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Rangeland degradation assessment in Kyrgyzstan: vegetation and soils as indicators of grazing pressure in Naryn Oblast

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Abstract: Rangelands occupy more than 80% of the agricultural land in Kyrgyzstan. At least 30% of Kyrgyz pasture areas are considered to be subject to vegetation and soil degradation. Since animal husbandry is the economic basis to sustain people's livelihoods, rangeland degradation presents a threat for the majority of the population. We present for the first time an ecological assessment of different pasture types in a remote area of the Naryn Oblast, using vegetation and soils as indicators of rangeland conditions. We analysed the current degree of utilization (grazing pressure), the amount of biomass, soil samples, and vegetation data, using cluster analysis as well as ordination techniques. Winter pastures (*kyshtoo*) are characterized by higher pH values (average of 7.27) and lower organic matter contents (average of 12.83%) compared to summer pastures (*dzailoo*) with average pH values of 6.03 and average organic matter contents of 21.05%. Additionally, summer pastures show higher above-ground biomass, and higher species richness and diversity. Our results support the hypothesis that winter pastures, which are located near settlements, suffer from over-utilisation, while the more distant summer pastures are subjected to much lower grazing pressure.

Keywords: Alpine meadows; Alpine steppes; Animal husbandry; Classification; Grazing management; Montane pastures; Ordination; Plant communities

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Introduction

Animal husbandry has always played a major role in the life of Kyrgyz people, and the livestock sector has been one of the strongest components of the regional economy during Soviet and post-Soviet times (Ludi 2003; Baibagushev 2011; Dörre 2012; Schmidt 2013). Montane and alpine rangelands, which occupy an area of more than 9 million hectares (45% of the Kyrgyz land area), represent the significant basis for this economic sector (Baibagushev 2011; Taft et al. 2011; Dörre

2012; Sakbaeva et al. 2012). Prior to the colonization by the Soviet Union, nomadism was predominant in Kyrgyzstan. The pastoral nomadic land use system was adapted to local arid and semi-arid ecological conditions. Most pastoralists practised mobile livestock keeping and their flocks moved between seasonal pastures. The herds were driven up to montane and alpine pastures (*dzailoo*) in summer, and they grazed on pastures at lower elevations (*kyshtoo*) in winter (Shigaeva et al. 2007; World Bank 2007; Jacquesson 2010). The core of Kyrgyz nomadic lifestyle was represented by sheep and horses. For the most part herds still consist of sheep and horses but there are also flocks of goats, cows and yaks (Steimann 2010).

Under the Soviet regime, the transhumant grazing system was largely maintained. At the same time, the livestock industry had been massively expanded. According to Schoch et al. (2010), the flock size was two or three times higher than the carrying capacity of the pastures. Sedentarization and collectivization campaigns were forced and the formerly autonomously acting pastoralists were replaced by *sovkhozes* (state owned farms) and *kolkhozes* (collective farms) according to the Soviet model of agriculture management. The Kyrgyz Socialist Soviet Republic (KSSR) was destined to develop a wool, milk, and meat production industry (Farrington 2005; Dörre and Borchardt 2012; Kreutzmann 2013). Like Schoch et al. (2010) pointed out: “All in all, the Soviet livestock sector can be described as a high-output but unsustainable system”. The first years after independence saw a drastic reduction in livestock numbers, and a temporarily decreasing grazing pressure. In the period from 1989 to 1996 the number of sheep decreased from 10.3 million to 3.7 million (Schoch et al. 2010; Schmidt 2013). In the further course of post-Soviet transformation, livestock numbers have increased again considerably. At least 30% of pasture areas are currently subject to vegetation and soil degradation (e.g. Baibagushev 2011; World Bank 2014; Kulikov et al. 2016).

After the Soviet era and the end of the state-dominated system, land and livestock were privatised. This period was marked by far-reaching political and economic transformations with various social and commercial restrictions, especially for communities on the local level (Blank 2007; Borchardt et al. 2010; Dörre and Borchardt 2012). For most of the Kyrgyz people, the return to a subsistence lifestyle was the only possibility to sustain their livelihood (Laruelle and Peyrouse 2010; Borchardt et al. 2011). The dissolution of the institutionalized organisation embodied by the *kolkhozes* and *sovkhozes* presented an unexpected challenge for the farmers under the post-soviet regime. They were not prepared for a self-dependent, non-governmental management (Borchardt et al. 2011; Schmidt 2013). The period of post-Soviet transformation is defined by low efficiency and instability of the pasture economy (Esengulova et al. 2008; Schoch et al. 2010).

The adoption of a sedentary lifestyle provoked severe changes of traditional pasture practices. During the occupation, the *kolkhozes* organised annual migratory herd movements (Ludi; 2003; Crewett 2012; Kreutzmann 2013), providing a more homogeneous distribution of grazing pressure. Nowadays the herders themselves are responsible for the migration of livestock, but remote summer pastures are particularly difficult to reach. High individual migration costs and long distances as well as a weak state of infrastructure are responsible for the under-utilization of remote pastures (Crewett 2012; Dörre 2012). Summer pastures at higher elevations experience increasing abandonment (Esengulova et al. 2008; Schmidt 2013; Shigaeva et al. 2013), while the utilization of winter pastures, which are located close to settlements, is intensified with an increasing risk of vegetation and soil degradation. The investigation of the ecological consequences of this discrepancy, in particular with regard to the local context, represents a current gap in research. The Naryn Oblast provides the main pasture lands in Kyrgyzstan, and will play a major role in ensuring the long term sustainability of livestock farming - the source of Kyrgyz livelihood (Imanberdieva 2015). However, the ecological state of Naryn rangelands and pasture resources has not been assessed to date.

The issue of degrading rangelands in the Kyrgyz Republic has been already addressed (e.g., Wagner 2009; Borchardt et al. 2011; Dörre and Borchardt 2012), but the study areas were mostly located in the South-West of Kyrgyzstan with its different climate and site conditions. Other related studies focused more on political aspects (Ludi

2003; Shigaeva et al. 2007; Crewett 2012; Schmidt 2013). Only very few studies (Farrington 2005; Taft et al. 2011; Imanberdieva 2015) provide some information relevant to our research area. To fill this research gap the focus is on analysing and comparing the ecological status of pastures under different grazing regimes. Since our study area (the *Kara-Kujur* valley in the Naryn Oblast) is considered as scientifically unexplored (Borchardt et al. 2011; Taft et al. 2011; Eisenman et al. 2013), the primary objective is to (1) determine principal soil physical and chemical properties; (2) to analyse floristic differentiation of (sub-) alpine pasture types and to classify characteristic plant communities; (3) and to assess the grazing impact. We hypothesize that the increasing utilization level of winter pastures results in a deterioration of soil properties, and that the contrasting grazing intensity of summer and winter pastures is reflected in vegetation traits such as floristic composition, species richness and species diversity. We further expect that a differentiation of the pasture types will be possible based on the indications of soil properties and vegetation characteristics.

1 Study Area

The Kyrgyz Republic is characterized by the Tian Shan mountain system, which covers the major portion of the country. About 94% of the land surface is mountainous (Farrington 2005; Eisenman et al. 2013; World Bank 2014). One quarter of the territory (474.708 km²) is classified as steppe. Steppe formations correspond to the general climatic conditions (aridity and strong winds), but have been enlarged due to human impact such as logging and grazing, which leads to an ongoing degradation of pasture land (Imanberdieva 2015). In this study we will use the term '*degradation*' in accordance with Johnson and Lewis (2007), who restrict the usage of the term 'land degradation' to cases where a considerable decrease regarding the productivity of a land system is assessed and where this decrease is the result of human-induced processes rather than natural events. Here, the decrease in productivity will be measured by indicators such as amount of biomass, maximum plant height and organic matter content and the impact of human activities will be assessed by indicators like grazing impact and bulk density (as a result of livestock trampling).

This study was conducted in the Middle Tian Shan, in the north-east of the Naryn Oblast (41° N, 76° E), which is characterized by (sub-) alpine steppes and meadows (Figure 1). Naryn is not only the largest Oblast in Kyrgyzstan (45.200 km²), but also the one with the highest percentage of Kyrgyz

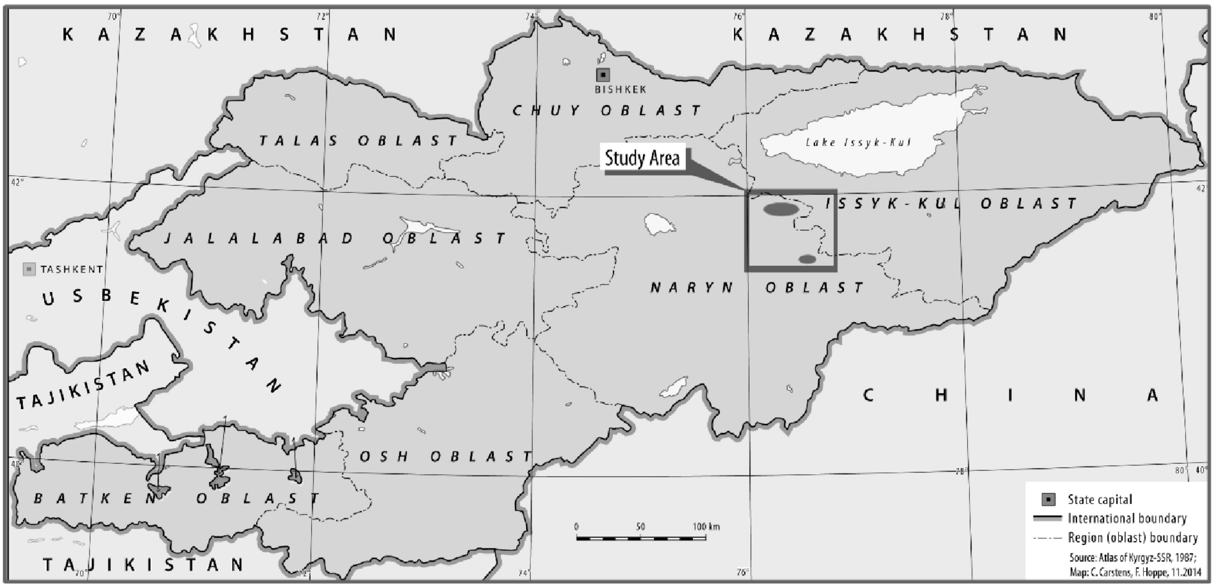

Figure 1 Location of study area. The Kara-Kujur valley is marked by the northern oval, while the smaller southern oval represents the State Reserve and its buffer zone.

pastures, approximately 30% (Crewett 2012). A large part of the Naryn Oblast is used as grazing land which sustains increasing livestock numbers (Blank 2007; UCA 2014). The climate in Kyrgyzstan varies from dry continental in the plains to cold and harsh at higher elevations. Due to the topography, the climate is characterized by sharp local differences. The *Kara-Kujur* valley is part of an inner basin landscape and is significantly drier than the northern and southern mountain range of Kyrgyzstan (Gottschling 2006). The average annual precipitation amounts to 200 to 300 mm only. Winters are cold and long with average temperatures of -15° in January. Accordingly, the vegetation period, i.e the agricultural season is comparatively short (Gottschling 2006; Eisenman et al. 2013; UCA 2014).

Kyrgyzstan has a rich flora which contains more than 4.100 species of vascular plants (approximately 450 species for fodder), characterized by a notable percentage of Middle Asian endemics (Taft et al. 2011; Eisenman et al. 2013, Ch. 1). The vegetation structure is extremely complex, with a huge variety of different vegetation types. The classification of plant communities is still a subject of discussion (Umralina and Lazkov 2008). The term 'Middle Asia' refers to the former Soviet Central Asian Republics Kazakhstan, Turkmenistan, Uzbekistan, Tajikistan and Kyrgyzstan (cf. Cowan 2007).

2 Materials and Methods

2.1 Data collection

Vegetation, biomass and soil samples were collected in the valley of *Kara-Kujur* in summer 2014. We completed 52 vegetation relevés according to the Braun-Blanquet approach (Dierschke 1994). We used a standard relevé size of 5 m × 5 m. We conducted stratified random sampling, with different slope inclinations and expositions as strata. Sample plots were placed randomly along an altitudinal gradient (between 2.800 m and 3.400 m, including winter and summer pastures). In addition, we sampled three plots in the Naryn State Reserve and its buffer zone (at elevations between 2.800 m and 3.150 m). These three plots serve as reference data for less grazed and ungrazed areas.

For the total of 52 plots we listed all vascular plants and assessed their cover-abundance according to the traditional Braun-Blanquet scale with 7 classes (Braun-Blanquet 1964; Kent 2012). The listed plants were determined in the herbarium of the National Academy of Sciences in Bishkek. The Nomenclature of vascular plant species follows Czerepanov (1995). Soil samples were taken (three subsamples of 100 cm^3 per relevé, using soil sampling rings) from the upper mineral horizon (0-15 cm depth). Further, biomass from the surface of one square meter within each plot was collected and air-dried. We complemented field sampling by an assessment of human impact. Grazing impact was estimated by direct observation of different parameters, such as plant height, vegetation cover, browsing damage and the amount of dung. We transferred those information into a grazing scale with 5 classes (1 = no grazing, 5 = heavy grazing).

2.2 Data analysis

2.2.1 Cluster analysis

We implemented a multivariate cluster analysis to determine different vegetation types. The original cover-abundance values were transformed according to van der Maarel (1979). The transformed scale is completely numeric and was used to apply the *hclust* function of the R-Package *vegan* (van der Maarel 2007). In this study we used a hierarchical-agglomerative method, which follows a bottom-up approach. The clustering is based on the average-linkage algorithm also known as *Unweighted Pair Group Method with Arithmetic mean* (UPGMA) (Gronau and Moran 2007; Loewenstein et al. 2008; Aggarwal and Reddy 2013). The algorithm presents a perfect adjustment between the minimum and maximum algorithm, which is more sensitive to outliers (Leyer and Wesche 2007; Vanselow 2011). The goodness-of-fit was tested by calculating the cophenetic correlation coefficient (c), given and discussed by Saraçli et al. (2013). This is a widely used measure, which allows the comparison of the deviance of a cluster from the original dissimilarity matrix (Sokal and Rohlf 1962). As stated in the study of McGarigal et al. (2000), a value of $c \geq 0.75$ signifies a good result for the cluster analysis. The calculation of the cophenetic correlation coefficient for our cluster analysis revealed a value of 0.79, which confirms a good representation of the original distance matrix used for cluster analysis (Oldeland et al. 2010).

2.2.2 Classification, indicator species and diversity analysis

To complement the cluster analysis and to differentiate plant communities of different pasture types, we applied the traditional classification method of the Braun-Blanquet approach (Dierschke 1994). The differentiation of vegetation units is based on diagnostic species. Determinations of diagnostic species followed the criteria of constancy differences proposed in Dierschke (1994). Species have to fulfill the criterion of a constancy difference of two classes to be classified as diagnostic species. In many cases manual and numerical classifications yield different results, that is one reason why the unification of traditional and numerical approaches is often recommended (Wildi 1989; De Cáceres et al. 2009). Thus, Indicator Species Analysis (ISA) was performed. By implementing ISA, an indicator value index is defined to measure the association between a site group representing habitat or community types and a species. The most characteristic species of each group (referring to our rankless communities) are identified that way as indicator species, indicating the strength of the association to the respective group and simultaneously the species' ecological preference (Dufrêne and Legendre 1997). The analysis reveals additional information about two components (A and B). In this case A is defined as specificity or positive predictive value, meaning the probability that inspected sites belong to the target site group due to the occurrence of this species. Component B represents sensitivity or fidelity, which stands for the probability that the species occurs on sites belonging to the target site group (Dufrêne and Legendre 1997; De Cáceres and Legendre 2009). Additionally, we calculated the Shannon-Weaver diversity index to define alpha-diversity (Shannon and Weaver 1963; Magurran 2004).

2.2.3 Soil investigation

We determined the following physical and chemical parameters in the laboratory of the Institute of Geography, University of Hamburg: soil pH, water and organic matter content, electric conductivity (EC), C/N ratio, effective cation exchange capacity (CEC_{eff}), bulk density and grain size distribution. Soil pH was measured in a 1:2.5 soil: 0.01 M calcium chloride solution. Kissel et al. (2009) recommended the measurement of pH using a 0.01 M $CaCl_2$ instead of a measurement in H_2O to minimize errors. The water content was determined after drying the samples at 105°C and the organic matter after drying them at 430°C. The electric conductivity (EC) was determined in a 1:2.5 soil: demineralized water solution. Before determining the C/N ratio, the pre-treated samples were grounded with a ball mill (Retsch Inc.). The C/N ratio was calculated after measuring the carbon and nitrogen content with a TruMac determinator (leco Inc.). For the effective cation exchange capacity (CEC_{eff}), and the analysis of element concentrations respectively, all samples underwent a percolation process with ammonium chloride (NH_4Cl). The element concentrations Al, Ca, Fe, K, Mg, Mn, and Na were determined with ICP-OES (Optima 2100, Perkin Elmer Inc.). Bulk density was calculated for each sample with the equation: bulk density = dry bulk density + 0.009 * *c* (mass of clay in %). For the grain size analysis all soil samples were pretreated with hydrogen peroxide (H_2O_2) to eliminate organic matter and partly with hydrochloride acid (HCL) to eliminate carbonates. Prior to the measurement, a dispersion medium of $Na_4P_2O_7$ was added. Sand fractions were determined through forming fabrics and a set of ASTM sieves. The separation of the smaller granulometric fractions was made using the fractionated sedimentation technique with subsequent drying and weighing. All these techniques are described in Carter and Gregorich (2008).

2.2.4 Ordination and measurement of spatial autocorrelation

We used NMDS (Non-metric Multidimensional Scaling) as ordination technique, because the priority lies on the representation of the objects in a small number of dimensions (usually two or three). For this purpose NMDS is an appropriate method (Legendre and Legendre 2012). To measure the goodness-of-fit of the monotone regression, we plotted the original distances (based on a Bray-Curtis triangle matrix) against the new distances in the ordination space (= R^2). Deviations from this condition of monotonicity are indicated by stress. The non-metric fit R^2 is defined as $R^2 = 1-S\times S$ where S indicates the stress value (Venables and Ripley 2002, Oksanen 2013). The higher the stress value is, the lower the R^2 will be and the condition of monotonicity will be restricted (Legendre and Gallhert 2001; Legendre and Legendre 2012). In our implemented analysis a stress value of 0.181463 was calculated, hence the R^2 with a value of 0.967 is still close to 1 (the optimum).

Spatial autocorrelation was tested by calculating a mantel statistic. The results, visualized in a mantel correlogram (Figure 2), indicate that there is no significant correlation between the species assemblages and their geographical distribution (Oden and Sokal 1986; Borcard et al. 2011; Diniz-Filho et al. 2013). It is important to assure that the different pasture types are not predetermined by the spatial structure. Additionally, a correlation matrix (Appendix 1) was implemented to evaluate the connection of the explanatory variables. The matrix is computed based on Pearson´s correlation coefficient. To test the significance of relationships, we used the chi-square statistic, which confirmed that the data are normally distributed (Legendre and Legendre 2012). For statistical evaluation, the collected data were analyzed in R© (R version 3.1.2; 2014-10-31) using the Packages *MASS*, *indicspecies, vegan* and *EcoGenetics* (Venables and Ripley 2002; De Cáceres and Legendre 2009; Oksanen et al. 2016; Roser et al. 2015).

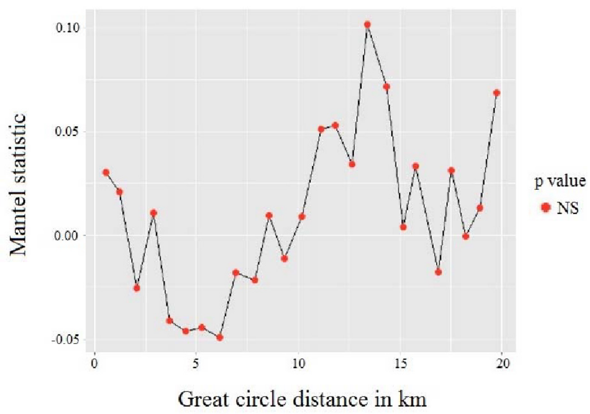

Figure 2 Mantel correlogram of the Hellinger-transformed and detrended species data after Holm correction. There is no significant (NS) correlation between both matrices.

3 Results

3.1 Classification of different pasture types

The classification using the average linkage cluster algorithm has been visualized by a cluster dendrogram (Figure 3). The upper end of the scale shows maximum dissimilarities, whereas the bottom end of the scale (ordinate axis) indicates relevés which are more similar to each other (Sokal and Rohlf 1962; Leyer and Wesche 2007). The dendrogram clearly shows two different pasture types: 18 plots were detected to be part of the winter pastures (on the left side of the dendrogram) and 28 plots to be part of the summer pastures (on the right side of the dendrogram). The cluster analysis additionally identified three plots of the State Reserve and its buffer zone (plots 3, 4, 5) as well as three outliers (plots 34, 50, 52). The same arrangement is presented by the ordination using NMDS (Appendix 2). For further investigations the outliers will be excluded. Based

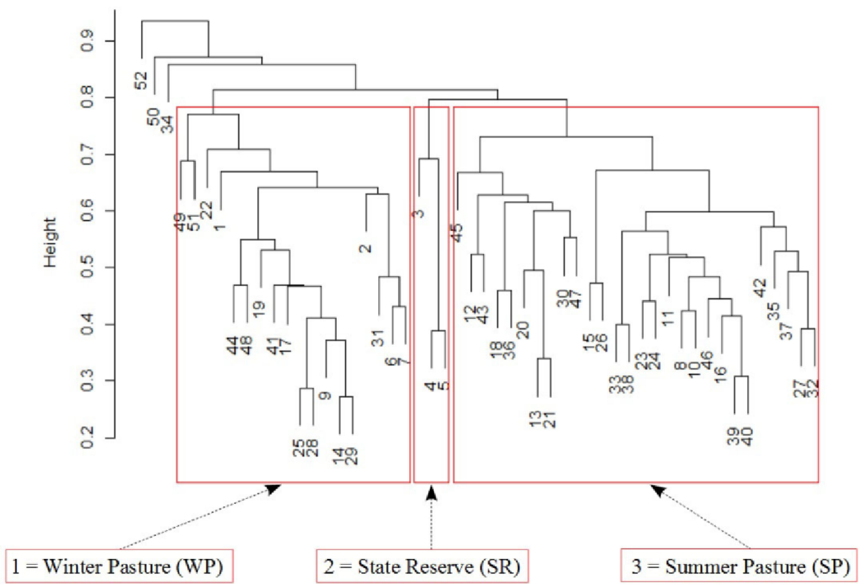

Figure 3 Results of the cluster analysis (based on the average-linkage algorithm) presented as dendrogram of different pasture types.

on the results of the Mantel test and the correlation matrix, we showed that the differentiation of pasture types is mainly driven by grazing impact, which is positively correlated with pH value and negatively correlated with soil organic matter content and maximum plant height. A weak negative correlation exists between grazing impact and altitude. However, by comparing plots of summer and winter pastures which are located at same elevations and which show similar exposition, we demonstrated that grazing pressure is the main driver for the differentiation of pastures types (Table 1).

3.2 Vegetation analysis

A total of 166 vascular plants were identified within the 52 plots. On average, 23 (standard deviation ± 7) species occurred per plot (minimum: 8, maximum: 35). The most species-rich genera were *Potentilla* (8 spp.), *Allium*, *Carex* (5 spp. each) and *Pedicularis* and *Stipa* (4 spp. each). *Gentiana karelinii, Trisetum spicatum*, *Gentianella turkestanicum* and *Cerastium pusillum* were identified as diagnostic species of summer pastures, while diagnostic species of winter pastures include *Bupleurum thianschanicum*, *Stipa purpurea*, *Plantago arachnoidea* and *Potentilla moorcroftii*. Additionally we identified four main companion species: *Festuca valesiaca*, *Taraxacum maracandium*, *Leontopodium ochroleucum and Kobresia humilis*. The complete list of species is presented in Appendix 3.

Complementarily, we performed an indicator species analysis (ISA). The results of the ISA (Table 2) revealed similar results with regard to the phytosociological identification of diagnostic species. The table only exposes species with a *p*.value = 0.001 (significant) and an indicator value index (*stat*) > 0.65. Species identified as diagnostic species of winter and summer pastures (as a result of the traditional classification) turned out to be at the same time significant indicator species, i.e. highly indicative of ecological conditions of respective relevé groups. Concerning the summer pastures, ISA indicates three additional species: *Carex stenocarpa*, *Trollius dschungaricus* and *Phlomoides oreophila*. These species show less constancy compared to diagnostic species, but occur with high cover-abundance, which explains high indicator value indices. Supported by this analysis we can differentiate the pasture vegetation types into two rankless communities: Winter pastures are covered by *Bupleurum thianschanicum-Stipa purpurea* communities, while summer pastures are occupied by *Trisetum spicatum-Gentiana karelinii* communities.

Species richness analysis showed highest values in the State Reserve and its buffer zone, with an average of 33 species per site (standard

Table 1 Vegetation patterns are more influenced by grazing pressure than by elevation. Altitude, exposition, species richness, and soil properties (pH = pH value, organ_mat = organic matter content, height_max = plant height) are listed for the winter and summer pasture sites at same elevations.

Winter pasture	Summer pasture
Plot 9 (3040 m)	Plot 35 (3035 m)
Exposition: 320°, 15 species	Exposition: 350°, 35 species
pH = 7.2, organ_mat = 12.95%, height_max=15 cm	pH = 6.5, organ_mat = 22.51%, height_max = 45 cm
Plot 17 (3110 m)	Plot 23 (3107 m)
Exposition: 180°, 12 Species	Exposition: 120°, 28 species
pH = 7.0, organ_mat = 11.67%, height_max=15 cm	pH = 5.8, organ_mat = 14.12%, height_max = 35 cm
Plot 41 (3221 m)	Plot 16 (3251 m)
Exposition: 200°, 20 species	Exposition: 220°, 34 species
pH = 7.4, organ_mat = 8.78%, height_max = 40 cm	pH = 5.5, organ_mat = 16.48%, height_max = 50 cm

Table 2 Indicator species analysis of winter and summer pastures

Group 1 (Winter pastures) #sps. 6				
Species	A	B	stat	p. value
Bupleurum thianschanicum	0.9216	0.8889	0.905	0.001***
Stipa purpurea	1.0000	0.5000	0.707	0.001***
Plantago arachnoidea	0.9167	0.5000	0.677	0.001***
Potentilla moorcroftii	0.9000	0.5000	0.671	0.001***
Group 3 (Summer pasture) #sps. 25				
Species	A	B	stat	p.value
Trisetum spicatum	0.9636	0.8214	0.890	0.001***
Gentiana karelinii	0.8772	0.8571	0.867	0.001***
Cerastium pusillum	0.9750	0.7143	0.835	0.001***
Gentianella turkestanorum	0.8600	0.6786	0.764	0.001***
Carex stenocarpa	0.9383	0.5357	0.709	0.001***
Trollius dschungaricus	1.0000	0.5000	0.707	0.001***
Phlomoides oreophila	0.8136	0.5357	0.660	0.001***

deviation ± 1.5). Summer pastures average out at a richness of 27 species per site (standard deviation ± 4). Winter pastures exhibit lowest species richness with 17 species per site on average (standard deviation ± 3). This pattern is confirmed by the Shannon´s diversity index. Summer pastures are generally characterized by a higher diversity index (between 2.8 and 3.4), while winter pastures show diversity indices between 2.2 and 3.0.

3.3 Biomass and assessment of grazing pressure

Aboveground dry weight biomass was measured as a comparative proxy for grazing pressure. Average values for winter pastures (45.5 g m^{-2}) were found to be much lower compared to summer pastures (126.3 g m^{-2}). The significant differences concerning the amount of biomass between summer and winter pastures were confirmed by implementing a t-test ($p \leq 0.05$). Dry weight biomass of the two plots in the buffer zone was more than twice as high as the weight calculated for summer pastures (Figure 4). Samples from the State Reserve were unfortunately rotten due to logistic inconveniences.

The assessment of grazing pressure revealed substantial differences between winter and summer pastures. All plots belonging to winter pastures were associated with a grazing pressure between class 3 (moderate) and 5 (heavy), whereas summer pastures never exceeded class 3. To date, the over-utilisation of winter pastures is an ongoing process. The number of livestock in the Naryn Oblast as well as in the *Kara-Kujur* valley increased continuously since 2008. The total number of grazing animals in the *Kara-Kujur* valley (including all kinds of domestic livestock: cow, horse, yak, sheep and goat) increased by 44%, from 11.293 in 2008 to 16.256 in 2014 (Asykulov and Esenaman uulu; unpublished data).

3.4 Soil properties

Soil properties of summer pastures are characterized by lower pH values and lower bulk density than winter pastures on the one hand, and higher carbon (C), nitrogen (N), water and organic matter content as well as higher CEC (cation exchange capacity) and higher amount of clay on the other hand (Table 3). Winter pastures have generally higher pH values (Figure 5a) and lower soil organic matter contents (Figure 5b), pointing to considerable differences between summer and winter pastures with regard to nutrient availability and other plant and soil interactions.

By implementing an ANOVA the differences were tested and the results showed that pH values [$F(1,44) = 56.21$; *** $p \leq 0.001$] and organic matter content [$F(1,44) = 47.99$; *** $p \leq 0.001$] are

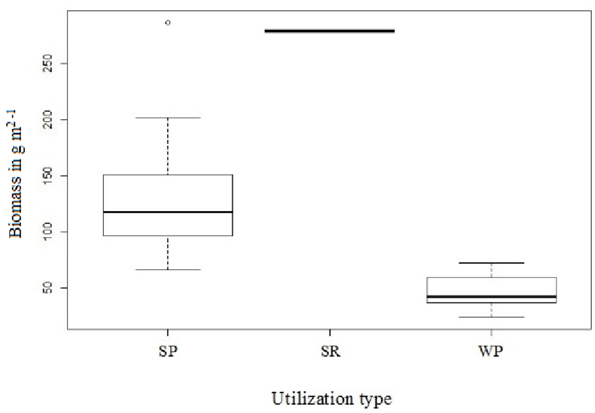

Figure 4 Dry weight biomass of the differentiated site groups.

Table 3 Soil properties (average values) of different pasture types. Standard deviations in brackets. S = sand, U= silt, T = clay.

Pasture type	pH ($CaCl_2$)	water content [%]	organic matter [%]	C [g/kg]	N [g/kg]	CEC_{eff} [µmolc/g]	bulk density [g/cm³]	grain size distribution [%]
State reserve (SR)	5.61 (± 0.35)	3.79 (± 0.93)	21.15 (± 5.23)	87.99 (± 25.79)	7.92 (± 1.79)	395.27 (± 53.74)	1.13 (± 0.06)	S: 1.50 U: 62,27 T: 36.23
Summer pasture (SP)	6.03 (±0.52)	4.24 (± 1.93)	21.05 (± 5.07)	91.41 (± 27.86)	7.58 (± 1.71)	449.60 (± 118.60)	1.15 (± 0.16)	S: 4.18 U: 55.71 T: 40.12
Winter pasture (WP)	7.27 (± 0.39)	3.12 (± 0.07)	12.83 (± 2.02)	52.72 (± 6.72)	4.69 (± 0.81)	423.89 (± 40.98)	1.29 (± 0.14)	S: 6.22 U: 57.87 T: 35.90

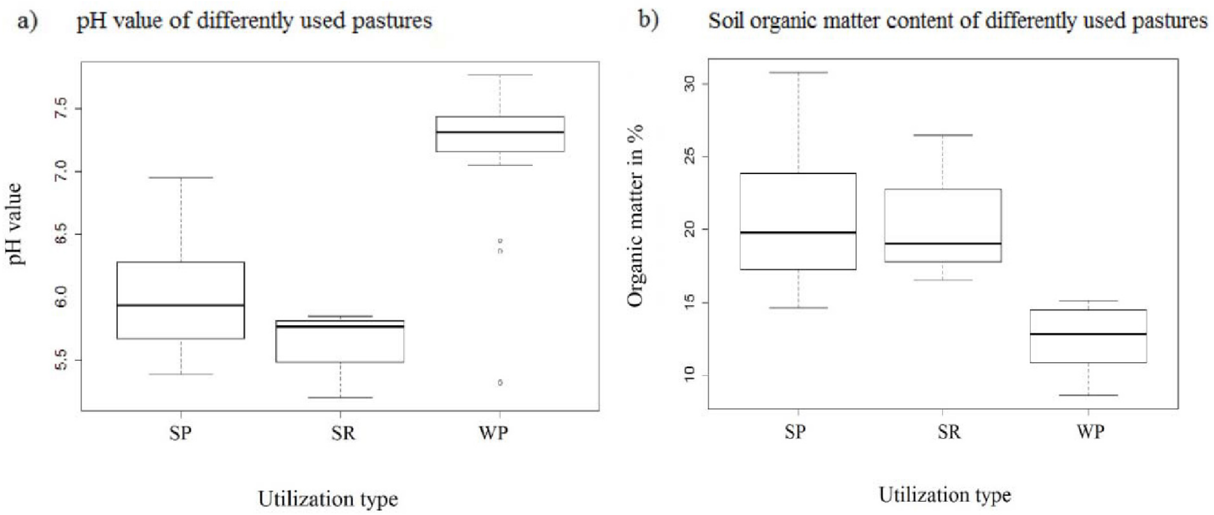

Figure 5 Boxplots of soil pH value (a) and soil organic matter content (b) of differentiated site groups. SP = summer pastures, SR = state reserve, WP = winter pastures.

significantly different between summer and winter pastures.

Soil analyses indicate a high base saturation around 99% for each plot, which is often related to elevated pH values as well as elevated clay contents. These soil characteristics suggest a potential high fertility. Our results indicate properties of *Kastanozem* soils, which are widespread in Kyrgyzstan and often show a drought-limited land use potential.

3.5 Indirect gradient analysis

Results of the gradient analysis clearly show that pH values are strongly correlated with grazing impact (Figure 6a). Both environmental factors are of significance for the differentiation of winter pastures. In contrast, altitude and soil organic matter content are the major environmental factors for the internal differentiation of summer pastures. Soil water content does not seem to be a driving factor concerning the differentiation of the pasture types. The influence of single nutrients is generally lower, compared to those of the pH value for example (length of the arrow). Nevertheless, the amount of primary nutrients tends to be higher on summer pastures (Figure 6b), so that they consequently can be described as nutrient-richer environments than winter pastures. Lower species richness on winter pastures is associated with a lower vegetation cover (Figure 6c). Summer pastures are correlated with a denser vegetation cover. Plant height (here the maximum plant height of each plot is measured) is strongly correlated with summer pastures (Figure 6d). This attribution is influenced by the near-natural plots of the State Reserve as well as the buffer zone, which is indicated by the drift of the arrow to the upper corner.

4 Discussion

Grazing regimes potentially affect rangeland ecology to a large extent. Since livestock farming is the most dominant land use in those ecosystems (e.g. Kreutzmann 2012; Alkemade et al. 2013), elaborated analyses as well as long-term monitoring of grazing impacts are needed as a basis to develop sustainable grazing management strategies. The number of studies on the ecological state (soil conditions and vegetation structure) of the Kyrgyz rangelands has grown in recent years, but up to date no detailed information on pastures in the Naryn region is available. It is difficult to transfer general conclusions or derived degradation trends from other regions to the Naryn Oblast. The present study focused on specific soil and vegetation indicators for habitat degradation (as defined in the study area section) which are discussed in the light of available knowledge from other mountain grazing lands in Kyrgyzstan and

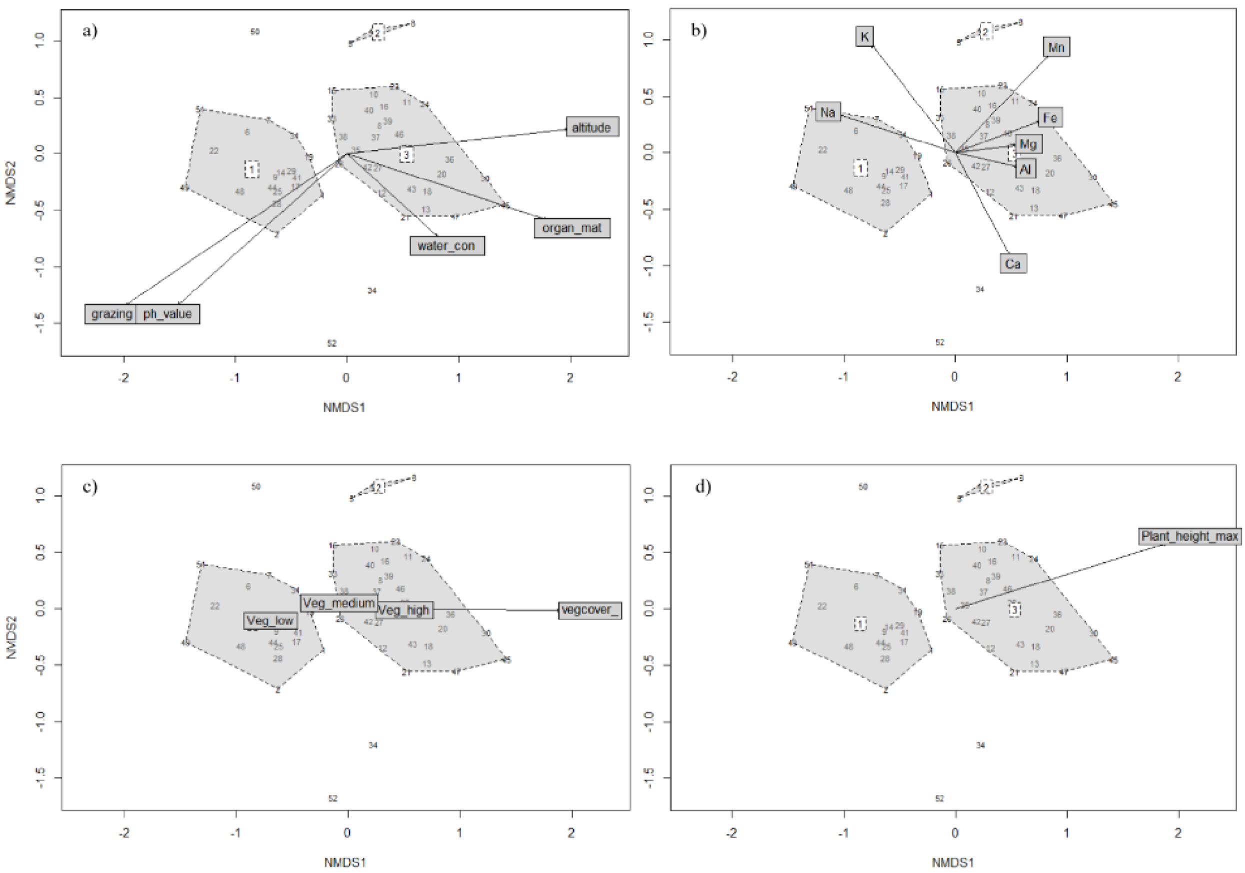

Figure 6 Indirect gradient analysis using different environmental factors. a) environmental factors: grazing impact, pH value, water content (water_con), organic matter content (organ_mat) and altitude; b) nutrients: sodium (Na), calcium (Ca), aluminium (Al), magnesium (Mg), iron (Fe), manganese (Mn), potassium (K); c) vegetation cover; d) plant height; winter pastures = 1, state reserve = 2, summer pastures = 3.

beyond.

4.1 Soil indicators

As presented in the results section, soil parameters of the heavily used winter pastures significantly differ from those of the summer pastures and indicate more unfavourable site conditions. Von Wehrden et al. (2012) considered soil condition to be the most reliable indicator for degradation of grazing lands because degraded soils do not recover rapidly. Several authors have already pointed out that parameters such as soil organic carbon, total nitrogen and cation exchange capacity show significantly lower values when a pasture is degraded (e.g. Wu et al. 2008; Xiong et al. 2014; Su et al. 2015). Our results corroborate this statement. Soil properties such as organic matter content, total nitrogen content as well as cation exchange capacity are lower on winter pastures compared to summer pastures (Table 3). Soil pH is known to be a crucial factor concerning soil organic matter accumulation and decomposition. Generally higher pH values on winter pastures, compared to lower pH values in the State Reserve and on summer pastures, suggest a relationship between grazing intensity and soil pH. Increasing pH values have most likely to be attributed to a higher amount of animal excreta arising from over-utilisation of pastures (Britton et al. 2005; Cui et al. 2005; Sakbaeva et al. 2012). Deteriorating soil conditions of winter pastures become obvious by comparing winter and summer pastures at same elevations (Table 1). Cui et al. (2005) analysed pastures with contrasting grazing intensity in Inner Mongolia and showed that over-grazing is related to trampling and the increase of soil hardening and bulk density, limiting water and soil organic matter transportation between soil horizons (see also Stavi et al. 2008; Tang et al.

2015). Decreasing soil organic matter and nitrogen content leads to reductions in soil fertility and quality (Yan et al. 2013), which may result in less dense vegetation cover. A dense grass cover, on the other hand, reduces surface runoff and provides essential protection against soil erosion in sloping terrain (Kulikov et al. 2016). The correlation between excessive pasture use and lower soil organic matter and nitrogen content has also been confirmed in other studies (Glaser 2000; Han 2008; Sakbaeva et al. 2012). Comparing the soil properties of winter pastures, summer pastures, and the State Reserve it becomes obvious that winter pastures show a much lower soil quality. Our results suggest that soil deterioration has to be attributed to the distinctly higher grazing pressure winter pastures are subjected to. This statement is supported by the fact that our data do not show significant spatial autocorrelation (Fig. 2), and by the assumption that the State Reserve and remote summer pastures represent near-natural conditions. Thus, recently increasing livestock numbers pose a challenge concerning the implementation of sustainable grazing management.

4.2 Vegetation patterns

Our differentiated rankless communities do not correspond to any other differentiated plant community on grazing lands in Kyrgyzstan to date, underlining the pioneer character of the present study. Similarities exist in terms of species assemblages and community structures influenced by grazing impact. Borchardt et al. (2011) detected two communities in alpine grazing lands of the Fergana Range (SW-Kyrgyzstan): one at high elevation under low grazing impact (*Phlomoides-Geranium*) and one at lower elevation with higher grazing impact (*Plantago-Polygonum*). The former, however, does not correspond to our *Trisetum spicatum-Gentiana karelinii* community of summer pastures since only one common species (*Phlomoides oreophila*) occurs in both communities. The *Bupleurum thianschanicum-Stipa purpurea* community of winter pastures indicates little similarities with the *Plantago-Polygonum* community of Borchardt et al. (2011). Both communities are subjected to high grazing impact and characterized by species of the genus *Plantago* (Borchardt et al. 2011). However, there are notable differences. The presumable diagnostic species of the differentiated communities in this study do not occur on mountain grazing lands in other parts of Kyrgyzstan (cf. Epple 2001; Wagner 2009; Borchardt et al. 2011; Taft et al. 2011; Imanberdieva 2015), pointing to a heterogeneous vegetation mosaic in comparable, but isolated habitats. Nonetheless, all diagnostic species are native to Middle Asia and listed in Czerepanov (1995). Interestingly, the diagnostic species of winter pastures (*Bupleurum thianschanicum*, *Stipa purpurea*, *Plantago arachnoidea* and *Potentilla moorcroftii*) are Middle Asian endemics, i.e. they do not occur in other regions like Caucasus or Siberia (Czerepanov 1995).

Stipa purpurea, in this study a major element of the *Bupleurum thianschanicum-Stipa purpurea* community, is known to be tolerant against cold and drought and dominant on alpine steppes of the Tibetan Plateau (Sheehy et al. 2006; Yang et al. 2015). The dominance of *Stipa purpurea* seems to be independent of the level of degradation (Tang et al. 2015), which is in line with its presence on heavily used winter pastures assessed in our study. *Plantago arachnoidea* is described as less palatable and mainly consumed by sheeps and goats (Rahim and Maselli 2011; Undeland 2012), which could explain the relatively strong presence on winter pastures. *Trisetum spicatum*, one of the diagnostic species of summer pastures (*Trisetum spicatum-Gentiana karelinii* community), is characterized by strong disturbance tolerance. Mark and Whigham (2011) showed that *Trisetum spicatum* can persist environmental changes such as nutrient enrichment and mechanical disturbance. Our most common companion species, *Festuca valesiaca*, shows a wide distribution on alpine and meadow steppes in Kyrgyzstan (Wagner 2009; Rahim and Maselli 2011; Taft et al. 2011, Imanberdieva 2015). Taft et al. (2011) found montane grasslands of the central Tien Shan to be dominated by F*estuca valesiaca*. This species is consumed by all traditional kinds of grazing animals but nevertheless classified as strongly grazing- (and drought-) tolerant (Rahim and Maselli 2011; Ma et al. 2014; Imanberdieva 2015). Taft et al. (2011) and Imanberdieva (2015) pointed out that F*estuca valesiaca* is positively selected by grazing impacts and may be used as an indicator of steppe degradation. All of the winter pasture plots, with one exception, are inhabited by this species.

4.3 Species richness, grazing impact and biomass

Our results showed that plant species richness increases from winter to summer pastures. At the same time, this increase occurs to some extent along an elevational gradient. Thus, the vertical pattern of increasing species richness could be attributed either to grazing impacts or to a natural altitudinal zonation. Several studies on elevational species richness and diversity gradients in arid to semi-arid mountain environments provided evidence that species richness increases from humidity-limited lower altitudes towards higher elevations before it decreases again when environmental conditions become too unfavourable (e.g. Richter 2000; Körner 2003; Rahbek 2005; Van de Ven et al. 2007). Peak species richness in arid and semi-arid mountains is found at altitudes where the interplay of temperature and precipitation provides optimum hygrothermal conditions. This is often the case in subalpine to lower alpine altitudinal zones (Körner 1995; von Wehrden and Wesche 2007). In the context of the non-equilibrium concept (Ellis and Swift 1988), von Wehrden et al. (2012) showed that rainfall variability is considered to be a critical driver in rangeland dynamics. In areas with lower rainfall variability the potential of degradation under grazing pressure is higher than in rangelands where rainfall variability is more pronounced. According to their 'global annual mean precipitation map' our study area is characterized by a lower rainfall variability (CV < 33%), which increases the potential of degradation given a sufficient size of herbivore populations (see also Vetter 2005; Wesche and Treiber 2012). It has to be taken into account though that much of the precipitation in Central Asia is of convective nature, resulting in high spatial and temporal heterogeneity of neighbouring sites (Ruppert et al. 2012; Wesche and Treiber 2012; Zhou et al. 2016). Thus, it is very likely that equilibrium and non-equilibrium dynamics co-occur in one ecosystem at a variety of spatial and temporal scales (cf. Fernandez-Gimenez and Allen-Diaz 1999; Silcock and Fensham 2013).

The increase in species richness towards higher elevations could be an effect of climatological vertical gradients. However, the comparison of different plots from same elevations subjected to contrasting grazing pressure (Table 1) suggests that decreasing grazing intensity towards summer pastures results in higher species richness and diversity as well as in a higher amount of biomass. Thus, the natural elevational gradient of species richness is obviously accentuated by grazing impacts in that way that winter pastures at lower elevations decrease in species richness, and summer pastures at higher elevations increase in species richness. This finding is supported by results of Gao et al. (2009), who examined the influence of grazing and drought on species richness in semi-arid steppes in Inner Mongolia, and found that heavy grazing significantly reduces species richness and diversity. Moreover, the effects of drought stress have greater impact on heavily grazed sites indicating an interaction of these parameters. Especially in arid and semi-arid grazing lands, species richness provides a positive effect on ecosystem services. In particular, ecosystem services linked to C and N cycling are maintained by species richness, which in turn sustain soil fertility and C sequestration (Maestre et al. 2012).

Borchardt et al. (2013) focused on the connection between plant functional traits and grazing impact in SW-Kyrgyzstan and found that vegetation types at same elevations vary in their species composition depending on grazing pressure. The factor grazing correlated significantly with traits such as 'low plant height', 'annual life cycle', 'basal growth form' and 'long flowering time'. Similarly, Epple (2001) showed that communities in SW-Kyrgyzstan subjected to high grazing pressure are characterized by particular features such as low coverage values of the herbaceous layer, stunted growth in most herbaceous species, and increased occurrence of shrub seedlings. In contrast, many authors have shown that moderate grazing may lead to an increase in species richness and diversity (e.g. Hart 2001; Borchardt et al. 2011; Taft et al. 2011), in line with the intermediate disturbance hypothesis, stating that diversity increases when disturbances are intermediate

(Connell 1978). High species richness in the buffer zone of the State Reserve and on most summer pastures subjected to low or moderate grazing pressure confirms this hypothesis. The assessment of grazing pressure using a grazing scale with five classes showed that exceeding an intermediate level of disturbance (class 3) results in decreasing species richness and deteriorating soil conditions – as exemplified by winter pastures of this study.

Many previous studies found evidence that effects of intense livestock grazing result in declining plant cover and biomass, trampling damages, destruction of root systems, and ultimately in habitat degradation and biodiversity loss (e.g. Alkemade et al. 2013; Yan et al. 2013; Gamoun et al. 2015; Tang et al. 2015). Nevertheless, the consequences of grazing on plant species richness or the amount of biomass depend on the grazing intensity as well as the particular environment as stated above (see also Olff und Ritchie 1998). A case study from arid and semi-arid areas in China clearly revealed a negative effect of grazing on total biomass (Yan et al. 2013). Biomass and plant cover are considered key indicators to evaluate the degree of grassland degradation (Xiong et al. 2014; Alkemade et al. 2013). The lower amount of biomass on winter pastures found in the present study corroborates this indicator function.

4.4 Requirement of sustainable management strategies

Mobile animal husbandry has nowadays gained increased attention as a useful adaptation to the effects of climate change such as drought and desertification (Reid et al. 2008; Steimann 2010). For sustainable pasture use in the Naryn Oblast, an improved coordination of seasonal migration is indispensable, not only to protect over-utilized winter pastures from degradation but also to prevent that abandoned summer pastures will be affected by an invasion of weeds and unpalatable secondary plant species, which will affect pasture´s economic value (Vallentine 2001; Esengulova et al. 2008). The recently introduced ‘pasture committees’ as the main actors in the management and control of pastures are responsible for the establishment of seasonal rotation and concepts of pasture use, but they appear to have low efficiency (Ibraimova 2009; Jacquesson 2010). A power asymmetry between wealthy herders with large herds of livestock and marginalized non-wealthy herders has been found to be one of the principle reasons. Wealthy livestock owners are often represented in new governance structures (pasture committees) and are able to protect their own interests (Dörre 2012; Kasymov and Thiel 2014). According to Esengulova et al. (2008), local users should be more strongly encouraged to participate and feel responsible in order to consolidate the pasture management on community level. But to date, the over-utilization of pastures is not always considered to be a fundamental issue. Unused remote pastures, for instance, are perceived by local people as never ending pasture resources (Liechti 2010). Grazing-induced degradation of rangelands is not only a problem in Kyrgyzstan, but has global dimensions (Reid et al. 2008). New approaches are needed to sustainably manage and better protect grazing lands, which provide several ecosystem services such as carbon storage. An increasing number of studies (e.g. Cui et al. 2005; Han et al. 2008; Sommer and Pauw 2011; Sanaullah et al. 2014) indicate, in the context of climate change, the high capacity of rangeland ecosystems to sequestrate C in soil. The soil C stock in grassland ecosystems could substantially change by intensive grazing, causing a modification of global cycles and potentially influence climate change (Cui et al. 2005; Han et al. 2008; Sommer and Pauw 2011). Thus, the relevance of sustainable grazing management and restoration of degraded pastures should not be underestimated.

5 Conclusions

The presented results indicate that rangeland conditions in the Naryn Oblast strongly depend on grazing intensity. Assessed effects of grazing impacts constitute a solid basis for the differentiation of pasture types. The hypothesis that winter pastures which are close to settlements and exposed to intense grazing pressure suffer from degradation could be verified, reflected by higher pH values, lower organic matter contents and biomass amount as well as lower species richness and diversity indices. Summer pastures at higher elevations are much less affected by grazing impacts, as evident from higher soil quality, higher stand density and biomass amount as well as higher species richness and diversity. Based on vegetation and soil indicators, efforts of management and biodiversity conservation of intensely used pastures should be reinforced. In order to implement a sustainable grazing management, we suggest considering the introduction of a specific rotation grazing system with a scheduled transfer of grazing and resting time between grazing units. 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. Currently, it seems that the complex interdependence between new formal institutions and traditional pasture rules is one of the major barriers for implementing sustainable grazing management. In any case, long-term monitoring is needed to derive adapted management options in order to prevent continued degradation of winter pastures and to minimize the risk of reductions in livestock performance.

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References

Aggarwal CC, Reddy CK (2013) Data Clustering - Algorithms and Applications. CRC Press, New York, USA. p. 622.

Alkemade R, Reid RS, van den Berg M, et al. (2013) Assessing the impacts of livestock production on biodiversity in rangeland ecosystems. Proceedings of the National Academy of Sciences of the United States of America 110(52): 20900-20905. DOI: 10.1073/pnas.1011013108

Baibagushev E (2011) Recent changes in pastoral systems: Case study on Kyrgyzstan. In: Kreutzmann H, Abdulalishoev K, Zhaohui L, Richter J (eds.). Pastoralism and Rangeland Management in Mountain Areas in the Context of Climate and Global Change, Bonn, pp 102-118

Blank M (2007) Rückkehr zur subsistenzorientierten Viehhaltung als Existenzsicherungsstrategie. Berlin Geographical Papers Vol 34. p 54 (In German)

Borcard D, Gillet F, Legendre P (2011) Numerical Ecology with R. Springer, New York. p. 306

Borchardt P, Oldeland J, Ponsens J, et al. (2013) Plant functional traits match grazing gradient and vegetation patterns on mountain pastures in SW Kyrgyzstan. Phytocoenologia 43(3): 171-181. DOI: 10.1127/0340-269X/2013/0043-0542

Borchardt P, Schickhoff U, Scheitweiler S, et al. (2011) Mountain pastures and grasslands in the SW Tien Shan, Kyrgyzstan - Floristic patterns, environmental gradients, phytogeography, and grazing impact. Journal of Mountain Science 8(3): 363-373. DOI: 10.1007/s11629-011-2121-8

Borchardt P, Schmidt M, Schickhoff U (2010) Vegetation patterns in Kyrgyzstan's walnut-fruit forests under the impact of changing forest use in post-soviet transformation. Die Erde 141(3): 255-275.

Braun-Blanquet J (1964) Pflanzensoziologie. Springer Berlin Heidelberg, Berlin, Heidelberg. p 866. (In German)

Britton AJ, Pearce IS, Jones B (2005) Impacts of grazing on montane heath vegetation in Wales and implications for the restoration of montane areas. Biological Conservation 125(4): 515-524. DOI:10.1016/j.biocon.2005.04.014

Carter MR, Gregorich EG (2008) Soil Sampling and Methods of Analysis. 2nd ed. Canadian Society of Soil Science; CRC Press, Boca Raton, FL. p 1224.

Connell JH (1978) Diversity in tropical rain forests and coral reefs. Science 199(4335): 1302-1310.

Cowan PJ (2007) Geographic usage of the terms Middle Asia and Central Asia. Journal of Arid Environments 69(2): 359-363. DOI: 10.1016/j.jaridenv.2006.09.013

Crewett W (2012) Improving the Sustainability of Pasture Use in Kyrgyzstan. Mountain Research and Development 32(3): 267-274. DOI: 10.1659/MRD-JOURNAL-D-11-00128.1

Cui X, Wang Y, Niu H, et al. (2005) Effect of long-term grazing on soil organic carbon content in semiarid steppes in Inner Mongolia. Ecological Research 20(5): 519-527. DOI: 10.1007/s11284-005-0063-8

Czerepanov SK (1995) Vascular Plants of Russia and Adjacent States (the former USSR). Cambridge University Press, Cambridge. p 516.

De Cáceres M, Legendre P (2009) Associations between species and groups of sites: indices and statistical inference. Ecology 90(12): 3566-3574. DOI: 10.1890/08-1823.1

De Cáceres M, Font X, Vicente P, et al. (2009) Numerical reproduction of traditional classifications and automatic vegetation identification. Journal of Vegetation Science 20(4): 620-628.

Dierschke H (1994) Pflanzensoziologie. E. Ulmer, Stuttgart (Hohenheim). p 683. (In German)
Diniz-Filho, José Alexandre F, Soares TN, et al. (2013) Mantel test in population genetics. Genetics and molecular biology 36(4): 475-485. DOI: 10.1590/S1415-47572013000400002
Dörre A (2012) Legal arrangements and pasture-related socio-ecological challenges in Kyrgyzstan. In: Kreutzmann H (eds.). Pastoral practices in High Asia. Dordrecht. Springer Netherlands. pp. 127-144. DOI: 10.1007/978-94-007-3846-1_7
Dörre A, Borchardt P (2012) Changing systems, changing effects - Pasture utilization in the Post-Soviet Transition. Mountain Research and Development 32(3): 313-323. DOI: 10.1659/MRD-JOURNAL-D-11-00132.1
Dufrêne M, Legendre P (1997) Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecological monographs 67(3): 345-366
Eisenman SW, Zaurov DE, Struwe L (2013) Medicinal Plants of Central Asia. Springer, New York. p 347.
Ellis JE, Swift DM (1988) Stability of African pastoral ecosystems: alternate paradigms and implications for development. Journal of Range Management Archives 41(6): 450-459.
Epple C (2001) A vegetation study in the walnut and fruit-tree forests of Southern Kyrgyzstan. Phytocoenologia 31(4): 571-604. DOI: 10.1127/phyto/31/2001/571
Esengulova N, Japarov A, Mamytbekov E (2008) Community Management of High-Alpine Grasslands in the Kyrgyz Republic: Social, Economic and Ecological Implications. Governing Shared Resources: Connecting Local Experience to Global Challenges, the Twelfth Biennial Conference of the International Association for the Study of Commons, Cheltenham, England. p14.
Farrington JD (2005) De-development in eastern Kyrgyzstan and persistence of semi-nomadic livestock herding. Nomadic Peoples 9(1): 171-197. DOI: 10.3167/082279405781826191
Fernandez-Gimenez ME, Allen-Diaz B (1999) Testing a non-equilibrium model of rangeland vegetation dynamics in Mongolia. Journal of Applied Ecology 36(6): 871-885. DOI: 10.1046/j.1365-2664.1999.00447.x
Gamoun M, Patton B, Hanchi B (2015) Assessment of vegetation response to grazing management in arid rangelands of southern Tunisia. International Journal of Biodiversity Science, Ecosystem Services & Management 11(2): 106-113. DOI: 10.1080/21513732.2014.998284
Gao YZ, Giese M, Han XG, et al. (2009) Land use and drought interactively affect interspecific competition and species diversity at the local scale in a semiarid steppe ecosystem. Ecological research 24(3): 627-635.
Glaser B, Turrion M, Solomon D, et al. (2000) Soil organic matter quantity and quality in mountain soils of the Alay Range, Kyrgyzia, affected by land use change. Biology and Fertility of Soils 31(5): 407-413.
Gottschling H (2006) Die Naturräume des Biosphärenreservates Issyk-Kul in Kirgisistan. Ernst-Moritz-Arndt-Univ., Greifswald. p 245. (In German)
Gronau I, Moran S (2007) Optimal implementations of UPGMA and other common clustering algorithms. Information Processing Letters 104(6): 205-210. DOI: 10.1016/j.ipl.2007.07.002
Han G, Hao X, Zhao M, et al. (2008) Effect of grazing intensity on carbon and nitrogen in soil and vegetation in a meadow steppe in Inner Mongolia. Agriculture, Ecosystems & Environment 125(1-4): 21-32. DOI: 10.1016/j.agee.2007.11.009
Hart RH (2001) Plant biodiversity on shortgrass steppe after 55 years of zero, light, moderate, or heavy cattle grazing. Plant Ecology 155(1): 111-118. DOI: 10.1023/A:1013273400543
Ibraimova A (2009) Legal and Institutional Framework for Empowerment of Rural Communities in the Kyrgyz Republic. Institute of Federalism; LIT-Verlag, Fribourg, Zürich. p 191.
Imanberdieva N (2015) Flora and plant formations distributed in At-Bashy valleys-internal Tien Shan in Kyrgyzstan and interactions with climate. In: Öztürk MA, Hakeem KR, Faridah-Hanum I, Efe R (eds.). Climate Change Impacts on High-Altitude Ecosystems. Cham, Springer International Publishing. pp. 569-590.
Jacquesson S (2010) Reforming pastoral land use in Kyrgyzstan: from clan and custom to self-government and tradition. Central Asian Survey 29(1): 103-118. DOI: 10.1080/02634931003765571
Johnson DL, Lewis LA (2007) Land Degradation. 2nd ed. Rowman & Littlefield, Lanham. pp 303.
Kasymov U, Thiel A (2014) Who is benefiting from pasture reforms in Kyrgyzstan? Designing institutions in a post-socialist transformation process. Paper prepared for presentation at the Inaugural WINIR Conference. Greenwich, London, UK. p 28.
Kent M (2012) Vegetation Description and Data Analysis. 2nd ed. John Wiley & Sons, Chichester, West Sussex, UK, Hoboken, NJ. p 414.
Kissel DE, Sonon L, Vendrell PF, et al. (2009) Salt concentration and measurement of soil pH. Communications in Soil Science and Plant Analysis 40 (1-6): 179-187. DOI: 10.1080/00103620802625377
Körner C (2003) Alpine Plant Life. 2nd ed. Springer, Berlin, New York. p 344.
Körner C (1995) Alpine plant diversity: A global survey and functional interpretations. In: Lange, Mooney et al. (Hg.). Arctic and Alpine Biodiversity 30. Berlin, Heidelberg. pp 45-62. DOI: 10.1007/978-3-642-78966-3_4
Kreutzmann H (2013) The tragedy of responsibility in high Asia: modernizing traditional pastoral practices and preserving modernist worldviews. Pastoralism: Research, Policy and Practice 3 (7): 1-11. DOI: 10.1186/2041-7136-3-7.
Kreutzmann H (2012) Pastoral practices in transition: Animal husbandry in high Asian contexts. In: Kreutzmann H (eds.). Pastoral practices in High Asia. Springer, Dordrecht, New York. pp 1-29. DOI: 10.1007/978-94-007-3846-1
Kulikov M, Schickhoff U, Borchardt P (2016) Spatial and seasonal dynamics of soil loss ratio in mountain rangelands of south-western Kyrgyzstan. Journal of Mountain Science 13(3): 316-329. DOI: 10.1007/s11629-014-3393-6.
Laruelle M, Peyrouse S (2010) L'Asie Centrale à l'Aune de la Mondialisation. IRIS, Institut de relations internationales et stratégiques; A. Colin, Paris. p 223. (In French)
Legendre P, Legendre L (2012) Numerical Ecology. 3rd English ed. Elsevier, Amsterdam, Boston. p 990.
Legendre P, Gallagher ED (2001) Ecologically meaningful transformations for ordination of species data. Oecologia 129(2): 271-280. DOI 10.1007/s004420100716
Leyer I, Wesche K (2007) Multivariate Statistik in der Ökologie. Springer, Berlin, Heidelberg. p 224. (In German)
Liechti K (2012) The meanings of pasture in resource degradation negotiations: Evidence from Post-Socialist rural Kyrgyzstan. Mountain Research and Development 32(3): 304-312. DOI: 10.1659/MRD-JOURNAL-D-11-00113.1
Loewenstein Y, Portugaly E, Fromer M, et al. (2008) Efficient algorithms for accurate hierarchical clustering of huge datasets: tackling the entire protein space. Bioinformatics (Oxford, England) 13: 41-49. DOI: 10.1093/bioinformatics/btn174
Ludi E (2003) Sustainable pasture management in Kyrgyzstan and Tajikistan: development needs and recommendations. Mountain Research and Development 23(2): 119-123. DOI: 10.1659/02764741(2003)023[0119:SPMIKA]2.0.CO;2
Ma Y, Staub JE, Robbins MD, et al. (2014) Phenotypic and genetic characterization of Kyrgyz fine-leaved Festuca valesiaca germplasm for use in semi-arid, low-maintenance turf applications. Genetic resources and crop evolution 61(1): 185-197.
Magurran AE (2004) Measuring Biological Diversity. Blackwell Pub., Malden, Ma. p 256.
Mark AF, Whigham PA (2011) Disturbance-induced changes in

a high-alpine cushionfield community, south-central New Zealand. Austral Ecology 36(5): 581-592. DOI: 10.1111/j.1442-9993.2010.02193.x

McGarigal K, Cushman S, Stafford SG (2000) Multivariate Statistics for Wildlife and Ecology Research. Springer, New York, USA. p 283.

Oden NL, Sokal RR (1986) Directional autocorrelation: An extension of spatial correlograms to two dimensions. Systematic Zoology 35(4): 608-617. DOI: 10.2307/2413120

Oksanen J, Blanchet FG, Kindt R, et al. (2016) Package 'vegan'. Community ecology package. p 285.

Oksanen J (2013) Multivariate Analysis of Ecological Communities in R: vegan tutorial. R package version 1.7. University of Oulu. p 43.

Oldeland J, Dorigo W, Lieckfeld L, et al. (2010) Combining vegetation indices, constrained ordination and fuzzy classification for mapping semi-natural vegetation units from hyperspectral imagery. Remote Sensing of Environment 114(6): 1155-1166. DOI: 10.1016/j.rse.2010.01.003

Olff H, Ritchie ME (1998) Effects of herbivores on grassland plant diversity. Trends in Ecology & Evolution 13(7): 261-265. DOI: 10.1016/S0169-5347(98)01364-0

Rahbek C (2005) The role of spatial scale and the perception of large-scale species-richness patterns. Ecology Letters 8(2): 224-239. DOI: 10.1111/j.1461-0248.2004.00701.x

Rahim IU, Maselli D (eds.) (2011) Herder´s Manual. University of Central Asia; NCCR-NS, Bishkek. p 124.

Reid RS, Galvin KA, Kruska RS (2008) Global significance of extensive grazing lands and pastoral societies: an introduction. In: Galvin, K.A., Reid, R.S., Behnke, Jr., R.H., Hobbs, N.T. (eds.). Fragmentation in Semi-Arid and Arid Landscapes - Consequences for Human and Natural Landscapes, Springer, pp 1-24.

Richter M (2000) A hypothetical framework for testing phytodiversity in mountainous regions: the influence of airstreams and hygrothermic conditions. Phytocoenologia (30): 519-542.

Roser L, Vilardi J, Saidman B, et al. (2015) Package 'EcoGenetics'. EcoGenetics: Spatial Analysis of Phenotypic, Genotypic and Environmental Data, Version 1.2.0-2. p 91.

Ruppert JC, Holm A, Miehe S, et al. (2012) Meta-analysis of ANPP and rain-use efficiency confirms indicative value for degradation and supports non-linear response along precipitation gradients in drylands. Journal of Vegetation Science 23(6): 1035-1050. DOI: 10.1111/j.1654-1103.2012.01420.x

Sakbaeva Z, Acosta-Martínez V, Moore-Kucera J, et al. (2012) Interactions of soil order and land use management on soil properties in the Kukart watershed, Kyrgyzstan. Applied and Environmental Soil Science 1: 1-11. DOI: 10.1155/2012/130941

Sanaullah M, Chabbi A, Girardin C, et al. (2014) Effects of drought and elevated temperature on biochemical composition of forage plants and their impact on carbon storage in grassland soil. Plant and soil 374(1-2): 767-778. DOI: 10.1007/s11104-013-1890-y

Saraçli S, Doğan N, Doğan İ (2013) Comparison of hierarchical cluster analysis methods by cophenetic correlation. Journal of Inequalities and Applications 1: 203. DOI: 10.1186/1029-242X-2013-203

Schmidt M (2013) Mensch und Umwelt in Kirgistan. Erdkundliches Wissen 153 Steiner, Stuttgart. p. 400. (In German)

Schoch N, Steimann B, Thieme S (2010) Migration and animal husbandry: Competing or complementary livelihood strategies. Evidence from Kyrgyzstan. Natural Resources Forum 34(3): 211-221. DOI: 10.1111/j.1477-8947.2010.01306.x

Shannon CE, Weaver W (1964) The Mathematical Theory of Communication. University of Illinois Press, Urbana, USA. p 125.

Sheehy DP, Miller D, Johnson DA (2006) Transformation of traditional pastoral livestock systems on the Tibetan steppe. Sécheresse 17(1): 142-151.

Shigaeva J, Wolfgramm B, Dear C (2013) Sustainable Land Management in Kyrgyzstan and Tajikistan: A Research Review. Mountain Societies Research Institute, University of Central Asia. p 92.

Shigaeva J, Kollmair M, Niederer P, et al. (2007) Livelihoods in transition: changing land use strategies and ecological implications in a post-Soviet setting (Kyrgyzstan). Central Asian Survey 26(3): 389-406. DOI: 10.1080/02634930701702696

Silcock JL, Fensham RJ (2013) Arid vegetation in disequilibrium with livestock grazing: Evidence from long-term exclosures. Austral Ecology 38(1): 57-65. DOI: 10.1111/j.1442-9993.2012.02374.x

Sokal RR, Rohlf, FT (1962) The comparison of dendrograms by objective methods. Taxon 11(2): 33-40.

Sommer R, Pauw E de (2011) Organic carbon in soils of Central Asia—status quo and potentials for sequestration. Plant and Soil 338(1-2): 273-288. DOI: 10.1007/s11104-010-0479-y

Stavi I, Ungar ED, Lavee H, et al. (2008) Grazing-induced spatial variability of soil bulk density and content of moisture, organic carbon and calcium carbonate in a semi-arid rangeland. CATENA 75(3): 288-296. DOI: 10.1016/j.catena.2008.07.007

Steimann B (2010) Making a Living in Uncertainty. Zurich Open Repository and Archive, Zürich. p 240.

Su X, Wu Y, Dong S, et al. (2015) Effects of grassland degradation and re-vegetation on carbon and nitrogen storage in the soils of the Headwater Area Nature Reserve on the Qinghai-Tibetan Plateau, China. Journal of Mountain Science 12(3): 582-591. DOI: 10.1007/s11629-014-3043-z

Taft JB, Phillippe LR, Dietrich CH, et al. (2011) Grassland composition, structure, and diversity patterns along major environmental gradients in the Central Tien Shan. Plant Ecology 212(8): 1349-1361. DOI 10.1007/s11258-011-9911-5

Tang L, Dong S, Sherman R, et al. (2015) Changes in vegetation composition and plant diversity with rangeland degradation in the alpine region of Qinghai-Tibet Plateau. The Rangeland Journal 37(1): 107-115. DOI: 10.1071/RJ14077

Umralina AR, Lazkov GA (2008) Endemic and Rare Plant Species of Kyrgyzstan (Atlas). Biotechnology Institute, National Academy of Science Kyrgyz Republic, Bishkek. p. 164.

Undeland A (2012) Herders' Manual. Mountain Research and Development 32(3): 380-381.

UCA, University of central Asia (2014) Quality of Life in Naryn Oblast, Bishkek. p 58.

Vallentine JF (2001) Grazing Management. 2nd ed. Academic Press, San Diego. p 659.

Van de Ven, Christopher M, Weiss SB, et al. (2007) Plant Species Distributions under Present Conditions and Forecasted for Warmer Climates in an Arid Mountain Range. Earth Interactions 11(9): 1-33. DOI: 10.1175/EI205.1

Van der Maarel E (1979) Transformation of cover-abundance values in phytosociology and its effects on community similarity. Vegetation 39(2): 97-114. DOI: 10.1007/BF00052021

Van der Maarel E (2007) Transformation of cover-abundance values for appropriate numerical treatment-Alternatives to the proposals by Podani. Journal of Vegetation Science 18(5): 767-770.

Vanselow KA (2011) The High-Mountain Pastures of the Eastern Pamirs (Tajikistan). PhD Thesis, Universität Erlangen-Nürnberg, Germany. p 226.

Venables WN, Ripley BD (2002) Modern Applied Statistics with S. 4th ed. Springer, New York, USA. p 495.

Vetter S (2005) Rangelands at equilibrium and non-equilibrium: recent developments in the debate. Journal of Arid Environments 62(2): 321-341. DOI: 10.1016/j.jaridenv.2004.11.015

Wagner V (2009) Eurosiberian meadows at their southern edge: patterns and phytogeography in the NW Tien Shan. Journal of Vegetation Science 20(2): 199-208. DOI: 10.1111/j.1654-

1103.2009.01032.x
Wehrden H von, Hanspach J, Kaczensky P, et al. (2012) Global assessment of the non-equilibrium concept in rangelands. Ecological Applications 22(2): 393-399. DOI: 10.1890/11-0802.1
Wehrden H von, Wesche K (2007) Relationships between climate, productivity and vegetation in southern Mongolian drylands. Basic and applied dryland research 1(2): 100. DOI: 10.1127/badr/1/2007/100
Wesche K, Treiber J (2012) Abiotic and biotic determinants of steppe productivity and performance - A view from Central Asia. In: Werger, Marinus JA; van Staalduinen, Marja A (eds.). Eurasian Steppes. Ecological Problems and Livelihoods in a Changing World, Springer Netherlands. pp 3-45.
Wildi O (1989) A new numerical solution to traditional phytosociological tabular classification. Numerical syntaxonomy 81(1-2): 95-106. DOI: 10.1007/BF00045515
World Bank (2014) Environmental and Social Management Plan. Vol. 1 of Kyrgyz Republic. E4534. p 105.
World Bank (2007) Kyrgyz Republic - Livestock Sector Review, Washington, DC. p 118.
Wu R, Tiessen H, Chen Z (2008) The impacts of pasture degradation on soil nutrients and plant compositions in alpine grassland, China. Journal of Agricultural, Food, and Environmental Sciences 2(2): 1-14.
Xiong D, Shi P, Sun Y, et al. (2014) Effects of grazing exclusion on plant productivity and soil carbon, nitrogen storage in Alpine Meadows in northern Tibet, China. Chinese geographical science 24(4): 488-498. DOI: 10.1007/s11769-014-0697-y
Yan L, Zhou G, Zhang F (2013) Effects of different grazing intensities on grassland production in China: a meta-analysis. PloS one 8(12): e81466. p 9. DOI: 10.1371/journal.pone.0081466
Yang Y, Dong C, Yang S, et al. (2015) Physiological and proteomic adaptation of the alpine grass Stipa purpurea to a drought gradient. PloS one 10(2): 1-27. DOI: 10.1371/journal.pone.0117475
Zhou N, Wu J, Shen Z, et al. (2016) Species-area relationship within and across functional groups at alpine grasslands on the northern Tibetan Plateau, China. Journal of Mountain Science 13(2): 265-275. DOI: 10.1007/s11629-014-3166-2