Grazing impacts on vegetation patterns in the Qilian Mountains, HeiHe River Basin, NW China

Dissertation

with the aim of achieving a doctoral degree

at the Faculty of Mathematic, Informatics and Natural Sciences

Department of Earth Sciences

at Universität Hamburg

submitted by

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born in

REVDA CITY, RUSSIA

Hamburg 2018

Accepted as Dissertation at the Department of Earth Sciences

Day of oral defense: 23.11.2018

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Summary

Domestic grazing is a wide-spread land use, known since prehistoric times. Grazing ecosystems all over the globe represent a vital source for livestock husbandry, sustaining the fragile balance between ecosystem integrity and human impact. Extended pastures are found on each of the five continents and account to 30-40 % of the total land cover of the globe. However, due to the global increase in grazing activity, many areas inevitably face the problems of soil degradation processes, maintaining watershed function and ecological integrity, i.e. problems of deteriorating rangeland condition. In arid/semi-arid grasslands, increasing grazing activity is often coupled with the process of land degradation, resulting in soil erosion and depletion of soil nutrients, and threatening floristic diversity and forage quality as well. This PhD dissertation aims to examine ongoing changes in vegetation patterns and underlying soil properties of pastures in the Qilian Mountains (NW China) on the northern edge of Tibetan Plateau, which are triggered by intensified domestic grazing in recent decades.

Transhumance pastoral system is still in use in the Qilian Mountains, where mixed flocks of sheep and goats, and yaks graze on the spring/autumn and summer pastures, over an altitudinal range of 2600-3600 m a.s.l. During field work, spatially differentiated and grazing-induced changes in vegetation patterns and corresponding environmental variables were investigated. Major rankless plant communities in the study area were identified: *Picea crassifolia* forest (1); *Salix gilashanica – Arctostaphylos alpina* shrubland (2); *Potentilla anserina - Geranium pratense* grassland (3); *Stellera chamaejasme* shrubby grassland (4), and *Stipa capillata* mixed grassland (5). A transformation from more homogeneous grassland less affected by grazing, dominated by *Stipa* spp. and *Agropyron* spp., to severely degraded *Stipa capillata* grassland, co-dominated by *Iris lactea* var. *chinensis* and *Stellera chamaejasme,* was observed.

Analyzing the forage quality of the spring/autumn and summer pastures, intensive grazing was found to decrease aboveground dry herbage biomass and to increase fiber content of the forages. Slightly grazing intensity was associated with the highest protein (16.3%) and the lowest fiber (51.3%) contents. The highest fiber content (59.2%) was found in the plots most disturbed by grazing. Maximum concentrations of the macro- and micronutrients were observed under low grazing intensity. However, no linearity was observed between nutritive value and grazing intensity.

Along the altitudinal gradient, soil water content, carbon and nitrogen, organic matter and electric conductivity increased, while soil pH and base saturation decreased. Vegetation patterns of spring/autumn pastures showed a direct response to grazing. Degraded montane grasslands, i.e. spring/autumn pastures (2600-3000 m a.s.l), are characterized by low biomass and vegetation cover as well as low content of soil organic matter, total nitrogen and carbon. This altitudinal zone was shown to be most affected by intensive grazing and vulnerable to changes of precipitation. By contrast, we found alpine meadows, i.e., summer pastures (3000-3600 m a.s.l.) showing different indications of vegetation and soil disturbances, to be more resistant to degradation. In terms of herbage biomass and total vegetation cover, north-, north-east- and north-west-facing slopes in forest-grassland and shrubland-grassland ecotones were found to be the most productive. Although all pastures were exposed to intensive grazing, the spring/autumn pastures (2600-3000 m a.s.l.) experienced more severe degradation in terms of dry herbage biomass, total vegetation cover, chemical and physical soil properties.

After all we consider the rangelands in Qilian Mountains to indicate land degradation to a large extent, but to be still capable to provide sufficient quality forage for the demands of grazing animals. At the same time, uncontrolled overgrazing could lead to further decrease of rangeland health by increased numbers of toxic and unpalatable plant species as well as by the depletion of topsoil nutrients and soil erosion accelerated by trampling.

The results of this dissertation project contribute to strategy-oriented implications for integrated management plans. In order to implement sustainable grazing regimes, we suggest to reduce the grazing pressure and to ban grazing of the most degraded rangelands for the purpose of recovery.

The Introduction chapter (Chapter 1) of the thesis includes the state-of-the-art and provides the objectives of the current research. Chapter 2 gives an overview of the climate, geology, soils and vegetation of the study area, and of pastoral polices in the past and present with emphasis on land uses and types of land degradation. In Chapter 3, vegetation patterns and aspects of grazing-induced changes are analysed. Chapter 4 presents the impacts of grazing on forage quality. The impact of environmental variables on the vegetation differentiation is in the focus of Chapter 5. The concluding chapter (Chapter 6) discusses the main findings together with their methodological aspects and the scope for further research.

Zusammenfassung

Beweidung ist eine weit verbreitete Landnutzung, die seit prähistorischen Zeiten betrieben wird. Weideökosysteme auf der ganzen Welt stellen eine wichtige Ressource für die Tierhaltung dar, wobei es eine Herausforderung darstellt, das fragile Gleichgewicht zwischen Ökosystemintegrität und menschlichem Einfluss aufrechtzuerhalten. Ausgedehnte Weideflächen finden sich auf allen fünf Kontinenten und machen 30-40% der gesamten Landbedeckung der Erde aus. Aufgrund der globalen Zunahme der Beweidungsaktivität stehen jedoch viele Gebiete unweigerlich vor dem Problem fortgesetzter Bodendegradierung und der Aufrechterhaltung hydrologischer Ökosystemleistungen und ökologischer Integrität, was in Konsequenz zu einem schlechteren ökologischen Zustand der Weiden führt. In ariden und semiariden Gebieten ist die zunehmende Beweidungsaktivität oft mit Degradierungsprozessen verbunden, die zu Bodenerosion und Erschöpfung der

Bodennährstoffe führen und die floristische Vielfalt und Futterqualität gefährden. Die vorliegende Dissertation beschäftigt sich mit den Veränderungen der Vegetationsmuster und der Bodeneigenschaften auf den Weiden im Qilian Mountains (NW China) am Nordrand des Tibetischen Plateaus, ausgelöst durch die Intensivierung der Beweidung in den letzten Jahrzehnten.

In den Qilian Mountains wird noch Transhumanz betrieben. Dabei grasen gemischte Schaf- und Ziegenherden sowie Yaks auf einer Höhe von 2600 - 3600 m NN auf Frühjahrs-/Herbstweiden sowie Sommerweiden. Während der Geländearbeit wurden räumlich differenzierte und durch Beweidung verursachte Veränderungen der Vegetationsmuster sowie der Umweltvariablen untersucht. Die ranglosen Pflanzengesellschaften, die im Untersuchungsgebiet bestimmt wurden, waren *Picea crassifolia-Wald* (1); Sa*lix gilashanica - Arctostaphylos alpina*-Buschland (2); *Potentilla anserina - Geranium pratense*-Grasland (3); verbuschtes *Stellera chamaejasme*-Grasland (4) und *Stipa capillata*-Grasland (5).

Anhand der Analyseergebnisse der Futterwerte der Frühjahrs-/Herbstweiden und Sommerweiden wurde herausgefunden, dass intensive Beweidung die oberirdische trockene Phytomasse und den Fasergehalt des Futters erhöht. Geringe Beweidungsintensität war mit den höchsten Rohprotein- (16,3%) und geringsten Fasergehalten (51,3%) assoziiert. Der höchste Fasergehalt (59,2%) wurde auf den am intensivsten beweideten Untersuchungsflächen verzeichnet. Höchste Konzentrationen von Makro- und Mikronährstoffen wurden bei geringer Beweidungsintensität beobachtet. Es konnte jedoch kein linearer Zusammenhang zwischen Nährwert und Beweidungsintensität festgestellt werden.

Wassergehalt, Kohlenstoff- und Stickstoffgehalte, Gehalt an organischer Substanz und elektrische Leitfähigkeit des Bodens nehmen entlang des Höhengradienten nach oben hin zu, während pH-Werte und Basensättigung abnehmen. Eine direkte Reaktion auf Beweidung konnte anhand von Vegetationsmustern der Frühjahrs-/Herbstweiden festgestellt werden. Dieses Muster zeigt degradierte Berggrasländer, d.h. Frühjahrs-/Herbstweiden, mit geringer Biomasse und geringer Vegetationsbedeckung sowie geringen Gehalten von organischer Bodensubstanz und Gesamtstickstoff und Gesamtkohlenstoff. Dieses Gebiet ist am stärksten von intensiver Beweidung betroffen und am stärksten durch Niederschlagsveränderungen verwundbar. Im Gegensatz dazu konnte gezeigt werden, dass Vegetation und Böden der alpinen Hochweiden, d.h. Sommerweiden (3000 - 3600 m NN), weniger stark gestört und damit resistenter gegenüber Degradation sind. Hinsichtlich der oberirdischen trockenen Phytomasse und der Gesamtdeckung der Vegetation waren die Nord-, Nord-Ost- und Nord-West-exponierten Hänge in den Wald-Grasland- und Buschland-Grasland-Ökotonen am produktivsten. Obwohl alle Weideflächen großflächiger/intensiver Beweidung ausgesetzt sind, sind die Frühjahrs-/Herbstweiden (2600 - 3000 m NN) in Bezug auf oberirdische trockene Phytomasse, Gesamtdeckung der Vegetation sowie hinsichtlich chemischer und physikalischer Bodeneigenschaften von stärkerer Degradation betroffen.

Zusammenfassend lässt sich sagen, dass die in den Qilian Mountains untersuchten Weideflächen Merkmale der Degradation aufweisen, aber dennoch ausreichend Futter liefern, das den Ansprüchen der dort weidenden Tiere genügt. Gleichzeitig könnte eine unkontrollierte Überweidung jedoch zu einer fortschreitenden Verschlechterung des Zustands der Weideökosysteme führen, verbunden mit einer Zunahme an giftigen und ungenießbaren Pflanzenarten, einer Erschöpfung der Nährstoffgehalte im Oberboden sowie einer verstärkten Bodenerosion durch Trittbelastung.

Die Ergebnisse des vorliegenden Dissertationsprojektes tragen zu einer strategieorientierten Handlungsempfehlung für einen Managementplan bei. Um einen nachhaltigen Managementplan umzusetzen, sollte der Beweidungsdruck reduziert und das am stärksten von Degradierung betroffene Weideland teilweise brachgelegt werden, um es zu regenerieren.

Die Einleitung (Kapitel 1) der Dissertation umfasst den Stand der Forschung und stellt die Ziele der Untersuchung dar. Das zweite Kapitel gibt einen Überblick über das Klima, die Geologie, die Böden und die Vegetation des Untersuchungsgebietes, sowie über die Beweidungsrichtlinien in der Vergangenheit und in der Gegenwart und betont dabei auch die Landnutzung und die Formen der Landdegradation. In Kapitel drei werden die Aspekte der durch Beweidung verursachten Veränderungen von Vegetationsmustern analysiert. Kapitel vier stellt die Auswirkungen der Beweidung auf die Futterqualität dar. Der Einfluss der Standortfaktoren auf die Vegetationsausprägung steht im Mittelpunkt von Kapitel fünf. Das letzte Kapitel (Kapitel 6) diskutiert die Hauptergebnisse in Bezug methodische Aspekte und den Umfang zukünftiger Untersuchungen.

No Man Is An Island

No man is an island,
Entire of itself,
Every man is a piece of the continent,
A part of the main.
If a clod be washed away by the sea,
Europe is the less.
As well as if a promontory were.
As well as if a manor of thy friend's
Or of thine own were:
Any man's death diminishes me,
Because I am involved in mankind,
And therefore never send to know for whom the bell tolls;
It tolls for thee.

John Donne, „Meditation 17“, 1623

Acknowledgements

First of all, I want to thank the establishers of the German-Chinese LOWQM Project, by which means my child-dream to visit and stay in China came true - Dr. Klaus von Wilpert and Dr. Heike Puhlmann, who both have initiated this international scientific cooperation. Not less I am grateful to both of my supervisors, Prof. Dr. Udo Schickhoff and Prof. Dr. Jürgen Böhner, who were contributing to LOWQM project and by these means made possible to initiate my dissertation work. Explicitly I would like to thank Prof. Dr. Schickhoff for his patience with my writings and reliable support at all times.

For providing support during the field trips in Qilian Mountains and organization of my stays in city of Zhangye, I am thankful to Dr. Liu Xiande and Dr. Jin Ming. For intensive field work and productive discussions on a mixture of English and Chinese, I am happy to thank Wang Shunli and Chinese students helping with translation: Lei Lei, Liu Simin, He Xiaoling and other students. For the support during the field investigation work and life on the research station, I would like to thank Jin Wen Mao and other workers of the AWRCFQM.

For a valuable impact in identification of the collected vascular plant specimens, I would like to thank the botanists and taxonomists of the Komarov Botanical Graden in St. Petersburg, including Dr. R. Ufimov, Dr. M. Mikhailova, and Dr. D.German from Altai State University. For the work on lichen identification, I am thankful to Dr. Tassilo Feuerer. I thank everyone who was contributing to the biomass and soil analyses: Prof. Dr. Joerg Ganzhorn, Dr. Caroline Stolter, Irene Tomaschewski, Ernestine Lieder, Ines Friedrich and stuff of the soil laboratory of the Forest Research Institute in Freiburg.

For the financial support on different stages of the dissertation project, I am grateful to University of Hamburg's Doctoral Funding Program (HmbNFG) and merit scholarship program, as well as to Hamburg University Equal Opportunity Funds.

For the inspirational conversations, new ideas and generouse help in many different troubles during the preparation of the current dissertation I am very grateful to Prof. Dr. Michael Vrahnakis, Dr. Jens Oldeland, Dr. Peter Borchardt, Dr. Suraj Mal, Claus Carstens and to the active members of our PhD working group: Niels, Maxim, Maria, Birgit, Franzi and Stanley.

For the unconditional love and presence in my life I would be always grateful to my family: Ibo - who helped me to believe that I can make it and provides his hand since now and then, and my son Aren - who is a motivating factor for me to work, to struggle, to live! They both have granted me that valuable time to make the small steps in my work, every day. I am also thankful to my parents – Tatiana and Nikolay, who have gave me that initial impulse to try doing, what I really want. And kept believing in me, no matter how far away I was travelling, living or studying. I am thankful for their support on every step on this long way.

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Abbreviations

ADF - Acid Detergent Fiber

ADL – Acid Detergent Lignin

BS – Base saturation

C – total Carbon

C/N – Carbon/Nitrogen ratio

CEC – Cation Exchange Capacity

CP – Crude Protein

DCA – Detrended Correspondence Analysis

EC – Electrical Conductivity

m a.s.l. – meters above sea level

N – total Nitrogen

NDF – Neutral Detergent Fiber

NMDS – Non-metric Multidimensional Scaling

OM – Organic Matter

SBD – Soil Bulk Density

TDN – Total Digestible Nutrients

Chapter 1. Introduction

Summary
In the Chapter 1 general context for the PhD research is presented, followed by the subject overview, where up-to-date status of the rangeland research in the study area is introduced. After what Objectives and Research Questions are formulated, followed by the structure of the dissertation. Publications related to dissertation and Institutions involved into the dissertation project are listed at the end of the Chapter 1.

1.1. General context of the research

Habitat destruction, according to E.O. Wilson (1985; 2002) is still on the first place in the list of five major causes of species extinction. There are different aspects of habitat destruction to be found in a variety of climatic zones in bio-geographical units on the globe. The focus of the current dissertation is placed on the mountainous areas, where semi-arid and cold-humid climates have formed two distinct states of ecosystem in terms of vegetation dynamics: equilibrium and non-equilibrium. Since both of them are highly and constantly affected by human impact through practising pastoralism activities, problem of habitat destruction in the form of land degradation comes into place, threatening not only the stability of the soil layer, but also affecting the species composition of the respective vegetation formations. It is especially pronounced in grasslands, where due to intensification of the utilization pressure, the decrease in floristic diversity is observed, followed by invasion of unpalatable and toxic species, altogether alarming deterioration of the grassland health

In China after the Cultural Revolution in 1950s crucial changes in political and social sectors have happened. For thirty years, system of communes was functioning in every economical sector including the agro-pastoral one. Under this system animal grazing was uncontrolled over the common pastures, resulting in significant decrease of the rangeland health. Even the change in rangeland low of 1985, diminishing the communes and assigning restricted pasture area per household, resulted in overall increase of the cattle numbers and further depletion of the grazing natural resources (Yang 1992; Miller 2000; Akiyama & Kawamura 2007; Harris 2010). Therefore, there is an essential need for modern estimations of pastoral conditions in order to identify the key environmental factors which together with grazing are responsible for the changes in vegetation cover and forage quality, and to make effective suggestions on the future pasture and grazing management planning and decisions.

1.2. Subject overview

The problem of land degradation is widespread in China, but it seems to be recognized by the State only in mid-1990s, when it was placed among one of the nation's most severe environmental challenges (Yamaguchi 2011). During the recent 50 years there was a constant increase in the numbers of livestock, in particular in the region of North West of

China and in Tibetan Plateau (Long et al.; Harris 2010). In Qilian Mountains (Heihe River Basin, Gansu Province, NW China) overgrazing was suggested as the main environmental problem in the region (Li et al. 2003;). However only a few preliminary studies on vegetation and its dynamic as well as on vegetation-environment relationships in the Qilian Mountains are available in the literature, most of them in Chinese.

As far as we know, the only phytocoenological study in this region, available in English, was conducted by Kürschner et al. (2005), providing an overview of the main phytocoenoses in different altitudinal zones in the Qilian Mountains. Studies on vegetation distribution have detected the maximum numbers of plant species richness and floristic diversity at intermediate portions of elevation gradient (Wang 2002; Wang et al. 2002; Wang et al. 2017b). Composition of the plant communities was reported to vary between north- and south-facing slopes (Wang et al. 2002; Huang et al. 2011). Due to increasing grazing pressure the high of the vegetation cover was decreasing during the growing season (Chang et al. 2004). In pastures, the percentage of unpalatable and toxic species was increasing, followed by the decline of floristic diversity (Chang et al. 2004). Totals of nitrogen and phosphorus of the alpine pastures decreased significantly, whereas pH and soil bulk density have significantly increased under intensive grazing (Sheng et al. 2009; Yuan & Hou 2015). Soil organic carbon was depleting under increased grazing pressure (Yuan & Hou 2015). The most recent study on variation of plant species and soil properties in the Qilian Mountains, showed the hump-shaped curve of the plant species distribution along the altitude, and the luck of explanatory value of soil physical properties within ordination space (Yang et al.. 2018). The above mentioned researchers outlined the luck of quantitative and qualitative vegetation analyses. The understanding of the functioning of the fragile mountain ecosystems under the impact of anthropogenic (long-term extensive grazing) and natural (climate change) disturbances, and, is imperative and more detailed investigations of plant-herbivore interactions and abiotic site factors are necessary.

More emphasizes on the mentioned above topics, describing natural vegetation stands as well as recent changes in vegetation cover, is made in Chapter 2. In particular a problem of rangeland health is discussed there for the region of Tibetan Plateau, and for the Qilian Mountains itself. Rangeland condition is described there in terms of carrying capacity, providing some numbers of sheep, goat and yaks, collected from the local villages in the study area. Modern understanding of rangeland ecosystem functioning is presented there on the examples of equilibrium/non-equilibrium and resilience concepts. After all, understanding of overgrazing and the problem of land degradation are seen in a different light by it means.

1.3. Objectives and Research Questions

In order to reduce existing research deficits, the objectives of the current dissertation project were to clarify hitherto unknown responses of the vegetation and its respective spatial/temporal patterns and underlying soil properties to increased grazing intensity in the rangelands of the Qilian Mountains, NW China. We hypothesised, that due to increased grazing: (a) habitat quality and floristic diversity are declining, (b) forage quality is diminishing, and finally that (c) there are non-linear responses of vegetation and soil properties in spring/autumn and summer pastures. In order to explore our hypotheses, the following **Research Questions (RQ)** were formulated:

A. Habitat Quality and Floristic Diversity

RQ1: What are the main plant communities comprising the spring/autumn pastures in Qilian Mountains?

RQ2: What are the grazing-induced and spatially differentiated changes in vegetation patterns?

B. Forage Quality

RQ3: How forage quality is affected by the differentiating grazing intensity?

RQ4: How forage quality varies during the growing season?

RQ5: How forage quality varies between two altitudinal zones?

C. Soil and Vegetation Responses

RQ6: What are the main vegetation groups, found in montane/sub-alpine and alpine rangelands of Qilian Mountains? Which abiotic factors are responsible for their differentiation?

RQ7: What are the main environmental factors responsible for vegetation differentiation in montane-subalpine and alpine rangelands of Qilian Mountains?

RQ8: How varies the response of montane-subalpine and alpine vegetation communities to grazing intensification?

The above mentioned research questions (RQ1-RQ7) are respectively addressed in the following Chapters 3, 4 and 5.

1.4. Structure of the dissertation

Chapter 2 is a review chapter, summarizing different aspects of climate, geology, soils and vegetation of the study area. It also analyzes the land use practices and pastoral polices of the past and present and describes the socio-economical aspects in the households of the local herders' minorities. In conclusion of Chapter 2, concepts of rangeland ecosystem functioning and issues related to land degradation in the Qilian Mountains are discussed.

Chapter 3 investigates the impact of grazing on the spring/autumn pastures in Qilian Mountains. It examines the changes in vegetation composition along the altitudinal gradient and provides an assessment of the pasture quality according to different indicators of pasture degradation.
Chapter 4 presents the grazing impacts on forage quality. It provides an estimation of the biomass, nutritive value and macronutrient content on different levels of grazing intensity in alpine and subalpine altitudinal zones during the growing season.

Chapter 5 deals with the impact of abiotic site factors on the vegetation differentiation. It examines the role of soil physical properties and topographic factors in differentiation of vegetation groups and observes the variation of grazing impact between identified vegetation groups.

In Chapter 6 research questions, outlined in Chapter 1, are addressed. Aspects of methodology and some particular findings of the current PhD dissertation are critically discussed, including the outlook of these findings for the further studies. At the end some management suggestions are made.

Chapter 1 presents a literature overview describing different aspects of the study area and is unpublished material. Chapter 2 and Chapter 3 are based on the publications of Baranova et al. 2016 and Baranova et al. (accepted) respectively. Chapter 4 contains novel material, which was partly presented on the recent conferences in 2018 and was not published so far (more details are given in the last section "Proceedings from the conferences").

1.5. Publications related to dissertation

Alina Baranova, Jens Oldeland, Shunli Wang & Udo Schickhoff. 2019. G*razing impact on forage quality and macronutrient content of rangelands in Qilian Mountains, NW China.* **Journal of Mountain Science 16(1)**: 43-53. DOI: 10.1007/s11629-018-5131-y

Jürgen Dengler, Viktoria Wagner, Iwona Dembicz, Itziar García-Mijangos, Alireza Naqinezhad, Steffen Boch, Alessandro Chiarucci, Timo Conradi, Goffredo Filibeck, Riccardo Guarino, Monika Janišová, Manuel J. Steinbauer, Svetlana Aćić, Alicia T.R. Acosta, Munemitsu Akasaka, Marc-Andre Allers, Iva Apostolova, Irena Axmanová, Branko Bakan, Alina Baranova, et al. & Idoia Biurrun. 2018. *GrassPlot – a database of multi-scale plant diversity in Palaearctic grasslands*. **Phytocoenologia 48(3):** 331-347. DOI: 10.1127/phyto/2018/0267

Alina Baranova, Udo Schickhoff, Shunli Wang & Ming Jin. 2016. *Mountain pastures of Qilian Mountains: plant communities, grazing impact and degradation status (Gansu province, NW China)*. **Hacquetia 15 (2)**: 21-36. DOI: 10.1515/hacq-2016-0014

Klaus v. Wilpert, Heike Puhlmann, Tobias Kawohl, Jürgen Böhner, Alina Baranova & Ernestine Lieder. *Long-term optimization of water yield from the Qilian Mountains to the HeiHe River*

basin by an integrated development of water protection forests and land-use. Final report (BN: 32.5.8003.0095.0). Forest Research Institute, Freiburg, Germany, 2014. 42 p.

1.6. Institutions involved into the project

Current PhD research was started in the Institute of Physical Geography (Department of Earth Sciences, University Hamburg, Germany) as a part of the German-Chinese joint project entitled "Long-term optimization of water yield from the Qilian Mountains to the HeiHe River basin by an integrated development of water protection forests and land-use", organized as scientific cooperation between Forest Research Institute (Freiburg, Baden-Württemberg, Germany) and Academy of Water Resource Conservation Forest of Qilian Mountains (AWRCFQM) (Zhangye, Gansu province, China). Additional cooperation during the research period was established with the Institute of Zoology (Department of Biology, Universität Hamburg, Germany) and with the Komarov Botanical Garden (Russian Academy of Sciences, St. Petersburg, Russia).

Chapter 2. Review of the Study Area

Summary

Chapter 1 provides a detailed overview of the geographical, climatological, geomorphological, and edaphic conditions of the research region. It also summarizes the development of the vegetation stands in the Late Pleistocene and during the Holocene based on pollen records. After that, an attempt is made to distinguish between the natural stand of the vegetation and changes in vegetation cover accelerated by anthropogenic activities. In addition, the past and current land use practices are discussed based on changes in political and economic systems during the formation and development of the People's Republic of China. The current pastoral status is reflected in the interviews with local minorities. In conclusion, the concept of land degradation and applicable assessments of the impact of animal grazing are discussed.

2.1. Study region

2.1.1. Location

The Qilian Mountain range (97 ° 24'-10 ° 46'E, 36 ° 43'-39 ° 42'N) is located in the northwest of China, covering the area of approximately 184 000 km², at an altitude of 2000–5500 m. a.s.l. (Li et al. 2001). It is spread over 850 km from the northwest to the southeast, has a width of 150–300 km, with average height exceeding 3500 m a.s.l. Current snowline starts at c. 4400 m a.s.l. (Kürschner et al. 2005) The Qilian Mountains lie along the Chinese provinces of Gansu and Qinghai in the central west of China over a length of about 850 km and forms the tectonically active north-eastern edge of the Tibetan plateau, bordering the Qaidam basin. In Gansu province, the Qilian Mountains are confronted with an elongated depression—middle part of the Hexi corridor (Table 1)—which comprises large amounts of aeolian sediments from the neighbouring desert areas. The Hexi corridor borders the Qilian Mountains in the south and the Longshou Mountains in Inner Mongolia in the north (Li et al. 2001).

Using geomorphologic, climatologic and ecosystem units, the southern, middle, and northern zones of the Heihe River Basin were identified (Figure 1). The upper, middle, and lower reaches extend from the middle of the Hexi Corridor to Qinghai and western Inner Mongolia. Administratively, the basin includes part of Qilian County in Qinghai Province, several counties and cities of Gansu Province, and part of Ejina Banner in the Alxa League of Inner Mongolia (Qi & Luo 2005).

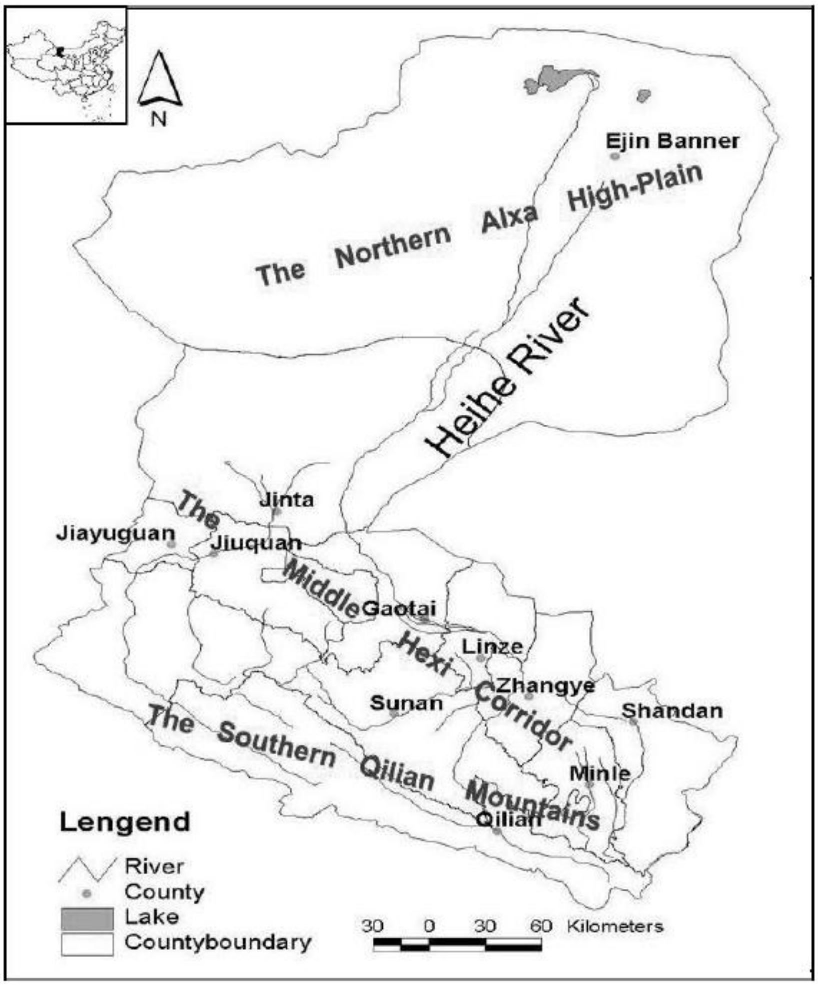


Figure 1. Heihe River: southern, middle and northern parts of the basin (after Qi & Luo 2005).

The southern unit—the Qilian Mountains belt—is covered by 43.61×10^4 ha of forests and 811.2×10^8 m^3 of glaciers, which are the headwaters of the Heihe, Shiyang, Shule, and 53 other smaller rivers (Yang et al. 2005). In hydrological and ecological terms, it plays a significant role by providing 4 millions of people living in the Hexi Corridor with fresh water, ensuring agricultural irrigation of the lowlands (Yang et al. 2005; Küster et al. 2006; Yu et al. 2010; Zhao et al. 2011; Deng et al. 2013).

Table 1. Morphology, climate, and land cover characteristics of the Heihe River Basin (after Li et al. 2001; Ma et al. 2004, Ma & Frank 2006).

Geomorphological unit	Elevation (m a.s.l.)	Mean annual values			Main land-cover type and vegetation
		Average Tempera-ture (°C)	Precipitatio n (mm)	Potential evaporation (mm)	
The Southern unit - Qilian Mountains	2000 - 5500	1.5–2.0	200–700	700	Grassland, forest; snow
The Middle unit - Hexi Corridor	1000 - 2000	5.0–10. 0	100–250	2000	Farmland; Gobi desert

The Northern unit - Alxa High-plain	About 1000	About 8.0	Less than 50	3700	Gobi desert; Natural oasis

2.1.2. Climate

The middle part of the Qilian Mountains has a semi-arid cold and mountain climate, where temperature and precipitation show a distinct vertical gradient. The annual mean precipitation increases with elevation (from 250mm to 700 mm), while annual mean temperature decreases with elevation (from 6.2 ◦C to −9.6 ◦C) (Zhao et al. 2011). However, more recent studies have shown a hump-shaped curve of annual precipitation variation along the altitude (Figure 2). In alpine areas above the treeline (3.100–3.700 m. a.s.l.), mean temperatures detected in the coldest and warmest months are -9.43 °C and 21.98 °C, respectively, with a mean annual precipitation of 87 mm only (Yang et al. 2018). In summer, diurnal difference in temperature on the high elevations is dramatic: from +32.4°C at day, down to -29.0 °C at night (Yang et al. 2018).

Annually, the highest amount of precipitation is seen between May and September (around 89% of total, with 63% between June and August) (Zhao et al. 2011). Low precipitation values are registered in the lower reaches of the Heihe River Basin and its north-western part. The amount of precipitation varies during growing seasons from 46 mm to 145.4 mm in July, and from 25.2 mm to 64.5 mm in May (Figure 3), with remarkable variation between the years (Figure 4). In general, the precipitation rate decreases from the east to the west and increases from the north to the south (Zhao et al. 2011).

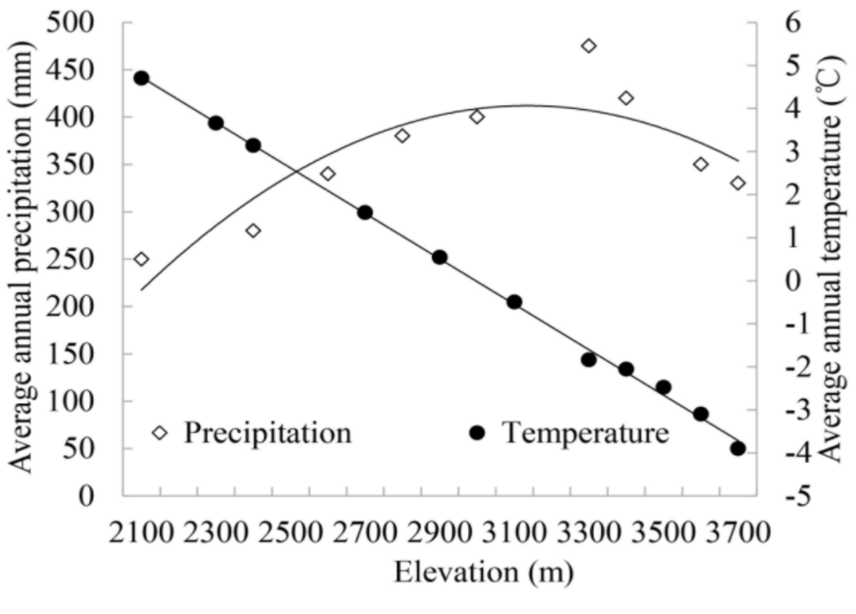


Figure 2. Variation of mean annual precipitation and mean annual temperature along the altitudinal gradient on the northern slopes of the Qilian Mountains (after Yang et al. 2018).

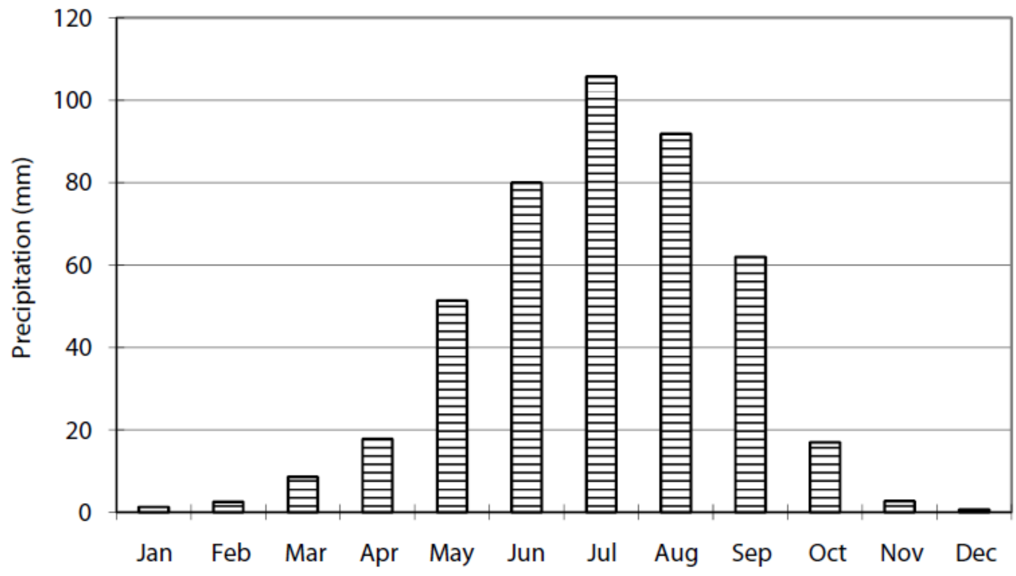


Figure 3. Climatic diagram of monthly mean precipitation from 1957 to 1995 at the Zhamashike meteorological station, close to our study area in the Qilian Mountains (after Zhao et al. 2011).

According to data from the Gansu Meteorological Bureau (Yuan & Hou 2015), during the last 55 years, the annual mean temperature in Sunan Yugur Autonomous County was about 3.6°C (Figure 4), with about 60% of daily photoperiod and 127 frost-free days per year. The mean annual rainfall in this period accounted for 260 mm (Figure 4).

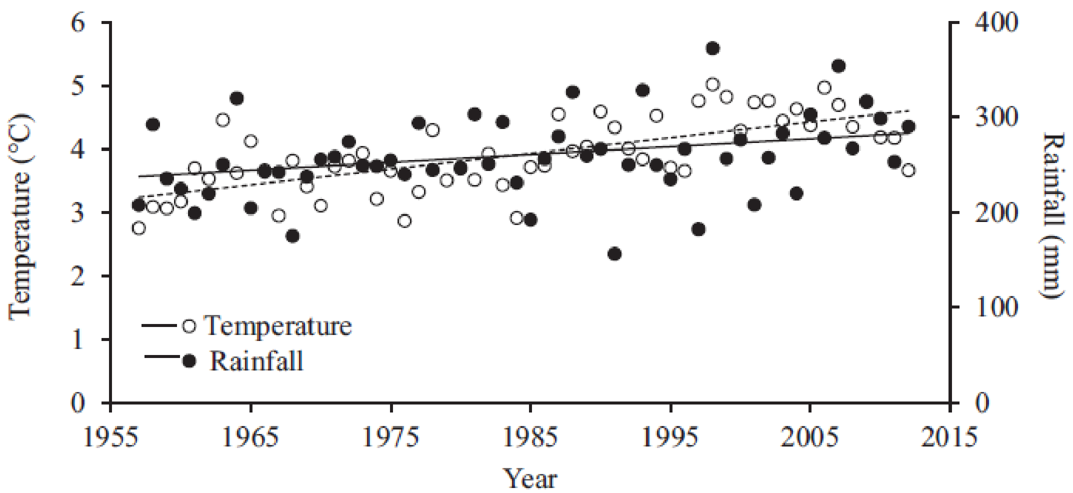


Figure 4. Climatic diagram of mean annual temperature and precipitation variation from 1957 to 2012 in the vicinity of Sunan Yugur Autonomous County (after Yuan & Hou 2015).

Climate change

There is evidence of global rising temperatures increasing the temperature within the Tibetan Plateau two times the global mean (Liu 2017). The rate exceeds the relative increase in temperature in the northern hemisphere, which altogether leads to changes in the local climate, e.g. drying the north-western part of the Tibetan Plateau (Cui & Graf 2009). Similarly, warming trends were detected in the Qilian Mountains, resulting in a significant reduction in glaciated and permafrost areas in the near future (Böhner & Lehmkul 2005) and drastically affecting vegetation on the dry south-facing slopes (Deng et al. 2013) (further discussed in section on vegetation).

2.1.3. Geological formation

The characteristics of the Qilian area are loess deposits from the Holocene, which in general are not limited to certain locations but represent a quite common phenomenon along the mountain front (Küster et al. 2006). The material is a result of aeolian transportation by strong northeast winds, which has the dominant wind direction to the southeast. This wind tunnel favours a convergent outflow regime towards the wider open landscape belt of the Loess Plateau, the western part of China (Küster et al. 2006).

In the Early Eocene (approx. 50 million years ago), the Qilian Mountains and other adjacent mountains were formed together with the Tibetan Plateau due to the collision of the Indian and Eurasian continental plates. The geology of the region corresponds to a complex rock composition of different ages, which is still subject to deformation, as the Indian continental plate continuously pushes to the north by about 50 mm per year (Lehmkuhl & Owen 2005). The study region is characterized by plutonic rocks from the Palaeozoic and Mesozoic Eras; it belongs to the Qinling–Qilian fold system and is found between the North Qilian and the Danghe Nan Shan-Sutur. The volume of the crust increases from the northeast to the southwest (from 42 km to 63 km) and is mainly formed during the Late Miocene (Liu et al. 2006).

There are three major geological units, surrounding the Qilian Mountains: Qinling–Qilian fold system, the Tibetan Plateau and the tectonically arched Haiyuan region. The Qinling–Qilian fold system is located in the northeast of the Tibetan Plateau and is an active system of folding and pushing, which has a large surface area (Liu et al. 2006). This vast region of rock formation has the same age and is bounded by the Kunlun fold in the south and the Altyn-Tagh in the northwest. The highest pressure is on the rising Kunlun fold, which continues along the northern border of Tibet. It separates the Songpan–Ganzi terrain from the Qinling–Qilian fold system (Liu et al. 2006).

The latest glaciation, which advanced approximately 15,000 years ago, is confirmed by lake sediments of the Qaidam Basin (Figure 5), which show positive correlation with lake sediments from West Kunlun and the Tian Shan Mountains. The duration and the extent of the last glaciation in the Tibetan Plateau, including the Qilian Mountains region, was a topic of debate for many years. Owing to the cold and arid climate of the region, the organic matter used in radio–carbonate dating primary refers to the Early Holocene (Lehmkuhl 1997)

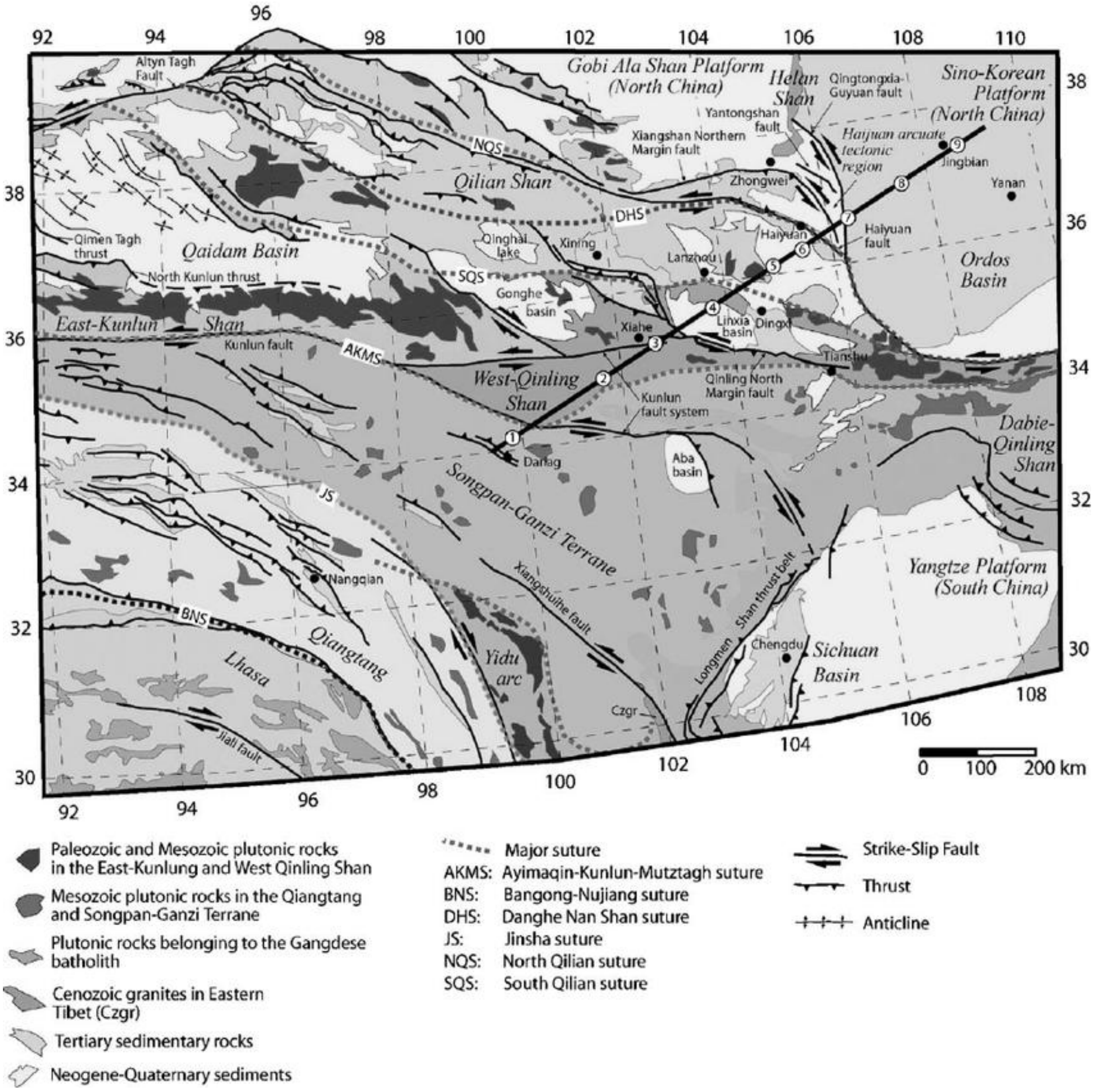


Figure 5. Tectonic map of the north-western part of the Qinghai–Tibetan Plateau (after Yin & Harrison 2000, modified by Liu et al. 2006).

2.1.4. Soils of the Qilian Mountains

Soil development in mountain areas is restricted by extreme climate conditions (e.g. daily and annual temperature variation) and topography. Dominant parent rock materials are sandstone, conglomerate, schist, phyllite, and agglomerates (Wang et al. 2002; Owen et al. 2003). At lower altitudes in the Qilian Mountains, steep slopes have sparse vegetation and are covered with coarse loess—a result of aeolian deposition. Loess accumulation began between 11,000 and 13,000 years ago. The average accumulation rate varies between 9 and 16 cm per 1,000 years. The northern part of the Qilian Mountains represents the less-disturbed loess in sand deposits (Küster et al. 2006). The soil types of the Qilian Mountains and their characteristics are summarized in Table 2.

Most of the dry south- and south-west-facing slopes demonstrate a weakly developed brown-desert soil (Wang 2002; Wu 1980). Haplic Regosols is another common soil type found in the arid mountain areas of the Qilian Mountains (Lieder 2013). According to FAO classification, haplic Calcisol, calcic Luvisol, and haplic Phaeozems are found in some locations (Yu et al. 2010).

Higher along the altitudinal gradient could be found subalpine-meadow soils and mountain grey-brown soil (also known as grey sierozem or mountain chestnut). These areas usually correspond to moist north-facing slopes and alpine meadows on higher elevations, where Cambisols are developed (Lieder 2013). Cambisols are characterized by a comparatively shallow soil profile, a silty loam texture, variation in pH values from 7 to 8, and often low concentrations of aluminium and/or iron, as well as organic matter on the intermediate level (FAO 2006).

Close to the summit and on the north-facing slopes in the middle- and high-elevation alpine cold desert soils, permafrost or temporary frozen soils—Cryosols—could be found (Wang 2002, Lieder 2013). These soils underlie the dense spruce forests, thus being protected from unfreezing process. For the whole Qilian Mountains, the extent of the permafrost region counts up to 10×10^4 km^2 (Sun et al. 2014).

Table 2. Soil types of the Qilian Mountains (Wang et al. 2002; FAO 2006; Lieder 2013).

Soil type	Location, altitude	Properties, land use type
Haplic Regosols	Semi-arid, arid mountainous areas, extensive in eroding lands; all elevations, mostly south-, exposures	Weakly developed, used for extensive grazing
Haplic Calcisols	Arid semi-desert environment, overlay alluvial, colluvial, and aeolian deposits of base-rich weathering materials. Different altitudes.	Humus-low soils. Substantial secondary accumulation of secondary carbonates; underlie sparse xerophytic vegetation; on higher elevations increase a rick of erosion due to the lack of aggregate stability. On lower elevations used for extensive grazing.
Calcic Luvisols	Common in previously glaciated areas; overlay unconsolidated materials including glacial till, aeolian, alluvial, and colluvial deposits of limestone weathering.	High clay content in subsoil; primary fertile, suitable for agriculture, well rotatable; on steep slopes require erosion control; used for extensive grazing and forest land.

Haplic Phaeozems	Develop on loess and loessy substrates	Humus-rich soils and typical of moist meadows and drier forest regions. Could be in use for agriculture.
Cambisols	Slight or moderate weathering of parent materials; subalpine – alpine meadows, middle to high elevations, north-facing slopes	pH from 7 to 8, comparatively shallow soil profile, silty loam texture, intermediate to low quantities of illuviated clay, organic matter, Al and/or Fe compounds; in use as forest land and for extensive grazing
Cryosols	Permafrost environment; middle to high elevations	Cryogenic soil formation; often found beneath the spruce forest.

Being used for extensive grazing, often in overgrazing conditions for a long period, rangeland soils have experienced significant loss oftotal nitrogen and total phosphorus and an increase in soil pH and soil bulk density (Sheng et al. 2009).

2.1.5. Vegetation–environment relationships

The distribution patterns of vegetation along the altitudinal gradient were first reported by Wang et al. (2002), who did a quantitative description of vegetation of the Northern Qilian Mountains with respect to altitudinal and climate zones (Table 3). According to soil moisture study (Zao et al. 2011), specific vegetation patterns are associated with certain ranges of the soil moisture index and overlap each other: sub-alpine shrubland (2.19-5.85), *Picea* forest (1.46-5.96) and grasslands (1.00–3.94). Plant species composition was also different between north-facing and south-facing slopes (Wang et al. 2002; Wang 2002; Huang et al. 2011).

Except for altitudes, slope exposure plays an important role in vegetation distribution. Dry, mostly south- and south-west-facing slopes, are examples of arid and semi-arid conditions; these are infested with xerophytic communities, including *Potentilla* and *Caragana* shrubs (Table 3). Arid grasslands are relatively resilient to animal grazing due to the dominance of annual grasses. Their seeds germinate only in the presence of water, meaning that in dry years less herbage is available for grazing. In this case, the amount of herbage biomass is correlated with the amount of precipitation (Vetter, 2005).

On moist north-facing slopes and in areas with humid conditions, Qinghai spruce (*Picea crassifolia)* forests are established (Table 3). The distribution of *Picea crassifolia* is often restricted by severe temperature and drought stresses due to high interannual fluctuations and damage by unsustainable forest use (Li et al. 2003). Nevertheless, the land suitable for forest growth accounts three times more than its actual cover.

Table 3. Vegetation cover classes in different altitudinal belts of the Qilian Mountains (after Wang et al. 2002; Zhao et al. 2006).

<table>
<tr><th colspan="2">Vegetation formations</th><th>Altitude (m a.s.l.)</th><th>Climate</th><th>Vegetation (main species)</th></tr>
<tr><td colspan="2">Forest (with understory)
Forest-steppe (meadows)</td><td>2500–3600</td><td>zone of temperate plateau, semi-humid climate</td><td>Picea crassifolia; Sabina przewalskii; Potentilla davurica, Berberis dubia, B. diafana, Spiraea alpina, Lonicera hispida</td></tr>
<tr><td colspan="2">Desert land</td><td>1400–1700</td><td>Dry arid climate</td><td>Reaumuria soogorica, Kalidiuim foliatum</td></tr>
<tr><td colspan="2">Dry grasslands</td><td>1700–1900</td><td rowspan="2">Continental wilderness steppes, dry climate</td><td rowspan="2">Stipa spp., Poa spp., Agropyron crystatum, Artemisia spp., Potentilla spp.</td></tr>
<tr><td colspan="2">Dry shrublands</td><td>1900–2400</td></tr>
<tr><td rowspan="2">(Sub)alpine</td><td>Shrub - lands</td><td>2400–3800</td><td>semi-arid dry climate</td><td>Dasiphora fruticas, Caragana jubata, C.stenophylla, Salix gilashanica, Spirea spp., Ajania fruticulosa, Arctous alpinus</td></tr>
<tr><td>Meadows</td><td>2400–3300</td><td>semi-arid, semi-humid climate</td><td>Stipa purpurea, S. przewalskii, Carex spp., Polygonium viviparum, P. bistorta</td></tr>
</table>

2.2. VEGETATION: PAST AND PRESENT. CHANGES IN VEGETATION COVER

2.2.1. Past: paleo vegetation

To estimate the change in vegetation composition over time, it is necessary to make a comparison with previous studies from the same region and describe vegetation cover following consequent stages of succession (in the earlier stages of grazing history). The earliest data could be derived from the sediment cores, providing the pollen analysis of paleo-vegetation. It suggests that coniferous forests of *Picea*, *Abies,* and *Pinus* occupied the slopes in the Qilian Mountains around 30,000 years ago (Brantingham et al. 2007). During the Last Glacial Maximum (21,000 years ago), when the climate was colder 4–7 degrees, sparse alpine vegetation and alpine deserts were established in the Qilian Mountains (Herzschuh et al. 2006), in some areas advancing over former *Picea* stands (Herzschuh & Liu 2007).

About 19,000–17,000 years ago, under increasing moisture conditions, steppe vegetation was detected initially (Herzschuh & Liu 2007). Due to climatic instability, more dry and cold conditions caused a general decrease in the vegetation cover in the Qilian Mountains, and high alpine deserts came up around 16,000 years ago. The following warm and moist period (c. 14,700–12,700 years ago) was beneficial for the first expansion of the coniferous forest in the Qilian Mountains, where steep and meadow vegetation was still dominating (Shen &

Tang 1996; Herzschuh & Liu 2007). The next return to glacial conditions (c. 12,800–11,500 years ago) was not much reflected in the vegetation records of the Qilian Mountains, which contained a high amount of *Picea* pollen. After the Pleistocene/Holocene transition, a high spread of species from *Chenopodiacea*, *Poacea*, and *Artemisia* families was recorded (Herzschuh & Liu 2007).

In the Early Holocene, steppes and shrublands gradually shifted northwards and westwards, in the areas which were dominated by temperate grasslands, xerophytic shrublands, and deserts (Ni et al. 2014). During this time, cool mixed and needle-leaved forests were common. The expansion of *Picea* and mixed *Picea-Betula* forests in the Qilian Mountains between 9,000 and 7,000 years ago was supported by an increase in temperature by at least 1–2 degrees over the present-day temperature (Herzschuh et al. 2005). The decrease in the number of *Picea* stands and the establishment of alpine meadows due to the rapid growth of *Cyperaceae* (*Artemisia*) and *Chenopodiaceae* families, along with the formation of desert steppe vegetation in lowlands, continued through the late glacial period (Madsen et al., 2007). It seems that alpine steppes and *Kobresia* meadows, as well as (sub)-alpine *Potentilla* shrub vegetation, which was established in the Middle Holocene (around 7,000 years ago), have remained stable until today (Herzschuh et al. 2006).

2.2.2. Natural vegetation. Vegetation descriptions

Several preliminary studies describing vegetation in the Qilian Mountains are available in the literature, many of these being in Chinese. The earliest known attempt was made in the 1960s by two groups from the Chinese Academy of Sciences: Qinghai and Gansu Integrated Survey Team (1963) and Xizang Integrated Survey Team (1966) to investigate the grassland potential of the Tibetan Plateau (Miller 2005). The first complete description of the vegetation units of the Qilian Mountains is found in 'The Vegetation Atlas of China' (Hou 2001), which is widely used in subsequent studies (Figure 6).

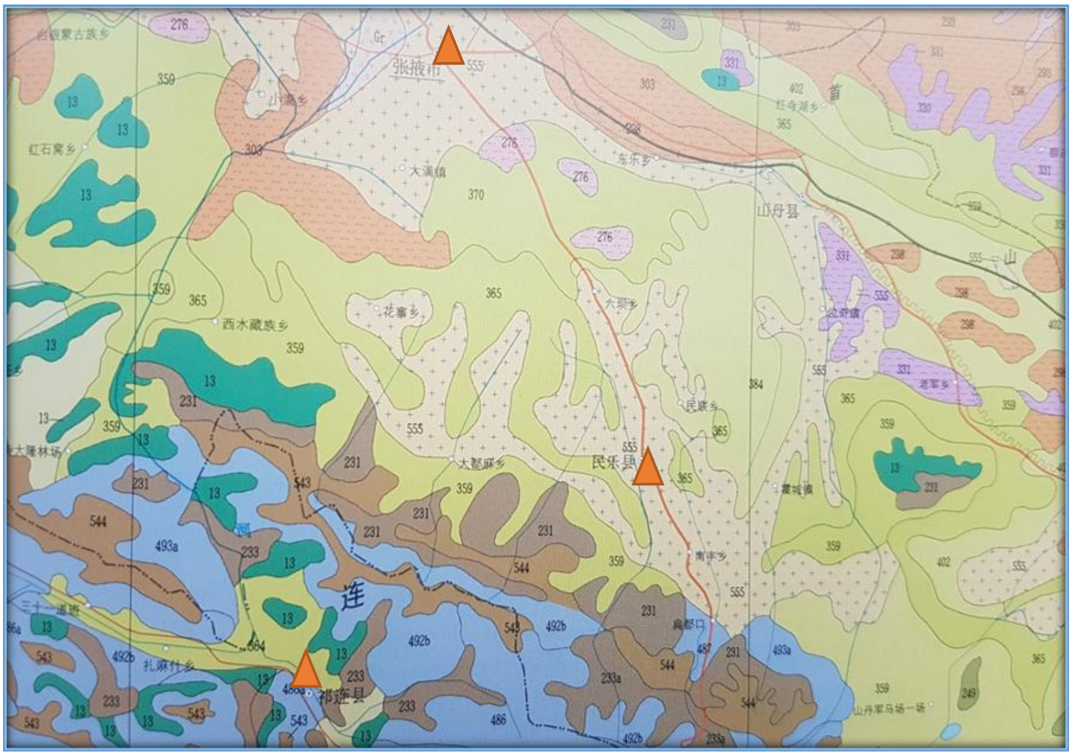


Figure 6. Formations of vegetation types. A shortcut of the middle section of the Qilian Mountains, including Zhangye, Minle, and Qilian settlements (orange triangles, meaning downwards) (after Hou 2001: “The Vegetation Atlas of China”).

Main vegetation formations in the middle section of the Qilian Mountains:

13 – *Picea crassifolia* forest
231 – *Salix gilashanica* scrub
233 – *Salix oriptera* scrub
233a – *Salix oriptera, Dasifora fruticosa, Caragana jubata* scrub
359 – *Stipa krilovii* steppe
364 – *Stipa penicillata* steppe
365 – *Stipa breuiflora, Stipa bungeana* steppe
405, 405a – *Stipa purpurea* steppe
486 – *Kobresia pygmaea* meadow
492b – *Kobresia spp*. meadow
493a – *K. schoenoides, Carex spp*. Meadow
495 – *Elymus nutans, Reogneria nutan*s meadow
543, 544 - *Saussurea spp*. Alpine sparce vegetation

Phyto-sociological descriptions

Due to long-term grazing, the original composition of the natural (sub)alpine vegetation in the Qilian Mountains is no longer distinguishable. On a smaller scale, vegetation units reveal patchy and mosaic structures (Figure 7). Results of the first floristic-coenological records collected from the north-eastern part of the Tibetan Plateau by Kürschner et al. (2005) are provided in Table 4.

Table 4. Phyto-sociological differentiation of (sub)alpine vegetation in the Qilian Mountains (following Kürschner et al. 2005).

Vegetation type	Association	Character species
Alpine meadow - *Kobresia* mats	Leontopodio souliei - Kobresietum humilis ass. nova	*Geum aleppicum, K. capillifolia, K. humilis, Leontopodium souliei, Taraxacum maurocarpum*
*Alpine grassland (winter pastures)	Morino chinensis – Elymetum nutans ass. nova	*Agrostis sinkiangensis, Anemone obtusiloba var. ovalifolia, Aster ferreri, Carex moorcroftii, Elimus nutans, Geranium pylzowianum, Medicago archiducis-nicolai, Morina chinensis, Oxytropis kansuensis, Pedicularis chieranthifolia, Poa rangkulensis*
(Sub)alpine shrubland	Kobresia royleana – Potentilla parviflora community	*Potentilla parviflora var. hypoleuca, Salix opriptera var.amnematchinensis, Caragana jubata. Spirae alpiina*

On alpine meadow was described **Leontopodio souliei - Kobresietum humilis** association, which serves as a main grazing resource for the herds of sheep, yaks and goats in summer. It was further divided into four 'communities' in terms of altitude (as proxy for temperature and frost), soil conditions (permafrost, solifluction), moist conditions, and the impact of grazing.

In alpine grasslands, which in the study of Kürschner et al. (2005) are used as winter pastures, the **Morino chinensis – Elymetum nutans** association was identified (Table 4; *althought in the further Chapters of the dissertation alpine areas always correspond to summer pastures). It could have formed as a replacement community for former forest and shrubland stands. Ruderal and grazing indicators, such as *Morina chinensis, Ajania fruticulosa, Potentilla anserina, Leimus secalinus, Polygonum sibiricum,* and *Stellera chamaejasme* were found there. It also contained interogressive species from neighbouring alpine meadows and (sub)alpine shrublands.

The (sub)alpine shrubland **Kobresia royleana – Potentilla parviflora** communityis characterized by the species with high clonal ability. Often *Potentilla* shrubs, together with *Kobresia* mats, have a patchy distribution over the landscape. This community has two layers and its total cover exceeds 100%. Most of the species are grazing indicators, which have a wide ecological and phytosociological range.

Being geographically a part of the Tibetan Plateau, vegetation of the Qilian Mountains and Qaidam Basin is more affiliated to Mongolian than the Tibetan floristic province. It is confirmed by Kürschner et al. (2005), who identified that plant associations are syntaxonomoically closely related to Mongolian species assemblages.

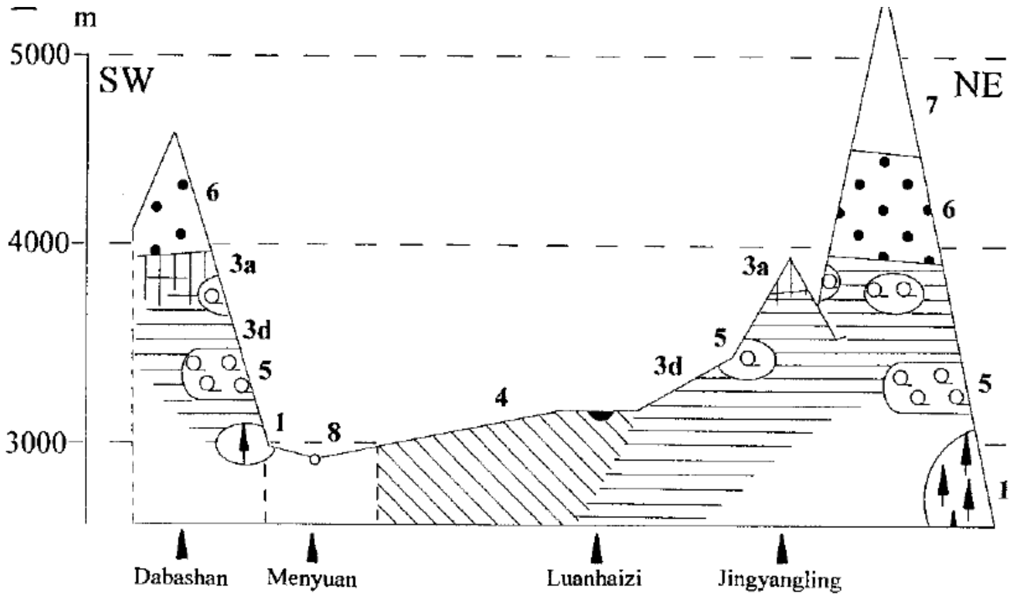


Figure 7. Schematic profile of the Qilian Mountains – Dabashan. Main vegetation types (3–5) and mosaic and patchy distribution of relict vegetation units from the north-eastern Qinghai–Xizang Plateau: 1- coniferous belt; 3,4 – alpine meadow belt; 5 – alpine bush belt; 6 – alpine scree; 7 – alpine/nival permanent glacier-snow belt; 8- area under cultivation (after Kürschner et al. 2005).

2.2.3. Changes in vegetation cover

In the recent decades, several major triggers have made an impact on the vegetation cover variation in the Qilian Mountains: climate change (annual increase in precipitation and temperature); overgrazing and soil erosion (Dai et al. 2011). However, it is hard to determine the impact of each of these factors separately due to strong interrelations (e.g. one factor can be triggered by another) and their cumulative effects.

The effect of climate change was apparent in different elevations and exposures in the Qilian Mountains. Increased precipitation showed a visibly positive impact on the gain in vegetation cover on lower elevations. In contrast, on the south-facing slopes (Pic. 1, 2), in areas on 2500 -3100 m a.s.l., vegetation cover frequently declined (Deng at al. 2013).

Picture 1. South-facing slopes (photo is taken on 2560 m a.s.l.) (30.07.2011).

As it would be further discussed (in the section **2.4. Land degradation**). Grazing assessments. Background), the impact of animal grazing on non-equilibrium ecosystems is usually overlooked or overlaps with the impact of local climate and other abiotic site factors. At the same time, in the mountain areas along the altitudinal gradient, it is hard to determine where the shift from non-equilibrium to equilibrium ecosystem dynamic actually appears. More research is needed to investigate the implications of the equilibrium theory of ecosystem functioning on the example of grassland patterns along the altitudinal gradient in the Qilian Mountains.

Picture 2. Grazing sheep on the south-facing slopes of the spring/autumn pastures (30.05.2012).

The composition and structure of vegetation has significantly changed in nearly all of the surveyed areas in the Qilian Mountains (Chen et al. 1994; Wang et al. 2002; Herzschuh et al. 2005; Kürschner et al. 2005). Steppe communities of *Achnatherum* and *Stipa* species are widely replaced by intensive agricultural activity (below 2600 m a.s.l.) and rapes cultivation (up to 3000 m a.s.l.). Alpine meadow communities have expanded over the degraded forest and shrublands. Former coniferous forest belts comprised of *Picea crassifolia*, *P. wilsoni*, *Pinus tabulaeformis, Sabina przewalskii* and *Betula platyphylla,* remained fragmentally on the north-facing slopes between 2600 and 3200 (Pic.3). Between 3200 and 3800 m a.s.l., shrublands consisting of *Potentilla fruticosa, Caragana jubata,* and *Salix* spp. are mixed with *Kobresia* mats, whose mosaic degree depends on the grazing intensity. The downward expansion of shrublands due to deforestation was observed (Herzschuh et al. 2005). The areas of the forests and grasslands have become secondary vegetation, with a high percentage of unpalatable, toxic and spiny plant species that have a lower grazing value and rarely form a closed vegetation cover (further detailes – in Chapters 3, 4 and 5).

Picture 3. *Picea crassifolia* forest on the north-facing slopes, forming forest/shrubland ecotones in the bottomes of the hills (25.07.2011).

2.3. Land use types: past and present. Local economy

2.3.1. Land use in the past. Rangeland rights

In 1949, as a consequence of the Chinese Cultural Revolution, rangelands were nationalized, and first land use changes in the form of collectivization took place. In the period between 1950s and 1970s, rangelands and livestock as a part of the agrarian sector were managed by collective units called communes (Renmingongshe), brigades (Dahui), and production teams (Schengchandui) (Yamaguchi 2011). During this time, no restrictions to mobile pastoralism were made (Miller 2005). At the end of the 1970s, the communes were resigned, and a new Household Responsibility System (HRS) took its place, according to which agricultural fields and livestock were distributed between the households based on the number of their members, while most of the rangelands were owned as common property, originally belonging to the federal state (Yamaguchi 2011; Goldstein 2012). As shown by later research, such community-based pastures were subject to overgrazing and triggered the early stage of land degradation (Ho 2000).

In 1978, the decollectivization of the agricultural sector began (Miller 2005), and in the 1980s several reforms were initiated to promote market growth. One of those was a policy called 'Rangeland Law', implemented in 1985 (Ho 2000). It brought to life a contract system of long-term leased pastures for 30 of 50 years. Exclusive rights to them could be inherited but not sold. Although many herders settled down and fenced the pastures allocated to them, no measures were taken for the future readjustment of the rangelands according to the changes in livestock numbers (Miller 2005). Since then numbers of cattle per household have significantly increased, resulting in a considerably decreased quality of pasturelands all over China (Yang 1992; Miller 2005; Akiyama & Kawamura 2007; Harris 2010). It caused a major problem of overexploitation and degradation of the land, when too many animals were allocated to the restricted pasture areas.

Picture 4. Grazing yaks on the summer pastures, close to the camp (3100 m a.s.l.), with grazing sheeps on the back. The senery behind: distinct differentiation of the two pasture areas, devided by the fance – heavily grazed shrubland on the right side and undisturbed alpine meadow on the left side (18.07.2013).

At the same time, certain restrictions were applied to the herding strategies of the local ethnic minorities and rotation of pastures. Transhumance practices were prohibited in several regions of the Tibetan Plateau, where it used to be a part of traditional culture. One of the reasons for the sedentarization measures implemented by the Chinese government was to stop animal losses during the explicitly cold winters, as well as to show a control over land degradation on the Tibetan Plateau. To reach the goal, a 'Four-Way Programme' was implemented (Miller 2005). It included selective fencing of more productive pasturelands, the construction of fixed houses for nomads and animal shelters on winter pastures, establishing small plots for hay cultivation, and fencing of degraded land for recover of vegetation with seeds and fertilizer. When promoting livestock numbers during the winter, the area of the spring/autumn and summer pastures remained the same, meaning enhanced deterioration of the rangeland (Pic.4, 5). By artificial intervention into self-regulated non-equilibrium ecosystem functioning (see Chapter "Land degradation") and sedentarization of the nomads, pasture degradation on the Tibetan Plateau was enhanced, and many families were left in poverty due to the severe loss of the cattle, followed after snowstorms and cold temperatures (Miller 2000).

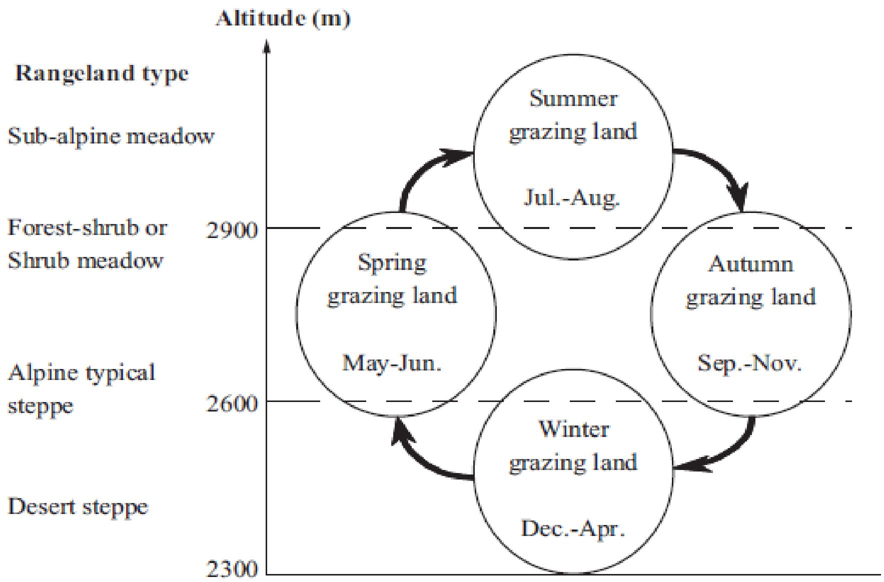


Figure 8. Schematic diagram of the altitudinal distribution of seasonal grazing rotation in the Qilian Mountains (transhumance) (after Yuan & Hou 2015).

2.3.2. Ethnic minorities. Economy of the local herders

Different ethnic groups inhabit the region of the Qilian Mountains and Hexi Corridor. These include Hui, Han and Zang, Uygur, Yugur and Tibetan people. Among these, Yugur is a unique nomadic minority. From a total number of 1260,000 Yugurs, only 260,000 are urban residents. Most of them are herders, farmers, and hunters. The Yugur people have inhabited the northern foot of the Qilian Mountains and the middle part of the Hexi Corridor (Yugur Autonomous Country of Sun'an) since that time when the Hexi Corridor was a gateway to the western valleys, a part of the Silk Road. Yugurs are closely related to the Uygur people of the Xinjiang Province (Li 2003). Many Yugur and Tibetan families still follow a nomadic lifestyle, although many were forced to change to semi-nomadic, or even to settle down due to the government's sedentarization policy (Vetter 2005). In our study area, the annual rotation cycle of herders with livestock is illustrated in Figure 8.

Picture 5. A view from the summit (3800 m a.s.l.) to the North: stipples hills on the plateau – winter pastures, and a fixed houses in a settlement – Ba Yi village) (24.07.2011). On the back: the foothills of the Qilian Mountains and a viewon the Hexi Corridor in th edirection of Zhangye city.

Interviews with herders' families in the study area. Stocking rates.

According to our observations, the number of sheep and goat for each family varies from 400 to 580, depending on the number of family members (Table 5). Six families were visited in the Ba Yi village close to the winter pastures (Pic. 5) and in two other locations in summer camps (Zhen Nan Gou and Lou Zhuang Zi – Pic. 4 and Pic. 6), partly including our investigation sites. Most respondents recognize themselves as 'zang' (Tibetan minority), who were born in this area. Size of the families varies from 4 to 7 people, excluding small children.

Picture 6. Overgrazing of the summer pastures in the proximity to summer camp. Flock of the yaks is grazing on the remains of Potentilla shrubland (3200 m a.s.l.) (24.07.2011).In front on the left side: bare ground – examples of soil erosion.

As mentioned by a 32-year-old Tibetan herdsman named Qin Bei, pasture degradation is recognized by the local authorities, and the herder families are subsidized with 2,000 RMB annually and additional 1.2 RMB for each mu of 'degraded pasture' to sustain their living (as degraded pasture in the Table 5 it is assumed to be the one which is in use). In 2012, the price of one yak was 4,000 RMB and that of one sheep was 1,000 RMB. Usually, herders would sell the sheep when they were 8 months old in September–October, in the city market of Zhangye. Altogether, the mean annual income per family accounted for 126,700.00 RMB (~16,106.78 euro).

Table 5. Socio-economic data on local inhabitants of the Qilian Mountains (based on interviews).

Households No, names of the representatives	**Ethnic group, local status**	**No. of family members**	**Economic activity**	**Size of the pasture area, mou (亩)**	**Number of cattle**	**Annual income, (RMB)**
1. Qin Bei	Zang (Tibetan) local	5 people, 1 child	herders	Total: 5000 In use: 2700	40 yak 560 sheep	120,000.00
2. Ba Xiang Cheng	Zang (Tibetan) local	7 people, 2 children	herders	Total: 6300 In use: 2800	100 yak 580 sheep	150,000.00
3. Gu Jian Jun	Zang (Tibetan) local	5 people	herders	1700	450 sheep	110,000.00
4. Gu Jian Guo	Zang (Tibetan) local	4 people	herders	1200	400 sheep	100,000.00
5. Fan Yu	Han (Chinese) not local	6 people	herders	2800	500 sheep	150,000.00
6. Fan Li Feng	Han (Chinese) not local	5 people	herders	Total: 2900 In use: 2000	500 sheep	130,000.00

Stocking rates

In the interviews, the herders did not differentiate between the numbers of sheep and goat (in Chinese language, these two kinds of animals are very close in meaning). Small ruminates varied between 400 and 560 per household, while reported numbers of yak were between 40 and 100. In China, it is common to estimate the carrying capacity of the land in animal units per hectare (AU/ha), 1AU/ha=50 kg sheep female. A male domestic yak weighs 300–500 kg, while a female yak weighs 200–300 kg. Usually most yaks in the household are females. Since we do not have any precise data on male yak numbers, we use an average yak weight (200 kg, about 4 sheep) to calculate the carrying capacity in total AU/ha (Table 6).

According to the provided data and our estimations (Table 6), the mean size of the actual pasture area accounts for 188.35 ha per family, with a mean stocking rate of 4.47 AU/ha. In comparison, in the north-eastern edge of the Tibetan Plateau, Miao et al. (2015) reported 5 AU/ha as the high stocking rate. In arid Inner Mongolia (mean annual precipitation (MAP) <400 mm), medium stocking rates vary from 1 to 1.5 AU/ha (Han et al. 2008), with high stocking rates of 3 AU/ha, already leading to overgrazing and a decrease in the rangeland health (Wang et al. 2011b). Typical stocking rates in the dry middle east vary from 0.8 to 2.3 animals/ha. These were used in modelling by Köchy et al. (2008), who reported that stocking rates could be increased from 1.8 up to 5.8 sheep equivalent/ha following MAP gradient from 300 to 800 mm, respectively. Based on the mentioned above findings, it can be concluded that in the Qilian Mountains stocking rate estimates show diverse numbers with extreme cases of overgrazing and mean stocking rates exceeding the prospective carrying capacity (cf. Retzer 2003; SDC: Green Gold project 2015). However, more important than long-term mean stocking rate estimations is the duration of grazing at a particular time and space point in the landscape where actual grazing pressure is applied (Vetter 2005).

Table 6. Numbers of sheep and yak, and the size of the pasture area, calculated for each household, as prescribed in Table 5.

House holds No	Grazing animals		Pasture area				Sheep SR	Total number of grazing animals		
	yak	sheep	In use, mou	Total, mou	in m²	In ha		SR	AU	AU/ha
1	40	560	2700	5000	1800009	180.00	3.11	3.33	800	4.44
2	100	580	2800	6300	1866676	186.67	3.11	3.64	1180	6.32
3	0	450	1700	0	1133339	113.33	3.97	3.97	450	3.97
4	0	400	1200	0	800004	80.00	5.00	5.00	400	5.00
5	0	500	2800	0	1866676	186.67	2.68	2.68	500	2.68
6	0	500	2000	2900	1333340	133.33	3.75	3.75	500	3.75

Size of the pasture area, mou (亩) (1 mou =666.67 m²)

SR - stocking rate: animals/area in ha

AU - animal units per ha, 1 AU = 50 kg sheep.

Other economic activities in the Qilian Mountains

The main economic activity of the local inhabitants is livestock husbandry and the delivery of dairy products from yak, such as milk, butter, cheese, whey, and yogurt (last three are not common among the Qilian Mountains herders). Other traditional contributions of yak—pack transportation, hides and hair, yak dung, etc.—are less common in the study area, as they are probably being substituted with modern commodities, e.g. motorbikes for transportation and coal for heating. We also witnessed sheeps hearing—another common practice in the beginning of summer. Sheep's wool mostly goes for sale. In July and August, when the conditions are favourable for mushroom grow, another activity takes place: Starting from the early morning, village mushroom collectors and incoming citizens inspect the spruce forests in order to win most harvest after the rain. Most of the collected mushrooms are dried and then sold for a high price in the city markets.

Commercial logging is another common practice in the Qilian Mountains, as well as across the whole Gansu Province, where, according to Li et al. (2003), only 25% of the suitable forest land is actually covered by forests. This could be the result of continuous deforestation in the earlier times and extensive logging during the period of Communes. In the study region, logging was completely prohibited in the 1970s because the Qilian Mountains coniferous forests were reserved for a water protection area (personal communication with the members of the Forestry Bureau). During fieldwork, we were able to estimate the average age of one of the oldest protection areas—the Xishui natural forest—which is considered 85–110 years old. Nevertheless, other activities, such as regular animal grazing, seasonal mushroom gathering and public hiking, are allowed in the region, making a visible impact on the stability of the forest and forest grassland ecotones' top soils by trampling, thereby increasing the soil runoff and erosion processes.

2.3.3 Problem of land degradation

The widespread problem of land degradation seems to have been recognized by the Chinese government and local agencies since the mid-1990s, when it was considered among one of the nation's most severe environmental challenges (Ho 2001; Steinfeld 2006; Harris 2010; Yamaguchi 2011). As per calculations for Northern Tibet, from 1981 to 2004, the extent of degraded alpine grasslands reached 50.8% of the total grassland area (Gao et al. 2010), influenced by increasing numbers of livestock (Li et al. 2003; Li et al. 2004). To solve this problem, several regional programmes have been launched, such as 'Retire livestock and restore pastures', which would include fencing and grazing exclusion to restore parts of the grasslands (Yan & Lu 2015). At the same time, new management policies were implemented, restricting the number of animals per household. But the system of control is not working properly, and herdsmen tend to keep more animals illegally, thus gaining profits due to the increasing market demand for meat. Still, some uncertainties remained regarding the rights to access transitional grazing lands, provoking uncontrolled grazing mostly on spring–

autumn pastures, which inhibit plant growth and reproduction (Yang 1992; Li et al. 2003). Moreover, extremely high grazing pressure is found in areas close to the camps on the summer pastures in alpine meadows in the Qilian Mountains. The definition and general causes of land degradation are discussed in more detail in the next section on land degradation.

2.4. Land degradation. Grazing assessments. Background

2.4.1. Equilibrium/non-equilibrium concepts

There are no attributes non-equilibrium systems and there is no dichotomy between equilibrium and non-equilibrium systems, rather there is a continuum in degree to which composition of the ecosystems is out of "favorable" state, or the ability of ecosystem to persist in more than one "stable state" (Walker 1997).

According to modern range ecology, there are two types of rangeland ecosystems: equilibrium and non-equilibrium ones (Ellis & Swift 1998; Behnke et al. 1993). In the first type of ecosystem, grazing pressure is directly counterbalanced by the natural regeneration of the vegetation, hence the name *equilibrium* (Vetter 2005). However, there are environments where variation in vegetation cover is rather connected with abiotic factors (e.g. variation in the precipitation rate) and the impact of grazing is not as apparent (Ho, 2001, Vetter, 2005). Because numbers of the animals are regulated by the available biomass, which is dependent on precipitation, grazing animals can hardly reach high numbers to have an impact on the degradation of the system as a whole (Retzer 2003). Such ecosystems are called *non-equilibrium* and there are different local criteria to define them (Ellis & Swift 1998; Behnke et al. 1993; Vetter 2005). However, mean annual rainfall variability is recognized as the primary driver of these conditions, rather than aridity (Wehrden et al. 2012). Thus, a large proportion of arid and semi-arid rangelands in China can be characterized as non-equilibrium ecosystems, where land degradation with high grazing pressure is accelerated by low (spatial and temporal) rainfall variability (Wehrden et al. 2012).

In non-equilibrium ecosystems, the estimation of the carrying capacity (as a measure of grazing impact, which would be discussed below) cannot be meaningfully applied (Retzer 2003; Vetter 2005; Heshmati & Squires 2009). Carrying capacity approaches are known to deal with the 'calculation of short-term livestock available feed and demand' and do not focus on the long-term land degradation, which appears in non-equilibrium ecosystems (Bartels et al. 1993). Land degradation induced by grazing mostly appears in conditions with high animal numbers and low rainfall variability (Wehrden et al. 2012). Due to this variability in precipitation, plant biomass changes remarkably from year to year, making it impossible to predict the best stocking rate and thus leading to overgrazing, as confirmed by the study in the Qilian Mountains (Miao et al. 2015). Nevertheless, the non-equilibrium concept is yet to be recognized by the Chinese rangeland policymakers, which might be one of the reasons for vast land degradation, especially pronounced in arid and semi-arid conditions, as described above.

2.4.2. Grazing assessment

In the scientific fields of rangeland ecology and management, several approaches to assess grazing pressure were developed under varying physical conditions of pastures (e.g. altitude, micro relief, annual rainfall and its variability, water availability). The most common approaches estimating grazing intensities, which could be used independent or in a complex (as grazing predictors for modelling purposes), are provided below:

- Estimation of the numbers of animals (e.g. stocking rates) on the land unit (in ha, m^2) to assess the pasture's carrying capacity (e.g. 'animal unit' [AU], which is in use in Chinese Rangeland Law, 1 AU/ha = one female 50 kg sheep) (Kemp & Michalk 2011; Miao et al. 2015; Yuan & Hou 2015).
- Estimation of grazing index values (GIVs), based on scores given to agronomic attributes of the plant species (productivity, forage values, perenniality) (duToit 2000).
- Piosphere concept, which accounts on the proximity to a fixed source holding/attracting the animals (i.e. water source, corral or permanent house/camp) (Andreew 1988; cf. Zimmerlich 2007; Dorji et al. 2013; cf. Wang et al. 2017b;).
- GPS tracking of grazing animals: different activities, time of trampling, and grazing (Schlecht et al. 2006; Schlecht et al. 2009).
- Track density (Pringle & Landsberg 2004).
- Duration of long-term grazing (Diaz at al. 1992).

- Interviews with local herders who determine the intensity of utilization in different pastures (Borchard et al. 2011; Hoppe et al. 2016).
- Numbers of grazing indications, including droppings, the amount of dry biomass, height of the standing crop and the number of palatable plant species (Jasmer & Holechek 1984; Pellant et al. 2005; Dorji et al. 2013; Baranova et al. 2016).
- Visual observations of site conditions (Brinkmann et al. 2009; Borchard et al. 2011; Hoppe at al. 2016).
- Visual observations of the behaviour of the grazing animals (Schlecht et al. 2009).
- Exclosure experiments to estimate the effects of the presence/absence of grazing activities (Oba et al. 2001; Wu et al. 2009; Yan & Lu 2015).

2.4.3. Land degradation vs rangeland health

There is an ongoing discussion about the definition and quantification of land degradation worldwide. Rangeland health overlaps with this issue to some extent, although the two are not always in contradiction. In the following, the qualitative and quantitative criteria of **rangeland health** are summarized:

- Grassland productivity (e.g. the amount of dry biomass weight), total plant cover, plant species diversity and plant functional diversity; plant life forms; invasive plant species cover, etc. (Brinkmann et al. 2011).
- Mortality rate of domestic animals (Behke & Scoones 1993).
- Soil quality, including soils physical and chemical properties (Wang et al. 2017b), and soil stability (Pellant et al. 2015).
- Hydrologic functioning of the soil, including soil infiltration rate and soil runoff, structure of soil layers and soil erosion (Pellant et al. 2015).-
- Biological integrity, including biotic functioning: soil microbial activity, litter accumulation; presence of common grassland invertebrate species, earthworms (=bioturbation) (Pellant et al. 2015).
- Soil organic carbon (SOC) as a measure for carbon sequestration by the grasslands (Liu 2017).

Disturbances

Certain types of disturbance are a natural and necessary part of all ecosystems. Healthy ecosystems are generally both resistant to external disturbances and resilient (e.g. able to recover), if external disturbances occur and would allow various communities to fluctuate over time within one stable state. Transitions rarely occur in response to the natural disturbance regime. However, resistance and resilience alone are not sufficient criteria for healthy ecosystems; degraded systems are often highly resistant to change (Pellant et al. 2005).

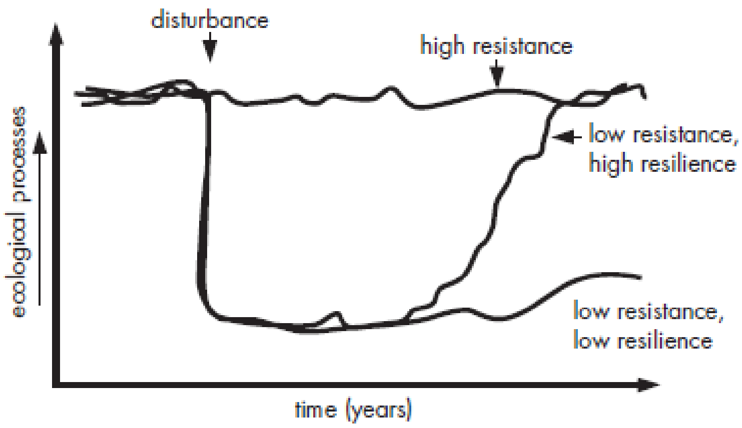


Figure 9. Changes in ecological processes over time, following disturbances in systems that are different in resistance and resilience (Pellant et al. 2005).

Plant-herbivory interactions should be not always treated in the sense of disturbance. There are certain conditions under which herbivores can increase primary production, processing the important nutrients for plant consumption (de Mazancourt et al. 1998). At the same time, nutrient turnover rates do not impact the long-term primary production of equilibrium systems (Bronstein et al. 2004), and grazing optimization occurs even when there is replacement of more productive plant species by less productive ones (de Mazancourt & Loreau 2000).

Chapter 3. Vegetation Patterns & Floristic Diversity

MOUNTAIN PASTURES OF QILIAN MOUNTAINS: PLANT COMMUNITIES, GRAZING IMPACT AND DEGRADATION STATUS (GANSU PROVINCE, NW CHINA).

Summary

Environmental degradation of pasture areas in Qilian Mountains 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, spatially differentiated changes in vegetation patterns. The study area is located in the pasture area of South Qilian Mountains between 2600-3600 m, and covered by five main vegetation types: spruce forest, alpine shrubland, shrubby grassland, mixed grassland, degraded mountain grassland. Quantitative and qualitative relevé data were collected for community classifications and for analysing gradual changes in vegetation patterns along altitudinal and grazing gradients. Vegetation was classified using hierarchical cluster analysis. Detrended correspondence analysis (DCA) was used to analyse variation in relationships between vegetation, environmental factors and differential grazing pressure. The results of DCA showed apparent data distribution along the grazing gradient. Two factors – altitude and exposure – have the strongest impact on plant community distribution. Comparing monitoring data for the 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.

3.1. 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 and shoot architecture of plants - short, prostrate and rosette plant forms are less sensitive (Diaz et al. 2006). In general, grazing favours rather annual than perennial plants (Diaz et al. 2006), and increases rather the abundance of herbs than those of grass and tall forbs species (Metera et al. 2010). Generally the effect of grazing is connected with the disappearance of good forage grasses and an increase in the rate of invasive species (Zhou et al. 2006).

According to the intermediate disturbance hypothesis (Connell 1978; Kershaw & Mallik 2013), diversity of grazed plant communities varies along a gradient of grazing pressure. Extensive (or moderate) grazing was proved to be an effective tool to maintain genetic and biotic diversity of grasslands, while species richness is lower under the complete exclusion of livestock, and overgrazing leads to the loss of biodiversity (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 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 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 aggravate the establishment of proper rangeland management (Li et al. 2003; Yang 1992). Grazing with sheep, goats and yak is taking place almost everywhere in the forests and adjoining rangelands, and seems to be the prime cause preventing natural regeneration of trees and shrubs. Uncontrolled increase 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 (Yang 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-lasting 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 of biodiversity and assessed that more than 50% of the pasture communities are composed of toxic plant species. Under overgrazing 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, detailed studies focusing on vegetation-environment relationships and on variation of vegetation patterns with changing site conditions and differential grazing impact are missing so far.

In order to reduce prevailing research deficits, the objectives of this study are to clarify hitherto unknown implications of increased grazing intensity for rangelands in the Qilian Mountains. We hypothesize that habitat qualities and biodiversity of grazing lands are declining due to increased utilization pressure under the conditions of recent socio-economic change in NW China. We focus (1) on main environmental variables influencing vegetation patterns along the vertical 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.

3.2. Methods

3.2.1. 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 10). 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 major percentage of water yield is derived from the meltwater of glaciers and snow-covered permafrost areas, which are protected by the continuous spruce forest cover (Yang 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 growing seasons 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 (Wang 2002; Wu 1980). According to FAO international classification 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-facing sunny slopes are occupied by grasslands with sparsely distributed drought-tolerant shrub patches.

In Qilian Mountains transhumance pastoral system is in use (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 stay on the 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 condition of 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.

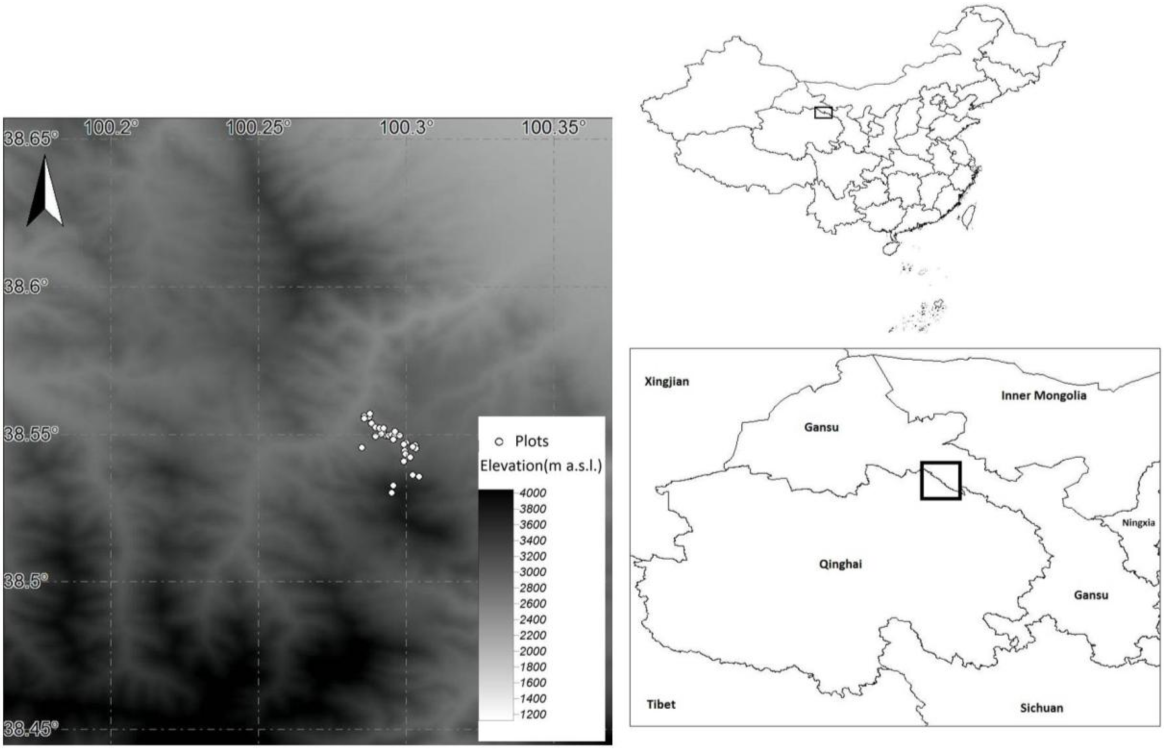


Figure 10. Location of the study area: North-West China, Gansu Province, Qilian Mountains, Pailugou Catchment (white spots mark sampling plots).

3.2.2. 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 (2650-3100 m a.s.l.) in different accessible slope exposures, including some sites at higher elevation (3600 m a.s.l.). The sampling was restricted by topography of the Pailugou catchment, therefore some slope exposures were not reachable or were not presented 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 10x10 m, 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 internet accessible 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 weighted. Dry weight was measured after treatment in oven 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, droughtness 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: slightly grazed (1), moderately grazed (2), intensively grazed (3).

3.2.3. 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 exposure degrees (0-360°) were recalculated into two independent variables “eastness” and “northness” after Zar (1999): Eastness = sin ((slope exposure in degrees x π)/180); Northness = cos ((aspect in degrees x π)/180).

To classify plant communities, Hierarchical Cluster Analyses was performed (using Euclidian dissimilarity distance measure and Ward's group linkage method). To check the significance of the differentiated clusters, 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 the 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 in a particular group, which allows setting a threshold for Cluster Analysis. To evaluate the statistical significance of indicator values for given species, we used 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 Mountains, relevés and species records of 2003 and 2012 were compared with respect to percent of palatable / unpalatable species. Species data of 2003 had been obtained in the framework of the 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 on 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 analyzed with respect to their palatability according to Damiran (2005), Lu et al. (2012) and Quattrocchi (2012). In order to contribute into framework of sustainable pasture management, species indicating specific site-environmental conditions were distinguished using sources of eFloras and Subject Database of China Plant.

Palatability of the plant species is changing in 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.

3.3. Results

3.3.1. Classification and distribution patterns of vegetation

The vegetation of the Pailugou catchment was divided into five types, obtained by cluster analyses (Figure 11): *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 in difference between species composition of distinguished groups was indicated by MRPP (Multi-Response Permutati on procedure): T =-10.42, A = 0.08, $p < 0.001$ (T = difference between observed and expected deltas; A = chance-corrected within-group agreement, p). The following plant communities were differentiated according to dominant species, identified by Indicator Species Analysis (App. Table 1).

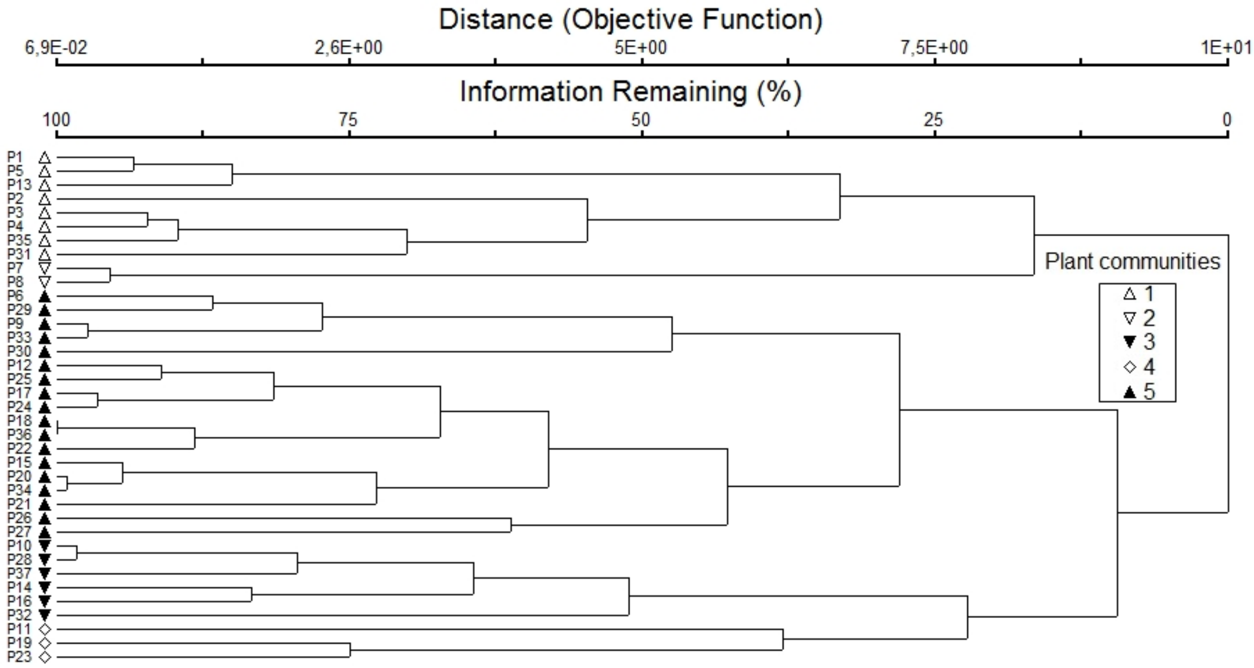


Figure 11. Dendrogram showing different vegetation units along the altitudinal gradient in Pailugou catchment obtained by Hierarchical Cluster Analyses.

3.3.2. 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 7, Figure 12).

Table 7: Pearson's correlation scores from PC-ORD DCA output for the first three axes with the 6 environmental variables and plant cover values (Figure 12).

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

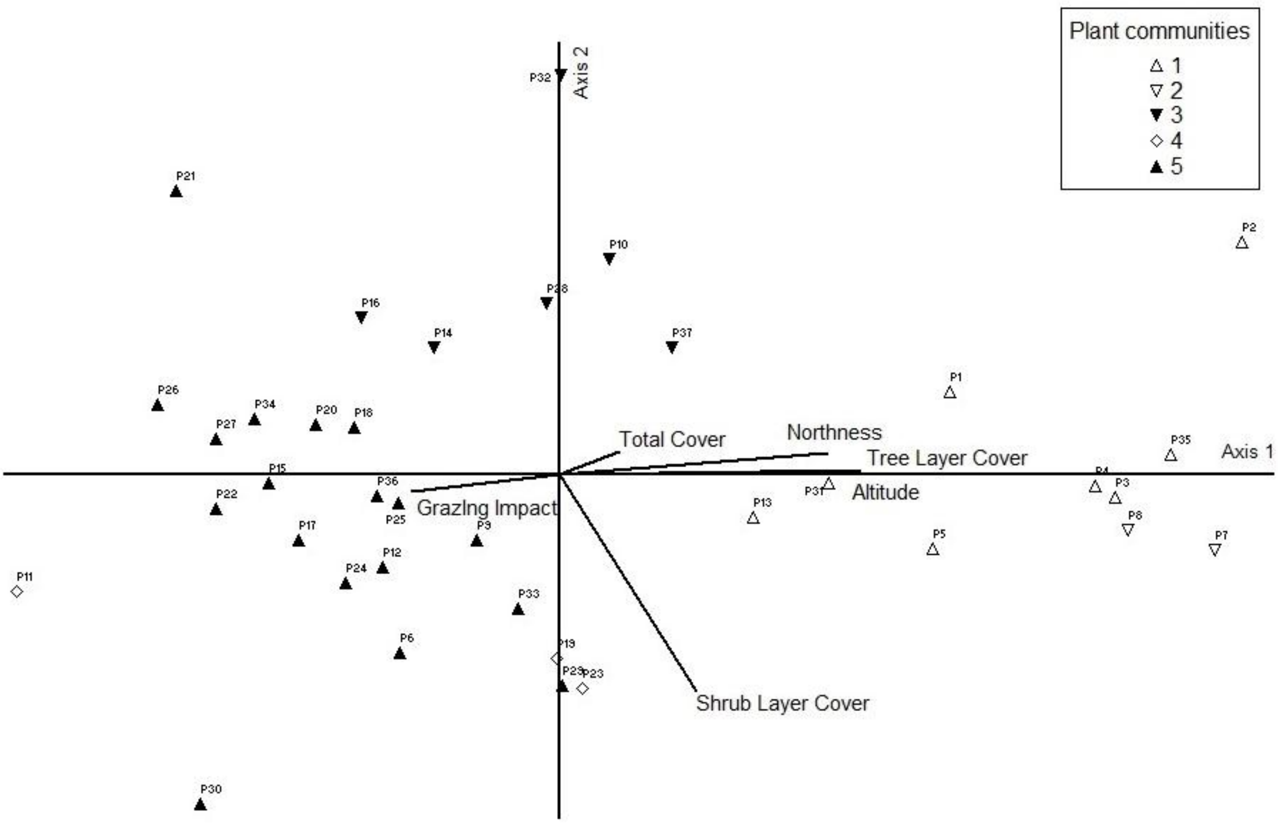


Figure 12. Ordination biplot: DCA of the vegetation distribution (plot data), environmental factors and plant cover values. Plant communities are the same as in Table 1: Picea crassifolia forest (1), Salix gilashanica - Arctostaphylos alpina shrubland (2), *Potentilla anserina - Geranium pratense* grassland *(3*), *Stellera chamaejasme shrubby* grassland (4), *Stipa capillata* mixed grassland (5).

The distribution pattern of vegetation types showed a clear dependence on altitude and slope exposure: *Stellera chamaejasme shrubby* grassland (4) community is distributed at lower altitudes, occupying south-east/south-west facing slopes, whereas *Picea crassifolia* forest (1) and *Salix gilashanica - Arctostaphylos alpina* shrubland communities (2) cover north/north-east/north-west-facing slopes at higher elevations. To elaborate the effect of grazing and related environmental factors, grassland communities have been analyzed separately (Figure 13, Table 8).

”Eastness” factor (r = 0.137), representing east-west exposure, and slope inclination (r = 0.058) had an insignificantly low influence with respect to vegetation distribution in grasslands; therefore these two factors are not represented on the biplot (Figure 13). Grassland communities, *Stipa capillata* mixed grassland in particular, were affected by grazing impact to a large extent (cf. Figure 13).

Table 8. 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 13).

	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

Main floristic gradients within mountain grassland along Axis 1 were determinated 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.

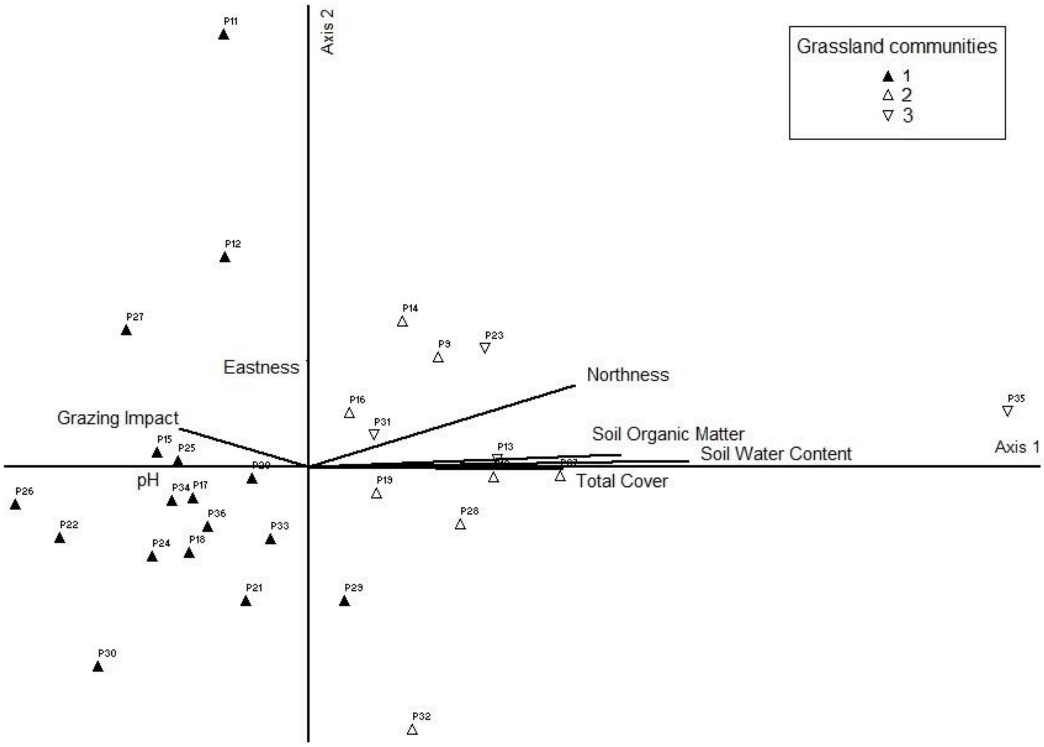


Figure 13. Ordination biplot: Detrended Correspondence Analyses of the mountain grassland vegetation showing the main gradients of environmental factors. Plant communities: 1 - *Stipa capillata* mixed grassland, 2 - *Potentilla anserina - Geranium pretense* grassland*, 3- Stellera chamaejasme* shrubby grassland.

3.3.3. Plant species richness, diversity and indicator species

In total 112 vascular, bryophyte, and lichen species from 34 families were identified, among which 29 families of angiosperms. Among the distinguished communities, species richness and diversity indices were calculated per 100 m² plot (Table 9). 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`s diversity index of 1.993 and Simpson`s 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`s and Simpson`s 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 9. Richness, Evenness and alpha diversity indices of the main plant communities obtained in cluster analyses.

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

ISA after Dufrêne and Legendre (1997) identified the species with highest indicator value (Table 10). 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.

The presence of 26 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 have been 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 having lower rate of disturbance, which is in turn reflected in the deviating species composition.

Table 10. Indicator Species Analyses for the taxa in the five plant communities in mountain grasslands of Qilian Mountains. Indicator value is given in percent of perfect indication (IV). Monte Carlo test of significance of the observed maximum indicator value for ea each species, with 999 randomisations, provides p-values.

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 alpina	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 anserina	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 pratense	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

Furthermore, species were distinguished indicating specific site-environmental conditions (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 palatability section)*;* species common on south-facing 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.

Picture 7. Expansion of the *Stellera chamaejasme* (summer pastures, 3230 m a.s.l.) (12.07.2013).

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*) was increasing (Figure 14: A), while constancy of the common fodder species in 2012 was decreasing (Figure 14: B). Change in constancy of *Agropyron cristatum* and *Stipa capillata* was more pronounce, than those of *Kobresia humilis* and *Polygonum bistorta*, which were found almost on the same level in 2003 and 2012. Recent field investigations of 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 (Pic. 7: A, B).

3.3.4. Palatability and grazing

When being subjected to long-term grazing, mountain pastures have experienced positive selection of species resistant to grazing due to its 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 Mountains, most common toxic species included *Stellera chamaejasme*, *Achnatherum* spp.*, Oxytropis* spp., and *Pedicularis* spp. The most widespread unpalatable species (Table 11) were *Iris lactea* var. *chinensis, Caragana jubata, Leontopodium leontopodioides* and *Sibbaldia procumbens*.

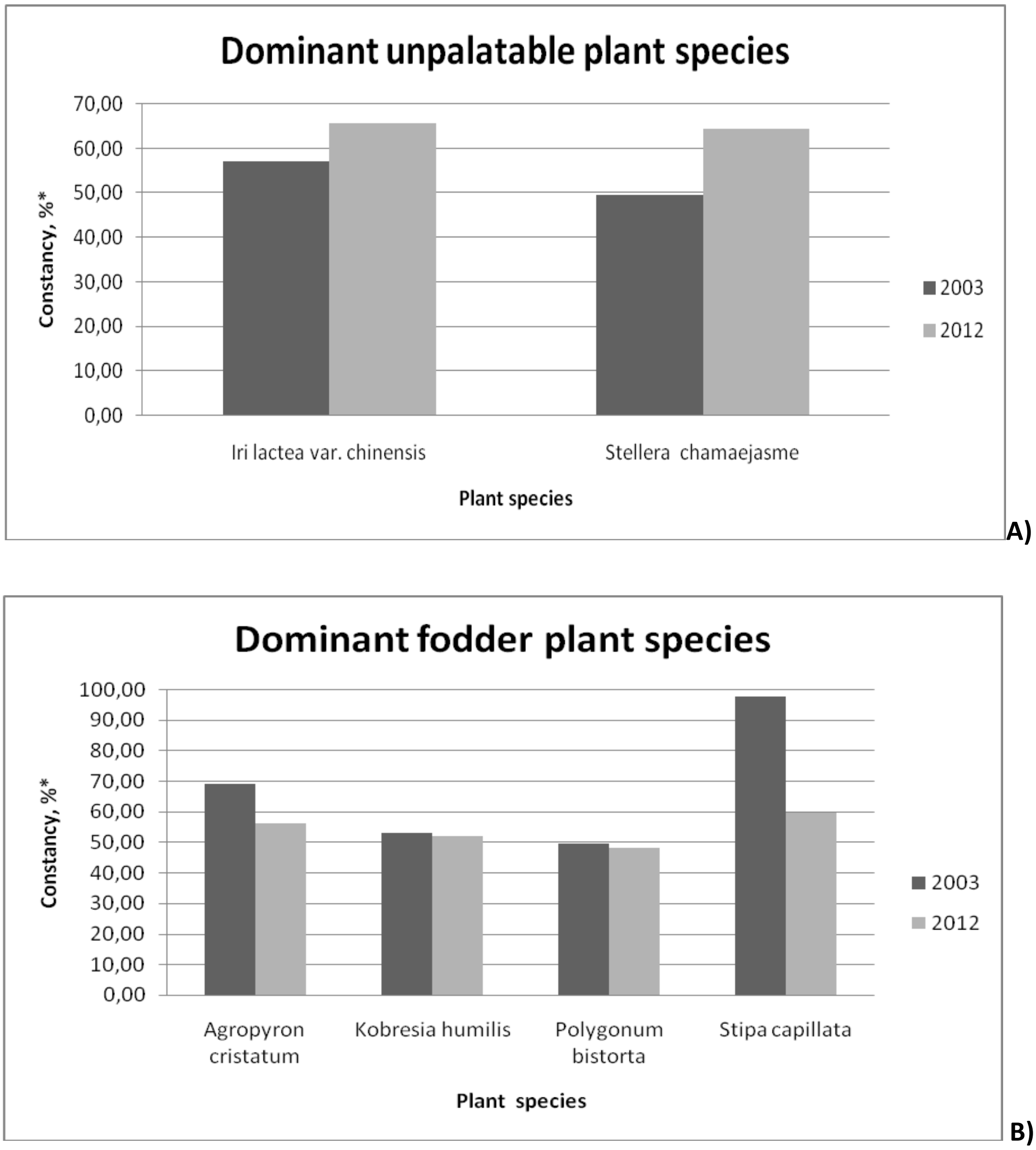


Figure 14: A, B. Diagram showing the dominant palatable (A) and unpalatable (B) plant species in comparison of species records from 2003 and 2012 (provided dominant species are those which were found in both datasets).

According to our observations, *Iris lactea* var. *chinensis* covered up to a half of the pastures and its amount is increasing from year to year, declining the forage quality and generally reducing the suitability of the area for animal husbandry. Similar trend is observed for *Stellera chamaejasme*, which was detected almost on every grassland plot as co-dominant species.

In particular, intensively grazed areas were identified on south-facing grasslands at lower altitudes (App. 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.

Species most preferred by grazing animals (sheep, goats and yaks) were perennial grasses (*Stipa capillata, S. breviflora, S. kirilovii, Agropyron cristatum*), sedges (*Kobresia humilis, K. pusilla, K. tibetica*) and forbs (*Medicago hispida* and *Polygonum viviparum*) (Table 6). Long-term grazing impact have repressed these formerly dominant and/or co-dominant plant species, while toxic species such as *Stellera chamaejasme* and *Iris lactea* var. *chinensis* have increased in cover and abundance.

Table 11. 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).

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, K. tibetica*
Oxytropis glabra.	*Chenopodium pamiricum*	*Geranium pratense*	*Medicago hispida*
O. melanocalyx	*C.karoi*	*G. sibiricum*	*Polygonum viviparum*
Pedicularis kansuensis P. oedri	*Iris lactea* var. *chinensis*	*Heteropappus altaicus*	*Poa pratensis*
P. longiflora	*Leontopodium leontopodioides*	*Leymus chinensis*	*Stipa capillata,*
Saussurea salicifolia	*Sibbaldia procumbens*	*L.secalinus*	*S. breviflora, S. kirilovii*
Stellera chamaejasme		*Potentilla acaulis*	
		P.anserina	
		P. bifurca	
		P. saundersiana	

Forest area (*Picea crassifolia* forest, app. Table 1) was not affected by *Stellera* and *Iris* invasion, but it was strongly trampled and disturbed by 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 have been 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).

3.4. DISCUSSION

3.4.1. Distribution patterns and vegetation-environment relationships

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 differentiates 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 corroborate 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 fertility properties 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).

3.4.2. 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 to that, Török et al. (2016) outlined that species diversity forms a hump-shaped curve along the increasing grazing gradient. At the same time, Lomolino (2001) emphasize, that diversity-elevational gradient is rather shaped by geographically explicit variables and interaction between them.

Results of ISA clearly reflect the grazing-affected successional stage of mountain grasslands. Low number of indicator species within *Stipa capillata* mixed grassland shows 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 species diversity of the Qilian Mountains 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 low index of species evenness and low variation of species richness among three plant communities in mountain grasslands of Qilian Mountains 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.

3.4.3. Palatability, grazing impact and degradation

Based on investigations in arid rangelands of NW China, Mongolia and 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.*, Pedicularis* spp. *Stellera chamaejasme* was detected as a threat for near-natural grasslands in different 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 have observed similar trends for the unpalatable *Iris lactea* var. *chinensis,* which currently dominates on most of the mountain pasture land in Qilian Mountains, and decreases its quality by preventing the spread of preferred and consumable fodder species.

As it was shown, shift in species composition with a decrease of good fodder grass and forb species and its replacement by unpalatable and toxic plant species is caused by continued heavy grazing (Diaz at al. 2006; Zhou et al. 2006; Bisigato et al. 2008). This degradation trend is observed in particular in southern aspects at altitudes between 2600 and 3000 m.a.s.l in mountain grasslands of Qilian Mountains. Such process amplifies on the dry south-facing slopes, which are explicitly exposed to 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). Grazing of the cattle was found to be beneficial for the plant diversity of the temperate grasslands, while grazing of the sheep causes decrease of the plant diversity due to the feeding selectivity 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 was not always resulting in restoration of plant diversity of the examined pastures (Jerrentrup et al. 2015) , but in the opposite, together with the high intensity of the pasture land use, leads to loss of plant diversity.

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, 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 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.

Chapter 4. Forage Quality

EFFECT OF CONTINUOUS GRAZING, GROWING STAGE AND ALTITUDE ON FORAGE QUALITY VARIATION AND THE FORAGE PLANT SPECIMENS IN MOUNTAIN GRASSLAND (QILIAN MOUNTAINS, NW CHINA)

Summary

An important indicator of the rangeland health, associated with land degradation, is the ability of semi-natural rangelands to provide forage of sufficient quality for livestock production. In Qilian Mountains (Gansu Province, NW China) biomass production and forage quality are dependent on the seasonality of precipitation and temperature; most of the precipitation falls during summer season, when sheep, goats and yaks graze mountain rangelands. To sustain the rangelands and to improve the management strategies, the assessment of the forage quality should be implemented. The purpose of this research was to study the response of biomass, forage quality and macronutrient content different levels of grazing intensity in Qilian rangelands. We sampled above ground biomass in the growing seasons 2012 and 2013 within spring/autumn or summer grazing regimes in two altitudinal zones below and above 3000 m a.s.l. (montane-subalpine and subalpine-alpine respectively). In order to estimate forage quality, biomass was sampled in 1 m x 1 m plots, assigned to the center of 10x10 m sites, from which we collected different indicator parameters of rangeland health. Mineral and fiber content of forage biomass was estimated under different levels of grazing intensity with regard to the growing period. It was found that an increase in grazing intensity led to a decrease in dry matter weight. No linearity was observed in the relationship between nutritive value and grazing intensity. The highest fiber content (59.20 %) was found in plots mostly disturbed by grazing. The highest protein (16.30 %) and the lowest fiber (51.30 %) contents were associated with slightly grazing intensity. Concentrations of the mineral elements, such as Zn, P, K, and S varied significantly and showed maximum values under low grazing intensity.

4.1. INTRODUCTION

Estimation of herbage nutritive value is a well-known approach in rangeland ecology to evaluate forage quality (Linn & Martin 1991; Horrocks & Vallentine 1999), reflecting the capacity of rangelands to provide sufficient forage supply and indirectly indicating the status of rangeland health. However, it is questionable weather nutritive value is just a simple indicator in terms of rangeland degradation, as some studies show that grazing positively affects forage quality, while other studies suggest the opposite. In arid and semi-arid environments, forage nutritive value was found to be dependent on the spatio-temporal variation of precipitation in the growing season and grazing intensity as well (Schönbach et al. 2009; Ren et al. 2016). It has been shown that short-term grazing improves herbage nutritive value by decreasing concentrations of fiber fractions (Schönbach et al. 2012). In contrast, long-term grazing alters plant species composition and reduces the herbage biomass and soil cover (Schönbach et al. 2011), and might have negative effects on herbage nutritive value in arid and semi-arid rangelands. Effects of short-term grazing could be related to differences in plant maturity stages: regular grazing during the growing season restrains plant species on the early maturity stage, when fiber fractions remain on lower levels (McEniry & O'Kiely 2013). In general, the digestibility of the forage plant material is decreasing with increasing maturity stage (Dønnem et al. 2011).

Several studies have been conducted to show the effects of continuous grazing on herbage biomass and to examine the status of arid and semi-arid rangelands in Inner Mongolia (Zhao et al. 2005; Su et al. 2005; Dønnem et al. 2011; Wiesmeier et al. 2012; Hu et al. 2015) and in the highlands of the Tibetan Plateau (Miller 2005; Zhou et al. 2006; Yang et al. 2009). Results have shown that the degradation of rangelands due to overgrazing leads to a considerable decrease of biomass and soil quality, while exclusion of livestock enhances vegetation recovery and soil fertility. At the same time, species composition was strongly affected by intensive grazing, with a decrease in palatable and an increase in unpalatable plant species. Several experimental studies in Inner Mongolia showed a positive effect of short-term grazing on nutritive values of forage plant species (Schönbach et al. 2012; Ren et al. 2016).

Chemical mineral composition provides a valid estimation of forage quality (Van Soest & Robertson 1980) and is an important contributor to the diet requirements of the grazing animals (NRC 2001; NRC 2007; Suttle 2010), however no data on the mineral content of forage plant material in mountain regions of NW China are available to date. In general, only very few studies including nutritive value and chemical composition of the forage biomass have been conducted in the highlands of the Tibetan Plateau, pointing to a substantial research deficit (Suttie et al. 2005; Miao et al. 2015).

Except for grazing, there are other factors affecting the performance of forage plants and determining the variation of nutritive value, like plant maturity stage and altitude. It was shown that with increasing maturity stage plant accumulates more lignin in cells, which decreases digestibility and protein component of the forages; also with increasing maturity stage concentrations of the fiber fraction were increasing (Andrighetto et al. 1993; Mountousis et al. 2008; Dønnem et al. 2011). Effects of altitude are associated with adaptations of plant physiology to the cooler environment; changes in plant metabolism have been shown to be reflected in an increase of protein and other digestible forage fractions, while fiber and lignin components of plant cells were decreasing (Guo et al. 2012).

The objective of this paper is to examine the complex relationship between grazing intensity and forage quality of the Qilian mountain rangelands. Therefore, we want to analyze how biomass yields, nutritive values and mineral concentrations are influenced by (i) different levels of grazing intensity, (ii) growing stage and (iii) altitude.

4.2. Materials and Methods

4.2.1. Study area

The Qilian Mountains are located on the north-eastern slope of the Tibetan Plateau (Figure 1, A,B), together with Kunlun and Arjin Mountains they outline its northern boundary (Suttie et al. 2005). The mountain ranges of the Qilian Mountains form the southern border of the Hexi Corridor, a long, narrow passage south of Inner Mongolia, stretching from near the modern city of Lanzhou (Gansu Province) in the east to the border of Xinjiang in the west. In comparison to the eastern and western parts of the Qilian mountain range, its center has higher values of annual average temperature (3.8°C), long-term average precipitation (389 mm) and annual evaporation (990 mm) (Li & Squires 2009). Deng et al. (2013) stated that along an altitudinal gradient from 2000 to 5500 m a.s.l., annual precipitation increases from 250 to 700 mm, whereas annual mean temperature decreases from 9.6 to 6.2°C.

In general, Qilian Mountains can be characterized by the plateau continental climate (Deng et al. 2013). Lower altitudes are marked as an arid environment according to the map of the world distribution of arid regions (UNESCO, Laboratoire de Cartographie thématique du CERCG, 1977). A part of our study area (below 3000 m a.s.l.) in Qilian Mountains belongs to the arid zone with dominant winter drought climate (aridity index, measured as precipitation/evapotranspiration ratio, is between 0.003 and 0.200). Higher elevations are more humid - and according to Nagy and Grabherr (2009) could be called alpine - zone with higher soil moisture content and dense vegetation cover (personal observations). Different strategies of livestock management are implemented in these two altitudinal zones. In Qilian mountains, transhumance pastoral system is still in use (Yuan & Hou 2015), i.e., local shepherds breed sheep, goats and yaks on rangelands near the villages in winter time only (2400-2600 m a.s.l.). In spring and autumn they move upwards to use montane-subalpine rangelands nearby (2600-3000 m a.s.l.), and for summer grazing migrate to summer camps in distant subalpine-alpine rangelands (3000-3300 m a.s.l.). Typical growing season in Qilian Mountains usually begins in the second half of May; blooming phase varies in mixed grasslands between July and August. During September the dry standing crop accumulates.

The study area (100°17’E, 38°24’N), extends over montane-subalpine and subalpine-alpine rangelands, dominated by *Stipa przewalskii–Stipa purpurea,* and *Polygonum viviparum* respectively (Wang et al. 2002). Intensive grazing activities affecting the rangelands in recent decades have resulted in a decline of biodiversity, with a loss of many species in semi-natural pasture communities (Chang et al. 2004). According to our own observations (Baranova et al. 2016), montane-subalpine rangelands of Qilian Mountains show signs of deterioration from semi-natural to degraded rangeland, where the common forage plant *Stipa capillata* L. is co-dominated by unpalatable *Stellera chamaejasme* L. and *Iris lactea* var. *chinensis* (Fisch.) Koidz; other widespread unpalatable plants are species of the genera *Achnatherum, Oxytropis* and *Pedicularis.* Species most preferred by grazing animals were the perennial grasses *Stipa capillata* L.*, S. breviflora* Griseb.*, S. krylovii* Roshev.*, Agropyron cristatum* (L.) Gaertn.), the sedges *Kobresia humilis* (C.A.Mey. ex Trautv.) Serg., *K. pusilla* (N.A.Ivanova)*, K. tibetica* (Maxim.), and the forbs *Medicago hispida* Gaertn. and *Polygonum viviparum* L*.*

4.2.2. Biomass sampling

We sampled aboveground biomass in 1-m^2-plots placed in the centers of 20 fixed sampling sites 10x10m, distributed in two altitudinal zones: in montane-subalpine rangelands of Pailugou catchment (below 3000 m a.s.l.) and in subalpine-alpine rangelands of Dayekou (above 3000 m a.s.l.) in central section of Qilian mountains. Subject to sampling were rangelands with spring/autumn and summer grazing (Pailugou and Dayekou respectively), as well as areas excluded from grazing. Based on the grazing history of the area and interviews with the local herders, we have assessed grazing impact following the guidelines for interpretation of rangeland health indicators (Pellant et al. 2005). To do so, on each sampling site (10x10m), the following indicator parameters were collected in the field: visual evidence of grazing (shortened plant specimens being clipped), relative moisture condition of the soil sample (dryness), steepness (degree), evidence of erosion (visual disturbance of the upper soil), percent of total vegetation coverage, percent of trampled ground (sheep and yak pathways), presence of sheep and yak excrements, number of poisonous plant species, percent cover of unpalatable and poisonous plant species and percent of dry standing crop (remaining vegetation of the last growing season). These parameters were graded from 1 to 3 and were assigned into a range condition scale (App. Table 2). As a result four grazing classes were formed: (a) not disturbed, (b) slightly, (c) moderately and (d) intensively grazed (with n=15 per grazing class). We replicated the sampling three times during the growing season 2012 and 2013 with an interval of 3-4 weeks, to assess the differences between three growing stages and to detect best grazing period (Wang et al. 2007; Dønnem et al. 2011). Plots harvested once were not sampled again. As we were focusing on understory vegetation, the aboveground biomass of woody species was not measured. For each plot, standing biomass was clipped on the ground level and separated from extraneous components; dry standing crops were excluded from the analyses. Biomass samples were oven-dried at 60°C for 24 hours, after what they were dried at 85°C to correct for residual moisture. In total, 120 biomass samples were collected during two growing seasons, 109 of them were suitable to use in analyses.

4.2.3. Laboratory analyses

We analyzed the mineral content (P, Ca, K, Mg, S, Mn, Fe and Zn) of the samples in concentrated aqua regia (HCl/HNO_3, 3:1) under reflux by atomic absorption spectrometry in the Department of Soil and Environment, Forest Research Institute, Freiburg, Germany. Nutritive value of the samples, in terms of Acid Detergent Fiber=ADF, Neutral Detergent Fiber=NDF, Acid Detergent Lignin=ADL, TDN=Total Digestible Nutrients, N=Nitrogen, CP=Crude Protein, and ash, was obtained from standard chemical analyses (cf. Ortmann et al. 2006; Stolter et al. 2005) in the Department of Animal Ecology, Hamburg University, Germany. There was no further differentiation made between the different ADF fractions. TDN values were calculated after Horrocks and Vallentine (1999): TDN (%) = (-1.29*ADF(%))+101.35; CP values were obtained by multiplying with standard conversion factor: CP(%)= N (%)*6,25.

4.2.4. Statistical analyses

We compared the variation of the examined forage parameters (i.e., biomass dry weight, nutritive value and mineral components) i) across the defined grazing classes, ii) during the growing period (three growing stages: June, July, August), and iii) in two different altitudinal zones, i.e., montane-subalpine (2600-3000 m a.s.l.) and subalpine-alpine (3000-3300 m a.s.l.). Therefore, we firstly tested for normality and homogeneity of variance using Shapiro Wilks and Bartlett´s test, respectively in order to verify whether the statistical assumptions for performing an ANOVA were met. If the data were suitable, one-way ANOVA was applied to compare the variation for each dependent variable followed by a Tukey post-hoc comparison of means. If the data were found to be not suitable for ANOVA, we applied a Kruskal-Wallis test, followed by a non-parametric post-hoc multiple comparisons after Siegel and Castellan (1998). Analyses were conducted with the software R (version 3.1.3, R Core Team 2015) and the additional package “pgirmess” (Giraudoux 2015) for the Kruskal Wallis multiple comparison procedure.

4.3. RESULTS

4.3.1. Effect of grazing

Analyses of variance showed significant variation of dry biomass weight between four grazing classes ($p \leq 0.001$). Within-class variations were also statistically significant (Table 12). The highest mean dry weight was found in “not disturbed” grazing class (202.6 g/m^2) and the lowest - in “intensively grazed” class (56.40 g/m^2).

Among the nutritive value parameters, NDF, CP and ash showed significant variation ($p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.05$ respectively). Mean NDF concentrations were similar in “not disturbed” (53.70%) and “moderately grazed” classes (54.60%) (Figure 15: C); the highest NDF value was found in “intensively grazed” class (59.20%), while the lowest - in “slightly grazed” class (51.30%). Mean NDF concentrations were significantly differing only between "slightly" and "intensively grazed" classes (Table 12). Mean CP concentrations showed significant variation between "slightly" (16.30%) and "moderately grazed" (13.20%) classes (Table 12; Figure 15: A). Ash concentrations, reflecting total amount of mineral content, were declining from "slightly" to "intensively grazed" classes and varied significantly between these two - 10.90% and 8.20% respectively (Figure 15: B).

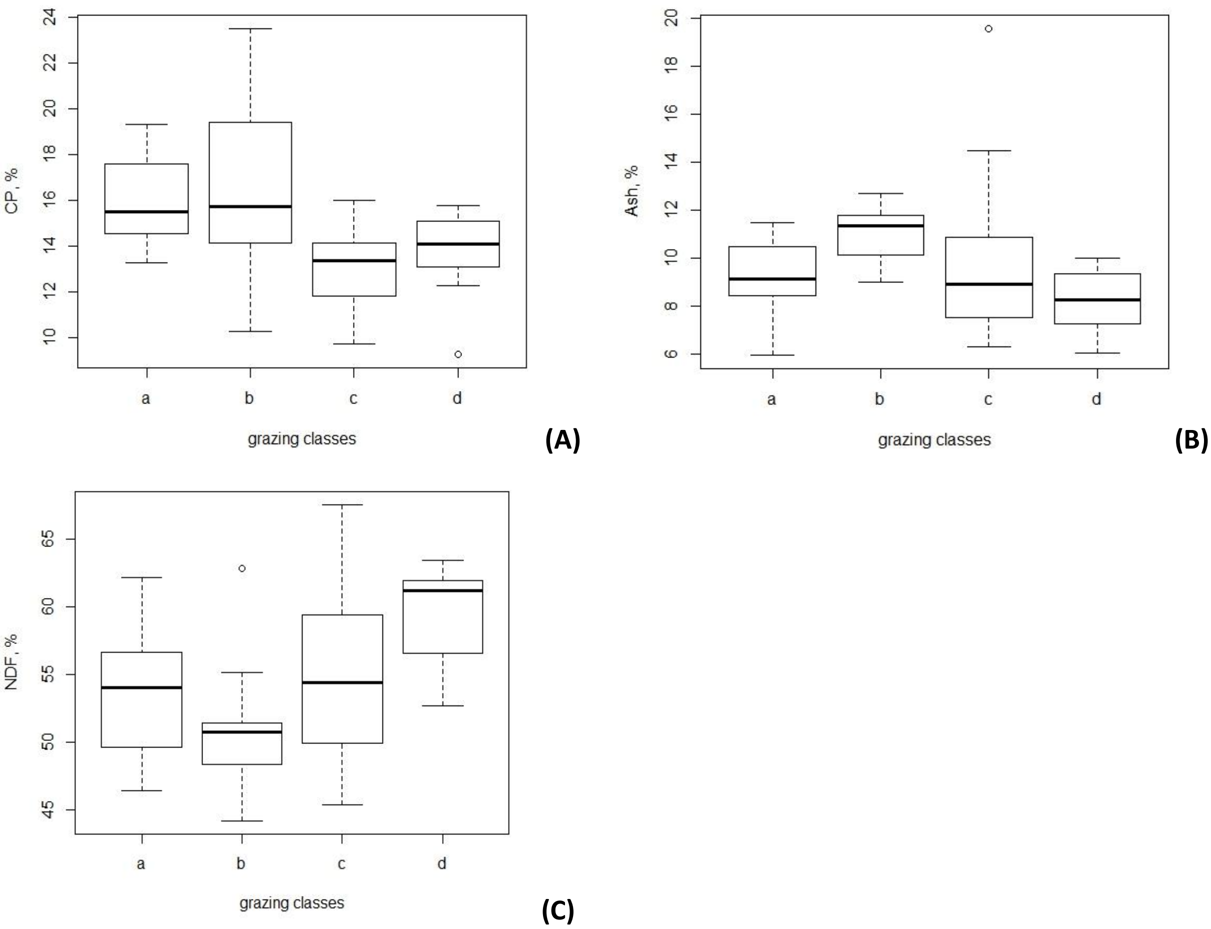


Figure 15. Effect of grazing on feed values variation. A - Crude Protein (%), B – Ash (%), C – Neutral Detergent Fiber (%). Grazing classes: not disturbed (a), slightly grazed (b), moderately grazed (c) and intensively grazed (d).

Among mineral content, iron and manganese, calcium and magnesium, were not significantly different between four grazing classes ($p>0.05$). Unlike sulfur, zinc, phosphorus and potassium significantly varied between only two grazing classes ($p\leq0.001$; Table 12). Mean concentrations of the mineral elements (except for iron and zinc) were highest in "slightly" and lowest in "intensively grazed" classes (Table 12). Under intensive grazing, mean concentrations of zinc and phosphorus were in range below the diet requirements of grazing animals (App. Figure 1; NRC 2001; NRC 2007). Median concentrations for the macro elements during growing season were: P 1.47, Ca 7.97, K 18.58, Mg 2.51, S 2.21 in g/kg DM (dry matter), and for the trace elements Mn, Fe and Zn were 0.07, 1.44 and 0.05 in g/kg DM respectively. Median concentrations of nutritive value parameters were NDF 55.31%, ADF 27.45%, ADL 5.69%, TDN 65.91%, CP 14.50%, and DM 126.82 g/m².

Table 12.Mean values (±stdv.) of the studied variables for four classes of grazing intensity (values in the same row followed by the same letter do not differ (α=0.05 significance level)).

Grazing classes / Variables	Not disturbed	Slightly grazed	Moderately grazed	Intensively grazed
Dry weight (g/m^2)	202.6 (±61.90) a	189.0 (±97.00) a	80.70 (±41.10) b	56.40 (±31.20) b
ADF (%)	27.70 (±2.10) a	26.10 (±4.10) a	26.50 (±3.10) a	27.00 (±1.70) a
NDF (%)	53.70 (±5.30) ab	51.30(±4.90) a	54.60 (±6.10) ab	59.20 (±4.10) b
ADL (%)	5.30 (±1.80) a	6.40 (±1.40) a	5.80 (±2.30) a	4.80 (±0.80) a
Ash (%)	9.10 (±1.70) ab	10.90 (±1.30) a	9.60 (±3.30) ab	8.20 (±1.40) b
TDN (%)	65.58 (±2.68) a	67.68 (±5.29) a	67.13 (±4.01) a	66.46 (±2.23) a
CP (%)	16.00 (±2.00) ab	16.30 (±3.90) a	13.20 (±1.60) b	13.60 (±2.30) ab
Ca (g/kg DM)	7.20 (±1.90) a	8.50 (±1.80) a	7.80 (±2.50) a	6.30 (±1.20) a
Fe (g/kg DM)	0.90 (±0.90) a	1.10 (±0.70) a	1.50 (±1.60) a	1.00 (±0.50) a
K (g/kg DM)	24.90 (±6.70) a	30.10 (±7.20) a	16.00 (±3.00) b	14.30 (±3.20) b
Mg (g/kg DM)	2.30 (±0.60) a	2.60 (±0.60) a	2.40 (±1.00) a	1.80 (±0.50) a
Mn (g/kg DM)	0.10 (±0.03) a	0.10 (±0.02) a	0.10 (±0.03) a	0.10 (±0.01) a
P (g/kg DM)	2.60 (±1.40) a	3.00 (±1.20) b	1.30 (±0.20) b	1.10 (±0.20) b
S (g/kg DM)	2.40 (±0.40) a	3.00 (±1.00) a	2.00 (±0.20) b	2.10 (±0.20) ab
Zn (g/kg DM)	0.10 (±0.03) a	0.10 (±0.03) a	0.04 (±0.01) b	0.02 (±0.01) b
Forb species (%)	3.4 (±1.0)a	2.8 (±0.80)ab	2.5 (±0.70)b	2.0 (±0.30)b

4.3.2. Effect of growing stage

According to analyses of variance, dry biomass weight showed significant variation between three growing stages, measured in June, July and August ($p \leq 0.001$). From June to August mean biomass dry weight had increased by a factor of 3-4 (June: 54.10 g/m², July: 122.00 g/m², August: 180.00 g/m²), while the difference between July and August harvests of dry biomass weight was lower (Table 13).

Table 13. Mean values (± stdv.) of the studied variables for three growing stage (values in the same row followed by the same letter are not different for α=0.05 significance level).

Growing stage / Variables	June	July	August
Dry weight (g/m^2)	54.10 (±29.80) a	122.00 (±84.77) b	180.00 (±77.06) b
ADF (%)	25.60 (±2.57) a	27.00 (±2.63) a	28.30 (±2.74) b
NDF (%)	52.00 (±4.91) a	54.80 (±5.02) a	57.40 (±5.36) b
ADL (%)	6.23 (±1.94) ab	5.48 (±1.72) a	6.65 (±1.91) b
Ash (%)	11.39 (±3.88) a	10.48 (±2.94) a	10.65 (±2.52) a
TDN (%)	68.11 (±3.32) a	66.47 (±3.39) a	64.84 (±3.54) a

CP (%)	14.20 (±1.52) ab	16.20 (±2.84) a	14.40 (±2.47) b
Ca (g/kg DM)	7.87 (±2.88) a	7.38 (±1.74) a	8.08 (±2.13) a
Fe (g/kg DM)	2.43 (±2.30) a	1.90 (±1.35) a	1.71 (±1.25) a
K (g/kg DM)	14.50 (±2.40) a	20.20 (±4.77) a	19.80 (±6.96) b
Mg (g/kg DM)	2.75 (±1.13) a	2.51 (±0.76) a	2.34 (±0.68) a
Mn (g/kg DM)	0.09 (±0.05) a	0.08 (±0.03) a	0.08 (±0.03) a
P (g/kg DM)	1.36 (±0.26) a	1.76 (±0.68) a	1.86 (±1.16) a
S (g/kg DM)	2.05 (±0.22) a	2.31 (±0.38) a	2.32 (±0.59) a
Zn (g/kg DM)	0.04 (±0.01) a	0.07 (±0.06) b	0.04 (±0.02) c

Effect of growing stage on the variation of nutritive value parameters was significant ($p \leq 0.05$) except for ash. Mean ADF concentrations showed significant variations, constant increase during the growing season from 25.60 % to 28.30 % (Table 13). The same trend was observed in NDF concentrations, increasing from 52% to 57.40% (Table 13). For both ADF and NDF concentrations, significant difference was observed but only between two growing stages (Table 13). Mean ADL concentrations decreased from 6.23% in June to 5.48% in July, and increased again in August to 6.65% (Table 13); significant difference of ADL concentrations was observed only between July and August growing stages (Table 13). TDN concentrations decreased from 68.11% to 64.84% in the growing season, with significant difference between two growing stages (Table 13). The highest mean CP concentration was detected in July (16.20%), with significant difference observed only between July and August (Table 13).

Variations in most mineral contents were not significant during the growing period, except for potassium ($p \leq 0.05$) and zinc ($p \leq 0.001$). Mean concentration of potassium showed a peak at 20.20 g/kg DM in July (Table 13), while significant difference was observed only between two growing stages (Table 13). Mean concentration of the trace element zinc also showed significant variation between two growing stages with its peak concentration in July (0.07 g/kg DM).

4.3.3. Effect of altitude

The effect of altitude was reflected in dry biomass weight distribution with significant variation between montane-subalpine and subalpine-alpine zones ($p \leq 0.001$). Mean biomass dry weight in the montane-subalpine zone amounted to 89.3 g/m² and subalpine-alpine zone 203.1 g/m² respectively (Table 14).

Table 14. Mean values (± stdv.) of the studied variables for two altitudinal zones (values in the same row followed by the same letter are not different between each other for α=0.05 significance level).

Variables \ Altitudinal zones	Montane-Subalpine (2600-3000 m a.s.l.)	Subalpine-Alpine (3000-3300 m a.s.l.)
Dry weight (g/m^2)	89.30 (±60.40) a	203.10 (±75.90) b
ADF (%)	55.20 (±5.60) a	52.60 (±5.90) a
NDF (%)	26.70 (±3.00) a	27.00 (±3.10) a
ADL (%)	5.50 (±1.90) a	6.00 (±1.90) a
Ash (%)	9.30 (±2.80) a	10.10 (±1.80) a
TDN (%)	66.94 (±3.83) a	66.52 (±3.95) a
CP (%)	13.60 (±2.00) a	16.40 (±3.10) b
Ca (g/kg DM)	7.50 (±2.30) a	7.80 (±2.00) a
Fe (g/kg DM)	1.20 (±1.30) a	1.20 (±0.80) a
K (g/kg DM)	17.30 (±5.90) a	27.60 (±6.90) b
Mg (g/kg DM)	2.30 (±0.90) a	2.50 (±0.60) a
Mn (g/kg DM)	0.10 (±0.03) a	0.10 (±0.02) a
P (g/kg DM)	1.40 (±0.40) a	3.00 (±1.40) b
S (g/kg DM)	2.20 (±0.70) a	2.60 (±0.40) b
Zn (g/kg DM)	0.04 (±0.02) a	0.10 (±0.03) b
Forb species (%)	2.5 (±0.80) a	4.4 (±1.20) b

Altitude did not show a significant effect on variation of the nutritive value parameters, except for CP content ($p \leq 0.01$), which had highest mean concentration (16.4%) in the subalpine-alpine zone (Table 14). Concentrations of phosphorus, potassium, sulfur and zinc showed significant variation between two altitudinal zones ($p \leq 0.001$, $p \leq 0.001$, $p \leq 0.05$ and ≤ 0.01 respectively) and the highest concentrations – in subalpine-alpine zone. At the same time, concentrations of these minerals in the mountain-subalpine zone were found to be lower by factor 2, with the exception of sulfur (Table 14).

4.3.4. Variation of functional groups and species richness

Among three plant functional types, graminoid and forb species distributions were affected by differential grazing pressure ($p \leq 0.01$ and $p \leq 0.001$ respectively), decreasing in mean total cover with increasing grazing intensity (Fig. 16: A, B). Mean total cover of forb species showed significant variation only between “not disturbed” and “intensive” grazing classes ($p<0.01$): total cover of forb species was under “destructive” grazing was two times lower. Effect of growing stage on plant functional types was not significant ($p>0.01$). Impact of the altitude was significant on graminoid and forb species variation ($p \leq 0.001$), with increment in total cover in the alpine compare to montane zone almost with factor 2 (Fig. 17: A, B); although variation of graminoid plant species was not significant (p>0.01). Species richness varied not significantly between grazing classes, maturity stages and altitudinal zones (p>0.01).

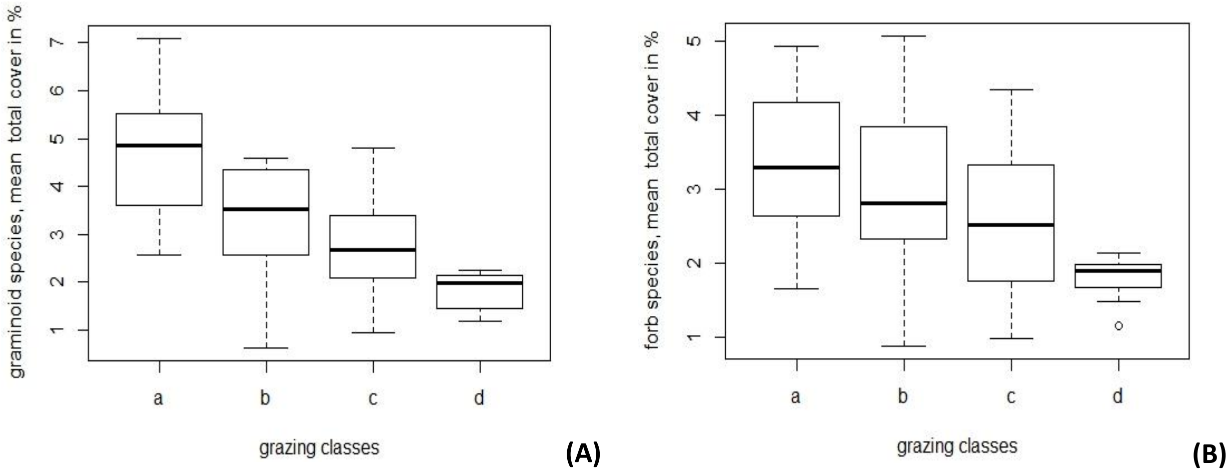


Figure 16. Effect of grazing on plant functional types- graminoid (A) and forb (B) mean total cover (in Braun-Blanquet scale, per 1 m²). Grazing classes: not disturbed (a), slightly grazed (b), moderately grazed (c) and intensively grazed (d).

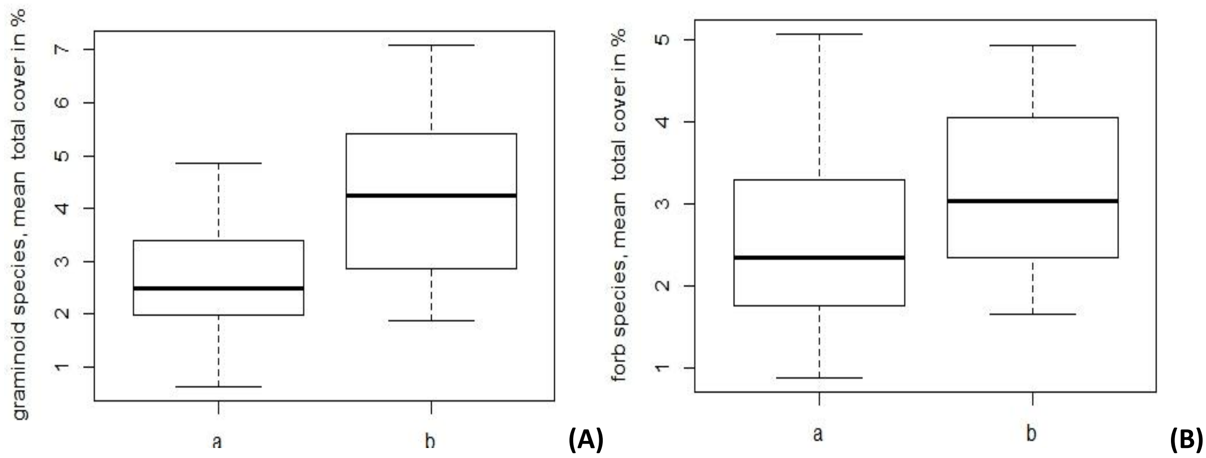


Figure 17. Effect of altitude on plant functional types - graminoid (A) and forb (B) mean total cover (%). Altitude: a – montane zone (below 3000 m a.s.l.), b - alpine zone (3000-3300 m a.s.l).

4.4. Discussion

4.4.1. Variation of biomass yield and nutritive value

The general response of biomass dry matter to increasing grazing intensity in arid and semi-arid rangeland ecosystems is well-known (Oba et al. 2001). Our findings correspond to those of previous studies, i.e., an increase in grazing intensity leads to a decrease in DM yields.

Some studies showed, however, that under moderately grazing pressure biomass yields still remain on high forage level (Gamoun 2014; Yuan & Hou 2015). In such cases, increase in herbage biomass yields is related to sufficient amount and adequate distribution of annual (or growing season) precipitation, with positive correlation between increasing precipitation rates and aboveground biomass production as recently shown by Yan and Lu (2015) for alpine rangelands on the Tibetan Plateau and by Miao et al. (2015) for subalpine-alpine rangelands of Qilian Mountains. Our results showed that DM yields in subalpine-alpine rangelands were higher with a factor of three than in montane-subalpine rangeland, where amount of precipitation was lower. Since there is no difference in grazing intensities - both montane-subalpine and subalpine-alpine rangelands have been exposed to extensive grazing practices during recent decades - precipitation and soil moisture should be responsible for this variation in DM yields. This suggests that subalpine-alpine rangelands show more resilience to grazing, and forage plants have a greater potential to recover, thus increasing the quality of the rangeland in terms of forage yield.

ADF and NDF are characteristics of the fiber content in plant cells. ADF reflects the total fiber, which consists of cellulose and lignin, basically showing indigestibility of the forage. NDF consists of total fiber and hemicelluloses, reflecting the amount of forage animals can consume. In NDF the higher share is digestible, than those in ADF. The lower the NDF concentrations, the higher is potential forage intake (Linn & Martin 1991). Our results reveal that the highest NDF concentrations were found in the plots most disturbed by grazing. Similar results were shown in a study of Wang et al. (2011a) in Inner Mongolia. In contrast to that, a study on the north-east edge of Qinghai-Tibetan Plateau (Miao et al. 2015) found that NDF and ADF concentrations decreased with increasing stocking rate on alpine rangelands. In our case, montane-subalpine and subalpine-alpine rangelands did not show significant difference in these two components: the lowest NDF concentrations were found on the plots with slightly grazing intensity, whereas ADF concentrations did not show significant differences between grazing intensity classes. The contrasting results could be attributed to differences in sampling design and grazing regimes: study of Miao et al. (2015) was conducted on paddocks, explicitly grazed by yaks, whereas our study was conducted on open rangelands experiencing mixed grazing by yaks, sheep and goats. In general, it supports the idea of a negative impact of long-term grazing on herbage nutritive values: most disturbed plots contain less palatable herbage material due to selective grazing, and therefore show the highest NDF concentrations.

Our findings are in consistence with those of Wang et al. (2007), showing that NDF concentrations tend to increase during growing season. At the same time there are other factors responsible for NDF concentrations variation, which could be taken into account. Miao et al. (2015) found that annual precipitation rate affects biomass as well as NDF variation: biomass weight tends to increase with increasing precipitation rate, whereas NDF is decreasing with increasing annual precipitation at higher elevations. Horrocks and Vallentine (1999) pointed out that not only maturity and climatic factors, but also species composition and soil fertility could be responsible for NDF concentrations variation. In our study, the value of NDF 55.3% reflects medium quality of forage plants according to the comparative scale in Horrocks and Vallentine (1999), suggesting that the studied rangelands are still capable to provide forage of sufficient quality for grazing animals demands. Nevertheless, ongoing overuse of the rangelands and uncontrolled grazing could lead to a decrease in forage quality and enhance rangeland degradation.

TDN concentrations, a measure of total nutrient yield (Horrocks & Vallentine 1999), were shown to increase with increasing stocking rate (Miao et al. 2015). Whereas, our study does not show significant variation of TDN concentrations under different grazing intensities. Our results rather reveal that TDN concentrations depend on growing stage and tend to be constantly decreasing during the growing season. This could also be explained by simultaneously increasing fiber content of the forage plant material at the end of the growing season (Andrighetto et al. 1993; Mountousis et al. 2008).

CP (Crude Protein) describes the potential intake of the forage and its quality; CP concentrations are higher in forages consisting of legumes than grasses (Linn and Martin 1991). Being influenced by plant maturity stage, CP concentrations tend to decrease during the growing season (Horrocks & Vallentine 1999; Wang et al. 2007). Wang et al. (2011a) also found decreasing CP concentrations from June to August and has indicated that degraded rangeland has the lowest CP concentrations. Our study is in line with aforementioned findings of Wang et al. (2007, 2011a) and Sasaki et al. (2012), but differ from the recent study of Miao et al. (2015). Most likely, the short-term exclosure experiments conducted by the latter author do not correspond to the situation on rangelands, which have been under the grazing pressure for a long time.

Other studies in arid grazing lands revealed complex relationships between grazing pressure and nutritive values. According to Sasaki et al. (2012) changes in herbage nutritive value are based on plant species composition; long term grazing entails the replacement of the perennial grasses and forbs with annual forbs, which often have a lower forage value. This was also reported by Schönbach et al. (2009, 2011, 2012) from Inner Mongolia, who outlined that long-term grazing affects the species composition and lowers the soil cover by reducing herbage biomass; whereas short-term grazing improves herbage nutritive values by an increase in the protein and a decrease in the lignin content of the forages. At the same time, a study on grazing intensities in Qilian Mountains showed that medium stocking rates have a positive effect on the forage nutritive value, sustaining the highest content of nitrogen and the lowest NDF and ADF concentrations (Zhang et al. 2015). In line with that are the results of a recent study on semi-arid rangelands in Pakistan (Islam et al. 2018), where controlled grazing was shown to improve the forage value, which also led to increase in productivity of the small ruminants.

Except for grazing activities, other factors shaping rangeland ecosystems were found in different mountain regions. According to Andrighetto et al. (1993) and Mountousis et al. (2008), the quality of the plant forages in mountain rangelands of South Europe is strongly related to growing stage: forage quality decreases rapidly as plant becomes more mature. In mountain areas of NW Greece, rangeland productivity changes with altitude: the highest herbage yield and the lowest fiber content were found in forages from the higher altitudes (Mountousis et al. 2008).

4.4.2. Mineral content variation and dietary requirements

Mineral content of forage plants provides an important information about the quality of the rangeland and its ability to supply feeding for the grazing animals on optimal levels (Knowles & Grace 2013). Nevertheless, data on mineral content for many pasture areas and plant species are missing in the literature, in particular for the highlands of the Tibetan Plateau. To estimate the quality of the pasture, mineral content of the forage species should be compared with feeding demands of the specific grazing animals. Such demands for small ruminants and cattle are well documented (NRC 2001; NRC 2007; Knowles & Grace 2013), whereas for yak are missing so far (Wiener et al. 2003). Deficiency of certain mineral elements varies according to environmental conditions (Wiener et al. 2003). Our study showed that most of the minerals are available in sufficient concentrations, and fulfil the dietary requirements for sheep and cattle (NRC 2001; NRC 2007; Knowles & Grace 2013), except for zinc and phosphorus concentrations. Sulfur and phosphorus concentrations vary widely in green and conserved forages; this variation mainly depends on plant species composition, availability of soil sulfur, phosphorus and nitrogen, on climate and on maturity stage of the forage plants (Suttle 2010). Our study demonstrates that the variation of zinc and phosphorus concentrations does not depend on maturity stage, but is affected by grazing intensity: under slightly grazing these concentrations were significantly higher and sufficient to meet dietary requirements of grazing animals, but reduced under intensive grazing.

4.4.3. Variation of plant functional types and species richness

Our study showed that with increasing grazing intensity the role of graminoid and forb species in total plant cover was decreasing, whereas, total cover of legume plant species under differential grazing pressure varied insignificantly. On the contrary, study from Hu et al. (2015) in Inner Mongolia suggested that, the presence of legume species might lead to reversal of degraded steppe in both species richness and species composition, promoting the recovery of degraded grasslands in semi-arid environments. Also in the same study, it was shown that legume biomass tend to increase with decreasing non-legume biomass followed by intensification of the land degradation. In our results such trend is not reflected.

In study of Wu et al. (2009) in the eastern Qinghai-Tibetan Plateau plant functional types have shown controversial relation to grazing: graminoid plant species have increased the cover after exclusion of grazing, whereas leguminous, forbs and noxious species have decreased. Our findings reveal that increasing grazing pressure resulted in overall decrease in graminoid and forb species total cover up to 2%, which could be explained by general decrease in total cover on most of degraded plots, which is consistent with previous study of Miehe et al. (2011) on Central Tibetan highlands, which showed that the cover of graminoid species was destroyed by grazing up to 2-4% in most of plant communities.

Furthermore, Dorji et al. (2014) shown that in Central Tibet the highest graminoid abundance was related to intermediate grazing pressure, whereas forb abundance with respect to grazing was changing along the altitude. Similarly to that, our data reflect significant variation in total cover of forb and graminoid species in two altitudinal zones. Greater total cover of graminoid and forb species in alpine compare to montane zone could be explained by increasing with elevation soil moisture and soil organic matter content (Dorji et al. 2014; Sun et al. 2015), which is also supported by our findings in **Chapter 5**.

Species richness

According to "intermediate disturbance hypothesis", species richness and diversity should be at the highest on moderate levels of disturbance (Wu et al. 2009). As it is suggested by Oba et al. (2001) for arid pastures in Kenya, the increase in species richness in arid environments could be related to increase in biomass and tends to decline after reaching a certain biomass level, following the hump-shaped curve. In both studies grazing exclosure has positive effect on species richness only in a short term. Wu et al. (2009) indicates that species richness, evenness and diversity indexes are significantly lower in non-grazing conditions and that grazed meadow has higher community density and species diversity, than non-grazed one. Our results are in consistent with findings of Ren et al. (2012) from Inner Mongolia, Dorji et al. (2014) and Yan & Lu (2015) from alpine grasslands in Tibetan Plateau, where grazing showed no significant effect on biodiversity indexes and species richness.

Chapter 5. Impact of abiotic site factors

VARIATION OF ABIOTIC SITE FACTORS AND THEIR IMPACT ON DISTRIBUTION OF MONTANE/SUB-ALPINE AND ALPINE VEGETATION PATTERNS IN NORTHERN QILIAN MOUNTAINS, NW CHINA

Summary

Degradation of mountain pastures in Qilian Mountains has increased in recent decades; soil erosion accelerated by extensive grazing is widespread. The aim of this study is to identify spatially differentiated and grazing-induced changes in vegetation patterns and associated changes in soil properties. The study area is located in the spring/autumn and summer pastures in the middle section of Qilian Mountains between 2600-3300 m a.s.l., representing montane/sub-alpine and alpine plant communities modified by continuous grazing with sheep, goat and yak. Quantitative and qualitative relevé data were collected for vegetation classification and analysing of gradual changes in vegetation patterns along altitudinal gradient. Vegetation was classified using hierarchical cluster analysis. Five vegetation groups were identified: (1) montane xerophytic shrubby grassland, (2) montane xerophytic grassland (3) montane grassland - forest meadow (4) grazing modified alpine shrubby meadow (5) alpine meadow. Direct gradient analysis was used to analyse variation in relationships between the vegetation and corresponding environmental variables. ANOVA was used to detect the differences between identified vegetation groups in given environmental conditions. The results showed distinct variation in soil pH, bulk density, OM, carbon, nitrogen and water content and soil minerals concentrations between the identified vegetation groups. Along the altitudinal gradient, increases in soil conductivity, carbon and nitrogen, organic matter and water content as well as decreases in soil pH and basic saturation were observed. Communities of degraded montane grassland with low concentration of soil OM, nitrogen and carbon were widespread on south-facing slopes at lower altitudes. Although different indicators of disturbances were apparent in alpine meadows, they showed the lowest level of degradation. In terms of dry biomass, N-, NE- and NW-facing slopes in forest-grassland and shrubland-grassland ecotones were found to be most productive. Although all pastures were exposed to extensive grazing, montane grasslands seem to experience more severe degradation in terms of herbage biomass, total cover, soil properties and mineral concentrations.

5.1. INTRODUCTION

The Qilian Mountains are of prime functional significance for maintaining the ecological integrity of the adjacent Alxa highlands and the hydrological stability of the HeiHe river lowlands and irrigation agriculture of the Hexi corridor (Zhao et al. 2011). Located on the northern edge of Tibetan Plateau, they represent both Mongolian and Tibetan floristic provinces (Kürschner et al., 2005; Froese 2012). *Picea crassifolia* forests play a major water protection role (Yang et al. 2005; Sun et al. 2017). Grasslands cover deforested slopes and are mostly used for animal grazing (Baranova et al. 2016). According to modeling results of Liu et al. (2004), actual forest cover has been significantly reduced and covers only 6% of potential forest areas.

Grasslands and shrublands in alpine and subalpine areas of the Qilian Mountains have been experiencing severe overgrazing in the recent past. Vegetation cover is very low during the growing season (Huang et al. 2011). The percentage of unpalatable and toxic species in grassland communities is increasing (Baranova et al. 2016). Total vegetation cover is comparatively low on the south-facing slopes, which are prone to erosion. Landslides and other types of soil erosion are often met in the vicinity of the herders summer camps in the alpine pastures (own observations).

Examining the environmental variables allows interpretations of ecologically regulating factors driving the vegetation patterns. In Qilian Mountains diverse spectrum of local ecological studies has been conducted, most of them are published in Chinese. Main focus of the research lies in the field of hydrology and its responses to environmental changes (Guojing et al. 2005; Li et al. 2009; Sun et al. 2016; Tian et al. 2017). Some studies were dealing with the response of forest stands to climate change (Deng et al. 2013; Yang et al. 2013). There are detailed descriptions of variation in soil organic carbon and nitrogen as well as in other edaphic factors along the altitudinal gradient (Yuan & Hou 2015; Yang et al. 2018). Other studies were focusing on the effect of grazing on plant composition, species richness and soil properties (Chang et al. 2004; Baranova et al. 2016; Wang et al. 2017a). Although some preliminary studies on the relations between vegetation structure, its dynamics and soil functioning were conducted (Wang et al. 2002; Yang et al. 2018), more extensive research covering unrepresented parts of the gradient is necessary. In particular, the lack of qualitative vegetation analyses (Kürschner et al. 2005) represents a gap in environmental studies to be filled in the coming years in order to get a better understanding of the balance in fragile mountain ecosystems under the impact of biotic and abiotic site factors, including anthropogenic disturbances, grazing impact and climate change in th e Qilian Mountains.

In the past mountain rangelands were assumed to represent ecosystems in equilibrium (Casimir 1992). Based on the modern theory of rangeland ecosystem functioning, both, equilibrium and non-equilibrium models are to be found in the mountain regions along the altitudinal gradient (c.f. Hoppe at al. 2016, Wang et al. 2017b). Abiotic site factors and animal grazing both affect rangeland ecosystems; however, the effect of grazing is more pronounced in the humid areas, while in the arid conditions unstable precipitation and its annual variations plays a major role and overwhelms the impact of grazing (Behnke et al. 1993; Ellis & Swift 1998). Therefore, for the Qilian Mountains we expect that grazing impact is more pronounced in humid alpine zone, while at the lower elevations in presence of more arid conditions, vegetation dynamic is controlled by the moisture regime (von Wehrden et al. 2012). Soil responses to grazing could reveal similar patterns due to the plant–soil interactions (Wang et al. 2017b).

Therefore we hypothesize that (a) in the alpine zone grazing impact on vegetation differentiation and underlying topsoil characteristics is more pronounced, than the impact of other abiotic site factors; (b) in montane-subalpine zone soil moisture (as a proxy for precipitation) and other related abiotic site factors would have a greater impact on the vegetation differentiation, while grazing effects would be less pronounced.

5.2. Methodology

5.2.1. Study area

The Qilian Mountains are located in the middle part of the Heihe River Basin (97°24′–102°08′ E to 37°44′–42°42′ N), adjacent to the Hexi corridor on the north and to the Tibetan Plateau on the south (Figure 1). The Qilian Mountains are covered by 43.61×10^4 ha of forests and 811.2×10^8 m^3 of glaciers which feed the headwaters of the Heihe, Shiyang, and Shule rivers and support 4 million people living in the Hexi Corridor (Guojing et al. 2005). The southern part of the Qilian Mountains is characterized by semi-arid cold and cold humid mountain climate. Temperature and precipitation show a distinct vertical gradient. The annual mean precipitation increases with elevation (from 250 mm to 700 mm), while annual mean temperature decreases with elevation (from 6.2 ◦C to −9.6 ◦C) (Zhao et al. 2006). A part of the study area belongs to the semi-arid zone with dominant winter drought, on higher elevations alpine conditions are presented (Nagy & Grabherr 2009).

Soils of the pastures of the study area were identified as haplic Leptosol, haplic cambic Regosol and Cambisol, with relatively shallow soil profile, rough texture (silt loam and silt) and intermediate organic matter content (Lider 2013). The results of Friedrich (2015) on the analyses of the soil physical properties along the wider altitudinal range (2600-3700 m a.s.l.), suggest that investigated soil types refer to haplic Phaeozem and calcic Luvisol (Zech 2014; Friedrich 2015); while Wang et al. (2002) was reporting about chromic Luvisols and Cambisols. Permafrost soils and seasonally frozen soil horizons are widespread in the middle and high elevations.

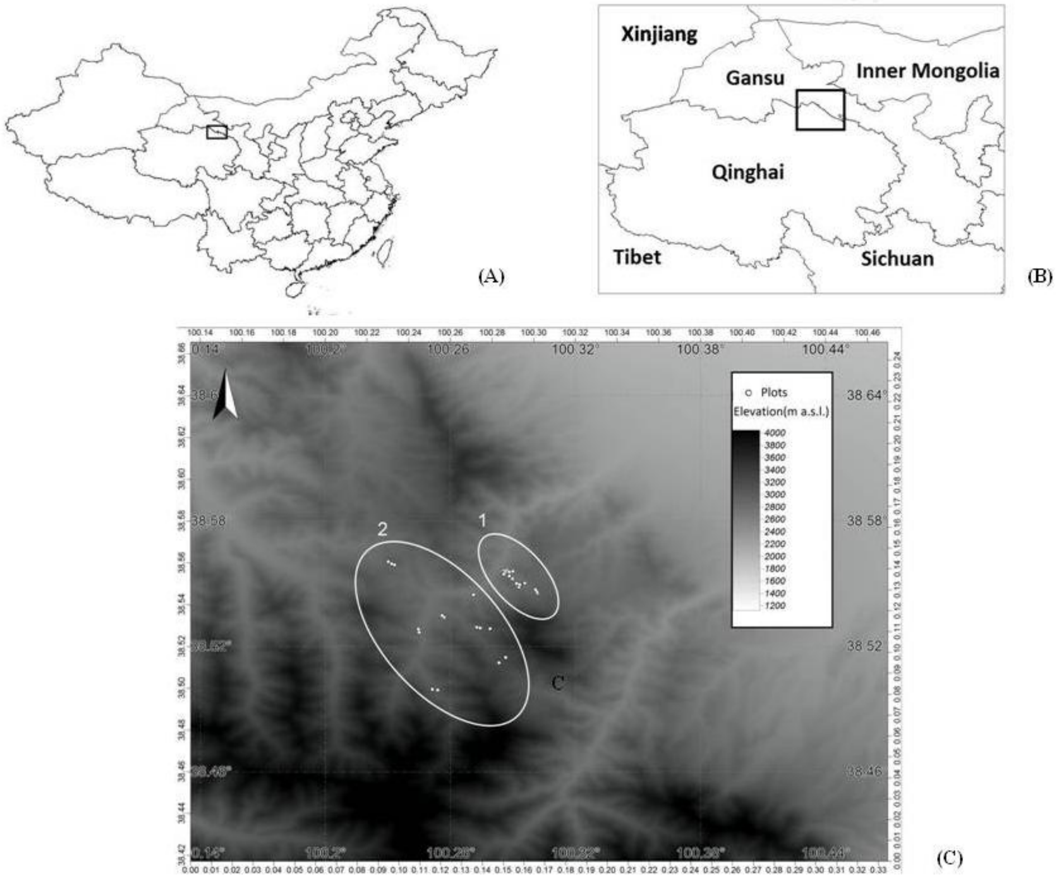


Figure 18. Location of area of the research in the maps of China (A) and Gansu Province (B). Pailugou spring/autumn pasture area (C: 1), Dayekou summer pasture area (C: 2).

In the Qilian Mountains, transhumance pastoral practice is in use (Yuan & Hou, 2015): the herds of sheep, goats and yaks are kept close to the villages during winter (2400-2600 m a.s.l.), in spring the animals are moved upwards to graze on montane-subalpine pastures. In the beginning of June herders move with their livestock to the summer camps in the alpine zone (above 3000 m a.s.l.). In autumn the animals are brought back to the areas where they grazed in spring (2600-3000 m a.s.l.). In the Qilian Mountains the growing season usually begins in the second half of May; the flowering of the mixed grasslands peaks in July and in the beginning of August. According to Wang et al. (2002) and Zhao et al. (2006), most common vegetation classes in the study area are sub-alpine and alpine shrubland, dominated by *Dasiphora fruticas, Caragana jubata, Salix gilashanica* and *Spirea spp*.; sub-alpine and alpine meadow (2400-3800 m a.s.l.), dominated by *Stipa purpurea, S. przewalskii, Carex lansuensis, Polygonium viviparum, P.bistorta, Dasiphora fruticas* and *Caragana jubata*; between 2500-3600 m a.s.l. forest-steppe vegetation is common, dominated by *Picea crassifolia* and *Sabina przewalskii.*

5.2.2. Sampling design

Vegetation sampling was conducted in the summer seasons of 2012 and 2013, following an adapted relevé method (Braun-Blanquet 1964, Kent 2012). We applied standard relevé size of 10x10 m for all plots, exceeding the requirement of minimal area size (Mueller-Dombois & Ellenberg, 1974). On each relevé plot, we described species data according to the Braun-Blanquet cover-abundance scale (7 classes), including the complete list of vascular, bryophyte and lichen species. In order to identify the species, we used collections of the herbarium in the Academy of Water Conservation Forest of the Qilian Mountains (AWCFQ, Zhangye, China), together with local flora catalogues (Xiande et al. 2001, Anlin & Zongli 2009) and internet accessible databases (eFloras, Subject Database of China Plant, The Plant List, Plantarium). Nomenclature of the plant species follows eFloras (2008). For the remaining unknown specimens we used additional expertise of the botanists in the Herbarium of the Komarov Botanical Institute of the Russian Academy of Sciences (St. Petersburg, Russia).

We conducted field sampling in the spring/autumn and summer pasture areas, covering the altitudinal range from 2650 to 3600 m a.s.l.(Figure 18). Altogether 71 sample sites were randomly selected in different accessible slope exposures, representing the variety of habitat types. On each sampled plot, data on altitude, latitude, longitude and slope angle were obtained using Garmin GPS 60 (with accuracy of 4-6 m) and inclinometer Suunto MB-6 Nord. We collected biomass data on 1x1m plots, placed in the centre of the relevé plot. We clipped the plant specimens on the ground level and measured wet biomass weight shortly after the sampling; we assessed dry biomass weight after oven-drying for 8-10 hours at 65 °C. Grazing impact was visually estimated on each plot, on the scale from 3 to 14, using a developed set of environmental indicators (Baranova et al. 2016). On each relevé plot we extracted soil samples from the uppermost mineral soil horizon using soil sampling rings (3 samples of 100 cm^3 per site; in 10–15cm depth). We stored fresh soil samples in plastic bags and determined the weight at the same day with sampling. Dry soil weight was measured after oven-drying for 5-6 hours at 105°C. Due to misconduct during the sample preparation in Chinese field laboratory, only 63 soil samples were used in further analyses, associated with 63 corresponding relevés, excluding samples from alpine shrub thickets (3400-3600 m a.s.l.).

We performed soil analyses in the Laboratory of the Department of Physical Geography, University of Hamburg. Soil bulk density, organic matter content, water and skeleton content, total nitrogen and total carbon*,* carbon/nitrogen ratio, pH (in CaCl2 and in H2O), electroconductivity (EC), cation-exchange capacity (CEC), base saturation (BS) and concentration of the mineral protons were measured. Standard soil analyses followed DIN 19684-1 (pH-value in H20 and in CaCl2), DIN ISO 11265 (conductivity), DIN ISO 11465 (water content), and DIN EN 12879 (organic matter). CEC, BS and mineral concentrations (in proton equivalent in µmol/g) were analyzed according to Meiwes et al. (1984), using Inductively-Coupled Plasmarelated-Optical Emission Spectroscopy (ICP-OES) and ICP-OES-Software. Remaining analyses were followed after HFA (2009).

5.2.3. Statistical Analysis

We performed all statistical analyses using the R software and packages "*indicspecies*" (De Cáceres & Legendre 2009), "*mass*", "*pgirmess*", "*plyr",*"*vegan*" (Oksanen et al. 2018) and "*stats*" (Hothorn et al. 2008) (R version 3.4.1, Foundation for Statistical Computing, Vienna, R Core Team 2015).

A) Data transformation

Environmental data

In order to perform multivariate statistic analyses, we converted the Braun-Blanquet scale according to Wildi (2010) into percentage values; slope exposure degrees (0-360°) were recalculated into two independent variables "eastness" and "northness" after Zar (1999): Eastness = sin ((slope exposure in degrees x Pi)/180); Northness = cos ((aspect in degrees x Pi)/180. Log- or square-root- transformation of the rest of environmental variables was performed when needed (Borcard et al., 2011).

Species data

We applied several transformation techniques on species data to compare the results. To reduce the importance of observations with high values, we applied square-root transformation of the species matrix using the function *decostand* (R package '*vegan').* We selected an appropriate combination of distance function and type of transformation in order to obtain a transformed species matrix, compatible with the further clustering and ordination techniques.

B) Classification

To identify vegetation patterns we applied agglomerative clustering using a function *hclust*. In order to obtain a metric distance matrix of ecological resemblance, species cover-abundance values were subject to transformation using the Hellinger distance measure (Ruokolainen & Blanchet 2014). Hellinger distance measure gives less weight to species abundances and resolves the double-zero-problem (Borcard et al. 2011; Oksanen 2015) and it is most similar to Bray-Curtis dissimilarity (Ruokolainen & Blanchet, 2014). Among the clustering methods, average-linkage clustering (UPGMA - Unweighted Pair-Group Method using Arithmetic averages) and advanced Ward's clustering were under consideration. UPGMA is more sensitive to outliers and it might be distorted when a large and a small group of objects are clustered together (Ruokolainen & Blanchet 2014). While advanced Ward's clustering, implemented with Ward's clustering criterion (Murtagh & Legendre 2014), affords to have dissimilarities values squared before cluster updating, and allows to find compact, spherical clusters (R version 3.4.1, Documentation). To verify the goodness of the clustering, we applied several approaches: with the first approach we aimed to test the performance of the selected clustering methods, while the second and third approach served to validate the results of the clustering based on the species composition and variation of environmental variables respectively.

With the *first approach* we measured the correlation between original distance and cophonetic matrixes (App. Figure 2). Here average-linkage clustering showed the highest cophonetic coefficient (cor=0.76), revealing the highest correlation between two matrixes. Advanced Ward's clustering method, in comparison with UPGMA, performed less successful (cor=0.5). Nevertheless, verified by Silhouette plot, advanced Ward's clustering had less misclassified objects, than UPGMA. Thus, in comparison with other clustering results, advanced Ward's clustering was the best possible combination of species transformation type, distance measure and method of clustering, derived after a number of tries.

The second approach served to analyze clustering results against environmental variables. At first we tested the significance of variation of different environmental variables within varying number of groups identified with cluster analysis, using one-way analysis of variance (ANOVA and Kruskal-Wallis test - prescribed below). Then an optimum number of groups was derived (k=5), based on the performance of the selected environmental variables - most of them showed significant difference between the groups (App. Table 3, App. Table 4).

The *third approach* was to verify the validity of selected groups according to indicator values of composing plant species of each group. For this purpose Indicator Species Analyses (ISA) was performed to verify vegetation groups, as well as to identify strong indicator species for each group (Dufrene & Legendre 1997). Indicator value is presented by two components: A – specificity, the probability that particular sites would belong to one group because of presence of that indicator species; B – fidelity, the probability that specie occurs in the sites belonging to one group (De Cáceres & Legendre 2009).

C) Ordination and spatial correlation

We applied NMDS (Non-metric Multidimensional Scaling) ordination technique, using function *metaMDS* in package *"vegan".* It is a favorable choice for representation of the objects in two- or three-dimentional space (Legendre & Legendre 2012) and often shows less deformed representation of the relationships among the objects than other ordination techniques could show on the same number of axes (Borcard et al. 2011). In order to assess the relevance of the NMDS and to observe the relationship between distance and cophenetic matrices, stress plot was performed (App. Figure 3). It shows the scatter around the regression between each pair of communities against their original dissimilarities (Borcard et al. 2011). Stress value, obtained from two-dimensional NMDS space, was still comparatively low (0.2215293), satisfying the condition of monotonicity and keeping the non-metric fit of R^2 close to 1 (Legendre & Legendre 2012).

Spatial correlation

To test the spatial correlation among the sampling sites, Mantel correlogram was obtained (App. Figure 4). This plot allows testing the spatial correlation against the distance classes using geographical coordinates of the sites. Usually, on the graph, spatial correlation will shows a positive value on the closer distances, then it would decrease to negative values and become not significant (Borcard et al. 2011). A similar trend was obvious in our data (App. Figure 4): significant positive spatial correlation was found in first three distance classes (i.e. between 5 and 17 m) and negative significant correlation in the fourth class (24 m), suggesting that pair of plots could be considered as spatially independent starting from 30 m distance in between.

D) Analysis of variance

We applied ANOVA statistics, followed by the post-hoc test, to detect the differences between vegetation groups in environmental conditions. First, in order to check if statistical assumptions for ANOVA statistics are met, we tested normality and homogeneity of variance using Shapiro Wilks and Bartlett´s test respectively. If the data were meeting the criterion of normality and homogeneity, one-way ANOVA was applied to compare the variation for each variable, followed by a Tukey post-hoc comparison of means. If the criterion of normality and homogeneity was not met, we applied the Kruskal-Wallis test, followed by non-parametric post-hoc multiple comparisons ($p>0.05$) after Siegel & Castellan (1998).

5.3. Results

5.3.1. Classification

Figure 19 presents the dendrogram of the cluster analysis: in vertical direction on the left-side the distance measure is shown; in horizontal direction relevé plots are placed, grouped together according to greatest species similarity. The dendrogram illustrates two major patterns: on the left side vegetation of montane and subalpine zone is depicted, while on the right side – plant communities of alpine zone are located, corresponding to distinct vegetation groups 1, 2, 3 and 4, 5 respectively.

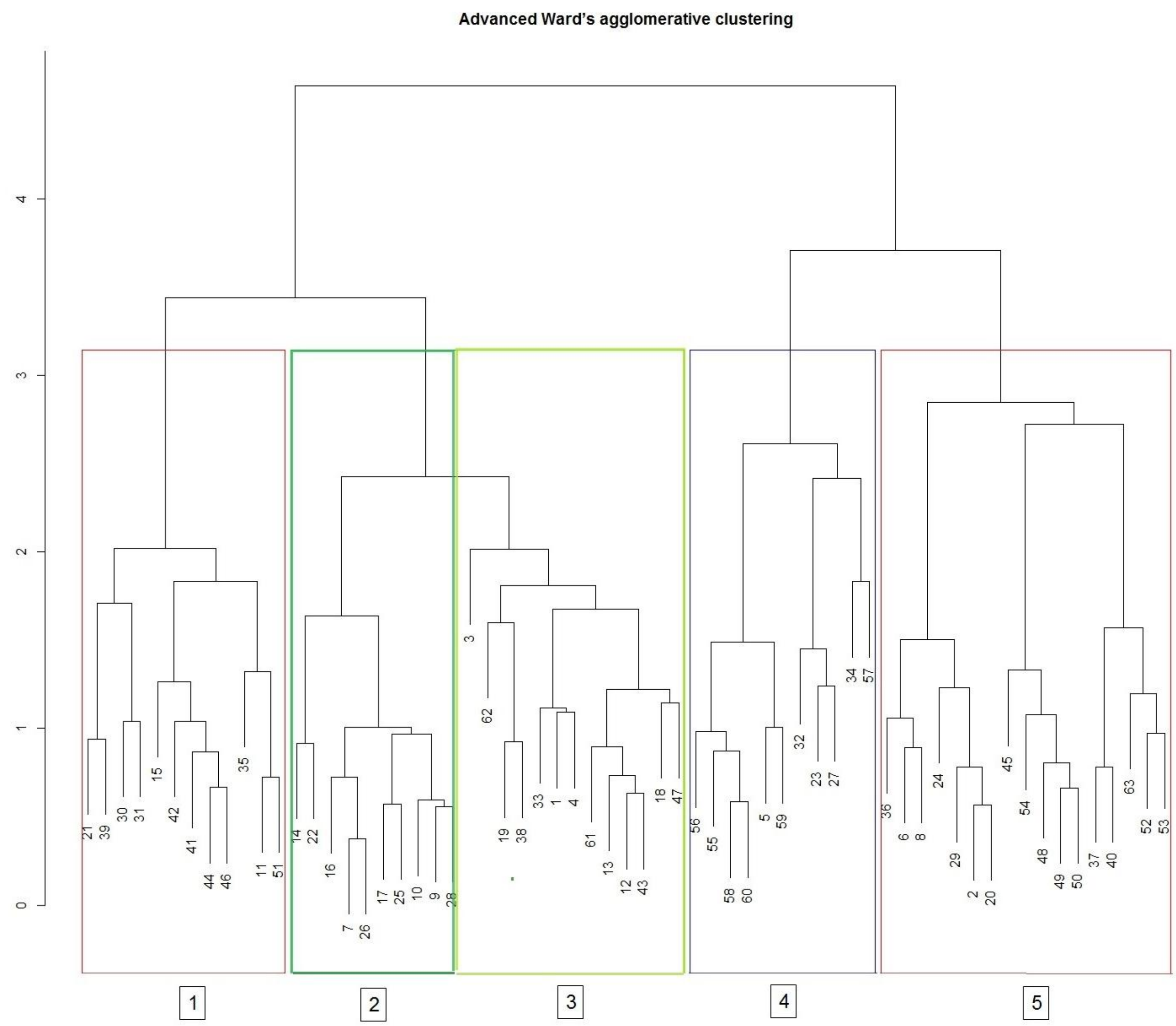


Figure 19. Dendrogram of Cluster Analysis, based on advanced Ward's agglomerative clustering and Hellinger transformed species data. In colors five vegetation groups are distinguished. The numbers refer as following: (1) montane xerophytic grassland, (2) montane xerophytic shrubby grassland, (3) montane mesophytic grassland, (4) grazing modified alpine shrubby meadow and (5) alpine meadow.

5.3.2. Diversity indexes and Indicator Species Analysis (ISA)

The analysis of species constancy shows that only 23 species out of 176 have high constancy level (above 2.5). Most of the species are perennial. Among the plant functional types, 11 forb, 6 graminoid and 5 legume common species were found, with additional species of Pinaceae (*Picea crassifolia*). Most species-rich (abundant) families were Rosaceae, Poaceae, Fabaceae, Cyperaceae and Asteraceae.

In total, only 171 species were used in the ISA and 5 species were excluded from the analysis because they were not suitable as indicators due to their presence in most of the plots. These were *Achnatherum* sp., *Adenophora* sp., *Leymus* sp., *Melandrium apricum* and *Oxytropsis imbricata*. Species richness analysis showed on average 23 (SD±5) species per plot, with a maximum of 37 and a minimum of 2 species. The lowest average number was found in group 4 – 19 (SD±8) species pro plot, while group 1 contained the highest average - 29 (SD±5) species per plot. Similar trend was observed in species diversity indices: Shannon entropy varied from 2.59 to 2.03 in the respective groups; similar trend was observed for Simpson diversity and Pielou evenness (N1, N2 and J: App. Table 5). Calculated with Hill's ratio instead (E1), Shannon diversity index picked at 0.47 in group 5 and had a minimum value of 0.45 in group 2 (App. Table 5).

According to results of ISA presented in Table 2, strong indicator species in group 1 were *Iris lactea var. chinensis, Kobresia humilis, Poa attenua* and *Artemisia austriaca.* Among them *Iris lactea var. chinensis* revealed absolute fidelity for the group 1, whereas *Poa attenua* and *Artemisia austriaca* showed absolute specificity. Group 2 presents the highest number of indicator species – 12, among them strong indicators: *Dracocephalum heterophyllum, Heteropappus altaicus, Gentiana* sp-2 and *Artemisia xerophytica*. These species serve as environmental indicators, corresponding to dry conditions of the study site. Altogether indicator species of the group 2 represent a typical pattern of south-facing dry slopes, heavily affected by erosion processes, grazing and trampling. A weak indicator index value of the only indicator in group 3 and Silhouette plot, mentioned in the Methods section, suggests that in clustering procedure most of the relevé plots in this group were misinterpreted. Based on the additional analysis of synoptic tables, group 3 shares the same vegetation pattern as group 2, with a few site-specific species, like *Stipa breviflora* and S. *krilovii instead* of *S. capillata.* In addition, companion species were identified: *Stellera chamaejasme, Agropyron cristatum* and *Leontopodium leontopodioides.*

Table 15. Indicator Species Analysis of five vegetation groups (without group combinations). List of species associated to each group. Indicator value components: A – specificity; B – fidelity. Only those species are shown, which indicator index value (stat) >=0.4, with significance level (p) >0.05). Significance codes: 0 '*** '. 0.001 ' **' . 0.01'*'. 0.05 '. ' (1), (2), (3) montane mesophytic grassland, (4) grazing modified alpine shrubby meadow and (5) alpine meadow.

Vegetation groups/ Indicator species	Indicator value			
	A	B	stat	p.value
1. Montane xerophytic grassland	#sps. 5			
Iris lactea var. chinensis	**0.3743**	**1**	**0.612**	**0.008 ****
Astragalus/Oxytropsis sp.	0.7177	0.4167	0.547	0.023 *
Kobresia humilis	**0.4828**	**0.5833**	**0.531**	**0.018 ***
Artemisia austriaca	**1**	**0.25**	**0.5**	**0.010 ****
Poa attenua	**1**	**0.25**	**0.5**	**0.016 ***
Cerastium sp.-2	0.6813	0.3333	0.477	0.038 *
2. Montane xerophytic shrubby grassland	#sps. 12			
Dracocephalum heterophyllum	**0.6738**	**0.7826**	**0.687**	**0.005 ***
Heteropappus altaicus	**0.6062**	**0.7261**	**0.651**	**0.002 ***
***Gentiana* sp-2**	**0.6682**	**0.6384**	**0.633**	**0.003 ***
Artemisia xerophytica	**0.8481**	**0.4269**	**0.582**	**0.003 ***
Allium przewalskianum	**0.403**	**0.8261**	**0.568**	**0.041 ***

Oxytropis melanocalyx	0.9714	0.3176	0.54	0.035 *
Allium cyaneum	0.727	0.4568	0.539	0.020 *
Thalictrum cultratum	0.4758	0.6487	0.534	0.017 *
Stipa capillata	0.5333	0.5454	0.516	0.050 *
Potentilla acaulis	0.8794	0.3256	0.514	0.030 *
Caragana opulens	0.5578	0.4678	0.472	0.041 *
Chenopodium pamiricum	0.9118	0.2341	0.427	0.047 *
3. Montane grassland - forest meadow	#sps.	1		
Carex sp.-4	1.0000 0	0.2308	0.5	0.021 *
4. Grazing modified alpine shrubby meadow	#sps. 6	6		
Anemone obtusiloba	**0.9963**	**0.3636**	**0.602**	**0.002 ****
Phaeophyscia sp.	0.712	0.4545	0.569	0.013 *
Kobresia pusilla	0.4881	0.6364	0.557	0.025 *
Carex sp.-1	0.4879	0.5455	0.516	0.038 *
Sibbaldia procunmens	0.7255	0.3636	0.514	0.015 *
Ranunculus indivicus	**0.9221**	**0.2727**	**0.501**	**0.031 ***
5. Alpine meadow	#sps. 11			
Plantago asiatica	**0.7536**	**0.6471**	**0.698**	**0.001 ****
***Elymus* sp.**	**0.8065**	**0.5882**	**0.689**	**0.003 ****
Viola bifurca	**1**	**0.4118**	**0.642**	**0.002 ****
***Poa* sp.-1**	**0.989**	**0.4118**	**0.638**	**0.001 ****
***Sassurea* sp.**	**0.8559**	**0.4118**	**0.594**	**0.003 ****
***Myosotis* sp.-1**	**1**	**0.2941**	**0.542**	**0.004 ****
Poa sect.	0.9706	0.2941	0.534	0.011 *
Polygonum viviparum	0.465	0.5882	0.523	0.041 *
Draba eriopoda	1	0.2353	0.485	0.024 *
Cerastium caespitosum	0.9829	0.2353	0.481	0.049 *
Parnassia oreophila	0.7073	0.2941	0.456	0.042 *

In group 4 (Table 15), *Anemone obtusiloba* and *Ranunculus indivicus* had specificity values close to 1, explaining their occurrence only in alpine meadows. Other strong indicators in group 4 were *Kobresia pusilla, Sibbaldia procumbens* and *Phaeophyscia* sp. (lichen species). Group 5 contains 11 indicators, among them some with absolute specificity values: *Viola bifurca* and *Myosoti*s sp.-1 (associated with forest biotopes) and *Draba eriopoda* (an indicator of grazing disturbance). Other strong indicators in group 5, associated with heavily grazed alpine meadows, were *Plantago asiatica, Elymus* sp., *Poa* sp. and *Saussurea* sp. *Salvia roborowskii,* did not apper in Table 15, is anothe grazing tolerant specie, common on alpine pastures (Pic. 8). A complete list of the plant species is provided in App. Table 6.

Picture 8. Grazing sheep herd on the alpine meadow. On the right side in front – an ungrazed stand of unpalatable *Salvia roborowskii,* which is an indicator of heavy grazing intencity (3300 m .a.s.l.; 03.08.2013).

Based on the results of agglomerative clustering, supported by ISA and the outcome of synoptic tables, vegetation of spring/autumn and summer pastures in Qilian Mountains was classified into five main groups with the following rankless communities (further named as vegetation groups):

1) montane xerophytic shrubby grassland (*Iris lactea var. chinensis - Artemisia austriaca*; with dwarf-shrubs *Potentilla davurica, Potentilla fruticosa)*;
(2) montane xerophytic grassland (*Dracocephalum heterophyllum - Heteropappus altaicus);*
(3) montane grassland - forest meadow (*Stipa krilovii - Potentilla multifida)*;
(4) grazing-modified alpine shrubby meadow (*Anemone obtusiloba - Ranunculus indivicus (with dwarf-shrubs Potentilla bifurca, Caragana jubata);*
(5) alpine meadow (*Anemone obtusiloba - Ranunculus indivicus).*

5.3.3. Ordination

According to the results of NMDS ordination, illustrated in Figure 20 (A - D), moist alpine communities (on the left part of the biplot) are determined by the increasing concentrations of soil nitrogen, carbon, organic matter and water content (Figure 20: D), as well as by the increasing concentration of soil potassium, manganese and iron ions (Figure 20: C). Xeric montane/sub-alpine communities show opposite trends. Their differentiation is predetermined by higher pH and basic saturation (Figure 20: D). We found concentrations of soil minerals not to be differentiating for these communities (Figure 20: C).

Altitude, north exposure, soil water content and concentration of iron showed the strongest correlation with the first NMDS axis (Table 16), which could be best characterized as an elevation/moisture gradient (Figure 20: A, C, D; App. Figure 5). The second NMDS axis could be interpreted as a slope/woody gradient, where increasing tree-, shrub-, and moss cover, as well as increasing number of species per plot, are associated with more steep slopes (Figure 20: A, B). At the same time, increase in herb cover was higher on less inclined slopes, and was related to high soil skeleton content and high concentration of potassium (Figure 20: C, D); most of the other soil minerals showed a negative correlation with the second NMDS axis (Table 3). Increase in carbon/nitrogen ratio was also associated with the slope/woody gradient, while increase in concentrations of carbon and nitrogen was strongly related to the elevation/moisture gradient (Figure 20: D).

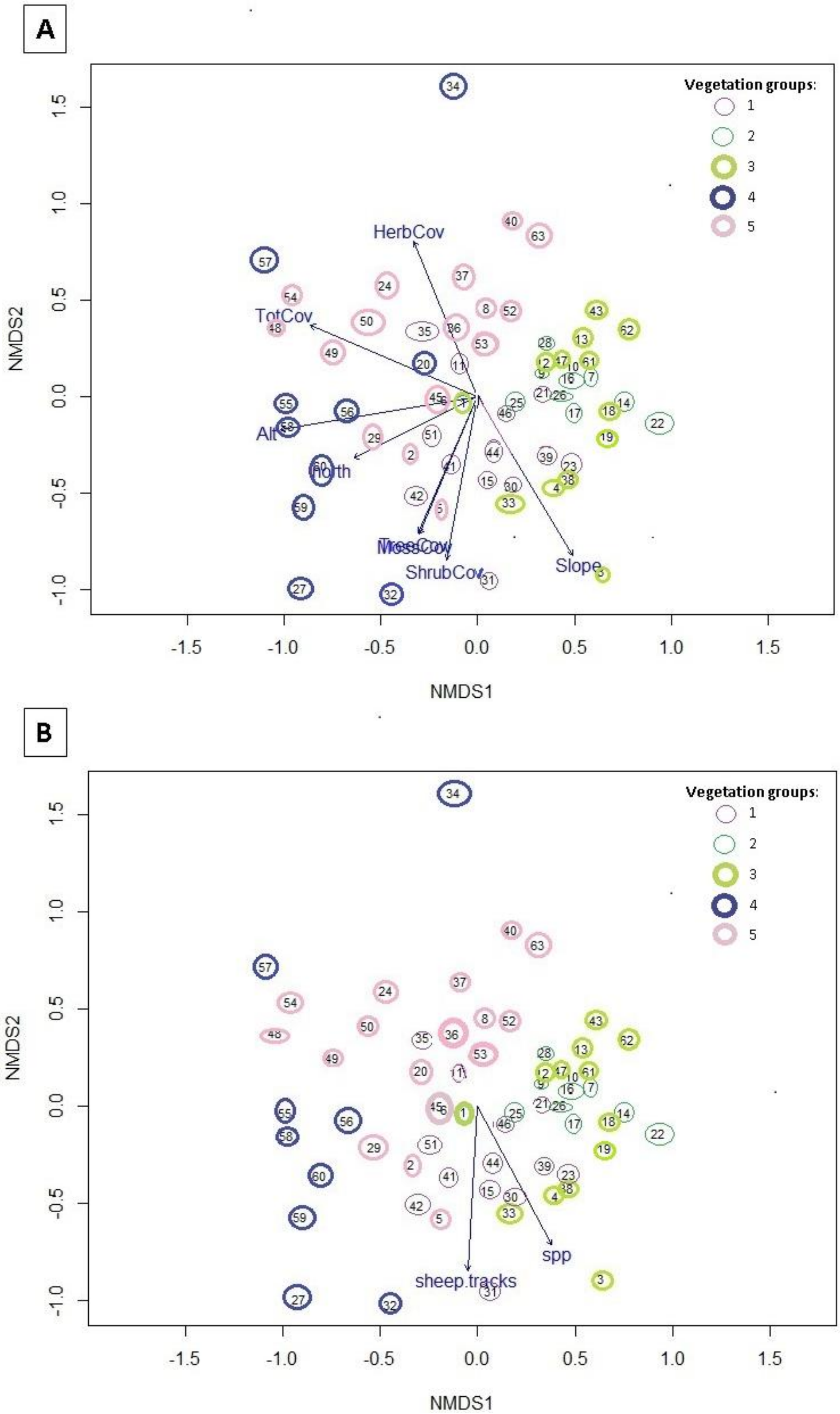


Figure 20: A, B (continued on the next page). Two-dimensional NMDS ordination of five vegetation groups against different environmental variables. Only vectors with significant correlation with NMDS axes are presented (p>0,05); detailed numbers of Pearson's rank correlation coefficients are provided in Table 16. Description of vegetation groups are the same as on the Figure 19 and Table 15. A) – altitude (Alt), slope, northness (north) and total cover, moss cover, shrub cover, herb cover; B) – Sheep tracks;

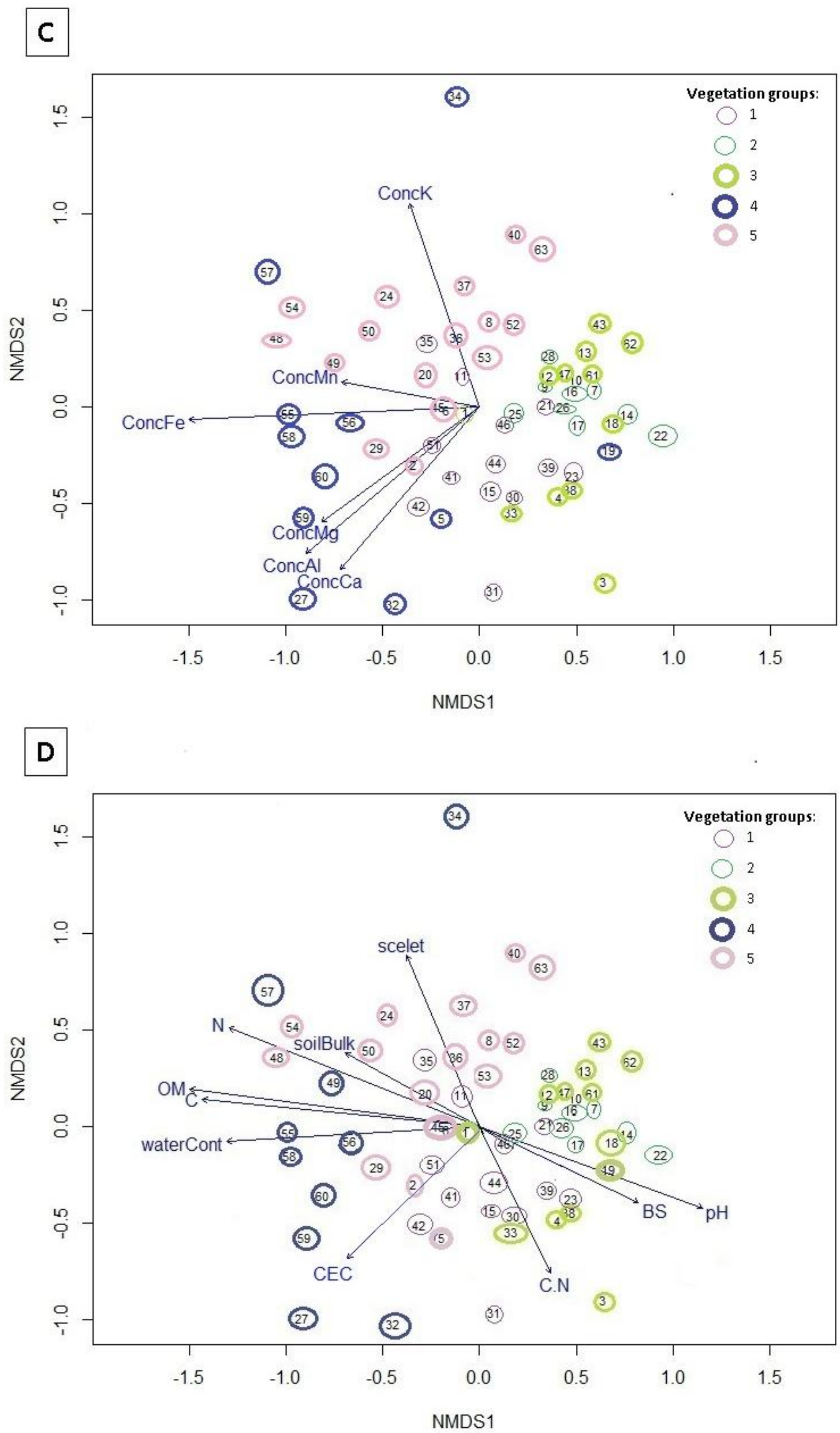


Figure 20: C, D (continued). C) – Concentrations of soil nutrients: potassium (ConcK), iron (ConcFe), manganese (ConcMn), magnesium (ConcMg), aluminum (ConcAl), calcium (ConcCa); D) – soil properties: soil skeleton (sceleton), soil bulk density (soilBulk), nitrogen (N), organic matter (OM), carbon (C), water content (waterCont), Carbon/Nitrogen ration (C.N), cation exchange capacity (CEC), basic saturation (BS), pH.

Among measured environmental variables, soil electric conductivity, aspect, eastness and grazing impact showed no significant correlation with NMDS axes and did not appear within the ordination space (Table 16).

Table 16. Pearson's rank correlation coefficients of the variables and two axes of Non-metric Multidimensional Scaling (NMDS), using monoMDS function. Specie data transformation: Wisconsin (sqrt) on Bray distances.

Variables	NMDS1	NMDS2	r2	Pr(>r)	signif.level
Soil Bulk Density [g/cm³]	**-0.87662**	**0.48118**	0.1458	0.008	**
Soil skeleton [%]	-0.39061	**0.92056**	0.2151	0.004	**
Water Content [%]	**-0.99839**	-0.0568	0.3982	0.001	***
OM [%]	**-0.99183**	0.12756	0.5303	0.001	***
pH (CaCl2)	**0.93947**	-0.34263	0.3506	0.001	***
EC [µS/cm]	0.85651	0.51613	0.0028	0.919	n.s.
C [%]	**-0.99534**	0.09638	0.4818	0.001	***
N [%]	**-0.92989**	0.36784	0.4516	0.001	***
C/N [%]	0.43416	**-0.90084**	0.1633	0.007	**
CEC [cmol/kg]	**-0.70667**	**-0.70754**	0.2832	0.001	***
BS [%]	**0.90274**	-0.43019	0.1925	0.003	**
Altitude	**-0.98633**	-0.16481	0.3274	0.001	***
Aspect	0.01168	0.99993	0.0045	0.869	n.s.
Slope (grad)	0.51248	**-0.8587**	0.2792	0.001	***
Total Cover [%]	**-0.91947**	0.39317	0.2713	0.001	***
Tree Cover [%]	-0.39898	**-0.91696**	0.1799	0.007	**
Shrub Cover [%]	-0.186	**-0.98255**	0.2259	0.001	***
Herb Cover [%]	-0.37984	**0.92505**	0.2301	0.001	***
Moss Cover [%]	-0.38759	**-0.92183**	0.1834	0.008	**
Northness	**-0.89475**	-0.44657	0.1569	0.005	**
Eastness	0.57618	-0.81732	0.0327	0.372	n.s.
Sheep tracks [%]	-0.06189	**-0.99808**	0.1524	0.022	*
Graizing impact	0.21438	-0.97675	0.0141	0.642	n.s.
Number of Species	0.4681	**-0.88367**	0.1389	0.017	*
Al [µmol/g]	**-0.76531**	**-0.64367**	0.3224	0.001	***
Ca [µmol/g]	**-0.65124**	**-0.75887**	0.2871	0.001	***
K [µmol/g]	-0.32627	**0.94528**	0.2901	0.001	***
Mg [µmol/g]	**-0.80804**	**-0.58913**	0.2387	0.002	**
Na [µmol/g]	0.59186	**-0.80604**	0.0288	0.394	n.s.
Fe [µmol/g]	**-0.99904**	-0.04378	0.5262	0.001	***
Mn [µmol/g]	**-0.98376**	0.1795	0.1226	0.019	*

Significance codes for Pr(>r) : 0 '***' 0.001 '**' 0.01 '*' 0.05; n.s. – not significant
Permutation: free. Number of permutations: 999
r2 - squared correlation coefficient between the factor and two matrixes
Pr(>r) premutational significance test

5.3.4. Vegetation groups and environmental variables

Applying the ANOVA statistic and Kruskal-Wallis tests the results showed significant differentiation between five vegetation groups (App. Table 3, App. Table 4), based on the following soil variables: water content, OM, pH, basic saturation and soil bulk density (App. Table 7, Figure 21 (A - E)), which were used as an identifying variables for the five vegetation groups.

Group 1 refers to S-facing shrublands and shrubby grasslands along the altitudinal gradient. Most of the identifying soil variables did not significantly differ within Group 1, except for soil bulk density, which showed the second high value after the Group 5 – “the group of productive grasslands” (Figure 21: E). Also it had the highest number of species per plot - 29.50(±4.80), suggesting that the shrub encroachment has a positive effect on the species diversity, reducing the grazing pressure.

Group 2, representing typical S-facing shrubby grasslands, showed higher pH, BS and CEC values, in comparison with moist north-facing “productive grasslands” – groups 4 and 5 (Figure 21: A, B, C). By contrast, group 5, shoed significantly higher water content, OM and SBD values, as well as higher content of soil carbon and nitrogen, which were different to S-facing grasslands almost in there times (App. Table 7). In group 3, the variables were performing very similar to group 2, without any statistically significant differences among them (App. Table 3, App. Table 4).

Groups 4 and 5 are representing plant communities on more gentle, N-/NW - exposed slopes along the altitudinal gradient. Identifying soil variables did not significantly vary between them (App. Table 3, App. Table 4, App. Table 7), although group 5 had the highest soil bulk density (0.91(±0.12)). At the same time grazing impact was the lowest in group 5 (5.35(±2.34)). Mean concentrations of soil potassium and manganese were reaching maximum in group 5. In group 4, the highest mean concentration of aluminum and iron was observed (Figure 23: A, D). Here mean calcium content reached a significant maximum of 521.55 µmol/g (App. Table 7, Figure 23: E).

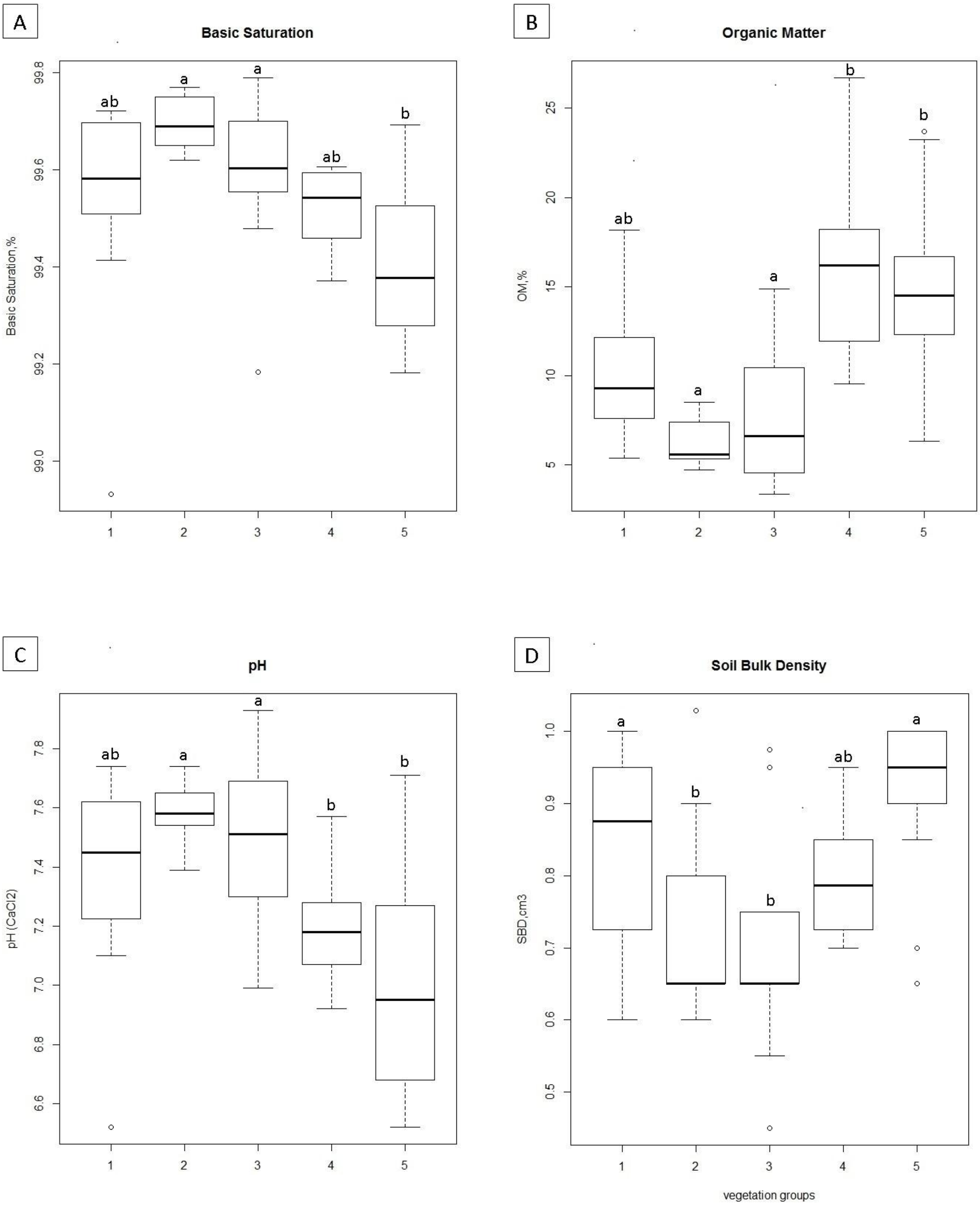


Figure 21: A – E (continued on the next page). Distribution of the identifying soil variables among five vegetation groups (p>0.05): A) – Basic Saturation (%); B) – Organic Matter (%); C) – pH (CaCl2); D) – Soil Bulk Density (cm³). Horizontal axes represents five vegetation groups, defined on the Figure 19 and Table 15.

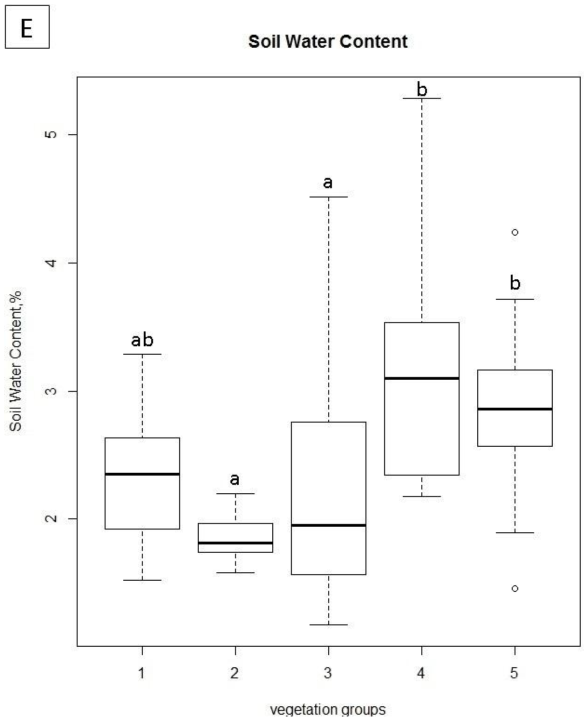


Figure 21: E (continued). Distribution of the identifying soil variables among five vegetation groups (p>0.05): E–Soil Water Content (%). Horizontal axis represents five vegetation groups, defined on the Figure 19 and Table 15.

5.3.5. Productivity of the pastureland

Kruskal-Wallis tests reveal that slope exposure is an important factor, differentiating productivity of the pastureland (Kruskal-Wallis χ^2 =32.953, p= 3.85E-03). Our results show that N-, NE- and NW-facing slopes in forest-grassland or shrubland-grassland ecotones as well as grassland areas in early stages of succsession are most productive in terms of dry biomass (Figure 22). Such slopes usually have total vegetation cover close to 100% and slope inclination between 4 to 13 degrees (App. Figure 7). They show less signs of disturbances, therefore the lowest grazing impact, in accordance to vegetation groups classified above.

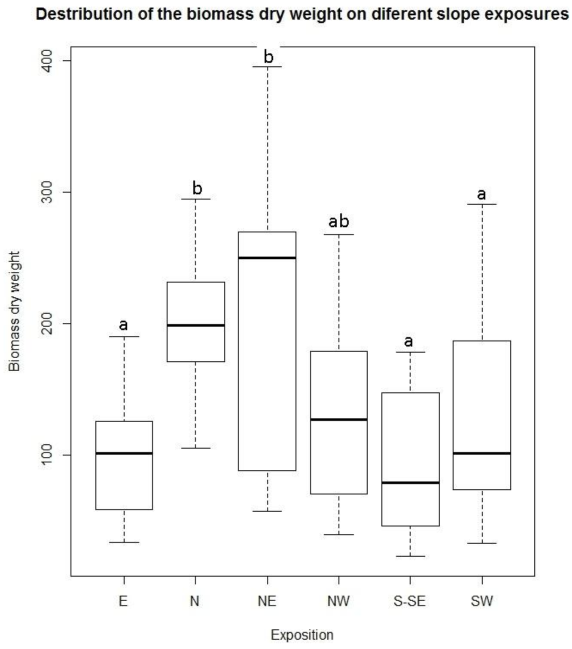


Figure 212. Distribution of the biomass dry weight on different slope exposures along the altitudunal gradient. Biomass dry weight is given in g/kg DM, exposition is measured in degrees (°).

5.3.6. Physical characteristics of the soils

Most of the sampled soils present a pH range indicationg neutral and slightly alkaline pH conditions (6.99 – 7.58); base saturation is often exceeding 99% (App. Table 7); on our ordination space BS and pH vectors follow in the same direction (Figure 20: D). Among most of the sites, especially in group 1 (EC=338.75, SD=264.88), wide range of electrical conductivity values is observed. The mean values for each vegetation group vary in the range between 120 and 435 µS/cm, without any significant difference; current range of EC refers to relatively low salt content in the soil solution (AK Standortskartierung 2003).

Our results reveal insignificalnt variation of the soil sceleton, electroconductivity, CEC and C/N ratio between identified vegetation groups (App. Table 4), corresponding to a broad range of values within each group (App. Table 7).

In general concentration of the organic matter in the investigated soil samples reveal high humus content (according to AK Standortskartierung 2003). On dry S-facing slopes (group 2) the lowest OM content was observed (App. Table 7). Vegetation groups referring to the lpine zone are associated with the highest OM content, even characterized as swampy conditions; therefore the water storing capacity of these soils is estimated as very high (according to AK Standortskartierung 2003). Variation of C/N ratio also corresponded to high humus content (10-15%) and was not significantly different between vegetation groups (App. Table 7).

Mineral composition of the soils is characterized by very high calcium content (App. Table 7), which showed significant variation among the identified vegetation groups (Figure 23: E). Mean iron, calcium, aluminum, potassium and manganese concentrations, peaking in groups 4 and 5, showed associated with the alpine zone (App. Table 7). Concentrations of the iron in the uppermost soil horizon increased with altitude and were comparatively higher under grazing- modified alpine shrubby meadow (App. Table 7). The length of the vector formed by iron reveals the strongest differentiation impact on the vegetation composition along the altitudinal gradient (Figure 20: C).

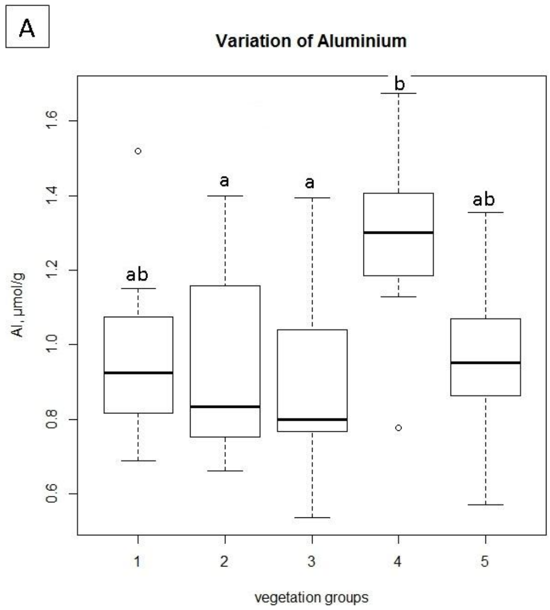
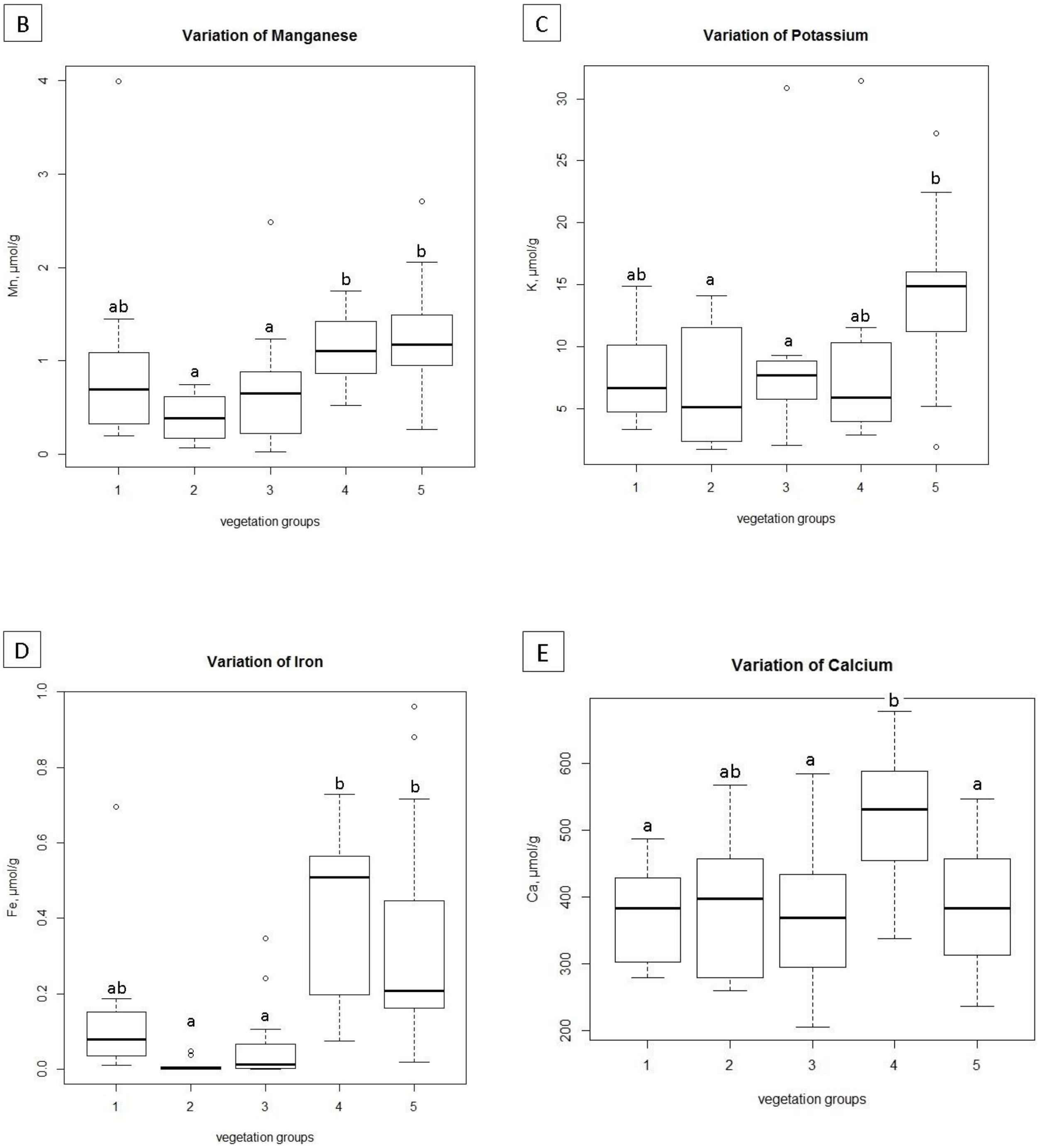


Figure 223: A-E (continued next page). Distribution of the soil minerals among five vegetation groups (p>0.05): **A** – Aluminium [µmol/g]; **B** –Manganese [µmol/g]; **C** – Potassium [µmol/g]; **D** – Iron [µmol/g]; **E** – Calcium [µmol/g]. Horizontal axis represents five vegetation groups, defined on the Figure 19 and Table 15.


B
Variation of Manganese
Mn, µmol/g
vegetation groups
ab
a
a
b
b
C
Variation of Potassium
K, µmol/g
vegetation groups
ab
a
a
ab
b
D
Variation of Iron
Fe, µmol/g
vegetation groups
ab
a
a
b
b
E
Variation of Calcium
Ca, µmol/g
vegetation groups
a
ab
a
b
a

5. Discussion

5.4.1. Species diversity and grazing impact

Area of the Qilian Mountains has been grazed since prehistoric times (Rhode et al. 2007; Miehe et al. 2009), therefore a composition of the plant communities indicates a high level of grazing-resistance (Milchunas & Lauenroth 1993; Suttie et al. 2005). At the same time the percentage of unpalatable and toxic plant species have been increasing in the recent decades (Chang et al. 2004; Baranova et al. 2016). Results of our study are consistent with previous findings, outlining the community-forming role of the unpalatable *Iris lactea var. chinensis* in montane xerophytic grassland, which had been expanding over the vast areas of the pastureland due to selective animal grazing. *Kobresia humilis,* occurring in montane grasslands in Qilian Mountains, similar in abundance *K. pygmaea* in Tibet, has developed morphological adaptations to store the main nutrients in belowground biomass, being an indicator of prolonged grazing by it means (Miehe et al. 2008; Etzold et al. 2015). In each of five vegetation groups, identified in our study, indicators of continuous grazing were found, suggesting a strong impact of intensive pasture utilization on the present composition of the plant communities.

With regard to altitudinal gradient, different studies show that species-richness curve usually has a hump-shape on the middle elevations (Lomolino 2001; McCain & Grytnrs 2010; Yang et al. 2018). In our study it is not confirmed (App. Figure 7). However an insignificant variation of the species richness along the altitude could be explained by the fact that altitudinal gradient was found to overlap the effect of grazing on plant species richness and diversity (Brinkmann et al. 2009). At the same time plant species richness and diversity were showen to decrease under moderate to high levels of grazing intensity (Herrero-Jáuregui & Oesterheld 2018). Also, our results reveal a maximum species number at 2850 m a.s.l., while in the study of Yang et al. (2018) it peaked at 3177 m a.s.l. Although both studies are conducted in the Qilian Mountains, such a difference could be explained by the sampling design: the latter study covers only north-facing slopes, which usually have more gentle slopes, higher herb cover and therefore reveal greater species diversity.

Addressing the distribution of the plant species richness along the elevation gradient, Etzold et al. (2015) suggested taking into account the effect of the land use and its intensity. Recent meta-analysis of Herrero-Jáuregui and Oesterheld (2018) revealed larger negative response of species richness to grazing on arid and low productive rangelands, than on humid and productive ones. By contrast, in our study most of the diversity indices show the highest values in montane xerophytic grassland, and the lowest – in grazing modified alpine shrubby meadow (App. Table 5), reflecting a higher negative impact of grazing on the plant species diversity in alpine communities in Qilian Mountains.

However there are two restrictions, making an estimation of species diversity more vulnerable - species abundance distribution and sampling density (Chao et al. 2014). Therefore in modern diversity measurements classical approach of Shannon entropy and other diversity indexes usually correlating with each other, is favored to estimations using Hill numbers (i.e. effective number of species) and ratios, expressed in the same units (Borcard et al. 2011; Chao et al. 2014). It allows incorporating relative abundance and species richness (Chao et al. 2014). In our study evenness indices calculated with the Hill numbers, varied differently in comparison to Pielou evenness: the latter was in line with classical diversity indexes, while evenness based on the Hill numbers have shown the higher values in alpine, instead of montane, vegetation communities (App. Table 5).

Species constancy highly depends on the plot size (Dengler et al. 2009). In natural communities usually a large number of species has relatively low abundances (Chao & Shen 2003). In our study 87% of the species were found to have low constancy level below 2.5%. For that reason square-root transformation of the species data was used prior to constancy analysis in order to decrease the impact of the high-score specie (Borcard et al. 2011). Nevertheless the results of the cluster analysis as well as the performance of the species within NMDS ordination space have shown a high species heterogeneity within each of the identified vegetation groups.

5.4.2. Main environmental gradients

Our results show that the elevation/moisture gradient is responsible for the strongest change in species composition in alpine areas of the Qilian Mountains, which is inline with different altitutudinal studies around the globe (Nagy & Garbher 2009; Etzold et al. 2016). North-facing slopes provide moist environments for grasslands and cause higher productivity compared to south-facing slopes. Within montane zone, edaphic moisture was identified as an important driving factor for the vegetation differentiation (Zimmrich et al. 2010). In our study in montane-subalpine zone, slope inclination and exposition have a distinguishable impact on vegetation distribution as well as on variation of the dry biomass along the altitudinal gradient. N-, NW- and NE-facing slopes contain most productive and less disturbed plant communities with total cover close to 100% (App. Figure 6). North exposure was found to be an important factor, differentiating grasslands in alpine areas, while in montane/sub-alpine areas north-facing slopes are mostly covered by *Picea crassifolia* forests.

5.4.3. Soil properties and interactions between them

The optimum pH of the humus accumulation and avaliability of the nutrients for the plant growth falls between 5,4 to 7,0 (in CaCl2) (AK Standortskartierung 2003). In more alkaline soils availability of nutrients for the plant growth is decreasing (White & Greenwood 2013; Brady & Weil 2014). Our results show neutral to slightly alkaline pH range, indicating medium conditions for the plant growth (AK Standortskartierung 2003). It is also supported by our ordination results, revealing the increase of soil pH in the opposite direction to accumulation of the soil organic matter, nitrogen and carbon concentration (Figure 20: D), which primary source is the amount of produced and decomposed biomass.

In arid and semi-arid areas with low-rainfall variation, cations of calcium, magnesium and natrium are forming an exchange complex, defining the value of cation exchange capacity and influencing other soil properties (Brady & Weil 2014). In our study cations of calcium play the major role in CEC, having mean calcium saturation percent of 86, therefore there is a strong correlation observed between calcium and CEC vectors (Figure 20: C, D). However our results reveal no distinct correspondence between them: increasing CEC has high correlation with both NMDS axes, therefore indicating that moisture gradient has the same impact on CEC values, as soil pH (Figure 20: D, Table 16).

Base saturation is mainly to be attributed to cations of Ca, K, Mg and Na. An increase in BS values indicates a tendency to neutrality or alkalinity in soil pH (Brady & Weil 2014). Our data reveal high values of base saturation in the range above 99 %, thus corresponding topsoils could be classifyed as highly elastish, with the high potential to intercept the soil disturbances (AK Standortskartierung 2003). Although in our study area high values of base saturation could have been affected by the high values of calcium ions (Friedrich 2015).

Variation in soil bulk density is ussually associated with the soil texture: sandy soils have higher values of SBD, than silt loams or clays, which could be explained by the presence of micropores in clayey particles. In our study area soil texture was defined as silt, silt loam and sandy loam (Lieder 2013; Tian et al. 2017), which corresponds to low values of soil bulk density with mean value of 0.80 g/cm³, corresponding to uncultivated forest and grassland vegetation types (Brady & Weil 2014). Yang et al. (2018) reported about dependency of the soil bulk density on the soil depth as well as on the elevation: in deeper soil layers on the high altitudes soil bulk density was increasing, whereas on the upper most soil horizon soil bulk density tend to decrease with altitude. The latter is only partly supported by our results: soil bulk density had the strongest correlation with elevation gradient, although minor correlation with slope/woody gradient was also observed, revealing unequal distribution of the fine and grain-textured soils (Brady & Weil 2014).

5.4.4. Soil organic matter

It was found that soil organic matter develops on the higher rates under the grassland instead of forest or shrubland, which is related to the type of the root system and its decomposing ability (Brady & Weil 2014). Results of our study illustrate the mentioned above: the direction of the carbon, nitrogen and organic matter accumulation follows elevation/moisture gradient, whereas the increase of total shrub and tree cover is presented as a separate slope/woody gradient (Figure 20: A, D). Instead of carbon and nitrogen, C/N ratio was found to be correlated with woody gradient, which is supported by the previous studies, showing the increase in C/N ratio under the forest/shrubland cover (Lieder 2013; Friedrich 2015). These two independent gradients represent the main cumulative forces of the vegetation differentiation in montane, subalpine and alpine areas of Qilian Mountains.

It is assumed that a value of C/N ratio >15% corresponds to sufficient supply of the nitrogen and moderate level of humus content (Lieder 2013). Our findings are consistent with mentioned above, showing the mean value of C/N ratio equals to 12%. In general the range of the C/N ratio in our samples revealed variation of 9-20 %, which was not predetermined neither by elevation, nor by vegetation type (Table 16, App. Table 7). Quit a narrow C/N ratio usually refers to calcium-rich soils underlying the semi-arid grasslands (Brady & Weil 2014). This tendency is confirmed by our findings, showing that described vegetation patterns have no significant variation in C/N ratio between each other and comparatively narrow range of C/N values corresponds to moderate levels of C/N content of soil organic matter (AK Standortskartierung 2003).

Our results indicate that, C/N ratio and CEC mean values are in-line with those related to Chernozems, whereas OM content is significantly lower and pH values are higher than expected for this soil type (Zech et al. 2014). By these means our results do not correspond to findings of Yau & Hou (2015) and Miao et al. (2015), who were reporting fertile soils on the alpine meadows below 3000 m a.s.l. in Qilian Mountains. This contradiction explains primary role of the topographic factors: mentioned above studies were hold in the outwash plains, where as our investigation plots mostly belong to the catchment areas with incomparably higher erosion rates and low soil water content. To complete the identification of the corresponding soil types according to FAO, detailed investigation of the soil profiles in varying geological units of corresponding pasture areas is necessary.

Some studies in mountain environment show that total amount of soil nitrogen and carbon content tend to increase in the topsoil with increasing elevation (Nagy & Grabbher 2009; Yang et al. 2018), which is also illustrated in our study (Figure 20: D). Depletion of soil carbon and nitrogen is often associated with increasing grazing pressure directly - by the reduction of the primery source of organic matter coming for the plant biomass, and indirectly - through the change in species composition and decrease of legume species (known for their N-fixator ability) due to selective grazing and decrease of species diversity (Wang et al. 2017a). However some studies have shown high nitrogen content in heavily grazed pastures close to the camp or water place (Hoppe et al. 2016; Wang et al. 2017b) due to direct depositing of the cattle dung. In Tibetan area yak dung is an essential source of fuel, which has been collected since former times (Rhode at al. 2006), therefore even in extremely grazed spots the concentration of soil nitrogen remains quite low (Miller 2005; Wang et al. 2017a).

5.4.5. Soil nutrients

Among the essential mineral elements required for the plant growth (White & Greenwood, 2013), we have analyzed variation of concentrations of potassium, calcium, magnesium, iron and manganese, and additional aluminum and natrium. Compared with results of Baranova et al. (2019), all the minerals were found in sufficient leaf concentrations for the plant growth. Except for iron, which concentration during the growing season was exciding toxicity levels (White & Greenwood 2013). Indirect ordination reveals a feasible increase of the iron concentration along the elevation gradient (Figure 20: C), which could be explained by decrease in redox potential and / or decrease of pH value (White & Greenwood 2013). The latter is supported by our results, where the pH values show a negative correlation with elevation/moisture gradient, pointing in the opposite direction to increasing iron concentration (Figure 20: C, D). Whereas increasing concentration of soil calcium showed an opposite trend to increasing soil pH, which is probably associated with leaching of calcium ions and longer accumulation of organic matter only possible on the higher altitudes (Etzold et al. 2016).

In general, soil erosion negatively affects soil nutrient availability causing depletion of organic matter from the topsoil (Bradly & Weil 2014). In our study area due to the high rates of the soil erosion on the S-, SW-facing slopes decreased concentrations of the soil nutrients were observed, therefore soil minerals were not playing an important role in the differentiation of the vegetation groups on the respective slope exposures on low elevations (Figure 20: C). Although investigating deeper soil layers (up to 90 cm), similar results were obtained, indicating a decrease of the soil minerals concentrations under intensified land use (Liu et al. 2017).

Chapter 6. Conclusions

In the following chapter the research questions, outlined in Chapter 1, are addressed and discussed in conjunction with the objectives of the research. Different aspects of methodology and some particular findings of the current Ph.D. dissertation are critically discussed, including the outlook of these findings for the further studies. At the end some management suggestions are made.

6.1. RESEARCH QUESTIONS ANSWERED

A. Habitat Quality and Floristic Diversity

RQ1: What are the main plant communities comprising the spring/autumn pastures in Qilian Mountains?

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).

RQ2: What are the grazing-induced, spatially-differentiated changes in vegetation patterns in corresponding rangeland area?

- Changes in small-scale vegetation patterns: south exposed slopes - *Stipa capillata* mixed grassland with high grazing impact; north-facing slopes - *Stellera chamaejasme* shrubby grassland, less affected by grazing.
- Changes in dominant species of grassland communities over time.
- Changes in species richness and evenness.
- Changes in pasture quality by increasing proportion of unpalatable and toxic plant species in rangeland communities.

Grazing gradient determines the vegetation distribution on the spring/autumn pastures, together with altitude and slope exposure. North-/south- differentiation in the distributional patterns of vegetation is pronounced. Intense grazing is associated with more alkaline soil conditions, usually on the south-facing slopes. In terms of species composition, ongoing transformation process was detected: from more homogeneous grassland less affected by grazing and dominated by species of *Stipa* and *Agropyron* to severely degraded *Stipa capillata* grassland co-dominated by *Iris lactea* var. *chinensis* and *Stellera chamaejasme*. Continuous overgrazing was found to affect the variation in the plant species evenness through variation in abundance of the dominant species: some of which have become dominant during the last decade facilitated by selective grazing. Moreover, increased number of toxic and unpalatable species was associated with decreases in the values of biodiversity indexes. With regard to shrub encroachment, grazing was suggested to be a preventing factor. Comparing monitoring data for the recent nine years, a trend of pasture deterioration is observed. Plant community successions and shift in dominant species from palatable to unpalatable and toxic plant species, positively selected by intensive grazing, are decreasing the productivity of the rangelands by it means.

B. Forage Quality

RQ3: How forage quality is affected by altering grazing intensity?

- There is a negative impact of long-term grazing on herbage nutritive values: most disturbed plots contain less palatable herbage material, due to selective grazing, and therefore show the highest fiber concentrations (NDF).
- An increase in grazing intensity was found to decrease dry yields of herbage (forage?) biomass (e.g. DM yields).
- In plots, most disturbed by grazing, the highest fiber concentrations (59.20%) were found, which corresponds to low potential forage intake (e.g. Linn & Martin 1991). The lowest fiber (51.30%) and the highest protein concentrations (16.30%) were found on the plots with slightly grazing intensity.
- Variation of zinc and phosphorus concentrations does not depend on maturity stage, but are affected by grazing intensity: under slightly grazing the concentrations were significantly higher and sufficient to meet dietary requirements of grazing animals, but reduced under intensive grazing.

RQ4: How forage quality varies during the growing season?

- TDN concentrations (measure of total nutrient yield) depend on growing stage and tend to decrease during the growing season.
- Fiber content of the forage plant material was simultaneously increasing at the end of the growing season.
- Protein concentrations (CP) had a high concentration in the middle of the growing season, then it tends to decrease, showing lower forage quality and lower potential forage intake in the beginning and at the end of the growing season.
- Variation of mineral concentrations in forage material does not depend on growing season.

RQ5: How forage quality varies between two altitudinal zones?

- In subalpine-alpine zone DM yields were higher with a factor of three than in montane-subalpine zone, where amount of precipitation is lower.

- In subalpine-alpine zone concentrations of protein (CP), zinc, phosphorus and sulfur were significantly higher than in montane-subalpine zone.

Overall our results suggest that the investigated rangelands in Qilian Mountains are still capable to provide forage of sufficient quality in terms of herbage biomass, nutritive value and concentrations of most of the minerals for the demands of the grazing animals. At the same time, uncontrolled overgrazing could lead to a decrease in forage quality and enhance ongoing rangeland degradation.

C. Soil and Vegetation Responses

RQ6: What are the main vegetation groups, found in montane/sub-alpine and alpine rangelands of Qilian Mountains? Which abiotic factors are responsible for their differentiation?

- Montane xerophytic shrubby (1), montane xerophytic (2), montane grassland - forest (3), grazing modified alpine shrubby meadow (4), alpine meadow (5).
- Significant difference between identified vegetation groups were observed in respect to soil pH, bulk density, organic matter, carbon, nitrogen and water content as well as soil minerals concentrations.

RQ7: What are the main environmental factors responsible for vegetation differentiation in montane/sub-alpine and alpine rangelands of Qilian Mountains?

- Elevation/moisture gradient is responsible for the strongest change in species composition in alpine zone. Together with north exposure they predetermine grassland productivity in terms of herbage biomass. Along the elevation/moisture gradient increases in soil conductivity, carbon and nitrogen, organic matter and water content, as well as decreases in soil pH and basic saturation were observed.
- In montane-subalpine zone, slope exposition and inclination were found to be important parameters for vegetation variation on lower altitudes. Other variables, responsible for vegetation differentiation in xerophytic environments, could have been moisture deficiency and additionally drier conditions occurring as an effect of climate change on the south-facing slopes.
- On the lower altitudes due to the high rates of the soil erosion, triggered by overgrazing, top-soils of the south-facing slopes revealed decreased concentrations of the soil nutrients. By it means soil nutrients did not play an important role in the differentiation of the vegetation groups on the respective slope exposures.

- Among the soil parameters the increase of soil pH in the opposite direction to accumulation of the soil organic matter, nitrogen and carbon concentration was observed.

RQ8: How varies the response of montane/sub-alpine and alpine vegetation communities to grazing intensification?

- In each of five vegetation groups, montane-subalpine and alpine vegetation, indications of continuous grazing were found, suggesting a strong impact of intensive pasture utilization on the present composition of the vegetation patterns.

- In terms of species richness and diversity, montane-subalpine communities showed less response to grazing than alpine communities.

- On the south-facing slopes in montane-subalpine zone degraded montane communities of low concentration of soil OM, nitrogen and carbon and soil minerals are observed, experiencing more severe degradation in terms of herbage biomass and total cover.

- The lowest level of degradation was observed in alpine grasslands, demonstrating the highest productivity in terms of herbage biomass and total cover, especially on north-facing slopes in forest-grassland and shrubland-grasland ecotones.

6.2. Critical review of the findings and methodologies presented in the Chapters 2-5, with the outlook for the further studies

Chapter 2. Review of the Study Area

In the final section of Chapter 2 the concept of rangeland ecosystem functioning needs further investigation. Until now, the non-equilibrium rangeland dynamic was a modern, although questionable, concept argued in different studies on pastoral ecosystems around the globe. A recent summary by Briske (2017) provides major advances on non-equilibrium ecology and resilience theory up to date. It became feasible that natural systems always reveal a balance, therefore pure non-equilibrium state is possible only on a part of the arid grazing land (during the wet season), whereas another part of the grazing land, in dry or winter season, is found in the equilibrium with population of grazing animals. Thus actual numbers of grazing animals in arid conditions are uncoupled with high amount of the biomass available during the wet season, and are rather controlled by the amount of biomass available during the dry season (Ilius & O'Connor 2000). Therefore, in arid environments inter-annual variation of precipitation no longer plays a significant role in estimation of plant-herbivore interactions, as it was proposed in earlier studies (Ellis & Swift 1988; von Wehrden et al. 2012). In addition to that ecological resilience theory allows acknowledging the presence of non-linear and non-reversible shifts between the stable states in rangeland ecosystem functioning, based on the separating thresholds and environmental indicators (Briske et al. 2017). To sum up, there are several dynamic interactions within the rangeland ecosystem: (a) linear equilibrium functioning, based on succession processes, in more productive grasslands (and during the wet season in arid rangelands); (b) non-equilibrium interaction between the grazing animals and forage biomass during the dry season; (c) multiple stable states with certain non-reversible thresholds and reversible individual states of the ecological site. Each of these interactions is important to take into account, identifying rangeland health. Location of the rangeland and certain climate conditions, predetermining the amount of forage biomass, together with other environmental indicators, are responsible for individual stable states in rangeland ecosystem functioning.

Chapter 3. Vegetation Patterns&Floristic Diversity

Discussing the possible limitations of the phytocoenological data used in the current study, sampling design could be modified, due to small-scale topographic variability in the study area. A number of the sampling plots (n = 37) might also be a reason for the incomplete documentation of the identified vegetation communities. There is a necessity to increase number of plots in each of the topographic units, and to have more broad understanding of the variation in vegetation communities within each topographical unit; in general, the study area, covered by vegetation inventories, should be expanded. By it means the problem of internal heterogeneity within identified grassland communities would be eliminated.

Apart from the visual estimations of grazing intensity, applied in the study, an additional tool, assessing the habitat quality, is an exclosure experiment. Also it allows to reveal the ‘memory effects’ of past land use patterns by means of vegetation successions. Unfortunately our exclosure experiment on alpine pastures was interrupted earlier than it was planned. Nevertheless our fencing experiment reveals dramatic differences between grazed and not grazed sites (data not shown). Obtained results over the period of 2-years show that it is a sufficient time for the alpine meadow to maintain itself; but it is definitely insufficient time for the *Potentilla* and *Caragana* shrubby meadow to recover. If the current experiment would be continued, further observation on fenced plots can reveal independent of grazing herb species succession and recovery of the shrub species. With regard to design of the experiment, it is advisory to set the experimental plots (fenced and grazed sites) in every altitudinal zone in statistically representative number in order to gain sufficient amount of data for the further statistical analyses.

Chapter 4. Forage quality

There are two groups of consumers - foregut and hindgut herbivore animals. Therefore, forage quality needs to be discussed in terms of consumer’s digesting abilities: sheep and cattle (including yak) are foregut grazers, meaning that they can digest cellulose - which is mostly assumed as a negative component of the forages (e.g. amount of fibre). By it means the results could be seen in controversial light. In order to separate indigestible part of the forages, it would be necessary to measure directly cellulose and hemicelluloses, instead of measuring ADF and NDF indexes, common in forage science. Because ADF value is comprised by cellulose and lignin, and NDF value already includes fiber and hemicelluloses, - so it is hard to distinguish only indigestible part.

Another important question of crop nutrition was not covered by the current study. Availability of the soil nutrients for the plant grow and the comparison of the mineral concentrations, found in the dry biomass, with those in corresponding soils, would reflect the level of sufficiency for the plant growth, as well as would provide the data on their toxicity (e.g. White & Greendoow 2013).

Further studies on leaf stoichiometry would reveal the undiscovered relationships between the nutrition pools, contained in the soils and in plant biomass (i.e. Niu et al. 2016). In addition, estimation of the carbon and nitrogen pools in soil and biomass could be made in order to provide an assumption on nitrogen and carbon sequestration rates, as well as the potential impact of degradation of the mountain grasslands on carbon stocks (e.g. Liu 2017).

Chapter 5. Impact of abiotic site factors

Discussing the results of indirect ordination analysis, only a few vectors responsible for the vegetation differentiation in montane/sub-alpine zone are shown. Therefore, more detailed investigation of the corresponding soil variables is necessary. Soil parameters should be measured not only for the top soil, but on the different depths along the soil profile. Measurement of the soil respiration would enrich the resulting vectors. At the same time, it is probable, that arid conditions and erosion of south-facing slopes have lead to depletion of the upper most soil horizon and to insignificant variation of the measured soil variables between identified vegetation groups by it means.

Also it is important to recognize zonation of the particular study area in Qilian Mountains, which is comprised by spring and autumn pastures (with semi-arid conditions on the south exposed slopes) and summer pastures (with more humid conditions and plain bases of the hills). Therefore, a combination of equilibrium and non-equilibrium conditions appears on the rangelands in the transitional environment (Hoppe et al. 2016; Briske et al. 2017, Wang et al. 2017b), meaning that both animal grazing and variation in annual precipitation are important factors, determining vegetation biomass and plant species composition in mountain environment (Fernandez-Gimenez & Allen-Diaz 1999, Miao et al. 2015). At the same time, it is a matter of scale, if the apparent grazing impact could be identified and measured. In our study we have implemented a community-level approach, and our results show both equilibrial and non-equilibrial properties in the studied pasture types. Since it was shown that grazing influence increases with decreasing spatial scale, it would be necessary to upscale the study design up to a landscape level. To confirm or reject the concept of equilibrium dynamic in the ecosystem, corresponding vegetation patches in each altitudinal belt could be clearly identified on the landscape level and related with certain equilibrial and non-equilibrial properties (c.f. Zimmerlich 2007).

6.3. Sustainable management suggestions

The results of this dissertation project contribute to strategy-oriented implications for integrated management plans. In order to implement integrated management plan, it should be included into general plant of the development of the region. 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 among respective 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.

Under the conditions of intensive grazing, palatable forage species are positively selected and decreasing in diversity numbers and total cover, while unpalatable and poisonous plant species are flourishing and expanding their dominants in increasing number of plant communities (Baranova et al. 2016). To prevent this happening, control over flowering and clonal activities of these plants should be a part of the pasture management measures. At the same time artificial re-seeding of the common graminoid species would increase the pasture quality (Shang et al. 2016) and other agricultural measures (Guo et al. 2003). There are already existing seed banks for common and potentially suitable grassland forage species around the Tibetan Plateau (Shang et al. 2016). Foremost, a positive short-term effect of fertilization was shown on the Maqu County: moderate addition of nitrogen positively affects pasture productivity and stability of the forage species numbers under moderate to high grazing intensity levels (Li et al. 2016). At the same time, the diverse results of fertilizing experiments around the globe confirm that fact, that addition of the nitrogen provides only temporal benefits for the introduced weed species (by replacing the native grassland species, adopted to low levels of nitrogen throughout the long history of herb-grazer interactions). By it means productivity of the native rangelands as well as species diversity tend to decrease on the long term (Brady & Weil 2014).

Not least importance has the foraging behavior: sheep was found to be a more selective grazer, compare to yak (Sanon et al. 2007; Jerrentrup et al. 2015). If yak and sheep are grazed on the same area, they still get enough of the herbage by selecting different forage species. Although for the rangeland health it seems to be an increased pressure on the plant communities, and, depending on the extent of grazing, fewer opportunities are left for the grasslands to recover.

VII. Postface

Most recent changes in land use happened in the Qilian Mountains in 2017. Following the decision of the State (e.g. the superior organs of Communist Party of China), a National Reserve Area is formed there with the goal of conservation "of the whole community of life: Mountains, Water, Forests, Grasslands and Farmlands" in frames of integrated management of the HeiHe River Basin (source: presentation slides in AWRCFQM). There are four levels of protection areas: core, shallow, mediate and distant. The core area, which includes summits, shrub thickets and alpine meadows, is completely closed for any land use activities. In the shallow area, including spring and autumn pastures, restricted number of domestic grazing is allowed. Further details about the measures and other levels of protected areas are available only in Chinese. A number of academic institutions are involved into the process of formation and monitoring of the National Reserve Area in Qilian Mountains.

In personal communication with the representatives of AWRCFQM in Zhangye, it was find out, that together with formation of the protected area, a new rangeland policy was implemented in Qilian Mountains (including our study area). Starting from 2017 onwards, 115 herdsman families were already moved out from the core areas of the National Reserve into the neighboring cities. Every family was receiving a single payment compensation of 1.000000 RMB for deconstruction of their house, build in the mountains. Some of the family members have got an opportunity to work as foresters in Qilian Mountains and to live in communes there. Others were provided with job opportunities in the cities according to the number of working family members. Some of the local people were happy to move out from the harsh mountain environment to civilization, and to be able to teach their children in the city's schools. Others did not want to move out and probably will remain in the Qilian Mountains below certain altitude, where the border of the core area is set. Those people most likely belong to a "zang" minority (e.g. Tibetans), who are herders in several generations and used to live in Qilian Mountains. Although it was already described in Chapter 1, section "Land use types: past and present", a trend to sedentarization of nomads all over the Tibet was undertaken by Communist Party of China. No respect is given to the historical role of the land use practices of the local minorities, as well as to their customs and former family's attachment to the area, - the straightforward decision of the Communist Party has no exceptions and must be undertaken with no room for negotiations with public and science.

The tremendous change in land use including vast areas of rangelands in Qilian Mountains, could not remain unaffected the transhumance practice of that region. The consequences of the extreme decision to completely prohibit grazing in the alpine areas (e.g. summer pastures) will definitely increase grazing pressure on the remaining montane areas, which, according to our findings, are already degraded to a high extend and are the most vulnerable to increase in grazing pressure. However moderate levels of grazing are important to maintain the rangeland health. Complete exclusion of grazing in alpine areas could alter a change in species composition and subsequent shrub encroachment. In order to assess the status of rangelands under the new management policy, appropriate rangeland health monitoring program should be implemented, involving not only regional Livestock Management and Grassland Bureaus of People's Republic of China, but also international rangeland expertise.

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Appendix

App. Table 1. Distribution of plant communities and subassociations in Pailugou Catchment.

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 c. 15 m only 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* represents the shrub layer, total shrub cover do not exceeds 30%. This grassland is already occupied by unpalatable *Iris* populations, positively selected by long-lasting grazing activities.	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

App. Table 2. Range condition scale.

Nr.	Indicator parameters	status
1.	Grazing evidence	no was grazed recently grazed
2.	Droughtness of the slope (relative condition of the soil sample and soil outcrops)	low mid high
3.	Steepness of the slope (degree)	>12 13 to 23 >23
4.	Total Plant Coverage (%)	>90% 90-65% <65%
5.	Sheep pathways (in % of Total Cover)	non or some >3% obvious 3-10% a lot (>10%)
6.	Sheep and yak dung (relative abundance)	no some presented
7.	Erosion evidence (visual disturbance of the upper soil)	no some (< 5%) obvious (>5%)
8.	Number of poisonous plant species	no, 1 or 2 2 - 4 more than 4
9.	Cover of unpalatable and poisonous plant species (after Braun-Blanquet cover-abundance scale)	no r, +,1 >=2
10.	Dry standing crop from the last growing season (in % of Total Cover)	>10% some no

App. Table 3. ANOVA results comparing performance of the variables among the five vegetation groups.

Variables	factor	Df	Sum Sq	Mean Sq	F value	p-value Pr(>F)	level of significance
Base Saturation [%]	groups	1	0	0.2782	10.95	0.00157	**
	Residuals	61	15.493	0.0254			
Slope [°]	groups	1	962	961.6	9.092	0.00374	**
	Residuals	61	6452	105.8			
Number of species	groups	4	6.066	15.166	3.34	0.0158	*
	Residuals	58	26.336	0.4541			
Water content [%]	groups	4	14.02	3.505	6.771	0.000153	***

	Residuals	58	30.02	0.518			
Electroconductivity [µS/cm]	groups	4	4466	4466	0.15	0.7	n.s.
	Residuals	58	1816537	29.779			
Nitrogen [%]	groups	4	1.860	0.4651	7.021	0.000111	***
	Residuals	58	3.842	0.0662			
Graizing impact	groups	4	95.6	23.910	3.846	0.00771	**
	Residuals	58	360.6	6.217			

Significance codes for Pr(>r) : 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05; n.s. – not significant

App. Table 4 Kruskal-Wallis test results comparing performance of the variables among the five vegetation groups.

Variables	chi-squared	p-value	level of significance
Soil bulk density [g/cm³]	18.112	0.001173	***
Soil organic matter [%]	31.877	2.03E-03	***
Cation Exchange Capacity (CECeff)[µmolc/g]	30.222	4.41E-06	***
Total vegetation cover [%]	27.414	1.64E-02	***
Northness	16.638	0.002272	**
Eastness	18.056	0.7715	n.s.
pH (in CaCl2)	25.185	4.62E-02	***
Carbon [%]	25.849	3.94E-06	***
Slope exposure	32.953	3.85E-03	***

Significance codes for Pr(>r) : 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05; n.s. – not significant

App. Table 5. Species richness, evenness and diversity indices of the five vegetation groups obtained in cluster analyses.

Vegetation group	N0	SD	H	N1	N2	E1	E2	J
gr1	29.42	4.50	2.593	13.713	10.434	0.470	0.356	0.770
gr2	23.90	4.07	2.352	10.726	8.143	0.451	0.341	0.744
gr3	24.38	5.94	2.359	11.022	8.203	0.457	0.345	0.746
gr4	19.55	7.74	2.039	8.498	6.342	0.482	0.382	0.742
gr5	22.71	5.42	2.348	10.848	8.193	0.484	0.369	0.759

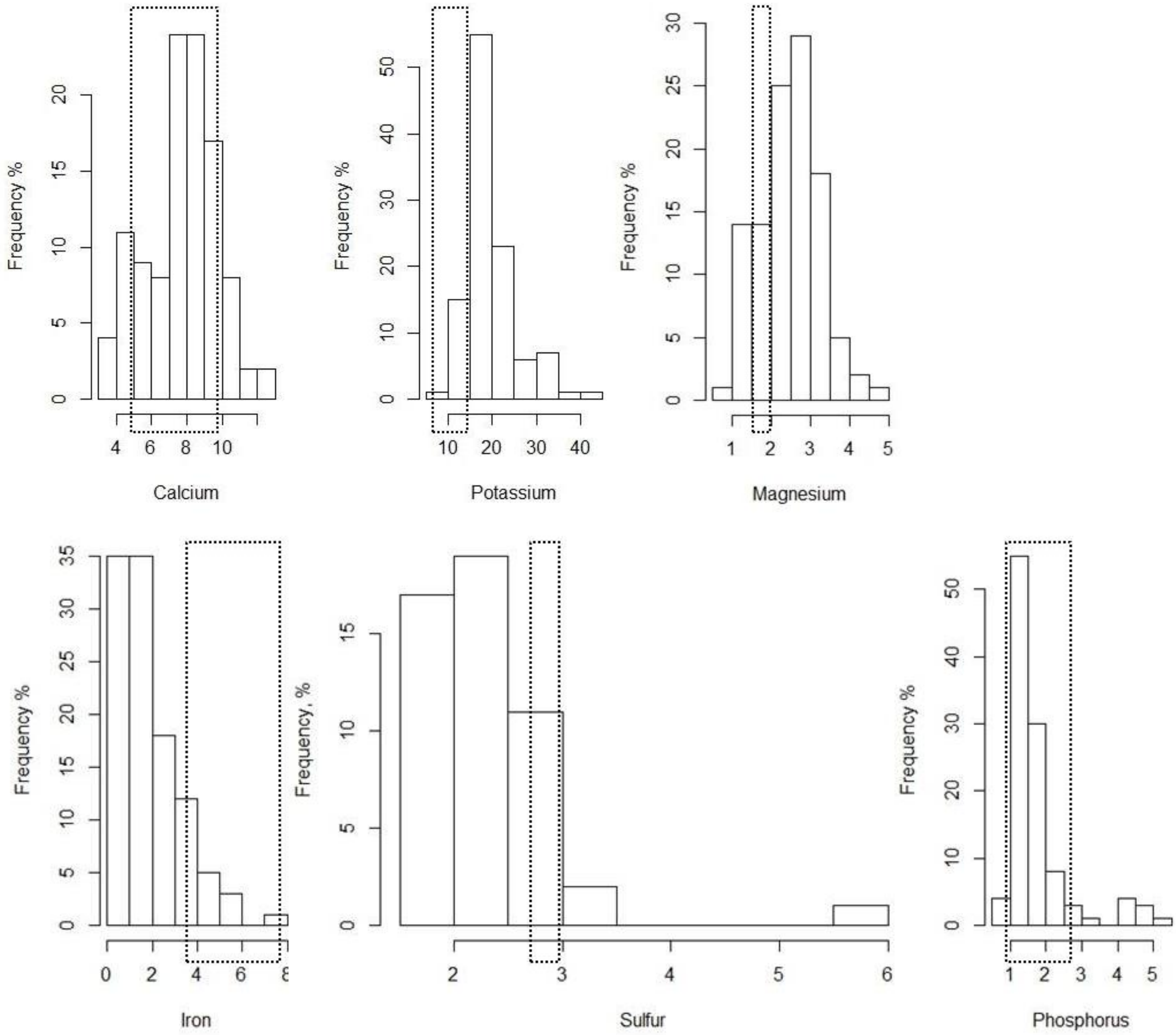
N0 - species richness
H - Schannon entropy
N1 - Schannon diversity number
N2 – Simpson diversity number (inv).
J – Pielou evenness
E1 = N1/ N0 – Schannon evenness (Hill’s ratio)
E2 = N2/N0 – Simpson evenness (Hill’s ratio)

App. Table 6. Species releve data (to be found in Excel file attached).

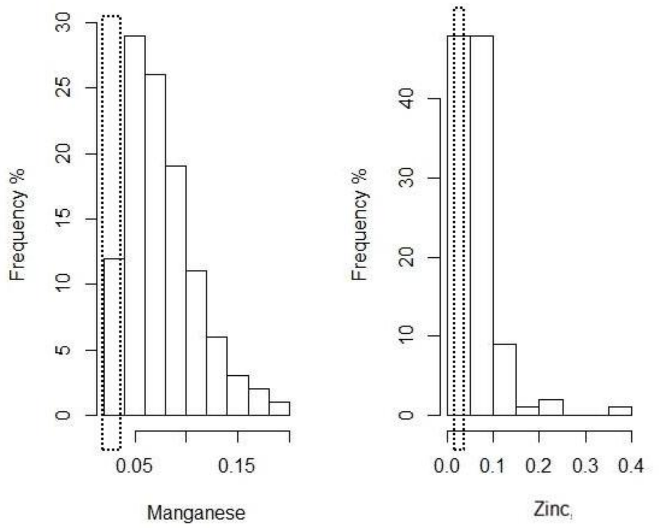
App. Table 7. Mean values (±stdv.) of the measured environmental variables for five vegetation groups (values in the same row followed by the same letter are not different for α=0.05 significance level, n.s. - no statistical differences, n.a. - not significantly different after ANOVA/K-W test statistic).

Vegetation groups / Variables	gr1	gr2	gr3	gr4	gr5
Soil Bulk Density [g/cm³]	0.84(±0.14)a	0.72(±0.14)b	0.69(±0.14)b	0.80(±0.09)ab	0.91(±0.12)a
Soil skeleton [%]	4.07(±6.74)n.a.	5.30(±4.48)n.a.	3.97(±4.71)n.a.	7.43(±7.55)n.a.	5.57(±5.55)n.a.
Water Content [%]	2.31(±0.51)ab	1.84(±0.19)a	2.17(±0.91)a	3.14(±0.91)b	2.94(±0.73)b
OM [%]	10.07(±3.66)ab	6.09 (±1.27)a	8.13 (±4.23)a	16.44(±5.29)b	15.17(±5.03)b
pH (CaCl2)	7.38(±0.34)ab	7.58(±0.10)a	7.50(±0.28)a	7.20(±0.19)b	6.99(±0.35)b
EC [µS/cm]	338.75(±264.88) n.a.	293.30(±40.72) n.a.	387.23(±251.63) n.a.	300.36(±100.95) n.a.	311.29(±79.22) n.a.
C [%]	4.79(±1.68)ab	2.81(±0.92)a	4.29(±2.09)a	7.90(±2.78)b	7.03(±3.28)b
N [%]	0.42(±0.18)ab	0.22(±0.07)a	0.37(±0.23)ab	0.64(±0.31)b	0.68(±0.34)b
C/N ratio [%]	12.35(±3.10)n.a.	13.04(±3.01)n.a.	12.52(±2.89)n.a.	12.72(±2.78)n.a.	10.68(±1.94)n.a.
CEC [µmolc/g]	47.72(±11.36)n.a.	44.62(±15.38)n.a.	47.60 (±12.65)n.a.	43.05(±8.36)n.a.	48.26 (±13.11)n.a.
BS [%]	99.54(±0.21)ab	99.70(±0.05)a	99.60(± 0.16)a	99.52(±0.09)ab	99.41(±0.15)b
Slope (grad)	23.42(±11.06)a	24.30(±6.77)a	28.31(±5.95)a	22.09(±10.68)ab	12.88(±11.46)b
Total Cover [%]	83.75(±14.16)ab	70.00(±10.00)a	66.54(± 11.62)a	81.82(±11.02)ab	92.35(±10.34)b
Northness	0.10(±0.60)ab	-0.71(±0.36)a	-0.34(±0.56)ab	0.15(±0.72)ab	0.32(±0.72)b
Eastness	-0.17(±0.83)n.a.	-0.10(±0.65)n.a.	0.09(±0.80)n.a.	-0.13(±0.73)n.a.	-0.25(±0.61)n.a.
Graizing impact	7.00(±3.28)ab	7.30(±1.57)ab	7.85(±1.86)a	8.91(±3.02)a	5.35(±2.34)b
Number of Species	29.50(±4.80)a	24.70(± 4.16)ab	25.00(±5.54)ab	20.36(±7.71)b	23.71(±6.35)ab
Al [µmol/g]	0.97(±0.23)ab	0.94(±0.24)a	0.92(±0.28)a	1.29(±0.23)b	0.99(±0.22)ab
Ca [µmol/g]	373.32(±69.63)a	393.41(±103.31)ab	376.11(±104.18)a	521.44(±102.54)b	383.46(±95.42)a
K [µmol/g]	7.46(±3.41)ab	6.35(±4.65)a	8.50(±7.14)a	8.64(±8.18)ab	13.88(5.96)b
Mg [µmol/g]	42.42(±15.24)n.a.	36.67(±8.37)n.a.	40.56(±17.40)n.a.	58.67(±20.02)n.a.	48.12(±16.15)n.a.
Na [µmol/g]	2.42(±1.24)n.a.	2.12(±1.61)n.a.	4.19(±6.53)n.a.	2.94(±0.49)n.a.	2.26(±0.86)n.a.
Fe [µmol/g]	0.14(±0.19)ab	0.01(±0.02)a	0.07(±0.11)a	0.42(±0.24)b	0.35(±0.29)b
Mn [µmol/g]	0.95(±1.03)ab	0.40(±0.26)a	0.71(±0.65)a	1.12(±0.38)b	1.30(±0.67)b

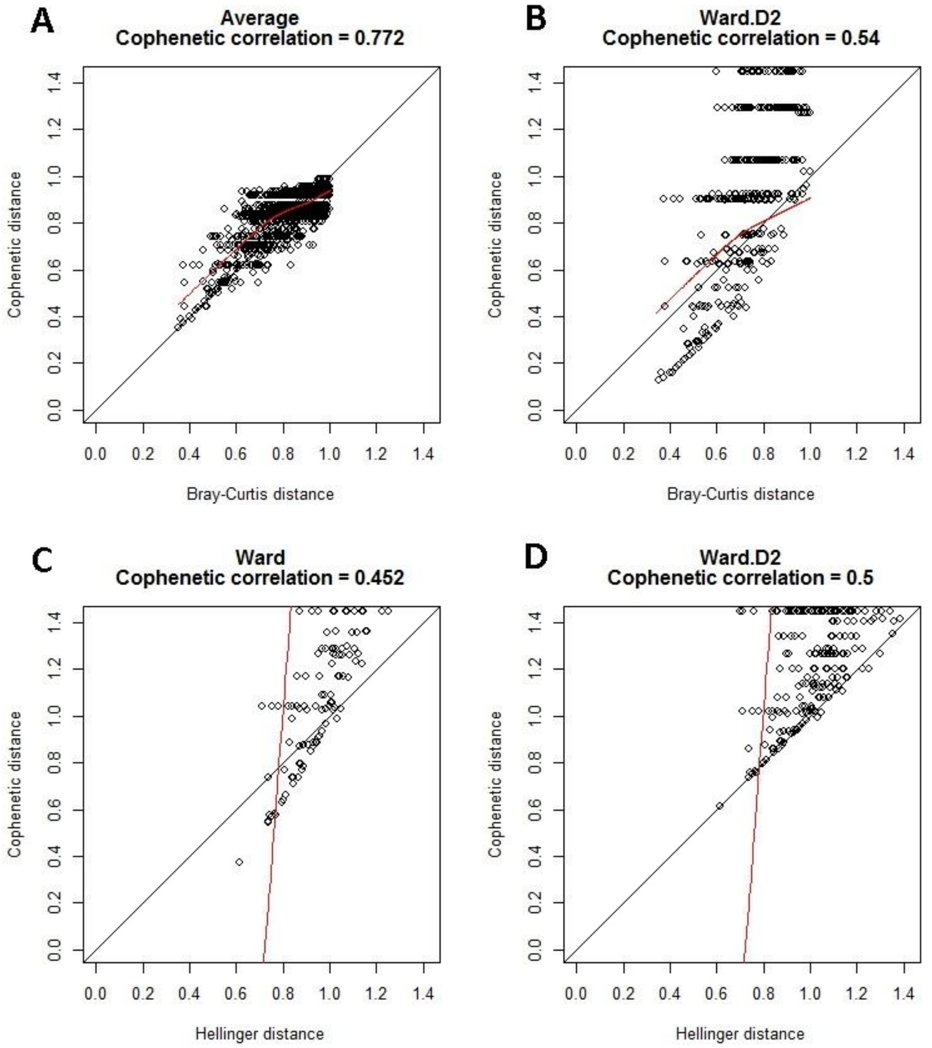
Appendix



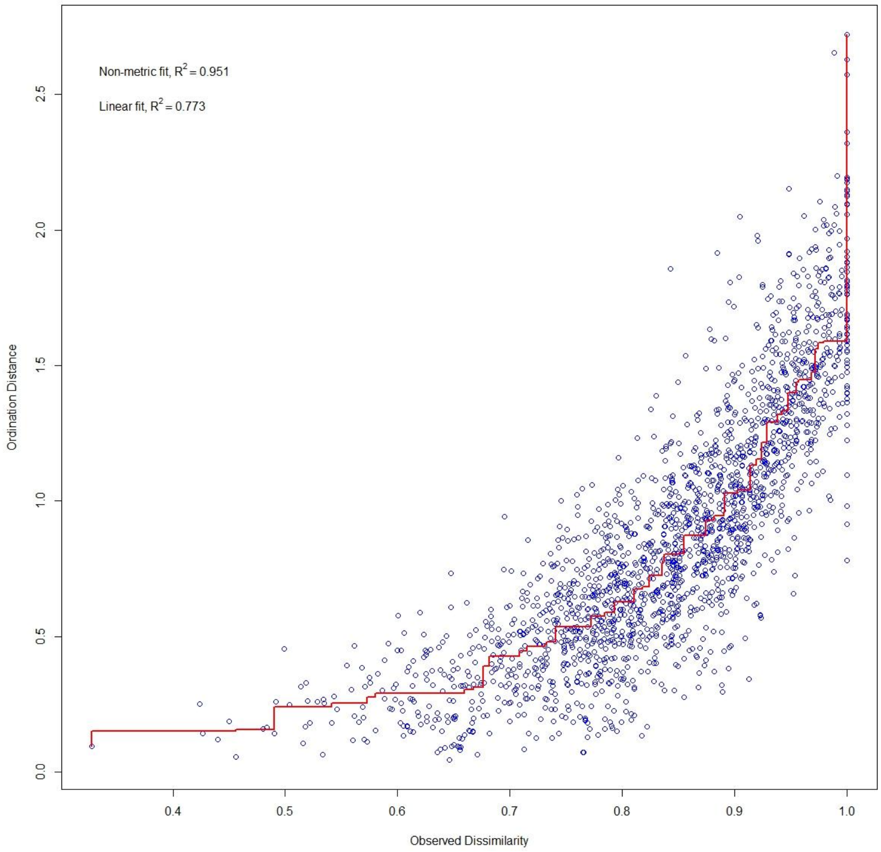
App. Figure 1 (contitued on the next page). Concentrations of mineral trace- and macro elements in forage plant species (g/kg DM). The range of concentrations, sufficient to support the diet of sheep and cattle is marked by dotted squares (after NRC 2001; NRC 2007).



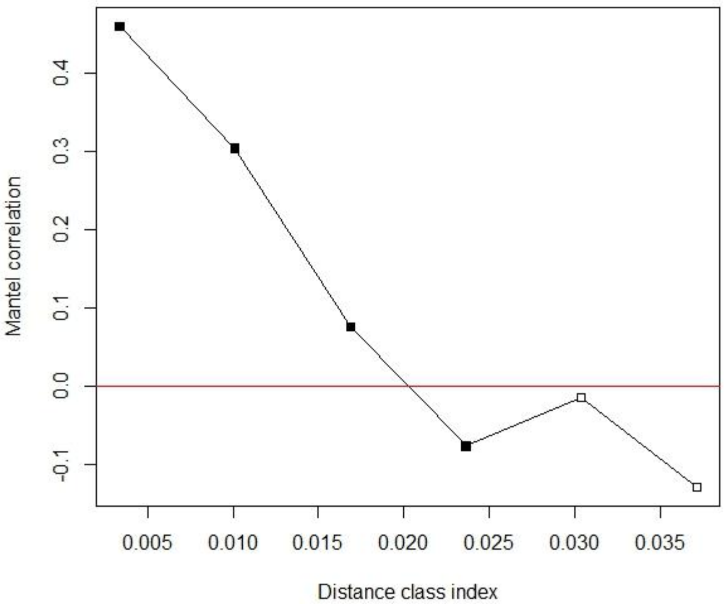
App. Figure 1 (continued) – Manganese and Zinc. Concentrations of mineral trace- and macro elements in forage plant species (g/kg DM). The range of concentrations, sufficient to support the diet of sheep and cattle is marked by dotted squares (after NRC 2001; NRC 2007).



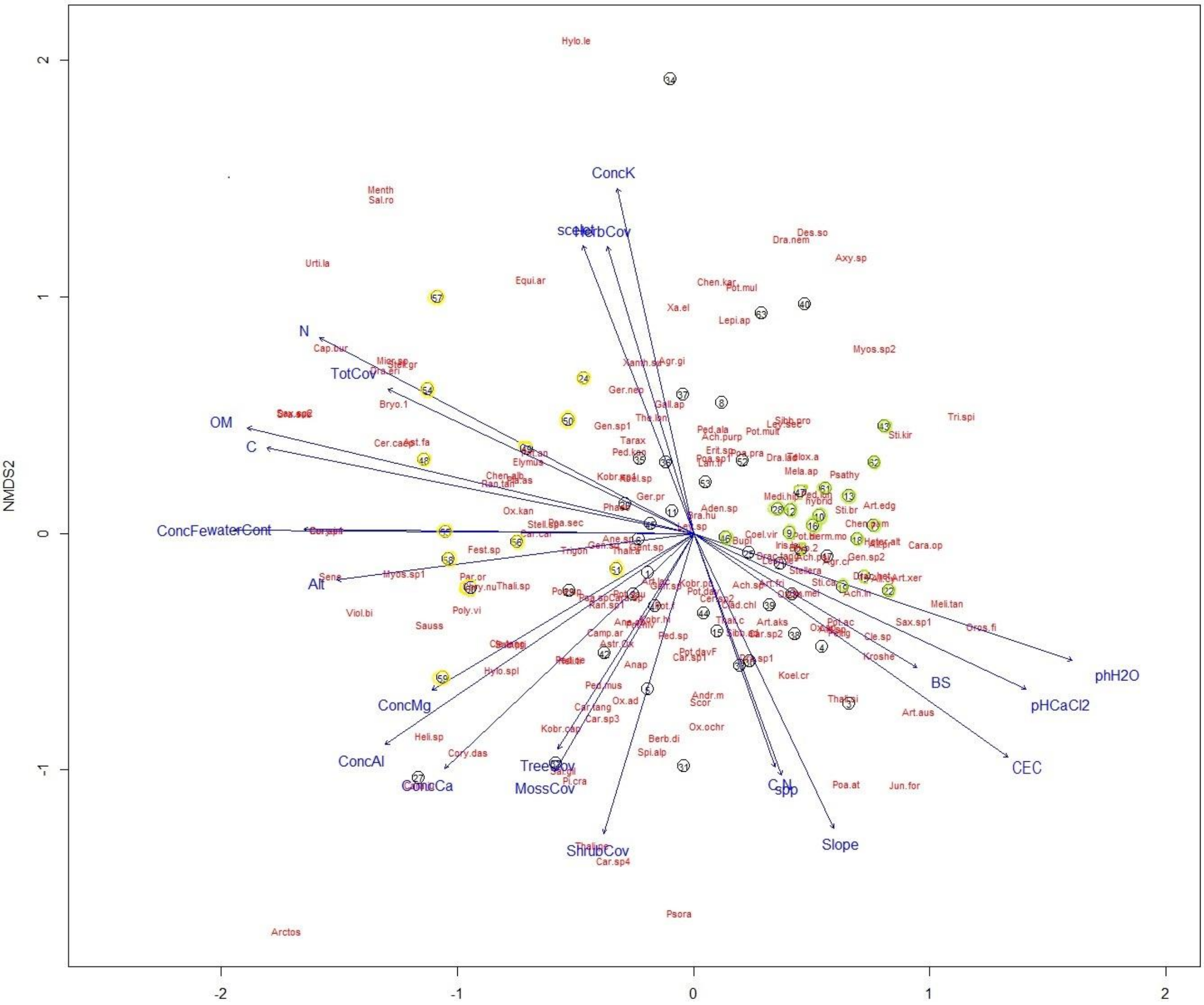
App. Figure 2. Shepard's plots, representing four cophenetic coefficients. A - average-linkage clustering, e.g. UPGMA (0.772), based on Bray-Curtis distance measure; B – advanced Ward's clustering (0.54), based on Bray-Curtis distance measure; C - Ward's clustering.



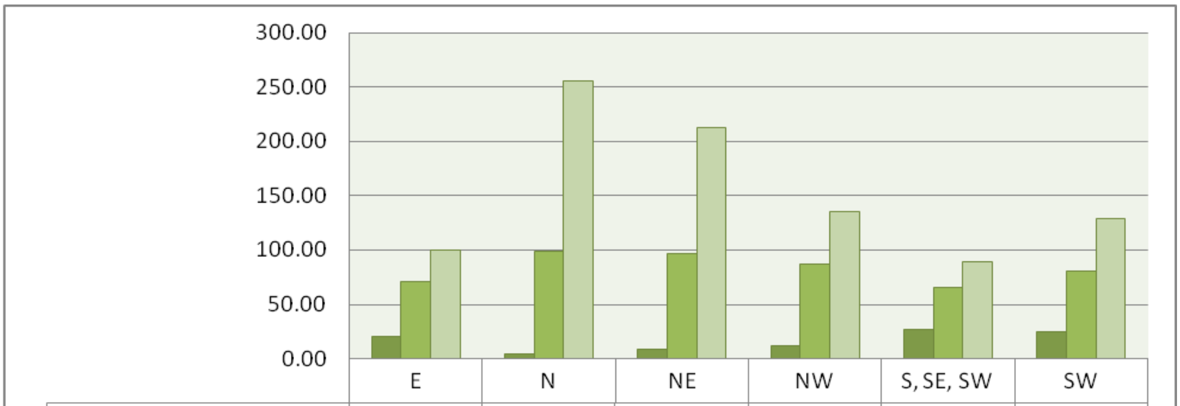
App. Figure 3. Stress plot, following the NMDS ordination, showing the relationship between ordination distance and observed dissimilarity (stress value =0.2215293). Non-metric R^2 =0.951.



App. Figure 4 Mantel correlogram based on Hellinger transformed species data. White points are those with negative significant correlation.

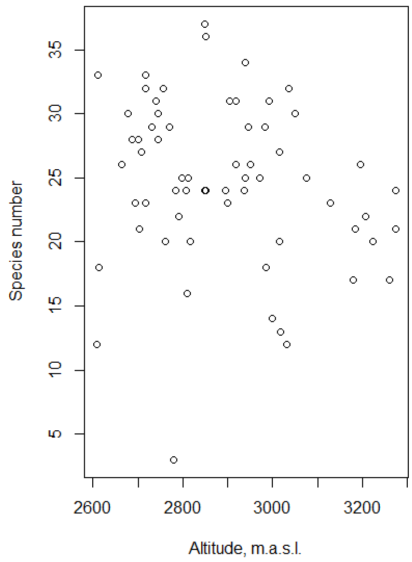


App. Figure 5 Joint plot: ordination space of the NMDS (Non-metric Multidimensional Scaling), showing the impact of the environmental factors on vegetation pattern distribution (alpine pattern – yellow-colored points on the left side from the center; montane/sub-alpine pattern – green-colored points on the right side from the center of the ordination space; points without color refer to transitional areas, or plots with extreme grazing pressure).



	E	N	NE	NW	S, SE, SW	SW
Slope inclination(°)	20.88	4.79	8.38	12.22	27.07	25.04
Total vegetation cover(%)	71.25	99.00	96.81	87.22	65.34	80.32
Biomass dry weight (g/m²)	99.59	256.21	212.42	136.01	89.73	128.70

App. Figure 6. Distribution of mean biomass dry weight on diferent slope exposures and its relation to slope inclination and total vegetation cover. Dimensions on the vertical axes rely to each individual variable respectively.



App. Figure 7. Species distribution along the altitude (extended database), r^2= 0.36, p>0.001

Declarations

VERSICHERUNG AN EIDES STATT

Hiermit versichere ich an Eides statt, dass ich die vorliegende Dissertation mit dem Titel: „Grazing impacts on vegetation patterns in the Qilian Mountains, HeiHe River Basin, NW China“ selbstständig verfasst und keine anderen als die angegebenen Hilfsmittel – insbesondere keine im Quellenverzeichnis nicht benannten Internet-Quellen – benutzt habe. Alle Stellen, die wörtlich oder sinngemäß aus Veröffentlichungen entnommen wurden, sind als solche kenntlich gemacht. Ich versichere weiterhin, dass ich die Dissertation oder Teile davon vorher weder im In- noch im Ausland in einem anderen Prüfungsverfahren eingereicht habe und die eingereichte schriftliche Fassung der auf dem elektronischen Speichermedium entspricht.

AFFIRMATION ON OATH

I hereby declare, on oath, that I have written the present dissertation by myself and have not used other than the acknowledged resources and aids.

______________________ ____

Hamburg