

Semi-desert vegetation  
of the Greater Caucasus foothills  
in Azerbaijan:

Effects of site conditions  
and livestock grazing

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*Es ist ein, wie für den Geologen, so für den Pflanzenkundigen durch seine Eigenthümlichkeit höchst interessanter Landstrich, der ... noch vielfache wichtige Ausbeute demjenigen liefern wird, der einer Beobachtung der Frühlingsvegetation obliegen dürfte.*

Nikolai von Seidlitz, 1857  
in » Botanische Ergebnisse einer Reise durch das  
östliche Transkaukasien und den Aderbaidtschan «

**Foto:** Der Schlammvulkan Turagai in Gobustan, Aserbaidtschan.  
September 2007.



# Outline of the thesis & personal participation

This doctoral dissertation consists of an introduction including an overview of the main results (chapter 1) followed by four co-authored manuscripts (chapters 2–5) that have been published in or submitted to peer-reviewed scientific journals. The present outline provides a brief summary of each chapter and explains my personal contribution to each of the articles.

## *Chapter 1*

### **Introduction and results**

In the introduction, I highlight the current state of nature conservation and rangeland management in Azerbaijan's winter pastures. After outlining some open questions of rangeland ecology, both general and with particular reference to the study region, I use them to develop the aims of the study. This is followed by descriptions of the study sites and the methods used. Finally, I provide an overview of the main results and discuss them with respect to practical recommendations for rangeland management and conservation in Azerbaijan.

## *Chapter 2*

### **Semi-arid rangeland vegetation of the Greater Caucasus foothills in Azerbaijan and its driving environmental conditions**

*Phytocoenologia (accepted 22.06.2009)*

*Jan Peper, Dorothea Pietzsch & Michael Manthey*

Vegetation types and their relationships to environmental parameters in the foothills of the Greater Caucasus were analysed. Data on vegetation composition and site conditions were gathered in the Gobustan and Jeiranchel rangelands in 2007 and 2008. D. Pietzsch and I carried out the fieldwork and species determination. I did the statistical analyses and literature research and wrote the manuscript, which was revised by M. Manthey.

## *Chapter 3*

### **Short-time effects of grazing abandonment on semi-arid rangelands in Azerbaijan**

*Annals of Agrarian Science 8 (1) 14–17; 2010*

*Jan Peper, Akbar Jabbarov & Michael Manthey*

We present the results of enclosure and clipping experiments. I carried out all botanical and statistical analyses and wrote the manuscript. A. Jabbarov was involved in organising and constructing the enclosures, as well as in fieldwork. M. Manthey gave valuable advice and corrected the manuscript.

*Chapter 4*

**Estimating grazing intensity along grazing gradients – the bias of non-linearity**

*Journal of Arid Environments 74 (10) 1351–1354; 2010*

*Michael Manthey & Jan Peper*

Based on theoretical considerations, we present an approach to estimate grazing intensity along transects perpendicular to grazing hotspots. M. Manthey first developed the idea for this paper, which we both refined. I wrote the bulk of the manuscript and analysed the data.

*Chapter 5*

**Patterns of plant species turnover along grazing gradients**

*Journal of Vegetation Science (major revisions)*

*Jan Peper, Florian Jansen, Dorothea Pietzsch & Michael Manthey*

We apply our findings on the estimation of grazing intensity from Chapter 4 and combine it with species response curves to detect patterns of species richness and species turnover along grazing gradients in Gobustan. F. Jansen, M. Manthey, and I carried out the statistical analyses while D. Pietzsch provided data from her Diplom thesis. I wrote the manuscript with the support of all co-authors.

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## 1.1 Background

Azerbaijan, located in the east of Caucasia (Fig. 1.1), has transformed from a member state of the USSR to a sovereign country with a prosperous economy driven by oil and gas exploitation. The environmental impact of this economic rise has manifested itself in the construction of new roads and pipelines and the expansion of settlements. The utilisation pressure on the environment has increased additionally both as a result of the Karabagh conflict, which lead to the displacement of thousands of people from the Lesser Caucasus to other districts of Azerbaijan, and because of population growth (Fig. 1.2).

Economic growth received an additional stimulus from the launch of the Baku–Tbilisi–Cheyhan pipeline in 2005, which carries to the Mediterranean Sea up to 1 million barrels of crude oil per day. However, the new wealth has been slow to seep into the rural regions, and the renewal of agricultural equipment and infrastructure has been very restricted.

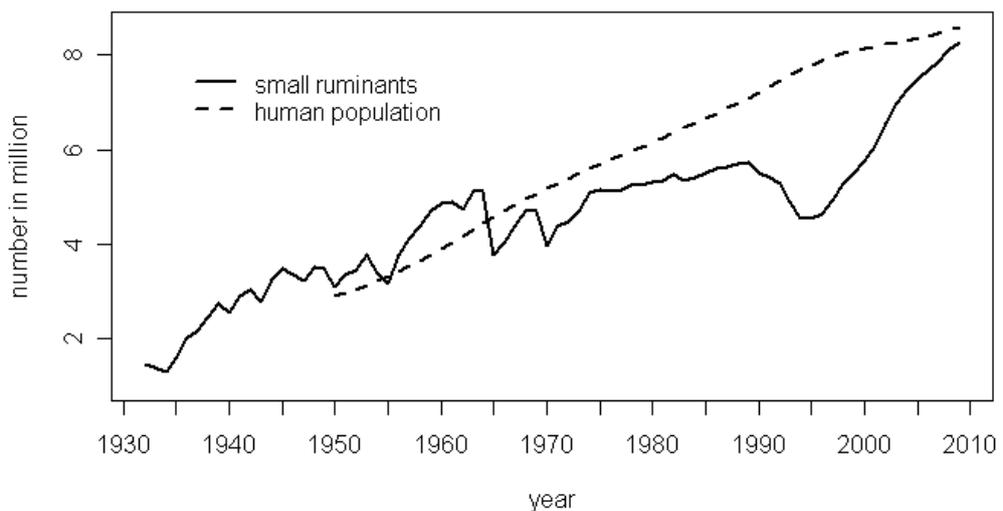
Livestock breeding is an exception, because owning large herds of sheep is a sign of societal influence and a good investment strategy in Azerbaijan (Neudert & Allahverdiyeva, 2009). But even in this context, investments rarely go towards the modernisation of farm infrastructure but often exclusively towards the enlargement of herds. According to data from the Azerbaijan State Statistical Committee, the number of small ruminant livestock nearly doubled from approximately 4 to 8 million animals within the last 15 years (Fig. 1.2).

Fig. 1.1: Map of Caucasia with Azerbaijan.



**Fig. 1.2:** Development of the populations of small ruminants (sheep and goats) and humans in Azerbaijan between 1932 and 2009.

Sources: *Livestock: State Statistical Committee of the Republic of Azerbaijan* ([www.azstat.org](http://www.azstat.org), accessed on 14 Jan. 2010); *Population: World Resources Institute* ([www.wri.org](http://www.wri.org), accessed on 12 Feb. 2010).

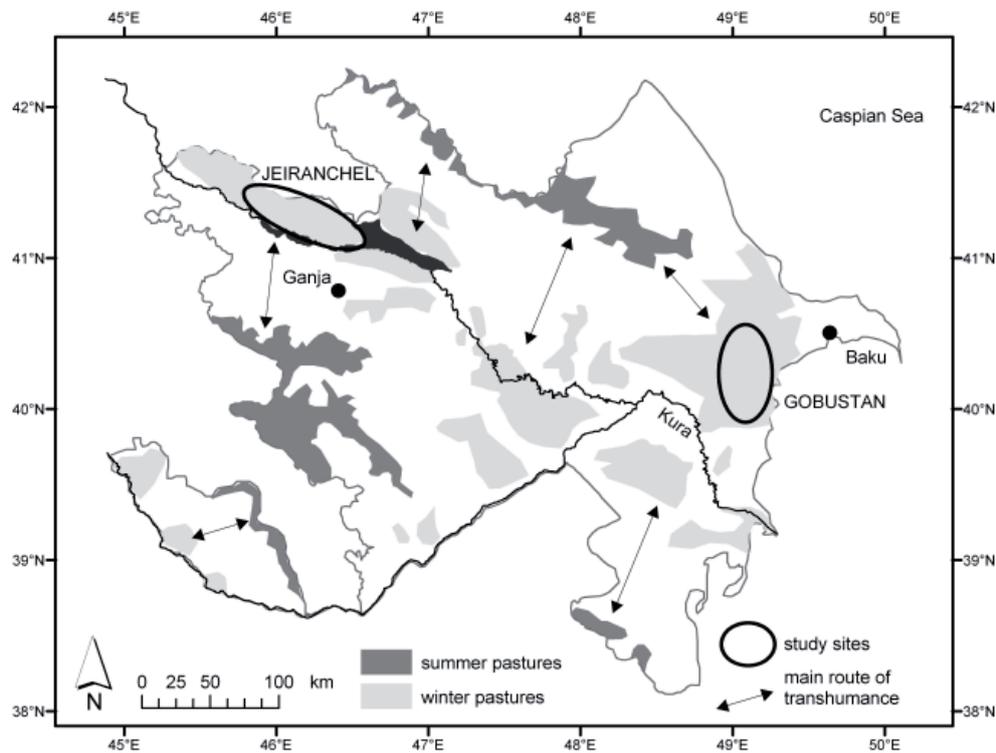


A typical feature of Caucasian livestock breeding is the seasonal migration between summer pastures in the sub-alpine and alpine belt, and winter pastures in the foothills and in the Kura-Arax depression (Fig. 1.3). Consequently, ecological damage due to excessive livestock keeping is expected to occur nearly everywhere in the country (Babayev, 2007).

The Institute of Botany and Landscape Ecology at the University of Greifswald has been very active in studying the problems of rangeland conservation in Azerbaijan. The resulting publications include ecological descriptions of the lowland semi-desert ecosystems (Gauger & Pietzsch, 2005; Strauss, 2005; Gauger, 2007; Schmidt, 2007; Schmidt & Pietzsch, 2007) and socio-economic reports (Burmester, 2005; Gaude, 2005). The Michael Succow Foundation assessed the state and potential of nature conservation in the country (Schmidt & Uppenbrink, 2009).

In previous publications, I analysed the influence of livestock grazing on alluvial forests along the Kura River and developed management proposals (Peper, 2007; 2008). I was also strongly involved in the preparation of the *Potential Analysis for Further Nature Conservation in Azerbaijan* (Schmidt & Uppenbrink, 2009) and worked in the dry foothills, the Talysh Mountains, the Island of Gil, and the Devici dunes (Tegetmeyer et al., 2007). In the same context, we inventoried mires and peatlands of the country (Thiele et al., 2008) and produced a case study on the distribution and conservation of the rare *Populus euphratica* in Caucasia (Peper et al., 2010).

Faced with the deteriorating situation of rangelands, the Ministry of Ecology and Natural Resources of Azerbaijan initiated a deeper investigation in order to develop recommendations for sustainable land use in large areas outside state reserves and national parks. Thus, in 2007, with funding from the Volkswagen Foundation, the research project *Proper Utilisation of Grasslands in Azerbaijan's Steppe and Mountains* (PUGASMAOS) was started as collaboration between the University of Greifswald, the Baku State University, and the Agricultural Academy of Azerbaijan (now Azerbaijan State Agrarian University).



**Fig. 1.3:** Overview of pastures in Azerbaijan, main corridors of migrating herds (modified after Aliev et al. 1965), and the study regions.

The aim of the project was to assess the ecological and socio-economic effects of the new trends in sheep keeping in both the mountains and the lowlands. This dissertation presents results of ecological studies concerning the vegetation at the foothills of the eastern Greater Caucasus, which were conducted as part of this project.

## 1.2 Framework and objectives of the study

### PREVIOUS GEOBOTANICAL STUDIES ON AZERBAIJAN'S WINTER PASTURES

The rangelands of the eastern Caucasus are an exciting object of study for vegetation ecologists. This region is probably the origin of many annual species that are also found on cropland or ruderal sites of Central Europe. The Caucasus is also known as a centre of endemism and high species diversity (Griffin, 1999). For these reasons, it has attracted the attention of many botanists since the 18th century.

After its step-by-step occupation of the Southern Caucasus (1783–1864), the Russian Empire sent scientists to explore the region in detail (Holubec & Krivka, 2006). The aim of the first botanists who visited the region was to describe new species. Among the first who studied winter pastures in the eastern Caucasus was Meyer in 1830, who compiled a list of vascular plant species (Meyer, 1831). In the second half of the 19th century, Radde published extensive studies of vegetation and landscape in the Caucasus (Radde, 1874; 1899).

Milestones in the investigation of Azerbaijan's flora and vegetation are the works of Grossgejm (Grossheim) in the first half of the 20th century. He initiated

the compilation of the *Flora Kavkaza* which contains detailed descriptions of all vascular plant species known in the region at that time, including precise maps of their distribution (Grossgejm, 1939–1967). In 1936, he published a study of the Caucasian flora and its history (Grossgejm, 1936), and later on *The Vegetation of the Caucasus* (Grossgejm, 1948).

Of special interest for rangeland ecologists is a series of publications that began in 1929. Here, Grossgejm and his co-workers described the winter pastures of Azerbaijan from a geobotanical point of view (Grossgejm, 1929). They published vegetation maps of the Jeiranchel steppe (Grossgejm & Kolakovskij, 1929) and Gobustan (Grossgejm & Sachokia, 1929) that have formed the basis for further investigation. Grossgejm's (1932) comprehensive summary of this body of rangeland research includes information on forage quality.

Later on, Isaev (1943) and Prilipko (1949) conducted experiments on rotational grazing to improve the rangeland management in the Kura-Arax lowlands. In the following years, Aliev investigated winter pastures dominated by *Salsola nodulosa* (Aliev, 1954) and recapitulated the state of rangeland ecology in Azerbaijan (Aliev et al., 1965). In the same vein, Bogdanov's (1953) doctoral dissertation updated the findings of Grossgejm in Gobustan, while Isaev (1957) described *Artemisia* semi-deserts of Azerbaijan.

It was in those years that the most important tool of botanists working in Azerbaijan was prepared, the still up-to-date *Flora of Azerbaijan* (Karjagin, 1950–61). Today, there are also some very useful illustrated guides to the flora of the Caucasus, but they all deal only with a part of the total diversity of vascular plant species (Holubec & Krivka, 2006; Gabrielian & Fragman-Sapir, 2008; Shetekauri & Jacoby, 2009). In the field of geobotany and landscape ecology, there have been several publications since 1970 which often address very specific questions of rangeland ecology (e.g. Jagubov, 1975; Ponomarenko, 1986; Dašdamirova, 1990; Atamov 2002).

#### RANGELAND CONSERVATION IN AZERBAIJAN

Pastoral landscapes – including heathlands, alpine meadows, open forests, and dry grasslands – have come into the focus of conservation in Europe and all over the world (Finck et al., 2002; Peart, 2008; Hampicke & Plachter, 2010). Such landscapes have been shaped by the co-evolution of vegetation and livestock grazing, often combined with other anthropogenic impacts like selective woodcutting or mowing. In contrast to cropland or forest plantations, where human impacts have caused abrupt changes, such semi-cultural formations have emerged in a slow shift from the original site conditions (Dierschke, 1994). Their gradual formation and their typical variety of microhabitats have fostered a high species richness. Today, rangelands in Europe have mostly become unprofitable and are abandoned, which in most cases is accompanied by species loss.

The opposite of this 'undergrazing' trend can be studied in Caucasia (Didebulidze & Plachter, 2002). However, the relationship between species richness and grazing pressure in systems with a long history of grazing depends first and foremost on moisture, according to the generalised model of grazing effects

(Cingolani et al., 2005). The model assumes that moderate grazing has a positive impact on species richness under humid conditions, a circumstance that is relevant in the summer pastures of Azerbaijan. On the other hand, the model claims that increasing grazing pressure reduces species richness in semi-arid to arid ecosystems. The latter scenario can be studied in the winter pastures of Azerbaijan and is associated with land degradation, as mentioned by Babayev (2007).

The government of Azerbaijan has tried to modify this trend by establishing or extending nature reserves that represent the country's main landscape types (Succow, 2005). For example, Shirvan National Park (NP) and Ag Göl NP represent lowland semi-deserts with halophytic dwarf-shrubs (e.g. *Halognemum strobilaceum* and *Kalidium caspicum*) on plains with mainly Solonchak soils (see Schmidt, 2007). However, the widespread *Artemisia lerchiana* and *Salsola nodulosa* semi-deserts of hillsides are only marginally protected by reserves like the Gakh Nature Reserve. Regarding the large amount of rangelands in Azerbaijan, which occupy approximately one third of the land area, state reserves can only protect a few selected reference sites. The bulk of rangelands needs to remain in use to safeguard the domestic supply with meat and milk, the latter mainly for cheese production.

To avoid a long-term decrease in rangeland productivity due to land degradation, it is necessary to combine measures of nature conservation with the development of sustainable land management. Azerbaijan bears a special responsibility for the conservation of several Caucasian lowland-pasture endemics like *Veronica amoena*, *Iris acutiloba*, *I. camillae*, and *Gypsophila stevenii* (Grossgejm, 1936).

#### QUESTIONS OF RANGELAND ECOLOGY AND STUDY AIMS

The studies collected in this dissertation arise from a number of open questions regarding both some methods of rangeland ecology and the specific ecology of Azerbaijan's winter pastures.

A general problem in rangeland ecology is the estimation of grazing intensity in vast rangelands with inhomogeneous grazing regimes. According to the piosphere concept (Lange, 1969), grazing intensity decreases in direct proportion to the distance from a grazing hotspot, like a watering point or farmyard (e.g. Ludwig et al., 1999; Pringle & Landsberg, 2004; Adler & Hall, 2005). However, several studies that use this approach produce non-linear patterns in their analysis of the relationships between environmental variables or vegetation change on the one hand, and grazing intensity on the other hand (Friedel, 1997; Smet & Ward, 2006).

Such patterns have been interpreted as threshold changes along grazing gradients (Sasaki et al., 2008). The question is whether such apparently widespread patterns represent real ecological relationships or should be dismissed as geometrical artefacts.

However, rangeland ecologists lack robust alternative methods for the detection of discontinuities in rangeland vegetation (Archer, 1996). Current approaches

that are based on moving windows or ordinations have several disadvantages (cf. Sasaki et al., 2008; Pärn et al., 2010). As far as I know, approaches using species environmental amplitudes (cf. Peppler-Lisbach & Kleyer, 2009) have not yet been applied and adapted to the questions of rangeland ecology.

Turning to the regional challenges of rangeland management and conservation, there is no integrative and applicable vegetation classification that could serve the purposes of monitoring and leasing regulation. The vegetation types in such a classification should closely reflect ecological conditions, grazing pressure, and forage capacity. Such an approach differs sharply from the currently applied dominant-species concept whose vegetation types tend to be based on species with very wide ecological amplitudes.

Furthermore, there is no validated information on the compensatory growth of herbaceous species on the winter pastures. Such information is necessary to evaluate the current grazing regimes and to derive recommendations for adapted rangeland management. To learn about potential risks of overgrazing for forage supply, ecologists need to study the responses of important forage species to increasing grazing pressure.

Each of the chapters in this dissertation is intended to help answer one of these open questions:

#### CHAPTER 2

What are the vegetation types of Gobustan and Jeiranchel? How are they related to environmental conditions and grazing?

#### CHAPTER 3

What is the short-time effect of grazing abandonment on standing crop production, vegetation structure, and species composition? Does the productivity of herbaceous species increase under grazing pressure?

#### CHAPTER 4

What would be a straightforward and rapid method to approximate grazing intensity in vast rangelands?

#### CHAPTER 5

How does grazing affect both individual plant species and species richness? How can we obtain patterns of species turnover along gradients of grazing intensity? What is a suitable test for the detection of discontinuities in species turnover?

### 1.3 Study site

#### LOCATION

The study site comprises the two largest winter pastures at the foothills of the Greater Caucasus in Azerbaijan. These are Gobustan (1500 km<sup>2</sup>) in the east and Jeiranchel (1300 km<sup>2</sup>) in the west (Fig. 1.3 & 2.1). We restricted our research to coherent rangelands in an altitudinal belt between 10 and 650 m a.s.l.

The characteristics of the landscape are well reflected by its Turkish names. For instance, Gobustan translates as ‘land of dry canyons’ and Jeiranchel as ‘gazelle steppe’. There is a political district called Gobustan, as well as the village of Gobustan by the river Sumgaitchay, and the town of Gobustan at the shores of the Caspian Sea, in the vicinity of a historical monument of rock engravings bearing the same name. However, the Gobustan I refer to in this study is that area which comprises the dry hillsides of the Greater Caucasus Mountains where they extend south-east towards the Caspian Sea (Mamedaliev, 1963).

The Gobustan study site is demarcated by the Baku–Shemakha road in the north, the 40° latitude line in the south, the margin of the Pirsatchay depression in the west, and the Caspian depression in the east. The eastern border runs as a straight line from the village of Sangachal northwards to the hill Bayanatadagh.

The Jeiranchel area is enclosed by the rivers Kura and Iori (Qabirri in Azeri) and, in the west, by the canyon of the Shorsu River. We excluded the steep slopes by the Kura River and all settlements with their surrounding cropland. Due to administrative difficulties, we also had to omit a 2 km wide belt along the Georgian border.

#### CLIMATE

Climatic conditions are highly diverse within Azerbaijan. The climatic differences result, for one, from the steep relief, with altitudes from –27 m a.s.l. up to more than 4000 m a.s.l. On the other hand, the region is located in a transition zone between the temperate and the subtropical climates (for references see Franz, 1973). In addition, the Caspian Sea has a moderating influence on winter temperatures in the coastal region (Madatzade & Šichlinskij, 1968). Both study sites are located in the lee of the Surami Mountains which form a north–south link between the Greater and Lesser Caucasus in Georgia.

Due to a lack of reliable and long-term meteorological data for the study areas, we characterise the climate using data both from the main climatic stations (Fig. 1.4) and from interpolated climate surfaces provided by the WorldClim dataset (Hijmans et al., 2005).

The study areas, Jeiranchel and Gobustan, receive between 260 and 560 mm precipitation per year, and evaporation exceeds precipitation during more than six months per year. This means that the climate is semi-arid (UNESCO, 1977). Generally, precipitation in both regions increases with altitude and from east

to west. The lower parts of Jeiranchel receive about 360 mm while annual precipitation increases to 560 mm in the upper regions, according to the WorldClim extrapolations. Gobustan is drier, with about 260 mm near the Caspian shore and 460 mm in the hills. The rainy season typically starts in October and peaks in spring while the summer months are dry.

Depending on the annual variability of precipitation, grazing–vegetation interactions are either described by equilibrium or non-equilibrium models of rangeland vegetation (e.g. Fernandez-Gimenez & Allen-Diaz, 1999; Vetter, 2005). Rangelands where the annual variability of precipitation is low (coefficient of variation (CV) < 30 %) and which in this sense have equilibrium conditions are expected to be very sensitive to overgrazing, because the number of grazers tends to remain unchecked over long periods. In more variable, non-equilibrium systems (CV > 30 %), drought events regularly reduce livestock numbers, so that long-term overgrazing and land degradation are prevented.

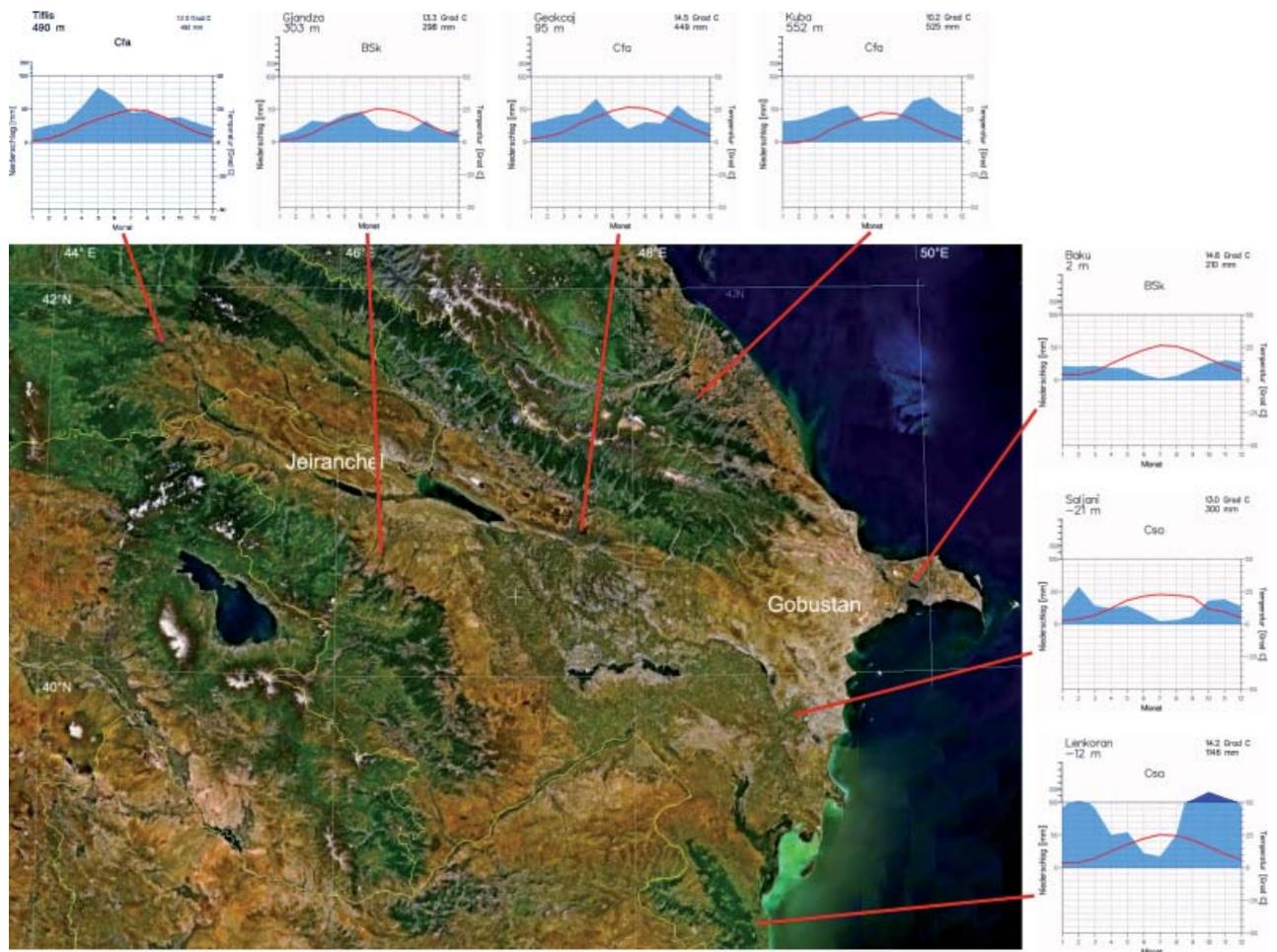
Since the annual variability of precipitation in the lower parts of Gobustan has a CV of approximately 28 % (period: 1955–1999; Huseynov & Malikov, 2009) and, in the upper regions, around 22 % (meteorological station Maraza, 1960–1990), the rangelands under study fall under the equilibrium definition. Therefore, we can assume that these ecosystems are potentially threatened by overgrazing.

More particularly, however, it is the amount of spring precipitation that limits the productivity of annual plants and therefore the productivity of rangelands. At the Maraza station in Gobustan, total rainfall in the four-month period from March through May varied between 49 mm and 237 mm in the 30-years observation period. This indicates that there was no drought event that could have seriously reduced the livestock population. The same holds for Jeiranchel, which is even slightly moister.

The average annual temperature in both areas is approximately 13 °C. The mean temperature in July, the hottest month, is 26 °C. There are small differences in mean winter temperatures. In the western part of Jeiranchel, they range between 0 and 2 °C, and only sites close to the Mingechevir water reservoir have up to 4 °C. Mean January temperature is between 3 and 4 °C in most parts of Gobustan, decreasing to 0 °C in altitudes above 500 m a.s.l.

On sites without additional water supply, the summer drought and winter cold result in a seasonal cycle with two growing seasons. The first one starts in March, when the mean monthly temperature exceeds 5 °C (Prilipko, 1949), and ends between early May and mid-June, depending on the altitude of the respective site. In dry years, this brief spring growing season may be reduced to a few days, as it was in eastern Jeiranchel in the spring of 2009.

The second, autumnal growing season begins in September or October, depending on the time and amount of the first strong rainfalls. The autumnal growing season ends when the mean monthly temperature drops below 5 °C, and so typically lasts until November in Jeiranchel, and until December in Gobustan.



No weather data are available for our observation period (2007–2009), but judging from our own experiences and our interviews with local farmers, the spring of 2007 was wetter than average. The spring of 2008 was slightly drier than average, and the spring of 2009 was extraordinarily dry. Especially in Jeiranchel, herds had to migrate towards the mountains as soon as the beginning of April, one month earlier than usual.

#### GEOLOGY AND RELIEF

Both study areas are affected by tectonic faults running in a northwest–southeast direction (Alizade, 2008). These faults are lined by ridges that rise up to 300 m above the surrounding landscape and often have steep south slopes and a northern fringe of gently sloped plains. In Jeiranchel and southern Gobustan, these ridges are of young Tertiary origin (Neogene), while in northern Gobustan older sediments (Paleogene) appear at the surface (Mamedaliev, 1963).

Most of these are clays and loams that contain high concentrations of gypsum and carbonates, but there are also some layers of massive limestone and breccia-like dolomite (Agabekov & Allachverdiev, 1972). The lower slopes and depressions of the escarpment systems are filled with Pleistocene material

**Fig. 1.4:** Satellite image of the eastern Caucasus with the two study areas, Jeiranchel and Gobustan. (source: NASA World Wind; Landsat 7; year 2000). Climate diagrams refer to the main meteorological stations ([www.klimadiagramme.de](http://www.klimadiagramme.de)). The lowlands between the Greater and Lesser Caucasus are semi-arid with decreasing annual precipitation from west to east.

consisting mostly of eroded bedrock from the ridges. Thick layers of recently deposited silty loams cover valley bottoms and depressions.

In Jeiranchel, the ridges are intersected at right angles by up to 200 m deep canyons, while in Gobustan the river Jeirankechmez has eroded a wide terraced valley running from northwest to southeast. The steep slopes of the canyons and ridges are often covered by heavily eroded, still expanding badlands. Notably, they are affected by so-called pseudo- or clay-karst (Franz, 1973), which means that erosion takes place below a more or less intact surface, creating subterranean gullies and dolines.

#### MUD VOLCANISM IN GOBUSTAN

A special feature of Gobustan are the mud volcanoes, whose lobes of extruded material cover about one fifth of the study area. This phenomenon is caused by tectonic activity in deep layers of sediment containing natural gas and petroleum under high pressure (Hudson et al., 2008). Where gas escapes to the surface, it is accompanied by fossil water and suspended sediments which form the mud volcanoes (Jakubov et al., 1971). These cold blowouts occur either as rare episodic events or more or less continuously, depending on the resistance and permeability of the above-lying rock (Kholodov, 2002).

As a result, there are two main types of mud volcano, which differ in vegetation cover. First, mud volcanoes above relatively permeable rock continuously extrude small amounts of salt-enriched mud, forming groups of small cones on plateaus or hilltops. Due to the continuous arrival of fresh sediment, their surroundings are bare of vegetation.

Second, mud volcanoes above less permeable rock display more violent, episodic blowouts because the rock layer inhibits the extrusion of gas until a critical pressure is reached. Huge amounts of mud and breccia including limestone and gravel are ejected within a short time (Kholodov, 2002). These events can create entire mountains, like the impressive Turagai Mountain (picture in the foreword). During the long inactive periods, the ejecta are colonised by vegetation.

#### SOILS

Gobustan and Jeiranchel are almost completely covered by clayey to silty, carbonate-rich substrates. Sand rarely constitutes the main proportion of fine soil, except in some parts of the Jeiranchel. Coarser materials like gravel, stones, and blocks of limestone or dolomite can sometimes be found on steep slopes and hills with rock outcrops.

The soil types show a clear altitudinal zonation (Mamedov et al., 2007): Calcic gypsisols (also called siero-burozems in the Russian nomenclature) dominate until approximately 150 m a.s.l. in Jeiranchel and 350 m a.s.l. in Gobustan (Mamedaliev, 1963). They are poor in humus but rich in soluble salts whose amounts decrease with increasing altitude (Salaev, 1991). Haplic kastanozems

(grey cinnamonic and light chestnut soils) are characteristic for the upper belt up to 650 m a.s.l. (Babaev et al. 2006). They contain more humus than calcisols but almost no soluble salts like sodium chloride.

There are also some azonal soil types. Solonchaks occur in depressions where salt accumulates as water evaporates from runoff pools or surfacing groundwater. Calcaric leptosols with their thin layers of fine material can be found around rock outcrops.

#### WATER REGIME

Groundwater aquifers are very rare in the study area (Mamedaliev, 1963), and only a small number of minor freshwater springs can be found near dolomite and limestone outcrops. Saline fossil water accompanied by petroleum and minerals reaches the surface in the process of mud volcanism, but affects only small areas which are often marked by stands of *Salicornia europaea*. In the valley of the Jeirankechmez River, there is some subsurface flow in pebble-rich soil layers.

One of the most important soil properties with regard to plant growth is the water-storage capacity. The fine texture of the soils in our study areas means low water absorption and high surface runoff, so that the topsoil dries out within a few days even after heavy rainfalls.

Natural ephemeral salt-lakes are typical for the western part of Gobustan. They occur where the clayey ejecta of mud volcanoes seal off the bottoms of depressions that fill with rainwater during winter. In addition, herdsmen build artificial ponds to catch the surface runoff as drinking water for livestock.

#### VEGETATION AND PLANT FUNCTIONAL TRAITS

The growth of vascular plants is limited by the harsh environmental conditions in the semi-arid eastern Caucasus, most importantly the summer drought. Most plants are also exposed to salt stress, which varies with altitude and soil substrate, and to browsing by both wild animals and livestock.

Dwarf shrubs, which occur widely in the semi-deserts of Middle Asia, belong to the species that are best adapted to these conditions (Lavrenko & Sotčavy, 1956; Walter, 1974) and dominate the natural vegetation types of the region (Prilipko, 1970; Gulisašvili et al., 1975; Komarov Botanical Institute, 1996). The most characteristic species which occurs in nearly all plant communities is *Artemisia lerchiana*, but dwarf shrubs of the genera *Salsola* and *Suaeda* are also very common.

Generally, we can distinguish two main types of adaptation to summer drought and high salinity, respectively (Fig. 1.5). Ephemeral species, or 'rain plants', (therophytes and some geophytes) only grow in humid seasons and thus avoid drought stress (Sitte et al., 1998). As their roots are limited to the uppermost soil layer within a few centimetres of the surface, where salinity is low after

rainfall, they also avoid salt stress. On the other hand, this means that they need to complete their life cycle before the topsoil dries out. Most of the ephemeral species can produce seeds within less than a month, even when the plant is just 1 cm tall.

The 'ephemeral perennials', or ephemeroïds, (Grossgejm, 1948) have evolved bulbs that store energy during the arid seasons, enabling the plants to start growing almost immediately after a rainfall. Common ephemeroïds are the grasses *Poa bulbosa* and *Colpodium humilis* which form lawns and stabilise the topsoil.

Dwarf shrubs follow a completely different strategy. Their roots spread into deeper soil horizons (Fig. 1.5) where moisture conditions are more stable than in the topsoil. But even there, soil water is scarce and saline, which calls for special mechanisms to minimise transpiration. Whereas the chenopod shrubs reduce water loss with thick cuticles and store salt in cell vacuoles, the less salt-tolerant *Artemisia* species rely on the dense hair of their stems and leaves to reduce transpiration.

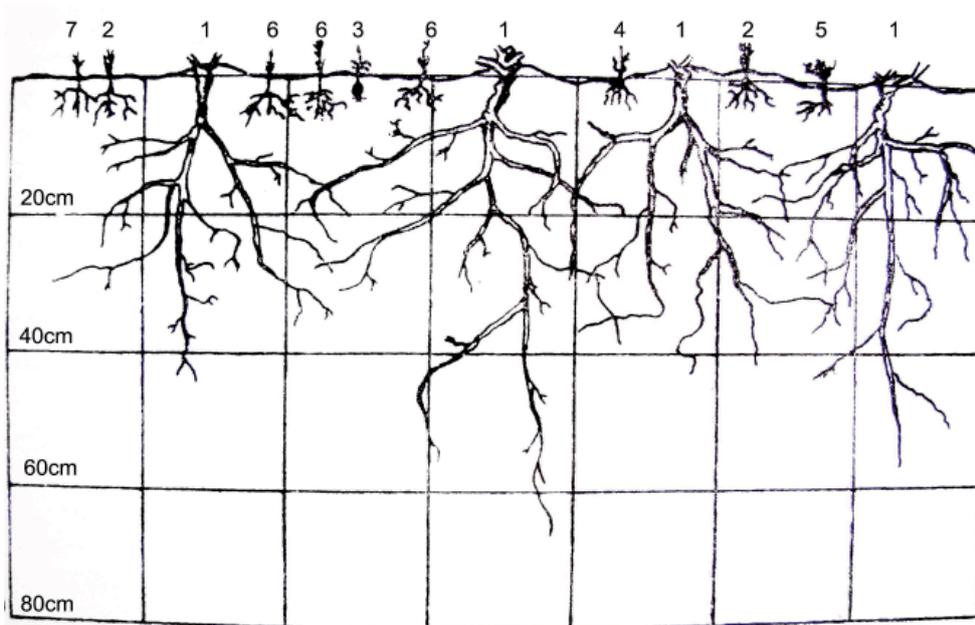
#### LAND USE

Between October and May, depending on weather conditions in the summer pastures, Gobustan and Jeiranchel are used as winter pastures for herds of sheep, cattle, and goats. Only a few sites around villages and in higher altitudes are used all year (4 % of all farms in Gobustan and up to 15 % in Jeiranchel). Livestock is kept on stationary farms that are scattered in the rangelands with an average mutual distance of 2–3 km. There are a total of 138 farms in Jeiranchel and 132 in Gobustan. A typical farm supports approximately 600 ewes, 30 goats, and 30 pieces of cattle on an area of 500 ha (Neudert & Allahverdiyeva, 2009). Some farms are up to 2000 ha large and support up to 1500 sheep. Furthermore, two dozens of camels are kept in Gobustan throughout the year.

Whereas sheep and goats are tended and return to the farms both at noon and at night, the cattle range freely during daytime. In addition, a number of horses, donkeys, and poultry are kept within the farmyards. In winter, herders implement a strip-grazing regime on the pastures, while in spring grazing is unrestricted.

In autumn, the animals feed on the straw-like remnants of ephemerals, before turning to the standing crop of dwarf shrubs which is the main type of winter fodder (cf. Prilipko 1949). There is abundant browse in the spring of most years when annual plants start to grow.

Almost all farms are commercial meat production enterprises that often rely on hired workers (Neudert & Rühls, in preparation). However, the pastureland they use is state property which the entrepreneurs lease for anything from one to 99 years, the most common term of lease being 15 years. The current lease regime contributes to land degradation because the provisions for sustainable use in lease contracts are insufficient and because pastures are commonly sub-leased for only one year at a time (Neudert & Rühls, in preparation).



**Fig. 1.5:** Subsurface cross section of a typical *Salsola nodulosa* semi-desert in Gobustan:  
 1 *Salsola nodulosa*  
 2 *Lolium rigidum*  
 3 *Allium rubellum*  
 4 *Poa bulbosa*  
 5 *Helianthemum salicifolium*  
 6 *Bromus japonicus*  
 7 *Amberboa glauca*  
 Source: Aliev (1954).

Some parts of the study areas are additionally affected by recently built infrastructure and ongoing resource extraction. In central Gobustan and a few places in Jeiranchel, there are petroleum production sites and limestone, dolomite and gypsum quarries. Gobustan in particular is crossed by a growing number of oil, water and gas pipelines. While quarries and oil wells affect the rangelands only in single spots, pipeline construction and petroleum exploration damage long strips of soil and vegetation that are slow to recover. Non-asphalted roads that change their course after every rainfall have a comparable effect.

#### 1.4 Methodical overview

This study is based on a set of 313 vegetation relevés combined with soil properties, grazing indicators, and topographic site conditions. Sampling sites were selected by terrain stratification according to altitude (2 classes), aspect (4 classes), and inclination (2 classes). Within each of the 16 pre-defined strata, sampling points were chosen randomly using *ArcMap* software. Furthermore, vegetation relevés were recorded along transects at representative farms in Gobustan.

We photographed each plot, determined the vascular plant species using the *Flora of Azerbaijan* (Karjagin, 1950–61), and collected specimens of each of the species. The specimens have been integrated into the herbaria at the University of Greifswald. In addition, we conducted exclosure experiments to study the impact of grazing on the number of plant species, the standing crop, and the vegetation composition within one spring vegetation period. In this context, we performed clipping experiments that imitated grazing to estimate the capacity of annual species for compensatory growth (see chapter 3). The aerial coverage of every

species was estimated for each plot according to the 10-point cover scale of Peet et al. (1998). We fed all data into the database software *Turboveg* (Hennekens & Schaminee 2001) and created synoptic tables using *Juice* (Tichy, 2002).

Soil samples were analysed in the soil laboratory at the University of Greifswald to obtain data on bulk density, carbonate content, pH-value, C/N ratio, conductivity, soil texture, and plant-available phosphorous (for details see chapter 2). Relying on all these data sets, we used the software *R* (R Foundation for Statistical Computing, 2009), with several additional packages and self-compiled scripts, to test for statistical correlations between environmental variables and vegetation characteristics and to derive unranked plant communities. The most important methods we employed were indirect ordination (nonmetric-multidimensional scaling) and hierarchical cluster analysis.

We applied least-square regression models to study relationships between different grazing intensities and site properties (see chapter 4). Species response curves along grazing gradients were generated from Huisman-Olff-Fresco models (Huisman et al., 1993) and then used to calculate patterns of species richness and species turnover. To decide whether a given turnover pattern supports the individualistic continuum model (Austin & Smith, 1989) or the community concept (Mueller-Dombois & Ellenberg, 1974), we developed a null model approach using the slopes of the original species response curves (see chapter 5).

### 1.5 Results and outlook

One major result of the present study is the classification of vegetation in the winter pastures of the eastern Caucasus, which provides the necessary baseline for monitoring and mapping as well as for decisionmaking in conservation and rangeland management. We identified 16 communities with altogether 272 species of vascular plants; most of them are semi-desert communities with a typical dwarf-shrub cover (*Artemisia lerchiana*, *Salsola nodulosa*, *S. ericoides*).

The plant communities are clearly separated along environmental gradients. The primary gradient is expressed by altitude and also reflects soil salinity and soil carbonate concentration, which both decrease with increasing altitude. In the lower zones (10–300 m a.s.l.), we found salt-shrub communities with *Salsola nodulosa* and *Suaeda dendroides*, whereas *Artemisia* semi-deserts are typical for the higher zones above 300 m a.s.l. Grass steppes are restricted to the moister parts of the upper Jeiranchel.

The second gradient reflects grazing intensity. As nearly all of our study sites were being used as pastures, we can distinguish only one plant community that is associated with strongly trampled and nutrient-enriched sites in the vicinity of farmyards and thus differs from all other communities on all other sites. The third gradient distinguishes between communities occurring on slopes (almost all of which were strongly eroded) and communities on the plains. Differences in the composition of the annual flora in *Artemisia* semi-deserts area correlated with differing sand concentrations in the soil.

Exclosure experiments revealed that short-time abandonment of grazing leads to higher species numbers and a denser vegetation cover as well as to increased heights of forbs and grasses. Clipping experiments indicated that grazing causes hardly any compensatory growth in annuals. This observation is highly important for rangeland management, as it underlines the urgent need to shift from unregulated grazing regimes towards rotational grazing to prevent species loss and a decline of forage availability. Unfortunately, we have very few data on grazing abandonment, because many of our exclosures were destroyed before we were able to study them. As a consequence, we have developed a new design based on guarded fences which would allow long-time treatments.

Based on theoretical considerations, we show that 'thresholds' along grazing gradients are often geometrical artefacts, because simple distance is used to estimate grazing intensity. Taking into account the concentric structure of grazing hotspots, we derive a new metric. It approximates the grazing intensity to be expected at a given distance from the hotspot by dividing the total number of livestock kept at the farm by the distance between plot and hotspot centre. At least in the Gobustan rangelands, this approximate value is in direct proportion to other grazing-related parameters like salinity, nutrient deposition, dung density, and trampling. Our model is a simple yet significant improvement over current approaches as it makes it possible to merge or compare data from different sampling sites and can help to prevent error-prone threshold interpretations.

We modelled vascular plant species responses, patterns of species richness, and species turnover along grazing gradients on farm transects in Gobustan. The resulting typical species response pattern along the finite grazing gradient is a sigmoid decrease. Only a small number of species that show unimodal response curves benefit from higher grazing pressure.

Species richness declines monotonically with increasing grazing intensity and thus conforms to generally acknowledged assumptions on the relationship between species richness and grazing pressure in semi-arid rangelands (Milchunas et al. 1988). Species turnover along the gradient was calculated from the slopes of species response curves.

At first sight, the resulting pattern gives evidence for a discontinuous change. However, it ranges within the 95 % confidence interval of a null model based on assumptions of the individualistic continuum concept. Thus, species composition seems to change continuously along grazing gradients in Gobustan. This new null model approach can probably be adapted and applied to all ecological gradients and is useful to validate individual-continuum or community models.

To summarise, the present study achieved four main objectives:

- (1) We developed a straightforward method to estimate grazing intensity in vast rangelands.
- (2) Our null model approach offers ecologists an alternative way to detect discontinuities in species turnover along ecological and spatial gradients.

- (3) We contribute to the mapping and analysis of Caucasian ecosystems, in particular the vegetation of semi-arid rangelands in Azerbaijan.
- (4) The results are an important baseline for management and conservation measures including the monitoring against overgrazing and the adaptation of grazing regimes.

### **1.6 Recommendations for proper rangeland utilisation and conservation**

From the results of our study I derive recommendations for a proper rangeland management that avoids overgrazing and ensures the conservation of species and landscape. Furthermore, I suggest guidelines for regional actors that are based on firsthand field experiences. All of these recommendations will be included in the management proposal of the PUGASMAOS project, which will be distributed among policy makers, livestock keepers, and other stakeholders in Azerbaijan.

#### RECOMMENDATIONS BASED ON SCIENTIFIC ANALYSIS

**Introduction of a rotational grazing regime:** Under the historically evolved grazing regime that is currently in practice, all of the spring pastures are permanently grazed between March and May. But because annual plants show almost no compensatory growth, unrestricted spring grazing damages rangeland productivity and abets erosion because it creates large areas of open soil. To use more fully the potential of spring pastures, large parts of a range should be allowed to recover for several days or weeks in turn. In other words, rotational grazing (which Prilipko recommended for the Kura depression as early as 1949) should be introduced in order to raise the total forage yield. This also means that sites threatened by erosion can be taken out of use without reducing the number of livestock.

**Mowing of the farm surroundings:** The *Hordeum leporinum-Salsola dendroides* semi-desert around farmyards is highly productive in terms of total biomass but low-grade in terms of fodder, because most of the species it consists of are unpalatable (Guliev, 1968). Alternatively, we recommend to mow these sites and to use the harvest as cheap shed litter. This would also reduce the nutrient enrichment around the farms.

**Grazing abandonment of endangered areas:** Our transect studies on farms in Gobustan indicate that even a small reduction of livestock numbers could have positive effects on species diversity and vegetation cover. Therefore, areas threatened by erosion or salt enrichment and sites with endangered plant species should be less intensively grazed.

#### RECOMMENDATIONS BASED ON CASUAL FIELD OBSERVATIONS

**Stabilisation of the road system:** The undirected creation of numerous alternating and unbanked road tracks abets erosion and reduces forage availability. Roads should be stabilised to minimise their impact on the landscape.

**Afforestation:** The current practice of planting trees on hilltops in the semi-desert of Gobustan should be abandoned. Instead, afforestation of valleys using salt-resistant shrubs and trees like *Tamarix* spp., *Elaeagnus* spp., and *Populus euphratica* is highly advisable to stabilise ephemeral rivers, to provide shadow trees for resting herds, and to produce fuel wood (Peper et al., 2010).

**Protection of gazelles:** Goitered Gazelles (*Gazella subgutturosa*) are a national symbol of Azerbaijan. During the summer, gazelles migrate from Shirvan National Park, where they are protected, into Gobustan where many of them are poached, or killed by dogs. As the co-existence of gazelles and livestock is highly desirable, we recommend that temporarily unused, regenerating rangelands be declared gazelle reserves. Such refuges could also offer protection for other threatened vertebrates.

**Protection of endemic plant species:** The semi-desert rangelands of Gobustan and Jeiranchel are the centre of distribution of five plant species that are endemic to the Caucasian lowlands. Therefore, Azerbaijan bears a special responsibility for ensuring their survival. We recommend that each species be protected according to its specific needs, i.e. its site conditions and response to grazing.

*Iris camillae* grows on sandy soils in the Jeiranchel steppe. *Iris acutiloba* and *Nonea rosea* grow on slopes and rock outcrops in Gobustan. While the stems and leaves of the *Iris* species are unpalatable, their flowers are eaten by livestock. *Gypsophila stevenii*, which is found on gravelly, carbonate-rich slopes, is also strongly threatened by grazing. The number of livestock foraging the sites where this species occurs should be restricted, especially during the few days of blooming, to allow sexual reproduction. The only one of the endemic species in the study area that is not threatened by grazing is *Veronica amoena*, an ephemeral species that occurs widely on silty, saline soils in the chenopod semi-deserts of Caucasia.

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# Semi-arid rangeland vegetation of the Greater Caucasus foothills in Azerbaijan and its driving environmental conditions

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## Abstract

We present the plant communities of two semi-arid rangelands at the foothills of the Greater Caucasus Mountains in Azerbaijan and describe their relationships to site conditions and grazing impact. We sampled a total of 313 vegetation relevés containing 272 vascular plant species with a stratified random design and along ten transects in the Gobustan and Jeiranchel regions, covering 1500 km<sup>2</sup> and 1300 km<sup>2</sup> respectively. To classify the rangeland communities we applied agglomerative hierarchical clustering, while the influence of site parameters was obtained by Nonmetric Multidimensional Scaling (NMDS) ordination. A total of 16 plant communities were classified, ranging from deserts with annual herbs, semi-deserts dominated by various chenopod shrubs, *Artemisia lerchiana* semi-deserts to steppes with perennial forbs and bunchgrasses. The strongest gradients in vegetation composition can be explained by a combination of salinity and acidity along an altitudinal gradient, by differences in soil texture, and by slope inclination. Whereas we detected only small alterations in the response to grazing impact on the whole pastures, vegetation in the close vicinity of farms differs strongly. The involvement of annual species in the analyses gives a more detailed picture compared to previous vegetation classifications based on dominant species.

## Keywords:

*Artemisia lerchiana*,  
chenopod shrubs,  
semi-desert,  
steppe,  
winter pasture



**Fig. 2.0:** Flowering ephemerals in Gobustan. May 2007.

### 2.1 Introduction

The semi-arid foothills of the Greater Caucasus have been used as winter pastures for at least 4000 years (Stadelbauer 1984). Here sheep and cattle are herded from October until May in large flocks. During summertime they are moved to the subalpine and alpine zone of the Caucasus Mountains.

Semi-deserts and steppes of *Artemisia lerchiana* and chenopod dwarf shrubs with lots of annual herb species (Fig. 2.0) are the typical vegetation components of the rangelands in Azerbaijan at the transition from the Irano-Turanian into the Southeastern-European floral region. Before 1950 the utilization of these pastures was restricted by natural forage supply and by the availability of rainwater collected in ponds. Since then trucking of additional water and fodder to the remote farms allowed an increase in livestock numbers and grazing intensity. As a consequence, changes in vegetation structure and composition can be assumed to have occurred, as were well documented in the comparable Anatolian steppes by Birand (1970).

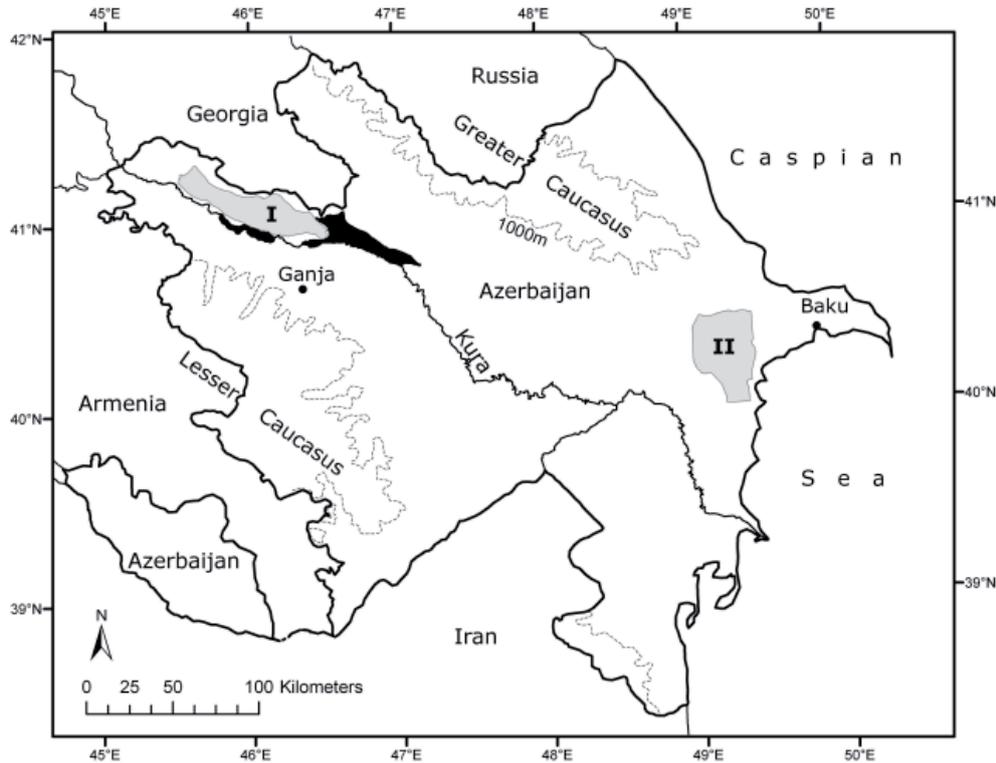
Knowledge about the spatial distribution of plant communities, which can serve as indicators for, e.g. salinity, grazing intensity and forage potential, is an essential tool for an appropriate rangeland management. The first scientific studies dealing with vegetation of winter pastures in Azerbaijan were conducted in the 1920s with the aim of estimating their agronomical potential (Grossgejm 1929, 1932, Grossgejm and Kolakovsky 1929, Grossgejm and Sachokia 1929).

Overviews of the whole vegetation of Azerbaijan were given also by Grossgejm (1948) and later by Prilipko (1970). More detailed descriptions with regard to the floristic composition and response to environmental factors are available for *Salsola nodulosa* semi-deserts in the lower rangelands (Aliev 1954), and for the steppe vegetation of Azerbaijan (Atamov 2002). The latest studies are focused in detail on the vegetation of solonchak deserts (Abd'ieva 2005), and on the chenopod shrub semi-deserts of Gobustan (Dašdamirova 1990). However, these do not differentiate between anthropogenic influences and natural site conditions affecting the structure and species composition of the observed vegetation.

Our study aims to close this gap by presenting a vegetation classification of semi-arid rangelands and by investigating the underlying driving environmental factors that explain the variance in species composition and vegetation structure. Particular emphasis is given to the influence of grazing on vegetation pattern.

### 2.2 Study area

The study area is located at the foothills of the Greater Caucasus Mountains in Azerbaijan. Within these foothills we selected the two traditional winter pasture regions Gobustan (1500 km<sup>2</sup>) and Jeiranchel (1300 km<sup>2</sup>) (Fig. 2.1), where we restricted the altitudinal range of plot sampling to between 10 and 650 m a.s.l. The geological composition of the foothills is represented by a series of young Pleistocene sediments and of Tertiary material in the upper regions (Alizade 2008). Shallow depressions and river valleys are filled with Holocene alluvial



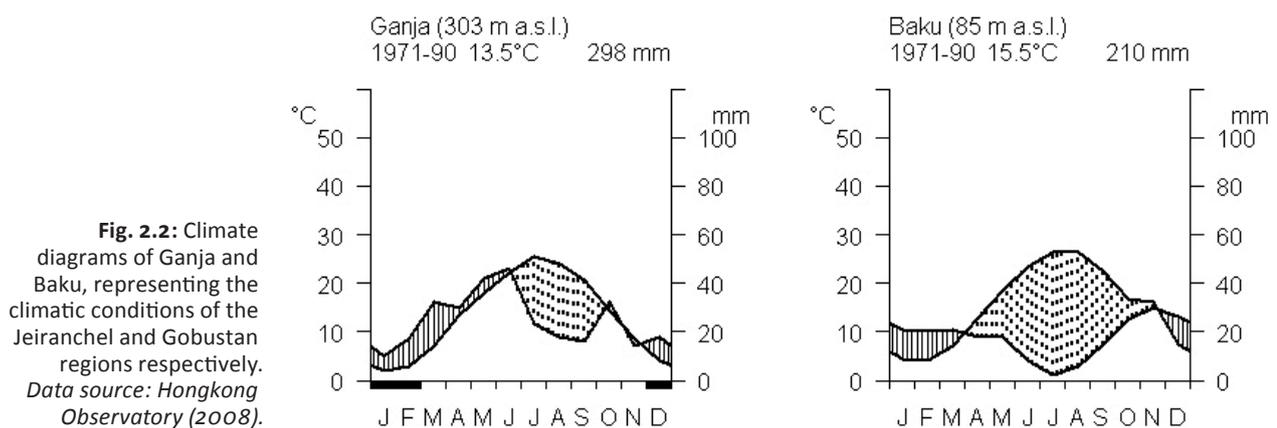
**Fig. 2.1:** Map of Azerbaijan with location of the study regions: I Jeiranchel; II Gobustan.

sediments. Dolomite rock outcrops as well as mud volcanoes with extrusion fans extending over several square kilometres are special geological features in Gobustan. The main relief structure is an escarpment system of gently undulated plains with steep stairs at their margins and some deep-cut riverbeds.

Soil substrates consist mainly of carbonate rich clays and silts. Compared to Gobustan, the soils in the Jeiranchel region have, on average, higher sand contents. Salinity is high in depressions and on mud volcano extrusions. Typical soils in the region are Calcic Gypsisols and Calcisols in lower altitudes that gradually change at their upper boundary into Kastanozems, while Solonchaks occur in pans (Babaev et al. 2006, Mamedov et al. 2007).

Following the Koeppen classification, climate can be classified as a cold steppe climate (Kottek et al. 2006) with cold humid winters and hot arid summers. The amount of annual precipitation declines from Jeiranchel in the west to Gobustan in the east. In the western region mean annual precipitation is about 300 mm and mean annual temperature is 13.5°C. The lower altitudes of Gobustan receive 210 mm rainfall per year with an average annual temperature of 15.5°C (Fig. 2.2). The potential evapotranspiration between April and September exceeds precipitation by 500 to 700 mm in the Jeiranchel and 700 to 1000 mm in Gobustan (Madatzade & Šichlinskij 1968).

The two regions are almost entirely used as winter pastures from the end of September until May, with stocking densities from one to four sheep or goat per hectare. Cattle are also kept in small numbers on the farms scattered in the contiguous rangelands (Fig. 2.0). The large herds, comprising 500–1000 head, are actively herded on the pastures during daytime, but spend every noon and all night at the farms.



### 2.3 Methods

#### VEGETATION SAMPLING

We sampled vegetation during spring 2007 and 2008 following a stratified randomised design. On the hypothesis that the main environmental gradients are altitude, aspect and inclination we divided each study area into strata by the use of a digital elevation model derived from Shuttle Radar Topography Mission (SRTM) data with a ground resolution of 90 m. Strata were defined by the combination of two altitudinal belts (10 to 300 m a.s.l. and 300 to 650 m a.s.l.), two inclination classes (below and above 2°) and four exposition classes with the cardinal points of the compass as centre of the quarters. This combination results in 16 strata.

We randomly selected 20 polygons per stratum and study region with a minimum size of 1 ha, and generated one random point in every polygon. We sampled a minimum of ten plots for each north- and south-facing stratum and a minimum of five plots for each west- and east-facing stratum per study region, resulting in a total of 253 plots for both Jeiranchel and Gobustan. Plot location in the field was supported and documented by a handheld GPS device (Garmin etrex). Due to the very high grazing and trampling pressure in the close vicinity of farmyards, plant communities with strong differences to the adjacent rangelands have developed. Because of their small spatial distribution, these vegetation patches would have been neglected by the stratified random sampling. Therefore, we additionally sampled 60 plots in Gobustan along ten transects of 800 m length, oriented along the strongest gradient of grazing intensity.

Within the consistent plot size of 100 m<sup>2</sup> (10 × 10 m) we noted all vascular plant species and estimated cover classes according to the ten-point cover scale of Peet et al. (1998), which is consistent with rough doublings of cover with increasing classes. Total vegetation cover as well as cover of different vegetation layers (lichens, bryophytes, dwarf shrubs, herbs) was estimated in percentages. The herb layer was additionally split into annual and perennial herbs. Mean height of all layers was estimated in cm. Vascular plant species were determined using the Flora Azerbaijan (Karjagin 1950–1961) and nomenclature follows the

**Tab. 2.1:** Applied classification of desert, semi-desert and steppe formations.

Formation	Cover perennials	Cover ratio of perennial forbs and graminoids to dwarf shrubs
Desert	< 10 %	/
Semi-desert	> 10 %	< 1
Steppe	> 10 %	> 1

Russian reference list (Czerepanov 1995). To identify the life-form type after Raunkiaer (1934) of each species we used the Flora Azerbaijan and Rothmaler et al. (2002). The life-form type of species lacking sufficient prior information was determined from our own field observations.

#### SITE CONDITIONS

We measured slope inclination in degrees by the use of an inclinometer, and altitude by a GPS device. To obtain proxy data for grazing intensity we estimated both the cover of faeces and the proportion of total vegetation cover grazed below 5 cm, in percentages. A composite soil sample of 200 cm<sup>3</sup> was taken from every plot at 5 to 10 cm depth. Fine soil texture was obtained by a laser particle sizer (Fritsch Analysette 22) and the CaCO<sub>3</sub> content by Scheibler gadgetry. Elemental analyses of total carbon and total nitrogen (N<sub>tot</sub>) were performed on an Elementar Vario-III elemental analyzer. Content of organic carbon and C<sub>org</sub>/N<sub>tot</sub> ratio was obtained by correcting for inorganic carbon content from CaCO<sub>3</sub>. Salinity was measured as electric conductivity ( $\sigma$ ) by a glass electrode. In the statistical analyses log( $\sigma$ ) was used. Acidity was obtained by pH measurements in H<sub>2</sub>O also with a glass electrode and plant available phosphate was measured by the Olsen P-Test (Olsen et al. 1954).

#### DATA ANALYSIS

All statistical analyses were run using the program R (version 2.6.0, [www.r-project.org](http://www.r-project.org)). To reduce noise in the vegetation data we excluded rare species occurring in less than four relevés. To classify the vegetation hierarchical agglomerative cluster analysis was applied using the non-transformed cover class values. As linking procedure Ward's minimum variance method (Ward 1963) was chosen; this minimises the squared error for each clustering step and produces relatively even-sized clusters easy to interpret in terms of environmental conditions and species composition. Since Ward's method requires a distance measure with metric properties we used the square root of the Bray-Curtis coefficient (Legendre & Legendre 1998).

For each cluster step, species indicator values were calculated to determine the optimal cutting level of the cluster dendrogram (Dufrêne & Legendre 1997). A species was only considered as indicator species if it had an indicator value above 0.2 and a p-level below 0.05. The dendrogram was cut at the cluster step

with the highest number of indicator species and the lowest p-level for all species (Dufrêne & Legendre 1997). The unranked communities were named by a combination of two characteristic species and their physiognomic formation type. Because there is no consistent system to distinguish between steppes, semi-deserts and desert formations (Lavrenko & Sočava 1956, Prilipko 1970, Schroeder 1998), we modified the classifications of Schultz (1988) and Walter (1968) using the coverage of perennial forbs and dwarf shrubs as attributes for a classification (Table 2.1). Species were manually sorted into species groups and a synoptic table using percentage constancies was compiled using the program Juice, version 6.5 (Tichy 2002).

We used Nonmetric Multidimensional Scaling (NMDS) (Kruskal 1964) as unconstrained ordination technique to represent the strongest gradients in species composition and to explore vegetation-environment relationships by post-hoc correlation of site variables with the resulting ordination axes. Only 281 relevés with a complete set of measured environmental parameters were involved in the ordinations. A Bray-Curtis dissimilarity matrix calculated from the untransformed species cover classes was used in the ordination.

The appropriate number of dimensions was determined by separate NMDS calculations of varying dimensions and by plotting a scree plot with the stress reduction against dimensionality. The task is to choose a number of axes beyond which reductions in stress are small (McCune & Grace 2002). After the number of axes has been determined we used the function metaMDS from the R package vegan (Oksanen et al. 2007). We ran the algorithm starting from random points and tested each run with a Monte-Carlo test with 200 iterations. A stable solution was found when two runs resulted in the same minimum.

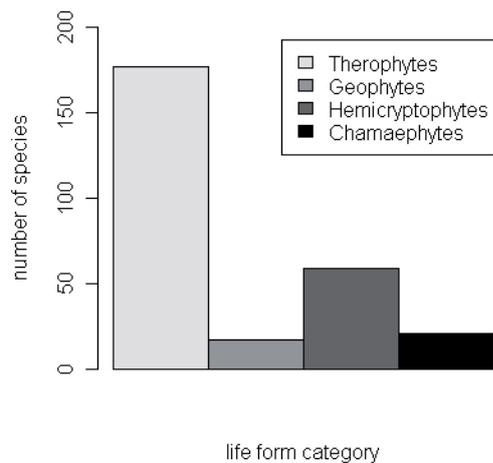
The proportion of total variance represented by the ordination was obtained by the  $r^2$  for the correlation between the original distance matrix of the vegetation data and the Euclidean distance matrix of the resulting ordination using the function ordcomp. For an easier interpretation of the gradients the ordination space was rotated, so that the highest variance in species composition is represented by the first axis. Axes are scaled to half-change units.

## 2.4 Results

### CLASSIFICATION

We sampled 313 plots with a total of 272 vascular plant species. Seventy five species occurred in more than 10 % of all plots while 79 species were restricted to one or two plot occurrences. Cluster analysis in combination with the indicator species approach suggested 15 to 17 clusters, so we chose a division into 16 relatively even-sized clusters.

According to the criteria of Table 2.1 only one community belongs to the desert formation and one to the steppes, while the remainders represent semi-deserts. All communities are characterised by a high amount of therophytes associated with dwarf shrubs (Fig. 2.3).



**Fig. 2.3:** Life-form categories of the 272 sampled plant species in the Gobustan and Jeiranchel regions of Azerbaijan.

In semi-deserts Lavrenko & Sočava (1956) differentiate non-woody plants into ephemerals, ephemeroids and all other herbaceous plants. According to these authors ephemerals are therophytes with a short developing period and ephemeroids are perennial herbs, mainly geophytes, with a short growing period (i.e. restricted to climatically favorable times during either spring or autumn).

To prevent confusion and in agreement with Walter (1968) we use the term ephemerals for both briefly developing therophytes and ephemeroids. The ephemeral species are of great importance in the study area while halophytic summer therophytes and the summer green perennial grasses and forbs are less frequent. Among the dwarf shrub species *Artemisia lerchiana* is most widespread. Its appearance varies strongly depending on site conditions from small rosettes to 40 cm-high and dense shrubs. With an ecological amplitude comparable to that of *Artemisia*, *Salsola ericoides* is also important, followed by *Salsola nodulosa*, which is typical for the lower semi-desert belt.

#### PLANT COMMUNITIES

*Artemisia lerchiana*, *Poa bulbosa*, *Erodium cicutarium* and five other species occur with variable constancies in all observed rangeland types. Besides this similarity, the 16 plant communities derived by the cluster analysis can be aggregated into four broadly defined vegetation types (Tab. 2.2). These are halophilous ephemeral deserts, semi-deserts with *Salsola nodulosa*, semi-deserts and steppes with predominating *Artemisia lerchiana* and a nitrophilous lawn around farmyards. A synoptic table of all communities, showing species groups and selected environmental parameters, is presented in Table 2.3, followed by a short description of every community with emphasis on typical species, site conditions, and grazing impact. The original relevé data are stored in Turboveg format in the vegetation database of the Institute of Botany and Landscape Ecology in Greifswald and can be obtained upon request from the corresponding author.

**Tab 2.2:** Overview of the 16 plant communities.

No.	Plant communities
Halophilous ephemeral desert	
1	<i>Gamanthus pilosus-Eremopyrum orientale</i> desert
<i>Salsola nodulosa</i> semi-deserts (sd)	
2	<i>Psylliostachys spicata-Salsola nodulosa</i> sd
3	<i>Reaumuria cystoides-S. nodulosa</i> sd
4	<i>Spergularia diandra-Suaeda dendroides</i> sd
5	<i>Malva iljinii-S. nodulosa</i> sd
6	<i>Eremopyrum triticeum-Salsola ericoides</i> sd
7	<i>Lepidium perfoliatum-S. ericoides</i> sd
8	<i>Erodium turcmenum-S. nodulosa</i> sd
<i>Artemisia lerchiana</i> semi-deserts and steppes	
9	<i>Plantago ovata-Artemisia lerchiana</i> sd
10	<i>Rhagadiolus hedypnois-A. lerchiana</i> sd
11	<i>Catabrosella humilis-A. lerchiana</i> sd
12	<i>Festuca rupicola-Kochia prostrata</i> sd
13	<i>Achillea biebersteinii-Agropyrum cristatum</i> steppe
14	<i>Consolida divaricata-A. lerchiana</i> sd
15	<i>Parentucellia latifolia-A. lerchiana</i> sd
Nitrophilous lawns	
16	<i>Hordeum leporinum-Salsola dendroides</i> sd

*Gamanthus pilosus-Eremopyrum orientale* desert (1) Fig. 2.4-a

The *Gamanthus pilosus-Eremopyrum orientale* desert has only been observed in the Jeiranchel region, where it is restricted to flat and badly drained pans. The alkaline soils (pH = 8.5 to 9) consist of alluvial material nearly free of sand with CaCO<sub>3</sub> contents of about 13 %. Halophytic annuals like *Veronica amoena*, *Gamanthus pilosus* and *Eremopyrum orientale* form a species-poor lawn that can reach a total coverage of about 30 %. Perennial species are rare and a moss layer is only sparsely developed or lacking. These sites are only slightly grazed, probably due to the low palatability of the predominating species.

*Psylliostachys spicata-Salsola nodulosa* semi-desert (2) Fig. 2.4-b

The semi-desert community is distributed on slopes with saline silty soils up to 400 m a.s.l. It shows a typical pattern of single halophytic dwarf shrubs, like *Suaeda dendroides* and *Salsola nodulosa*, on bare soil. Occurrences of *Psylliostachys spicata*, *Anthemis candidissima*, and halophytic annuals are restricted to the protecting canopy of the shrubs. Trampling density is high and almost all sites are affected by erosion.



**Fig. 2.4-a:** *Gamanthus pilosus*-*Eremopyrum orientale* desert with *E. orientale* in the foreground. Jeiranchel in April 2008.



**Fig. 2.4-b:** *Psylliostachys spicata*-*Salsola nodulosa* semi-desert with the dwarf shrub *Suaeda dendroides* in the foreground. Gobustan in April 2007.

**Tab. 2.3:** Synoptic table of 16 rangeland plant communities of the Gobustan and Jeiranchel regions in Azerbaijan, based on a cluster analysis of 313 relevés.

Species frequencies are given as percentages (in bold if > 33 %). Communities are numbered as in Tab. 2.2. Environmental parameters are given with mean, minimum and maximum values. Regions are indicated by G (Gobustan) and J (Jeiranchel). LF = life forms: C chamaephyte, G geophyte, H hemicryptophyte, T therophyte.

community no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
number of relevés	12	19	8	15	21	21	29	15	37	24	25	18	28	12	12	18
region	J	J/G	J/G	J/G	G	J	G	J/G	J/G	G	J	J/G	J	J	G	G
altitude [m a.s.l.]	187	253	266	121	116	202	334	266	253	389	294	347	509	390	472	282
inclination [°]	180-197	107-422	154-461	22-287	17-306	89-543	265-502	137-449	53-422	240-577	113-440	96-591	341-637	309-458	428-568	146-326
skeleton [%]	0-3	0-37	2-37	0-33	0-18	0-15	1-6	3-18	1-21	1-21	0-20	1-32	0-12	0-3	1-4	1-4
sand [% of fine soil]	0-6	0-19	1-49	0-49	8-53	0-48	0-16	0-54	0-42	0-19	5-56	3-78	6-54	1-44	0-7	1-30
clay [% of fine soil]	14	17	14	13	10	10	13	10	13	14	7	6	6	8	16	11
pH	8.6	8.1	7.9	7.9	8.1	8.5	8.3	7.9	7.9	8.0	7.8	7.8	7.9	7.7	7.6	8.1
electric conductivity [mS/m]	7.9-9.0	7.0-8.9	7.3-8.4	7.0-8.7	7.3-8.8	8.0-9.2	7.8-8.8	7.3-8.5	6.6-8.6	7.1-8.8	6.8-8.7	7.3-8.5	6.2-8.8	6.3-8.4	6.0-8.5	7.3-8.6
CaCO <sub>3</sub> [%]	0.7	2.1	1.9	1.7	0.7	0.4	0.5	0.5	0.2	0.3	0.3	0.5	0.3	0.2	0.2	0.8
N <sub>tot</sub> [g/kg]	0.3-1.7	0.2-8.7	0.5-2.6	0.2-3.8	0.2-2.9	0.2-1.6	0.2-1.7	0.1-2.1	0.1-0.4	0.2-2.2	0.1-2.0	0.1-2.2	0.1-1.0	0.1-0.3	0.2-0.4	0.3-2.5
C/N ratio	13	11	13	11	16	14	9	20	4	6	4	12	4	7	1	8
PO <sub>4</sub> <sup>3-</sup> [mg/kg]	12-15	1-19	2-21	1-23	7-39	6-19	1-27	3-43	0-16	0-19	0-12	0-49	0-16	0-16	0-2	1-17
cover of faeces [%]	1	0.9	0.6	1.1	1	1.3	1.5	1.2	1.8	2.0	1.3	1.3	1.6	1.9	1.8	2.5
proportion total vegetation cover grazed below 5 cm [%]	0.8-1.3	0.2-1.9	0.4-1.1	0.6-1.9	0.5-1.7	0.4-2.5	1.0-2.6	0.4-2.2	1.0-3.7	1.4-4.0	0.6-2.1	0.5-2.9	0.5-3.0	0.1-0.3	1.1-2.6	1.0-5.0
cover total [%]	6.1	5.5	5.7	7	7.1	6.9	8.1	7.9	8.2	8.9	7.9	8.3	8.7	9.6	8.6	8.6
cover shrub layer [%]	4.6-7.7	2.5-9.5	2.2-7.7	3.2-10.3	3.3-11.3	2.2-18.1	5.2-11.0	2.5-17.8	6.4-9.6	6.5-15.1	2.4-13.3	1.2-15.7	3.8-10.7	5.4-19.3	7.1-10.3	5.9-9.9
height shrub layer [cm]	7	4	3	4	4	5	6	1	6	5	7	4	7	6	4	73
cover herb layer [%]	1.8-13	0.3-13	0.2-8	0.3-9	1.2-11	0.8-25	3.5-16	0.3-3.7	0.8-29	2.3-10	2.4-15	0.2-8	1.0-20	0.2-11	2.0-6	3.3-193
mean height herb layer [cm]	2	2	3	4	4	3	6	2	7	4	3	3	2	1	3	13
cover moss layer [%]	1.4	0.5	1-6	1-8	1-10	1-8	2-13	0-7	0-13	2-8	1-7	1-5	1-5	0-3	1-6	6-55
cover lichen layer [%]	14	20	27	47	52	31	40	18	51	25	41	22	25	15	5	49
number of species	3-30	0-80	5-60	5-80	20-90	5-70	10-85	0-50	0-80	0-60	2-95	5-70	5-80	3-30	0-20	5-80
<i>Artemisia lerchiana</i>	C	25	<b>58</b>	<b>100</b>	<b>73</b>	<b>95</b>	<b>100</b>	<b>96</b>	<b>100</b>	<b>39</b>						
<i>Poa bulbosa</i>	H	25	<b>37</b>	<b>50</b>	<b>100</b>	<b>100</b>	<b>90</b>	<b>97</b>	<b>100</b>	<b>83</b>	<b>100</b>	<b>89</b>	<b>100</b>	<b>100</b>	<b>92</b>	<b>94</b>
<i>Filago pyramidata</i>	T	<b>83</b>	<b>53</b>	<b>75</b>	<b>67</b>	<b>95</b>	<b>95</b>	<b>97</b>	<b>100</b>	<b>83</b>	<b>100</b>	<b>78</b>	<b>89</b>	<b>75</b>	<b>100</b>	<b>39</b>
<i>Erodium cicutarium</i>	T	<b>75</b>	<b>42</b>	<b>38</b>	<b>80</b>	<b>90</b>	<b>86</b>	<b>100</b>	<b>87</b>	<b>97</b>	<b>96</b>	<b>76</b>	<b>61</b>	<b>89</b>	<b>100</b>	<b>72</b>
<i>Medicago minima</i>	T	<b>33</b>	<b>47</b>	<b>100</b>	<b>93</b>	<b>81</b>	<b>86</b>	<b>69</b>	<b>87</b>	<b>100</b>	<b>96</b>	<b>100</b>	<b>89</b>	<b>93</b>	<b>92</b>	<b>61</b>
<i>Lolium rigidum</i>	T	17	<b>68</b>	<b>63</b>	<b>73</b>	<b>57</b>	<b>76</b>	<b>79</b>	<b>87</b>	<b>65</b>	<b>92</b>	<b>12</b>	<b>39</b>	<b>54</b>	<b>42</b>	<b>89</b>
<i>Salsola ericoides</i>	C	<b>33</b>	16	.	7	10	<b>71</b>	<b>76</b>	<b>33</b>	<b>78</b>	<b>75</b>	<b>72</b>	<b>39</b>	11	<b>100</b>	25
<i>Veronica polita</i>	T	<b>92</b>	16	13	7	5	<b>62</b>	<b>52</b>	.	<b>70</b>	17	<b>48</b>	17	<b>61</b>	<b>83</b>	<b>42</b>
<i>Bromus japonicus</i>	T	<b>33</b>	<b>42</b>	13	<b>33</b>	24	<b>81</b>	<b>52</b>	<b>67</b>	<b>62</b>	<b>50</b>	<b>80</b>	<b>50</b>	<b>64</b>	<b>100</b>	<b>50</b>
<i>Eremopyrum orientale</i>	T	<b>100</b>	<b>63</b>	<b>63</b>	<b>40</b>	24	<b>90</b>	24	13	3	4	<b>40</b>	.	<b>43</b>	<b>75</b>	8
<i>Catabrosella humilis</i>	H	<b>33</b>	11	<b>63</b>	.	.	<b>86</b>	.	7	.	.	<b>76</b>	11	<b>57</b>	.	.
<i>Heterocaryum rigidum</i>	T	<b>33</b>	5	13	7	10	24	24	<b>47</b>	8	4	32	17	.	.	.
<i>Phleum paniculatum</i>	T	<b>58</b>	11	.	.	.	14	.	.	3	.	8	.	14	<b>58</b>	.
<i>Euphorbia falcata</i>	T	25	5	.	.	.	.	.	.	.	8	4	.	21	<b>58</b>	.
<i>Eremopyrum triticeum</i>	T	<b>92</b>	21	.	20	5	<b>67</b>	<b>62</b>	7	3	.	20	.	7	8	17
<i>Gamanthus pilosus</i>	T	<b>100</b>	32	<b>38</b>	.	.	<b>33</b>	10	.	3	17	.	6	11	<b>33</b>	.
<i>Erysimum repandum</i>	T	<b>83</b>	26	.	13	.	19	<b>34</b>	7	11	.	8	.	4	.	6
<i>Veronica amoena</i>	T	<b>100</b>	16	.	.	.	14	28	.	4	.	.	.	.	.	.
<i>Trigonella orthoceras</i>	T	<b>33</b>	11	.	.	5	<b>38</b>	3	.	3	.	.	.	.	8	.
<i>Sideritis montana</i>	T	<b>33</b>	16	.	.	.	19	.	.	.	.	.	.	7	.	.
<i>Psylliostachys spicata</i>	T	.	<b>42</b>	.	<b>87</b>	10	10	17	7	5	.	.	.	.	.	.
<i>Suaeda dendroides</i>	C	.	32	.	<b>80</b>	14	.	.	.	.	.	.	.	.	.	.
<i>Strigosella africana</i>	T	.	11	13	<b>40</b>	24	19	.	.	.	4	.	.	.	.	.
<i>Astragalus ammophilus</i>	T	.	16	.	7	24	.	.	7	.	.	.	6	4	.	.
<i>Alopecurus myosuroides</i>	T	8	16	.	.	.	19	.	.	.	.	.	.	.	8	.
<i>Erodium oxyrhynchum</i>	T	.	16	.	.	.	.	.	7	3	4	.	6	.	.	.
<i>Atriplex tatarica</i>	T	.	16	.	.	.	5	.	.	.	.	.	.	.	.	.
<i>Suchtelenia calycina</i>	T	.	11	.	.	.	.	.	.	.	.	.	.	.	.	.
<i>Astragalus psiloglottis</i>	T	.	26	<b>38</b>	13	14	.	10	.	11	25	.	6	4	.	11
<i>Lepidium vesicarium</i>	T	.	16	25	.	.	5	3	7	.	.	4	11	.	8	.
<i>Eremopyrum distans</i>	T	8	16	25	7	.	5	.	7	.	.	6	4	.	.	.
<i>Bongardia chrysogonum</i>	G	.	11	13	7	.	.	.	13	.	17	.	.	.	.	.
<i>Chardinia orientalis</i>	H	.	11	25	.	.	.	3	.	.	13	.	.	4	.	.

Tab. 2.3: (continued)

community no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
number of relevés	12	19	8	15	21	21	29	15	37	24	25	18	28	12	12	18
<i>Salsola nodulosa</i>	C	.	63	100	100	95	33	14	67	11	13	8	.	.	.	6
<i>Koelipia linearis</i>	T	.	42	25	40	48	33	7	53	14	.	16	17	.	.	.
<i>Spergularia diandra</i>	T	.	11	25	100	43	43	31	7	8	.	4	.	.	.	.
<i>Parapholis incurva</i>	T	.	26	38	33	19	52	14	7	3	.	.	.	.	.	6
<i>Reaumuria cystoides</i>	C	.	26	100	13	10	5	3	20	.	13	4	11	.	.	8
<i>Anisantha rubens</i>	T	.	37	13	87	76	5	86	80	81	96	.	11	.	.	42
<i>Plantago coronopus</i>	T	.	26	.	87	62	71	76	27	41	17	4	.	.	.	83
<i>Lagoseris glaucescens</i>	T	.	53	38	60	71	24	83	80	95	100	12	39	68	83	75
<i>Allium rubellum</i>	G	.	42	75	40	86	19	72	53	54	25	80	44	64	17	25
<i>Trigonella monspeliaca</i>	T	8	16	25	40	52	67	93	67	41	63	32	28	43	33	8
<i>Hordeum leporinum</i>	T	.	21	25	33	33	43	55	20	54	25	36	22	46	17	8
<i>Gagea bulbifera</i>	G	.	16	.	27	71	19	14	13	19	8	36	11	21	8	25
<i>Scorzonera laciniata</i>	H	.	74	25	93	62	71	90	20	41	29	16	.	46	8	83
<i>Carduus cinereus</i>	T	.	42	13	40	24	52	41	33	46	42	8	11	50	42	44
<i>Sonchus oleraceus</i>	T	.	32	.	27	10	.	7	7	5	21	.	.	14	33	33
<i>Helianthemum salicifolium</i>	T	.	32	88	40	95	24	83	93	81	92	44	94	86	42	8
<i>Neoturularia contortuplicata</i>	T	8	47	38	67	76	52	45	80	54	33	48	39	21	25	.
<i>Astragalus asterias</i>	T	17	32	38	53	90	33	90	87	19	54	16	39	21	.	17
<i>Herniaria hirsuta</i>	T	17	16	38	47	57	71	97	73	30	21	52	33	7	8	.
<i>Trachynia distachya</i>	T	.	16	100	27	67	19	7	80	8	79	16	50	79	33	.
<i>Adonis bienertii</i>	T	8	26	.	7	10	38	41	27	19	8	.	11	18	42	.
<i>Anthemis candidissima</i>	T	8	37	.	.	.	.	45	20	3	42	.	17	.	67	.
<i>Onobrychis vaginalis</i>	H	.	.	50	.	.	.	.	.	.	.	8	11	.	.	.
<i>Stachys fruticulosa</i>	C	.	.	50	.	.	.	.	.	.	.	.	6	.	.	.
<i>Astragalus albanicus</i>	H	.	.	38	.	.	.	.	7	.	.	.	6	.	.	.
<i>Limonium meyeri</i>	H	.	.	25	.	.	.	.	.	.	.	.	.	.	.	8
<i>Rostraria glabriflora</i>	T	8	5	.	47	95	86	14	53	59	33	36	39	.	8	.
<i>Stipa lessingiana</i>	H	.	5	.	75	.	5	.	.	40	5	8	12	61	39	33
<i>Agropyron cristatum</i>	H	.	.	.	38	.	.	.	.	20	.	4	.	44	82	33
<i>Noaea mucronata</i>	C	.	.	.	25	.	.	.	.	13	19	29	20	50	4	.
<i>Bothriochloa ischaemum</i>	H	.	.	.	50	.	5	.	.	.	.	12	56	64	17	.
<i>Teucrium polium</i>	C	.	.	.	75	.	5	.	.	.	4	8	72	25	8	.
<i>Astragalus stevenianus</i>	H	.	.	.	38	.	.	.	7	.	.	.	39	4	.	.
<i>Linum austriacum</i>	H	.	.	.	25	.	.	.	.	.	.	8	28	11	8	.
<i>Alyssum turkestanicum</i>	T	.	.	.	13	.	19	29	52	87	81	63	88	50	93	83
<i>Medicago rigidula</i>	T	.	11	.	13	.	24	.	24	40	54	71	48	39	68	67
<i>Meniocus linifolius</i>	T	.	.	.	38	7	14	19	3	87	3	8	48	67	46	67
<i>Kalidium caspicum</i>	C	.	11	.	47	.	5	.	.	.	.	.	.	.	.	.
<i>Medicago denticulata</i>	T	.	.	.	33	.	5	.	.	3	4	.	.	.	.	25
<i>Aizoon hispanicum</i>	T	.	.	.	27	.	5	.	.	.	.	.	.	.	.	.
<i>Sphenopus divaricatus</i>	T	.	.	.	20	.	.	.	.	.	.	.	.	.	.	.
<i>Schismus arabicus</i>	T	.	.	.	33	24	.	3	20	.	.	.	.	.	.	11
<i>Leptaleum filifolium</i>	T	.	.	.	13	38	.	14	.	.	.	.	.	.	.	.
<i>Bupleurum gerardii</i>	T	.	.	.	67	71	.	.	62	60	35	.	.	.	.	17
<i>Climacoptera crassa</i>	T	.	.	.	47	19	.	.	38	7	8	.	.	.	.	11
<i>Malva iljinii</i>	T	.	11	.	60	86	43	34	27	46	38	.	6	.	.	6
<i>Plantago ovata</i>	T	.	5	.	40	67	19	3	7	76	8	12	.	.	.	22
<i>Ceratocephala falcata</i>	T	8	.	.	13	10	33	.	20	.	.	20	28	.	.	.
<i>Lepidium perfoliatum</i>	T	.	16	.	33	10	5	83	7	22	.	8	.	21	8	42
<i>Matricaria praecox</i>	T	8	.	.	27	38	14	24	.	27	4	4	.	.	.	58
<i>Calendula persica</i>	T	.	.	.	33	.	.	.	40	.	14	.	.	.	.	.
<i>Astragalus tribuloides</i>	T	.	5	.	7	29	14	41	33	5	4	8	6	.	.	.
<i>Vicia peregrina</i>	T	8	5	.	10	29	14	.	.	17	.	6	4	42	.	.
<i>Althaea hirsuta</i>	T	.	.	.	7	24	.	33	.	.	.	4	7	50	.	.
<i>Hypecoum pendulum</i>	T	.	.	.	.	29	.	7	.	4	20	6	.	33	.	.
<i>Arenaria serpyllifolia</i>	T	.	.	.	5	38	38	47	70	21	76	78	86	75	33	6
<i>Galium ghilanicum</i>	T	.	11	.	7	19	10	13	30	50	28	28	79	92	83	.
<i>Linaria simplex</i>	T	.	.	.	.	33	7	60	11	13	76	56	46	75	.	.
<i>Torilis stocksiana</i>	T	.	21	.	7	29	24	.	14	42	.	11	7	50	92	11
<i>Salsola dendroides</i>	C	.	.	13	13	5	.	38	7	27	.	4	.	14	.	17
<i>Iris acutiloba</i>	G	.	11	.	7	38	.	.	60	5	4	.	.	.	.	.
<i>Nonea rosea</i>	T	.	5	.	.	.	.	3	40	11	4	.	6	.	.	.
<i>Eruca sativa</i>	T	.	.	.	5	.	.	.	40	.	.	.	.	.	.	.
<i>Galium verticillatum</i>	T	.	.	.	.	.	.	.	27	11	21	.	11	.	.	.
<i>Androsace maxima</i>	T	.	.	.	5	.	.	3	27	3	21	.	6	.	.	.
<i>Arnebia decumbens</i>	T	.	5	.	10	.	.	.	27	3	.	4	.	.	.	.
<i>Linum corymbulosum</i>	T	.	.	.	.	.	.	.	27	.	.	.	.	.	.	.
<i>Clypeola jonthlaspi</i>	T	.	.	7	24	.	17	.	67	70	29	.	17	.	8	.
<i>Valerianella</i> sp.	T	.	16	.	.	.	.	.	13	8	21	4	33	50	83	8
<i>Erodium turcmenum</i>	T	.	.	7	.	10	3	.	67	8	4	20	28	29	58	.
<i>Buglossoides arvensis</i>	T	.	11	.	.	5	3	.	27	8	8	12	28	46	25	.
<i>Rapistrum rugosum</i>	T	.	5	13	.	10	5	3	.	11	58	.	39	4	.	17
<i>Rhagadiolus hedyppnois</i>	T	.	.	.	.	.	14	3	.	16	71	.	6	.	.	17
<i>Parentucella latifolia</i>	T	.	.	13	10	.	21	13	.	32	50	.	11	.	.	100
<i>Ranunculus oxyspermus</i>	H	.	.	.	.	.	.	3	.	65	50	16	17	50	75	25
<i>Vulpia ciliata</i>	T	.	.	.	.	.	.	3	13	.	32	29	24	17	71	25
<i>Aegilops cylindrica</i>	T	.	5	.	.	19	14	.	7	16	42	20	44	43	92	25
<i>Rochelia disperma</i>	T	.	5	.	7	5	14	7	.	24	29	16	6	36	50	.
<i>Tragopogon</i> sp.	H	.	11	13	7	.	.	3	33	16	46	4	33	11	8	42
<i>Ornithogalum kochii</i>	G	.	.	13	.	.	.	7	.	5	17	.	17	25	8	42
<i>Sedum caespitosum</i>	T	.	.	.	7	14	5	.	7	65	.	60	11	61	8	67
<i>Queria hispanica</i>	T	.	.	.	.	5	.	.	7	16	.	68	39	86	33	8
<i>Veronica verna</i>	T	.	.	.	.	10	.	.	.	14	.	56	39	36	17	33



**Appendix to Table 2.3**

**Rare species:** community no. (frequency)

**Chamaephytes:** *Acantholimon* sp. 13 (4); *Astracantha microcephala* 12 (6);  
*Astracantha stenonychioides* 12 (6); *Caragana grandiflora* 12 (11); *Ephedra distachya* 8,12 (13,6);  
*Halocnemum strobilaceum* 2 (5); *Rhamnus pallasii* 5 (5); *Scutellaria orientalis* 12 (11);  
*Stachys fruticulosa* 12 (6); *Thymus karamarjanicus* 12 (6)

**Geophytes:** *Cardaria draba* 16 (11); *Iris camillae* 3,12 (13,6); *Merendera* sp. 3 (13);  
*Orchis caspia* 10 (4); *Phlomis pungens* 12 (11); *Ranunculus illyricus* 13 (4); *Thesium arvense* 3,12  
(13,11)

**Hemicryptophytes:** *Alhagi pseudalhagi* 13 (4); *Amberboa glauca* 3 (13); *Beta maritima* 16 (6);  
*Cousinia orientalis* 13 (11); *Eryngium campestre* (13 (4); *Gypsophila* sp. 12 (6);  
*Jurinea arachnoidea* 5,12 (5,11); *Jurinea elegans* 12 (6); *Lappula barbata* 8,12 (13,11);  
*Marrubium vulgare* 13 (4); *Matthiola odoratissima* 3,8 (13,7); *Moltkia caerulea* 3,12 (13,11);  
*Peganum harmala* 9,13 (3,4); *Phlomooides laciniata* 10,12 (4,11); *Plantago lanceolata* 2,6 (5,5);  
*Plantago notata* 5 (5); *Scorzonera* sp.12 (6); *Stipa prilipkoana* 12,13 (11,11);  
*Stipa pulcherrima* 12,13 (11,4); *Veronica multifida* 12 (6); *Zygophyllum fabago* 16 (6)

**Therophytes:** *Aegilops triuncialis* 10,12 (17,6); *Asperula prostrata* 12,13 (6,7); *Brassica* sp. 14 (17);  
*Bupleurum* sp. 2,4 (5,7); *Callicephalus nitens* 6,14 (10,17); *Cardamine* sp. 11 (4); *Cirsium* sp.10,15  
(4,25);  
*Cistanche fissa* 2,8 (5,7); *Crepis marschallii* 12,13 (6,4); *Crepis* sp. 10,15 (13,17);  
*Convolvulus arvensis* 13,14 (4,17); *Cruciata articulata* 14 (17); *Daucus carota* 6 (5);  
*Draba nemorosa* 11,12 (8,6); *Geranium dissectum* 6 (10); *Hymenolobus procumbens* 3(13);  
*Koelpinia* sp. 6(5); *Linum* sp. 13(4); *Medicago* sp. 16(6); *Myosotis ramosissima* 13(4);  
*Nepeta amoena* 2 (5); *Nonea caspica* 8,12 (7,6); *Nonea lutea* 12,13 (6,4); *Phalaris brachystachys* 4 (7);  
*Poa annua* 16 (6); *Polygonum aviculare* 2 (5); *Salsola soda* 12 (6); *Salvia verticillata* 14 (17);  
*Sameraria armena* 2 (5); *Silybum marianum* 16 (11); *Sinapis arvensis* 9 (5);  
*Spinacia tetrandra* 6,7 (5,3); *Stellaria media* 16 (6); *Tribulus terrestris* 6 (5);  
*Trigonella gladiata* 10,12 (4,11); *Trigonella monantha* 13 (4); *Vicia angustifolia* 15 (8); *Vulpia* sp. 12  
(6); *Ziziphora capitata* 12,14 (6,8); *Ziziphora persica* 8,12 (7,6); *Ziziphora tenuior* 12,14 (11,8)

*Reaumuria cistoides*-*Salsola nodulosa* semi-desert (3) Fig. 2.4-c

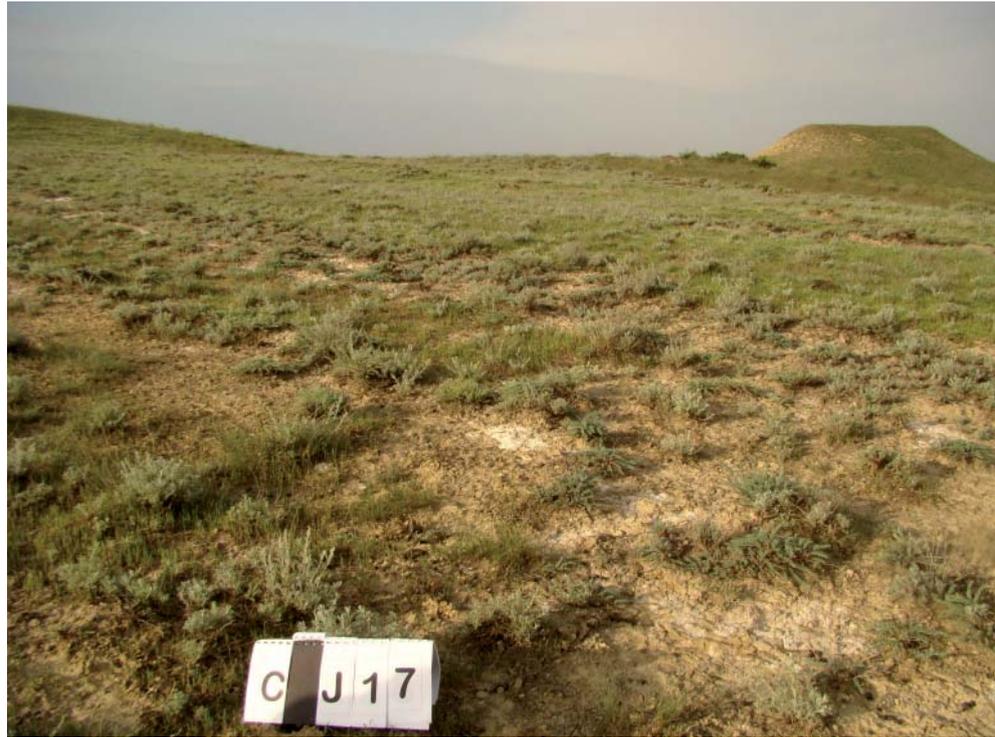
This community is characterised by the salt-excreting shrub *Reaumuria cistoides* and occurs on upper slopes with nitrogen-poor soils ( $N_{\text{tot}} < 1 \text{ g} \cdot \text{kg}^{-1}$ ). In contrast to the previous community, perennial forbs and grasses like *Onobrychis vaginalis* and *Stipa lessingiana* in association with dwarf shrubs such as *Teucrium polium* and *Stachys fruticulosa* are typical. The most abundant ephemerals are *Trachynia distachya* and *Astragalus psiloglottis*. Most of the sites are strongly affected by trampling and erosion.

*Spergularia diandra*-*Suaeda dendroides* semi-desert (4) Fig. 2.4-d

The *Suaeda dendroides* semi-desert is widespread in Gobustan up to an altitude of 200 m a.s.l. It grows on colluvial fine soils at lower slopes and on valley bottoms with high salt contents (mean  $\sigma = 1.7 \text{ mS} \cdot \text{m}^{-1}$ ). The vegetation is dominated by the chenopod shrubs *Kalidum caspicum* and *Suaeda dendroides*, which are associated with halophytic annuals like *Climacoptera crassa*, *Spergularia diandra* and *Plantago coronopus*. Total vegetation cover rarely exceeds 60 % and the sparse herbs between the shrubs are grazed intensively.

*Malva iljinii*-*Salsola nodulosa* semi-desert (5) Fig. 2.4-e

This community also grows in Gobustan up to 200 m a.s.l. mainly on slightly inclining slopes with lower erosion rates. Compared to the previous one, soil salinity is lower ( $\sigma = 0.6 \text{ mS} \cdot \text{m}^{-1}$ ) and the sand content is higher with a mean of



**Fig. 2.4-c:** *Reaumuria cistoides*-*Salsola nodulosa* semi-desert with crusts of gypsum. Most of the plants in the lower right part are *R. cistoides*. Jeiranchel in April 2008.



**Fig. 2.4-d:** *Spergularia diandra*-*Suaeda dendroides* semi-desert on the upper slope of a mud volcano. Gobustan in May 2007.



**Fig. 2.4-e:** *Malva iljinii*-*Salsola nodulosa* semi-desert with *Calendula persica* and *Neotorularia contortuplicata*. Gobustan in April 2007.



**Fig. 2.4-f:** *Eremopyrum triticeum* sheltered by a *Salsola ericoides* shrub. Jeiranchel in April 2008.

20 %. Single shrubs of *Salsola nodulosa* with a maximum height of 30 cm are scattered within homogeneous flat lawns of *Poa bulbosa* and small *Artemisia* plants. Highly abundant ephemerals are *Helianthemum salicifolium*, *Astragalus asterias*, *Rostraria glabriflora* and *Malva iljinii*. Mosses and lichens are sparsely present. The mats are grazed down to a height of 3 cm and trampling generates open patches.

*Eremopyrum triticeum-Salsola ericoides* semi-desert (6) Fig. 2.4-f

Within the Jeiranchel region the lower altitudinal belt up to 250 m a.s.l. is dominated by the *Eremopyrum triticeum-Salsola ericoides* semi-desert. The community grows on plain sites with clayey alkaline soils (pH of 8.5) that are rich in carbonates (5–20 %). With a maximum height of 40 cm *Salsola ericoides* is the dominant dwarf shrub, associated with the smaller species *Salsola nodulosa* and *Artemisia lerchiana*. The perennial grasses *Catabrosella humilis* and *Poa bulbosa* cooccur with halophytic annuals like *Eremopyrum triticeum*, *E. orientale*, *Plantago coronopus* and *Parapholis incurva*. Lichens cover on average five percent of the soil. This community is moderately grazed. Nevertheless bare soil covers an area equal to at least one third of the sites.

*Lepidium perfoliatum-Salsola ericoides* semi-desert (7) Fig. 2.4-g

The *Lepidium perfoliatum-Salsola ericoides* semi-desert has only been observed in Gobustan between 250 and 500 m a.s.l. on slightly inclining slopes with alkaline silty soils (pH = 7.8 to 8.8). It can be distinguished from the *Salsola ericoides* semi-desert (6) in Jeiranchel by the occurrence of additional species (e.g. *Salsola dendroides*, *Lepidium perfoliatum*, *Anthemis candidissima*, *Bupleurum gerardii* and *Anisantha rubens*). Moss and lichen layers are often well developed, each with a cover of up to 20 %. The cover of faeces is between 2 and 9 % and up to 85 % of the plants are grazed to a height below 5 cm, so grazing pressure is high.

*Erodium turcmenum-Salsola nodulosa* semi-desert (8) Fig. 2.4-h

This community grows on slopes with rock outcrops or gravel layers in both study areas below 150 m a.s.l. Soils are rich in carbonates (mean  $\text{CaCO}_3 = 20\%$ ) but poor in nitrogen ( $\text{N}_{\text{tot}} < 2 \text{ g} \cdot \text{kg}^{-1}$ ). The depth of the fine soil layer is often below 20 cm. On these sites both *Artemisia lerchiana* and *Salsola nodulosa* are well developed. Characteristic perennials are *Iris acutiloba* and *Stipa lessingiana*, accompanied by annuals like *Clypeola jonthlaspi*, *Koelpinia linearis* and *Heterocaryum rigidum*. Lichens are particularly well developed on rocks and gravel. Due to the compact and stony substrate the sites are less prone to erosion and trampling.

*Plantago ovata-Artemisia lerchiana* semi-desert (9) Fig. 2.4-i

This type of *Artemisia lerchiana* semi desert is the most widespread in Gobustan, preferring plains and gentle slopes. Its large range covers altitudes from 50 to 430 m a.s.l. Soils are poor in carbonates (< 10 %) and salts ( $\sigma < 0.3 \text{ mS} \cdot \text{m}^{-1}$ ). The species-rich community is characterised by a dense lawn of forbs and grasses, together with a sparse dwarf shrub layer of *Salsola ericoides* and *Artemisia ler-*



**Fig. 2.4-g:** View from a farmyard into the *Lepidium perfoliatum*-*Salsola ericoides* semi-desert. Gobustan in April 2007.



**Fig. 2.4-h:** *Iris acutiloba* flowering in the *Erodium turcmenum*-*Salsola nodulosa* semi-desert on an almost non-grazed table mountain. Gobustan in April 2007.

*chiana*. Among some ephemerals that are widespread in the *Salsola nodulosa* semi-deserts like *Plantago ovata* and *Malva iljinii*, also species of the dry steppes occur (e.g. *Ranunculus oxyspermus* and *Sedum caespitosum*). The dense lawn is heavily grazed with an average cover of faeces of about 7 %, but it shows only slight signs of erosion.

*Rhagadiolus hedynois*-*Artemisia lerchiana* semi-desert (10) Fig. 2.4-j  
Most gentle slopes in Gobustan above 300 m a.s.l. are covered by this community. The soils are rich in skeleton and alkaline (mean pH = 8). Again, *Artemisia lerchiana* and *Salsola ericoides* are the dominant dwarf shrubs covering about one third of the area. A contrast to the previous community is expressed by the occurrence of different herb species. So *Lagoseris glaucescens*, *Anisantha rubens* and *Rhagadiolus hedynois*, associated with a lawn of *Trachynia distachya*, occur on almost all sites. The density of farms in these areas is low because of high snowfall probability in winter. As a result, the sites are only slightly and selectively grazed.

*Catabrosella humilis*-*Artemisia lerchiana* semi-desert (11) Fig. 2.4-k  
This community has been observed in the Jeiranchel between 200 and 440 m a.s.l. on plains and flat slopes. The soils are poor in carbonates and have a low salinity but a larger sand content (30 %) than in the adjacent *Eremopyrum*



**Fig. 2.4-i:** *Plantago ovata* and *Astragalus tribuloides*. Jeiranchel in April 2008.



**Fig. 2.4-j:** *Rhagadiolus hedynois-Artemisia lerchiana* semi-desert. Gobustan in May 2007.



**Fig. 2.4-k:** *Catabrosella humilis-Artemisia lerchiana* semi-desert. Jeiranchel in April 2008.

*triticeum-Artemisia lerchiana* semi-deserts. In gaps between the dominating *Artemisia* shrubs, widespread species such as *Medicago minima*, *Filago pyramidata* and *Poa bulbosa* are common. *Catabrosella humilis*, *Minuartia sclerantha* and *Linaria simplex* are also typical ephemerals. Although density of farmyards is high in these regions, erosion is low due to the flat relief.

*Festuca rupicola-Kochia prostrata* semi-desert (12) Fig. 2.4-l

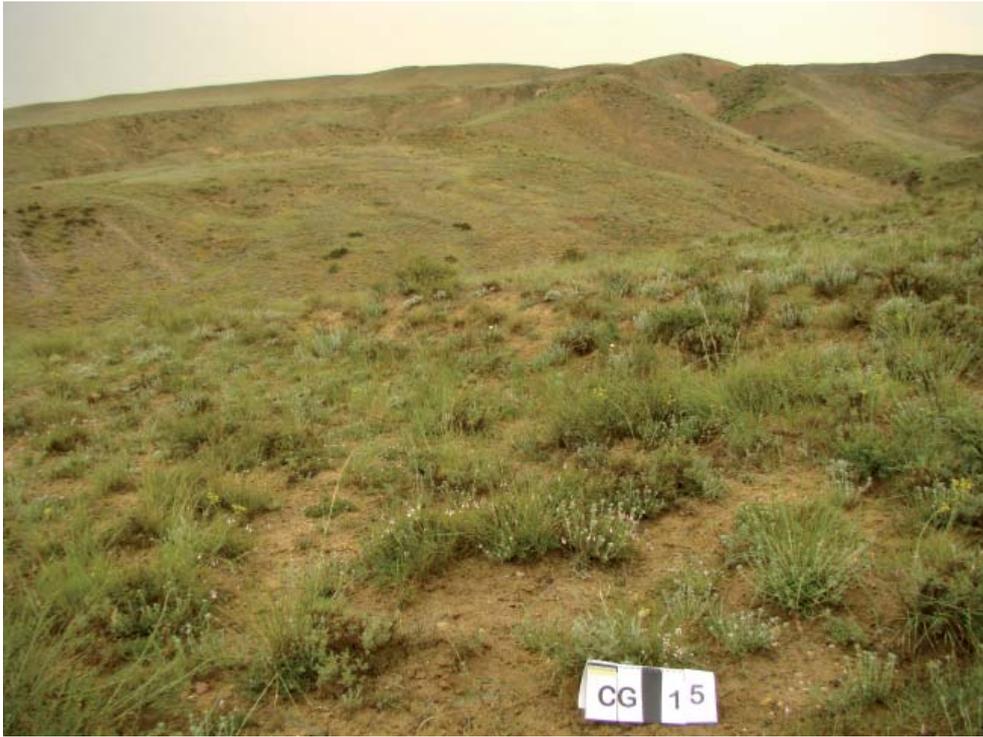
Most of the upper slopes above 100 m a.s.l. in both study regions are covered by this community. Soil texture is very coarse in most cases, with skeleton content of 10 %, and even the surface can be fully covered with gravel. Salinity is low compared to other communities on slopes. The perennial bunchgrasses *Festuca rupicola* and *Stipa lessingiana*, perennial forbs (*Euphorbia seguieriana*, *Gypsophila stevenii*) and the dwarf shrubs *Kochia prostrata*, *Noaea mucronata*, and *Teucrium polium* form this community. A network of trampled paths covers the sites and facilitates erosion.

*Achillea biebersteinii-Agropyrum cristatum* steppe (13) Fig. 2.4-m

The only steppe community that has been observed in our study occurs in the Jeiranchel above 400 m a.s.l. on plains and slightly inclining slopes. Soils are poor in carbonates and the soil reaction ranges between pH 6.2 and 8.8. The most dominant plant species are hemicryptophytes, especially *Botriochloa ischaemum*, *Achillea biebersteinii* and *Agropyrum cristatum*. Typical annuals are *Trifolium arvense* and *Helianthemum lasiocarpum* widespread in the transition zone between semi-desert and steppe. Compared to the semi-deserts, farm sizes in the steppe are larger because they are often used during the whole year. Thus, livestock density during winter is lower than on exclusive winter pastures, and recent grazing traces were low during the observation period.

*Consolida divaricata-Artemisia lerchiana* semi-desert (14) Fig. 2.4-n

This community has been detected within a small altitudinal range between 300 and 450 m a.s.l. in the Jeiranchel region on valley bottoms and lower slopes. The soils have low salt contents ( $\sigma > 0.09 < 0.3 \text{ mS}\cdot\text{m}^{-1}$ ) but higher carbonate contents than the steppe community (mean  $\text{CaCO}_3 = 7 \%$ ). The dwarf shrubs *Salsola ericoides* and *Artemisia lerchiana* predominate with maximum heights of 45 cm. Annual indicator species are *Holosteum glutinosum*, *Consolida divaricata* and *Lamium amplexicaule*. Many other species can be found under the canopy of the dwarf shrubs. Most of the sites are only slightly grazed.



**Fig. 2.4-l:** *Festuca rupicola*-*Kochia prostrata* semi-desert with *Teucrium polium* and *Stachys fruticulosa* dwarf shrubs. Jeiranchel in May 2008.



**Fig. 2.4-m:** *Achillea biebersteinii*-*Agropyrum cristatum* steppe in a dry year. Jeiranchel in May 2008.

*Parentucellia latifolia-Artemisia lerchiana* semi-desert (15) Fig. 2.4-o

It is the most important community in Gobustan above 400 m a.s.l. Soils are poor in carbonates and nearly free of sand. The total vegetation cover is about 90 %, and the cover of *Artemisia* can exceed 70 %. A high diversity of ephemerals (e.g. *Vulpia ciliata*, *Parentucellia latifolia*, *Erodium cicutarium*, *Filago pyramidata*) occurs in all plots. Unlike the communities in the upper Jeiranchel, perennial grasses are lacking. The areas occupied by this community are used as transition pastures during the move to and from the summer pastures in late spring and autumn, so there was very little recent grazing influence during the investigation in spring.

*Hordeum leporinum-Salsola dendroides* semi-desert (16) Fig. 2.4-p

This ruderal community is distributed around all farmyards on the winter pastures. We analysed it detailed in Gobustan in the vicinity of five farms at 300 m a.s.l. Due to the accumulation of faeces around the corrals, the topsoils accumulated the highest amount of nitrogen,  $2.5 \text{ g} \cdot \text{kg}^{-1}$ . *Salsola dendroides* is the only dwarf shrub that benefits from nutrient-rich soils under strong grazing. Among the herbs ruderal and less palatable species like *Hordeum leporinum*, *Lepidium ruderae* and *Sisymbrium irio* predominate. The typical physiognomy of the community is a dense lawn that rapidly changes into bare soil at the farms. It is used as a resting site for livestock.



**Fig. 2.4-n:** *Consolida divaricata-Artemisia lerchiana* semi-desert with different species of *Stipa*. *Salsola ericoides* at the lower margin of the picture. Jeiranchel in May 2008.

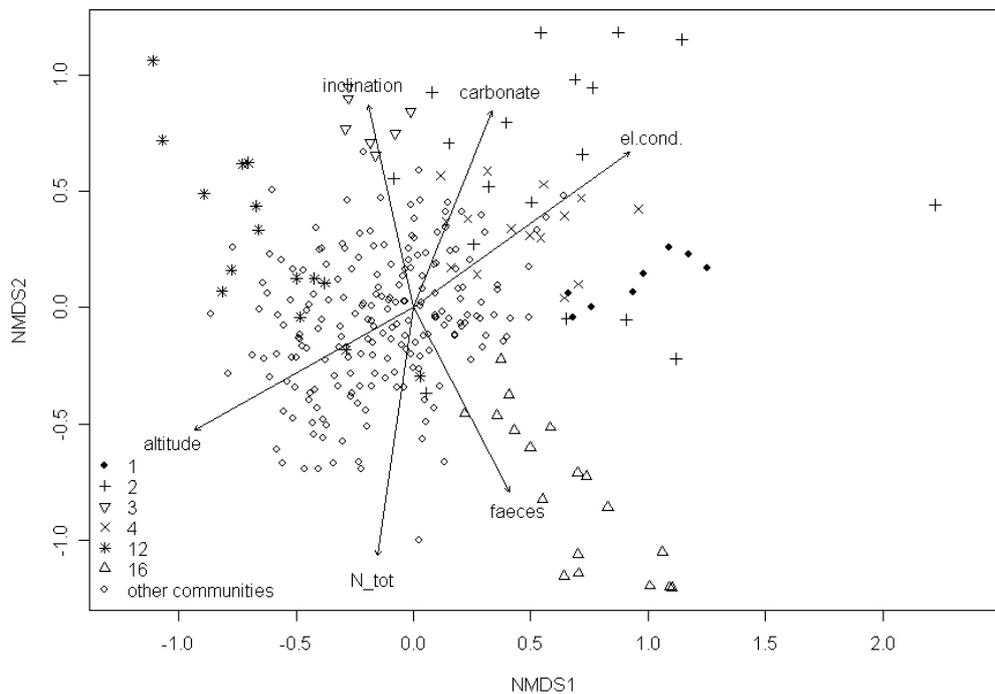


**Fig. 2.4-o:** *Parentucellia latifolia*-*Artemisia lerchiana* semi-desert. Two stems of *P. latifolia* at the lower left margin and *Vulpia ciliata* waving in the wind. Gobustan in May 2007.



**Fig. 2.4-p:** *Hordeum leporinum*-*Salsola dendroides* semi-desert with *Silybum marianum* near a farmyard. Gobustan in May 2007.

**Fig. 2.5:** NMDS ordination of 281 relevés from the Jeiranchel and Gobustan regions. The communities at the margins of the ordination are indicated by symbols:  
 1 *Gamanthus-Eremopyrum orientale* desert  
 2 *Psylliostachys-Salsola nodulosa* semi-desert  
 3 *Reaumuria-S. nodulosa* semi-desert  
 4 *Spergularia-Suaeda dendroides* semi-desert  
 12 *Festuca-Kochia prostrata* semi-desert and  
 16 *Hordeum-Salsola dendroides* semi-desert.  
 Abbreviations of plotted parameters: carbonate = CaCO<sub>3</sub> content, el.cond. = electric conductivity, faeces = cover of faeces, N<sub>tot</sub> = total nitrogen.

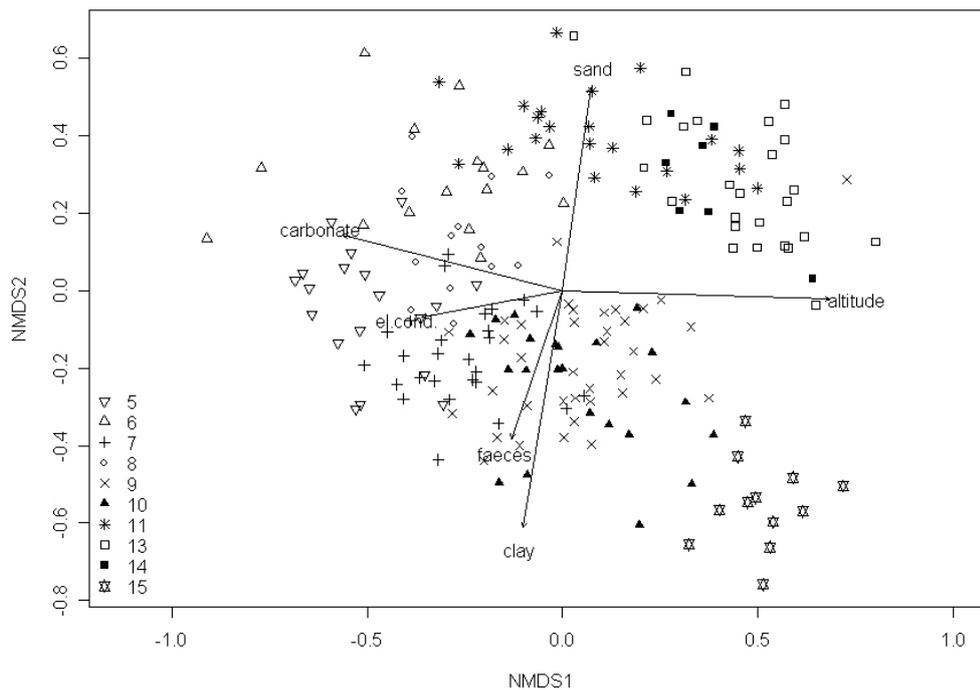


**Tab. 2.4:** Spearman-correlations of environmental parameters with the axes of the NMDS containing all plant communities. Values in bold are significant with  $p < 0.001$ .

n = 281	Axis 1	Axis 2	Axis 3
Electric conductivity	<b>0.55</b>	<b>0.25</b>	-0.13
Altitude	<b>-0.54</b>	<b>-0.36</b>	0.10
pH	<b>0.38</b>	-0.01	0.13
Sand	<b>-0.37</b>	0.03	0.24
Carbonate	<b>0.35</b>	<b>0.57</b>	-0.03
Clay	<b>0.28</b>	-0.01	<b>-0.41</b>
Grazing below 5 cm	<b>0.27</b>	-0.16	-0.02
Cover of faeces	<b>0.27</b>	<b>-0.39</b>	<b>-0.29</b>
Inclination	<b>-0.26</b>	<b>0.43</b>	-0.23
C <sub>org</sub> /N <sub>tot</sub> -ratio	<b>-0.24</b>	<b>-0.38</b>	-0.07
N <sub>tot</sub>	-0.19	<b>-0.54</b>	-0.13
Skeleton	-0.16	0.16	-0.12
Phosphate	0.15	<b>-0.37</b>	0.14

#### ORDINATION

An initial three-dimensional NMDS calculation, including the total data set for which a complete set of environmental data was available, revealed a clear separation of six communities located at the margin of the ordination space. Their position indicates strong floristic independence with respect to each other and to the majority of plots in the ordination centre (Fig. 2.5). A stable solution was obtained after 17 runs with a stress of 15.9; this explains 83 % of the variance of the vegetation data. The first axis is correlated with elevation and electric conductivity (i.e. salinity), while the second axis is related to changes in inclination, cover of faeces, and total nitrogen (Tab. 2.4). Thus, communities restricted to steeper slopes are found on the upper margin of the diagram (*Psyl-*



**Tab. 2.5.** Spearman-correlations of environmental parameters with the axes of the NMDS containing ten plant communities. Values in bold are significant with  $p < 0.001$ .

n = 200	Axis 1	Axis 2	Axis 3
Carbonate	<b>-0.69</b>	0.07	<b>0.25</b>
Altitude	<b>0.67</b>	-0.04	0.07
N <sub>tot</sub>	<b>0.39</b>	<b>-0.32</b>	0.02
Electric conductivity	<b>-0.34</b>	-0.13	-0.17
pH	<b>-0.33</b>	-0.02	-0.21
C <sub>org</sub> /N <sub>tot</sub> -ratio	<b>0.28</b>	-0.13	0.10
Skeleton	<b>-0.26</b>	0.05	<b>0.31</b>
Grazing below 5 cm	-0.23	-0.03	-0.23
Cover of faeces	-0.17	<b>-0.46</b>	<b>-0.24</b>
Inclination	-0.15	-0.07	<b>0.50</b>
Clay	-0.13	<b>-0.64</b>	-0.17
Phosphate	0.12	0.09	-0.11
Sand	0.10	<b>0.54</b>	0.21

**Fig. 2.6:** NMDS ordination of ten plant communities (200 relevés) bulked in the centre of the first ordination (see Fig. 2.5). Communities are indicated by symbols:  
 5 *Malva iljinii*-*S. nodulosa* semi-desert  
 6 *Eremopyrum triticeum*-*S. ericoides* semi-desert  
 7 *Lepidium perfoliatum*-*S. ericoides* semi-desert  
 8 *Erodium turcmenum*-*S. nodulosa* semi-desert  
 9 *Plantago ovata*-*A. lerchiana* semi-desert  
 10 *Rhagadiolus hedynois*-*A. lerchiana* semi-desert  
 11 *Catabrosella humilis*-*A. lerchiana* semi-desert  
 13 *Parentucellia latifolia*-*A. lerchiana* semi-desert  
 14 *Achillea biebersteinii*-*Agropyrum cristatum* steppe  
 15 *Consolida divaricata*-*A. lerchiana* semi-desert.  
 Abbreviations of plotted parameters see Fig. 2.5.

*liostachys-Salsola nodulosa* semi-desert (2), *Reaumuria-S. nodulosa* semi-desert (3), *Festuca-Kochia prostrata* semi-desert (12). A combination of high salinity and low altitude is typical for the *Gamanthus-Eremopyrum orientale* desert (1), the *Psylliostachys-Salsola nodulosa* semi-desert (2) and the *Spergularia-Suaeda dendroides* semi-desert (4), all located at the (upper) right side of the ordination. The plots of the ruderal *Hordeum leporinum-Salsola dendroides* semi-desert (16) are placed at the lower part of the diagram characterised by high nitrogen and faeces values.

To investigate the vegetation-environment relationships of the communities concentrated in the centre of the first ordination we applied a second three-

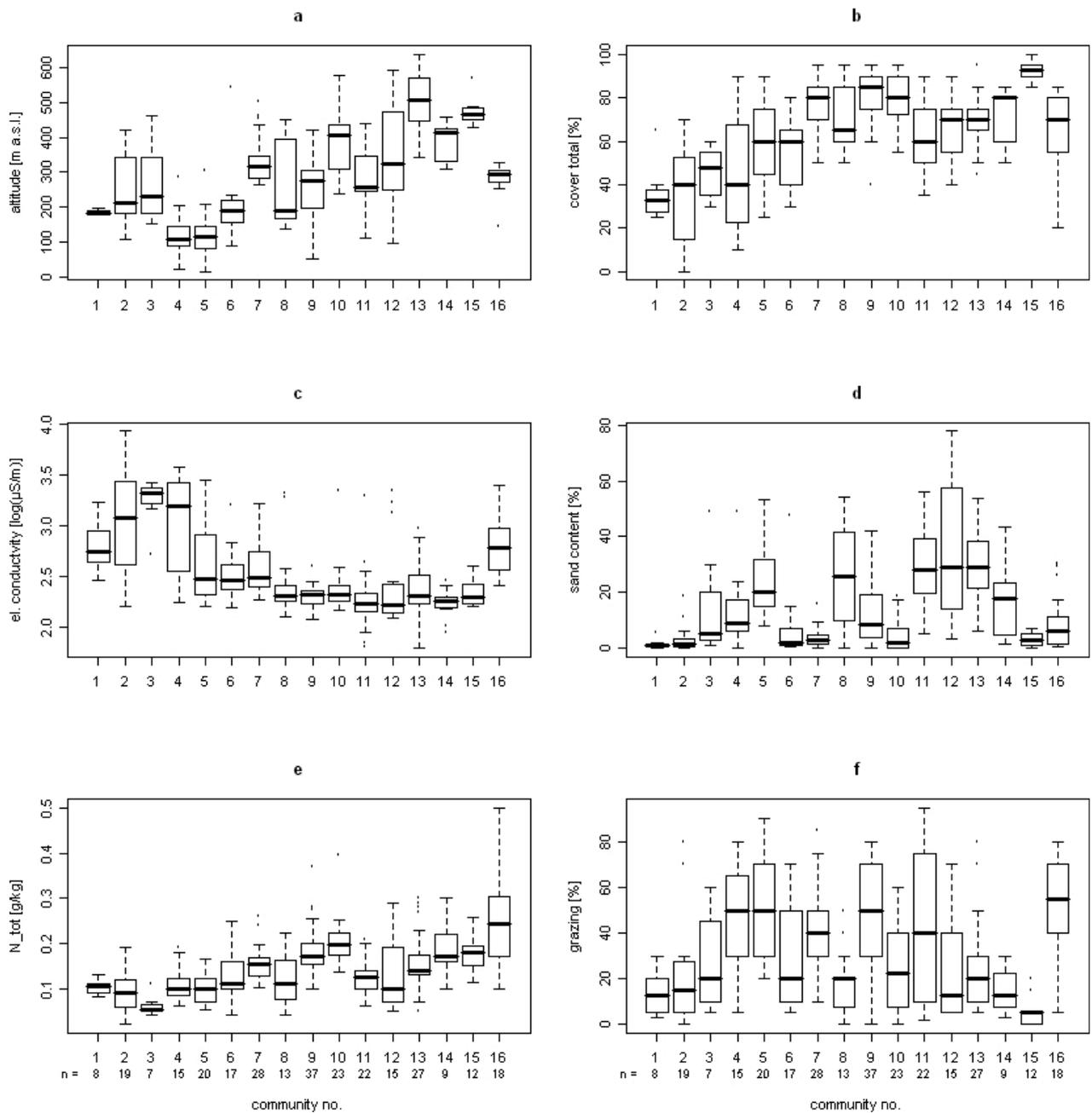
dimensional NMDS after removing the six outlying communities mentioned above (Fig. 2.6). The calculation reached a stable solution after seven runs with a stress of 17.9. This solution explains 75 % of the variance in the vegetation data and, within the first two dimensions, shows also two environmental gradients along which the communities can be separated. Axis one can be described as an altitudinal gradient that is negatively correlated with carbonate content and electric conductivity while axis two represents a gradient in soil texture (Tab. 2.5). Slope inclination is best fitted to the third axis and further separates the communities that overlap in the first two dimensions.

## 2.5 Discussion

### VEGETATION RESPONSE TO TOPOGRAPHY AND EDAPHIC FACTORS

Two main complex edaphic factors explaining a high proportion of variance in the vegetation data can be detected. The first one is a gradient in soil texture from fine clayey to coarser sandy soils (Fig. 2.7), reflecting differences in soil moisture supply and storage. The second gradient implies differences in soil salinity and soil reaction and is expressed by carbonate content, electric conductivity and pH values. Using both gradients a triangle between halophytes deserts, ephemeral semi-deserts and psammophytes semi-deserts can be constructed, which is comparable to the observations of Walter (1968) in the Irano-Turanian vegetation in Turkmenistan. He also mentioned that ephemeral semi-deserts or deserts are restricted to loamy ('loesslike') substrates. Within our study we did not observe pure sand deserts with the typical psammophytic vegetation (Schmidt 2007, Tegetmeyer et al. 2007). Average values for sand content in the plant communities never exceed 25 %. The four most sandy vegetation types are mostly restricted to Jeiranchel, where some Pleistocene ridges are made of sand. Here, a higher water storage capacity in lower soil layers provides fair conditions for perennial plants like *Kochia prostrata*, *Achillea biebersteinii* and *Agropyrum cristatum*. Also various ephemeral species, like *Queria hispanica*, *Minuartia sclerantha* and *Hohenackeria exscapa*, are restricted to more sandy soils in Jeiranchel.

Halophytic vegetation is not only restricted to depressions with salt enrichments in the study regions (cf. Freitag et al. 2001, Breckle 2002) but also occurs on slopes with salty soils. While groundwater is important for halophytic communities with *Salicornia*, *Halocnemum*, and *Halostachys* that are typical for the Kura lowlands and the Volga delta (Golub & Corbadze 1989, Schmidt 2007), our observed halophytic communities are almost exclusively fed by rain water. The only exception to this is *Kalidium caspicum*, which occurs in the *Spergularia diandra-Suaeda dendroides* semi-desert. We observed on active cliffs that the roots of this species can reach permanent wet soil layers down to five metres depth on mud volcanoes or on lower terraces of ephemeral rivers. In depressions with the *Gamanthus pilosus-Eremopyrum orientale* desert rainwater temporarily accumulates in spring but evaporates also in late spring, so that groundwater-



**Fig. 2.7:** Boxplot-distribution of selected environmental and vegetation parameters within the plant communities:  
a) altitude  
b) total cover  
c) electric conductivity  
d) sand content  
e) nitrogen total  
f) proportion of total vegetation cover grazed below 5 cm.

dependent plants like *Salicornia* spp. are lacking or restricted to springs. An obvious difference to the ephemeral semi-desert communities is the total vegetation cover below 50 %.

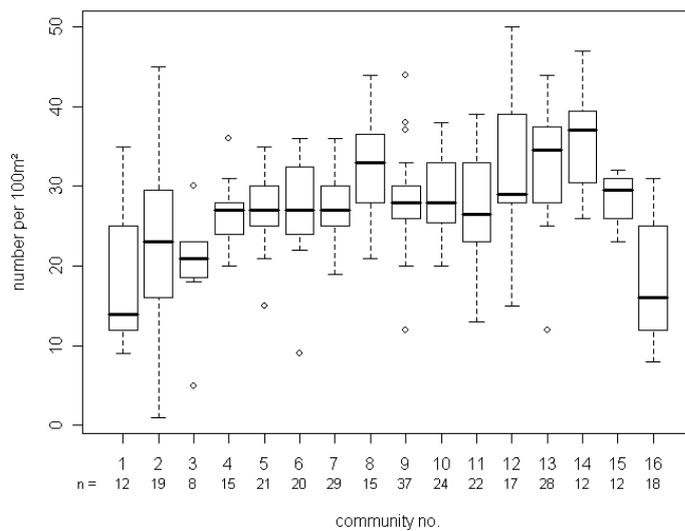
The negative correlation between salinity and altitude can be explained by the combination of higher potential evapotranspiration and lower precipitation rates in lower altitudes, resulting in salt accumulation. Furthermore, carbonate content is higher on slopes, probably due to erosion leading to permanent exposure of carbonate rich bedrock. Thus, altitude and to some extent also inclination can be used as proxy for salinity and acidity.

#### VEGETATION RESPONSE TO GRAZING

Since the regions were used as pasturelands for thousands of years, recent vegetation should be well adapted to grazing. The most important plant species of the rangelands is *A. lerchiana* Web., which is often used by its synonym *A. fragrans* Willd. (Czerepanov 1995). It belongs to the subgenus *Seriphidium* (Vallés et al. 2003), whose species are dominant features in semi deserts and steppes ranging from Anatolia and Middle Asia up to the Hindu Kush (Birand 1970, Breckle 2002, Peer et al. 2007). The discussion about the indicator potential of *Artemisia* for grazing is still controversial. Peer et al. (2001) presume that the monotonous *Artemisia* semi-deserts are a result of overgrazing. In contrast, Breckle (2002) states that due to grazing abandonment a thick litter layer is accumulating that would promote *Artemisia* development. Reverse observations were made in Utah on *A. tridentata*, which is suppressed by *Bromus tectorum* without grazing (Booth et al. 2003).

However, pollen analyses from south-eastern Anatolia detected Chenopodiaceae and *Artemisia herba-alba* (subgenus *Seriphidium*) pollen from the early Holocene until today in almost stable amounts (Wick et al. 2003). This is a clue that *Artemisia* was not in all cases promoted by human-induced grazing. On the upper parts of our study regions with higher precipitation rates we observed a stronger competition for light between dwarf shrubs and ephemeral grasses. On previously burned sites a dense vegetation of annuals, perennial grasses, and forbs has been developed, with hardly any *Artemisia* detectable. Under such conditions the re-establishment of dwarf shrubs is obviously indirectly enhanced by selective grazing. According to this assumption *Artemisia* can be considered as a grazing indicator in more humid areas, but can also be a naturally dominant vegetation component in dryer areas.

A clear impact of different grazing intensities on vegetation is visible in the extreme case of the ruderal *Hordeum leporinum*-*Salsola dendroides* semi-desert, which only occurs in the close vicinity of farmyards. In this community, most of the dwarf shrub species including *Artemisia lerchiana* are mechanically destroyed by livestock. The pronounced changes in herbaceous species composition can be explained by a combination of greater mechanical disturbance together with an excess of available nutrients, both of which result from the temporal and spatial concentration of livestock in a more or less circular area of about 100–150 m radius around farmyards



**Fig. 2.8:** Boxplot-distribution of the number of vascular plant species per 100 m<sup>2</sup> within the plant communities.

At these sites the concentration of plant-available phosphate increases tenfold (mean: 73 mg\*kg<sup>-1</sup> soil) and total nitrogen concentration is doubled compared to adjacent rangeland communities. The area is strongly grazed by resting livestock and additionally by horses and poultry. For the remaining plant communities grazing indicators are of minor importance for the explanation of variance in species composition compared to soil and topographical parameters.

#### BIODIVERSITY AND ENDEMISM

With an average density of 28 vascular plant species per 100 m<sup>2</sup> and a total of 272 species, the observed rangelands are more diverse than comparable ones in the lowlands of Turkmenistan, where 10–15 species per stand (note that no reference has been given to stand size) and a total of 50 species were recorded (Walter 1968). This marked difference in Alpha- and particularly in Gamma-diversity may be partially explained by the Mediterranean range of more than one third of the species (Grossgejm 1936) that do not extend their ranges beyond the Caspian Sea. Also, many of the recorded species in our study are rare and restricted to slopes.

Particularly species-poor communities are the *Hordeum leporinum*-*S. dendroides* semi-desert (Fig. 2.8), where the dominant grass *Hordeum leporinum* is able to develop a dense lawn that is very competitive against the establishment of other species, and the *Gamanthus pilous*-*Eremopyrum orientale* desert, where probably the accumulation of water on clayey soils in wet years prevents the establishment of perennial plants. Schmidt (2007) also found communities with lowest species numbers on saline plains in the Shirvan National Park southwards of Gobustan. The greatest variability in species numbers is exhibited by the *Festuca rupicola*-*Kochia prostrata* and the *Psylliostachys spicata*-*Salsola nodulosa* semi-deserts that are confined to slopes. Here, on strongly eroded sites only a few individuals and species survived while on less disturbed sites the number of species that can grow in micro-habitats is much higher. On plain sites the average species density raises with elevation from 27 up to 36 species. It is not the steppe community but the *Consolida divaricata*-*Artemisia* semi-desert that

**Tab. 2.6:** Comparison of the communities with other vegetation classifications of Azerbaijan's winter pastures. Aliyev (1954) described exclusively *Salsola nodulosa*-dominated vegetation.

Community	Prilipko (1970)	Grossgejm (1948)	Aliyev (1954)
<i>Gamanthus pilosus</i> - <i>Eremopyrum orientale</i> desert	<i>Artemisia</i> desert with halophytic annuals	Ephemeral semi-desert	
<i>Psylliostachys spicata</i> - <i>Salsola nodulosa</i> semi-desert	Semi-desert vegetation of sparse slopes	Salsoletum nodulosae	<i>S. nodulosa</i> semi-desert with halophytic annuals
<i>Reaumuria cystoides</i> - <i>S. nodulosa</i> semi-desert			<i>S. nodulosa</i> semi-desert with salt shrubs
<i>Spergularia diandra</i> - <i>Suaeda dendroides</i> semi-desert	Desert predominated by <i>Kalidium</i> or <i>Suaeda</i>	Kalidietum; Suaedetum	
<i>Malva iljinii</i> - <i>S. nodulosa</i> semi-desert	<i>S. nodulosa</i> desert	Salsoletum nodulosae	
<i>Eremopyrum triticeum</i> - <i>Salsola ericoides</i> semi-desert	<i>Artemisia</i> - <i>S. ericoides</i> desert	Salsoletum ericoides	<i>S. nodulosa</i> semi-desert with <i>Artemisia</i> and ephemerals
<i>Lepidium perfoliatum</i> - <i>S. ericoides</i> semi-desert			
<i>Erodium turcmenum</i> - <i>S. nodulosa</i> semi-desert	<i>Artemisia</i> - <i>S. nodulosa</i> desert	Salsoletum nodulosae	
<i>Plantago ovata</i> - <i>Artemisia</i> <i>lerchiana</i> semi-desert			
<i>Rhagadiolus hedypnois</i> - <i>A. lerchiana</i> semi-desert	<i>Artemisia</i> semi-desert	Artemisietum	
<i>Catabrosella humilis</i> - <i>A. lerchiana</i> semi-desert			
<i>Festuca rupicola</i> - <i>Kochia prostrata</i> semi-desert	<i>Botriochloa</i> - <i>Artemisia</i> steppe	Artemisieto- Stipetum lessingianae	
<i>Achillea biebersteinii</i> - <i>Agropyrum cristatum</i> steppe		<i>Botriochloa</i> semi-steppe	
<i>Consolida divaricata</i> - <i>A. lerchiana</i> semi-desert	<i>Artemisia</i> semi-desert	Artemisietum	
<i>Parentucellia latifolia</i> - <i>A. lerchiana</i> semi-desert			
<i>Hordeum leporinum</i> - <i>Salsola dendroides</i> semi-desert	<i>Artemisia</i> - <i>S. dendroides</i> desert	Salsoletum dendroidis	

harbours the most species. We assume that annual species suffer from competition of the well-developed perennials in the steppe community.

While the Caucasus is mentioned as a centre of biodiversity and endemism (Griffin 1999), its eastern lowlands and foothills shelter only 720 vascular plant species (Grossgejm 1936), almost 40 % of them detected in our study. According to Grossgejm (1936) six of the recorded species are considered as Caucasian endemics: *Veronica amoena* Bieb., an annual species, is the most frequent one, occurring in halophytic communities. *Iris acutiloba* C.A. Mey. and *Nonea rosea* (Bieb.) Link were found in Gobustan in *Salsola nodulosa* communities, while *Orchis caspia* Trautv. was detected in the upper regions. *Gypsophila stevenii* Fisch. ex Schrank is growing on slopes rich in skeleton in Jeiranchel and *Iris camillae* Gross. can be found on sandy substrates in the same region.

#### REMARKS ON CLASSIFICATIONS

Previous vegetation classifications of Azerbaijan's winter pastures (e.g. Grossgejm 1948, Aliev 1954, Dašdamirova 1990, Abd'ieva 2005) are mainly based on the dominant species concept (Rabotnov 1995). The classification of Prilipko (1970) seems to involve both dominant species and the physiognomy of the

vegetation. Grossgejm (1948) used the ending ‘-etum’ for his communities but did not describe them in a syntaxonomical way.

Thus, the available classifications are mainly based on perennial species and most of the vegetation units are more broadly defined compared to our revealed communities, which are described by ephemeral and perennial species (Tab. 2.6). This is especially obvious for the *Artemisia* semi-deserts, where *Artemisia lerchiana* is always dominating and all other species are of less importance. While we distinguish between five *Artemisia* semi-desert types indicating different site conditions, Grossgejm (1948) and Prilipko (1970) merge all *Artemisia* stands into the type ‘*Artemisietum*’ or ‘*Artemisia* semi-desert’, respectively. Due to the random-sampling design we neglected rare and probably locally restricted communities like the *Atraphaxis spinosa* semi-desert described by Aliev (1954).

A syntaxonomic classification for comparable semi-deserts in the Northern Caspian Lowlands is given in the USSR Vegetation Syntaxa Prodromus (Korotkov et al. 1991): *Artemisia lerchiana* semi-deserts are pooled in the class Artemisietea lerchianae Golub 1987 and the alliance Artemision lerchianae Golub 1987 but only two associations are described. One of them is a Kochietum prostratae Golub 1987 with some character species (*Neotorularia contortuplicata*, *Catabrosella humilis*) also occurring in our *Festuca rupicola*-*Kochia prostrata* semi-desert and a Salsoletum dendroidis Golub 1987 that resembles our *Hordeum leporinum*-*Salsola dendroides* semi-desert. Associations of typical *Artemisia* semi-deserts were not described.

## 2.6 Conclusion

Compared to previous studies the consideration of both perennial and annual plant species in our investigations in combination with the measurement of an extensive set of site parameters allows a more detailed vegetation classification. Among the large number of ephemeral species are many good indicators for certain site conditions. To obtain an appropriate tool for bioindication and forage estimations, the use of socio-ecological species groups including annuals should be given priority over classifications based on dominating species only. Our stratified random-sampling design gives an objective picture of the widespread communities but neglects rare and locally restricted communities.

## Acknowledgements

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Raw data on attached CD:

Species data: species\_data.csv  
 Header data: site\_data.csv  
 Data description: metafile.xls



# Short-time effects of grazing abandonment on semi-arid rangelands in Azerbaijan

3

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## Abstract

*Livestock exclosure experiments were run for two years in semi-arid rangelands of the Eastern Caucasus in Azerbaijan. Short-time response of vegetation to livestock abandonment was studied in 15 fenced plots with an area of 10 m<sup>2</sup> each. Using a nested plot design, species numbers at different spatial scales were compared inside and outside the fence. Also differences in parameters related to productivity like standing crop, total cover and height as well as size of dwarf shrubs were analysed. The ability for compensatory growth of herbaceous plants was investigated by a clipping experiment. To evaluate the effects of certain treatments including livestock exclosure on vegetation, a proposal for a long-time field experiment is given.*



**Fig. 3.0:** Construction of an exclosure in Jeiranchel. April 2007.

### Краткосрочные эффекты исключения выпаса домашних животных на сухих пастбищах Азербайджана

#### Выводы

Ян Пепер  
Акбар Джабаров  
Михаэль Мантей

*Эксперименты с изгородями, исключаящими доступ домашних животных к растительности, проводили в течение двух лет на пастбищах восточного Кавказа в Азербайджане. Кратковременная реакция развития растительности на исключение доступа домашних животных изучалась на основании 15 огражденных участков земли по 10 кв м каждый. Используя «вложенный» тип делянок, на различных пространственных шкалах сравнивалось число видов внутри и снаружи сооруженных изгородей. Также сравнивались параметры, связанные с продуктивностью собранной растительной биомассы, совокупное покрытие и высота, а также размер полукустарников. Способность компенсаторного роста травянистых растений изучалась на основании эксперимента срезания растений. Чтобы оценить эффект некоторых методов воздействия, в том числе исключение доступа домашних животных к растительности, был сформулирован план долгосрочного полевого эксперимента.*

#### 3.1 Introduction

Semi-natural rangelands are widespread in the Southern Caucasus region. Besides their utilisation for husbandry they provide habitats for more than one thousand vascular plant species and breeding and migration sites for birds (Gauger, 2007). As a consequence of a steadily growing meat demand in Azerbaijan, livestock numbers are rising strongly. This development leads to unsustainable rangeland management and triggers land degradation (Babayev, 2007).

To estimate the potential productivity and species richness of these semi-arid rangelands it is necessary to study sites where grazing is excluded. However, undisturbed grasslands are very rare in the region and restricted to exceptional sites like young shore plains or rock outcrops. In the absence of undisturbed areas, fenced plots are commonly used to exclude livestock (Fig. 3.0). In these so called enclosure experiments the impact of grazing on vegetation can be studied by comparing the inner and outer sites. We established enclosure experiments in two semi-deserts in Azerbaijan in 2007 and 2008 to answer the following questions:

- (1) Are there short-term effects of grazing enclosures on plant species richness?
- (2) What is the potential productivity (estimated as standing crop, total vegetation cover and vegetation height) of the investigated rangeland sites?, and
- (3) Do herbaceous species respond on clipping with compensatory growth?

### 3.2 Study area

We conducted enclosure experiments in different types of *Artemisia lerchiana* semi-deserts between 180 and 470 m a.s.l. in the Gobustan and Jeiranchel rangelands of Azerbaijan. The regions are characterised by a steppe climate with mean annual temperatures between 13 and 16 °C. Average annual precipitation ranges between 280–460 mm in Gobustan and 360–560 mm in the Jeiranchel region (Madatzade & Šichlinskij, 1968). The semi-deserts are used as winter pastures with stocking densities between one to four sheep or goats per hectare from October until May.

### 3.3 Methods

We constructed a total of 22 enclosures with a size of 3.5 × 3.5 m each. Twenty plots were established before the beginning of the vegetation period in 2007 and two similarly in 2008. During the study time seven fences had been lost due to demolition by cattle, so analyses were restricted to 15 plots. Additionally, an inaccessible and thus non grazed table mountain in Gobustan was used as natural enclosure for compensatory growth experiments.

Vegetation was sampled outside and inside the enclosures one month after the construction at the end of April. We used a logarithmic nested plot design with four spatial scales, including 0.01, 0.1, 1 and 10 m<sup>2</sup>, to record all vascular plant species. Total plant cover and cover of layers was estimated in percentages while mean height of layers was measured. We distinguished between lichen, moss, herbaceous plant and dwarf shrub layers. Also the number of *Artemisia* shrubs, their diameters and heights were obtained.

Standing crop of the herbaceous plants was harvested on representative 0.5 m<sup>2</sup> subplots at 1 cm height above the surface and then oven dried at 105 °C. After three weeks the harvested subplots were clipped a second time. Additionally, standing crop of adjacent undisturbed subplots within the enclosures were sampled to compare the yield of both treatments and to investigate possible compensatory growth effects. Plant species were determined using the Flora Azerbajdžana (Karjagin, 1950–61).

### 3.4 Results

#### SPECIES RICHNESS

A total number of 125 vascular plant species, among them 93 annuals, 26 herbaceous perennials and six dwarf shrub species were recorded. The most important ones are *Artemisia lerchiana*, *Salsola ericoides*, *Poa bulbosa* and *Medicago minima* occurring in almost every sample. All four species are widespread in the rangelands. The average number of species inside the enclosures is higher than outside at all spatial scales (Tab. 3.1). However, a significant difference ( $p < 0.05$ ) is only detectable on the largest area size of 10 m<sup>2</sup>, where the number of species ranges inside between 10 and 33 with an average of 23, and outside between 10 and 31 with an average of 20.

**Tab. 3.1:** Mean inside/outside ratios of plant species richness at different spatial scales from rangeland exclosures in Gobustan and Jeiranchel.

Significance of difference between inside and outside species numbers was tested by a one sided Wilcoxon signed rank test.

Plot size (m <sup>2</sup> )	Species inside/outside	p (n = 15)
0.01	1.05	0.360
0.1	1.13	0.128
1	1.07	0.112
10	1.12	0.018

**Tab. 3.2:** Mean inside/outside ratios of vegetation parameters from rangeland exclosures in Gobustan and Jeiranchel.

Significance of difference between inside and outside for all parameters was tested by a one sided Wilcoxon signed rank test.

Vegetation parameter	ratio in/outside	p (n=15)
Standing crop	1.76	<0.001
Total cover	1.08	0.007
Cover herbs	1.15	0.009
Cover dwarf shrubs	1.06	0.287
Mean height herbs	1.55	0.002
Mean height <i>Artemisia</i>	1.35	0.007
Mean diameter <i>Artemisia</i>	1.13	0.124

#### STANDING CROP AND VEGETATION PARAMETERS

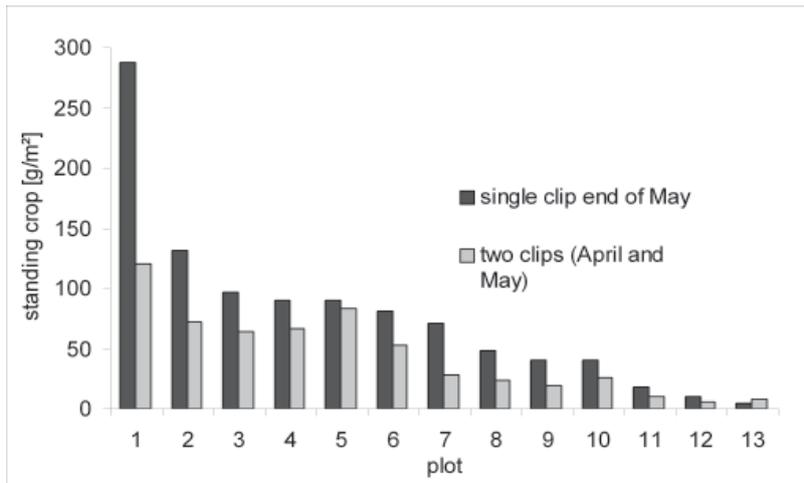
Standing crop is consistently higher inside the fences than outside, with an excess varying between 10 and 260 %. Mean productivity inside is 8.5 while the maximum is at 22.7 dt\*ha<sup>-1</sup>. Also parameters that are related to productivity such as total cover as well as cover and height of herbaceous plants are significantly higher inside (Tab. 3.2). No clear differences can be detected in dwarf shrub cover and in mean canopy diameter of *Artemisia* shrubs. Only mean height of *Artemisia* was significantly higher inside.

#### COMPENSATORY GROWTH

Typical pasture or meadow plants are known to react on grazing or other herbivory with compensatory growth and thus higher standing crop productivity. However, no compensatory growth was detectable. Single harvesting of undisturbed plots at the end of spring vegetation period showed on average 1.7 times higher yields than the sum of two clips in April and May (Fig. 3.1).

### 3.5 Discussion

The increase of plant species numbers inside the exclosures within one month can be explained on the one hand by the grazing behaviour of sheep (Rook & Tallowin, 2003) that select the most palatable species first. Given the short experimental time of one month this selection process can only be effective for annuals with short life cycle. On the other hand, it has to be mentioned that strongly grazed plant individuals may have been neglected in the records. The two palatable ephemerals *Arnebia decumbens* and *Microthlaspi perfoliatum* are rare in the rangelands but occurred within some exclosures. They support the first assumption, while the effect of grazing on species coverage can be studied on the geophyt *Bongardia chrysogonum* or the perennial herb *Scorzonera laciniata* that were recorded inside with higher abundances. A more pronounced difference in species inventory is expected for a longer time of livestock exclosure, as it is reported from Anatolian steppes (Firincioglu *et al.*, 2007).



**Fig. 3.1:** Development of standing crop in enclosure experiments. Black bars indicate the yield of subplots with one clip at the end of spring season (May) and grey bars show the sum of two clips in April and May.

The variance in the excess of standing crop is interesting, because all sites were grazed with comparable stocking densities. It can be assumed that the excess is related to environmental parameters, but clear correlations were not found. The benefits of grazing abandonment are higher for herbaceous plants, while there is no increase in shrub coverage (cf. Yeo, 2005). *Artemisia* is rarely eaten in spring, so its different heights seems to be more likely driven by light competition with herbs than being a result of grazing. A long-time domination of herbs could suppress this dwarf shrub.

The effect of decreasing productivity by a double clipping treatment is of high importance for rangeland management. Annuals represent the main proportion of the standing crop. They store no energy in their root system, and thus are unable to regenerate after deep clipping or grazing. Especially clipping of seedlings or young plants leads to a loss of productivity. The current herding practice uses the total available grazing area every day. A daily restriction to smaller portions of the pasture is assumed to allow higher productivity on the whole area.

#### THE NEED FOR A LONG TIME STUDY

Based on the results of our experiment the following hypotheses on rangeland development under long-time changing grazing practices in the *Artemisia* semi-deserts can be stated:

- (1) Plant species composition changes under grazing abandonment, especially the proportion of *Artemisia* shrubs decreases.
- (2) A shifting grazing practice is more productive than continuous grazing of the whole area.
- (3) Mowing and hay conservation at the peak of vegetation development and storage for unfavourable times would be a better utilisation than grazing down to the soil.
- (4) We also postulate that additional sowing of winter barley in distant lines of slit soil can enhance the productivity.

**Fig. 3.2:** Proposed experimental design for the long-time experiments. Capital letters show different treatments. E is outside the fenced area.

E	A	C	D	B	
	D	B	A	D	E
E	B	D	C	C	
	C	A	B	A	E

To test these hypotheses we propose to establish long-term field experiments in a split-block design with a minimum time horizon of five years. The trials should be implemented as repeated blocks in the two most abundant semi-desert types which are the *Artemisia lerchiana* and the *Salsola nodulosa* semi-deserts. The fenced blocks have to be split into 16 equal sized plots. In a randomised allocation each of the following treatments has to be applied on four plots (example see Fig. 3.2). The treatments are named with capital letters. A: Abandonment of grazing, B: Mowing at peak of vegetation development in spring, C: same as B but with additional sowing of winter barley in autumn and D: imitation of a shifting grazing management by three to four mowing actions in spring. To compare the results with the common utilisation, four further plots (E) have to be studied outside the fence.

To monitor the developments in each of the plots analyses have to be done on  $10 \times 10$  m sites. Soil analyses of samples from the upper soil (0–10 cm) have to be sampled at the beginning and at the end of the investigations. Parameters to be measured are pH,  $\text{CaCO}_3$ , electric conductivity, bulk density, C/N ratio, soil organic matter and soil texture.

Since vegetation will more rapidly response to changes in utilisation then soil properties, sampling has to be conducted every year at the beginning of May. The same analyses as applied for this study should be made to notice changes in species richness and composition as well as in vegetation structure. Special attention has to be paid to the ratio of dwarf shrubs to annual and perennial herbs. The most interesting feature of the monitoring is the development of standing crop productivity in spring and autumn. In each plot the standing crop of herbs has to be clipped at the development peak of vegetation in May in a quadrat of  $1 \text{ m}^2$ . The location of the quadrates has to be changed every year.

The standing crop of plots with repetitive mowing has to be sampled before each action. In autumn the availability of dwarf shrub leaves is of importance, so palatable phytomass of the shrubs has to be clipped on  $1 \text{ m}^2$  in each subplot. After clipping the phytomass has to be oven-dried at  $105 \text{ }^\circ\text{C}$  for 24 h. The results of this field experiment can be implemented in new management strategies and will be of interest for regional agricultural consulting.

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# Estimation of grazing intensity along grazing gradients – the bias of nonlinearity

Michael Manthey & Jan Peper

*Journal of Arid Environments*, 74 (2010) 1351–1354 – short communication

## Abstract

*Distance to grazing hotspots like watering points or farms is regularly used as proxy for grazing intensity in vast rangelands. In many studies the resulting patterns between distance and grazing dependent variables are nonlinear with strong changes in the vicinity of the centre, a distinct transition zone, and hardly any changes on remote sites. Here we propose that this typical pattern just reflects the nonlinear relationship between grazing intensity and distance in circular grazing hotspots. Theoretical considerations as well as other proxies of grazing intensity like dung density or salinity suggest that reciprocal distance better represents grazing intensity. It is a more realistic description of the temporal distribution of livestock and often reveals linear relationships to grazing dependent variables preventing misinterpretations of thresholds that might be important for rangeland management.*

**Keywords:**  
ecological threshold,  
grazing hotspot,  
piosphere,  
rangeland,  
state-and-transition-  
model,  
trampling

## 4.1 The use of grazing gradient analyses

Influences of livestock grazing on productivity, species composition and soil properties in rangelands are of crucial interest for range managers and grassland ecologists. However, direct measurements of animal activities like defoliation, trampling or defecation are complex and time consuming. Also, the use of livestock density in paddocks as a parameter of grazing intensity has been criticised because of the inhomogeneous spatial distribution of animals (Andrew, 1988; Barnes et al., 2008).

Transect analysis around grazing hotspots like watering points, resting sites, or livestock camps is a widely used approach to overcome such restrictions in semi-arid and arid ecosystems (e.g. Adler and Hall, 2005; Fensham and Fairfax, 2008; Ludwig et al., 1999; Pringle and Landsberg, 2004; Todd, 2006). It is a rapid and easy method to estimate the effects of varying grazing intensities on soil and vegetation parameters in homogeneous and vast rangelands. In such studies 'grazing intensity' includes all animal activities affecting the rangeland ecosystem. It is assumed to decrease with distance from the hotspot and thus, can be represented by distance (Sasaki et al., 2008). In many but not all applications of the approach grazing effected parameters respond in a nonlinear way to distance (e.g. Friedel, 1997; Sasaki et al., 2008; Smet and Ward, 2006).

Such patterns suggest transition zones or even thresholds that indicate irreversible parameter changes along a continuous gradient of grazing intensity. Strong changes are detectable within the first metres, while behind a more or less conspicuous threshold little or no responses can be detected. This pattern is

basically described by the 'piosphere' concept (Andrew and Lange, 1986; Lange, 1969). A piosphere consists of a 'sacrifice zone' directly at a hotspot that is free of vegetation (Graetz and Ludwig, 1976), followed by a transition zone that shifts into a nearly homogeneously grazed zone. This grazed zone merges gradually into undisturbed natural vegetation that is hardly influenced by grazing. However, the number of such zones varies between landscapes and studies (Thrash and Derry, 1999). The occurrence of apparent thresholds within these patterns would support state and transition concepts (Briske et al., 2008; Westoby et al., 1989) and has been proposed to be used as indicator for adapted rangeland management (Fensham and Fairfax, 2008; Sasaki et al., 2009). However, it has to be noted here that even a nonlinear parameter response doesn't necessary imply a threshold in terms of reversibility.

While we acknowledge that distance is appropriate to describe the spatial pattern of piospheres we question its general suitability to investigate processes coupled with grazing intensity. Such relationships are distorted by the circular nature of grazing hotspots which implies a nonlinear relationship between grazing intensity and distance.

Here we build on the assumption of Fernandez-Gimenez and Allen-Diaz (2001) that grazing intensity might be linearly related with reciprocal distance to grazing hotspots. Based on theoretical considerations and relationships between alternative proxies of grazing intensity and distance in semi-arid rangelands of Azerbaijan we show that reciprocal distance is indeed an alternative possibility for a better estimation of grazing intensity.

#### 4.2 Linear relationship between grazing intensity and reciprocal distance

To understand this proposed relationship, the general meaning of grazing intensity has to be considered. As it includes all impacts of livestock or wild herbivores on a certain site, it can be expressed as the number of animals per unit area.

When applying this density term to an ideal circular grazing range, we have to make an assumption for the temporal distribution of livestock. The simplest one would be a constant likelihood for the presence of an individual animal at every distance between the centre and the edge of the grazing range. Following this assumption, variation in grazing intensity can be expressed as the number of animals per area of consecutive annuli with constant widths around the hotspot. With increasing distance the area gets larger and animal density would decrease.

Generally, the area of an annulus is calculated by equation (1)

$$A_i = \pi (r_1^2 - r_2^2) \quad (1)$$

Here  $A_i$  is the area,  $r_1$  the outer radius, and  $r_2$  the inner radius of the annulus. With our model restrictions of  $i = N_1 = \{1,2,3,\dots\}$ ,  $k =$  constant width of annuli and  $r = i \times k$  (the radius can only be a natural multiple of  $k$ ) we can replace  $r_2$  with  $r_1 - k$ :

$$A_i = \pi (r^2 - (r - k)^2) \quad (2)$$

Equation (2) can be further simplified via the intermediate steps (3–5):

$$A_i = \pi (r^2 - (r^2 - 2rk + k^2)) \quad (3)$$

$$A_i = \pi (r^2 - r^2 + 2rk - k^2) \quad (4)$$

$$A_i = \pi (2rk - k^2) \quad (5)$$

to:

$$A_i = \pi k(2r - k) \quad (6)$$

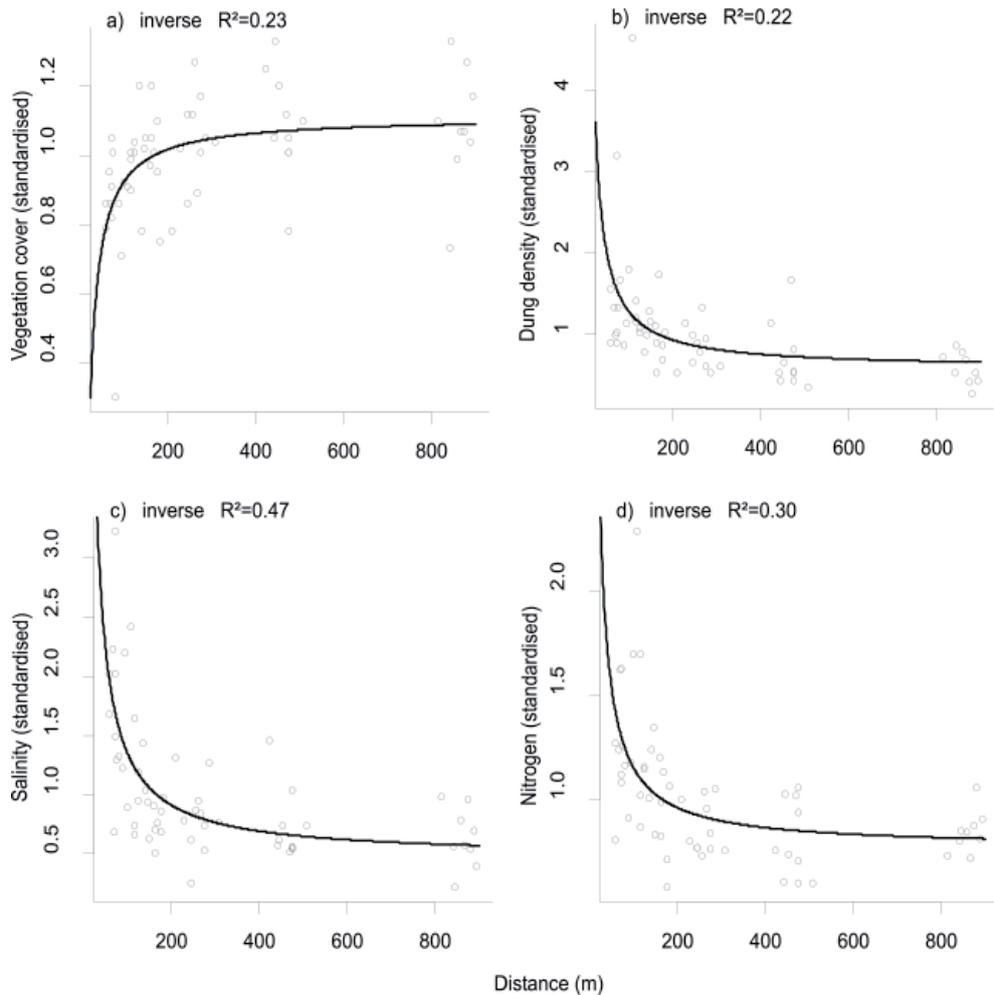
Equation (6) shows that, under our model restrictions, the areas of consecutive annuli with constant width  $k$  are directly proportional to the radius  $r$ . When  $k$  becomes very narrow (i.e. within the margin of error of distance measurements) we can replace the radius  $r$  by distance. Subsequently we can simplify the expression of grazing intensity from animals per area to animals per distance. If animal counts are unavailable, we can estimate relative grazing intensity as 1 per distance (assuming total livestock numbers as a constant). That implies a strong decrease of grazing intensity within the first metres from a grazing centre and only little differences between remote points.

### 4.3 Relationships between other grazing proxies and distance

To test this theoretical derivation we analysed the relationships between other grazing proxies and distance/reciprocal distance respectively. Our data set was collected at the foothills of the Greater Caucasus Mountains in the Gobustan region of Azerbaijan in May 2007. The climate of the study region is continental semi-arid with wet, cool winters and dry, hot summers. Average annual precipitation is 236 mm, with an interannual variability of about 27 % (based on a 40 year observation period of the climate station Baku (unpublished data obtained from National Hydrometeorology Service Department at the Ministry of Ecology and Natural Resources, Baku, Azerbaijan). Mean July temperature reaches 26.4 °C, and mean January temperature is 2.1 °C.

We sampled data in winter pastures around five permanent farms in similar types of *Artemisia lerchiana* semi-deserts with comparable site conditions. The size of the investigated farm ranges varies between 500 and 2000 ha and the stocks of sheep and goats between 750 and 1500 heads, differing between the years. All small ruminants are herded by shepherds until the range borders every morning and afternoon but return to the farm at noon and at night, while horses and some cattle are free-ranging during the day. To focus on the effect of

**Fig. 4.1:** Minimal adequate regression models (all inverse) with fits ( $R^2$ ) fitting the relationships between grazing dependent parameters and distance to farmyards in semi-deserts of Azerbaijan: a) total vegetation cover, b) dung density, c) salinity, and d) total nitrogen.

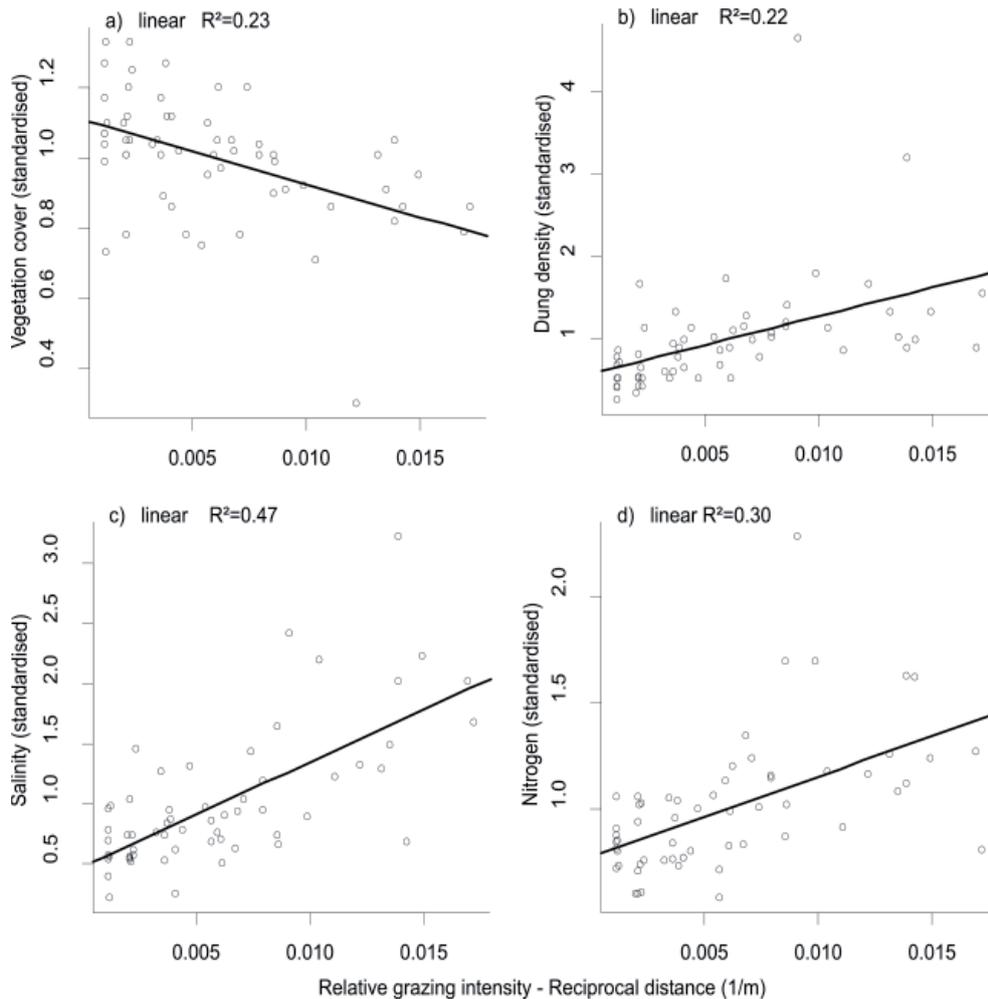


grazing intensity and to avoid additional noise in the data due to different site conditions we limited the analyses to plains and slightly inclining lower slopes with similar soil substrates.

We established two transects of 800 m length at each of the five farms starting with the first plot at the edge of the vegetation free sacrifice zone. Five consecutive plots were placed in distances of 50, 100, 200, 400 and 800 m to the first plot, sampling a total of 59 plots with a constant plot size of 100 m<sup>2</sup> (10 × 10 m). Larger distances were not taken into account because of potential overlap with neighbouring farm ranges and increasing variability in other site conditions. We measured the distance to the centre of the farm for each plot to account for different extensions of the sacrifice zones.

To get alternative proxies of grazing intensity we focussed on the parameters dung density, total cover of vegetation, and the chemical soil parameters total nitrogen and salinity.

Dung density was reported in previous studies as a parameter with strong correlations to animal activities (Stumpp et al., 2005; Turner, 1998). Total cover of vegetation is negative proportional to the density of livestock tracks that reflect trampling activities (Lange, 1969). Both parameters were estimated



**Fig. 4.2:** Minimal adequate regression models (all linear) with fits ( $R^2$ ) fitting the relationships between grazing dependent parameters and reciprocal distance as estimator of relative grazing intensity to farmyards in semi-deserts of Azerbaijan: a) total vegetation cover, b) dung density, c) salinity, and d) total nitrogen.

in percentages. Salinity may depend on urination (Hendricks et al., 2005) and possibly also on the extend of open and trampled sites because of higher evaporation (Popp et al., 2009). It was measured as electric conductivity by a glass electrode in a soil suspension. Total nitrogen content was measured by an elemental analyser Vario EL III (*Elementar*) and included in the analyses because it may integrate the long-term distribution of dung and urination, accumulated in the soil organic matter.

Since we were primarily interested in general trends of parameter responses to distance and not in the variances between the five farms, we standardised the data at the mean value per farm range. To test for significances of the bivariate correlations between the chosen parameters and distance we used a two sided Spearman rank correlation test. Please note that this rank-based nonparametric test is invariant to monotonic data transformations and thus gives the same correlation coefficients but with opposite signs for reciprocal distance.

To analyse general response patterns we fitted least square regression models to the relationships between distance as well as reciprocal distance (in both cases denoted as  $x$ ) and the response variables ( $y$ ). We used four models: linear [ $y = ax + b$ ], inverse [ $y = a/x + b$ ], exponential [ $y = a \exp(-cx) + b$ ], and

piecewise linear [ $y = ax + b$  if  $y \leq Y$ ;  $y = ax + b + c(y - Y)$  if  $y > Y$ ] where  $Y$  is  $y$  at the breakpoint. The model with the smallest value of the Bayesian information criterion (BIC) was selected (Gideon, 1978).

The observed relationships between site parameters and distance are all significant with  $p < 0.01$  (vegetation cover:  $r = 0.50$ , dung:  $r = -0.69$ , salinity:  $r = -0.62$ , nitrogen:  $r = -0.60$ ).

All parameter responses are best fitted by inverse models that indicate strong changes within the first 100 m, followed by a transition zone towards relatively invariant states (Fig. 4.1). If we use reciprocal distance as alternative predictor variable for the proxies of grazing intensity, all responses are best fitted by a linear model (Fig. 4.2). This general pattern conforms the assumption of Fernandez-Gimenez and Allen-Diaz (2001) and our theoretical considerations that grazing intensity is indeed linearly related to reciprocal distance in circular grazing hotspots. Thus, nonlinear responses in grazing effected parameters that would potentially suggest the existence of thresholds along a continuous gradient of grazing intensity cannot be detected in our data.

#### 4.4 Caveats and Conclusion

One crucial assumption of our model is the equal likelihood of the temporal distribution of animals at every distance between the centre and the edge of the range. Only if this assumption is true we should expect a linear relationship between grazing intensity and reciprocal distance. We acknowledge that our assumption in reality will never be fully valid. Distortions from such a pattern can virtually occur everywhere, but are most likely to be found directly at the centre where animals are often kept overnight for disproportionately long times and inevitably at the outermost edge of a range.

Other factors like the existence of a water body or a well at the centre of a piosphere as well as strong changes in other site conditions would also introduce confounding effects on the observed pattern. However, the linear relationships in Fig. 4.2 show that for typical semi-arid winter pastures in Azerbaijan with otherwise homogeneous site conditions the assumption is realistic. It is certainly more realistic than to assume a temporal distribution of animals that would lead to linear relationships between grazing intensity and distance.

When focussing on the effects of grazing intensity on other environmental variables in grazing gradient studies we propose to use reciprocal distance as a first proxy for relative grazing intensity. It better represents animal distribution in a circular range and often reveals linear relationships to grazing intensity. Thus, nonlinear responses of grazing-mediated parameters along distance as proxy for grazing intensity that have been interpreted as thresholds in other studies might simply be the reflection of the nonlinear relationship between grazing intensity and distance.

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# Patterns of plant species turnover along grazing gradients

Jan Peper, Florian Jansen, Dorothea Pietzsch & Michael Manthey

*Journal of Vegetation Science* (major revisions; Co-Editor Peter Adler)

## Abstract

Questions: *How are plant species distributed along grazing gradients? What is the shape of species richness patterns? Is the species turnover pattern consistent with the community concept?*

Location: *Semi-deserts in the eastern Caucasus, Azerbaijan, Gobustan district.*

Methods: *We studied the distribution of vascular plant species along transects of 900 m length perpendicular to five farms and estimated grazing intensity as current livestock units per distance. We modelled species response curves with Huismann-Olff-Fresco (HOF) models and calculated species turnover by cumulating the first derivatives of all response curves. To test for potential discontinuities in changes of vegetation composition along the grazing gradient, we developed a null model based on the individualistic continuum concept.*

Results: *Most species show a sigmoidal negative response to grazing intensity, while only few species respond with a unimodal pattern. The monotonic decrease in species richness with increasing grazing intensity marks a process of overgrazing that leads to the complete extirpation of plant species. Although the species turnover pattern shows a clear peak, it does not deviate significantly from the null model of continuous changes along the gradient and provides evidence for the range succession model.*

Conclusions: *Our approach offers a method of differentiating between transition zones and continuous shifts along ecological gradients. It also provides a valuable tool for rangeland management to test state-and-transition models and gives deeper insights into ecological processes affected by grazing.*

## Keywords:

continuum concept, Caucasus, ecological gradients, HOF-model, null model, piosphere, species richness

## 5.1 Introduction

The discussion about continuities and discontinuities in vegetation along environmental gradients is still controversial (Shipley & Keddy 1987, Austin 2005). On the one hand, the 'community-unit-concept' assumes clustered species responses and distinct transitions between species assemblages or communities along a gradient (Mueller-Dombois & Ellenberg 1974, Whittaker 1975, Allen & Hoekstra 1992). On the other hand, the continuum concept bases on individualistic species responses to environmental changes (Gleason 1926, Austin et al. 1989).

These two contrasting concepts are also of concern in rangeland ecology (Stafford Smith 1996). Here, the main question is how species composition or vegetative cover do change in space or time due to increasing grazing pressure.

To understand patterns of plant species richness and turnover along gradients of grazing intensity is crucial for rangeland management and conservation because grazing-induced shifts can influence important ecosystem functions like soil stabilisation, nitrogen fixation or fodder supply.

The range succession model (Dyksterhuis 1949, Ellison 1960) reflects the continuum approach and is based on individualistic species responses (Gleason 1926, Austin et al. 1989). It assumes that changes in vegetation due to grazing can be continuously reversed during periods of low or absent grazing pressure. On the opposite site, the state-and-transition model (Westoby et al. 1989, Briske et al. 2005) hypothesizes different resilient states or communities that can turn into another state when a threshold along the gradient is crossed (Sasaki et al. 2008). It is mainly applied in arid and semi-arid rangelands. Such transitions can be displayed in strong changes in species composition but also in strong shifts of species abundances.

There are still methodological gaps to detect transition or threshold zones in vegetation ecology, especially in rangeland ecology (Archer 1996). One approach uses compositional turnover derived by detrended-correspondence-analysis (DCA) (Sasaki et al. 2008). Regression models are applied to model the relationships between the scores of single vegetation samples along an ordination axis (one that shows strong correlation with grazing intensity) and the measured values of grazing intensity. If the minimal adequate fitting model is non-linear, thresholds are assumed. However, the ordination process strongly distorts the distances in species composition between samples, e.g. by rescaling of axes.

Discontinuities in species composition can be also detected by a split moving window approach that considers species dissimilarities between adjacent plots (e.g. Cornelius et al. 1991, Hennenberg et al. 2005, Pärn et al. 2010). However, this technique is restricted to samples that are distributed with equal distances along the gradient (Shipley et al. 1987).

A third approach is the use of species response curves to derive a pattern of species turnover such as the shape of transition between different plant assemblages (Peppler-Lisbach & Kleyer 2009). They also enable to provide information on patterns of species richness. In this study we investigate species turnover rates by following the concepts of Oksanen & Tonteri (1995) and Peppler-Lisbach & Kleyer (2009), whose analyses were based on Huisman-Olff-Fresco (HOF) species response curves (Huisman et al. 1993).

To give evidence for a discontinuity, the resulting turnover pattern has to be tested against a null-hypothesis. That is in our case an individualistic continuum shift of species along the grazing gradient. While Peppler-Lisbach & Kleyer (2009) applied a null model exclusively based on beta-response curves to detect distinct peaks of species turnover along pH-gradients, we develop this approach to be applicable for the first time also on finite gradients and regarding the different shapes of species responses. Therefore, we constructed a null model (Gotelli & McGill 2006) that uses the original species response curves but rearranges them at random along the gradient.

A problem of grazing gradient analyses is the widespread use of a biased metric to estimate grazing intensity (Manthey & Peper 2010). Here we use an alternative metric that represents grazing intensity by using a quotient of livestock numbers kept at a farm and distance of the sampled plot to the farm. This metric allows the combination of data from several grazing hotspots and is in direct proportion to other grazing indicators like dung density or livestock tracks (Manthey & Peper 2010).

Concerning these objectives, we studied grazing gradients around farms in semi-arid rangelands at the foothills of the eastern Greater Caucasus. Hence our data provide deeper insights into patterns of plant species diversity of pastoral ecosystems in this region and help to estimate the effects of intensified grazing regimes on it. Here we address three main questions:

1. How do single plant species respond along a gradient of grazing intensity?
2. Is the revealed pattern of species richness consistent with assumptions of the generalised model of the effects of grazing on grassland community structure by Milchunas et al. (1988)?
3. Does the pattern of species turnover support the community or the individualistic continuum concept?

## 5.2 Methods

### STUDY SITE

Data were collected in rangelands of the Gobustan hills in Azerbaijan at the outermost eastern part of the Greater Caucasus in May 2007. The study site is located at N 40°18' and E 49°19' with an altitude of 300 m a. s. l. The climate is continental semi-arid with wet, cool winters and dry, hot summers. Baku Airport is the meteorological station nearest to the study site. Here, average annual precipitation was 277 mm (coefficient of variation = 28 %) between the years 1955 to 1999 with peaks in November and April (Huseynov & Malikov 2009). The warmest month is July with 26.4 °C in average, while January is the coldest month with 4.2 °C.

The typical vegetation in these areas comprises semi-deserts with homogeneously distributed dwarf shrubs of the species *Artemisia lerchiana* and *Salsola ericoides*. Their canopy cover is about 15 % and their heights range between 15 and 35 cm. In between the shrubs, annuals like *Erodium cicutarium* and *Medicago minima* as well as perennials like *Poa bulbosa* are associated with an average cover of 30 %. The mean plant species richness is 28 species per 100 m<sup>2</sup>, with the main proportion of annual species (Peper et al. in press). While only some winter annuals start germinating in late autumn, most of the ephemeral species develop between March and May before they die back within a few weeks.

All of the observed sites are winter pastures with a long history of grazing, where livestock is kept between October and May at least for the last 60 years but most likely with changing intensities since the Bronze Age (Stadelbauer 1984).

Dwarf shrubs supply natural winter fodder, herbs are grazed in spring, and under unusually harsh conditions additional fodder and water are transported to the farms. Historically, additional grazing pressure was most likely caused by indigenous herbivores like Goitered Gazelles (*Gazella subgutturosa*), but the species is now under serious threat and thus of no importance regarding grazing intensity (Schmidt & Pietzsch 2007). In the study region grazing, together with disturbances by alternating dirt roads, is the only direct anthropogenic impact on land cover.

We measured vegetation at five farms with similar site conditions and limited the analyses to plains and slightly inclining lower slopes ( $< 2^\circ$ ) to minimise the influence of topography. Soil properties were also similar with pH around 8 and a substrate of clayey silt. The ranges of the farms vary between 500 and 2000 ha. Livestock consists of sheep, goats, cattle and horses. Sheep accounts for 80 % and goats for 10 %. Both are herded by shepherds in a regularly pattern within the whole farm ranges. The herds return back to the stables twice a day at noon and at night. Cattle herds are small with 10–20 heads and 1 to 5 horses or donkeys are also present on the farms. They are free ranging during the day.

The number of livestock per farm can change between the years depending on the economic situation of the owners and on forage supply. Since data on former livestock numbers were unavailable, we used recent livestock numbers and scaled them to tropical livestock units (TLU), where one TLU equals 250 kg of animal weight. In the five farms livestock units range from 249 to 547 TLU (Table 5.1).

#### SAMPLING DESIGN AND DATA COLLECTION

We established two transects of about 900 m length at each of the five farms. Therefore we choose the parts of the farm ranges showing level terrain. The angle between the two transects was larger than  $90^\circ$  in all cases. Coming from the centre of the farm we started sampling within the vegetation-free 'sacrifice zone' at a distance of 40 m. Sampling is impossible below this distance due to corrals, stables and other farm structures. We added consecutive plots at every 10-m distance until we reached the margin of the sacrifice zone. The sacrifice zones had diameters between 100 and 190 m with an average of 140 m. These additional plots sum up to a number of 29 for all farms and never exhibited any growth of vascular plant species.

At the first appearance of vascular plants a vegetation relevé was recorded and five consecutive relevés were positioned at distances of 50, 100, 200, 400 and 800 m from this plot. Larger distances were not taken into account because of overlap with neighbouring farm ranges and changes in other site conditions. We recorded all occurring vascular plant species within the plots of 100 m<sup>2</sup> (10 × 10 m). A compilation of all plant species occurring within the five farms is available in Peper et al. (in press).

**Tab. 5.1:** Characteristics of the five farm ranges analysed in Gobustan. Livestock numbers in spring of 2007 in Tropical Livestock Units (TLU) equalling 250 kg animal live weight.

Farm	Rangeland size (ha)	Livestock numbers (TLU)	Stocking density (TLU/ha)
1	1000	296	0.30
2	1500	249	0.17
3	750	547	0.73
4	500	399	0.80
5	2000	336	0.17

#### DATA ANALYSIS

Since grazing intensity is a complex parameter including all animal activities affecting a rangeland, such as trampling, defoliation, or nutrient displacement, it is frequently estimated by proxies, e.g. dung cover or track density (Lange 1969, Stumpp et al. 2005). These parameters are often correlated with distance to grazing hotspots in a non-linear way (Andrew 1988, Landsberg et al. 2004). Here we use a modified metric to estimate grazing intensity along grazing gradients according to Manthey & Peper (2010). They propose to use a quotient of the total livestock numbers at a hotspot and the distance between the hotspot's centre and the sampled plot.

The derived metric estimates grazing intensity in  $\text{TLU} \cdot \text{m}^{-1}$  and regards the non-linear pattern between distance and grazing intensity. At our analysed farms, the metric is well correlated with nitrogen content, electric conductivity, dung density and trampling in a linear way at each single farm and in the pooled data (Manthey & Peper 2010).

We pooled all data from the five farms due to the small number of plots per farm. We are aware that this combination might be problematic, because site conditions, grazing histories and livestock assemblages may differ between the hotspots. Nevertheless, our approach is supported by the facts that (i) 59 % of all analysed species occurred at all farms (among them all dwarf-shrub species and the dominant annuals), (ii) only eight analysed species are restricted to less than four farms, (iii) the complete data set was recorded within one week, (iv) sheep constitute the main proportion of all animals at each farm, and (v) the systems of range management are similar.

Species responses on grazing were analysed in previous studies using different approaches that often enable only a classification into 'increaser' and 'decreaser' species (e.g. Vesik & Westoby 2001). However, a species with a unimodal response curve can therefore belong to both classes depending on the observed position and length of the gradient. Landsberg et al. (2003) used simple regression models to obtain response curves of plant species along 15-km transects in Australian rangelands. Another approach was applied by Brooks et al. (2006), who used

generalised linear mixed models to specify the behaviour of native and invasive species near watering points. Other possibilities are Gaussian response curves, generalised additive models or beta response models (Lawesson & Oksanen 2002, Oksanen & Minchin 2002).

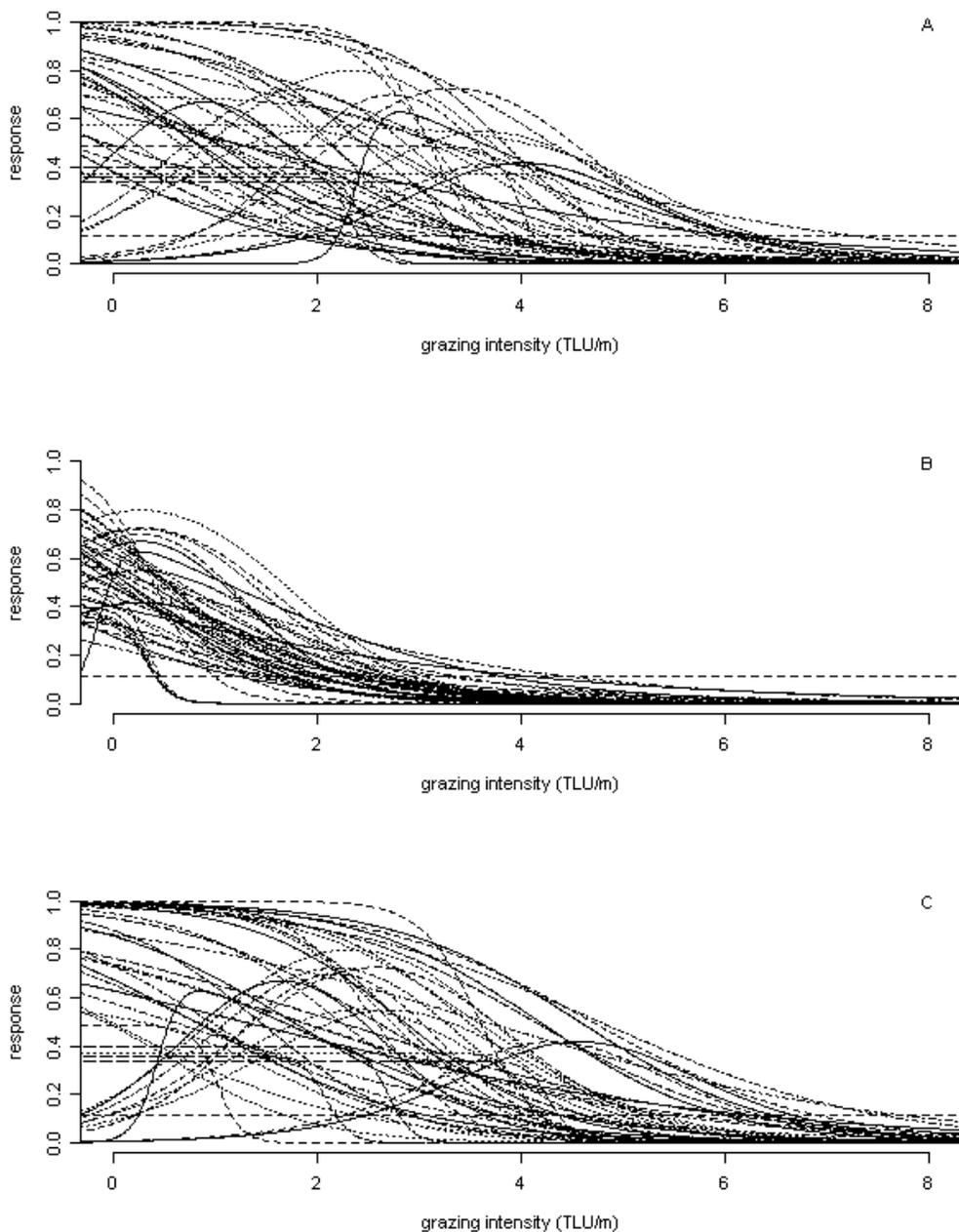
In this study we apply Huisman-Olff-Fresco (HOF) models (Huisman et al. 1993) that provide a set of five hierarchical models constituting ecologically well interpretable response patterns (cf. Oksanen & Tonteri 1995, Peppler-Lisbach & Kleyer 2009). The five hierarchical HOF models of increasing complexity are (I) no trend, (II) monotone sigmoid with a top at maximal abundance, (III) monotone sigmoid with a plateau below the maximal upper abundance value, (IV) a unimodal symmetric model and (V) a unimodal skewed model.

Species showing type I responses are indifferent to grazing. Species of type II and III can be either grazing averse with a plateau at low grazing intensity or strongly promoted by grazing with a plateau at high grazing intensities. The difference between both models is that species of type III show a lower frequency at the optimum than type II species that are abundant in almost all plots around the optima. Species with unimodal curves (type IV) are promoted by low grazing intensities but are not able to withstand a strong grazing impact. A modification are type V curves that mark a threshold with an abrupt abandonment of the species either towards stronger or lower grazing intensities.

HOF curves were fitted to species presence/absence data and grazing intensity as explaining variable using the package `vegdata.dev` (<http://geobot.botanik.uni-greifswald.de/download>, version 0.0.20) for the statistical computing environment R (R Development Core Team 2010) written by the second author. Only species with a minimum plot frequency of 10 have been included in the analysis. The original five HOF models were fitted with maximum likelihood estimation and binomial distribution family (log link function). For model selection Bayesian information criterion (BIC, Gideon 1978) was used. Besides estimated model parameters, we extracted the optimum location of all unimodal species as well as the location of the upper niche borders. For the latter we used the definition of Heegaard (2002) that the niche border is the point at the gradient where the response curve is  $e^{-0.5}$  times lower than the maximal probability of occurrence found within the gradient.

We used two approaches to predict species richness along the grazing gradient. The pattern of richness for all species occurrences was modelled by a generalised additive model (GAM, Hastie & Tibshirani 1987). For frequent species we additionally calculated the species richness pattern following the approach of Peppler-Lisbach & Kleyer (2009) by using the sum of predicted occurrence probabilities from the HOF models of the species.

The total species turnover rate at a certain point of the gradient can be calculated as the sum of absolute slopes of all modelled species responses predicted at that point (Oksanen & Tonteri 1995). Therefore, the first derivative of each species response curve was calculated, its absolute value at every 0.005 gradient step was arc tangent transformed and values of all species were summed



**Fig. 5.1:** Steps to simulate a turnover pattern according to the individualistic continuum concept.  
 A: Original distribution of HOF-curves along the gradient of grazing intensity.  
 B: Response curves with optima (types IV & V) or upper niche border (types II & III) shifted to zero.  
 C: Randomly distributed HOF-curves with upper niches between the theoretically lowest possible upper niche border and the maximum upper niche border of the original data.

up. Arc tangent transformation down-weights the influence of species with very steep slopes and measures turnover rates in radians (Peppler-Lisbach & Kleyer 2009).

#### TESTING FOR DISCONTINUITIES

The turnover pattern at the transition between two communities should show values exceeding the expected stochastic deviance of a null model of continuous change in species composition (Gotelli & McGill 2006) as assumed by the individualistic continuum concept. Here, we developed a null model that uses the original shape (model type, slope, and maximum response) of the response curves (Fig. 5.1A) but introduces random variation of the position of the curves along the gradient.

**Tab. 5.2:** Number of species showing certain HOF-model types. For detailed graphs and parameters see supporting information!

Model type	I	II	III	IV	V	total
all species	1	26	7	9	1	44
Annual forbs	1	17	4	6	1	29
Annual grasses		4	2	1		7
Perennial forbs and grasses		3	1	1		5
Dwarf-shrubs		2		1		3

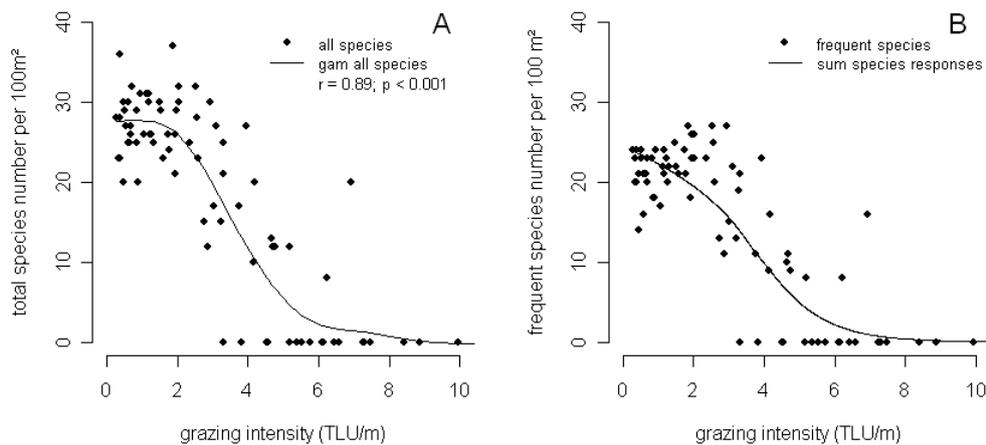
In a first step we equalised the original distribution of response curves by shifting type II & III curves with their upper niche borders to an arbitrary point outside the observed gradient, in our case 0 TLU\*m<sup>-1</sup> (Fig. 5.1B). To conserve the original model type ratios in the simulations, unimodal models (types IV & V) were only shifted until their optima reached zero, because they would turn into sigmoidal curves (type II or III) if only the decreasing part remains in the investigated range. Since all species showed either unimodal or decreasing responses along the gradient of increasing grazing intensity it was suitable to sort all species to one side of the gradient. In cases with increasing and decreasing responses, the decreasers have to shift towards the lower side and the increasers towards the upper side.

The next step was to randomly shift each species curve along the gradient, with the restriction that its upper niche border does not exceed the maximal upper niche border found within the original data (5.36 TLU\*m<sup>-1</sup>) (Fig. 5.1C). At the lower end of the gradient, the upper niche borders or optima respectively were not allowed to fall below a point where theoretically the lowest upper niche border of a species could be located. This point is calculated using a HOF-model of a dummy species that exclusively occurs in the lowest 10 observation values along the gradient. Its upper niche border is calculated at 0.55 TLU\*m<sup>-1</sup>.

We permuted the random allocation of species response curves 1000 times and calculated the mean species turnover and a 95 % confidence interval for each point in steps of 0.005 TLU\*m<sup>-1</sup> along the gradient. The existence of a transition indicating an abrupt change between two plant communities is rejected if the observed turnover pattern is inside the 95 % confidence interval of the null model.

### 5.3 Results

We recorded a total of 117 vascular plant species in 59 vegetation plots. Annuals were predominant, with 96 species, while dwarf shrubs were present with six species. The remaining 15 species were perennial forbs and grasses. Thirty-five species occurred in only one or two plots, while 44 species were present in at least ten plots and were therefore involved in the analyses. Plot species richness ranged from 8 to 37 per plot except for the plots in the sacrifice zone with zero species. Among farms average species numbers varied between 22 and 30 per 100 m<sup>2</sup>.



**Fig. 5.2:** A: Number of all species per plots of 100 m<sup>2</sup> in relation to grazing intensity and fitted generalised additive model  
 B: Number of species occurring in at least 10 plots in relation to grazing intensity and the sum of probabilities of species occurrences derived from HOF-models.

All but one of the 44 analysed species show a response to grazing intensity (Table 5.2 and Supporting Information Figure SA1 and Table SA1). The most common responses of annuals as well as perennials belong to type II or type III (i.e. monotonically decreasing). The remaining ten species respond in a unimodal pattern with optima ranging between 1.2 for *Neotorularia contortuplicata*, a widespread annual herb, and 4.3 TLU\*m<sup>-1</sup> for *Sclerochloa dura*, a trampling-resistant grass. *Sisymbrium irio* is the only species with a skewed response and shows a sharp transition towards moderate grazing and a slow decrease under stronger grazing. The small clover species *Amoria retusa* does not significantly respond to grazing (type I).

The GAM model for species richness (considering all species) shows a plateau at low grazing intensities with about 28 species per 100 m<sup>2</sup> between 0.3 and 1.5 TLU\*m<sup>-1</sup> before it declines to zero at 8 TLU\*m<sup>-1</sup> (Fig. 5.2 A). Modelled richness calculated from the response curves of frequent species underestimates total species richness as expected (Fig. 5.2 B). Nevertheless, it shows the same trend as the GAM for all species but without a clear plateau at low grazing intensities. Both modelled richness patterns are strongly correlated ( $R^2 = 0.992$ ,  $p < .001$ ).

The total turnover rate shows a clear peak around 3 TLU\*m<sup>-1</sup> before it declines to zero at 10 TLU\*m<sup>-1</sup> (Fig. 5.3). It is in all parts within the confidence interval of the null model, which also shows a clear peaked pattern and turns towards zero at 10 TLU\*m<sup>-1</sup>.

## 5.4 Discussion

### PATTERNS OF SPECIES RESPONSES

In contrast to typical gradient analyses in vegetation ecology, where the length of environmental gradients is restricted to established vegetation, the upper end of the grazing gradient in our study exceeds the tolerance threshold of all plants of the regional species pool. The zones of highest grazing intensity are near the farm centres, where trampling pressure by the bulked livestock during night and noon is so strong that no vascular plant is able to resist. As a result, each species disappears at its species-specific grazing intensity so that almost

all show clear response patterns. However, such patterns also occur along other finite environmental gradients like elevation or water depth, in alpine and aquatic ecosystems respectively.

The length of the investigated grazing gradient covers nearly the whole spectrum of existing grazing intensity in Gobustan, where the farms are relatively evenly distributed with average distances of 2 to 3 km. Considering the great range of grazing intensities, it seems unusual that the majority of species (approx. 70 %) show monotonic responses (type II & III) and not unimodal ones such as can be expected at long gradients (Rydgren et al. 2003). All these species are negatively affected by strong grazing pressure. Nevertheless, we think that for most species with monotonic responses the ecological behaviour is realistically modelled and would not change into unimodal curves if the gradient is extended to completely ungrazed sites. This implies also a similar species assemblage under low grazing around all studied farms. Indeed, nearly all widespread species like *Erodium cicutarium*, *Artemisia lerchiana* and *Salsola ericoides* also grow on the few remote sites in Gobustan that are not influenced by grazing, and potentially belong to the climax vegetation of this semi-arid region.

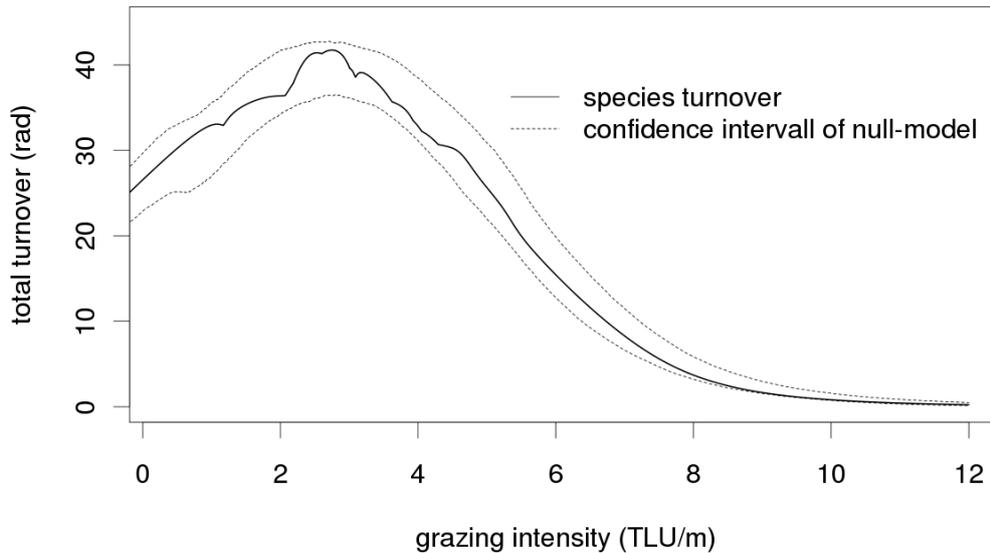
A complete absence of grazing at large temporal and spatial scales is only hypothetical in the study area because today's livestock has replaced the grazing of large herds of Goitered Gazelle (Schmidt & Pietzsch 2007). However, in the nearby Shirvan National Park, grazing by gazelles shows much smaller impacts on vegetation than livestock grazing. It is also mainly restricted to sites with lots of palatable species.

Every species has its own upper niche border and rate of decline towards higher grazing intensities, indicating its individualistic potential to withstand grazing pressure. Regional rangeland management must consider this to avoid a reduction in fodder quality and quantity.

A small group of species responds in a unimodal way and is thus promoted by grazing. In contrast to other studies (Milchunas & Lauenroth 1993, Pakeman 2004) the ratio of annual to perennial species in the grazing-promoted group is not higher than in the group of monotonic decreaseers, which might be a result of the general dominance of annual species in the semi-arid survey area. Most of the species with unimodal responses are unpalatable weeds less consumed by livestock (Guliev 1968) and possibly promoted by higher nutrient availability due to urine and faeces near the corrals. They sometimes form dense stands and can thus outcompete common rangeland species but are themselves destroyed by trampling under higher grazing intensities.

#### PATTERNS OF SPECIES RICHNESS

The pattern of declining species richness along the grazing gradient (Fig. 5.2) supports the generalised model on grazing effects by Milchunas et al. (1988) that predicts such patterns for rangelands with low productivity or moisture and a long evolutionary history of grazing (Cingolani et al. 2005). In contrast to Milchunas et al. (1988), we included extremely high grazing intensities in our study, resulting in a complete loss of species. The high correlation between the



**Fig. 5.3:** Turnover rate in radians calculated by the cumulated arc tangent transformed slope angles of species response curves and null model with 95 % confidence interval along the grazing gradient.

GAM of the full dataset and the HOF-modelled species richness ( $R^2 = 0.992$ ) and the analogous monotonic decline towards zero show that frequent species drive the patterns of species richness. This justifies the calculation of species turnover by using only the frequent species.

The number of grazing promoted species is lower than the number of extirpating species. Thus, no hump shaped pattern of species richness can occur. Therefore, an increasing number of livestock in the semi-arid rangelands of Gobustan will most likely reduce the number of species. This is especially of interest for nature conservation with a focus on species diversity.

#### PATTERNS OF SPECIES TURNOVER

At first sight, the observed pattern seems to give strong evidence for a discontinuity in species turnover at the peak around 3  $\text{TLU} \cdot \text{m}^{-1}$  (Fig. 5.3). This peak would indeed exceed the confidence interval of a simple null model based on individualistic distributed Gaussian response curves (models IV & V, not shown here) that might be applicable for gradient segments without finite ends (Peppler-Lisbach & Kleyer 2009). However, on the upper side of the gradient the finiteness of species occurrences towards high grazing intensities must inevitably result in decreasing turnover.

The relatively small turnover at the lower gradient might be caused by two circumstances. First, species with plateau shaped response curves show almost no changes in this section of the gradient. Second, rare and strongly grazing intolerant species are not included in the calculations. They would probably increase the turnover to some extent in the lower gradient section. Together these properties can lead to the observed turnover peak at intermediate grazing intensity. To avoid false conclusions we incorporated these properties in the null model by using the shapes of the original response curves and by keeping the ratio between monotonic and unimodal curves constant in the simulations with random species positions along the gradient.

In consequence, the null model is dominated by monotonic curves and shows a hump-shaped turnover pattern. The original turnover pattern is within the 95 % confidence interval of the null model and suggests an individualistic continuum distribution of species along grazing gradients in Gobustan. Regarding only species composition, in the study area the range succession concept of Dyksterhuis (1949) seems to be a more appropriate consideration for rangeland management than the state-and-transition model (Westoby et al. 1989), which would expect a zone of strong transition between two communities. Our approach can be expanded on species abundance data and take regard to strong changes in the abundance of dominant species that are important for rangeland health. However, this would inevitably marginalise the importance of species with low abundances but with probably high ecological indication potential.

Our results indicate that species differ individualistically in palatability and resistance against grazing pressure including trampling and defoliation. The probability of abrupt and not reversible shifts in rangeland conditions due to an increasing number of livestock is therefore low. Nevertheless, thresholds might occur under the influence of discontinuously distributed co-variables (e.g. nutrient concentration or water supply) with strong effects on species occurrences, in areas with another climate or with different grazing history.

It is also obvious that most species are not promoted by livestock grazing in the region. However, when including sites with long-time grazing abandonment, some of the monotonic responding species might change to unimodal responding ones indicating a preferential of low grazing pressure. Such low grazing pressures might equal the potential natural grazing impact of the gazelles.

### **5.5 Conclusion**

The use of HOF-models in combination with the applied measure of grazing intensity is an appropriate tool to describe species responses and patterns of species turnover along grazing gradients for purposes of rangeland management and ecology. Our presented null model approach – which includes decreasing species richness along finite gradients and the original ratio of different niche model types – provides an alternative test for discontinuities in species turnover along restricted and unrestricted environmental gradients.

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## Supporting information to chapter 5

**Tab.SA1:** Species that occur in at least 10 of 59 plots along grazing gradients in Gobustan (Eastern Caucasus; Azerbaijan) and parameters of response patterns along the grazing gradients calculated by HOF-models.TLU\*m<sup>-1</sup> = Tropical Livestock Units per distance to a farm's centre in metres. For graphs see Fig. SA1.

species name	abbreviation	model type	HOF-model parameters				upper niche boundary (TLU*m <sup>-1</sup> )	optimum
			a	b	c	d		
annual forbs								
<i>Alyssum turkestanicum</i>	ALYUTUR	II	-1.71	12.01	.	.	1.92	.
<i>Amoria retusa</i>	AMORRET	I	2.05	.	.	.	.	.
<i>Arenaria serpyllifolia</i>	ARENSER	II	-0.85	10.11	.	.	1.64	.
<i>Astragalus asterias</i>	ASTGAST	II	-0.83	9.24	.	.	1.75	.
<i>Astragalus tribuloides</i>	ASTGTRI	II	0.15	11.84	.	.	1.08	.
<i>Bupleurum gerardii</i>	BUPLGER	II	-1.06	15.82	.	.	1.23	.
<i>Capsella bursa-pastoris</i>	CAPSBUR	IV	-6.57	17.12	3.06	.	4.97	3.62
<i>Carduus cinereus</i>	CARUCIN	III	-39.10	100	0.52	.	4.87	.
<i>Clypeola jonthlaspi</i>	CLYPION	II	-0.87	16.22	.	.	1.13	.
<i>Erodium cicutarium</i>	ERODCIU	II	-6.41	19.86	.	.	3.86	.
<i>Erysimum repandum</i>	ERYSREP	II	0.49	10.76	.	.	1.07	.
<i>Filago pyramidata</i>	FILGPYR	II	-7.56	28.72	.	.	3.23	.
<i>Helianthemum salicifolium</i>	HELISAL	II	-3.66	20.43	.	.	2.19	.
<i>Herniaria hirsuta</i>	HERNHIR	II	-0.68	6.71	.	.	2.18	.
<i>Lagoseris glaucescens</i>	LAGRGLA	II	-3.38	16.44	.	.	2.47	.
<i>Lepidium perfoliatum</i>	LEPIPER	II	-0.48	4.87	.	.	2.70	.
<i>Lepidium ruderale</i>	LEPIRUD	IV	-5.44	15.23	4.24	.	2.86	4.05
<i>Malva iljinii</i>	MALVILJ	II	-0.23	13.66	.	.	1.06	.
<i>Medicago minima</i>	MEDCMIN	II	-2.38	8.78	.	.	3.20	.
<i>Medicago rigidula</i>	MEDCRIG	II	0.04	6.31	.	.	1.83	.
<i>Neotorularia contortuplicata</i>	NEOTCON	IV	0.08	-21.18	-3.10	.	2.20	1.17
<i>Plantago coronopus</i>	PLANCOO	III	-33.59	100	0.06	.	4.22	.
<i>Plantago ovata</i>	PLANOVA	IV	-3.48	15.07	1.36	.	3.48	2.19
<i>Rochelia disperma</i>	ROCHDIS	II	0.67	6.41	.	.	1.55	.
<i>Sedum caespitosum</i>	SEDUCAE	III	-20.79	100	0.57	.	2.70	.
<i>Sisymbrium irio</i>	SISMIRI	V	-2.74	8.98	20.25	100	4.54	3.09
<i>Sisymbrium runcinatum</i>	SISMRUN	IV	-6.73	22.17	3.45	.	4.02	3.01
<i>Trigonella monspessulana</i>	TRINMOS	III	-5.47	17.23	-0.83	.	3.76	.
<i>Veronica polita</i>	VEROPOL	IV	-4.53	18.51	1.05	.	3.31	2.07
annual grasses								
<i>Anisantha rubens</i>	ANISRUB	II	-2.53	11.47	.	.	2.64	.
<i>Bromus japonicus</i>	BROUJAP	II	-0.88	12.83	.	.	1.36	.
<i>Eremopyrum triticeum</i>	EREYTRI	II	0.28	6.39	.	.	1.69	.
<i>Hordeum leporinum</i>	HORELEP	III	-7.67	16.92	-0.30	.	5.36	.
<i>Lolium rigidum</i>	LOLURIG	II	-1.63	5.96	.	.	3.47	.
<i>Rostraria glabriflora</i>	ROSTGLA	III	-19.42	100	0.40	.	2.54	.
<i>Sclerochloa dura</i>	SCLOUDUR	IV	-5.60	14.76	4.38	.	3.06	4.30
perennial forbs and grasses								
<i>Allium rubellum</i>	ALLURUB	II	-1.40	11.03	.	.	1.84	.
<i>Malva neglecta</i>	MALVNEG	IV	-5.48	14.42	3.38	.	5.28	3.93
<i>Poa bulbosa</i>	POA.BUL	II	-4.57	12.61	.	.	4.20	.
<i>Ranunculus oxyspermus</i>	RANUOXY	III	-27.57	100	0.66	.	3.50	.
<i>Scorzonera laciniata</i>	SCOZLAI	II	-1.13	13.36	.	.	1.43	.
dwarf shrubs								
<i>Artemisia lerchiana</i>	ARTELER	II	-10.77	41.28	.	.	3.25	.
<i>Salsola dendroides</i>	SALSDEN	IV	-5.66	18.04	1.40	.	4.03	2.60
<i>Salsola ericoides</i>	SALSERI	II	-2.74	15.55	.	.	2.16	.

**Fig. SA1:** Response patterns (HOF-curves) of frequent species (at least 10 of 59 plots) along grazing gradients in Gobustan (Eastern Caucasus; Azerbaijan).

For parameters and species names see Tab. SA1. Filled dots = species occurrences, open dots = plots without species; model types are indicated by colours: black (I), red (II), green (III), dark blue (IV), bright blue (V).

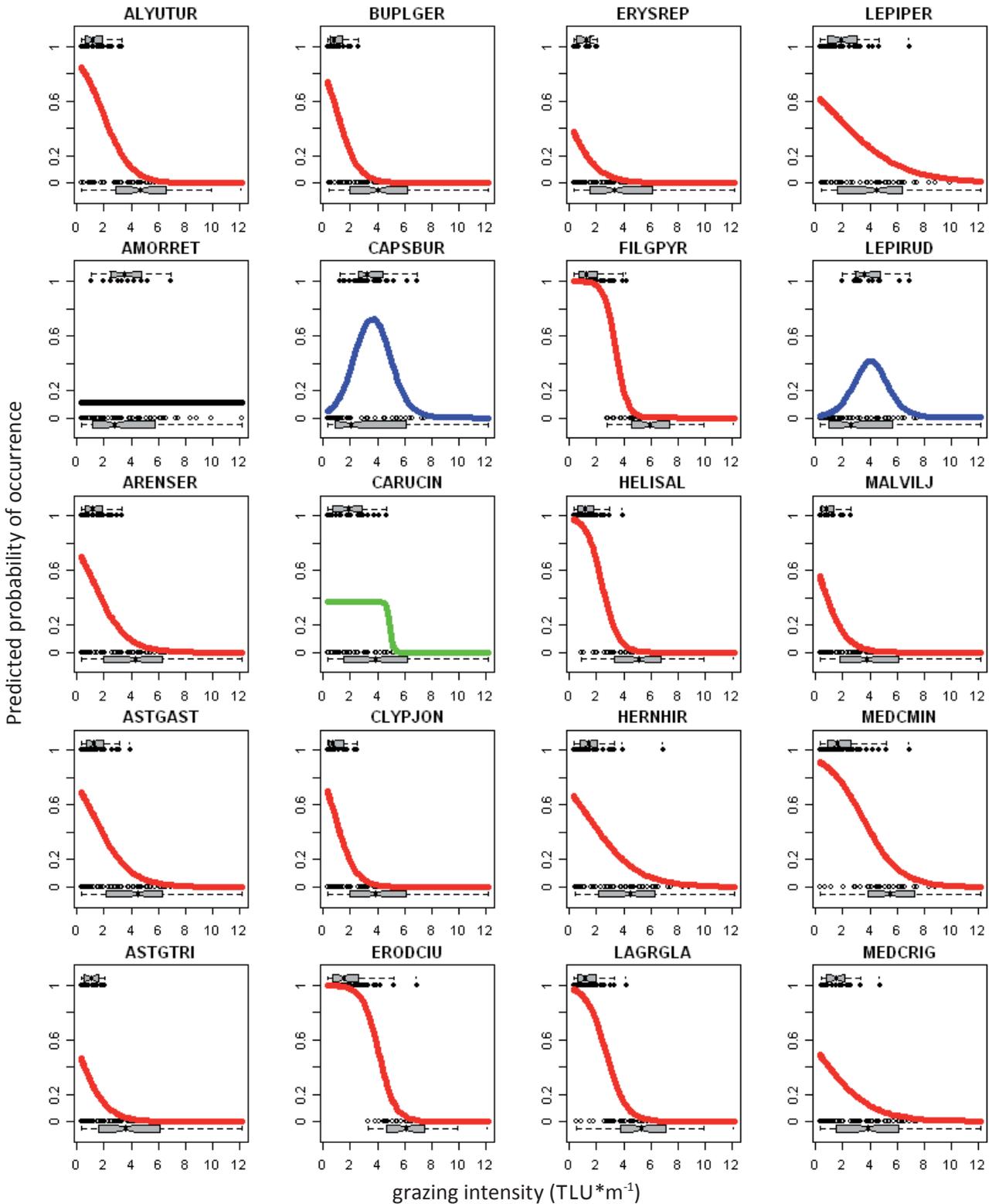
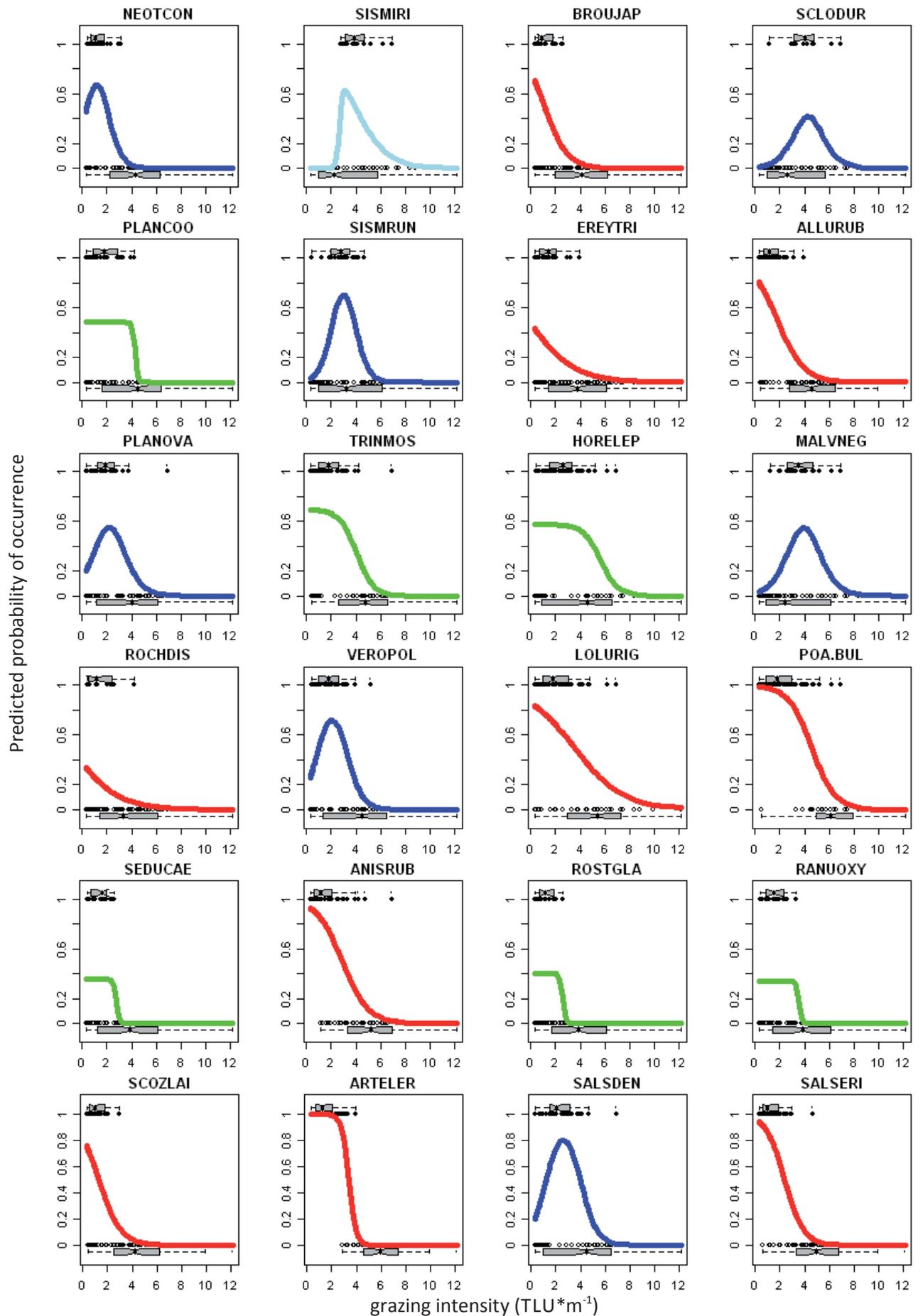


Fig. SA1: continued





# Summary

This dissertation evaluates the effects of site conditions and livestock grazing on the vegetation of Azerbaijan's winter pastures. We improved methods to estimate grazing intensity in vast rangelands and enhanced an approach to detect discontinuities in vegetation changes along environmental gradients. All analyses use field data from the semi-arid rangelands of Gobustan and Jeiranchel, at the foothills of the Greater Caucasus mountains. The data set comprises 313 vegetation relevés, each sized 100 m<sup>2</sup>, based on a pre-stratification using topographical parameters. Additionally, we included data from farm transects and enclosure experiments. For each plot, selected site and soil variables were determined.

## VEGETATION AND SITE CONDITIONS

By means of cluster analysis, we derived 16 vegetation types with a total of 272 vascular plant species. Our vegetation classification, which is closely linked to site conditions, is an important groundwork for adapted rangeland management and monitoring. The study areas are dominated by semi-deserts with a high coverage of dwarf shrubs, and the mean number of vascular plant species was found to be about 28 per 100 m<sup>2</sup>.

According to ordination analysis (NMDS), species composition changes primarily along the altitudinal gradient, gradually proceeding from the *Salsola nodulosa* semi-deserts of the lowest parts (below 300 m a.s.l.) to the *Salsola ericoides* and *Artemisia lerchiana* semi-deserts of the upper regions (300–650 m a.s.l.). Soil salinity and carbonate concentration decrease as altitude increases.

A second gradient reflects grazing intensity. One plant community that is typically found on intensively grazed sites in the vicinity of farmyards stands apart from the rest, which are subject to lower grazing and trampling pressures. A third factor that differentiates plant communities is the sand concentration of the soils. Additionally, communities that occur on steep slopes differ from communities that occur on level terrain.

## EXCLOSURE EXPERIMENTS

Exclosure experiments revealed that short-time abandonment of grazing leads to an increase in the number of annual species, in vegetation coverage, and in the heights of forbs and grasses. Clipping experiments indicated that the herbaceous species show hardly any compensatory growth in response to grazing.

## ESTIMATING GRAZING INTENSITY

A recurrent theoretical problem in rangeland research is the spatial modelling of grazing intensity around grazing hotspots like farms or watering places, the so called piospheres. In a widely used approach, grazing intensity is assumed to decrease in direct proportion to the distance from a hotspot. The resulting response patterns, which relate characteristics of the vegetation or site condi-

tions to grazing intensity, are often nonlinear, and have been interpreted as indicating threshold changes or different state-and-transitions along grazing gradients.

However, we show that these 'thresholds' are usually geometrical artefacts. Taking into account the concentric structure of grazing hotspots, we suggest a new approach that approximates grazing intensity as the ratio of the total number of livestock kept at the farm to the distance between a given plot and the hotspot centre. Our approach is a simple yet significant improvement over current approaches because it enables us to merge or compare data from different sampling sites and because the approximation is in direct proportion to other grazing indicators like dung density or soil salinity.

#### SPECIES TURNOVER PATTERNS

Combining our new grazing pressure model with species presence/absence data, we modelled vascular plant species responses, patterns of species richness and species turnover along grazing gradients on farm transects in Gobustan. The derived typical species response pattern along the finite grazing gradient is a sigmoid decrease. Species richness declines monotonically with increasing grazing intensity and thus conforms to generally acknowledged assumptions on the relationship between species richness and grazing pressure in semi-arid rangelands.

Species turnover along the gradient was calculated using the slopes of species response curves. At first sight, the resulting pattern gives evidence for a discontinuous change. However, it ranges within the 95 % confidence interval of a null model based on assumptions of the individualistic continuum concept. Thus, species composition seems to change continuously along grazing gradients in Gobustan. This new null model approach can probably be adapted and applied to all ecological gradients and is useful for the validation of individual-continuum or community concepts.

#### PRACTICAL RECOMMENDATIONS

Based on the results of our research, we formulate a catalogue of recommendations for proper rangeland management and conservation in the study area. The most important ones are: (1) Rotational grazing regimes should be also applied between March and May. (2) Grassland around farms should be mown to produce litter. (3) In areas threatened by erosion, grazing should be abandoned. In combination, these measures can help to improve the productivity as well as the species richness of the Gobustan and Jeiranchel rangelands under the precondition that livestock numbers do not increase.

# Zusammenfassung

Deutscher Titel der Arbeit: *Vegetation der Halbwüsten am Fuß des Großen Kaukasus in Aserbaidschan: Einflüsse von Standortfaktoren und Beweidung*

In der Dissertation werden die Einflüsse von Standort und Beweidung auf die Vegetation der Winterweiden Aserbaidschans untersucht. Dabei wurde eine Methode zur Abschätzung von Beweidungsintensität verbessert und ein Ansatz weiterentwickelt, mit dessen Hilfe abrupte Änderungen in der Artenzusammensetzung entlang ökologischer Gradienten nachgewiesen werden können.

Der zugrunde liegende Datensatz wurde in den semiariden Weidegebieten Gobustan und Cheiranchöl am Fuß des Großen Kaukasus erhoben. Er umfasst 313 Vegetationsaufnahmen von je 100 m<sup>2</sup> Fläche, die zufällig über das vorher in topographische Strata aufgeteilte Gebiet gelegt wurden. Zusätzlich wurden noch Zäunungsexperimente und Transektanalysen an Hofstellen durchgeführt, sowie für jede Aufnahme ausgewählte Standorts- und Bodenparameter bestimmt.

## VEGETATION UND STANDORTFAKTOREN

Eine Clusteranalyse ergab 16 Vegetationstypen, in denen insgesamt 272 Gefäßpflanzenarten vorkommen. Diese Klassifikation ist eine wichtige Grundlage für Langzeitstudien und für die Optimierung der Beweidungspraxis. In der Region dominieren Halbwüsten mit einem vorherrschenden Anteil von Zwergsträuchern an der Gesamtdeckung und einer mittleren Anzahl von 28 Pflanzenarten auf 100 m<sup>2</sup>. Ordinationsanalysen (NMDS) zeigen, dass sich die Artenzusammensetzung in erster Linie entlang eines Höhengradienten verändert.

So finden sich *Salsola nodulosa*-Halbwüsten bis 300 m ü. NN, die mit zunehmender Höhe in *Salsola ericoides*- und *Artemisia lerchiana*-Halbwüsten bei 300–650 m ü. NN übergehen. Entlang dieses Gradienten nehmen auch die Salz- und Carbonatgehalte der Böden ab. Der zweite Gradient trennt einen stark beweideten Vegetationstyp in der Nähe der Hofstellen von allen anderen geringer beanspruchten und weniger durch Tritt gestörten Typen ab. Ein dritter Gradient verdeutlicht Unterschiede, welche mit höheren Sandanteilen im Boden einhergehen. Außerdem unterscheidet sich die Vegetation hinsichtlich der Hangneigung.

## ZÄUNUNGSEXPERIMENTE

Der kurzzeitige Ausschluss von Weidetieren im Frühjahr bewirkt die Zunahme einjähriger Pflanzenarten, der Vegetationsbedeckung und der Höhe der krautigen Pflanzen. Das Mahdexperiment in Gattern ergab, dass Kräuter und Gräser kaum mit Kompensationswachstum auf Verbiss reagieren.

## ABSCHÄTZUNG VON BEWEIDUNGSINTENSITÄT

Ein verbreitetes theoretisches Problem in der Weideforschung ist die räumliche Abschätzung von Beweidungsintensität um sogenannte Piosphären-Hotspots. Das sind z.B. Wasserstellen oder einzelne Höfe in ausgedehnten Weidegebieten. Der am häufigsten verwendete Ansatz geht davon aus, dass der Beweidungs-

druck proportional mit der Entfernung zum Hof abnimmt. Daraus ergeben sich aber fast immer nicht-lineare Beziehungen zwischen Standortparametern oder Artenwechsel und Beweidungsintensität. Diese Muster wurden bisher als durch Beweidung verursachte abrupte Grenzen interpretiert.

Der hier vorgestellte Ansatz zeigt jedoch, dass es sich dabei meist um geometrische Artefakte handelt. Es wird vorgeschlagen, Beweidungsintensität als Quotient aus der Anzahl an Tieren in einer Piosphäre und dem Abstand des betrachteten Punktes zum Zentrum zu messen. Damit wird die konzentrische Form von Piosphären berücksichtigt und der ermittelte Quotient verhält sich zumeist direkt proportional zu anderen Beweidungsindikatoren wie Dungkonzentration oder Salzgehalt.

#### MUSTER DES ARTENWECHSELS

Die Reaktionsmuster von Pflanzenarten, Artenzahl und Artenwechsel (»turnover«) auf zunehmende Beweidungsintensität wurde entlang von fünf Transekten in Gobustan ermittelt. Es zeigte sich, dass die Vorkommenswahrscheinlichkeit für fast alle Pflanzenarten mit zunehmender Beweidung monoton-sigmoid abfällt. Dadurch nimmt auch die Gesamtartenzahl stetig ab.

Aus den Anstiegen der einzelnen Reaktionskurven der Pflanzenarten wurde das Muster des Artenwandels ermittelt. Auf den ersten Blick scheint ein deutlicher Grenzbereich hervorzutreten, in dem sich die Artenzusammensetzung sehr stark ändert. Dennoch liegt das Ergebnis im Konfidenzintervall eines speziell entwickelten Nullmodells, welches die Annahmen des Kontinuumskonzepts widerspiegelt. Demzufolge vollzieht sich der Artenwandel entlang der Beweidungsgradienten kontinuierlich. Das neue Nullmodell ist in modifizierter Form auf andere ökologische Gradienten übertragbar, wodurch Hypothesen zum Kontinuumkonzept oder zu abrupten Wechseln der Vegetation entlang von Gradienten getestet werden können.

#### PRAKTISCHE EMPFEHLUNGEN

Auf der Grundlage dieser Ergebnisse wurde ein Katalog mit Maßnahmen für eine angepasste Bewirtschaftung der Winterweiden Aserbaidshans zusammengestellt. Die wichtigsten sind: (1) Einführung einer Umtriebsweide im Frühjahr, (2) Mahd im näheren Umkreis der Höfe zur Einstreugewinnung, und (3) Aufgabe von Beweidung auf besonders erosionsgefährdeten Standorten. Durch eine Kombination dieser Maßnahmen könnte vermutlich die Produktivität und Artenvielfalt der Gebiete erhöht werden. Voraussetzung wäre allerdings der Verzicht auf eine weitere Erhöhung der Viehbestände.

# Danksagung

Ich danke allen, die mich bei der Vorbereitung und Erarbeitung der Studien sowohl in Aserbaidschan als auch in Deutschland unterstützt haben. Besonders gilt dies für Dorothea Pietzsch, Marlén Schönfeld und Sebastian Olschewski, die mich zwischen 2007 und 2009 bei der Feldforschung in Gobustan und der Cheiranchel begleiteten.

Michael Manthey hat mir als Betreuer Freiräume bei der Erarbeitung der Themen gelassen und war mir als Co-Autor eine unschätzbare Hilfe. Der Sommerweidenexperte Jonathan Etzold hat mich in allen Phasen der Arbeit unterstützt und mit seinem goldenen Händchen so manche Kostbarkeit der regionalen wissenschaftlichen Literatur zu Tage gefördert. Michael Rühs hat als Koordinator das Projekt sicher und unerschütterlich durch den rauen Alltag gelenkt.

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Ohne die Finanzierung der Volkswagen Stiftung hätte es das Projekt im Rahmen der Initiative »Between Europe and the Orient – Middle Asia/Caucasus in the focus of science« nicht gegeben. Schon im Vorfeld ermöglichte mir die Michael-Succow-Stiftung erste Erfahrungen in Gobustan und der Cheiranchöl zu sammeln, und DUENE e.V. leistete technische Unterstützung im Projektverlauf.

Zum Schluss gilt mein Dank und Gedenken Martin Uppenbrink, der mit seinen Visionen anregende Impulse für das Projekt gab. Leider kann er den Abschluss unserer Arbeiten nicht mehr miterleben.

# Auszeichnungen

2009 1. Nachwuchsförderpreis der Floristisch-Soziologischen Arbeitsgruppe  
für den Artikel: Peper, J. 2008. Struktur und Artenzusammensetzung  
beweideter Auenwälder entlang der Kura in Aserbaidshan (Kaukasus).  
*Tuexenia* 28: 103–120.

# Eigene Publikationen

## ERST-AUTOR

- Peper, J., Jansen, F., Pietzsch, D. & Manthey, M. Patterns of plant species turnover along grazing gradients. *Journal of Vegetation Science*. major revisions.
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## KO-AUTOR

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## IN BEARBEITUNG

- Peper, J., Oldeland, J., Neudert, R., Hartleib, J. & Manthey, M. Assessing spatial and temporal overgrazing in semi-arid rangelands. in preparation

# Eidesstattliche Erklärung

Hiermit erkläre ich, dass diese Arbeit bisher von mir weder an der Mathematisch-Naturwissenschaftlichen Fakultät der Ernst-Moritz-Arndt-Universität Greifswald noch einer anderen wissenschaftlichen Einrichtung zum Zwecke der Promotion eingereicht wurde.

Ferner erkläre ich, dass ich diese Arbeit selbständig verfaßt und keine anderen als die darin angegebenen Hilfsmittel benutzt habe.

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