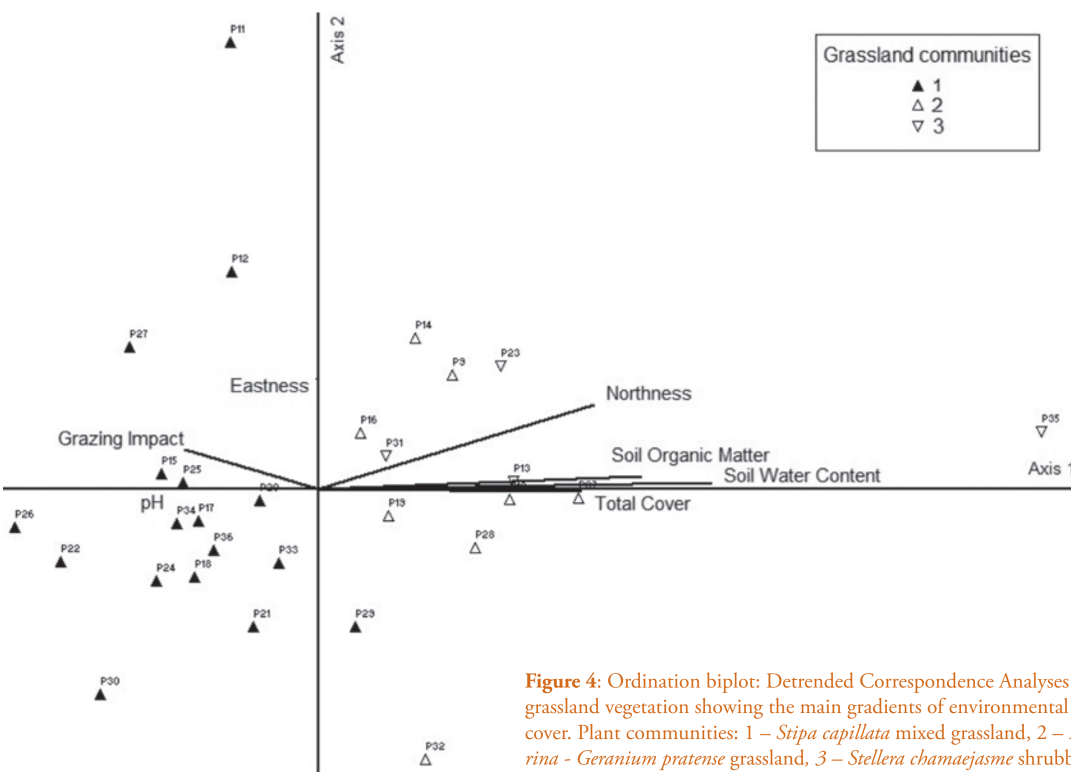

Figure 4: Ordination biplot: Detrended Correspondence Analyses of the mountain grassland vegetation showing the main gradients of environmental factors and total cover. Plant communities: 1 – *Stipa capillata* mixed grassland, 2 – *Potentilla anserina - Geranium pratense* grassland, *3* – *Stellera chamaejasme* shrubby grassland.

Slika 4: Ordinacijski diagram: DCA gorskih travišč z glavnimi gradienti okoljskih dejavnikov in skupno pokrovnostjo. Rastlinske združbe: 1 – mešano travišče *Stipa capillata*, 2 – travišče *Potentilla anserina - Geranium pratense, 3* – grmičasto travišče *Stellera chamaejasme*.

Table 3: Pearson's correlation scores from PC-ORD DCA output for the first three axes with the 7 environmental variables and plant cover values determined for grassland plant communities (Figure 4).

Tabela 3: Pearsonove korelacijske vrednosti v točkah iz PC-ORD DCA za prve tri osi s sedmimi okoljskimi spremenljivkami in pokrovnostjo rastlinskih vrst za travniške rastlinske združbe (Slika 4).

Axis	1	2	3
Pearson's correlation	R	r	r
Total Cover	0.714	-0.077	-0.406
Grazing Impact	-0.510	0.279	0.237
Slope Inclination	-0.319	0.259	0.194
Eastness	-0.044	0.463	0.183
Northness	0.732	0.406	-0.187
pH	-0.488	0.000	0.397
Soil Water Content	0.875	0.115	-0.230
Soil Organic Matter	0.793	0.157	-0.249

The factor "Eastness" (r = 0.137), representing east-west exposure, and slope inclination (r = 0.058) had a non-significantly low influence with respect to vegetation distribution in grasslands; therefore these two factors are not represented on the biplot (Figure 4). Grassland communities, *Stipa capillata* mixed grassland in particular, were affected by grazing impact to a large extent (cf. Figure 4).

Main floristic gradients within mountain grasslands along Axis 1 were determined by soil water content (r = 0.875), soil organic matter (r = 0.793), and exposure (variable "northness"; r = 0.732) as well as by grazing impact (r = -0.51), which was negatively correlated with Axis 1. "Eastness" showed relatively high positive correlation with Axis 2, differentiating communities on east- and west-facing slopes. *Stipa capillata* mixed grassland (1) was mostly determined by exposure, occupying south-facing slopes with higher alkalinity (pH), less organic content and less water content in the soils. By contrast, *Potentilla anserina - Geranium pratense* grassland (3) and *Stellera chamaejasme - Potentilla davurica* shrubby grassland (4) were concentrated on more humid soils rich in organic matter, also showing higher total cover and preferring more northern exposures.

Soil water content showed high positive correlation with total vegetation cover, soil organic matter and northness, while a significantly negative correlation was assessed with soil pH and grazing impact, and a weaker negative correlation with soil water content and soil organic matter. At the same time soil pH had a positive correlation with number of cattle tracks and grazing impact.

Plant species richness, diversity and indicator species

In total, 112 vascular plant, bryophyte, and lichen species from 34 families were identified, including 29 families of angiosperms. Species richness and diversity indices were calculated per 100 m² plot for the communities (Table 4). The average number of species per plot was 24. *Salix gilashanica - Arctostaphylos alpina* shrubland (3400-3600 m) showed the highest values of these indices, with 32 species per plot, Evenness index of 0.787, Shannon`s diversity index of 2.728 and Simpson`s diversity index of 0.910. On the other hand, *Picea crassifolia* forest communities (3000–3300 m) exhibited comparatively low diversity indices: 18.9 species per plot, Evenness of 0.693, Shannon diversity index of 1.993 and Simpson diversity index of 0.813. The range of variation in species richness among grassland communities (2680–3020 m) was from 25.1 to 27.6 species, with maximum species per plot in *Stellera chamaejasme - Potentilla davurica* shrubby grassland. Evenness, Shannon and Simpson diversity indices did not vary much among the grassland communities, *Potentilla anserina - Geranium pratense* grassland showed highest values (E = 0.747, H = 2.407, D = 0.872).

Table 4: Richness, evenness and alpha diversity indices of the main plant communities obtained in cluster analyses.

Tabela 4: Pestrost, indeks izenačenosti in alfa diverziteta glavnih rastlinskih vrst, dobljenih z analizo razvrščanja v skupine.

Groups	S*	E**	H***	D****	Altitude
Picea crassifolia forest (1)	18.9	0.693	1.993	0.813	2650–3300 m.a.s.l.
Salix gilashanica - Arctostaphylos alpina shrubland (2)	32.0	0.787	2.728	0.910	3400–3600 m.a.s.l.
Potentilla anserina - Geranium pratense grassland *(3)*	25.1	0.747	2.407	0.872	2680–3020 m.a.s.l.
Stellera chamaejasme shrubby grassland (4)	27.6	0.724	2.396	0.865	2660–3000 m.a.s.l.
Stipa capillata mixed grassland (5)	24.8	0.744	2.379	0.872	2700–2900 m.a.s.l.

*S = Richness = mean number of species
**E = Evenness = H/ln (Richness)
***H = Shannon's diversity index = – sum (Pi*ln(Pi))
****D = Simpson's diversity index for infinite population = 1 – sum (Pi*Pi), where Pi is importance probability in element i (element i relativized by row total)

ISA after Dufrêne and Legendre (1997) identified the species with highest indicator value (Table 5). Several species were detected as perfect indicators (indicator value 100) for particular plant communities, e.g., *Kobresia setschwanensis*, *Xanthoria elegans*, *Lonicera hispida*, *Pedicularis alashanica*, *Lonicera hispida*, *Saxifraga atrata*, *Saxifraga egregia* for the alpine shrubland, *Carex atrata* (99.60) and *Chrysosplenium nudicaule* (98.30) for *Salix gilashanica - Arctostaphylos alpina* shrubland.

Table 5: Indicator Species Analyses for the taxa in the five plant communities in mountain grasslands of Qilian Shan. Indicator value is given in percent of perfect indication (IV). Monte Carlo test of significance of the observed maximum indicator value for each species, with 999 randomisations, including p-values.

Tabela 5: Analiza indikatorskih vrst za taksone v petih združbah gorskih travišč iz območja Qilian Shan. Indikatorske vrednosti so podane v odstotkih popolne indikacije (IV). Monte Carlo test statistične značilnosti opazovanih maksimalnih indikatorskih vrednosti za vsako vrsto z 999 slučajenji, vključene p-vrednosti.

Taxa	Indicator value*	Mean	Standard Deviation	p**
Picea crassifolia forest (1)				
Carex atrata	99.60	19.90	9.96	0.001
Hylocomium splendens	70.30	21.10	11.14	0.011
Picea crassifolia	69.20	21.80	10.49	0.007
Fragaria orientalis	50.00	18.9	11.77	0.010
Salix gilashanica - Arctostaphylos alpina- shrubland(2)***				
Salix gilashanica	91.80	16.40	11.38	0.004
Arctostaphylos alpine	65.90	20.10	11.90	0.018
Caragana jubata	60.40	21.00	11.35	0.020
Leontopodium leontopodioides	55.70	29.20	9.41	0.010
Cerastium caespitosum	99.80	19.00	12.15	0.002
Pedicularis alashanica	100.00	15.70	10.60	0.002
Draba oreades	85.60	20.40	12.44	0.002
Caragana jubata	60.40	21.00	11.35	0.020
Chrysosplenium nudicaule	98.50	23.80	13.17	0.001
Lonicera hispida	100.00	15.90	10.76	0.002
Corydalis dasyptera	86.60	18.20	11.13	0.001
Saxifraga atrata	100.00	15.10	09.98	0.037
Kobresia setschwanensis	100.00	15.20	10.06	0.002
Viola biflora	49.00	15.20	10.13	0.042
Saxifraga egregia	100.00	15.50	11.22	0.002
Xanthoria elegans	100.00	15.80	11.22	0.002
Potentilla anserina - Geranium pratense grassland (3)				
Potentilla anserine	62.90	25.20	11.19	0.014
Carex sp.	57.10	19.50	11.24	0.004
Ranunculus brotherusii	55.00	20.90	12.99	0.022
Geranium pretense	72.3	22.60	11.60	0.008
Iris lactea var. *chinensis*	57.00	28.70	7.12	0.001
Stellera chamaejasme shrubby grassland (4)				
Stellera chamaejasme	64.0	30.4	9.11	0.001
Stipa capillata	61.5	25.6	9.02	0.001
Medicago hispida	43.6	27.9	8.18	0.044
Stipa capillata mixed grassland (5)				
Sabina przewalskii	59.80	25.00	13.37	0.012
Potentilla acaulis	57.90	23.80	13.37	0.025

*observed maximum Indicator value: 1 (no indication) –100 (perfect indication);
**p = (1 + number of runs ≥ observed)/(1 + number of randomized runs)
***in total 25 significant indicator species (p > 0.05)

The presence of 25 significant indicator species within the *Salix gilashanica - Arctostaphylos alpina* shrubland community showed the discreteness of the high altitude flora. Some of these species also occurred at lower altitudes, where they are not assumed to be indicators. Almost none of the unpalatable or toxic species were found within the alpine shrubland community. It is represented by locally rare non-random flora. The species composition is considerably different compared to other plant communities, and shows the highest number of indicator species per plot and highest diversity indices. These high altitude shrublands are difficult to access for grazing animals, thus have a lower disturbance rate, which is in turn reflected in the deviating species composition.

Furthermore, species were distinguished indicating specific site-environmental conditions (based on information from eFloras, Subject Database of China Plant): significant indicators of grazing include *Iris lactea* var. *chinensis*, *Stellera chamaejasme*, *Oxytropis melanocalyx*, *Pedicularis* spp. *Achnatherum* spp., and *Clematis* spp. (will be further discussed in the palatability section); species common on south-exposed loess slopes and indicating high trampling intensity included *Potentilla acaulis*, *Potentilla bifurca* and *Sibbaldia procumbens; Rosa* spp., *Caragana* spp., and *Salix* spp. are shrub species which are resistant to grazing, and provide shelter for herb layer species.

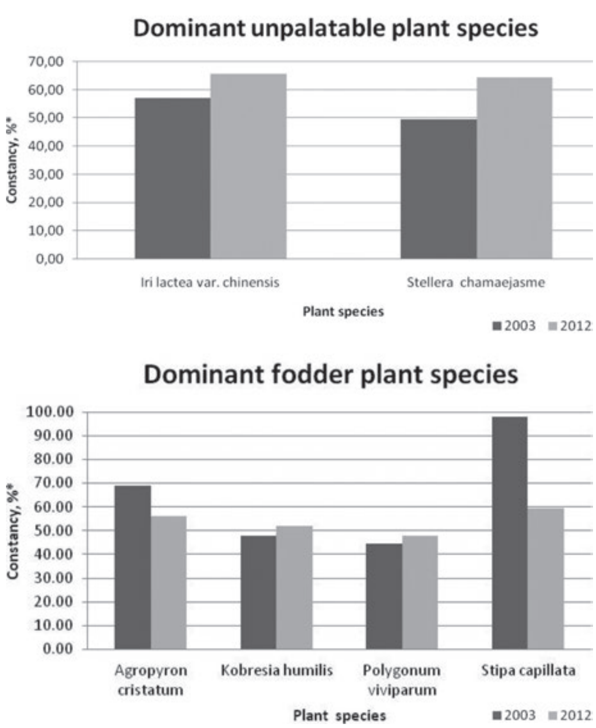

Figure 5: Diagram showing the dominant palatable (A) and unpalatable (B) plant species in comparison of species records from 2003 and 2012 (provided dominant species are those which were found in both datasets).

Slika 5: Diagram dominantnih užitnih (A) in neužitnih (B) rastlinskih vrst ter primerjava podatkov iz let 2003 in 2012 (prikazane so samo dominatne vrste, ki so prisotne v obeh podatkovnih nizih).

Dominant herb and grass species of the plant communities were identified according to abundance in the entire dataset. After comparison of the constancy of the dominant species detected in 2003 and 2012, significant changes in species composition of the grassland communities were identified. Comparing both datasets, constancy of unpalatable species (*Stellera chamaejasme*, *Iris lactea* var. *chinensis*) increased (Figure 5: A), while constancy of the common fodder species in 2012 decreased (Figure 5B). Change in constancy of *Agropyron cristatum* and *Stipa capillata* was more pronounced than those of *Kobresia humilis* and *Polygonum viviparum*, which were almost the same in 2003 and 2012. Recent field investigations in 2012 showed high total cover and high constancy of both *Iris lactea* var. *chinensis* and *Stellera chamaejasme* in the majority of sampled plots revealing the trend of grassland deterioration.

Palatability and grazing

When being subjected to long-term grazing, mountain pastures have experienced positive selection of species resistant to grazing due to their physical (unpalatable, thorny, spiny) or chemical (toxic) qualities. According to Suttie et al. (2005) there are 731 species of toxic plants in the grasslands of China, belonging to 152 genera and 49 families. In the mountain grasslands of Qilian Shan, the most common toxic species included *Stellera chamaejasme*, *Achnatherum* spp., *Oxytropis* spp. and *Pedicularis* spp. The most widespread unpalatable species (Table 6) were *Iris lactea* var. *chinensis*, *Caragana jubata*, *Leontopodium leontopodioides* and *Sibbaldia procumbens*.

According to our observations, *Iris lactea* var. *chinensis* covered up to a half of the pastureland. Its coverage was increasing from year to year, causing a decline in forage quality and generally reducing the suitability of the area for animal husbandry. A similar trend wass observed for *Stellera chamaejasme*, which was detected almost on every grassland plot as a co-dominant species.

A particularly intense grazing impact was identified on south-facing grasslands at lower altitudes (Table 1). Widespread *Stipa capillata* mixed grassland was co-dominated by *Stellera chamaejasme* and *Iris lactea* var. *chinensis*, which indicated a shift from near-natural grassland dominated by *Agropyron* and *Stipa* species to degraded grassland, connected with a decrease in biodiversity.

The species most preferred by grazing animals (sheep, goats and yaks) were perennial grasses (*Stipa capillata*, *S.*

Table 6: Palatability of the common grass and forbs species for the potential animal users (sheep, goat, yak) during the growing season (after Damiran 2005, Lu et al. 2012, Quattrocchi 2012).

Tabela 6: Užitnost splošno razširjenih trav in zelišč za živali (ovca, koza, jak) med rastno sezono (po Damiran 2005, Lu et al. 2012, Quattrocchi 2012).

Toxic	Not consumable	Consumed, but undesirable	Preferred and desirable
Achnatherum inebrians A. splendens	*Artemisia scoparia*	*Clematis tangutica*	*Agropyron cristatum*
A. purpurensis	*Axyris hybrida*	*C. aethusifolia*	*Kobresia humilis*
Anemone obtusiloba	*Caragana jubata*	*Gentiana* spp.	*K. pusilla*
Oxytropis glabra.	*Chenopodium pamiricum*	*Geranium pratense*	*K. tibetica*
O. melanocalyx	*C.karoi*	*G. sibiricum*	*Medicago hispida*
Pedicularis kansuensis P. oedri	*Iris lactea* var. *chinensis*	*Heteropappus altaicus*	*Polygonum viviparum*
P. longiflora	*Leontopodium leontopodioides*	*Leymus chinensis L.secalinus*	*Poa pratensis*
Saussurea salicifolia	*Sibbaldia procumbens*	*Potentilla acaulis P.anserina*	*Stipa capillata*
Stellera chamaejasme		*P. bifurca*	*S. breviflora*
		P. saundersiana	*S. kirilovii*

breviflora, *S. kirilovii*, *Agropyron cristatum*), sedges (*Kobresia humilis*, *K. pusilla*, *K. tibetica*) and forbs (*Medicago hispida* and *Polygonum viviparum*) (Table 6). Long-term grazing has repressed these formerly dominant and/or co-dominant plant species, while toxic species such as *Stellera chamaejasme* and *Iris lactea* var. *chinensis* increased in cover and abundance.

The forest area (*Picea crassifolia* forest, Table 1) was not affected by *Stellera* and *Iris* invasion, but it was strongly trampled and disturbed by the constant migration of sheep, goats and yak herds to summer pasture areas and back, while young shoots and small *Picea* trees were grazed together with shrubby underwood (*Potentilla fruticosa*, *P. davurica*, *Caragana jubata*, *C. opulens*). Moreover, considerable anthropogenic interferences were observed, in particular at the end of July when collecting mushrooms is a widespread seasonal activity. At this time of the year, soil compaction and destruction of the moss layer is strongly increased (own observations).

Discussion

Distribution patterns and vegetation-environment relationships

The Pailugou catchment is located between 2600 and 3600 m.a.s.l., being a part of an altitudinal gradient from lowlands to highlands, from hot arid and semi-arid areas over more humid mid-altitudinal zones up to cold humid alpine and nival zones. We have identified communities with explicit ecological indicator function for different parts of this gradient. The altitudinal zonation of the differentiated communities reflects an environmental gradient from dry-warm to cold-wet conditions: *Stipa capillata* mixed grassland occurs in drier and intermediate wet habitats, *Picea crassifolia* forest was found on wet shady slopes, and *Salix gilashanica – Arctostaphylos alpina* shrubland is confined to the cold wet alpine belt. Our results correspond to the findings of Wang et al. (2002), who identified communities indicating this altitudinal gradient in the Qilian Mountains.

In the Qilian Mountains, a clear difference was observed between vegetation on north-facing slopes (Wang et al. 2002, Wang 2002, Huang et al. 2011) and south-facing slopes (Chang et al. 2004, Sheng et al. 2009). This phenomenon is common in temperate and subtropical mountain ranges, but much more pronounced in many mountain ecosystems in dry Central Asian regions, where dense forests and other hygrophilous vegetation are often restricted to moist northern exposures, whereas steppe vegetation covers the southern aspects (Holtmeier 2009). Slope exposure affects the vegetation mosaic in many ways. On south-facing slopes, high insolation rates in summer result in very high temperatures, which affect soil water conditions and soil mineralization process (Nagy & Grabherr 2009). Our results support the crucial role of slope aspect by showing that exposure (northness) has a greater impact on vegetation differentiation than altitude in the whole catchment area. By contrast, slope inclination is far less important and becomes a significant factor only in the distribution of grassland communities.

Soil moisture is considered to be one of the key factors determining vegetation cover in the Qilian Mountains (Wang et al. 2002). Our research showed that main floristic gradients of mountain grasslands were determined by soil water content, soil organic matter, slope exposure and grazing impact. *Potentilla anserina - Geranium pratense* grassland and *Stellera chamaejasme* shrubby grassland mainly occupied humid soils rich in organic matter, whereas *Stipa capillata* mixed grassland was distributed on sites with high pH, less organic content and less water content of the soils. The latter sites were most severely affected by grazing. A coincidence of more alkaline sites with higher grazing pressure was also shown by Sheng et al. (2009). Further investigation of significant soil parameters (e.g., soil texture, available phosphorus, total nitrogen, C/N ratio) is necessary to clarify the fertility of the soils underlying degrading grasslands (Jones et al. 2011), and its connection with species richness and plant species distribution (Sheng et al. 2009, Rana et al. 2011).

Plant species richness, diversity and indicator species

Our results show a peak in species richness in the alpine shrubland at altitudes between 3400 and 3600 m.a.s.l., whereas species richness and diversity of the grassland communities at altitudes between 2680 and 3020 m.a.s.l. is lower and does not vary much. By contrast, Wang et al. (2002) reported a maximum of species richness and diversity at c. 2700 m and argued that diversity of plant communities may vary according to different utilization intensity of the grasslands. In addition, Török et al. (2016) outlined that species diversity forms a hump-shaped curve along the increasing grazing gradient. At the same time, Lomolino (2001) emphasized that the diversity-elevational gradient is mainly shaped by geographically explicit variables and the interactions between them.

The results of the ISA clearly reflect the grazing-affected successional stage of mountain grasslands. The low number of indicator species within *Stipa capillata* mixed grassland illustrates the high internal heterogeneity of this community. The grazing-modified *Stipa capillata* community, as differentiated by Cluster Analysis, might be simply too large to identify a greater number of indicator species (cf. Brinkmann et al. 2009). These results support the idea of an ongoing transformation process from more homogeneous grassland less affected by grazing and dominated by species of *Stipa* and *Agropyron* (Wang et al. 2002) to severely degraded *Stipa capillata* grassland co-dominated by *Iris lactea* var. *chinensis* and *Stellera chamaejasme*.

Chang et al. (2004) found that the species diversity of Qilian Shan mountain grasslands showed signs of deterioration at low altitudes, increasing the percentage of toxic plant species populations and decreasing the consumable ones. Our research corroborates these results. We found a low species evenness index and low variation of species richness among the three plant communities in mountain grasslands of Qilian Shan indicating that there are several dominant species with high relative abundance. Thus, the variation in community evenness could be driven by variation in abundance of the dominant species (cf. Dorji et al. 2014). Some of these species have become dominant during the last decade, facilitated by continued overgrazing of spring and autumn pastures.

Palatability, grazing impact and degradation

Based on investigations in arid rangelands of NW China, Mongolia and the Qinghai-Tibet Plateau (Damiran 2005, Miehe et al. 2011, Lu et al. 2012, Jambal et al. 2012), several toxic species were identified during our research, serving as indicators of continuous grazing pressure: *Achnatherum inebrians, Stellera chamaejasme*, *Anemone obtusiloba*, *Oxytropis glabra*, *O. melanocalyx*, *Equisetum arvense*, *Saussurea salicifolia*, *Ranunculus pulchellus, Rumex* spp. and *Pedicularis* spp. *Stellera chamaejasme* was detected as a threat for semi-natural grasslands in various studies published by Chinese scientists; its appearance was associated with a decrease of biodiversity indices (Zhao et al. 2004, Wang et al. 2006, Gang et al. 2008). We observed similar trends for the unpalatable *Iris lactea* var. *chinensis,* which currently dominates most of the mountain pasture land in Qilian Shan, and decreases its quality by preventing the spread of preferred and consumable fodder species.

Long-term heavy grazing causes a shift in species composition with a decrease of good fodder grass and forb species and their replacement by unpalatable and toxic plant species (Diaz at al.2006, Zhou et al. 2006, Bisigato et al. 2008). We observed this degradation trend in particular in areas with southern aspect at altitudes between 2600 and 3000 m.a.s.l in the mountain grasslands of Qilian Shan. This process is amplified on the dry south-facing slopes, which are exposed to greater soil erosion and to soil compaction by animal trampling (cf. Blackburn 1984, Borchardt et al. 2011).

However decrease of diversity of the fodder plant species is associated with the type of animal grazers, affecting the species composition and plant functional types by selective browsing (Metera et al. 2010, Wrage et al. 2011). Cattle grazing was found to be beneficial for the plant diversity of the temperate grasslands, while sheep grazing decreases the plant diversity due to the selective feeding of the sheep (Jerrentrup et al. 2015). In the study area of the Qilian mountains, so called "mixed grazing" is in use – sheep, goats and yak are sharing the same pasture area during the grazing season. Such type of the grazing strategy did not always result in restoration of plant diversity of the examined pastures (Jerrentrup et al. 2015). Instead, together with the high intensity of the pasture land use, it leads to loss of plant diversity.

The effects of grazing on the structure of grassland plant communities often include modifications of shrub cover and abundance. We found highest shrub cover in *Stellera chamaejasme* shrubby grassland on north-facing slopes that are less affected by grazing, whereas the percent of detected shrub cover was much lower in *Stipa capillata* mixed grassland on south-facing slopes with considerably higher grazing impact. Shrub cover had a low correlation with other environmental variables. Our results seem to support the hypothesis that prevention of grazing could lead to shrub encroachment (e.g. Bisigato et al. 2008), contradicting the notion that shrub encroachment could be considered as a generalized response of steppe pastures to grazing (cf. Cesa & Paruelo 2011). Further investigations on the relationships between shrub cover and abundance and abiotic site factors and grazing impact are necessary to clarify this problem.

Conclusions

The extent of environmental degradation in the vast pasture areas of the NW of China has increased rapidly in the past decades. Overgrazing is the major cause. Our results show that local and regional case studies are needed in order to estimate the extent of overgrazing, and to elaborate a scientific basis for deriving strategies to avoid overexploitation of the land and to develop adequate, ecologically sound solutions. From the perspective of the pasture management, the current study provides a foundation on which future strategy-oriented research can be based. In order to implement a sustainable grazing management, our results suggest considering the introduction of a rotation grazing system with a scheduled transfer of grazing and resting time between grazing units along the altitudinal gradient. Grazing pressure should be reduced in particular on south-facing slopes exposed to erosion. Rotation grazing should be incorporated into management plans which generally specify a reduced time period of grazing within the overall grazing season in order to optimize the quantity and quality of forage produced and its utilization by grazing animals.

Acknowledgements

The authors are grateful to Dr. Klaus von Wilpert (Forest Research Institute, Freiburg, Germany) and Dr. Liu Xiande (Academy of Water Resource Conservation Forest of Qilian Mountains (AWRCFQM), Zhangye, Gansu Province, China) for establishing this research initiative. For assistance in laboratory work we thank Dr. Elke Fischer and Ines Friedrich. We are grateful to the Robert Bosch Foundation (No.070610), the Special Fund for Forestry Scientific Research in the Public Interest (No.201204101), and CFERN & GENE Award Funds for financial support of this international joint project. We also acknowledge sustainable cooperation between partners in China and Germany. Financial support of the PhD research project was provided by University of Hamburg's Doctoral Funding Program (HmbNFG). We also thank two anonymous reviewers for their helpful comments on an earlier version of this manuscript, and Dr. Laura Sutcliffe for improving the English.

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