Carrying capacity and forage competition between livestock and a small mammal, the Mongolian Pika (*Ochotona pallasi*) in a non-equilibrium ecosystem, South-Gobi, Mongolia

Vroni Retzer

Dissertation zur Erlangung des Doktorgrades der Naturwissenschaften (Dr. rer. nat.), dem Fachbereich 19 Geographie der Philipps-Universität Marburg vorgelegt von Vroni Retzer geb. 25.07.1974 in München, Marburg/Lahn 2003

Erstgutachter: Prof. Georg Miehe
Zweitgutachter: Prof. Jörg Bendix

Die vorliegende Publikation wurde als Dissertation unter folgendem Titel im November 2003 am FB 19 Geographie der Philipps-Universität Marburg eingereicht und angenommen: "On the role of a burrowing small mammal, the Mongolian Pika (*Ochotona pallasi*), in the mountain ranges of the Gobi Gurvan Sayhan, South-Gobi, Mongolia – Forage competition between pika and livestock, the mountain ranges as productive islands, the function of the Mongolian Pika in the ecosystem, and long-term livestock carrying capacity, assessed by field experiments and a simulation model."

Contents

List of Tables

List of Figures

Summary

In Mongolia nomadic pastoralism has a long tradition and is of great economic importance. During the transition from socialism to a free-market economy since 1990 livestock was privatized and livestock numbers have risen dramatically. The carrying capacity for livestock and the impact of potential pests on forage availability therefore are of immediate interest.

Against this background this study presents the results of a full-year empirical field study on the forage competition between pika and livestock, on the altitudinal distribution of domestic and wild large herbivores and the consequences for nature conservation, and on the impact of pika in the mountain-steppe. The findings of these field studies were then integrated into a model of forage competition between pika and livestock. The model was used to determine the quality of the understanding of most important ecosystem processes and to generalize the findings.

1. **Forage competition between pika and livestock**

   Generally we have to conclude that there indeed is potential for forage competition between pika and livestock. Both groups overlap in habitat and forage plants, and forage is not always sufficient to fulfill the needs of both groups.

   In a year of drought, such as 2001, forage is scarce and competition can be observed. The results of an exclosure experiment show that in 2001 above-ground net primary productivity was 184 kg/ha. Of this 107–143 kg/ha were consumed by livestock on treatment *only livestock*, 148–167 kg/ha by pika on treatment *only pika*, and 150–172 kg/ha on the treatment accessible to both groups.

   Pika consume a higher percentage of the vegetation than livestock does. Pika also dominate the pattern of consumption on the area accessible to both groups of herbivores. Therefore pika are competitively superior to livestock: probably due to their smaller size they can access forage which is out of reach for livestock.

   Nevertheless both groups can coexist, as they have access to mutually exclusive forage resources. For pika this is the forage below the biting height of livestock and livestock can reach forage on pastures far away by migrating.

2. **The special situation of the mountains**

   The mountains in the Gobi Gurvan Sayhan National Park are the habitat of a number of endangered animals. The mountains are humid islands in an arid environment and therefore provide higher amounts of phytomass than their surroundings.

   Along the whole transect from the pediment at 2000 m to the mountain top at 2800 m the impact of livestock is much higher than that of wild large herbivores. A clear altitudinal zonation of wild and domestic animals can be observed. Horses are the dominant species along the whole transect (40–52 %), camels and gazelles are preferably found on the pediment (2000–2350 m), while herds of sheep and goats also mainly graze on the pediment but occasionally reach an altitude of 2700 m in summer. Argali (wild sheep) concentrate in the lower mountainous areas and ibexes and yaks are mainly observed in the summit region.

   In a year of drought the large herbivores argali and ibex are under double stress. Apart from the low forage availability they additionally face increasing competition by livestock which is intruding into the mountains in search of forage.

   So on one hand the mountains provide an additional forage supply for herders' livestock. But on the other hand this contributes to the stress argali and ibex face. Any additional stress may be critical for the populations as the habitats of both species are isolated biogeographic islands.

3. **The function of pika in the ecosystem**

   Pika are found to be ecosystem engineers: by their digging activity and dung collection they enhance nutrient availability in the upper soil layer. Therefore the burrows show higher vegetation cover and a 2.7–times higher productivity than the surrounding steppe-matrix. Below-ground biomass is higher on the burrows, but the difference is not significant. Also important forage plants such as *Agropyron cristatum* start off earlier on the burrows and provide valuable first forage in spring for pika and livestock alike.

   Pika's potential as pest is low. Although their burrows affect considerable areas (7–12 %) and they compete for forage with livestock, the devastation caused by the animals is low and they are not likely to show mass population outbreaks. They have positive effects on primary productivity on their burrows which at least partially is used by livestock, too. Therefore they cannot be considered a pest.

4. **Model simulation of carrying capacity and the impact of transformation**

   The presented model is capable of simulating pika and livestock densities and forage competition between both groups as a reaction to variable precipitation input.

   The model results show that the drastic increase in livestock numbers after the transformation was a result of changing herding strategies. The sharp increase observed was supported by a series of years of above-average precipitation, but cannot be explained by this fact alone. Herders on average took a greater risk in

the 1990s by stocking the range higher than previously. This risky strategy took its toll in the years 1999–2002, when a large fraction of livestock starved.

It can be concluded that the long-term carrying capacity has already been reached in the socialistic period. Distinctively higher stocking rates can only be achieved for short favorable periods, but cannot be maintained in the long-term.

Zusammenfassung

Nomadische Viehhaltung ist ein wichtiger Wirtschaftszweig in der Mongolei. Im Zuge der Wende vom Sozialismus zur Marktwirtschaft Anfang der 1990er Jahre wurden die staatlichen Viehherden privatisiert und die Viehzahlen stiegen auf bisher unerreichte Größen an. Vor diesem Hintergrund sind Fragen zur Tragfähigkeit der Weiden für Weidevieh und zum Einfluss von Weideschädlingen von großer Bedeutung.

Die vorliegende Studie präsentiert die Ergebnisse 15-monatiger Feldarbeiten im Gobi Gurvan Sayhan Nationalpark. Untersucht wurde die Futterkonkurrenz zwischen Pfeifhasen und Weidevieh, die Verteilung der wilden und domestizierten Großherbivoren entlang eines Höhengradienten und die Bedeutung der Ergebnisse für den Naturschutz im Park, und des Weiteren die Rolle der Pfeifhasen als Weideschädlinge bzw. Ökosystem-Ingenieure (”ecosystem engineer”). Um die erzielten Ergebnisse zu überprüfen und zu generalisieren, wurde anschließend ein prozessorientiertes Modell entwickelt.

1. **Futterkonkurrenz zwischen Pfeifhasen und Weidetieren**

   Zuerst ist festzustellen, dass es tatsächlich zu Futterkonkurrenz zwischen Pfeifhasen und Weidevieh kommen kann: Beide Gruppen leben im selben Habitat, nutzen die gleichen Futterpflanzen, und es gibt nicht immer ausreichend Futter, um die Bedürfnisse beider Gruppen vollständig zu befriedigen.

   Während der Dürre im Sommer 2001 wurde die Futterkonkurrenz mit Hilfe eines Beweidungsausschlussexperimentes untersucht. Die oberirdische Phytomasseproduktion betrug 184 kg/ha. Davon konsumierten Pfeifhasen auf den nur für sie zugänglichen Flächen 148–167 kg/ha und Weidevieh unter Pfeifhasenausschluss 107–143 kg/ha. Auf den für beide Gruppen gemeinsam zugänglichen Flächen wurden 150–172 kg/ha pflanzlicher Biomasse entnommen.

   Pfeifhasen konsumieren also einen höheren Prozentsatz der Phytomasse und dominieren die Biomasseentnahme auch auf den gemeinsam genutzten Flächen. Pfeifhasen sind vermutlich deswegen konkurrenzstärker, weil sie durch ihre geringere Körpergröße die Pflanzen tiefer abfressen können und damit mehr Futter erreichen als das Weidevieh.

   Dennoch können Pfeifhasen und Weidevieh koexistieren, da auch das Weidevieh über exklusiven Zugang zu weiteren Futterressourcen verfügt. Während Pfeifhasen Pflanzen tiefer abfressen und in Notzeiten auch Wurzeln ausgraben, kann das Weidevieh – gelenkt von den Viehhaltern – bei lokal ungünstiger Futterlage durch

Wanderungen auf weiter entfernte Weideflächen ausweichen, die für Pfeifhasen unzugänglich sind.

2. **Die besondere Stellung der Berge im Gobi Gurvan Sayhan**

   Die Berge des Gobi Gurvan Sayhan stellen eine Art grüne Inseln in der sie umgebenden Wüstensteppe dar. Im Vergleich zu ihrer Umgebung fallen in den Bergen höhere Niederschläge, die wiederum zu einer erhöhten Phytomasseproduktion führen.

   Die Weidetiere treten entlang des gesamten Höhentransektes von 2000 m bis in die Gipfelregionen in 2800 m Höhe in deutlich höher Dichte auf als die wilden Herbivoren. Es zeichnet sich eine deutliche Höhenstufung des Vorkommens der einzelnen Arten ab: Pferde dominieren das Artenspektrum entlang des gesamten Transektes (40–52 %), dagegen sind Kamele und Gazellen vornehmlich auf den Pedimenten (2000–2350 m) zu finden. Schaf- und Ziegenherden weiden ebenfalls vor allem auf den Pedimenten, werden im Dürresommer 2001 aber bis in Höhen von 2700 m getrieben. Argali-Wildschafe sind in den tiefergelegenen Bergregionen (2300–2600 m) anzutreffen, wogegen Steinböcke und Yaks vor allem in den Gipfelbereichen oberhalb 2600 m beobachtet werden können.

   Für die großen wilden Herbivoren, wie Argali und Steinbock, stellt ein Dürrejahr wie 2001 doppelten Stress dar. Abgesehen von der dürrebedingt geringen Futterverfügbarkeit nimmt die Futterkonkurrenz mit Weidetieren zu, die auf der Suche nach besseren Weiden in die Berge getrieben werden.

   In Dürrejahren stellen die Berge daher einerseits eine wertvolle Futterreserve für das Weidevieh dar, aber andererseits setzt die intensivierte Beweidung in diesem Zeitraum die geschützten Wildtiere verstärktem Druck aus. Da deren Populationen inselartige Vorkommen darstellen, kann solch zusätzlicher negativer Stress den Fortbestand der Arten im National Park bedrohen.

3. **Die Rolle der Pfeifhasen im Ökosystem**

   Pfeifhasen können als "Ökosystem-Ingenieure" bezeichnet werden, da sie ihre biotische und abiotische Umgebung nachhaltig verändern. Durch ihre Grabaktivitäten und ihr Dungsammeln verbessern sie die Nährstoffverfügbarkeit auf ihren Bauten. Die Bauten zeigen daher eine höhere Vegetationsdeckung und eine 2,7–fach höhere Phytomasseproduktion als die sie umgebende Steppenmatrix. Die unterirdische Phytomasse ist auf Pfeifhasenbauten nicht signifikant höher. So beginnen wichtige Futterpflanzen, wie z.B. *Agropyron cristatum*, ihre phänologische Entwicklung zuerst auf den Pfeifhasen-Bauten. Damit steht auf den Bauten wertvolles Frühfutter zur Verfügung, das auch von Weidetieren genutzt wird.

   Pfeifhasen sind keine Weideschädlinge, obwohl ihre Bauten beachtliche Flächenanteile einnehmen (7–12 %) und sie mit Weidevieh um die gleichen Futterpflanzen konkurrieren. Sie neigen nicht zu Massenvermehrungen und Verwüstungen ganzer Landstriche wie die Brandtsche Wühlmaus. Im Gegenteil, sie beeinflussen die

Vegetationsentwicklung auf ihren Bauten positiv, was zumindest teilweise auch dem Weidevieh zugute kommt.

4. **Modellierung der Tragfähigkeit unter Transformationsbedingungen**

   Das vorgestellte Modell wurde entwickelt, um die Dichte von Weidetieren und Pfeifhasen als Reaktion auf variierende Niederschläge und auftretende Futterkonkurrenz zu simulieren.

   Die Ergebnisse der Sensitivitätsstudien zeigen, dass der dramatische Anstieg der Viehzahlen nach 1990 nicht alleine mit der günstigen Niederschlagsentwicklung in diesem Zeitraum erklärt werden kann. Vielmehr haben die Viehhalter parallel mit dem Übergang zur Marktwirtschaft ihre Beweidungsstrategien geändert. Sie haben mehr Vieh auf die Weiden gestellt als das früher der Fall war, und sind damit im Durchschnitt ein größeres Risiko von Viehverlusten in schlechten Jahren eingegangen. Diese Strategie ging in den regenreichen Jahren bis 1999 auf, aber anschließend verhungerte ein großer Prozentsatz des Bestandes in den Jahren 1999–2002 und die Viehzahlen gingen auf das Niveau vor der Transformation zurück.

   Dies zeigt, daß die Grenze der langfristigen Tragfähigkeit bereits während der sozialistischen Zeit erreicht wurde. Deutlich höhere Viehbestände können nur während kurzer Gunstperioden erzielt werden, sind aber auf lange Sicht nicht nachhaltig tragbar. Die ökologischen Folgen extrem stark schwankender Viehbestände sind bis dato noch nicht abzusehen.

Preface

The basis for this study was laid in 1996, when Dr. Sabine Miehe worked as a short-term specialist for the GTZ Nature Conservation and Buffer Zone Development Project. Back then, Dr. Sabine Miehe and Prof. Dr. Georg Miehe travelled the Gobi Gurvan Sayhan National Park extensively in order to compile a first description of its vegetation units. During their travels they got the impression that pika densities are higher at locations of high grazing pressure in the mountains. This observation was alarming, as they knew of the case of another small mammal, the Brandt's vole in central Mongolia, which benefits from high grazing pressure and in turn initiates further range degradation. If the Mongolian Pika could initiate a similar vicious circle here, this would contradict the conservation goals of the park.

After the Miehes returned to Germany, they applied to the German Science Foundation (DFG), and the German Ministry for Economic Co-operation and Development (BMZ) for the funding to support a Mongolian-German joint research project. The framework for the cooperation was provided by a memorandum of understanding between the department of geography, Philipps-University of Marburg, and the biological faculty of the Mongolian State University, Ulaanbaatar, Mongolia, signed in 1999. In this memorandum both parties agreed on joint research on the carrying capacity of mountain-steppe biocenoses of the Gobi Gurvan Sayhan National Park with respect to the transformation of nomadic pastoralism. Support by DFG and BMZ was granted in July 2000 and the project commenced in August.

While this study focuses on range ecology, a second PhD-student Karin Nadrowski studies the ecology of the Mongolian Pika. In this study the following central questions were investigated:

1. How severe is forage competition between pika and livestock? And how do pika and livestock coexist in the long-term?
2. What importance does the higher forage availability in the mountains of the Gobi Gurvan Sayhan National Park have for livestock and large wild herbivores?
3. Apart from forage competition with livestock, do pika directly or indirectly modulate the availability of resources to other species? Or, what is the role of pika in the mountain-steppes of the Gobi Gurvan Sayhan National Park?
4. How does the transformation in the 1990s affect the long-term carrying capacity for livestock?

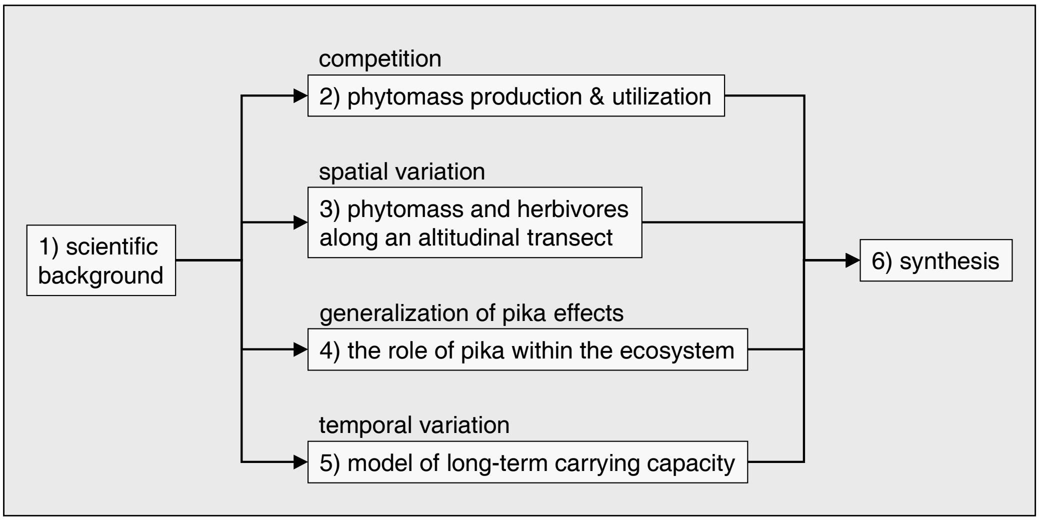


Figure 0.1.: Schematic diagram of the structure of the study. Own draft. See text for further explanations.

Structure of the study

The study covers these questions in separate parts. Each chapter can be read separately. The scientific introduction (chapter 1) and the synthesis (chapter 6) provide the framework of the study (fig. 0.1). Within the experimental part the chapters are sorted according to a more and more expanding view. The second chapter (p. 75) focuses on phytomass production and utilization by pika and livestock, respectively. It is the central part of the study and evaluates the forage competition between both the herbivore groups. However, this view of competition between the different herbivore groups is expanded subsequently in the following chapters in terms of spatial variation, generalization of pika effects, and temporal variation. This expansion of the view is necessary to derive implications which are not limited to a single site or case only.

The third chapter (p. 131) expands the spatial view from a single point along an altitudinal transect from 2000 m to the summit region at 2800 m. Here, precipitation, standing crop, and phenological development along the transect are described and the consequences of the competition between livestock and large wild herbivores are discussed. It highlights the special role of mountains in dry years.

Chapter four (p. 153) turns attention to a smaller scale again and assesses pika's status within the mountain-steppe ecosystem. As can be shown the effects of pika on its environment and therefore also indirectly also on livestock are much more varied than simple forage competition. It describes the effects of pika burrows on soil, vegetation, and ecosystem processes. Pika's status as pest and ecosystem engineer is evaluated.

Finally the fifth chapter (p. 183) develops and tests a model attempt to summarize the processes which have been identified previously. First of all it serves as a check whether the relevant system processes are understood. It provides a tool to transfer the data of the investigation period to years with different rainfall regime by understanding the underlying processes and thus allows to expand the view to a much longer time horizon. Furthermore, it is used to assess the impact of transformation and to derive implications on the long-term carrying capacity.

The methods used are described separately in each chapter, and will be explained in the order of appearance. Whenever a method has already been described earlier, a shorter explanation is given in the following chapters for better understanding with references to the full description. This is supposed to avoid unnecessary double descriptions of methods on the one hand and to achieve a more readable text on the other hand. Mongolian terms, technical terms, and abbreviations are explained in the glossary on page 242.

1. Scientific background

This chapter first of all introduces the different types of steppes and their distribution. Special emphasis is put on the role of small mammals in steppes, pastoral nomadic land use, ecological dynamics, and carrying capacity. After this general introduction the text turns to the Mongolian natural environment and its history of pastoral land use, focusing on the transition to a free-market economy following the 1990s. Subsequently, the study area in the Gobi Gurvan Sayhan National Park is described in further detail.

1.1. Range ecology

1.1.1. Definition of range

Rangeland or range is a colloquial term used to describe landscapes or vegetation units which are suitable for grazing by livestock. This leads to relatively complicated formal definitions such as: rangeland is "all land in the world that is not cultivated farmland, dense forest, barren desert or land covered with solid rock, concrete, or glaciers" (Launchbaugh, not dated). Or: "land on which the historic climax community is predominantly grasses, grasslike plants, forbs or shrubs. [It] includes lands revegetated naturally or artificially when routine management of that vegetation is accomplished mainly through manipulation of grazing" (Butler et al., 1997).

An approach to reach a more scientific definition was made by the Environmental Monitoring and Assessment Programme (EMAP) of the US Environmental Protection Agency (EPA): rangelands are "terrestrial systems characterized by a climate regime where the potential evapotranspiration exceeds precipitation, annual precipitation ranges from less than 50 to 600 mm, and air temperatures range from -40°C to 50°C. The vegetation is dominated by woody shrubs, grasses, cacti and leaf succulents, and drought resistant trees." (cited in Baas et al., 2000). In my opinion, also this definition accomplishes hardly more than describing open landscapes in which livestock grazing is possible.

Rangelands therefore include "natural grasslands, savannas, shrublands, most deserts, tundra, alpine communities, coastal marshes, and wet meadows." (Butler et al., 1997). Rangelands are characterized by no more than their open structure and the suitability for livestock grazing (Ferguson, 2003). Also the question whether rangelands are natural or cultural landscapes is only rarely asked and discussed. Nevertheless the term is useful for the comparison of grazing management around the world. But as ecosystem processes greatly differ from each other in the ecosystems mentioned above, it is of crucial importance to apply great care when comparing different regions. For a geography of grassland ecosystems see Singh et al. (1983).

Rangelands are generally areas of multiple use, such as tourism, management of wildlife, livestock herding, mining, and the protection of endangered species (Blench, 2001; Launchbaugh, not dated). This makes them a playground of different interests which have to be balanced by suitably integrated management strategies.

1.1.2. Definition of range ecology

The aim of range ecology is to understand the complex interaction between abiotic and biotic factors on rangelands. These factors, among others, include yearly and summerly precipitation, precipitation variability, edaphic conditions, land use history, recent use, herbivore densities, herbivore dynamics, and grazing management (Behnke et al., 1993; Schulte, 2001).

Because of this broad approach range ecology uses an array of different methods to assess these complex interactions. This may include methods from vegetation, animal, and social science, as well as climatic measurements and soil studies. The methods actually used have to be combined and adjusted according to the aims of the actual study. Table 1.1 gives an overview of the main variables and parameters which are in the focus of the present study.

variables	investigated parameters
precipitation	daily, monthly, and annual sums
vegetation	standing crop, height, cover, below-ground biomass, phenology
livestock	densities, distribution, intake, body condition
large wild herbivores	densities, distribution
pika	intake, impact on soil and vegetation properties on burrows

Table 1.1.: Main variables and parameters investigated in this study. See text for further explanation.

The investigated parameters were chosen according to the aim of the study. Primarily these were factors affecting primary productivity such as standing crop, vegetation height, vegetation cover, and precipitation data. The parameters herbivore densities, distribution, and intake, and body condition of livestock served to assess the forage competition between different herbivore groups.

In order to evaluate the impact of pika in their environment further parameters such as vegetation below-ground biomass, phenology of important forage species, and pika's impact on soil and vegetation properties on burrows were included in the study. This set of parameters was supposed and proved to be sufficient to describe the main elements and interactions of the investigated ecosystem regarding the question of forage competition and long-term carrying capacity.

1.2. Range ecology of steppes

1.2.1. Steppes

The English word ”steppe” is derived from the Russian ”stepj”. The original meaning of the Russian word is unclear, some claim it can be translated as ”flat grassland” (Jätzold, 1984), others that it is a legal term describing public land commonly used for grazing (Miehe, G., pers. comm.). Similar grasslands in North America are named ”prairie” (Schroeder, 1998), and Sala (2001) prefers the term ”temperate grasslands” although not all of them are temperate. Within this study the term steppe will be used, because it is the most widely used for the Central Asiatic region.

Steppes cover about $15 \cdot 10^6$ km^2, hence accounting for 11 % of the terrestrial surface of the earth (Sala, 2001). Their distribution is essentially identical with that of semi-arid and arid regions. The characteristics for the distribution are (after Schultz, 1995):

- vegetation growth during maximum 5 months due to the restricted availability of sufficient warmth and humidity,
- limited water availability even in the rainy season because of high variability in precipitation, and/or low water storage in the soils,
- therefore agriculture without irrigation is not possible, or at least highly risky,
- the natural vegetation is characterized by xeromorphic attributes, the occurrence of halophytes, and by no longer closed vegetation cover,
- rivers are filled with water only episodically, and usually end in depressions without further drainage.

The largest expanses of steppes are found in the Great Plains in North America and in the Eurasian steppe belt, smaller areas exist in South Africa, South America (Patagonia), Australia, and New Zealand (tussock grassland on the eastern side of the south island) (Jätzold, 1984). Steppes as ”grasslands” are mainly defined via their open character, the absence of forest, and by the high proportion of grass. The relative contribution of the major plant functional types ”shrubs” and ”grasses” depends on the seasonality of the precipitation and soil texture (Sala, 2001). The larger part of the plants in steppes are hemicryptophytes, a large proportion can also be spring geophytes or therophytes (Schultz, 1995). The latter two, however, are absent in Central Asia due to the low availability of moisture in spring.

Along a precipitation gradient steppes are located between forests and deserts. Along the same gradient they can further be subdivided into four subcategories: forest-steppe, longgrass-steppe, shortgrass-steppe, and desert-steppe (table 1.2). Transition between the different varieties is gradual. However, the vegetation types in Mongolia seem to be adapted to lower levels of precipitation (see Hilbig 1995, 2000a and fig. 1.4, p. 40 and fig. 1.6, p. 44).

The available moisture also determines the agricultural potential of the different types of steppe. The more humid regions have been turned into high intensity agricultural

types	prec.(mm)	(semi-)arid	(sub-)humid	typical soil
forest-steppe	> 900–1200			
longgrass-steppe	350–900	< 6 months	> 6 months	chernozem
shortgrass-steppe	200–500	7–10 months	< 5 months	castanozem
desert-steppe	< 250	≥ 1 month	≤ 1–2 months	burozem
desert	< 150			xerosol

Table 1.2.: Differentiation of different types of steppe and adjacent vegetation formations along a precipitation gradient (compiled from Jätzold, 1984; Schroeder, 1998; Schultz, 1995).

farmland. Main crops in North America and in the states of the former Soviet Union are maize and wheat. While maize mostly covers the place of former forest-steppes and wetter varieties of the longgrass-steppes, wheat is mainly found in the drier longgrass-steppes and the wetter shortgrass-steppes. In drier regions agricultural use is no longer possible without irrigation and the dominant land-use is usually extensive livestock keeping (Jätzold, 1984).

Especially the steppes of Eurasia and North America were home to large herds of ungulates such as wild horses and saiga-antelopes in the Old World, and bison and pronghorn in the New World. Their numbers have been reduced dramatically in the past. Among the small mammals marmot, vole, guinea pig, prairie dog, pocket gopher, hare, and pika are typical inhabitants of steppes. The role of small mammals in steppes will be highlighted in chapter 1.2.2. The predators feeding on all these animals are different kinds of wolves and foxes as well as a variety of birds of prey (Jätzold, 1984; Schultz, 1995).

1.2.2. On the role of small mammals in steppe-ecosystems

Small mammals are widespread in the (semi-)arid steppe-ecosystems of the world. Most of them create underground structures such as burrows, warrens, colonies, or tunnels. The creation of burrows as shelters is a common feature among small mammals in steppes. As Kinlaw points out "the possession of a cool, moist burrow with stable temperatures underground is especially critical for survival in arid zones that are hot and dry with greatly fluctuating temperatures on the surface" (Kinlaw, 1999, p. 127).

The most important species of small mammals found in arid ecosystems are: pocket gopher (*Thomomys* spp. or *Geomys* spp.) and prairie dog (*Cynomys* spp.) in North America; guinea pig (*Cavia* spp.) in South America; and marmot (*Marmota* spp.), vole (*Microtus* spp.), and pika (*Ochotona* spp.) in the whole Northern hemisphere (Nowak, 2003).

Figure 1.1 summarizes the main direct and indirect impacts of burrowing small mammals on their environment. Small mammals are prey for many carnivores. Some predators such as the black-footed ferret (*Mustela nigripes*) even depend on a single prey species, in this case the black-tailed prairie dog (*Cynomys ludovicianus*). As the prairie

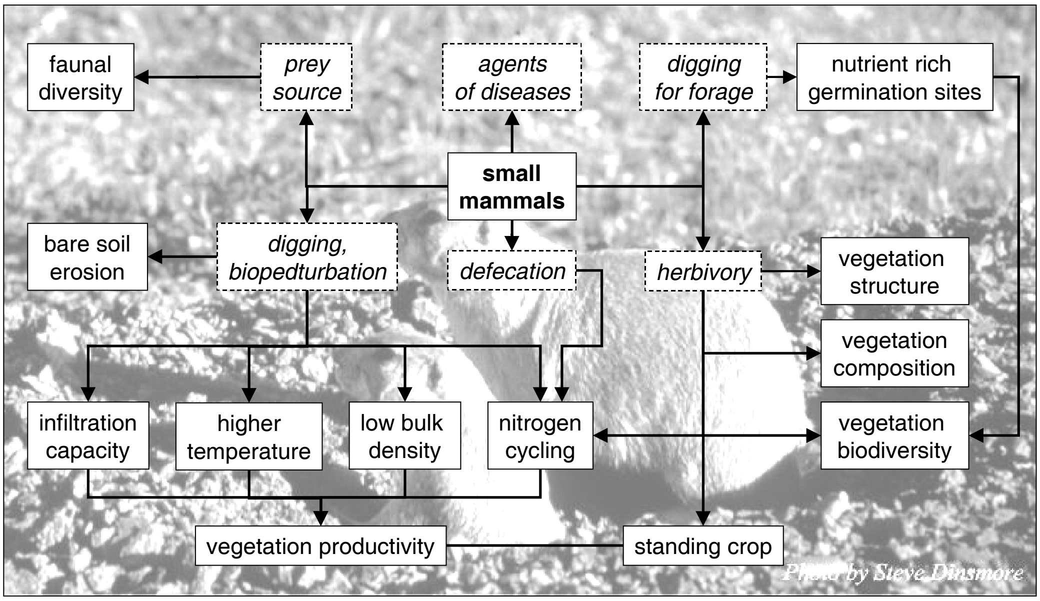


Figure 1.1.: Schematic diagram of the most important effects of small mammals on their biotic and abiotic environment. Own draft. See text for further explanations.

dog is their sole prey, the ferrets' numbers declined parallel to that of the prairie dog (Carrier & Czech, 1996). Smith & Foggin (1996) suggest that on the Tibetan Plateau the polecat (*M. eversmanni*) is tied in some way to the population dynamics of the Plateau Pika (*Ochotona curzoniae*). Small mammals which do not hibernate, such as pika and prairie dogs, provide especially valuable prey for a number of predators during times of low prey availability in winter (Schaller, 2000; Smith et al., 1990).

Some different species make use of the burrow structure of the burrowing small mammals as well. The black-footed ferret is not only known to feed on prairie dogs, but it depends on the prairie dogs' burrow systems for dens and shelter (Fagerstone & Ramey, 1996). The burrows also provide habitat for a number of other species but the degree of dependence is still unclear in many cases (see Kotliar et al., 1999). It is well established that at least the burrowing owl (*Athene cunicularia*) and the mountain plover (*Charadrius montanus*) are strongly dependent on prairie dog colonies (Kotliar et al., 1999). Burrowing owls use abandoned colonies as nesting sites, cover, and for feeding (Fagerstone & Ramey, 1996). Also burrows constructed by the Plateau Pika offer breeding habitat for symbiotic species such as Hume's ground jay (*Pseudopodoces humilis*), several species of snowfinch, and native lizard species (Smith & Foggin, 1996).

Small mammals can also be the carriers of diseases which may affect other animals or even humans. For example, the marmots in Mongolia are known to carry the plague pathogene (UB Post, 2003b,c).

The effects of small mammals on vegetation characteristics are both direct and indirect. Through their grazing they can alter the vegetation structure such as height, cover, and vegetation composition and thus influence vegetation diversity (e.g. Winter et al., 2002). Fahnestock & Detling (2002) found a higher plant species diversity on prairie dog colonies than off-colony. The digging activity indirectly influences vegetation structure via soil parameters. When they dig for forage, small mammals create small-scale disturbances, little holes which soon are refilled with loose soil and act as nutrient-rich germination sites for plant species, thus increasing plant species diversity (see Whitford & Kay, 1999, and references therein).

In contrast to the relatively stable burrows of prairie dogs and many pika species, the Brandt's voles frequently abandon old burrows and dig new ones. By doing so they create a patchy mosaic of areas with different burrow history. On their burrows they initiate a vegetation succession cycle which gradually regenerates to "natural" steppe vegetation (Samjaa et al., 2000).

The nutrient cycling on burrows of small mammals can be influenced in three ways, as has been shown for prairie dog colonies (Coppock et al., 1983a; Krueger, 1986):

1. Burrow systems which are inhabited by harvesting animals are characterized by a higher content of organic matter in the soil
2. Biopedturbation from the animals' digging activity increases the rates of mineralization and of litter decomposition.
3. Defecation of small mammals on their burrows may lead to a concentration of nutrients in the soil and subsequently in the plants (Whitford & Kay, 1999).

Digging activities therefore influence soil properties, which in turn affect plant productivity. The digging loosens the soil and increases the infiltration capacity (Whitford & Kay, 1999). The burrows of prairie dogs have a higher temperature than the surrounding area (Archer & Detling, 1986). This, plus the enhanced nutrient cycling, again affects plant productivity. But studies actually measuring plant productivity on the burrows of small mammals are rare. Krueger (1986) found no significant differences of phytomass between exclosures and control plots on prairie dog colony centers, edges, and uncolonized area.

The parameter more frequently investigated is standing crop, which shows a tendency to be lower on-burrow than off-burrow (Coppock et al., 1983a; Fahnestock & Detling, 2002). But as grazing intensity seems to be higher on–burrow than off-burrow (by large and small herbivores alike) as well (Coppock et al., 1983b; Krueger, 1986), lower standing crop is not necessarily a prove for lower productivity. Possibly small mammals can facilitate soil erosion, because the bare soil on the burrows is prone to wind erosion but data are still lacking (Whitford & Kay, 1999).

The perception of small mammals by humans varies widely and changes with time. Especially the fact that most small mammals are herbivores and therefore potentially compete with livestock for forage has qualified many of them as pests. Zhang et al. (2003c) state that rodents, and other small mammals such as pika, cause serious problems in grasslands of China. Especially species such as prairie dogs, Daurican Pika, and Brandt's vole have been identified as pests and were (Miller et al., 1994) – and the latter two still are – in the focus of eradication programs (Shi et al., 2002; Zhang et al., 2003b,c).

1.2.3. Nomadic pastoralism

Nomadic pastoralists[1], according to Dyson-Hudson & Dyson-Hudson (1980, p. 18), are people who

- are primarily dependent on livestock for their livelihood,
- live in environments with marked seasonality, and
- choose movement of their herds rather than bringing forage to the herds as their basic strategy for providing year-round forage for their livestock.

Scholz (1991, p. 30f) defines nomadism as a mobile way of life and business which is distinguished by the following characteristics:

- Livestock-keeping is the economic basis.
- Sheep, goats, camels, cattle and/or horses are the means of production.
- The aim is self-sufficiency in terms of animal products and transport.
- Livestock grazes on natural pastures which are usually scarce in forage.
- The exploitation of these pastures necessitates frequent movements of livestock and herders' homes to better pasture often over great distances.

Further differentiation can be made according to whether their income relies exclusively, primarily, or only partially on their livestock; whether they herd their own animals or additionally those of other people, whether they cultivate no, some, or many additional crops, whether they only live in mobile homes or also make use of solid constructions during some time of the year, and whether the only restriction to their migration patterns is the well-being of their livestock, or whether there are other reasons restricting the free movement of the herds (Scholz & Janzen, 1982; Scholz, 1991).

Nomadism as a way of life has long been regarded as some primitive form of human social and economical organization. But nomadism is not inferior to other ways of life, nor does it represent a less developed state of the human society (Fernandez-Gimenez, 1999; Scholz, 1997). On the contrary, it is an own independent form of civilization which requires enormous knowledge and herding skills to survive (Lattimore, 1962; Janzen, 1999). Scholz (1995) regards pastoral nomadism as an independent socio-ecological culture, which is well adapted to the ecological and socio-political requirements within the Old World dry belt.

These ecological requirements are primarily the high inter- and intra-annual variation in precipitation and the associated variation in forage availability for livestock. Pastoral nomads employ mobility strategies which allow them to react quickly to changes in forage availability. This mobility is the key for the successful exploitation of heterogenous resources (see also chapter 1.2.4). This is the reason why pastoral nomadism has been called "a highly successful adaption to a very difficult environment" (Schwartz, 1980,

---

[1] Within this study the terms nomadic, mobile, and migratory pastoralism are used without difference, provided that migration is characteristic for the movement strategy rather than an exception.

p. 287), or a strategy to survive in extreme environments (Nauheimer, 1991, p. 214). Regardless of the ruling power, high mobility pastoral nomadism is considered the best system to use the vast land under the given difficult abiotic conditions (Fernandez-Gimenez, 1999).

In the last decades the movement radius has been reduced by factors such as sedentarization schemes or expansion of rain-fed agriculture at the cost of former pastures (Scholz, 1994). Reduced mobility frequently leads either to the abandonment of the nomadic way of life or to an increase of the pressure on the remaining resources. Restrictions of mobility are the reason why the end of pastoral nomadism has been announced recently (Humphrey & Sneath, 1999; Scholz, 1999).

1.2.4. (Non-)equilibrium rangeland dynamics and carrying capacity

Traditional ecological thinking strongly emphasized the idea of equilibrium. The premise of the existence of a "balance of nature" has influenced the perception of ecologists since antiquity (DeAngelis & Waterhouse, 1987; Wiens, 1984). Although from the late 18th century evidence accumulated that at least not all ecosystems behave in a equilibrium way, the concept persisted until the 70s and 80s of the twentieth century (Baker, 2000). Since then the assumption of non-equilibrium being the norm rather than equilibrium has become more widely accepted (Baker, 2000; Holling, 1973; Wiens, 1984). DeAngelis & Waterhouse (1987, p. 451) stated that "natural communities should be viewed as being arrayed along a gradient of states ranging from non-equilibrium to equilibrium". This study follows the definition and terminology of Wiens (1984).

Figure 1.2 illustrates the characteristics of the two extremes of the gradient, equilibrium and non-equilibrium systems. An equilibrium system is characterized by low abiotic variability. This makes the abiotic variables predictable and the biota can adjust to this situation. Therefore the system is mainly regulated by the interactions of the biotic elements. This is why competition gains great importance in equilibrium systems; the interactions of species therefore show a strong density dependence.

In non-equilibrium systems, on the other hand, the abiotic factors are extremely variable and therefore determine the ecosystem much more than the interaction of biota. The overwhelming influence of abiotic parameters results in a decoupling of the biotic interactions. This means that species respond much more to environmental variations than to the actions of other species. Population dynamics of species in non-equilibrium systems are therefore regulated by abiotic factors and are largely independent from density. Abiotic inputs of high variability trigger the whole non-equilibrium system, and as they are unpredictable, the system has a highly stochastic component (Baker, 2000; Wiens, 1984). All this applies to livestock as well as to populations of wild large herbivores such as zebras (Georgiadis et al., 2003).

Probably no ecosystem is exclusively an equilibrium or a non-equilibrium system, most will be somewhere intermediate along the gradient. Also, the situations may change with prevailing equilibrium conditions under certain circumstances and prevailing non-

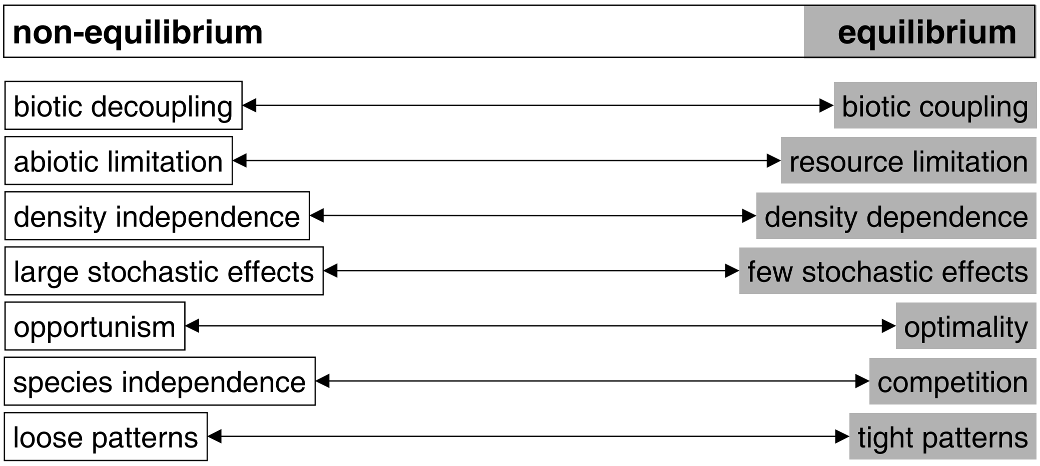


Figure 1.2.: Idealized gradient between non-equilibrium and equilibrium states. The main characteristics describing the two states are denoted below (after Wiens, 1984, p. 451).

equilibrium dynamics at other times (Baker, 2000; Briske et al., 2003). Nevertheless, this concept provides a valuable framework to describe important features of ecosystem dynamics.

The application of the above-mentioned characteristics of non-equilibrium and equilibrium dynamics to rangeland ecosystems are summarized by Ellis & Swift (1988): In non-equilibrium grazing systems

1. stochastic abiotic conditions (such as precipitation) lead to equally high variability in plant growth,
2. plant-herbivore interactions therefore are only loosely coupled,
3. herbivore population dynamics, especially animal deaths are regulated by forage availability and therefore are relatively independent from herbivore density and,
4. carrying capacity is too dynamic for close herbivore population tracking (see also Fernandez-Gimenez & Allen-Diaz, 1999, p. 872).

For the case of rangelands, evidence for non-equilibrium dynamics accumulated in semi-arid and arid pastoral economies especially in Africa (see Behnke et al., 1993, and references therein, and Fynn & O'Connor, 2000; Oba et al., 2000; Pflaumbaum, 1995; Sturm, 1999; Sullivan, 1996). The application of equilibrium concepts to non-equilibrium rangelands often resulted in a calculation of fixed stocking rates which did not take into account the temporal and spatial precipitation variability (Behnke & Scoones, 1993; De Leeuw & Tothill, 1990; Hary et al., 1996). According to these stocking rates, ranges were considered highly overstocked, and ”degradation” as a result of ”overgrazing” was predicted. But it could be shown that many of the changes were reversible and that the investigated systems were long-term sustainable. Often degradation did not take place due to non-equilibrium dynamics. Most of the investigated ecosystems are so tightly coupled with precipitation and its variation that livestock only seldom reached densities high enough to initiate density dependent degradation processes (Coppock et al., 1986; Sullivan, 1996, 1998; Ward et al., 1998). The relevance of non-equilibrium in arid and semi-arid grazing systems has since been hotly debated (Illius & Connor, 1999; Sullivan & Rohde, 2002). The difficulty is the separation of the effects of climatic variability and human impact or grazing (Dube & Pickup, 2001; Wiegand & Jeltsch, 2000; Ward et al., 2000). A thorough discussion of the misuse and misunderstanding of terms such as degradation and desertification is too much out off track for this study, please refer to Müller-Hohenstein (1993) and Sullivan (1996).

The main factor along the gradient between equilibrium and non-equilibrium systems is the variability of the driving abiotic parameters. This is mainly the variation in precipitation because precipitation is directly connected to primary productivity in arid and semi-arid systems, which in turn forms the basis for secondary productivity (Lauenroth & Sala, 1992; Pickup, 1996; Sala et al., 1988b; Sala, 2001). The criteria for distinguishing between equilibrium and non-equilibrium dynamics therefore are based on the coefficient of variation in annual precipitation, mean annual precipitation and the presence or absence of El-Niño-Southern Oscillation effects (Ellis, 1995, and Ellis & Chuluun, 1993 cited in Fernandez-Gimenez & Allen-Diaz, 1999).

For the reasons mentioned before, actual carrying capacity (forage availability) in non-equilibrium systems is extremely variable (Ellis & Swift, 1988). Carrying capacity "means different things to different people" (Bartels et al., 1993, p. 89), but has been basically defined as a fixed stocking rate which allows for long-term sustainable use of a rangeland (see Bartels et al., 1993, for a further discussion of meanings and definitions). In a non-equilibrium environment it does not make any sense to define a fixed stocking rate for a certain region, because this ignores spatial and temporal variability as the major characteristics of such a system (Bartels et al., 1993; De Leeuw & Tothill, 1993; Pastor et al., 1997). Behnke & Scoones (1993) show in a remarkable example that under heterogenous conditions stocking rates under a migratory grazing regime can be potentially much higher than those under a settled one. Migratory pastoralism is the answer to such heterogenous environmental conditions. This is why Scholz (1997) states that nomadism is a reaction to (variable) environmental conditions, and that under these conditions nomadism as such can come into life again any time and anywhere. It can mediate the small-scale variability and reach a relatively stable and sustainable level of livestock densities on a larger scale (Baker, 2000).

In non-equilibrium systems the average stocking rate is well below the average potential carrying capacity. This results from the different time scales of the relevant processes steering forage availability and herbivore starvation and reproduction. Idealized forage availability is a variable which reacts directly to the annual level of precipitation, and according to this, a certain amount of vegetation is available which determines the "actual carrying capacity". If livestock numbers are higher than the "actual carrying capacity" livestock begins to starve. In this case the "realized stocking rate" will be efficiently reduced to the "actual carrying capacity" within the same year: there is no delay in the reaction of the stocking rate to insufficient forage availability. But when the "actual carrying capacity" permits higher stocking rates there is a delay, because reproduction

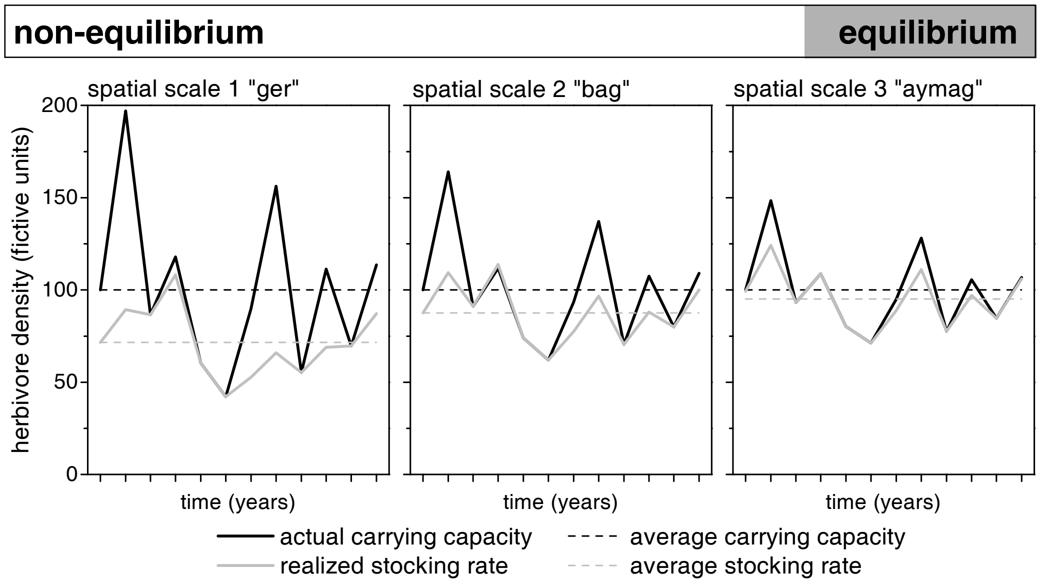


Figure 1.3.: Fictive example of the changing precipitation variability with increasing scale and its effect on carrying capacity and stocking rate. The variability of precipitation decreases from left to right. The lines show the actual carrying capacity (black, solid), the average actual carrying capacity over the investigation period (black, dotted line), the realized stocking rate (grey, solid line), and the average stocking rate (grey, dotted line). See text for further explanation.

of large herbivores is a much slower process than starvation (Georgiadis et al., 2003). Within one year 50–70 % of the livestock in one area can die of starvation, but reproduction rates are typically between 5 % and 25 % (Ellis & Swift, 1988; Nauheimer, 1991; Scoones, 1993a). Years with extreme below-average precipitation therefore are sort of a "reset" of a non-equilibrium system.

As precipitation variability is scale dependent, the questions of non-equilibrium and equilibrium and that of carrying capacity are as well (Oba et al., 2003). Figure 1.3 shows a fictive example. The three panels can be interpreted as a gradient between three different landscapes or as a gradient in scale within one landscape, with the smallest area to the left and the largest to the right. The coefficient of variation for the precipitation decreases along this gradient from 35.6 % in the left, to 23.5 % in the middle panel, and to 17.8 % in the right panel.

The "realized stocking rate" is always lower as, or maximum equal to the "actual carrying capacity". It can clearly be seen that with decreasing precipitation variability the difference between "realized stocking rate" and "actual carrying capacity" becomes smaller. "As a result, the greater the variation in rainfall, the greater the proportion of time the population spends below carrying capacity" (Georgiadis et al., 2003, p. 125). In the left panel the average herbivore population density (=stocking rate) is around 71.5 % of the average carrying capacity. This proportion increases to 87.5 % in the middle panel and to 95.2 % in the right panel. Other factors such as livestock epidemics or armed conflicts adding to the unpredictability of the system (Scoones, 1993a) are not included in this example.

This also illustrates the benefit of mobile pastoralism: by covering a greater area by moving (if necessary), pastoralists can reduce the variability of precipitation encountered in one place and thus partially stabilize their herds. A bigger movement radius is therefore a common strategy to cope with drought and a prerequisite for sustainable management (Ellis & Swift, 1988; Pamo, 1998). Movement of livestock is therefore crucial in non-equilibrium-systems. The sedentarization of nomads and changes to the traditional grazing management which is adapted to an erratic rainfall regime are counterproductive to sustainable land-use and degradation may be the consequence (Robinson et al., 2003; Scholz, 1999).

1.3. Mongolia

1.3.1. Natural environment

Topography and soils

Mongolia is situated in Central Asia and stretches between 52°06' and 41°32' north and between 87°47' and 119°54' east (Barthel, 1990). It is a landlocked country far from the next ocean. The distance from Ulaanbaatar to the nearest ocean, the Yellow Sea, is more than 1400 km. Mongolia also is a country of high elevations. More than 85 % of its area are above an altitude of 1000 m asl (Barthel, 1990). The average altitude of the country is 1580 m asl (Murzaev, 1954). The highest elevations are found in the Mongolian Altai in the north-western part of the country (4362 m) (Barthel, 1990).

Orographically, Mongolia is divided into two parts. The southeastern and eastern part of Mongolia is characterized by flat plateaus and gentle hills. Regionally these patterns are superimposed by mountains of volcanic (quaternary) origin (Opp, 1996). The western part of the country is dominated by mountain chains stretching predominantly from NW to SE. The area between the mountain chains is occupied by basins and valleys which often harbor salt- and freshwater lakes or salt pans (Barthel, 1983; Opp, 1996). Typically, the lakes do not have an outlet. One of the major mountain ranges is the Mongolian Altai, which gradually loses height from NW to SE and changes into the Gobi Altai further south-east. The Khangai mountains cover a large area (approximately 600 x 200 km) in northern central Mongolia, while the Khentii and Khuvsgul mountains form the major mountain range in northern Mongolia. The depression of the great lakes is situated between the Mongolian Altai and the Khangai Mountains (Barthel, 1990).

The distribution of soils in Mongolia is tightly coupled with the relief and the climatic situation (Opp & Hilbig, 2003b). Therefore, they are closely connected to the zonal climatic gradient in the eastern part of the country, and are differentiated by altitude in the northern and western parts (Opp, 1994). A soil map of Mongolia was compiled by Opp (1994, 1996). Main climatic features influencing the formation of soils are fluctuations in daily temperatures, amount of precipitation in summer, length of the winterly frost period, and occurrence of permafrost (Haase, 1983).

A simplified catena in eastern Mongolia from north to south that means from higher to lower precipitation, includes continental (dry) steppe soils (chernozems, para-chernozems, and castanozems) which are gradually being replaced by continental soils of the desert-steppe (solonetzs, burozems, and serozems) and – with aridity increasing further – by continental desert soils (serozems, solonchaks, solonetzs, and regosols). The soils in the steppe region commonly have a deep Ah-horizon (-80 cm) with a high humus and iron content. Burozems are characterized by a thin upper soil layer with a low humus content. The deeper soil layer is compacted by the enrichment of carbonates and salts. The soils of the desert zone show a low humus content and often signs of salinization (Haase, 1983; Opp, 1994).

Along the altitudinal gradient, the soils from the steppe region gradually are replaced by soils of the mountain taiga and mountain-steppe (cryotaiga-soils, chernozems, para-chernozems, and castanozems). When decomposition of organic matter is hampered by low temperatures, the accumulation of humus can result in the development of para-chernozems. Patches of permafrost are often covered with cryotaiga-soils (Haase, 1983). In the highest elevations of the Mongolian Altai and in northern Mongolia periglacial and cryoturbation processes prevail. These lead to the formation of high mountain soil types such as tundra-gleys, tundra podzols, and lithosols (Haase, 1983; Opp, 1994).

Climate

The most important feature of the Mongolian climate is its continentality. It results in extreme amplitudes of temperature and equally high inter- and intra-annual variations in precipitation (Barthel, 1990; Murzaev, 1954; Thiel, 1985). This variation increases with lower precipitation, because mean annual precipitation is inversely correlated with its coefficient of variation (Snyman, 1998).

In winter, all of Mongolia is under the influence of the stable Siberian-Mongolian anticyclone. This durable high pressure situation is characterized by deep temperatures, low cloud cover, absence of strong winds, and extremely low precipitation. January is the coldest month with average temperatures below -15°C for all stations in Mongolia. In the long-term mean, only 4–10 % of the mean annual precipitation falls in the time from November until April. A high and closed snow cover therefore is seldom in Mongolia (Barthel, 1990).

During the relatively short transitional spring season the anticyclone loses its strength and a cyclonal west weather situation begins to dominate. Spring is the time of the year with the most unreliable weather, with high irregularities in temperature, and with strong storms. Precipitation normally starts in June and is concentrated during the summer months. During this time Mongolia is influenced by the northern hemispheric west wind drift. The south-eastern part may also receive some rains from the north-westernmost ridges of the monsoon, or these may reactivate the cyclones of the west wind drift (Barthel, 1983; Kripalani & Kulkarni, 2001; McGinnies, 1979). Rainfall is concentrated in the summer months from June to August: 65–75 % of the mean annual precipitation fall during this period. This temporal distribution is especially important

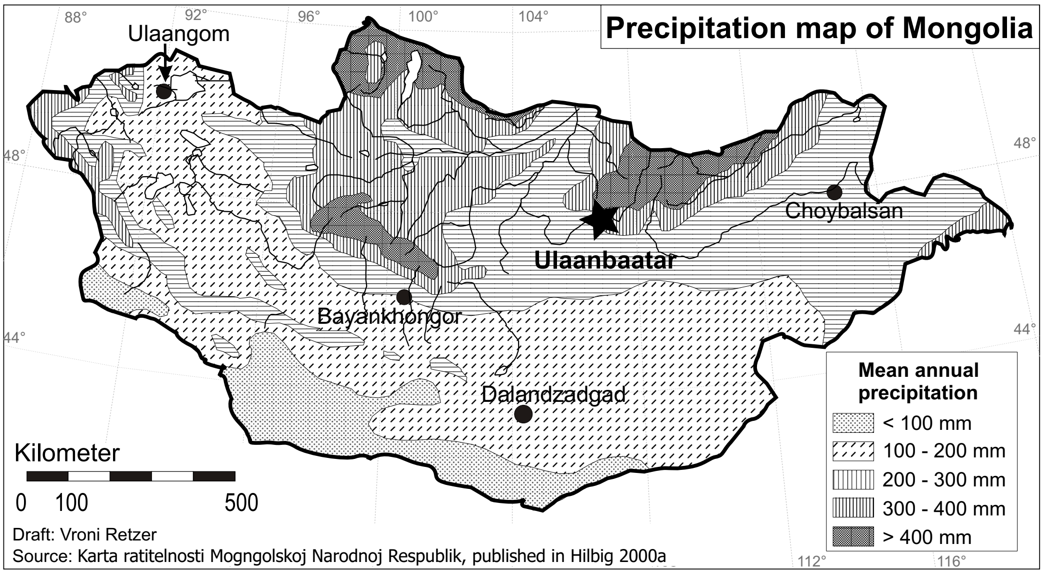


Figure 1.4.: Map of mean annual precipitation in Mongolia (after Hilbig 1995, changed in Hilbig 2000a).

for vegetation development. This means that most of the precipitation is available at a time during which the temperatures permit plant growth (Barthel, 1990).

In autumn (September and October) the influence of the west wind drift ceases and the anticyclone regains its influence. That results in an unsteady wind direction. The drop in temperatures is often relatively sharp and precipitation levels go down quickly. Cloud cover is low and this leads to strong diurnal temperature fluctuations. The first night frosts usually occur in September, and in October also the day temperatures often remain below zero.

The regional climatic differentiation is determined by two factors: latitude and altitude. The latitudinal differentiation with increasing precipitation, decreasing variability of precipitation, and decreasing temperatures is modified by the altitude. Similar gradients therefore run from southern Mongolia to northern Mongolia and from lower to higher elevations (Haase, 1983; Barthel, 1990).

Figure 1.4 shows the distribution of the mean annual precipitation in Mongolia. A clearly latitudinal zonation with increasing precipitation from South to North is overlaid by an altitudinal gradient. The great mountain ranges of the Khangai, Khentii, and the Mongolian Altai can easily be depicted on the map from the precipitation levels that are higher than in their surroundings. Other climatic parameters such as temperature, precipitation variability, and number of (semi-)arid months roughly follow the same pattern (Haase, 1983; Barthel, 1990).

The growing season is short in Mongolia. Temperatures permit plant growth usually from the beginning of May onwards. The daily average of 5°C is reached between April, 20^{th} and May, 10^{th} (Barthel, 1983). But as the rains do not set in until June, soil moisture is not sufficiently available. Parallel, temperatures rise continually. Consequently the highest soil moisture deficit occurs in spring. The winterly dormancy of the

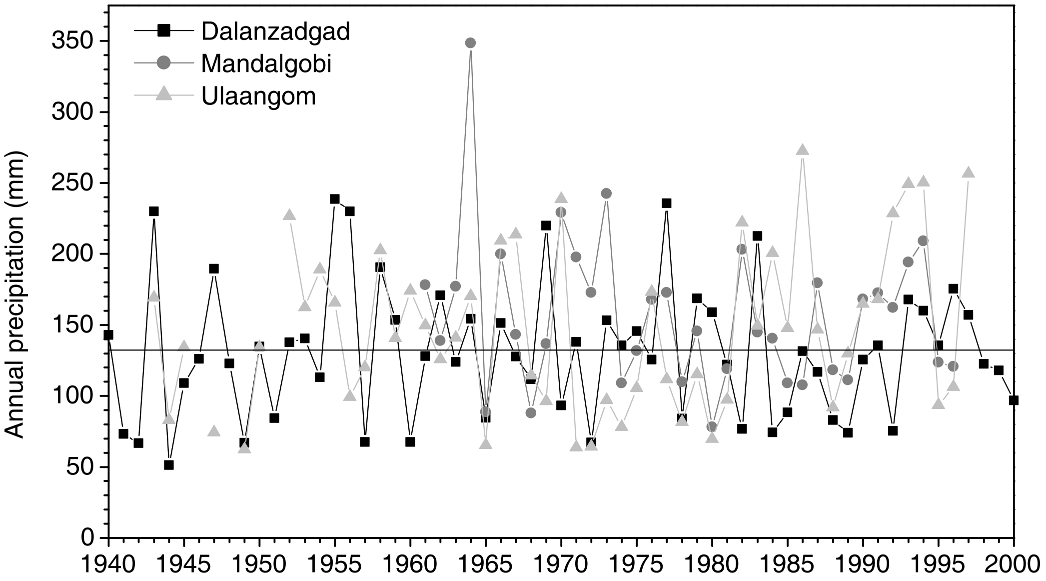


Figure 1.5.: Development of the annual precipitation from 1940 to 1998 at three stations in Mongolia: Dalandzadgad, Mandalgov and Ulaangom. The black line represents the average precipitation in Dalandzadgad during this period. Data from the National Statistical Office of Mongolia, cited in Bergius (2002).

vegetation is therefore prolonged by dryness in spring. Vegetation growth thus usually begins with the onset of the first adequate rains (Weischet & Endlicher, 2000). The growing season ends with first night frosts at the end of September. This is the time when daily mean temperatures drop below 5°C (Barthel, 1983).

Climatic variability

Climatic variability is of extreme importance for the nomadic pastoralism in Mongolia. On the one side the large inter-annual and spatial differences (fig. 1.5) in precipitation are the basis for the non-equilibrium behavior of large fractions of the Mongolian grasslands (see chapter 1.2.4, p. 34). However, by the herders these natural variations are perceived as hazards.

Natural hazards: drought and dzud Two extreme climatic events have dramatic impact on the pastoral economy of Mongolia: drought and dzud. The Mongolian term "dzud" describes harsh winter conditions, when sudden snowfall and ice cover bury the pastures, so that livestock cannot dig through to the vegetation below (Enkh-Amgalan, not dated). Often also the terms "white dzud" for the winterly dzud and "black dzud" for the summerly drought are used.

Drought and dzud result in the starvation of large proportions of the national herd (see also figure 1.8, p. 51). According to the statements of herders a severe winter is often followed by a drought (Mearns, 1993, p. 99). Historical losses of livestock production caused by drought and dzud (UN–Mongolia, 2001) are shown in table 1.3. Both hazards are not rare – on the contrary, the large variability of climatic conditions leads to frequent occurrences of these natural phenomena. These events are not a special situation but typical for the Mongolian environment. However, dzud events are extremely rare in the Gobi, due to the low amount of winterly precipitation.

Years	Disaster type	Coverage	Mortality adult		Mortality young	
			# (Mio.)	%	# (Mio.)	%
1874-75	dzud	eastern Mongolia				
1882-83	dzud	Gobi region				
1886-87	dzud	eastern & central				
1892-93	dzud	eastern Mongolia				
1894-95	dzud	Gobi region				
1900-01	dzud	central Mongolia				
1904-05	dzud	Gobi region				
1907-08	dzud	eastern Mongolia				
1912-13	dzud	eastern & northern				
1922-23	dzud	central Mongolia				
1925-26	dzud	central Mongolia				
1928-29	dzud	Gobi & central				
1931-32	dzud	central Mongolia				
1933-34	dzud	eastern Mongolia				
1935-36	dzud	Gobi & central				
1938-39	dzud	central Mongolia				
1944-45	drought&dzud	9 aymags, 65 %	8.1	33.2	1.1	17.0
1950-51	dzud	central Mongolia				
1954-55	dzud	9 aymags	1.9	8.2	0.3	4.0
1956-57	dzud	11 aymags	1.5	6.2	0.9	12.0
1967-68	drought&dzud	13 aymags, 80%	2.7	11.9	1.7	21.6
1976-77	dzud	15 aymags, 90 %	2.0	8.6	1.6	10.7
1986-87	dzud	11 aymags, 80 %	0.8	3.6	0.9	9.0
1993	dzud	3 aymags, 30 sums	1.6	6.4	1.2	13.0
1996-97	dzud	11 aymags, 69 sums	0.6	2.1	0.5	5.4
1999-00	drought&dzud	12 aymags, 157 sums	3.0	8.9	1.2	12.1

Table 1.3.: Frequency and severity of historical dzud and drought disasters. Aymags (province) and soums (district) are administrative units in Mongolia. Sources: for the period 1874–1951 Thiel (1985, p. 262) and for 1945–2000 UN–Mongolia (2001).

Potential impact of climate change During the Holocene the Central Asian region has seen many fluctuations in precipitation and temperature regimes (Lehmkuhl, 2003; Grunert et al., 2000; Walther, 2003). The long-term climatic trend in Central Asia since the holocene climatic optimum about 7000–8000 BP shows a trend of increasing aridity as can be judged from lake level fluctuations in northern China (Tarasov et al., 2000; Wünnemann et al., 1998; Wünnemann, 2003). Geobotanical findings show a recent aridization of the Gobi region (Gunin & Slemnev, 2000). Recordings of temperatures have shown a rise in air temperatures in the last century which was especially pronounced in the 1980s in Uzbekistan (Ososkova et al., 2000), on the Tibetan Plateau (Liu & Chen, 2000) and in Mongolia (Opp, 1996).

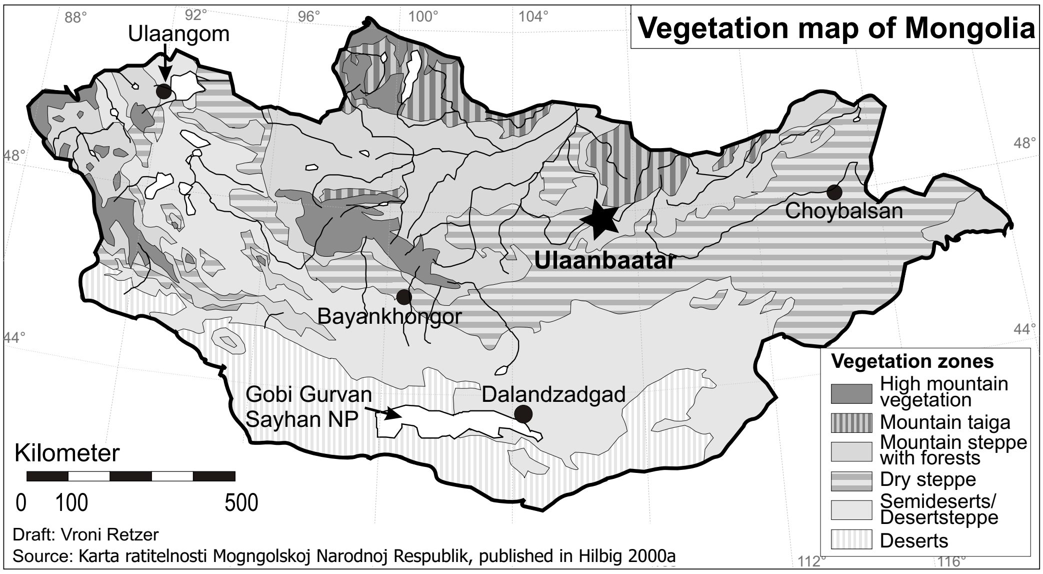
For temperate Asia global climate models project the mean annual surface temperature to rise by about 1.0—3.5°C by the year 2100. Warming is projected to be more pronounced in winter than in summer and in arid/semi-arid regions than in humid areas (Watson et al., 1997). The projections of the effects of climate change on precipitation are not consistent. "Model projections suggest that precipitation will increase slightly (0.5—1.0 mm/d) in the northern part of the region (Siberia) and by more than 1 mm/d over the Korean peninsula, the Japanese islands, and the south-western part of China. In contrast, precipitation changes show a decline in the northern, western, and southern parts of China [...]. The projected decline in rainfall over most of China is substantial in numerical experiments that include the effects of sulfate aerosols" (Watson et al., 1997).

For Mongolia and Inner Mongolia almost all models consistently predict an increase in temperature (Batima & Dagvadorj, 2000; Batima et al., 2002; Bolortsetseg & Tuvaansuren, 1996; Xiao et al., 1995). The data from tree ring chronologies in northern Mongolia also support an unusual increase in temperature during the 20^{th} century relative to the past 450 years (D'Arrigo et al., 2000; Jacoby & D'Arrigo, 2000; Pederson et al., 2001a). This trend can be seen in the temperature data since 1937 from Mongolian stations as well (Opp, 1996).

For the development of annual precipitation no clear trend is found. Although the dendroclimatic data display an increase in precipitation for the years preceding the 1940s, this increase is within the range of long-term variations (Jacoby et al., 2000; Pederson et al., 2001a). Data from three Mongolian climatic stations in Ulaangom, Mandalgov, and Dalandzadgad do not show a trend for the annual precipitation over the last 60 years (Bergius, 2002). Furthermore, projections of global climate models regarding the development of annual precipitation are inconsistent (Batima & Dagvadorj, 2000; Batima et al., 2002; Bolortsetseg & Tuvaansuren, 1996; Xiao et al., 1995).

The consequences for Mongolia's herding economy are still to be assessed. Bolortsetseg & Tuvaansuren (1996) predict the impact of climate change on pasture production to be negative in the Gobi zone area and favorable in colder regions. In the Gobi zone the effect of increasing evapotranspiration with increasing temperature will outweigh possible higher annual precipitation and therefore plant available moisture will decrease in the growing season. Therefore the effect of climate change on primary production will be negative, although the growing season is projected to become longer. It is projected that increasing temperatures lead to a general decline in livestock intake and average daily weight gain especially in late summer (Batima & Dagvadorj, 2000; Batima et al., 2002; Bolortsetseg & Tuvaansuren, 1996). Also Batima et al. (2002) and Batima & Dagvadorj (2000) project decreasing standing crop and significant negative impacts on the pasture capacity.

The zones of desert-steppe and desert are regarded as most vulnerable to climatic change (Batima et al., 2002; Bolortsetseg & Tuvaansuren, 1996). An expansion of drier vegetation zones into the regions of steppes and mountain and forest-steppes is projected,



Draft: Vroni Retzer
Source: Karta ratitelnosti Mogngolskoj Narodnoj Respublik, published in Hilbig 2000a

Figure 1.6.: Map of the vegetation zones of Mongolia (after Lavrenko et al. 1979, in Hilbig 2000a, adapted).

too (Batima & Dagvadorj, 2000; Watson et al., 1997). Gunin & Slemnev (2000) have already shown the expansion of drier *Ephedra* desert communities on the cost of *Stipa-Allium* desert-steppes in the Gobi region. All these results indicate that climate change may lead to a lower overall productivity of the livestock sector in Mongolia.

Vegetation

The distribution of vegetation zones follows closely the climatic gradient of precipitation and temperature. Again, this gradient is modified by the topographic situation especially in the high mountains of the Khangai and the Mongolian and Gobi Altai (Barthel, 1983), and additionally by anthropo-zoogenic land-use (Miehe, 2003). Following the gradient of increasing aridity, six zonal vegetation types can be distinguished from north to south (fig. 1.6): alpine vegetation, taiga, mountain-steppe and forest-steppe, steppe, desert-steppe, and desert (Hilbig, 1990, 1995, 2000a; Opp & Hilbig, 2003b). The terms steppe, desert-steppe, and desert are used and defined differently by many authors (Karamysheva & Khramtsov, 1995; Walter, 1990). Within this work the terms will be used according to the classification of Hilbig (1990) for Mongolia, and according to Wesche et al. (submitted) for the Gobi Gurvan Sayhan National Park.

In northern Mongolia some southern outposts of the Siberian taiga forest can be found. Mean annual precipitation is more than 400 mm (Hilbig, 2000a). It covers about 4 % of the Mongolian surface. Different *Larix sibirica*-communities with *Pinus sibirica* and *Abies sibirica* dominate the taiga forests (Hilbig, 1990). The valleys are often covered with swamps, because the permafrost layer does not allow water to infiltrate into deeper soil layers (Barthel, 1990). Alpine vegetation covers about 3 % of Mongolia. It is restricted to higher altitudes of the mountain ranges of the Khentii, Khangai, Khuvsgul, and Altai. The most common vegetation type in this zone are alpine *Kobresia*-mats (Thiel, 1985). These are preferred grazing grounds of yaks.

The zone of mountain-steppe and forest-steppe is again confined to the higher mountain ranges (Khentii, Khangai, and Altai). It receives between 300 mm and 400 mm of annual precipitation. The lower boundary of this zone is 1000–1200 m in the north, about 1400–1500 m further to the south-east, and about 1800–2000 m in the drier Mongolian Altai. For this zone a typical distribution of forest and steppe vegetation is characteristic. The northern exposures are covered with forest while the slopes with southern exposures carry open steppe vegetation (Gunin et al., 1999). This distinctive vegetation pattern is intensified or even created by human impact via fire, wood cutting, and livestock grazing. The forests consist of the same species as those of the taiga plus *Betula platyphylla*, *Populus tremula*, and *Ulmus pumila*, but are more open and have more dense understorey (Hilbig, 1990). Today, the forest only remains in the wetter northern exposition, where it creates and preserves favorable microclimatic moisture conditions. After clear-cutting permafrost thaws thus changing the microclimate and therefore forests may not be able to regenerate (Treter, 1996). The mountain-steppe consists of meadow-steppe communities which are rich in herbs. The dominant species are Poaceae such as *Festuca ovina*, *Koeleria gracilis*, *Poa botryoides*, and *Agropyron cristatum* (Hilbig, 2000b). The forest-steppes and mountain-steppes belong to the climatically favorable regions in Mongolia. Here human population density is highest, pastures are rich, and it is the only zone in which farming without irrigation is possible, although not free of risk (Barthel, 1990).

The eastern parts of Mongolia are largely covered with zonal steppe vegetation. The steppe-zone covers 26.1 % of Mongolia (Barthel, 1990). Vegetation cover and species richness decrease from north to south in this zone. Mean annual precipitation ranges from 200 mm to 300 mm (Hilbig, 2000a). The most important species is *Stipa capillata* and its allies Karamysheva & Khramtsov (1995). The southern border of its distribution also denominates the transition from steppe to even drier desert-steppe vegetation.

Characteristic species for all types of steppe are: *Koeleria macrantha, Agropyron cristatum, Poa attenuata, Potentilla bifurca, P. acaulis, Bupleurum bicaule, Veronica incana, Dontostemon integrifolius*, and *Thermopsis lanceolata* (Hilbig, 1990). The characteristic community of the steppe zone is the *Cymbario-Stipetum krylovii.* It is characterized by a high percentage of relatively high growing grasses, especially bunch grasses. The grasses include *Stipa krylovii*, *Cleistogenes squarrosa*, *Elymus chinensis*, *Koeleria macrantha*, *Agropyron cristatum*, and *Poa attenuata.* Two subassociation occur: the typical form and one with interspersed *Caragana microphylla*-shrubs. The latter is grazed intensively. The *Arctogeron gramineum* subassociation mediates between other communities on scree slopes, and the *Galium verum* subassociation connects to the wetter mountain-steppes (Hilbig, 1990). The steppes in general are good pastures, and are suitable for all kinds of livestock. The *Stipa-Aneurolepidium* type is preferred by the herders to the drier *Cleistogenes-Stipa* type (Thiel, 1985).

Further south the climate gets drier and the vegetation gradually changes to desert-steppe communities. Precipitation averages 100-200 mm per year (Hilbig, 2000a). The

Figure 1.7.: The animals in the focus of the study. From left to right: Mongolian Pika moving a stone, a stallion decorated with a blue scarf, cattle, fat-tailed sheep (upper row), Mongolian Pika watching out, camel with winter wool, yak at 2800 m, and a goat climbing on a wall (lower row).

desert-steppe zone covers 27.1 % of Mongolia (Barthel, 1990; Hilbig, 1990). The change is subtle in reference to species composition, but the vegetation cover gets sparser, and the plants show increasingly xeromorphic features (Thiel, 1985). Characteristic are grasses, above all the small species of the genus *Stipa* from the series Barbatae, especially *S. gobica*, and *S. glareosa*. The desert-steppes (or semi-deserts) can be subdivided into the main subtypes shrub-semi-deserts with *Caragana leucophloea*, and *Eurotia ceratoides*, and *Stipa-Allium*-steppes with *S. glareosa*, *Allium polyrrhizum*, *A. mongolicum*, and *Anabasis brevifolia* (Hilbig, 1990).

The driest vegetation units (<100 mm/a) in the southernmost parts of Mongolia belong to the desert zone (Hilbig, 2000a). This zone occupies about 15.5 % of the Mongolian territory (Barthel, 1990; Hilbig, 1990). It extends further south into neighboring China. A large percentage of the area is covered with gravel and scree with only very low vegetation cover. The most important components of the vegetation are shrubs and semi-shrubs from the families of Chenopodiaceae (such as *Anabasis, Haloxylon, Iljinia, Kochia, Salsola*), Asteraceae (*Ajania, Artemisia*), Polygonaceae (*Calligonum, Atraphaxis*), Zygophyllaceae (*Zygophyllum, Nitraria*), Tamaricaceae, Fabaceae, and Convolvulaceae (Hilbig, 1990). A prominent vegetation type is that of saxaul *Haloxylon ammodendron* shrublands. Saxaul is a leafless tree or shrub with green shoots and extremely hard wood. Camels graze saxaul, and generally are the kind of livestock best suited for the desert zone (Thiel, 1985).

1.3.2. Pastoral land use in Mongolia

Almost 80 % of the Mongolian territory is grassland forming suitable pasture for nomadic pastoralism (Barthel, 1990). Arable land consisted of less than 0.5 % in the 1980s

(Barthel, 1990) and is even less nowadays (Bastian, 2000). Livestock herding contributes almost 36.5 % of the Mongolian Gross Domestic Product, and 48.6 % of all people are employed in agriculture, hunting, and forestry (figures from 2000, National Statistical Office of Mongolia, 2001).

Mongolian herders own five kinds of livestock: camels (Bactrian type), horses, cattle/yaks, sheep and goats. The proportion of the species varies with the ecological zone (Bazargur, 1998). The percentage of camels is higher in the Gobi, while cattle numbers are higher in central Mongolia. Yaks are herded only in regions with high mountains (Bazargur, 1998; Mongolian Atlas, 1990).

The diversification of the herd by managing mixed flocks with different grazing strategies minimizes the risk and allows herds to exploit unevenly distributed resources (Oba et al., 2000). For example, sheep, cattle and horses which are grazers and goats and camels which are browsers use different plant resources. Within the two groups of browsers and grazers the animals are further differentiated by their body size. Mixed animal grazing therefore optimizes the use of different forage resources (Duffy, 2002; Nolan et al., 1999). Mixed livestock flocks can be regarded as a sort of a grazing "lawnmower" because together they make use of virtually all available forage (Coppock et al., 1986; Kay, 1997).

All traditionally kept breeds of livestock are well adapted to the local environmental conditions and can resist harsh weather conditions (Tumurjav & Tsolmon, 2000). They rapidly build up fat reserves in the growing season to survive the strong winter. Camels store fat in their hump, sheep in the fat tail. Yaks, camels, and goats (cashmere!) develop winter down which prevents their bodies from the cold (Suttie, not dated).

Prehistoric times

Most likely the Gobi was used already by hunter-gatherer populations in the Palaeolithic. Colonization took place during the early Upper Palaeolithic (45–22ka) and again in the late Upper Palaeolithic (18–10ka), while the populations were possibly extirpated in between during the extremely cold and arid Last Glacial Maximum (22–18ka) (Brantigham et al., in press). These findings correspond to palaeoclimatic findings on lake levels (Lehmkuhl & Haselein, 2000; Walther, 1999) and on permafrost development and degradation (Owen et al., 1998). Highly developed Neolithic economies were present in the lower elevations of the Tibetan Plateau about 5000 years BP (Brantigham et al., 2001). From these Neolithic communities pastoralism in Mongolia may have developed about 5000 years BP (Chang, 1986 in: Brantigham et al., 2001).

The onset of nomadic pastoralist land use in the holocene is difficult to determine. Grunert et al. (2000) interpret the formation of parabolic dunes and barchanes at 5000 years BP in north-western Mongolia as being not only climatically induced, but facilitated by being grazed by large herds of domestic livestock.

Frank Schlütz from the University of Göttingen, who investigated pollen data from our study region, found that grazing influence has been abundant within all the profiles, which date back up to 2500 years BP (Schlütz, 2003, , pers. comm.). S. Fowell and co-workers found Urticales-pollen as indicators for grazing starting in a depth of 237 cm which corresponds to about 4100 years BP in their cores from lake Telmen. *Allium* species and the grazing weed *Iris* are common today, but no pollen of these species could be found in the samples from the core. (Fowell et al., 2003, and pers. comm.).

Furthermore, archeological findings indicate that different nomadic people have used the territory of Mongolia since the 3rd century BC (Brentjes, 1988 in: Müller, 1999).

Although the onset of nomadic pastoralism in Mongolia cannot be pinpointed to a certain date or period, it is safe to conclude that the country has been used for the grazing of domestic livestock for millennia.

Historical land use: 13^{th}–20^{th} century

The first written documents on the land use date back to the times of Chinggis Khan in the 13^{th} century. The customary law was laid down in a written form, the Great Yassa law-code in 1229. This, among others, included the permission of rotational use of pastures by individual families or small herding communities, the so-called khot ails. The main guidelines were ethical norms such as friendship and mutual assistance. The organizational structure was the tribe, and animals were herded in large groups (Mearns, 1993; Müller & Bold, 1996).

From the 17^{th} until the beginning of the 20^{th} century Mongolia was under imperialist rule of the Manchu Chinese. All land rights formally belonged to the emperor, who gave land rights as fief to the nobility or high ranking lamas (Buddhist monks). The noble himself used the best pastures and let the other land to his herders, who had to remain in the administrational unit in which they were born. The herders united in informal groups and served a noble. Herds were managed at the level of khot ails and were therefore smaller than previously (Mearns, 1993; Müller & Bold, 1996). Little is known about the numbers of wild large herbivores during this period. But Schaller (2000) describes large herds of wild ungulates on the Tibetan Plateau, perhaps numbering millions, as late as in the late 1890s.

Socialist period 1921-1990

In 1911 Mongolia gained autonomy from the Manchus, and the Soviet-inspired revolution of 1921 resulted in the formation of the Mongolian People's Republic in 1924. At this point all land was transferred into state property and the herders gained freedom of movement. At the beginning of the 1930s an administrative reorganization was carried out. The old network of nobles and monasteries was deprived of power and more than 900 monasteries were physically destroyed. This resulted in a total breakdown of the social and economic infrastructure. This time was somewhat anarchic and de facto no regulations concerning the use of pastures existed until 1947. What remained and survived were the khot ails (Mearns, 1993; Müller & Bold, 1996; Müller & Janzen, 1997).

In the 1930s the first attempt to collectivize the pastoral economy was an absolute failure. The next attempt in the 1950s was much better organized and successful. By 1959 99.3 % of all herder families had joined the cooperatives, the so-called nedgel. The negdel then accounted for 73.3 % of the national herd. The remaining livestock was owned privately (50–75 private animals were allowed). The herding in the negdel was restructured. Two to three families jointly herded animals of one species (and often one sex or age structure). The size of the herd depended on the kind of livestock and ranged from about 300 camels to about 1000 sheep. The grazing rights were transferred to the negdels and within those the decisions on the movements of herders were made. Except for the change in herd composition, in practice almost everything remained the same for the herders (Mearns, 1993; Müller & Bold, 1996; Müller & Janzen, 1997).

In the 1950s a new secular infrastructure network was built up. An elaborated system of urban centers from aymag down to soum and brigad centers replaced the old ecclesiastical Buddhist centers. Often those settlements were erected on or near the old place of a monastery, and "soum" even means church in Mongolian. The communist government tried to settle the nomads, and the level of urbanization increased. The soums hosted all necessary infrastructure such as hospitals, schools, post and telecommunication office. In the 1970s soums and negdels were united. The pastoral production and administration should be managed as a unity. The average negdel-soum was about 5000 km^2 in size, and owned 68,000 head of livestock (Mearns, 1993; Müller & Janzen, 1997).

With the introduction of the negdels the communists aimed at increasing production efficiency. Increased efforts were made to optimize the pastoral economy. A transport system with trucks was set up, which was used for long-distance movements of herds. A state-wide distribution system of hay and forage for difficult winters and dzud was installed. Even an insurance against disastrous livestock losses during dzud was introduced. Moreover, 40,000 new wells were dug and more than 60,000 winter shelters were built. A veterinary service took care of livestock health. The breeding of new sheep and goats breeds with higher wool and cashmere production was successful (Mearns, 1993; Müller, 1999; Potkanski, 1993).

Transformation since 1990

The collapse of the communist system in the Soviet Union in the early 1990s also was the starting signal for the political transition of the Mongolian People's Republic into a democratic free-market economy. The transformation in Mongolia was one of the smoothest transitions of all post-communist countries (Fish, 2001). The first free elections took place on February 26th, 1992 (Bastian, 2000). As with the dissolving Soviet Union also the monetary assistance for the formerly satellite state ceased, a rapid restructuring was necessary (Müller, 2003).

The land remained state property and for pastures private ownership was explicitly not allowed (Law of Mongolia on land, Anonymous, 2002). Since then land users have to pay land use fees depending on the number of livestock they herd (Law of Mongolia on land fees, Anonymous, 1997). Livestock and the means of production on the other hand were rapidly privatized. The privatization of the negdels was already completed by 1992/3. Also people who formerly had not belonged to the negdel could participate in the privatization of livestock. This resulted in relatively small herds of mixed stock. Parallel, the organizational support from the negdel such as the veterinary and transport services broke down. Moreover, the trade with livestock products broke down because spare parts for the repair of the Russian trucks were missing, fuel was scarce and road conditions deteriorated due to lack of maintenance. Herding regulations did not exist anymore and the herding economy was thrown back to subsistence level. Overall, the situation was very similar to the 1930s. In this situation herders reorganized themselves on a small scale in khot ails (Bazargur et al., 1993; Cooper, 1993; Janzen & Bazargur, 1999; Mearns, 1996; Müller, 1994; Schmidt, 1995; Sneath, 1993).

The political transformation and the breakdown of the communist system resulted in the dismissal of many former state employees and a high unemployment rate in the aymag and soum centers. Many of these jobless people returned to the countryside and started to make a living as pastoralists, the so-called "new nomads" (Mearns, 1993; Müller & Bold, 1996; Müller & Janzen, 1997; Müller, 1999).

The number of livestock-owners increased by the factor 2.8 from 1989 to 1994. But not all of these stock owners necessarily herd their animals themselves, many give especially small numbers to relatives. Müller (1994) reports that in 1992 and 1993 each year 20–30 % of the families in soum-centers actually moved into the countryside. A high percentage of the livestock also was simply slaughtered and consumed during the difficult economical situation at the beginning of the 1990s. The percentage of people employed in agriculture rose from 32 % in 1989 to 49.5 % in 1999, parallel the share of agriculture at the national gross domestic product rose from 15.5 % to 36.5 % (UN common country indicators Mongolia, National Statistical Office of Mongolia, not dated). Both figures not only demonstrate the increasing importance of the pastoral sector, but also reflect the collapse of the industrial sector (Forkert, 1993).

Parallel to the migration drift towards the countryside the composition and size of the national herd changed dramatically (fig. 1.8). The numbers of goats increased, because they produce the high-priced cashmere wool, while the numbers of camels decreased, probably because these animals are difficult to herd in small groups. The overall number of livestock increased tremendously. Two factors contribute to this development. For one thing a higher number of people relied on livestock for their livelihoods. Especially the new herders were interested in accumulating enough stock to live of the herd without continually depleting it. As a rule of thumb, at least 100 head of livestock are needed to feed a small family.

Moreover, with the breakdown of the marketing structures the possibilities to get financial return from the sale of spare stock diminished (Forkert, 1993; Janzen, 2000). The second factor is the development of the precipitation pattern in the early 1990s (fig. 1.5, p. 41). Especially in the years 1991–1994 precipitation in Mongolia was continually above-average. This is a strong contrast to the distribution of annual precipitation, at least since the beginning of the regular recordings in Mongolia. Usually above- and below-average years alternate frequently.

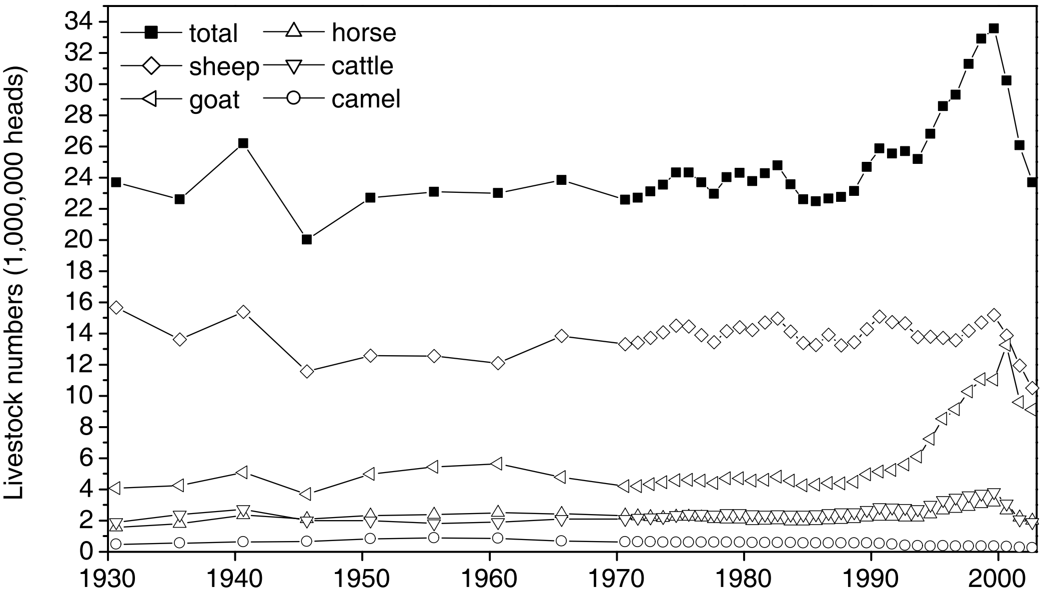


Figure 1.8.: Development of livestock numbers and species composition in Mongolia from 1930 to 2002. Data from the National Statistical Office of Mongolia (1996, 1998, 2000, 2001, 2002, 2003) and UB Post N°4/2003.

A first slowing down of the continual increase could be observed in 1995/6. But until 1999 livestock numbers increased further to a historical maximum of 33,568,900 head of livestock (fig. 1.8). This is about 1.4 times of the average number for the period from 1930 to 1990. But the bad weather and pasture situation from 1999 to 2002 led to an equally dramatic decrease in livestock numbers. At the end of 2002 23,700,000 head of livestock were counted (UB Post, 2003a), a number which is comparable to the average livestock densities reached during the socialist period (National Statistical Office of Mongolia, 1996, 1998).

A further development of privatization was the reduction of frequency and distance of herders' movements (Müller, 1994). There are several reasons for this reduced mobility. In search of better living and production conditions herders congregate along the major traffic lines and rivers (Janzen & Bazargur, 1999). These settlements again attract more and more nomads because of the market opportunities and the possibility of additional non-pastoral economic activities (Bazargur, 2000; Müller & Janzen, 1997). The attraction of soum centers is also high because of the available infrastructure. This is paralleled by a migration drift of people in search of extra-pastoral opportunities towards the large cities (Janzen & Bazargur, 1999, 2003; Janzen, 2000) and the gap between rich and poor is growing (Cooper, 1993; Janzen, 2000).

The mobility of Mongolian herders is crucial for the sustainable use of the pastures. High mobility as a strategy to exploit highly variable environments has been called "opportunistic" management (Westoby et al., 1989), and that holds true: herders make best use of the environmental opportunities. The dramatic consequences of reduced mobility can be observed in Inner Mongolia (China) where the grazing lands have been fenced (Dee Mack, 1996; Humphrey & Sneath, 1999; Katoh et al., 1998; Neupert, 1999; Sneath, 1998, but see also Runnström 2003). Policy makers need to provide incentives to maintain or even improve the mobility of the Mongolian herders. As Ho (2001); Humphrey & Sneath (1999, p. 3) stated: "maintenance of herd mobility is the main key to sustainable pastoralism in the region".

With the increase in livestock numbers in the 1990s the concern over possible degradation by "overgrazing" arouse (Opp & Hilbig, 2003a). Especially the rising proportion of goats caused worries because they are believed to destroy pasture by pulling out perennial plants with the roots (Batkhishig & Lehmkuhl, 2003; Müller & Bold, 1996). However, up to now no clear causal evidence of degradation away from the immediate surroundings of centers of utilization could be found (see Sullivan & Rohde, 2002).

As stated above (see chapter 1.2.4, p. 34) the vegetation of a grazing system which behaves mainly in a non-equilibrium way should not be drastically affected by the observed changes in livestock densities. But the destruction of the regeneration ability of perennial plants has devastating impact, also in a non-equilibrium system. Nevertheless, the question remains what effects potentially increasing amplitude of livestock densities may have on resources such as soil fertility (Batkhishig, 2000). Changes of this kind may drive the whole system into a new and less favorable state (Schulte, 2001).

1.3.3. Ecosystem dynamics in Mongolia

According to the description of equilibrium and non-equilibrium models the ecosystems in Mongolia can be put in the gradient from equilibrium to non-equilibrium ecosystems. Ellis (1995) and Ellis & Chuluun (1993, both cited in Fernandez-Gimenez & Allen-Diaz, 1999) suggest that in Mongolia regions with a coefficient of variation in annual precipitation of more than 33 % and mean annual precipitation of less than 250 mm are driven by non-equilibrium dynamics. Ecosystems in the drier south should therefore behave in a more non-equilibrium way, and those in the wetter north more in a equilibrium way. The same precipitation gradient can be found with increasing altitude.

Fernandez-Gimenez & Allen-Diaz (1999) investigated the dynamics in the desert-steppe, steppe and mountain-steppe ecological zones of Bayankhongor Aymag. The dynamics there of course are more complex than can be predicted from such a generalizing model. But nevertheless they found that the vegetation of the ecological zones of mountain-steppe and steppe which receive more precipitation, react sensibly to grazing pressure. In contrast, the vegetation of the drier desert-steppe did not show any significant variation in species composition along a grazing gradient. The authors therefore concluded that this zone basically reacted in a non-equilibrium way (see also Fernandez-Gimenez & Allen-Diaz, 2000).

Basically, the same results were obtained by Miehe (1998) in her investigations on the vegetation of the Gobi Gurvan Sayhan National Park. Although she does not focus on non-equilibrium – equilibrium dynamics in her work, indicators for the ecosystem dynamics can be found in her study: for the whole area she found it difficult to name plants which serve as indicators for intensive grazing. This is an indicator for the prevalence of non-equilibrium dynamics in the whole area because it shows that defense mechanisms against being grazed do not pay off in terms of higher abundance. This in turn is typical for non-equilibrium environments. Under non-equilibrium conditions defense mechanisms are not advantageous because in good years when there is a surplus of forage almost all plant species can complete their regenerative cycle.

But she also found indicators for increasingly equilibrium-dynamic with increasing altitude, which is equivalent to increasing precipitation in this area (see chapter 3.3.1, p. 138). In the wetter (mountainous) regions she found only few toxic species (*Stipa inebrians, Arenaria meyeri*) and two less palatable species as well (*Artemisia frigida, A. santolinifolia*), while all species in the desert-steppe zone (pediment) were consumed by livestock, at last at some time during the year. The classification of *Artemisia frigida, A. santolinifolia* as "less palatable" is questionable, because herders classified these species as high quality forage in interviews of the author and Stumpp (2002) and *Artemisia frigida* was grazed intensively on the plots of the exclosure experiment.

The non-equilibrium character of the pediment zones in the Gobi Gurvan Sayhan National Park is further underlined by soil and vegetation investigation from centers of utilization by Stumpp (2002). Apart from the immediate surroundings of these wells and springs he could not find any significant connection between grazing pressure and vegetation composition. Although a significant gradient in soil nutrient (C and N content) could be found.

Also the works of Rachkovskaya (2001) on the degrees of anthropogenic transformation of vegetation in the Gobi point towards increasing vulnerability and degradation with increasing humidity.

From this evidence we can conclude that large fractions of the drier regions in Mongolia can be classified as non-equilibrium ecosystems. In detail, the location of the research camp reacts mainly in a non-equilibrium manner, while the vegetation in the mountains tends towards a more equilibrium, and that in the desert in the lower elevations to an even more non-equilibrium behavior.

1.4. Introduction to the Gobi Gurvan Sayhan National Park

The Gobi Gurvan Sayhan National Park is situated in the south of Mongolia in the South-Gobi Aymag. Figure 1.9 shows the park boundaries, the main settlements around it, roads and the relief. The park has been named after the Gurvan Sayhan mountain range which means "Three Beauties of the Gobi". Covering an area of more than 21,700 km^2 square-kilometers the Gobi Gurvan Sayhan National Park is among the largest national parks worldwide (Reading et al., 1999a). It has been extended in the north-western border in 2001, but the new coordinates of the boundaries are not available yet (H. von Wehrden, pers. comm.).

The mountain ranges of the Gobi Gurvan Sayhan are green islands in the semi-desert and desert-steppes surrounding them (Wesche et al., submitted). This is why they are called the "Three Beauties of the Gobi": for the herders in constant search of good pasture "green" is equivalent to "beautiful". The mountains usually receive more precipitation than their surroundings and "host the moistest and most productive plant communities apart from the salt meadows" (Wesche et al., submitted) within the region. On the other hand the grazing range in the mountains is regarded as being dangerous for especially small or young livestock because it is the home of many wild predators such as Pallas' cat, lynx, snow leopard and wolf (see also Reading et al., 1999a). For the herders the mountain ranges also provide one of the most extreme outposts of suitable habitat for yaks. Here is one of the rare regions where the grazing range of camels and yaks overlap, at least occasionally.

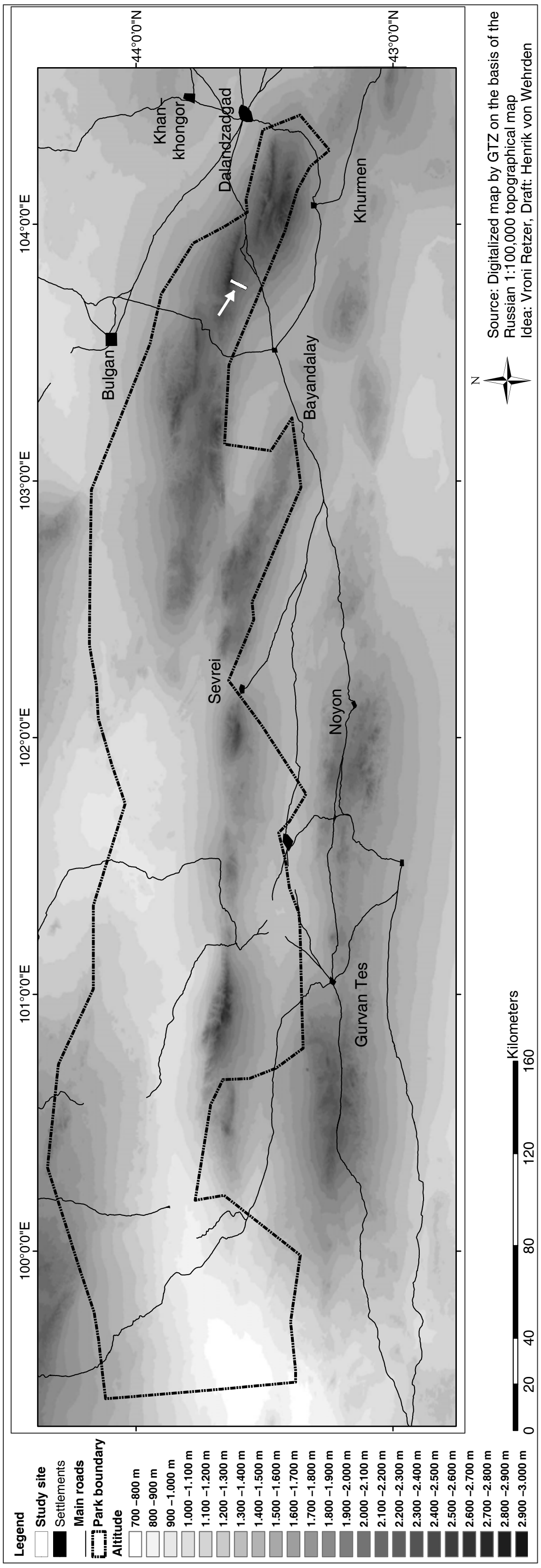
The mountains can be regarded as habitat islands for the plant and animal species which inhabit them. They are isolated outpost of the Gobi Altai, the next suitable habitat can be found only in other mountain ranges of the Gobi Altai several 100 km towards the north-west. As the Gobi Altai is not a continuous mountain chain, but broken into many smaller pieces (Barthel, 1990), every range is an island in a sea of semi-desert. For mountainous plants, such as *Galitzkya macrocarpa, Potentilla ikonnikovii, Saussurea saichanensis*, and *Papaver saichanense*, and animals, such as the ibex, argali, lynx, or snow leopard, the setting of the Gobi Gurvan Sayhan therefore presents an island biogeographical situation sensu McArthur & Wilson (1967).

1.4.1. Formation and history of the park

The park was established in 1993 following a suggestion of the World Wide Fund for Nature (WWF, 1993). It included the Yolin Am area in the Dzuun Sayhan which has been under protection since 1965 (Hilbig & Tschuluunbaatar, 1989).

Conservation objectives of the park are: guaranteeing long-term sustainable use, protection of rare wildlife, and (endemic) plant species, and special landscape features as well as the undisturbed development of the ecosystems (Reading et al., 1999a; WWF, 1993).

In order to meet these goals the park has been split up into zones of different usage (The South Gobi National Protected Areas' Administration, not dated). Six "special zones" in which no human use except scientific research and grazing during times of necessity is allowed. These zones are primarily based on the distribution of rare wildlife in the park. Within the Gurvan Sayhan range all high mountain areas are designated "special zones". Around the "special zones" so-called "tourism zones" have been established which serve as a buffer towards the "limited-use zones" which cover the rest of the area of the park (Steinhauer-Burkart, 1999; WWF, 1993). The zonation exists on paper, but apart from a few entrance signs on the main roads no marks of the zonation itself can be found in the landscape.



Source: Digitalized map by GTZ on the basis of the Russian 1:100,000 topographical map
Idea: Vroni Retzer, Draft: Henrik von Wehrden

Figure 1.9.: Topographical map of the Gobi Gurvan Sayhan National Park. The study site is indicated by an arrow. Figure 1.12, p. 71 gives a more detailed overview over the study area.

The park administration is located in the Aymag capital Dalandzadgad. It employs an administrative staff of seven and eleven rangers. The GTZ (German Technical Cooperation) assists via their "Nature Conservation and Bufferzone Development project" (Reading et al., 1999a; Schmidt, 2002) in park management and staff training, and contributes to scientific base-line studies on vegetation (Dasch & Tschimedregsen, 1996; Miehe, 1996, 1998; Wesche & Nadrowski, 2000), wildlife (Lchagwasuren, 1996; Mix, 2000; Reading, 1997; Reading et al., 1996, 1999a), livestock management (Bedunah, 1998, 2001a,b), and socio-economy (Bazargur, 1995).

1.4.2. Geological and geomorphological features and soils

The Gobi Gurvan Sayhan National Park is part of the Gobi Altai mountain range (Haase, 1983). The Gobi Altai is the south-easternmost outcrop of the Altai mountain ranges and the part with the lowest altitudes. While the Ikh Bogd still reaches 3957 m, the highest peak of the Gobi Gurvan Sayhan range is the Dzuun Sayhan which reaches 2815 m above sea level. The Gobi Altai is barely wider than 100 km and is composed of many separate small mountain ranges (Haase, 1983).

The Gobi Altai-Terran has been formed in the Palaeozoic during the Ordovicium, Silur and Devon periods (Mongolian Atlas, 1990). The rocky mountain ranges consist mainly of gabbros, sandstones, slate, and tonalit, while granodiorites are only of minor importance. Regionally volcanic rocks (basalts) are interspersed. These layers were covered with sediments (sandstone and claystone) in the upper Cretaceous period of the Mesozoic (Mongolian Atlas, 1990). During the Tertiary the formation of mountain chains started when the basement blocks broke up along the WNW-ESE running Gobi Altai structure fault.

The mountain ranges of the Gobi Altai are therefore a relatively young range and the area still is tectonically active. As recently as 1957 one of the world's largest recorded intra-continental earthquakes (Barthel, 1990; Bayarsayhan et al., 1996; Kurushin et al., 1997) in the Ikh Bogd area killed 1200 people (Asian Disaster Reduction Center, 2003). Also the region around Dalandzadgad is subject to frequent earthquakes (Mongolian Atlas, 1990). However, the pediments formed parallel to the uplifting of the mountain ranges are of remarkable stability (Haase, 1983) apart from small-scale tectonic interruptions.

In the park glacial remains have not been described previously, but Wesche et al. (submitted) detected remains in two locations. They found buried morainic substrate at the southern slope of Nemegt Uul (2220 m) and in the Barun Sayhan range (Gegeetiyn Am) at 1850 m, as well as deposits in form of a terminal moraine.

Within the Gobi Altai three major landforms can be differentiated: mountain ranges, pediments and inter-montane basins (Haase, 1983; Murzaev, 1954). The mountains are characterized by deeply intersected valleys and steep slopes. On the stabler slopes solifluction under grass cover can be found, while the steeper slopes are covered with scree. Frost-weathering is common.

The rocky mountain massifs are embedded in gently sloping pediments. The pediments are linearly eroded by gullies, which are only temporarily water-filled. The pediment angle, which separates the plain pediment area from the mountains, is found at about 2350 m at the Dund Sayhan. The pediments reach down to the inter-montane basins between 1300 m and 1500 m. The main geomorphological processes are water erosion after high intensity rainfall events and permanent eolian erosion especially during the storms in spring. The surface of the pediments therefore is covered with deflation pavements. "Wüstenlack", desert varnish on rocks, indicates that the pediment surface is long-term stable – with the exception of the gullies. The inter-montane basins are areas of inland drainage. They are sometimes filled with salt pans or salt water lakes which expand and retreat according to available moisture. The park features one impressive sand dune, the so-called singing sands of Khongoryn Els, but sand dunes are not common (Jäkel & Grunert, 2003). About 6 % of the area of the national park are covered with sand dunes (Von Wehrden, 2003).

The Gobi Gurvan Sayhan is situated in the soil geographic zone of Burozem steppe-desert soils as described by Hardin (1968). The toposequence of soil types is relatively similar to the one described by Haase (1983) for the Bayan Tsagaan. Where water is near the surface in the inter-montane basins, salt-dominated soil types such as Solonetzs and Solonchaks prevail. On the sand dunes Arenozols are found.

The Burozem is the most important soil type on the pediments. From the inter-montane basins towards the pediment angle the Burozems get better developed and change from a light towards a dark Burozem (see also Borisova & Popova, 1985). The concentration of rain in the summer months provides enough percolating water for the transport and re-distribution of especially Calcium and dissolved salts. Deeper layers of the Burozems horizons frequently show clay accumulations which cannot be explained under recent climatical conditions. Haase (1983) interpret these Bt-horizons as remains from very early soil formation processes, possibly in the Pleistocene or Tertiary. On the southern slopes of the mountain ranges the Burozems are replaced by Castanozems which change from a light to a dark version with increasing altitude (see also figure 3.2). They differ from the Burozems in that they lack carbonate and contain more humus. The northern side of the Dund Sayhan is covered with Loess sediments on which Chernozems and Parachernozems are developed. They may have been formed under a more humid period in the Atlanticum (T. Hennig, pers. comm.).

1.4.3. Climate

As the Gobi Gurvan Sayhan National Park is situated in southern Mongolia, the temperatures are higher, and precipitation totals lower but more highly variable than the Mongolian average (see chapter 1.3.1, p. 39).

All meteorological stations within and around the park are situated at lower elevations in the inter-montane basins. Therefore no records of the altitudinal variations are available. Indirect parameters, basically vegetation have to be used to estimate the changes in precipitation with increasing altitude.

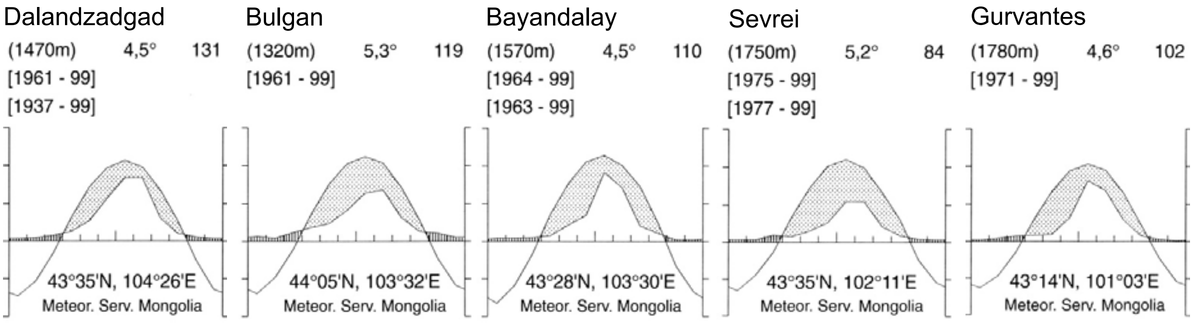


Figure 1.10.: Walter-Lieth diagrams of the climatic stations within the park, sorted from east to west. Data from the Meteorological Service Mongolia (1937-1999), draft, C. Enderle, Department of Geography, Philipps-University Marburg.

For the climate station of Dalandzadgad (43°35'N, 104°25'E) at 1470 m the mean annual temperature is 4.5°C (fig. 1.10). The lowest monthly mean is -14.5°C in January and the highest temperatures are reached in July with an average of 21.3°C. The patterns of the other stations in and around the Gobi Gurvan Sayhan National Park are similar.

The mean annual precipitation of Dalandzadgad is 131 mm. In contrast to the temperatures within the park, there is a clear trend of increasing aridity from east to west (Bergius, 2002). This is also obvious in the distribution of vegetation units (Miehe, 1996, 1998; Von Wehrden, 2003; Wesche & von Wehrden, 2002). This kind of distribution may be the result of the last weak outliers of monsoonal influence from southeasterly directions (Barthel, 1983; McGinnies, 1979). The ranges of the Gobi Gurvan Sayhan block these clouds and receive more rain than the westerly ranges.

Although the influence of the monsoon is much questioned for Mongolia (Weischet & Endlicher, 2000), it seems to be a suitable explanation, at least for parts of the observed pattern (see also Yatagai & Yasunari, 1995). The western mountain range of the Nemegt Uul is situated more than 150 km west of the Dzuun Sayhan and reaches almost the same height (2769 m versus 2815 m), but the vegetation indicates much drier conditions than that around the Dzuun Sayhan (Miehe, 1998; Wesche et al., submitted). If the main rain really came with the west wind drift, the situation would be reversed.

However, climatological data from the region of the park are too scarce to draw any final conclusion at this point. But the possibility that the monsoon may have at least partial influence on the precipitation gradient within the park cannot be rejected yet.

1.4.4. Flora and vegetation

The Gobi desert belongs to the Central Asiatic desert region. It is distinguished from the steppe zone, which covers the larger part of Mongolia. While in the steppe zone tall grasses and forbs dominate the physiognomical character of the vegetation, these are replaced by dwarf semi-shrubs and small bunch grasses in the Gobi desert (Hilbig, 1995; Karamysheva & Khramtsov, 1995).

The differentiation of the floristic regions is similar. The steppe flora is part of the Mongolian sub-region of the Central Siberia-Dauria-Mongolian region, while the desert flora belongs to the Central-Asiatic region (Malyshev, 2000). However, both are sometimes included in the Central-Asiatic region (Meusel et al., 1992).

Flora

The flora of the Gobi Gurvan Sayhan National Park is composed of about 600 species. Most of these are common in Mongolia and in the surrounding countries. Less than ten are endemic or sub-endemic to the Gobi Altai. Most of these belong to difficult taxonomic groups so that their taxonomical status and thus their degree of endemism is not well established yet. Most of the well-known sub-endemics of the Gobi Altai, *Galitzkya macrocarpa, Potentilla ikonnikovii, Valeriana saichanensis, Saussurea saichanensis*, and *Papaver saichanense*, have their habitat in the high-altitude rocky outcrops or swards of the mountain ranges. There they are relatively abundant and not directly affected by livestock grazing (Undrakh et al., 2003; Wesche et al., submitted; Wesche & Undrakh, 2003).

The vegetation of the semi-desert is characterized by woody perennials, among which the family of Chenopodiacea shows the highest species diversity. *Reaumuria soongorica* (Tamaricaceae) and *Caragana leucophloea* (Fabaceae) are other characteristic species. Typical representatives of the herbaceous plants are pennate feather grasses of the closely related species *Stipa glareosa* and *S. gobica* as well as several onions (*Allium mongolicum, A. polyrrhizum*). Furthermore, several herbaceous species of Fabaceae from the genera *Astragalus* and *Oxytropis* and dwarf-shrubs such as *Artemisia frigida* dominate the vegetation.

Phanerophytes are generally rare. They only found primarily in extrazonally moist, mostly montane habitats. Examples are stands of *Betula platyphylla* and *B. microphylla* in the Dzuun Sayhan which connect to similar stands in northern and central Mongolia (Grubov, 2001). Saxaul (*Haloxylon ammodendron*) is one of the most characteristic species of the Gobi. True Saxaul forests are rare, however, more commonly Saxaul forms various types of open semi-desert shrublands which cover vast areas in the driest desert regions of the park. Furthermore, two poplar species can be found: a single small *Populus laurifolia* gallery forest in the Dzuun Sayhan mountains, *Populus diversifolia* woodlands constitute dense stands and even forests in the oases in the western semi-deserts of the park (Von Wehrden & Wesche, 2002; Wesche et al., submitted).

Vegetation

The Gobi Gurvan Sayhan National Park lies in the vegetation zone dominated by desert-steppe vegetation (fig. 1.6). The relief within the park results in an altitudinal vegetation sequence, which is not included in the overview of figure 1.6, but follows a gradient of increasing precipitation as well. Along the altitudinal gradient the vegetation of the Gobi Gurvan Sayhan National Park roughly shows a sequence from drier to moister vegetation communities similar to the one described for Mongolia (see chapter 1.3.1, p. 44).

Apart from the extrazonal woodlands the vegetation communities follow the precipitation gradient in the park. Relative moisture-demanding vegetation communities are located on top of the highest mountains and especially in northern exposures. These include different forests such as *Betula microphylla - Salix bebbiana*, and *Populus laurifolia* forests, as well as scrubs, such as *Grossularia acicularis - Spiraea media* and *Juniperus sabina* scrub. Mats of *Kobresia myosuroides* are found only in the highest altitudes of the Gurvan Sayhan range on northerly-exposed upper part of slopes. *Helictotrichon schellianum - Festuca* meadow-steppes, which in northern and central Mongolia are regarded as replacement communities of forest vegetation (Sommer, 1998; Sommer & Treter, 1999), are strictly confined to the immediate surroundings of the above mentioned birch forests (Cermak & Opgenoorth, 2003; Miehe, 1998; Wesche et al., submitted).

The investigations of the remaining forests also revealed that they formerly may have been connected to the forest-steppe vegetation belt the border of which nowadays is found several hundreds of kilometers away from the Gobi Gurvan Sayhan (Cermak & Opgenoorth, 2003).

Dry mountain-steppes dominate the vegetation of the mountain ranges of the park. Their lower limit reaches down to 1900 m in the Gurvan Sayhan and increases westwards, until in the Nemegt Uul it lies above 2300 m (Miehe, 1998). *Agropyron cristatum, Stipa krylovii*, and *Artemisia frigida* are the characteristic species here. Further down the pediments they are replaced by *Stipa gobica*-communities and in even drier sites by semi-desert-steppes with *Anabasis brevifolia.* These semi-desert-steppes cover vast areas in the western parts of the park. Salt-tolerant plant communities are found in the depressions between the mountain ranges which often are filled by lakes or salt pans. The same communities are also found in other elevations where the saline habitat is available. A vegetation map of the park derived from ground-checked Landsat TM images is now available (Von Wehrden & Wesche, 2002; Von Wehrden, 2003). Figure 1.11 shows a small part of it covering the southern face of the Dund Sayhan around the study site.

Wesche et al. (submitted) describe 29 plant communities for the area of the park. They are subdivided into six major groups. These groups are

1. the extrazonal vegetation of relatively moist mountain sites,
2. the dry mountain-steppes dominated by *Agropyron cristatum* and *Stipa krylovii* and their replacement communities,
3. *Stipa gobica* steppes and pastures of the upper pediment areas,
4. the (semi-)desert-steppes of the lower elevations,
5. communities of saline habitats, and
6. the extrazonal woodlands.

For the interested reader the following more detailed description of the vegetation types of the Gobi Gurvan Sayhan National Park is included as there is no published vegetation study of the park yet. It is based on the manuscript ”Plant communities of the Gobi Gurvan Sayhan National Park (South Gobi Aymag, Mongolia)” by Wesche, Miehe, and Miehe. The focus is on the communities of the mountain ranges where the study site is situated. Therefore, communities of the more arid western parts of the park are described only briefly.

Extrazonal vegetation of relatively moist mountain sites Although the communities of relatively moist mountain sites account for only small areas in the park (except the *Juniperus* shrub), they are of high value for biodiversity conservation. These communities support the highest species diversity of plants and, furthermore, are habitat for endangered species such as argali or snow leopard.

Wesche et al. (submitted) combine the three communities of *Betula microphylla-Salix bebbiana* forest, *Grossularia acicularis-Spiraea media* scrub, and *Populus laurifolia*-forest under the label of extrazonal forests and shrubs. All three communities occur only in sites with at least temporary water surplus.

The sole two small fragments of ***Betula microphylla-Salix bebbiana* forest** are found in steep mountain slopes of the Dzuun Sayhan with northerly exposures. The forest is dominated by the tree species *Betula microphylla* and *Salix bebbiana* which often are multi-stemmed and reach up to 7 m in height. The outer fringe of the forests is subject to grazing, but the inner zone is not regularly grazed. The forests are regarded to be remains of an formerly more extended forest belt of the Mongolian and Gobi Altai (Opgenoorth, 2003). Today they are separated from the nearest known other birch forest in the Ikh Bogd by 350 km (Cermak, 2002; Cermak & Opgenoorth, 2003).

***Grossularia acicularis-Spiraea media* scrub** is confined to extremely steep ravines and boulder streams of the mountain ranges. This difficultly accessible location supplies them temporarily with surplus water and protects the shrubs from intensive grazing. The shrubs reach up to 2 m in height. Herbaceous species composition is similar to neighboring vegetation types. The dominant shrubs *Spiraea media*, *S. flexuosa*, and *Grossularia acicularis* also constitute the differential species.

***Populus laurifolia*-forests** are represented by a single stand in a steep valley in the north–eastern Dzuun Sayhan. The only really characteristic species is the poplar itself, apart from various plants which are common on the surrounding slopes and annuals of river beds. The trees are mostly single-stemmed and up to 6 m high. Human impact is mainly grazing. Because trees are sacred in the Gobi, logging is not important. Similar forests in various other parts of the country were named *Artemisia dracunculi-Populetum laurifoliae* by Hilbig (2000b).

***Juniperus sabina* scrub** is the community of closed woody vegetation which covers the largest areas in the park. In the wetter mountain ranges to the east it is found zonally and preferably in southern exposures, while it retreats to extrazonally water surplus sites in the western mountains. Typical patches of *Juniperus sabina* scrub are

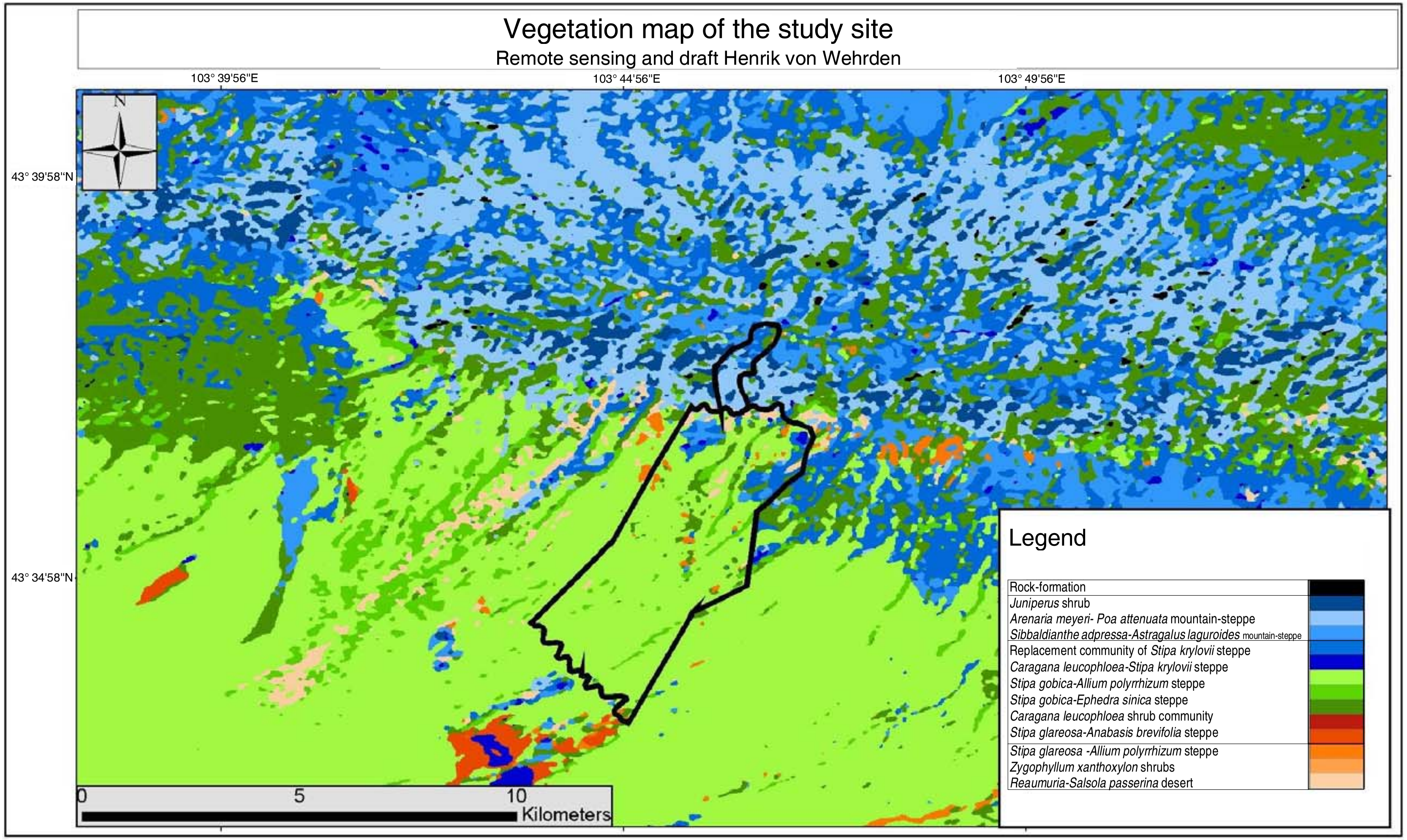


Figure 1.11.: Map of the vegetation in the southern declivity of the Dund Sayhan. The outline of the observation area is indicated. Remote sensing and draft by von Wehrden, H.

10–100 m^2 in size and cover 40–70 %. Apart from *Juniperus sabina* the characteristic species are *Poa stepposa* and *Silene repens*. The shrub *Lonicera microphylla* is often found growing inside the larger patches. Wesche et al. (submitted) differentiate three sub-communities with respect to moisture conditions.

Fragmented ***Kobresia myosuroides*** **mats** are found in depressions and flat valleys with mainly northern exposure on the upper part of slopes in the easternmost ranges. Cover is high ($\geq$ 80 %) and plants are rarely taller then 10 cm. The community is grazed intensively, above all by yaks. With up to 38 species per relevé, *Kobresia myosuroides* mats show the highest plant species diversity of all communities in the park (Wesche et al., submitted). Wesche et al. (submitted) regard these stands as relics of a more widespread vegetation during moister phases of the early Holocene.

In northern and central Mongolia ***Helictotrichon schellianum-Festuca*** **meadow steppes** are replacement communities of forest vegetation (Sommer, 1998; Sommer & Treter, 1999). In the Gobi Gurvan Sayhan they are confined to the border of the birch forests described above. The herbs attain up to 85 cm in height and cover is well above 80 %. Again, species richness is high. The species set include species which can be found nowhere else in the park (*Bromus inermis/pumpellianus, Erigeron acris*). The meadow steppes in the Gobi Gurvan Sayhan are an impoverished version of the true meadow steppes found in northern Mongolia (Wesche et al., submitted).

Dry mountain-steppes and their replacement communities Dry mountain steppes with *Agropyron cristatum*, *Stipa krylovii*, and *Artemisia frigida* and their replacement communities are the dominant vegetation type of all mountain ranges of the Gobi Gurvan Sayhan National Park. Generally, the lower limit of the communities and single species rises with increasing aridity from east to west. The principal habitat types are: steep scree slopes, weakly inclined slopes of the upper pediment areas, rocky outcrops of the lower mountain ranges, and areas with replacement vegetation due to heavy grazing or soil disturbance (Wesche et al., submitted).

Arenaria meyeri-Poa attenuata **forb-rich steppes** typically are found on sites with active debris movement and large fractions of stones and rocks. They are dominated by Poaceae (e.g. *Poa attenuata*) and various cushion plants (e.g. *Arenaria meyeri*), while woody perennials are almost completely absent. Their lower limit ranges from 2200 m in the Dzuun Sayhan to above 2500 m in the Nemegt Uul. Grazing is common in this community. Character species are *Arenaria meyeri, Allium eduardii* and *Pedicularis flava*. The phytosociological position is not easily assessed but near to Hilbig's alliance Thymion gobici (Hilbig, 2000b).

The *Arenaria meyeri-Poa attenuata* forb-rich steppes can be further divided into five sub-communities which differ from each other in respect to moisture availability and, to a lesser extent, various degrees of debris movement.

Weakly inclined slopes in the moister mountain ranges are typically covered by ***Sibbaldianthe adpressa-Astragalus laguroides*** **steppes**. They are restricted to the lower slopes and upper pediments of the Three Beauties. The species set comprises species of grass and semi-desert steppes. Of these *Allium polyrrhizum* and *Stipa gobica* are most common, while *Arenaria meyeri* and its allies are missing. Shrubs are scarce and cover 2 % at most. The small perennials *Sibbaldianthe adpressa* and *Astragalus laguroides* are the character species. Cover is well developed and ranges between 40 % and 60 %. The community is grazed intensively. Phytosociologically, these mountain-steppes belong to the alliance STIPION KRYLOVII by Hilbig (2000b) (Wesche et al., submitted).

Wesche et al. (submitted) summarize a range of heterogenous communities of neighboring vegetation types under the heading of **replacement communities of *Stipa krylovii* steppes**. The communities of this group are floristically and physiognomically very heterogenous, but nevertheless share a common set of species. All are characterized by various degrees of different disturbance regimes including debris movement, impact by burrowing small mammals and grazing livestock. Therefore, the differential species are indicators of disturbance, such as *Chenopodium album* s.l. and *Lepidium densiflorum.*

This group includes "*Artemisia santolinifolia-Chenopodium acuminatum* scrub" of steep slopes in the moister ranges of the study area, where soils are usually deep but rather disturbed by the activity of small mammals, the "*Chenopodium album-Lepidium densiflorum* community" on the sites most heavily influenced by livestock such as the immediate vicinities of wells and winter gers, and "*Achnatherum inebrians* tall-grass steppe" in (sub-)saline sites with heavy grazing and soil disturbance.

In the heavily grazed mountain-steppes shrubs are generally rare, and mainly confined to steep and rocky slopes. In the ***Caragana leucophloea-Stipa krylovii* scree vegetation** cover of shrubs ranges between 1 % and 40 % and cover of herbaceous plants between 10 % and 20 %. *Caragana leucophloea* is the dominant shrub species, and is often accompanied by the dwarf-shrubs *Ephedra sinica* and *Eurotia ceratoides.* Although no exclusive character species could be found Wesche et al. (submitted) nevertheless maintain the vegetation unit because "it is clearly recognized in the field".

Stipa gobica steppes and pastures of the upper pediment cover the larger part of the upper foot zones around the mountains. The *Stipa gobica* steppes mediate between the mountain-steppes and the colline semi-desert steppes. This can easily be seen in the species set, as virtually all typical species are shared with the neighboring communities. The communities are therefore primarily characterized by a lack of exclusively montane (e.g. *Stipa krylovii*) and semi-desert species rather than by characteristic species of their own. Phytosociologically, the communities are intermediate between the class of steppes and meadow steppes, AGROPYRETEA CRISTATI, and that of deserts and semi-deserts, STIPETEA GLAREOSAE-GOBICAE (Hilbig, 2000b).

Three communities represent this group in the Gobi Gurvan Sayhan National Park: *Stipa gobica-Allium polyrrhizum* steppes are replaced by *Stipa gobica-Ephedra sinica* steppes in the drier western mountain ranges, while *Caragana leucophloea* shrublands occur in all ranges on inclined slopes.

***Stipa gobica-Allium polyrrhizum* steppes** are the most common semi-desert steppes. Apart from the two species naming the community, *Ajania achilleoides, Con-*

volvulus ammanii, and *Cleistogenes songorica* are frequent. Grasses dominate the field layer which covers 10–45%. Shrub cover never exceeds 10 %. The vegetation is always grazed therefore reaching a height of 15–20 cm. Wesche et al. (submitted) suggest a further subdivision into "*Stipa gobica* pastures with annuals and shrubs", which are replaced by "*Stipa gobica* pastures without *Caragana leucophloea*" under higher grazing impact, and a "shrub- and species-poor sub-community" covering the driest sites.

***Stipa gobica-Ephedra sinica* steppes** dominate on the of the upper pediments and the lower parts of the inter-montane valleys in the western part of the park. The species set is similar to that of the previous community, but annuals and *Caragana leucophloea* are rare. *Ephedra sinica* is the only characteristic species, but it is equally common in the *Caragana leucophloea-Stipa krylovii* scree vegetation described above. The "*Eurotia ceratoides* sub-community" at moister sites can be distinguished from "species-poor *Ephedra sinica* stands" which even lacks the drought-tolerant *Eurotia ceratoides.*

***Caragana leucophloea* scrub** is characterized by a well-developed shrub layer covering more than 10 %. It is composed of *Caragana leucophloea, Eurotia ceratoides, Caryopteris mongolica,* and *Artemisia dracunculus.* The latter two and *Setaria viridis* are character species. This community belongs to the CARAGANION LEUCOPHLOAE after Hilbig (2000b).

Wesche et al. (submitted) further differentiate "open *Caragana-Stipa gobica* stands" which are transitory to grasslands in the upper pediment areas, "dense shrublands with *Artemisia dracunculus*" on weakly developed soils of stepper and drier slopes, and open stands of "*Caragana-Eurotia-Stipa glareosa* shrublands" growing in the upper pediment regions and wadis north of the Barun and Dund Sayhan.

(Semi-)desert-steppes of the lower elevations This group includes the most drought-tolerant communities within the Gobi Gurvan Sayhan National Park. The set of common species includes *Stipa glareosa* and *Anabasis brevifolia.* The communities of this group share species with those of the previous section but much less with montane vegetation types. All communities are part of the class STIPETEA GLAREAOSAE-GOBICAE (Hilbig, 2000b).

***Stipa glareosa-Allium polyrrhizum* steppes** replace the *Stipa gobica* steppes with increasing aridity. The species set resembles the vicinity to this group. Character species are *Gypsophila desertorum* and *Oxytropis aciphylla.* The field layer is approximately 10–20 cm high, shrubs may reach 20 cm.

Three sub-communities can be differentiated. In the "steppes of the lower pediments with a relatively rich shrub-layer" species from the upper pediment areas can be found along with those from semi-desert steppes. Under even drier conditions further west this sub-community looses *Allium polyrrhizum* and thus transforms into the "typical sub-community without *Allium polyrrhizum*". The "degraded sub-community with few shrubs" is restricted to the surroundings of Dalandzadgad and characterized by intensive disturbance by grazing and "off-road" driving.

***Stipa glareosa-Anabasis brevifolia* steppes** cover large areas of the arid regions of the park. The aridity facilitates the upward transportation of minerals and thus leads to a high PH and alkaline conditions. With increasing aridity woody perennials gain competitive dominance over grasses. No exclusively characteristic species can be found for this group, as all species are shared with other communities. The unique feature is the joint occurrence of *Stipa glareosa* and the dwarf-shrub *Anabasis brevifolia.* Dryness and intensity of grazing impact permit a differentiation of four sub-communities.

***Reaumuria soongorica-Salsola passerina* semi-desert shrublands** is the most common semi-desert community in the lowest parts of the park. The community is almost permanent moisture limited and dwarf-shrubs replace the herbaceous species of the former communities. The naming species are the most common ones, but none has exclusive character.

***Artemisia sphaerocephala* scrub** is found in temporarily flooded dry river beds in the drier areas of the parts. *Artemisia sphaerocephala* itself is the character species and grows up to 1 m in height. The stands are open with the shrub layer covering 5–35 %, while the herbaceous field layer covers less than 15 %.

***Zygophyllum xanthoxylon* semi-desert shrublands** grow in wadis and depressions. The succulent *Zygophyllum xanthoxylon* forms very open stands. Most species are shared with the previous community but *Artemisia sphaerocephala* is missing.

***Haloxylon ammodendron* (saxaul) shrublands** are dominated by saxaul, a leafless shrub or small tree with somewhat succulent shoots which often is multi-stemmed and reaches 2–3 m in height. But it can also grow single-stemmed reaching up to 5 m in height. Saxaul shrublands cover the driest sites in the Gobi Gurvan Sayhan National Park in the western parts of the park. The principal character species, physiognomically and phytosociologically is *Haloxylon ammodendron* itself. Other dominant species are shared with semi-desert communities.

***Caragana bungei* semi-desert shrublands on sand dunes** are found mainly in the inter-montane basins of the park. *Caragana bungei* is the character species of this community of sandy substrate.

Communities of saline habitats The vegetation of the moistest sites within the Gobi Gurvan Sayhan National Park is arranged under this heading. Abiotic characteristics are the seasonally high groundwater table and generally saline soil conditions, as most communities grow in depressions where saline water gathers and salt accumulates after evapotranspiration. Soil texture is rather fine and ranges from clay to loam. Due to the good supply of moisture all communities have a dense field layer.

***Nitraria sibirica* semi-desert shrublands** are typically found around saline depressions where each *Nitraria sibirica* shrub builds up a small micro-dune or hummock of up to 1.5 m in height and 3 m in diameter. These hummocks are formed by the shrub itself which constantly traps sand and grows with the increasing height of the hummock.

Takyr communities are found in the moistest parts of salt pans and at the shorelines of semi-permanent water bodies. These sites offer extremely harsh conditions for vegetation growth and are mainly inhabited by succulent Chenopodiaceae and specialized annuals. Probably due to the high salt content none of the dominant species is grazed by livestock.

Saline meadows comprise the most salt-tolerant vegetation types. Usually they are moist throughout the year and thus have a closed field layer. The community of "Halerpestes salt meadows" is found at sites with a permanently high groundwater table but without extensive flooding. This favorable moisture availability supports an extremely high productivity. Therefore, it belongs to the most intensively grazed vegetation units of the park. The character species is *Glaux maritima*. In the neighborhood at some distance to the shoreline frequently "*Suaeda corniculata-Achnatherum splendens* tall grass steppe" is found. Here, the dominant species are avoided by grazing livestock as long as other forage is available.

***Phragmites communis* communities** cover only small areas in two different localities: firstly it lines the shores of permanent water bodies ("tall *Phragmites communis* reed beds"), which are extremely rare in the park. Here, the reed can grow up to 2 m in height and is not grazed by livestock. Furthermore, *Phragmites* invades heavily grazed salt meadows resulting in "*Iris lactea* reed beds". This community borders salt meadows, and here reed is grazed down to a height of less than 10 cm.

Extrazonal woodlands The most striking feature in the (semi-)arid altitudes below 2000 m is the occasional occurrence of trees. Most of these are single individuals.

"***Populus diversifolia* woodlands**" form dense stands and even forests up to 8 m and more in height in the western oases of the park. Single individuals of lower heights can also be found at erosion gullies south-south-west of the Nemegt Uul. At none of the sites seedlings were observed by Wesche et al. (submitted).

Planted "***Ulmus pumila*** stands" can be found around Bulgan and Guarantees, were saplings were planted in 1991 and watered until 1993. Since then they grow up to a height of 5 m without any additional water. Some more (< 20) other single individuals can be found in steep gullies or rock crevices elsewhere in the park which reach a height of up to 10 m (Wesche et al., submitted).

Human impact on the vegetation

The vegetation of the park is almost completely shaped by human influence. Especially the long history of grazing by livestock has altered the vegetation over thousands of years (Wesche et al., submitted). All herbaceous and semi-woody species are so well-adapted to grazing that no regional indicator species for grazing could be identified (Miehe, 1998; Wesche et al., submitted). Only two species of the pediments, (*Stipa inebrians*, and *Iris bungei*) are regarded toxic, but of the latter at least the flowers and partially the leaves are consumed by the Mongolian Pika (personal observation). The most important forage plants such as *Stipa* spp., *Agropyron cristatum*, or *Allium polyrrhizum* are hemicryptophytes or geophytes. The regenerative organs are next to or below the ground so that they cannot be damaged by grazing and the plant can regenerate from surviving buds or shoot apices in spring (Hilbig, 1990; Miehe, 1998; Wesche et al., submitted). True spring geophytes or therophytes often encountered in other semi-arid grasslands (Schultz, 1995) are missing due to the low moisture availability in spring (Miehe, 1998, Thiel, 1985, p. 81).

The impact of human activity on woody plants remains unclear. While Miehe (1998) found that the cover of *Caragana leucophloea* and *Eurotia ceratoides* increases with distance from settlements and wells, Stumpp (2002) did not find any change in vegetation composition with increasing distance from gers. However, the woody perennials have to endure twofold impact. Apart from being grazed especially in winter they are also used for fuel, at least when dried dung is scarce (Miehe, 1998; Wesche et al., submitted). The occurrence of sporadic *Ulmus pumila* trees may indicate a potential for a higher proportion of woody species than can observed today (Wesche et al., submitted).

1.4.5. Fauna

The Gobi Gurvan Sayhan National Park harbors large populations of wild animals. For some species the populations in the park are the largest remaining in Mongolia. Especially the mountains are habitat for endangered and protected species such as argali, Siberian ibex, and snow leopard. The most spectacular are the herds of large ungulates and the accompanying predators (Reading, 1997; Reading et al., 1999a). Two species have become extinct in the park area during the last century: the Przewalski's wild horse and the Asiatic wapiti or elk (Bedunah & Schmidt, 2000). But a number of large and also endangered animals remains.

The mountain ranges of the park are home to a number of wild animal species. Ibex live in the most rugged and steep areas. Their population is estimated to be approximately 19,000 animals and regarded as being healthy (Steinhauer-Burkart, 1999). In the mountainous, but not so rocky areas lives the argali wild sheep (*Ovis ammon*). The argali is globally endangered and also listed in the Mongolian Red Book. The population of the park, which is about 3,000 animals is considered to be the largest in Mongolia (Steinhauer-Burkart, 1999).

Two species of gazelle live within the park. The Mongolian or white-tailed gazelle (*Procapra gutturosa*) is found mainly in the northern and southern surroundings of the Gobi Gurvan Sayhan mountains. The population in the park is a subpopulation which is isolated from the central population in Eastern Mongolia by the fenced-off Trans-Mongolian railway. After the erection of the fence most of the scattered subpopulations became extinct. The herds in the Gobi Gurvan Sayhan National Park today represent the largest concentration of this species outside of Eastern Mongolia (Mix, 2000). The habitat of the Goitered or white-tailed gazelle (*Gazella subguttorosa*) are the desert and desert-steppe zones in the western part of the park. It is listed as rare in the Mongolian red book (Mix, 2000).

The population of the khulan, or Asiatic wild ass (*Equus hemionus luteus*) is concentrated around the eastern edge of Khongoryn Els. Although khulan is its Mongolian name, and is also used frequently in the English literature, Denzau & Denzau (1999) refer to it as "Dschiggetai". Its preferred habitat is the desert-steppe and steppe. This species is considered globally threatened as well and is listed as rare in the Mongolian Red Book. Nevertheless the Mongolian populations are considered to be relatively healthy (Mix, 2000; Steinhauer-Burkart, 1999). Further extremely rare inhabitants of the Gobi Gurvan Sayhan National Park are the Gobi Bear and the wild bactrian camel. Both are sighted only occasionally in the western desert regions (Reading et al., 1999a).

The park is also home for a number of carnivore predators. The most spectacular of those are the snow leopard and the grey wolf, but also Palla's cat (manuul), lynx, fox, and others live there. The snow leopard occupies large territories in the mountains. It preys on ibex and argali, and occasionally also on livestock which grazes in the mountains. Due to its hidden lifestyle the snow leopard is sighted only rarely. It is a globally endangered species, too, but the populations in the Gobi Altai may represent one of the few remaining strongholds of this species (Reading et al., 1999a; Leyhausen et al., 1988).

The small mammal fauna includes species from the orders of Rodentia and Lagomorphs, such as Mongolian Gerbil, Mongolian and Daurican Pika, Tolai hare, hamsters, and jerboas (Reading et al., 1999a). The population ecology of the Mongolian Pika is not well investigated yet (Schneider, 1988). The Mongolian Pika reaches its south-eastern distribution limit in the Gobi Gurvan Sayhan (Mongolian Atlas, 1990). It is found only in the higher mountain ranges. Its density increases from the pediments into the mountains and remains relatively constant up into the summit regions. In the Dund Sayhan, the lowest single burrows can be found at an altitude of about 2000 m (Nadrowski et al., 2002).

The avifauna of the park is rich (Steinhauer-Burkart, 1999). About 240 species have been described. Many species of birds of prey are found in the park, including several species of vultures, eagles, hawks, buzzards, harriers, and falcons.

1.4.6. Human impact

Within the park there live about 1,000 families of pastoralists, herding 200,000-300,000 head of livestock (Khuukhenduu & Bidbayasakh, 2001; Reading et al., 1999a). Almost the complete area of the park, except the rockiest mountain areas, is used for herding livestock (Reading et al., 1996). But Schmidt (2000) reports that after the transformation the pattern of usage changed, as many wells in the desert-steppe broke down and herders therefore moved towards the mountains because of the abundance of natural springs there.

Like the whole country the region has been used as pasture for nomadic pastoralists for a long time. Pollen samples from within the study area were analyzed by Frank Schlütz from the University of Göttingen. He found that the grazing influence has been abundant throughout the entire profile, which dates back up to 2500 years BP (pers. comm., Schlütz, 2003). Especially the natural springs have probably always attracted wild herbivores and livestock alike.

Apart from grazing also the collection of woody species for firewood is of importance. Especially the wood of saxaul trees is highly valued due to its high density Rachkovskaya (2001). But also *Caragana* and *Juniperus* species and *Artemisia santolinifolia* shrubs are used as fuel (Miehe, 1998; Wesche et al., submitted, and own observation). The formerly larger forests in the Dzuun Sayhan may have been reduced to their actual size this way and their existence is threatened under continuous pressure (Cermak & Opgenoorth, 2003).

The vegetation of the whole area has been shaped by the influence of continuous grazing for millennia. It is a cultural landscape formed by man and his herding activities which have shaped the composition of vegetation communities. As a general trend under increasing grazing pressure moisture-depending plants are replaced by those from drier sites. No natural vegetation has been left, and "it is even difficult to imagine what it might have been" (Wesche et al., submitted). Wesche et al. (submitted) also conclude that the floral biodiversity of the park is not endangered by human impact as most of the (sub-)endemic species grow at rocky outcrops or swards near the mountain summits, where grazing pressure is relatively low.

Small artificially irrigated areas in the park are used to grow vegetables. One is found in Bayan Bag, north of Bayandalay, another in Bulgan, just outside the northern boundary of the park. Covering some hectares at best, these irrigated gardens are extremely small in comparison to the total area of the park and the impact is only local (personal observation).

The main attractions for tourists in the park are the Yolin Am valley, filled with ice sheets which persist until July, the impressive Khongoryn Els sand dunes, and the places of dinosaur fossils in the western part of the park. Tourists are also attracted by the possibility of catching sight of wild animals such as ibex, argali, gazelle and possibly wolf or even snow leopard (Steinhauer-Burkart, 1999). Places which are regularly visited by tourists in turn attract herders who rent out horses or try to sell handicrafts. This leads to an accumulation of herders and livestock especially around Yolin Am, which may be the cause of degradation tendencies observed there (Miehe, 1996). After the opening of the country after the 1990 transformation, tourism has increased in Mongolia and is believed to increase further (Saffery, 2000). The problem has been recognized and the GTZ bufferzone development project supports the tourism services and conservation activities of a local group of herders (Schmidt, 2002).

With the increasing use of motorized transport the problem of road erosion seems to get more and more important (Opp, 1996). Without the shelter from vegetation the surface runoff from summerly intensive rains has a highly erosive effect. When the lanes get too deep the drivers just start a new track next to the old one. The disturbance indicator *Artemisia santolinifolia* then colonizes the old tracks (Wesche et al., submitted).

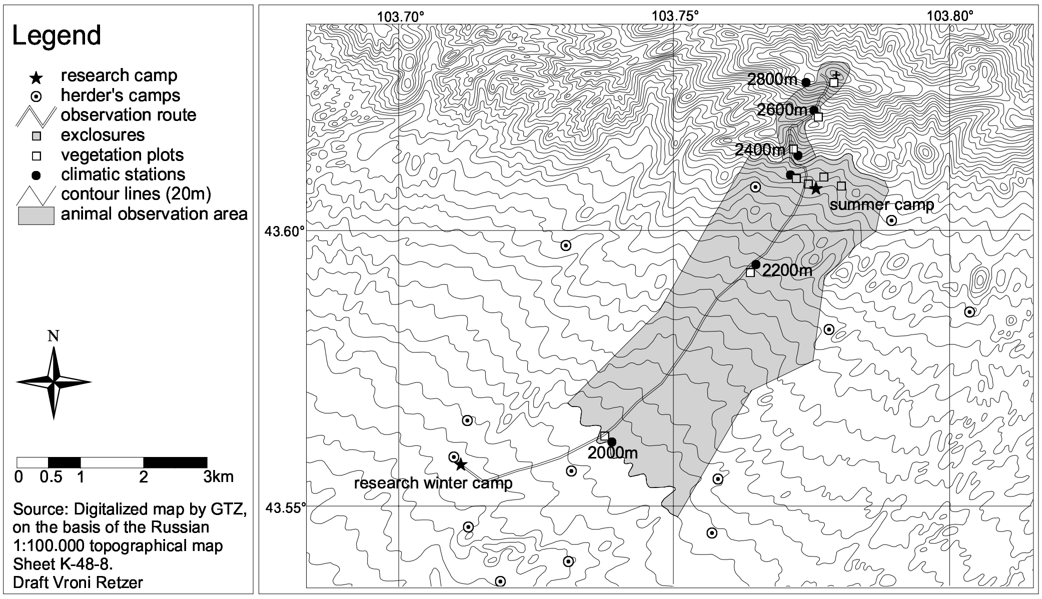


Figure 1.12.: Overview over the study area: the locations of the research camp (summer and winter camp), climatic and vegetation plots, the exclosures, the animal observation area and route, and herders' camps in the vicinity are indicated.

1.4.7. Study site

Our main study site lies on 2330 m on the southern slope of the Dund Sayhan Mountain (Middle Beauty) on the upper pediment. The location was chosen after several reconnaissance trips because it provided it is relatively easily accessible and features high densities of pika, herders, and livestock. Figure 1.12 shows the location of the camps, the exclosures, the animal observation area and route, and herders' camps in the vicinity.

The research camp moved with the seasons, as did our neighbors. From June until October 16^{th}, 2000 and again from April 14^{th}, 2001 until the end of September 2001 it was located on the upper pediment next to the study site at about 2330 m. During winter it moved about 8 km southwest down the pediments to the winter-place at about 1930 m. The upper end of the pediment is grazed by horses, camels, cattle and occasionally yaks all year round while sheep and goats reach it only in summer. About five herder families have their usual summer-places within a 4 km radius around the research station.

At the study site pika density is high, as it is typical for the elevations between 2300 m and 2600 m in the Three Beauties.

1.5. Design of the study

Following the conceptual thoughts and the evidence from Mongolian ecosystems it is possible to propose a model of the dynamics in the investigated ecosystem (fig. 1.13). The focus is on the interactions between pika and livestock. The model concentrates

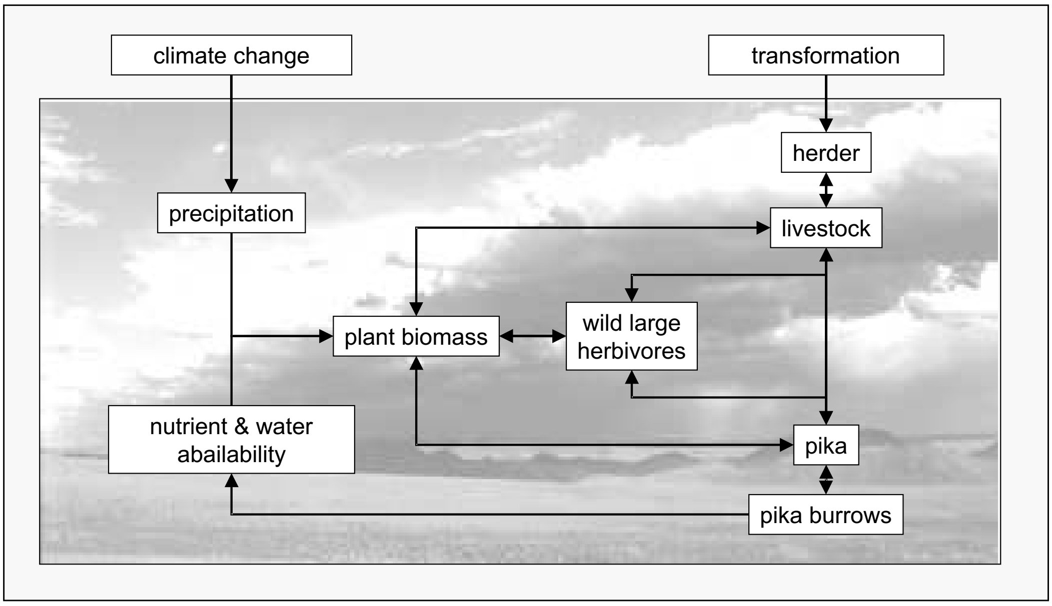


Figure 1.13.: Model graph showing the most important interactions in the investigated ecosystem. For further explanation refer to the text.

only on the main players within the system. At the trophic producer level this is the primary production of phytomass which directly reacts to the precipitation of a given year. The dominant secondary producers and primary consumers are large and small, wild and domestic herbivores. As this study focuses on pika and livestock, and both account for the majority of the impact by small and large herbivores, respectively, their names are used. The third trophic layer of wild predators has not been investigated and is therefore not depicted in the graph.

The main interactions in figure 1.13 are indicated by arrows: production of phytomass is triggered by precipitation and modified by water and nutrient availability on pika burrows. Phytomass is the forage for all herbivores, which are split into the two primary subjects of the investigation, pika and livestock. The herds of livestock form the basis of the herders' livelihoods and on the other hand the herders control the numbers and distribution of their animals. Pika depend on their burrows as shelter especially during winter. At the same time they change the environment on their burrows and influence water and nutrient availability on them.

Two external processes may have crucial influence on the stability of the system. This is firstly the impact of climate change, which is projected to lead to a decrease in plant available moisture in the Gobi (Bolortsetseg & Tuvaansuren, 1996), and secondly the changes in the pastoral sector caused by the transformation from a socialist satellite state to a free-market economy since the 1990s. Both factors possibly have a tremendous influence on the ecosystem investigated, but cannot be measured directly in the field. The simplified model of the ecosystem outlined above provides a framework for the studies and determines which parameters have to be analyzed:

1. **Production of phytomass** How much phytomass can be produced under the observed amounts of precipitation?
2. **Competition for phytomass by pika and livestock** How much of the phytomass produced is consumed by which herbivore? Is there forage competition? How severe is it? If there is forage competition: How is it possible that pika and livestock coexist nevertheless?
3. **Function of pika in the ecosystem** How large is pika's impact on the ecosystem? How much of the area do they use, and which changes do they cause on their burrows? Do they influence productivity on their burrows via changing water and nutrient availability there?
4. **Status of pika as pests** From a herder's point of view, are the summarized direct and indirect influences of pika on livestock positive or negative?
5. **Precipitation and productivity in the mountain ranges** How does precipitation and parallel primary productivity change in the mountains along an altitudinal transect?
6. **Competition between large domestic and wild herbivores** How are wild and domestic herbivores distributed along the altitudinal transect, and what impact does grazing have on wildlife?

The study consists of three major experiments: the exclosure experiment, on grazing impact and competition between pika and livestock (”Exclosure”), the distribution of animals and vegetation dynamics along a altitudinal transect (”transect”), and on experiments on the impact of pika burrows (”burrow”). Table 1.4 lists the parameters investigated within this study in order to answer the questions posed above.

All the data can be integrated into a model of the ecosystem in order to investigate the reaction of pika and livestock densities to variable precipitation input. The model provides a test tool for our understanding of the ecosystem processes investigated such as forage competition between pika and livestock. Additionally, it can be useful to extrapolate the observations in the field in order to understand and possibly project the possible impacts of climate change and transformation.

abiotic parameters	exclosure	transect	burrow
daily precipitation	x		
monthly precipitation		x	
soil water content	x		
soil properties on burrows			x
distribution of dung			x
burrow characteristics			x
vegetation parameters	exclosure	transect	burrow
vegetation cover	x	x	x
vegetation height	x	x	x
standing crop	x	x	x
primary productivity	x		x
plant phenology		x	x
below-ground biomass			x
animal parameters	exclosure	transect	burrow
livestock intake	x		
pika intake	x		
livestock body condition	x		
livestock densities	x	x	
livestock species composition	x	x	
livestock altitudinal distribution		x	
large herbivore densities	x	x	
large herbivore species composition	x	x	
large herbivore altitudinal distribution		x	

Table 1.4.: List of investigated parameters within the major experiments of this study.

2. Phytomass production and its utilization by pika and livestock

2.1. Introduction

Mountain-steppe accounts for a significant proportion of the area of the park. Its phytomass forms valuable forage for wild and domestic herbivores. The main herbivorous players are the Mongolian Pika (*Ochotona pallasi*) and livestock.

Mongolian Pika are small polyphagous herbivores. Adult pika reach a weight of approximately 200 g. They show diurnal behavior and are active all year round. In autumn they collect hay to supply themselves with energy during the winter months (Kaetzke & Traglauer, 1998; Retzer & Nadrowski, 2002; Schneider, 1988).

Livestock within the park consists of six species: camels, horses, Mongolian cattle, yaks, sheep and goats. These can be subdivided into "large" and "small" stock. The large livestock species, camels, horses, cattle, and yaks roam freely in herds of one species. Herders look for them regularly and move them to better pasture whenever necessary. Sheep and goats are herded together in mixed flocks. Because of this sheep and goats often are also summarized in the artificial term "shoats". The herds of small livestock return to the ger every night. The grazing radius is thus about 3–4 km from any suitable ger place.

The study site is situated at the upper end of the pediment and is grazed by pika, horses, camels, cattle and occasionally yaks all year round while sheep and goats only reach it in summer (see also fig. 2.16, p. 115).

Competition between pika and livestock is analyzed in the form of resource competition. Resource competition is "the negative effect [...] of acquisition of a particular resource by one species due to the use of this resource by another species" (Van der Wal et al., 1998, p. 228). In the case of forage competition this means changes in quantity and quality of the animal's diet with impact on the nutritional status of the animal. Three conditions generally regarded as prerequisites for forage competition (Crawford, 1996; Hulbert & Andersen, 2001; Van der Wal et al., 1998) are:

- overlap in habitat use,
- share of the same forage plants, and
- limited forage availability.

Within this chapter the findings of resource competition between pika and livestock in a year of drought will be presented. An exclosure experiment was set up in order to investigate forage competition between pika and livestock. It consisted of four different treatments. One was accessible to livestock (*only livestock*) only, the second to pika only (*only pika*), the third was accessible to both the herbivore groups (*pika & livestock*), and the fourth excluded both groups (*no grazing*). Within the exclosure experiment the parameters vegetation cover, vegetation height, standing crop, above-ground primary productivity (ANPP), and standing crop were investigated and used to assess consumption and subsequently forage competition by pika and livestock.

In general, forage consumption by herbivore groups depends on four main factors:

- forage availability,
- herbivore density,
- forage requirement of the herbivores, and
- physiological limits to the digestion.

Basically there are two possible situations. Either the herbivores within the area of consideration (density) can meet their forage requirement or they cannot. In the first case forage availability exceeds the potential intake required, and therefore the factors herbivore density, forage requirement, and physiological limits to digestion set the maximum limit of herbivore intake. In the latter case the requirements cannot be met and therefore forage availability limits the intake of the herbivores. Forage availability and herbivores density have been investigated within this study. Nutritional requirements have not been studied, but with the livestock equivalent "Mongolian Sheep Unit" a robust estimation of the forage requirements of the different livestock species exists. Additionally, information on body condition of livestock, precipitation, soil water content, and large herbivore densities was recorded.

2.2. Material and methods

2.2.1. Investigation period

The field work for this study started at the end of August 2000 and ended at the end of September 2001. The setup of experiments began in September 2000 and proceeded subsequently. The investigation period therefore covers one full year from September 2000 to September 2001. This period of time forms the basis for the calculation of balances over one year's time. As some experiments did not run the full time the actual sampling period is given with the description of every single experimental setup.

2.2.2. Measurement of precipitation

A Hellmann rain gauge with 100 cm^2 catching area was put up at a height of about 50 cm. This is not the standard height for this kind of measurements, but it was chosen for the comparison with the measurements made at the transect (see chapter 3.2.2, p. 134).

The Hellmann rain gauge was used because it is easy to handle, although it has high error rates especially during winterly snowfall events. However, this was supposed to be not relevant for the measurements, as winter precipitation is low anyway, and of almost no importance for vegetation growth.

The gauge was emptied after every precipitation event and the amount of precipitation measured. Because of the intensive sampling frequency the gauge had to stay near the camp and thus had to be moved from summer- to winter-camp and back. From July 2000 until the beginning of October 2000 and again from April 2001 until the end of September 2001 it was situated at the summer-place at about 2350 m at the upper end of the pediment. In the meantime it was located at the winter-place of the research camp about 8 km south-southwest from this point at about 1930 m. Collection of data was done jointly with Karin Nadrowski.

2.2.3. Measurement of soil water content

Soil moisture samples were taken at approximately monthly intervals until April 2001 and at about weekly intervals later on. Three replicates of samples were usually taken near the camp at a depth of 0–5 cm. During sampling it was tried to avoid roots. Sample size was approximately 50 g fresh weight (Schlichting et al., 1995, p. 193).

Samples were directly weighed when taken (=fresh weight) and dried on the ger stove until no further reduction in weight could be measured (=dry weight). Afterwards, the soil was sieved (2 mm) and stones bigger than 2 mm were subtracted from fresh and dry weight in order to eliminate errors caused by different concentrations of stones which do not store water (Schlichting et al., 1995, p. 193).

Soil moisture was calculated as water content in % weight of dry matter < 2 mm by comparing the fresh and the dry weight of the samples. The depth of 5 cm is relatively shallow, but as most roots are concentrated in the upper part of the soil, it seems reasonable to use these values at least as an indicator.

2.2.4. Setup for the study on phytomass production and consumption

The data on standing crop from two experimental setups, the exclosure experiment (see p. 78) and the mobile cages (see p. 81) were combined in order to cover a full year.

Exclosure experiment

The exclosure experiment was started on September 30^{th}, 2000. It consisted of four replicates of four different treatments (table 2.1). Each treatment had a size of about 4.5 x 4.5 m. The four replicates were built up on the upper ends of four different pediments approximately 300–500 m apart from each other (table 2.2).

In this context "treatment" means the status of being grazed or not grazed by pika and/or livestock, respectively. A "plot" is the single square-meter plot actually investigated. One "exclosure" is the array of one set of the four treatments, which where named after the Mongolian word for exclosure (hashaa) and numbered from east to west: H1–H4 (fig. 2.1 and fig. 2.1).

abbr.	treatment	description
n	*no grazing*	inaccessible to pika and livestock
l	*only livestock*	accessible to livestock but not to pika
p	*only pika*	accessible to pika but not to livestock
lp	*pika & livestock*	accessible to pika and livestock

Table 2.1.: Description of the four treatments of the exclosure experiments.

These treatments were realized with different types of fences. For the exclosure of livestock a stable wire fence (wire diameter 3 mm, mesh size 5 x 5 cm) of 170 cm in height was used. Below the fence enough space (5–10 cm) for pika to roam freely was left. The exclosure of pika was realized with a finer fence (wire diameter 0.1 mm, mesh size 1.5 x 1.5 cm). The fence was 30 cm high and was bent over to the outside to prevent pika from climbing over it. On the ground it overlapped about 10 cm and was fixed to the ground with nails to prevent pika from slipping through under the fence. Pika never dug under the fence. Long iron nails were used to give stability to the construction. As in spring the juveniles were able to slip through this fence, the treatment *only pika* was realized by a new movable 1.2 x 1.2 m fence, which was additionally protected at the lowermost 10 cm with a very fine mesh of 0.5 x 0.5 cm. This new fence was placed inside the old *only pika* fence and relocated after each harvest. For the treatment *no*

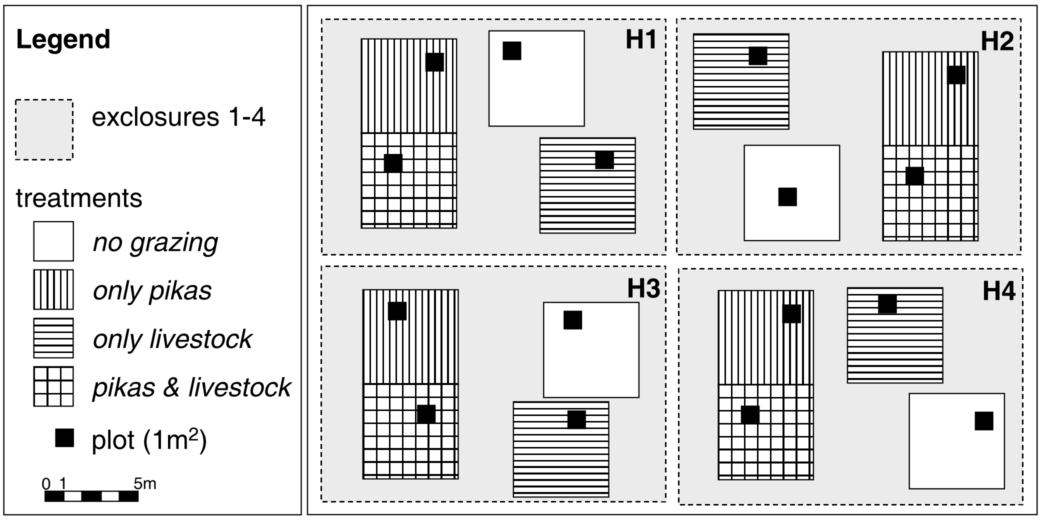


Figure 2.1.: Schematic overview over the design of the exclosure experiment. The exclosures were situated approximately 300–500 m apart from each other at different pediments.

exclosure	latitude	longitude	height asl	exposure	inclination
H1	43 ° 36.815'	103 ° 46.763'	2332 m	222 °	5 °
H2	43 ° 36.909'	103 ° 46.570'	2333 m	190 °	8 °
H3	43 ° 36.833'	103 ° 46.398'	2315 m	170 °	7 °
H4	43 ° 36.893'	103 ° 46.268'	2322 m	210 °	4 °

Table 2.2.: Overview over the positions of the exclosures.

grazing both fences of different mesh-width were combined to exclude small and large herbivores alike. The area for the treatment *pika & livestock* was marked, but not fenced. Snow accumulations in winter were removed from the fenced areas. Figure 2.1 gives a schematic overview over the design of the exclosure experiment.

The treatments are named after the intention of the experiment – to evaluate competition between pika and livestock. Of course the treatment *only pika* apart from livestock also excludes other large herbivores including wild herbivores such as gazelles, ibex and wild sheep - and on the other hand allows access to other small mammals such as Mongolian Gerbil (*Meriones unguiculatus*) or Grey Hamster (*Cricetulus migratorius*) too. But as livestock accounts for more than 95 % of large herbivores (see p. 114), and the Mongolian Pika (*Ochotona pallasi*) for more than 95 % of small mammals (Nadrowski et al., 2002) the terms "livestock" and "pika" will be used within the context of competition between both the herbivore groups.

All treatments are also accessible to small invertebrates such as grasshoppers. This fact was not taken into consideration for two reasons. On the one hand, this can be regarded as some kind of "background noise" which affects both investigated treatments alike, and on the other hand errors appear to be small because grasshopper densities were low in the summer of 2001 (own observation).

Sampling started in October 2000 and took place every four to six weeks. Plots of 1 m^2 in size were used within every treatment and replicate. A double-sampling technique (Bonham, 1989; Catchpole & Wheeler, 1992) was applied. Usually on half of the plots (alternately all treatments of two exclosure) phytomass was harvested by clipping with hair scissors at minimum height and length (∼4 mm). Due to weather and time constraints it was not possible to harvest always exactly half of the plots. But this did not matter, as the harvested plots were sufficient to give a good data basis for the double-sampling. Plots harvested once were not sampled again in the course of this study. Phytomass was dried on the ger stove to constant weight. Exact drying temperature could not be determined, because the thermometer melted, but was well above 70 ° C.

These data were used to estimate standing crop for all plots. Phytomass was not separated into different fractions such as living, recently dead, standing dead, and litter for the following reasons: litter was found in very small quantities during the whole sampling period and thus not sampled separately.

Standing crop was not subdivided either because livestock is hardly able to make this distinction and sampling should resemble grazing. As plants dry out from the top, one plant would have had to be split into different fractions and this did not seem feasible. And finally calculations for productivity which differentiate are highly correlated with calculations without such distinction (Singh et al., 1975) – thus separation seemed unnecessary.

Standing crop on the plots not harvested was predicted by two factors (Bonham, 1989) - namely vegetation cover and height. Both parameters have been used successfully in a number of studies (Huennecke et al., 2001; Singh et al., 1975; Ward et al., 1998) and are recommended for pasture and herbaceous vegetation (Catchpole & Wheeler, 1992). On all plots vegetation cover , divided into grass, herb, shrub, moss and lichen, and cover of earth, stone, dung, litter and snow was estimated directly in percent.

For the three most abundant plant species or taxonomic groups *Allium* spp. *(= A. prostratum* and *A. polyrrhizum)*, *Stipa* spp. *(=S. krylovii* and to a lesser extent *S. gobica)*, and *Agropyron cristatum* the maximum height was measured with a ruler for each 20 individuals (or all if less than twenty).

The species had to be grouped because identification down to the species level was not possible in winter and even remained difficult during the summer of 2001 due to the drought (see Stumpp, 2002). Grouping is feasible for several reasons. 1) Only species from the same genera with similar morphology were grouped together, assuming that morphologically similar species of the same genera exhibit similar traits. 2) Calculations of standing crop are not based on species level but on much more general vegetation volume information (see p. 83). Fernandez-Gimenez & Allen-Diaz (1999) exhibited the same problems for *Allium*, *Stipa* and other species. They also combined them in taxonomical groups and used these groups successfully in their analysis.

Mobile cages

From August 26th, 2000 onward a first set of the four treatments was set up as small mobile cages on the pediment of H4. This set was constructed first because it was our intention to construct all four replicates this way in order to allow for compensatory growth (see chapter 2.4.1, p. 119). But as the construction of the mobile cages proved too labor-intensive, the small exclosures were used no longer after the large exclosure experiment had been installed. The two treatments excluding livestock were constructed in the form of tents, the treatment *only livestock* was realized as described above (p. 78) and treatment *pika & livestock* was only marked. All four treatments were re-investigated at the end of September and October, respectively. Sampling was performed according to the procedures described in the previous chapter on page 78. The cages were relocated after each harvest.

2.2.5. Livestock body condition

Body Condition Scoring is a method to evaluate livestock's fitness by feeling the level of fat and muscling deposition over and around the vertebrate of the loin region (Suiter, 1994; Thompson & Meyer, 1994). It is easy to learn and simple to apply, even for untrained personnel (Kleiböhmer et al. (1998); Mauch (2000), and pers.comm.). Originally, it was planned to evaluate also the body condition of large livestock. But as those animals roam freely it is extremely difficult and time-consuming to find the animals regularly in order to score them.

Therefore, body condition of sheep and goats from one herder who lived near the research station was estimated from the end of November 2000 until September 2001. At the beginning of the scoring always the same ten female goats and ten female sheep were scored to minimize variability between single individuals. Females were used, because they are supposed to be under higher stress from lambing and milking than males. Adult animals of different ages were chosen. Always two animals were aged two, three, four, five, and six years, respectively. For the last three scorings one sheep had to be replaced by another one of the same age because the original one had been killed by a wolf.

How to feel for fat cover and muscle development is shown in figure 2.2. The body condition method used is described by Thompson & Meyer (1994) for sheep. As no extra scheme could be found for goats, the same evaluation sheet was also used for goats. As the distribution of body fat is different in both species it was not sure whether the method would work, but it was tried nevertheless.

The following criteria were used to evaluate the body condition:

"Condition 1 (Emaciated) Spinous processes are sharp and prominent. Loin eye muscle is shallow with no fat cover. Transverse processes are sharp; one can pass fingers under ends. It is possible to feel between each process.

Condition 2 (Thin) Spinous processes are sharp and prominent. Loin eye muscle has little fat cover but is full. Transverse processes are smooth and slightly rounded.

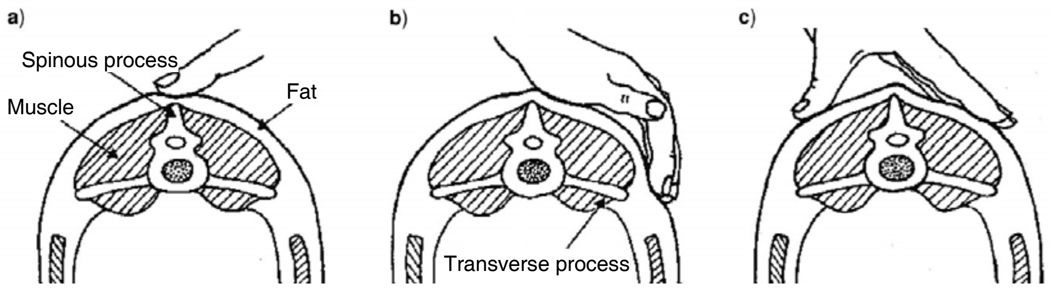


Figure 2.2.: Demonstration of the three steps to evaluate sheep's body condition score: a) Feel for the spine in the center of the sheep's back, behind its last rib and in front of its hip bone. b) Feel for the tips of the transverse processes. c) Feel for fullness of muscle and fat cover (after Thompson & Meyer, 1994, adapted).

It is possible to pass fingers under the ends of the transverse processes with a little pressure.

Condition 3 (Average) Spinous processes are smooth and rounded and one can feel individual processes only with pressure. Transverse processes are smooth and well covered, and firm pressure is needed to feel over the ends. Loin eye muscle is full with some fat cover.

Condition 4 (Fat) Spinous processes can be detected only with pressure as a hard line. Transverse processes cannot be felt. Loin eye muscle is full with a thick fat cover.

Condition 5 (Obese) Spinous processes cannot be detected. There is a depression between fat where spine would normally be felt. Transverse processes cannot be detected. Loin eye muscle is very full with a very thick fat cover." (Thompson & Meyer, 1994)

Additional information on the livestock numbers of this family was gathered during interviews in 2000 and 2001 by the author and in 2002 by Karin Nadrowski.

2.2.6. Animal observations

Direct observation was used to estimate the densities of large herbivores (livestock and wild herbivores). For all observations identical Russian binoculars (8 x 30) were used. Date and time of the observation were noted, and for every sighting the number and kind of animals, their distance and the direction from the observation point was recorded. The species was recorded as accurately as possible.

Camels, yaks, cattle, horses, wild sheep, and ibexes could be identified down to the species level. The two species of gazelles could not be differentiated over large distances and therefore were grouped together as "gazelles". For the herds of small livestock composed of sheep and goats differentiation of the two species was not possible either. These herds were recorded as herds of "shoat".

From September until the beginning of October 2000 and again from the end of April until the end of September 2001 a small hill next to the summer place of the research camp served as observation point for the pediments. Situated on top of the pediments this hill provided a good view down the pediments. The observation area stretched for roughly 9 km in south-southeastern direction and was about 3 km wide. It covered the altitudes of about 2000–2400 m.

In winter trips from the winter place towards the mountains were used to collect additional data. As the vehicle track from the winter place towards the summer place passed directly through the observation area it provided a good view. During the drive the number and kind of animals observed was noted. Their distance and direction from a known point along the route was estimated to compute their position (Reading et al. (see also 1999a), and p. 89). During the observation period a total of 210 observations were conducted. During these observations 1278 animal groups comprising more than 61,000 individuals (table 2.3) were recorded.

animal	observations	individuals
camels	252	1,327
cattle	123	1,247
horses	563	3,629
shoat	226	53,357
yak	31	166
wild sheep	12	66
ibex	17	104
gazelle	55	1,160
wild ass	0	0

Table 2.3.: Numbers of animal observations and of animals observed. These numbers include sightings along the altitudinal transect.

2.2.7. Methods of analysis

Calculation of standing crop

Double-sampling In order to obtain a complete set of data on standing crop for all time intervals and all treatments the double-sampling technique was used. The principle is that parameters which are indicative for phytomass are measured on all investigated plots, and standing crop is harvested on some of the plots. Later the parameters measured are used to calculate regression functions for the plots on which standing crop was actually harvested. The derived regression functions then are applied to the plots on which only the parameters were measured, but which were not harvested. The double-sampling method is a widely accepted compromise between direct harvesting methods and estimations of phytomass. On the one hand it is not as labor-intensive as harvests of standing crop on all plots and therefore allows for a higher number of replicates. And on the other hand it is much more precise than phytomass estimations (Bonham, 1989).

Within this study approximately 50 % of all plots were harvested during each sampling date. For the other plots data on vegetation structure – cover and height – were gathered. This allowed for a maximum range of measured values for the parameters standing crop, cover and height for calculations (Catchpole & Wheeler, 1992). The parameters cover and height were used to estimate the phytomass of the harvested plots as accurately as possible. Afterwards the equations found were applied to the rest of the data to estimate standing crop on the plots not harvested.

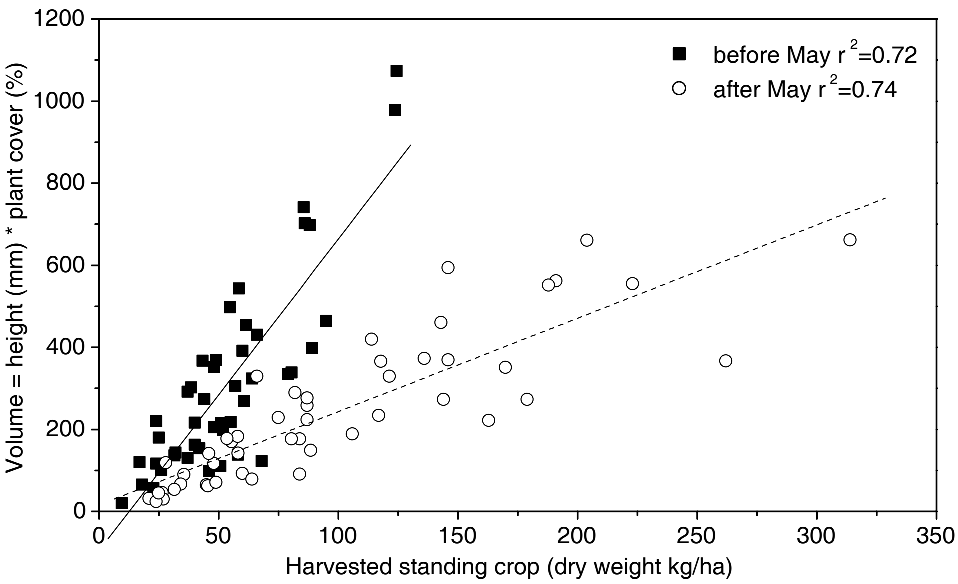


Figure 2.3.: Explanation of harvested dry weight standing crop by the multiplied parameters cover·height. Data are split into two subsets harvested before (■) and after (o) May 1^{st}, 2001. Linear fit regression lines are given (see equation 2.1 and 2.2).

From different available parameters for vegetation height, average height of vegetative tillers (Guevara et al., 2002) of the most important species or species groups (see p. 78) was used. First the average maximum height of the single groups was computed and then the average of the groups was calculated. This results in one single value of "average maximum height" per plot. These data were available for the whole period of time and proved to be good indicators of standing crop (r^2=0.56). Other parameters tested explained less variation in standing crop (r^2=0.59 for estimated vegetation height) or were not available for the whole investigation period (r^2=0.75, for average height composed of more species). For the second dimension the parameter vegetation cover was used. Vegetation height or volume worked well as predictor of standing crop in a number of other studies (Guevara et al., 2002; Huennecke et al., 2001; Paton et al., 1999; Ward et al., 1998)

Data set split in time While working with the data it was striking to see that they seemed to be distributed around two linear lines with different slopes (fig. 2.3). Further analysis showed that the two areas represent different dates of harvest during and before the growing season of 2001. So the data were split up into two parts before and after different dates. The beginning of May as splitting date assigned maximum explanation to the split data sets. This seems reasonable as during this time the freshly grown phytomass exceeded the amount of dry phytomass from the previous year. A physiological reaction may be responsible for the different relationships between vegetation volume and biomass. The necessity of developing new equations for every year because of substantial year-to-year differences between regression equations has also been shown by Johnson et al. (1988).

parameter	**all dates**		**before May 1st**		**after May 1st**	
cover	0.03	p=0.067	0.55	p<0.001	0.60	p<0.001
height	**0.56**	p<0.001	0.59	p<0.001	0.52	p<0.001
cover · height	0.26	p<0.001	**0.65**	p<0.001	**0.74**	p<0.001
multiple linear regression	**0.56**	p<0.001	0.64	p<0.001	0.72	p<0.001

Table 2.4.: Explanation of harvested dry weight standing crop (r^2) by linear regression of the parameters cover and height alone, multiplied (cover·height), and by multiple regression. Values are given for all harvests (all dates) and harvests before (before) and after (after) May 1st, 2001. The highest r^2 for each data set is marked bold.

The most pronounced effect of splitting the data into two subsets is observed with the explanatory value of vegetation cover for standing crop. Whereas the parameter vegetation cover has no significant explanatory value in the combined data set ($r^2=0.03$, p=0.067), it explains 55 % of the variation of standing crop before and 60 % after May 1st, 2001 ($p<0.001$, see table 2.4). For the calculation of standing crop the parameters cover and height alone and in multiple regression as well as vegetation volume (=cover·height) were tested. Vegetation volume provided better estimations than any single parameters or even multiple linear regression (table 2.4).

As the correlation between vegetation volume and standing crop is not necessarily a linear one (see e.g. McNaughton, 1984), other forms of functions were tested as well. The functions tested included 2nd and 3rd grade polynomials, exponential association, root function and several more with similar shapes. But as the distribution of the data (fig. 2.3) did not suggest the use of another function and none of those tested explained clearly more variation in the data, the simple linear equation was used in order make the interpretation of the results as simple and comprehensible as possible (Huennecke et al., 2001).

The actual regression equations were equation 2.1 for the data subset before May 1st, 2001 and equation 2.2 for the data subset after May 1st, 2001.

$$\text{standing crop} = 2.41 + 0.0095 \cdot \text{cover}\cdot\text{height} \qquad (2.1)$$

$$\text{standing crop} = 2.05 + 0.033 \cdot \text{cover}\cdot\text{height} \qquad (2.2)$$

The average deviation of calculated standing crop from harvested standing crop is -0.00083 and the standard deviation of this deviation is 3.41. Calculated values of standing crop for all plots were used for further analysis.

The data exhibit the effect of "regression to the mean" (Nachtigall & Suhl, 2002) because the two parameters vegetation volume and harvested phytomass are not perfectly correlated parameters taken from the same basis. That means that the values for calculated standing crop are nearer to the average than the values from the harvested standing crop. Plotting calculated standing crop (y-axis) against the harvested standing crop (x-axis) exhibits a slope lower than 1 (fig. 2.4). As this is not a methodological error but intrinsic to the calculation of linear regressions, no further corrections were made.

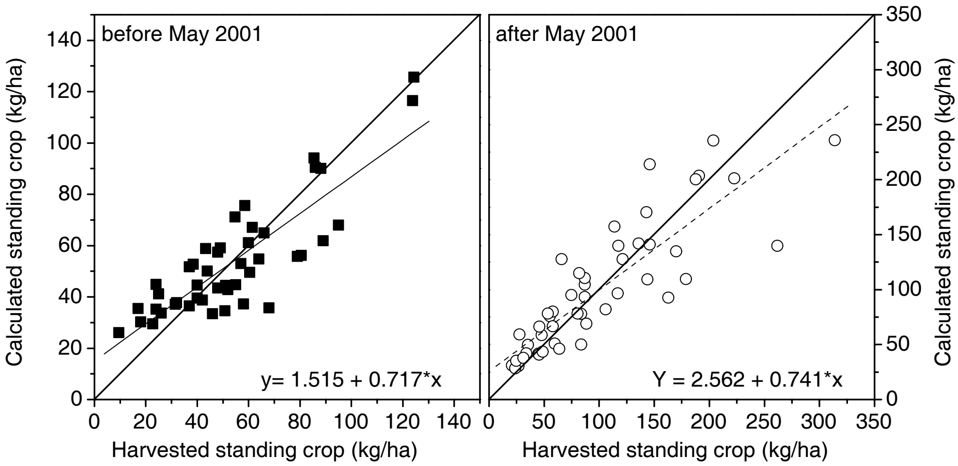


Figure 2.4.: Correlation between calculated standing crop and harvested standing crop before (■, left) and after (o, right) the May 1^{st}, 2001. Linear fit regression line is given. The diagonal line symbolizes perfect correlation between both parameters. The data exhibit the regression to the mean effect.

Correction for intruding pika into treatment "no grazing" Pika managed to invade some plots of treatment *no grazing* during the summer of 2001. Unfortunately all measures to keep them out were not successful. The damage seriously influenced the calculations of above-ground net primary production (ANPP) and consumption, which thus had to be corrected. The development of standing crop under *no grazing* where no signs of pika activity could be detected were compared to the development of standing crop under *no grazing* where signs of pika activity were noticed. That means that the development of standing crop as observed on the exclosures without pika activity is proportionally transferred to the plots with pika activity.

For the periods June-July and August-September the growth rates from the exclosures H1 and H4, and for the period July-August only the growth rate on exclosure H1 could be used. The corrected values were used for all further calculations.

Calculation of productivity and consumption

The calculated and corrected values for standing crop (see p. 83 and p. 86) for all treatments and harvest dates form the basis for computing productivity and intake for pika and livestock. The term "intake" may be partially misleading as pika collect and store hay for winter and spring. Although not all "intake" is consumed immediately, the term is nevertheless used for comparability with other studies. Data were transformed from dry weight in g/m^2 into kg/ha by multiplying the values with the factor 10 in order to allow comparisons with other data such as animal densities which were recorded per hectare (see chapter 2.2.6).

As the data collection on the plots could not be completed within one day, an "average" date over one data collection event was used. In case the "average" date was exactly between two dates, the earlier date was used. Usually four samples were available for calculating the average calculated standing crop except for some harvest dates in winter, when snow cover prevented sampling on some plots. For the first measurements (August until October 2000) data from the movable cages experiment (see 2.2.4) without replicates were used in order to complete the data from the exclosure experiment to cover a whole year. Table 2.5 lists the experiment used and the number of replicates available for each harvest date.

For the calculation of consumption the paired-plot method was used (Bonham, 1989). This method involves a caged plot protected from grazing and an uncaged reference plot. "Biomass from plots protected from grazing represents total herbage production, and biomass from grazed plots represents the unused herbage biomass." (Bonham, 1989, p. 293).

Within each of the four exclosures first the average daily differences for each treatment (*no grazing*, *only livestock*, *only pika*, *pika & livestock*) from one date to the next were determined. These daily differences were used to make periods of different sampling intervals comparable. Missing values for a treatment of one exclosure were replaced with the mean of the other exclosures for this treatment. The next step was to calculate growth or consumption separately for each exclosure. Afterwards average and standard deviation for the four exclosures were computed.

harvest	# rep	experimental setup
26/08/00	1	mobile cages
27/09/00	2	mobile cages
25/10/00	1	mobile cages
01/12/00	3	exclosure experiment
24/01/01	4	exclosure experiment
10/03/01	4	exclosure experiment
22/04/01	4	exclosure experiment
21/05/01	4	exclosure experiment
21/06/01	4	exclosure experiment
27/07/01	4	exclosure experiment
24/08/01	4	exclosure experiment
22/09/01	4	exclosure experiment

Table 2.5.: Overview over the available data for the calculation of standing crop: date of sampling, number of replicates (# rep), and experimental setup.

Calculation of productivity ANPP was calculated by summing up the average of all positive increments on treatment *no grazing* (ORNL DAAC, 2002; Singh et al., 1975). This is equivalent to the "IBP Standard Method" of Milner & Hughes (1968, cited in ORNL DAAC, 2002) which assumes that production increases are equal to increases in live phytomass between two successive samples, and is zero when phytomass decreases or remains the same. Annual primary production is then calculated by summing the increases. This method provided a reliable estimation of ANPP for a semi-arid grassland steppe (Defosse & Bertiller, 1991) and for a more humid grassland in Argentina as well (Pucheta et al., 1998). The growing season in 2001 was short. Due to the drought it lasted only from April to July. Positive increments in the treatment *no grazing* could be detected for the first time between March 10*th* and April 22*nd*, 2001 and for the last time between June 21*st* and July 27*th*, 2001.

Calculation of consumption Consumption by herbivores was calculated by comparing standing crop on an area exposed to grazing (treatment *only livestock*, *only pika*, *pika & livestock*) to standing crop on a reference treatment (*no grazing*) protected from grazing (Bonham, 1989). Values are given in kg/ha·d.

Consumption has to be calculated differently for phases of vegetation growth and non-growth conditions. These phases were distinguished by plant growth in the *no grazing* treatment. Before and after this growing season a combination of decay processes such as aging, drying out, mechanical destruction, and blowing away, leads to a disappearance of phytomass from the plots. Plant growth on treatment *no grazing* was observed between April and July 2001. Therefore this period was classified as the growing season 2001. Consumption was calculated as average daily consumption during the time interval between two harvest dates in order to make the different sampling intervals comparable (Frank & McNaughton, 1992).

Consumption during vegetation growth conditions During vegetation growth conditions the intake of the excluded herbivores is determined by subtracting ANPP on the grazed area from ANPP within the exclosure (Bork & Werner, 1999; Pucheta et al., 1998). That means that plant growth was assumed to be similar on all treatments, neglecting possible compensatory regrowth effects (see discussion on page 119) as well as trampling effects under grazing. Equation 2.3 shows the exemplary calculation for the consumption by pika. Consumption is calculated in an analogous way for livestock and for plots with grazing of both the herbivore groups.

$$consumption(pika) = sc(n2) - sc(n1) + [sc(p1) - sc(p2)] \tag{2.3}$$

$sc(n1)$ is standing crop on treatment *no grazing* at date 1
$sc(n2)$ is standing crop on treatment *only pika* at date 2
$sc(p1)$ is standing crop on treatment *no grazing* at date 1
$sc(p2)$ is standing crop on treatment *only pika* at date 2

Consumption during non-growth conditions In order to calculate consumption by herbivores the three processes of plant growth, grazing, and plant decay had to be considered. For the growing season the influence of plant decay was assumed to be negligible for the calculation, while it was an important process during winter and had to be included in the calculations. Wiegert & Evans (1964, cited in Singh et al. 1975, p. 185f) assumed the same disappearance of dead matter on both paired plots they investigated and used proportional reduction calculations. Thus the percentage of decay observed on the treatment *no grazing* (term $\frac{sc(n1)-sc(n2)}{sc(n1)}$ in equation 2.4) was proportionally subtracted from the standing crop on the other treatments before computing consumption. Consumption is calculated in an analogous way for livestock and for plots where both groups graze.

$$consumption(pika) = (1 - \frac{sc(n1) - sc(n2)}{sc(n1)}) \cdot sc(p1) - sc(p2) \tag{2.4}$$

$sc(n1)$ is standing crop on treatment *no grazing* at date 1
$sc(n2)$ is standing crop on treatment *only pika* at date 2
$sc(p1)$ is standing crop on treatment *no grazing* at date 1
$sc(p2)$ is standing crop on treatment *only pika* at date 2

Consumption during one year Consumption for pika and livestock during the whole year of investigation was calculated in two different ways. Method A calculates consumption by adding up **all** increments observed during one year, including the negative values. The idea of this is that negative values of consumption are not possible and therefore represent errors in the calculation. By including these negative values they make up for the same errors which are also inside the positive values. This method is generally recommended to minimize errors (Biondini et al., 1991; Catchpole & Wheeler, 1992; McNaughton et al., 1996; Sala et al., 1988a). As a comparison a second method B was computed. This method adds up all **positive** increments of consumption. The idea behind this method is that negative values of consumption are not possible and therefore should not be included in the calculation. This method may be suitable, when the errors made during positive consumption for some reasons seem to be much lower than those which cause the negative values. In our case low sample sizes in winter lead to negative values of consumption during this time, while sample size was higher in summer, where the positive values of consumption originated from. Therefore the results for both methods of calculation are given and discussed in this context.

Analysis of animal observations

The data from the animal observations were stored in a database and analyzed with a GIS. As the sightings were recorded in relation to other reference points, e.g. the observation point, longitude and latitude values for the sightings had to be calculated. For the reference points longitude and latitude were known from GPS readings. The distance from the reference point to any sighting in northern and eastern direction can subsequently be calculated by the rule of three.

In order to get the distance in degree two reference points which had a maximal distance in northern and eastern direction were used. Their longitudes and latitudes were known as well as their distance and the direction from one to the other. Thus it could be calculated that within the observation area 1 km in northern direction equals 0.009267 ° and 1 km in eastern direction equals 0.009596 ° . These values were used to calculate the longitude and latitude of all observed animal groups. It is an approximation only, but it is robust enough for data derived from distance estimations. Data were controlled and obvious errors corrected while the observations were recorded and digitalized. For animal densities around the exclosure experiment the observations from 2300–2400 m were used.

Conversion of animal numbers into stocking units For better comparability livestock numbers were converted into stocking units, using the Mongolian standard of the "Mongolian Sheep Unit" or short MSU (Bedunah, 2001b; Bedunah & Schmidt, 2000; Shurentuja et al., 2002). The definition of MSU is based on the average amount of forage consumed by an animal per day. 1 MSU is equivalent to the intake of 1 kg of dry forage matter per day or 365 kg/a, respectively. A sheep is assumed to consume exactly that amount of forage and all other species are compared to it (table 2.6). A solution had to be found for the conversion of mixed flocks of small livestock. Sheep and goats are herded together and during observation no separation between the species can be made. Thus the number of "shoat" was estimated as a whole and was assigned a conversion factor of 0.94 MSU. This was calculated from the average proportion of goats to sheep in the flocks of herders in the vicinity of the research camp as derived from interviews.

livestock	horse	cattle/yak	camel	sheep	goat
MSU	7	6	5	1	0.9
kg liveweight/head	286.5	260.2	477.1	41.1	34.3

Table 2.6.: Conversion of livestock numbers in stocking units (MSU, "Mongolian Sheep Units") and average slaughter weight of the species calculated from meat production (1000 tons live weight) and number of livestock slaughtered (1000 heads) in Mongolia for the periods 1986-1990 and 1991-1995 (data source: National Statistical Office of Mongolia 1996, 1998).

wild large herbivores	livestock	argali	gazelle	ibex
MSU	1	2.5	0.7	1.5
kg liveweight	66.2	65-180	20-39	35-130

Table 2.7.: Conversion of the numbers of wild animals into stocking units and the weight of the wild herbivores (data source: Huffman 2003).

It has been criticized that through the use of livestock units differences between the single species become blurred, and that the grazing impact of grazers and browsers with different grazing preferences should not be analyzed together (see e.g. Hobbs & Carpenter, 1986; Scarnecchia, 1986). But for the purpose of this study it seems feasible, because it focuses on the impact of livestock and not of a single species.

For the wild herbivores no such conventions exist. For the purpose of this study the following conversion factors based on the weight of the species in comparison with the average weight of 1 MSU of domestic animals (table 2.7) were calculated: wild sheep (argali) 2.5 MSU, ibex 1.5 MSU, and gazelle 0.7 MSU.

Statistical methods

For basic statistic calculations such as statistical mean and standard deviation the standard procedures of the software-packages Origin 6.0 or Excel 97 were used. The software-package SPSS was used to analyze vegetation data such as species height and cover.

As the data were not distributed normally (tested with the Kolmogorov-Smirnov-test), which is a prerequisite for ANOVAs, the Mann-Whitney-U-test was used for testing the significance of the height difference of single species between different treatments. For the same reason the Mann-Whitney-U-test was used to test the significance of differences in vegetation cover between sampling dates and between the treatments of the exclosure experiment.

2.3. Results

2.3.1. Precipitation

The precipitation data recorded for the research camp are shown in figure 2.5. As a comparison the corresponding data for the Soum-capital Bayandalay and for the Aymag-capital Dalandzadgad are included as reference values in figure 2.6[1].

The station Dalandzadgad was chosen as a comparison because it provides the longest and most complete series of precipitation measurements in the vicinity of the research camp. But Dalandzadgad is not directly comparable with the research camp because two oppositely orientated gradients exist between the two stations. Following the gradient of decreasing precipitation from east to west the research camp should receive less precipitation than Dalandzadgad because it is situated in the rain shadow of the Dzuun Sayhan mountain range. On the other hand precipitation increases with increasing altitude and as the research station at 2350 m lies about 1000 m higher than Dalandzadgad at 1400 m precipitation should be higher at the research camp.

In order to get more precise information on the effects of both gradients, the station Bayandalay is included as a comparison as well. This station lies on about the same altitude as Dalandzadgad, and on approximately the same eastern longitude as the research camp. This allows to assess the single effect of changing precipitation from east to west at one altitude of ∼1500 m between Dalandzadgad and Bayandalay and the second gradient on one longitude with increasing altitude from 1500 m in Bayandalay to 2350 m at the camp. Therefore the data from Bayandalay were included although data collection generally is not very reliable and especially the data from Bayandalay are far from being complete. Due to the gaps in monthly data the database for yearly precipitation in Bayandalay is extremely small. Data covered a full range of twelve months during two years only. As it is not sufficient to use these values as reasonable indicators, primarily the monthly values from Bayandalay are used.

All three data sets show the typical distribution of precipitation with a clear peak in summer and very low precipitation in winter as generally described for Mongolia (Haase, 1983; Bergius, 2002). At both sites about 86 % of the yearly precipitation falls in the five months of the growing season from May to September. The inter-annual and intra-annual variabilities are high. At both sites all medians of the single months are lower than the corresponding mean (table 2.8). This implies that there are some relatively high monthly precipitation sums which increase the mean, but that the majority of the monthly precipitation sums lies below the value of the mean. For the yearly precipitation sum in Dalandzadgad median and mean are much more similar.

The coefficient of variation for monthly and annual precipitation is high. The variability of precipitation is lower in the summer months than in winter at both stations. This again underlines the relative "reliability" of the summer rain peak, which is extremely

---

[1] Please note that the figure covers the range from October 1^{st}, 2000 until October 1^{st}, 2001. This is the standard period covered also by subsequent graphs. The single letters always indicate the first day of the respective month in this and all further figures.

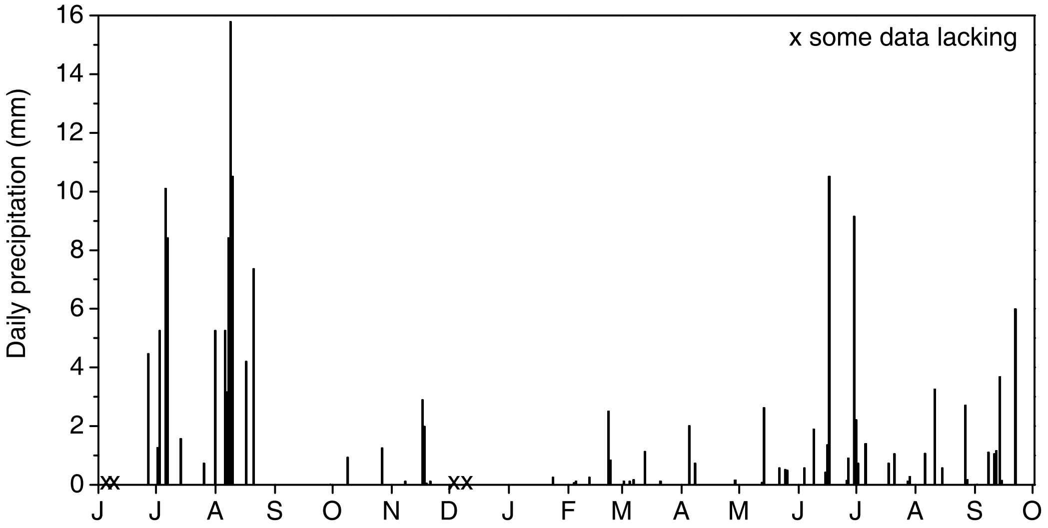


Figure 2.5.: Daily precipitation at the research camp (mm/d) from July 2000 until the end of September 2001. The measuring gauge was located at the summer place at about 2350 m asl from July to October 2000 and again from April to September 2001. In the meantime it was located at the winter camp 1930 m asl.

important for the herders which rely on the summer rains for the phytomass production to feed their livestock. The database may not be sufficient but there seems to be a trend to higher variability of precipitation in the more arid Bayandalay – especially at the beginning and end of the growing season, in May and September.

In the period from 1966 to 1999, Bayandalay received an average yearly precipitation of 113.4 mm and Dalandzadgad of 132.7 mm. The distance of 75 km in western direction results in a difference in annual precipitation of about 19 mm. This means Dalandzadgad receives on average 17 % more precipitation than Bayandalay.

For the research camp data exist from July of 2000 until September 2001. From the Mongolian Meteorological Service monthly data for Bayandalay and Dalandzadgad are available for this period. Unfortunately two independently acquired data sets for the precipitation of Bayandalay differed greatly for the investigation period. These could not be used as comparisons. Therefore only the data from Dalandzadgad can be compared with the measurements at the research station (table 2.9). At the research station the total precipitation within the growing season 2001 is 56.8 mm, total precipitation from January until September 2001 65.4 mm.

In Dalandzadgad the period 1/10/00–31/12/00 received relatively much precipitation: 71.7 mm represent 83 % of the average rainfall during this period. Rainfall in 2000 was extremely concentrated in August, with 56.9 mm in this month only. This represents almost 170 % of the average precipitation in August. The spring and summer of 2001 (1/1/01–31/9/01) on the other hand were dry. 70.3 mm of rain in this period are less than 60 % of the average rainfall during this time of the year. The situation is similar during the growing season 2001: 66.9 mm of rain represent only 60 % of the average precipitation during this time.

The absolute amounts of precipitation in Dalandzadgad and around the camp are approximately the same magnitude (table 2.9). The two precipitation gradients within

	Bayandalay (1966-1999)					Dalandzadgad (1936-1999)				
	N	mean	median	SD	CV	N	mean	median	SD	CV
January	18	1.7	0.9	1.9	115	59	1.2	0.8	1.2	106
February	19	1.6	0.5	2.3	145	59	1.5	0.9	1.8	120
March	19	2.3	1.7	2.4	107	60	3.1	1.8	3.5	113
April	21	3.0	2.2	3.2	106	58	5.3	2.7	7.7	147
May	29	8.4	4.3	16.4	195	60	10.8	8.5	9.6	89
June	31	14.3	13.5	10.2	71	60	22.9	17.0	19.9	87
July	30	36.7	36.3	22.8	62	60	33.0	29.0	21.7	66
August	25	26.6	18.4	22.5	84	58	33.6	28.4	27.1	81
September	25	12.5	8.4	22.3	178	60	12.0	9.3	10.6	88
October	19	4.2	3.3	4.0	96	58	4.0	1.6	6.5	165
November	21	1.3	0.6	2.0	154	60	2.2	1.2	2.5	114
December	17	1.0	0.8	1.0	102	56	1.2	0.9	1.3	106
year		113.4				51	130.8	131.4	47.6	36

Table 2.8.: Characteristics of the rainfall distribution in Bayandalay and Dalandzadgad. Mean, standard deviation (SD), median and coefficient of variation (CV) for monthly and annual precipitation sums are given. For Bayandalay the mean yearly precipitation is calculated from the mean monthly values, because only two complete data sets for a whole year were available. Many values are missing as indicated by the number of samples in row N. Data from the Meteorological Service Mongolia.

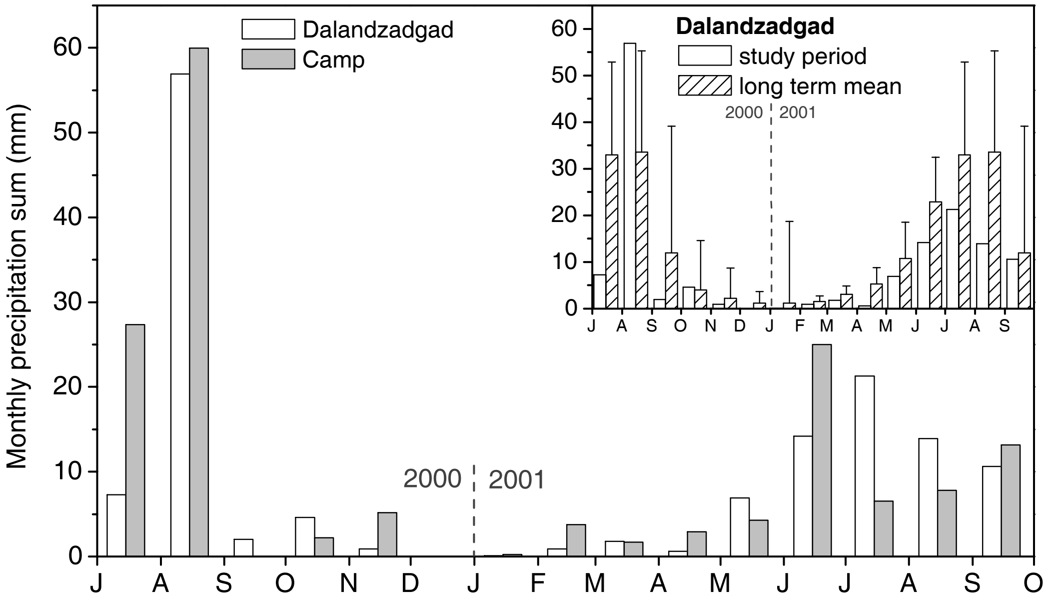


Figure 2.6.: Monthly precipitation at the station Dalandzadgad, and near the camp (mm/month) from July 2000 until September 2001. The inset shows a comparison of the average monthly precipitation 1961-1999 (error bars = standard deviation) with the actual precipitation at Dalandzadgad during the investigation period. Letters indicate the beginning of each month. Data for Dalandzadgad are from the Meteorological Service of Mongolia, camp data from own measurements.

period		Dalandzadgad	% of mean	camp
July–December 2000	1/07/00–31/12/00	71.7	83	94.7
January–September 2001	1/01/01–31/09/01	70.3	57	65.4
growing season 2001	1/05/01–31/09/01	66.9	60	56.8
investigation period	1/10/00–31/09/01	75.8	58	72.8
July & August 2000	1/07/00–31/08/00	64.2	96	87.3
July & August 2001	1/07/01–31/08/01	35.2	53	14.3
July & August 2002	1/07/02–31/08/02	24.4	37	27.3

Table 2.9.: Precipitation at the station Dalandzadgad, and at the camp for seven different periods from July 2000 until summer 2002. The column "% of mean" shows how much precipitation Dalandzadgad received in these periods in comparison to the long-term mean of the respective period. Data for Dalandzadgad are from the Meteorological Service of Mongolia, camp data 2000-2001 from own measurements, for 2002 from K. Wesche, K. Nadrowski, and coworkers.

the park (see chapter 1.4.3, p. 57), decreasing aridity from east to west and with altitude, may neutralize each other. In 2001 the distribution of rains was even less favorable at the camp than in Dalandzadgad. At the camp a high proportion of the precipitation fell before the growing season (table 2.9). The high inter-annual and spatial variability of rainfall (Haase, 1983; Bergius, 2002; Weischet & Endlicher, 2000) makes any further interpretation of the short-term measurements at the camp difficult.

From the few data available it can be assumed that the average rainfall at the research camp is relatively similar to that measured in Dalandzadgad. For the whole investigation period and the summer of 2002 the precipitation sums are relatively similar. In the period from July to December 2000 precipitation is higher at the research camp while in turn from January to September 2001 precipitation is higher in Dalandzadgad. Therefore the data do not show a clear gradient between the two stations.

The year 2001 brought a severe drought in the whole of southern Mongolia. The South-Gobi Aymag was seriously affected. The herders in the vicinity of the research camp referred to the summer of 2001 as a heavy drought and described the situation as extremely bad. Precipitation at the research camp in July and August of 2001 was only 16 % of the amount received the year before, and only 53 % for Dalandzadgad.

In the summer of 2002 the situation was similarly bad or partially even worse. In Dalandzadgad precipitation in July and August equalled only 37 % of the average precipitation during this time. At the research camp precipitation was almost twice as much as during the same period in the previous year, but this still represents only 31 % which was recorded during the same period in 2000.

The data show the high inter- and intra-annual variability of precipitation on this semi-arid region. The variation between the highest and lowest precipitation sum of the two months July and August in the three summers of 2000, 2001, and 2002 alone is more than 260 % for Dalandzadgad, and more than 600 % at the research camp.

2.3.2. Soil water content

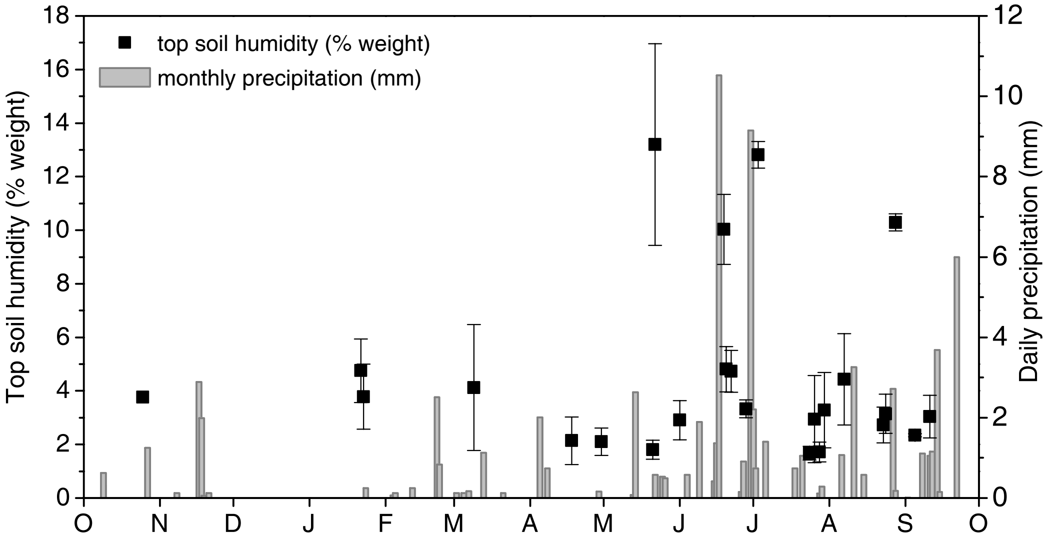


Figure 2.7.: Evolution of top soil humidity (in % dry weight) at 2300 m asl. As a comparison daily precipitation at the research camp is shown at the right y-axis.

The data of top soil humidity generally show low levels of humidity in the uppermost 5 cm (fig. 2.7). Values range from a minimum of 1.7 % to a maximum of 13.2 %. The median is 3.3 %, the average 4.5±0.7 %. The pattern is irregular. Shortly after a rain event soil humidity rises up to about 10–12 % and decreases again soon after. In winter top soil humidity is low. It usually does not exceed 5 %. During the growing season soil water contents are also generally low except for some peaks closely connected to single rainfall events. The measurements at May 22^{nd} which show the high standard deviation were actually taken during a short rain shower which yielded 0.58 mm. This explains why there is no larger precipitation peak connected to this value as well as the high variability in the samples.

These data are another indicator for the drought experienced in the summer of 2001: precipitation is never sufficient to infiltrate through the soil deep enough to build up a water reservoir in order to increase soil humidity for a period long enough to support plants with continuous water supply for efficient growth.

2.3.3. Vegetation data

Species height

Species height was recorded as an important parameter to calculate standing crop with the double-sampling method (see p. 83). Apart from that, monitoring of species height provides indirect information on the growth pattern of different species. By comparing height development of one species on the different treatments of the exclosure experiment inferences on the foraging selectivity and grazing preference of the investigated herbivore groups pika and livestock can be drawn.

The height development of *Allium* spp. is very similar on all four treatments (fig. 2.8 and table 2.10). During winter *Allium*-heights on all treatments vary around 10 mm. The grazing effect of the year 2000 on *Allium*-height decreases during winter until in March almost no significant differences between any of the treatments can be detected any more. In April, and even more pronounced in May, a significant differentiation between all grazed treatments and the treatment *no grazing* can be observed, while all grazed treatments do not show significant differences (10/03/01 until 21/05/01).

The rains in June initiate *Allium*-growth relatively late and abrupt. This growth levels the differences on all treatments, so that no significant difference in *Allium*-height can be detected in June and only little in July. *Allium*-growth still continues on treatment *no grazing* up to a height of about 40 mm on average. While *Allium* maintains this height afterwards on all grazed treatments until the end of the investigations, the differentiation of the treatments sets in again in August. From then on *Allium*-height on the *no grazing* treatment gets increasingly dissimilar from all grazed treatments. A clear treatment effect can be seen towards the end of the study when no other forage was available.

During winter the height of *Stipa* is similarly low on all treatments (∼ 20–25 mm) (fig. 2.8). The treatment effect of the summer of 2000 diminishes until from 4/12/00–10/03/01 the height of *Stipa* is not significantly different on the treatments (table 2.11).

In the course of spring, parallel to the growth of *Stipa*, differentiation of the treatments starts. This results in a grazing effect in April, when *Stipa*-height on treatment *pika & livestock* is significantly different from all other treatments. The impact of the treatments gets more pronounced in May and June, until in July *Stipa*-height on treatment *no grazing* is significantly different from that on all other treatments.

The lack of rain brings *Stipa*-growth to a halt, and continued grazing again results in a differentiation between all treatments. While in August no difference between the treatments *only pika* and *only livestock* can be found, a clear differentiation between all treatments emerges in September. During the whole growing season *Stipa* height is larger on the treatment *no grazing* than on all grazed treatments. The treatments *only pika* and *pika & livestock* show much lower height, while the height of treatment *only livestock* is intermediate in height between the other grazed treatments and treatment *no grazing*.

The height of *Agropyron cristatum* during the whole investigation period is the lowest of all species, a fact that is especially obvious during summer (fig. 2.8). Although *Agropyron* can grow upright when protected from grazing, it sneaks at the ground when being grazed. Most probably this is an adaption to protect its leaves from being bitten off by herbivores. The different growth forms can be seen clearly at the exclosure experiment and they are also reflected in the heights of *Agropyron* in the different treatments.

Agropyron, just as *Allium* is grazed down to an extremely low height of about 10 mm in winter. In October and March *Agropyron*-height does not differ significantly between any

***Allium* spp.**

date	26/09	25/10	4/12	24/1	10/3	22/4	21/5	21/6	27/7	24/8	22/9
year	2000	2000	2000	2001	2001	2001	2001	2001	2001	2001	2001
n-l	**0.001**		**0.028**	n.s.	n.s.	**0.005**	**0.002**	n.s.	n.s.	**<0.001**	**<0.001**
n-p	**<0.001**		n.s.	**0.031**	**0.005**	**0.024**	**<0.001**	n.s.	n.s.	**0.026**	**<0.001**
n-lp	**<0.001**		**0.001**	**0.039**	n.s.	**<0.001**	**<0.001**	n.s.	**0.007**	**<0.001**	**<0.001**
l-p	n.s	n.s.	n.s.	**0.012**	n.s.	n.s.	n.s.	n.s.	n.s.	**<0.001**	**0.018**
l-lp	**0.006**	n.s.	n.s.	**0.009**	n.s.	n.s.	**0.013**	n.s.	n.s.	n.s.	**0.001**
p-lp	n.s.	n.s.	**0.004**	n.s.	n.s.	n.s.	n.s.	n.s.	**0.009**	**<0.001**	n.s.

Table 2.10.: Significance of differences in average height of *Allium* spp. between the treatments of the exclosure experiment over time calculated by the Mann-Whitney-U-test. Treatments are: n - *no grazing*, l - *only livestock*, p - *only pika* and lp - *pika & livestock*. Significant results are indicated in bold, p-values higher than 0.05 are indicated as not significant (n.s.).

***Stipa* spp.**

date	26/09	25/10	4/12	24/1	10/3	22/4	21/5	21/6	27/7	24/8	22/9
year	2000	2000	2000	2001	2001	2001	2001	2001	2001	2001	2001
n-l		n.s.	n.s.	n.s.	n.s.	n.s.	**<0.001**	**0.014**	**<0.001**	**<0.001**	**<0.001**
n-p	n.s.	**<0.001**	n.s.	n.s.	**0.026**	**0.009**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
n-lp	**0.001**	**<0.001**	n.s.	**0.020**	**0.013**	**<0.001**	**<0.001**	**0.007**	**<0.001**	**<0.001**	**<0.001**
l-p	**0.014**	**<0.001**	n.s.	n.s.	n.s.	n.s.	n.s.	**0.001**	n.s.	**<0.001**	**<0.001**
l-lp	**0.000**	**0.018**	n.s.	**0.004**	n.s.	**<0.001**	**0.019**	n.s.	n.s.	**0.002**	**<0.001**
p-lp	**0.022**	**0.003**	n.s.	**0.039**	n.s.	**<0.001**	**<0.001**	**0.001**	n.s.	n.s.	**0.001**

Table 2.11.: Significance of differences in average height of *Stipa* spp. between the treatments of the exclosure experiment over time calculated by the Mann-Whitney-U-test. For a description of treatments and the significance of p-values see table 2.10.

Agropyron cristatum

date	26/09	25/10	4/12	24/1	10/3	22/4	21/5	21/6	27/7	24/8	22/9
year	2000	2000	2000	2001	2001	2001	2001	2001	2001	2001	2001
n-l		n.s.	n.s.	n.s.	n.s.	n.s.	**<0.001**	n.s.	**0.002**	**<0.001**	**<0.001**
n-p	**0.017**	n.s.	n.s.	**<0.001**	n.s.	**0.031**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
n-lp	n.s.	n.s.	n.s.	**0.002**	n.s.	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
l-p	n.s.	n.s.	n.s.	**<0.001**	n.s.	n.s.	n.s.	**<0.001**	**<0.001**	**<0.001**	**<0.001**
l-lp	n.s.	n.s.	n.s.	**0.011**	n.s.	**<0.001**	n.s.	**<0.001**	**<0.001**	**<0.001**	**<0.001**
p-lp	n.s.	n.s.	**0.034**	n.s.	n.s.	**<0.001**	n.s.	n.s.	n.s.	n.s.	**<0.001**

Table 2.12.: Significance of differences in average height of *Agropyron cristatum* between the treatments of the exclosure experiment over time calculated by the Mann-Whitney-U-test. For a description of treatments and the significance of p-values see table 2.10.

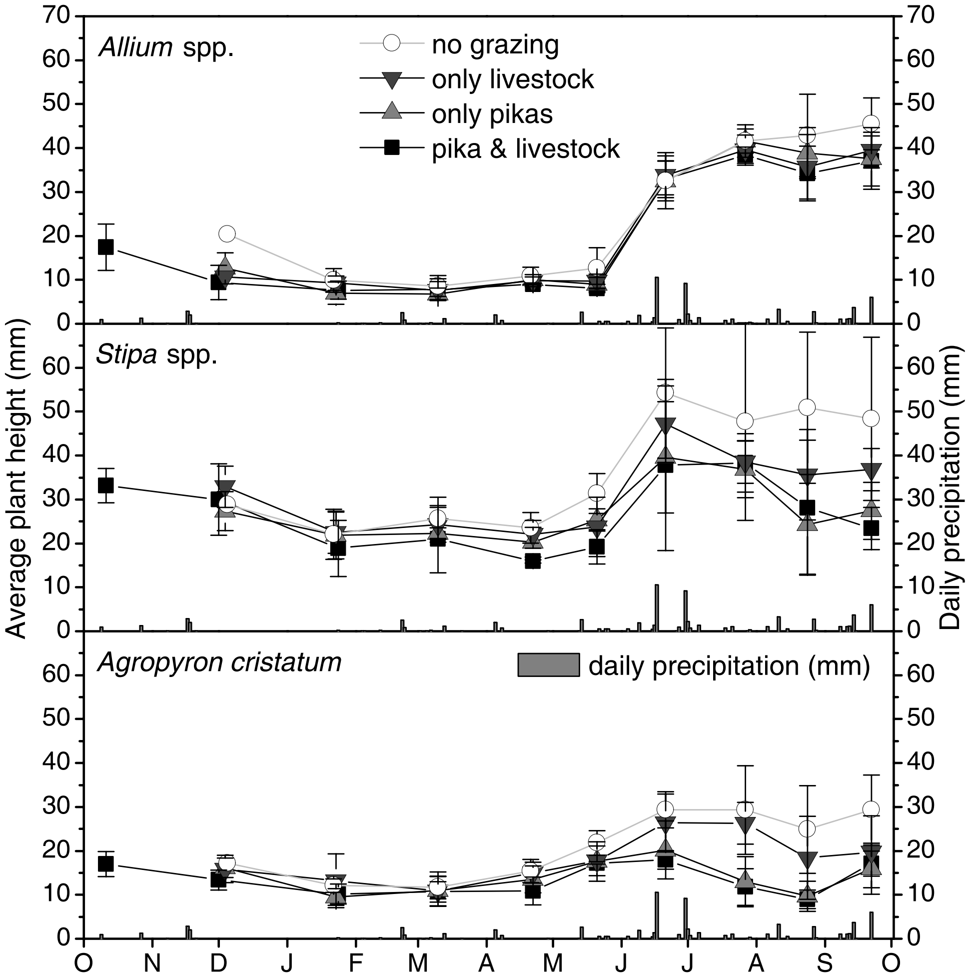


Figure 2.8.: Height development of important species and species groups within the different treatments of the exclosure experiment. Error bars represent standard deviation. Daily precipitation is indicated on the right y-axis.

of the treatments (table 2.12). *Agropyron*-growth sets in relatively early and continues steadily (22/4/–21/6/01). Grazing takes effect in April, when on treatment *pika & livestock Agropyron*-height is significantly different from all other treatments. In May the same is true for treatment *no grazing*. For the rest of the season *Agropyron*-height declines on all treatments, until a second growth peak can be detected in September (fig. 2.8). In parallel to that the different grazing treatments take effect resulting in significantly different *Agropyron*-heights between all treatments. The differences between the treatments *only pika* and *pika & livestock* are not significant until the last sampling date in September.

Vegetation cover

The general trend of plant cover on all treatments from the winter of 2000 to the autumn of 2001 is a decreasing one with a small hump during the growing season 2001 (fig. 2.9).

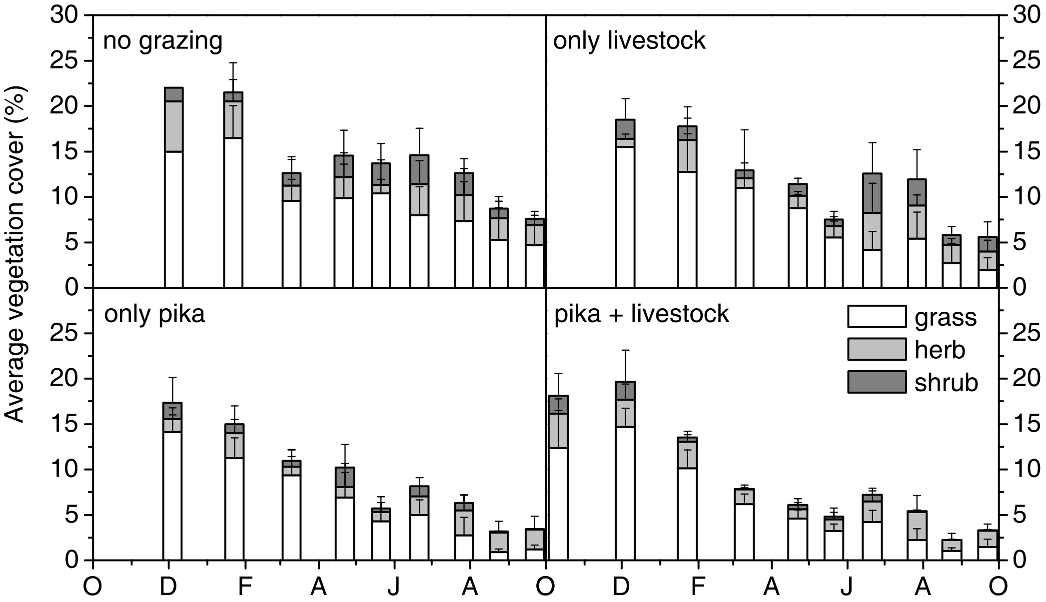


Figure 2.9.: Average vegetation cover (grass, herb, shrub) from October 2000 until late September 2001 on the exclosure treatment. Error bars indicate positive standard deviation of the single functional groups.

During the summer of 2001 a slight increase in vegetation cover can be observed on all treatments which never equals the cover observed in December 2000. A downward trend can be expected between the end of the last and the start of the following growing season due to the drying-out of the vegetation on the *no grazing* treatment and additionally due to grazing on the grazed treatments. But the fact that vegetation cover on all treatments in the summer of 2001 is lower than in the winter of 2000 must have different causes: the drought inhibits the expansion of vegetation cover. The maximum cover in the growing season of 2001 at the end of June is 14.6 % on treatment *no grazing*, 12.6 % on treatment *only livestock*, 8.3 % on treatment *only pika*, and 7.2 % on treatment *pika & livestock*, respectively. After this date the cover decreases again on all treatments.

A comparison with the cover data from 1996 confirms this (Miehe, 1998). In the summer of 1996, which was a wet year (175 mm = 135 % of average precipitation in Dalandzadgad see also fig. 2.6, p. 93) the mountain-steppe communities showed a vegetation cover of more than 35 % up to 55 % under grazing. Vegetation cover reacts very sensible to available soil moisture.

The impact of grazing by both the herbivore groups on vegetation cover can be assessed from the development of vegetation cover on the different treatments. The development of vegetation cover on treatment *only livestock* follows that on treatment *no grazing* closely while the development on *only pika* resembles that on treatment *pika & livestock* (table 2.13). Vegetation cover on the latter two is never significantly different during the whole investigation period (table 2.13 last row p–lp). For the treatments *no grazing* and *only livestock* significant differences can be found in May and June, only (first row n–l). The highest number of significant differences is found between the most "extreme" treatments *no grazing* and *pika & livestock* (3^{rd} row n–lp).

differences in vegetation cover between treatments								
date	24/1	10/3	22/4	21/5	21/6	27/7	24/8	22/9
n-l	n.s.	n.s.	n.s.	**0.021**	**0.043**	n.s.	n.s.	n.s.
n-p	n.s.	n.s.	n.s.	**0.021**	**0.021**	**0.021**	**0.043**	**0.043**
n-lp	n.s.	**0.021**	**0.009**	**0.021**	**0.021**	**0.043**	**0.021**	**0.043**
l-p	n.s.	n.s.	n.s.	n.s.	**0.043**	n.s.	n.s.	n.s.
l-lp	n.s.	n.s.	**0.009**	n.s.	**0.021**	**0.021**	**0.043**	n.s.
p-lp	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table 2.13.: Significance of differences in vegetation cover between the treatments of the exclosure experiment in 2001. Treatments are: n - *no grazing*, l - *only livestock*, p - *only pika* and lp - *pika & livestock*. Significance of p-values are from a Mann-Whitney-U-test. Significant results are indicated in bold, p-values higher than 0.05 are indicated as not significant (n.s.).

Only few differences in vegetation cover are significant during winter until a grazing effect emerges in late May. Then treatment *no grazing* is significantly different from all grazed treatments. The different grazing by both the herbivore groups takes effect in June and results in a clear treatment effect. The only two treatments which do not show significantly different vegetation cover then are *only pika* and *pika & livestock*. Under continued grazing during the rest of the growing season this effect diminishes. The drought causes a levelling of the differences by autumn 2001. Also the vegetation cover on the treatment protected from grazing decreases until in September only the two treatments grazed by pika are still different from treatment *no grazing*.

Generally vegetation cover exhibits less distinctive differences between the treatments of the exclosure experiment than species height. This may be due to the smaller numbers of samples – about 80 (20 measurements times 4 plots) per date for species height and 4 (1 estimation per plot) per date for vegetation cover.

For the different species-groups *Allium*, *Stipa*, and *Agropyron* sufficient data are available for analysis in 2001. But no pattern in the distribution of cover between the treatments of the exclosure experiment can be found. There are almost no significant differences in cover between the different treatments.

Impact of drought on vegetation

The best assessment of the impact of drought on vegetation structure is possible with treatment *no grazing* because on this treatment grazing impact is missing and changes in vegetation have to be attributed to other impacts. For better illustration average height and cover of *Allium, Stipa*, and *Agropyron* are given in figure 2.10 for the treatment *no grazing* and for treatment *pika & livestock* as a comparison.

All three species show their minimum height on treatment *no grazing* during the winter months and respond with growth to the rains in June. Under the bad conditions in 2001, the process of vegetation growth starts off, but is slowed down soon by the low water availability. This results in much lower overall vegetation height than observed

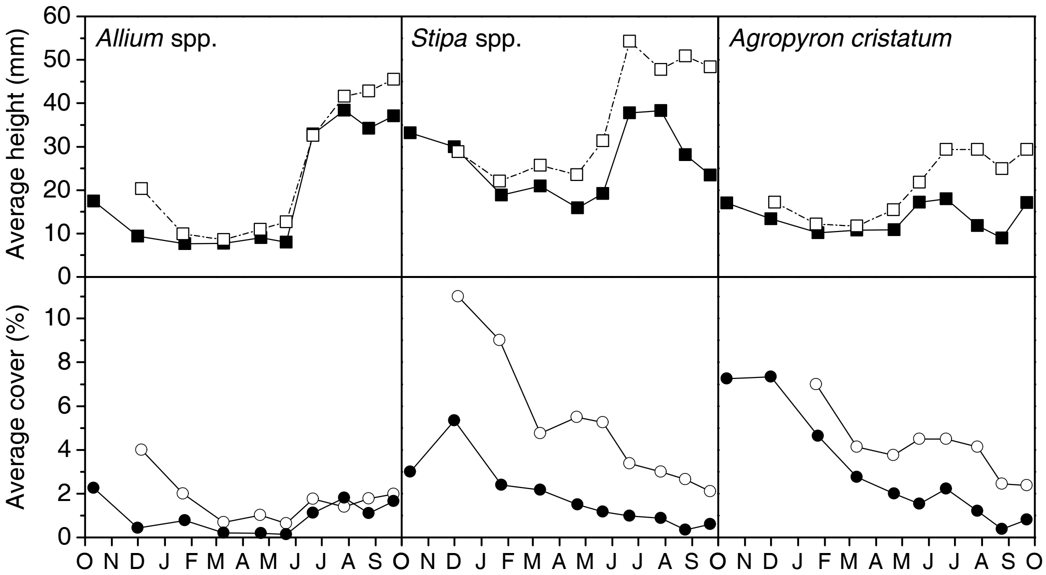


Figure 2.10.: Comparison of the development of average species height (above) and cover (below) on the treatments *no grazing* (open signatures) and *pika & livestock* (filled signatures). Standard deviations are not printed for better readability.

in the previous year (K. Wesche, pers. comm.). The growing season usually lasts until September (Haase, 1983).

The development of average vegetation cover during the investigation period shows a different pattern (fig. 2.10, below). On treatment *no grazing* cover was higher during the winter of 2000/01 than in the autumn of 2001. Especially *Stipa* and *Agropyron* show a continuous downward trend in cover during the whole investigation period, slowed down only by a short increase in early summer. But even during this time cover is lower than it had been at a much later time during the previous year.

A comparison with the figures of 2000 shows that the drought of 2001 has greater impact on vegetation cover (fig. 2.9, p. 99) and species cover than on vegetation growth, indicated by species height. Total vegetation cover is the main predictor Mongolian herders use for the evaluation of pasture conditions (Fernandez-Gimenez, 1997, cited in Fernandez-Gimenez & Allen-Diaz 1999). This demonstrates again the extremely low forage availability during the drought of 2001.

Above-ground net primary production

Net primary productivity can be calculated as the sum of positive increments of subsequent harvests on treatment *no grazing*. It amounts to 184 kg in the growing season 2001. Maximum standing crop on treatment *no grazing* is reached in July with 227 kg/ha. Until September 65.4 mm of precipitation were recorded at the research camp. This results in a rain use efficiency (RUE, after Le Houerou 1984) of 2.8 kg/mm for the growth in 2001 and in 3.5 kg/ha for maximum standing crop. If the values recorded in 2000 are used to substitute the missing months of 2001, the estimated annual precipitation in 2001 is 72.8 mm. This results in a rain use efficiency of 3.1 kg/mm for maximum standing crop. As most other authors calculate RUE from values for maximum standing crop (Le Houerou, 1984), and as the remaining old phytomass from the previous year is replaced during the course of the vegetation period, it seems more suitable to use maximum standing crop for the calculation of RUE than net primary productivity. Therefore, for all further comparisons the values of 227 kg/ha as ANPP and 72.8 mm as annual precipitation are used.

Sala et al. (1988b) proposed a formula for the grasslands of North America ($r^2=0.90$; $p<0.01$), where above-ground net primary productivity (ANNP) can be estimated from the annual precipitation (APPT) as:

$$\mathrm{ANPP}(kg/ha) = 6 \cdot (\mathrm{APPT}(mm/a) - 56). \tag{2.5}$$

Sala et al. (1988b) also calculated the same best fit regression ($r^2=0.63$; $p<0.01$) for data from Central Asia reported by Rodin (1979) as:

$$\mathrm{ANPP}(kg/ha) = 5.9 \cdot (\mathrm{APPT}(mm/a) - 50.8). \tag{2.6}$$

Both equations are quite similar. The 56 mm and 50.8 mm, respectively, which are subtracted from the annual precipitation can be interpreted as "ineffective precipitation", which is lost for the vegetation either by evaporation or runoff (Noy-Meir, 1973). In Mongolia also the winterly snowfalls, which sublimate back into the atmosphere without filling up the soil water reservoir, contribute to the ineffective precipitation. The problem of the setting of such a fixed "ineffective precipitation" is that the formula may not be suitable for lower annual precipitation, although there still might be vegetation growth.

Applied to the data of this study equation 2.5 estimates a productivity of 100.8 kg/ha and equation 2.6 a productivity of 129.8 kg/ha. Both equations therefore underestimate productivity. This indicates that the water use efficiency of the vegetation in the mountain-steppes in the Gobi Gurvan Sayhan is much higher than that of the species in the North American prairie and also higher than that of the Central Asian desert sites of Rodin (1979). The reason may be that both data sets used for the calculation of the equations 2.5 and 2.6 were derived from locations wetter than the study area. None of the sites used for calculating equation 2.5 received less than 250 mm annual precipitation, none of those used for equation 2.6 less than 99 mm. Furthermore, the study sites of Rodin (1979) partially received considerable proportions of precipitation outside the growing season which resulted in a higher ineffective precipitation than can be expected in the South-Gobi.

Lauenroth & Sala (1992) suggest that a fundamental problem of such functions for estimating ANPP may be the extrapolation in space rather than in time. Regional models which incorporate the ANPP of different vegetation units responding to different levels of precipitation may not be useful for extrapolating ANPP at one site. The vegetation of each site is adapted to average conditions (and variations) in water availability, therefore, its response to changes in precipitation level is physiologically limited. Furthermore, changes in vegetation structure are rather slow. According to Lauenroth & Sala (1992) these constraints are the reason why the regional model underestimates ANPP under dry conditions and overestimates it under wet conditions. The authors present a equation derived from long-term measurements in the shortgrass steppe sites of the Central Plains Experimental Range (mean annual precipitation=321 mm, CV=31):

$$\text{ANPP}(kg/ha) = 56 + 1.3 \cdot \text{APPT}(mm/a). \tag{2.7}$$

The form of this equation seems to be intuitively more satisfying, as it at least never results in a negative ANPP because no ”ineffective precipitation” is subtracted. On the other hand, this formulation also projects an ANPP of 56 kg/ha even if no precipitation would be recorded. However, if this equation is applied, the measured precipitation at the study site is estimated to produce 150.6 kg/ha. This is closer to the measured productivity than any of the previous estimations.

In the same article equation 2.5 is cited with a modified intercept for ”ineffective precipitation” as:

$$\text{ANPP}(kg/ha) = 6 \cdot (\text{APPT}(mm/a) - 34). \tag{2.8}$$

Why the intercept was reduced from 56 mm to 34 mm is not explained. However, this equation estimates a production of 234 kg/ha for the study site. This estimation is most close to the maximum standing crop actually recorded.

For the study site ineffective precipitation can be calculated from the precipitation outside the growing season (September-April=16 mm) plus ineffective precipitation in summer which can be estimated from the reaction of the vegetation to different levels of summer precipitation along the altitudinal transect (≃10 mm see chap. 3.3.2, p. 139, especially tab. 3.2). Therefore, ineffective precipitation amounts to 26 mm. Thus the equation for the study site can be written as:

$$227(kg/ha) = 4.9 \cdot (72.8(mm/a) - 26). \tag{2.9}$$

The values found for ineffective precipitation and rain use efficiency both range at the lower end of the scale proposed by Noy-Meir (1973). In his review he suggests ineffective precipitation to range between 25 mm and 75 mm and typical efficiency between 5–20 kg/ha·y for arid and semi-arid ecosystems.

The cited examples show that although the concept of rain use efficiency, and thus indirectly the possibility to predict ANPP from annual precipitation, is widely accepted today, it is far from being easily applied. The crucial factor for the application of the functions is the knowledge about the intercept for ineffective precipitation. Although most areas from which the equations were derived and to which they were applied exhibit a concentration of precipitation in summer, the differences in estimating productivity are enormous.

This confirms again that the concentration of rains in the growing season is of extreme importance for the production of phytomass. And this is the prerequisite for the relatively high productivity of Mongolian steppe and desert-steppe ecosystems and therefore for successful pastoral nomadism in this landscape.

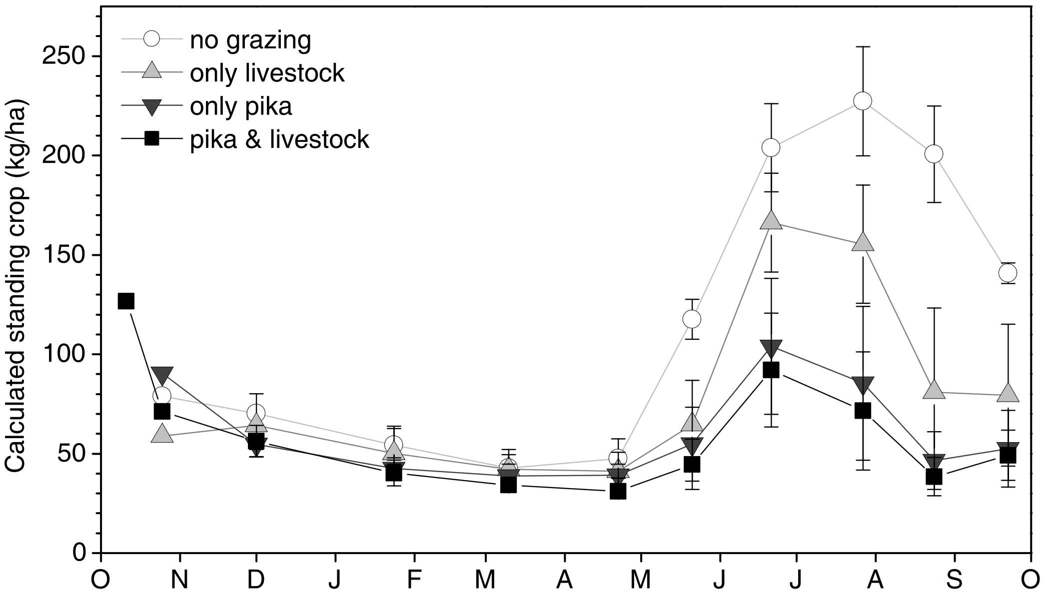


Figure 2.11.: Average standing crop on the different treatments of the exclosure treatment during the investigation period. Error bars indicate standard deviation within one harvest date.

Standing crop

The changes in standing crop on the exclosure experiment during the investigation period are illustrated in figure 2.11. The rhythm follows the seasons closely and therefore is similar on all four treatments. After the end of the growing season 2000 a fast drop to low amounts of standing crop can be observed. The minimum amount of standing crop is reached in late winter to early spring in March and April. This amount of approximately 30 kg/ha is similar on all treatments. It seems to represent phytomass which could be harvested by the researcher, but was neither accessible to pika nor to livestock. For the short period from May to June standing crop increases on all treatments. On the grazed treatments this growth is almost instantly followed by a decrease in the following months. Only on treatment *no grazing* standing crop increases further until the end of July.

When comparing the standing crop on the different treatments of the exclosure experiment, a clear distinction between winter and summer can be seen. Before the harvest in April almost no significant difference between the treatments can be detected (table 2.14). Grazing takes first effect with the onset of plant growth in May: standing crop on treatment *no grazing* and *only livestock* is significantly different from that on treatment *pika & livestock*. A clear grazing effect emerges in May, when treatment *no grazing* is significantly different from all other treatments, but these are not from each other (table 2.14). This grazing effect persists throughout the growing season. Additionally the treatments *only livestock* and *pika & livestock* are significantly different from each other, but *only livestock* and *only pika* as well as *only pika* and *pika & livestock* are not. This indicates that standing crop on the treatment *pika & livestock* is more similar to treatment *only pika* than to treatment *only livestock*. Standing crop on treatment *only livestock*

differences in standing crop between treatments

2001	24/1	10/3	22/4	21/5	21/6	27/7	24/8	22/9
n-l	n.s.	n.s.	n.s.	**0.021**	n.s.	**0.021**	**0.021**	**0.014**
n-p	n.s.	n.s.	n.s.	**0.021**	**0.021**	**0.021**	**0.021**	**0.009**
n-lp	n.s.	**0.043**	**0.009**	**0.021**	**0.021**	**0.021**	**0.021**	**0.009**
l-p	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
l-lp	n.s.	n.s.	**0.009**	n.s.	**0.021**	**0.021**	**0.043**	n.s.
p-lp	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table 2.14.: Significance of differences in standing crop between the treatments of the exclosure experiment after the Mann-Whitney-U-test. Treatments are: n - *no grazing*, l - *only livestock*, p - *only pika* and lp - *pika & livestock*. Significant results are indicated in bold, p-values higher than 0.05 are indicated as not significant (n.s.).

differences in standing crop between sample dates

sample dates	*no grazing*	*only livestock*	*only pika*	*pika & livestock*
24/1–10/3/01	n.s.	n.s.	n.s.	n.s.
10/3–22/4/01	n.s.	n.s.	n.s.	n.s.
22/4–21/5/01	**0.014**	n.s.	n.s.	**0.027**
21/5–21/6/01	**0.021**	**0.021**	**0.043**	**0.043**
21/6–27/7/01	n.s.	n.s.	n.s.	n.s.
27/7–24/8/01	n.s.	n.s.	**0.043**	**0.043**
24/8–22/9/01	**0.014**	n.s.	n.s.	n.s.

Table 2.15.: Significance of differences in standing crop between the harvest dates on the exclosure experiment calculated by the Mann-Whitney-U-test. Treatments are: n - *no grazing*, l - *only livestock*, p - *only pika* and lp - *pika & livestock*. Significant results are indicated in bold, p-values higher than 0.05 are indicated as not significant (n.s.).

remains higher than on the other grazed treatments throughout the investigation period (fig. 2.11).

Overall livestock grazing seems to have less impact than pika grazing or combined grazing. Furthermore, the impact by pika grazing is very similar to that by grazing of both the herbivore groups: treatment *pika & livestock* never shows significant differences in standing crop from treatment *only pika* (table 2.14, row 4).

Regarding the development of standing crop between subsequent harvest dates, only few changes are significant (table 2.15). On treatment *no grazing* standing crop increases significantly from April to June, and shows a significant decrease from August to September. Vegetation growth is significant on treatment *pika & livestock* already in May, and on all grazed treatments in June. This is the only month within the investigation period during which plant growth is considerably higher than consumption by herbivores. The decrease of standing crop on the treatments *only pika* and *pika & livestock* is significant in August.

Impact of drought

The severity of the summer drought of 2001 can be recognized by comparing the standing crop under grazing in 2000, 2001, and 2002. Data are available from fieldwork within this study beginning at the end of August 2000. Additionally, unpublished data for June 2000 are available from Karin Nadrowski (table 2.16) and data for 2002 from Matthias Pietsch (pers. comm.).

standing crop (kg/ha)	2000	2001	%
end of June	108	92	86
end of August	175	38	22
end of September	124	49	40

Table 2.16.: Comparison of the development of standing crop under grazing (treatment *pika & livestock*) in 2000 and 2001. The last row shows the proportion of standing crop in 2001 in relation to 2000. Data for June 2000 are from K. Nadrowski (unpublished), all other data for 2000 and 2001 from this study.

The data demonstrate the differences in the development of standing crop under grazing in both years. As the herders interviewed regarded the summer of 2000 as an average or even good year in terms of phytomass production, it is possible to use the data from 2000 as a reference. The development until the end of June is relatively similar in both years, in 2001 standing crop amounts to 86 % of the standing crop observed in 2000. This is probably due to the rains observed in June 2001. But at the end of August the drought results in large differences of standing crop between both years. In 2000 the amount of standing crop is more than 4 times larger than in 2001. The difference becomes smaller in September, but still standing crop during this month is 2.5 times higher in 2000. Borisova & Popova (1985) report an even bigger span of 59–283 kg/ha for standing crop in a similar vegetation unit on the northern side of the Gurvan Sayhan range.

The summer of 2002 has seen another drought. In 2002 standing crop on July 13^{th} was 71.5 kg/ha, on August 13^{th} 59.7 kg/ha, and on September 3^{rd} 48.4 kg/ha. These values indicate a drought of almost the same severity as in 2001. Although the peak standing crop may have been missed by the relatively late sampling date, the peak standing crop of 71.5 kg/ha is even lower than the peak standing crop in 2001. During the summer months forage availability is comparable to 2001.

As these data were derived from grazed plots, it is not possible to extrapolate the primary production in 2000 from them. Nevertheless, it seems safe to conclude that ANPP was considerably higher in 2000 as in 2001. Judging from the maximum standing crop in 2000 of at least 195 kg/ha and the maximum standing crop in 2001 of 92 kg/ha, productivity was presumably at least twice as high in 2000 than in 2001, which means that production in 2001 is less than half of the average productivity.

2.3.4. Dynamic of intake by herbivores

The dynamic of intake by pika and livestock during the investigation period is shown in figure 2.12. The graph is based on the data on standing crop from the exclosure experiment. It summarizes interacting processes including consumption, harvest by pika,

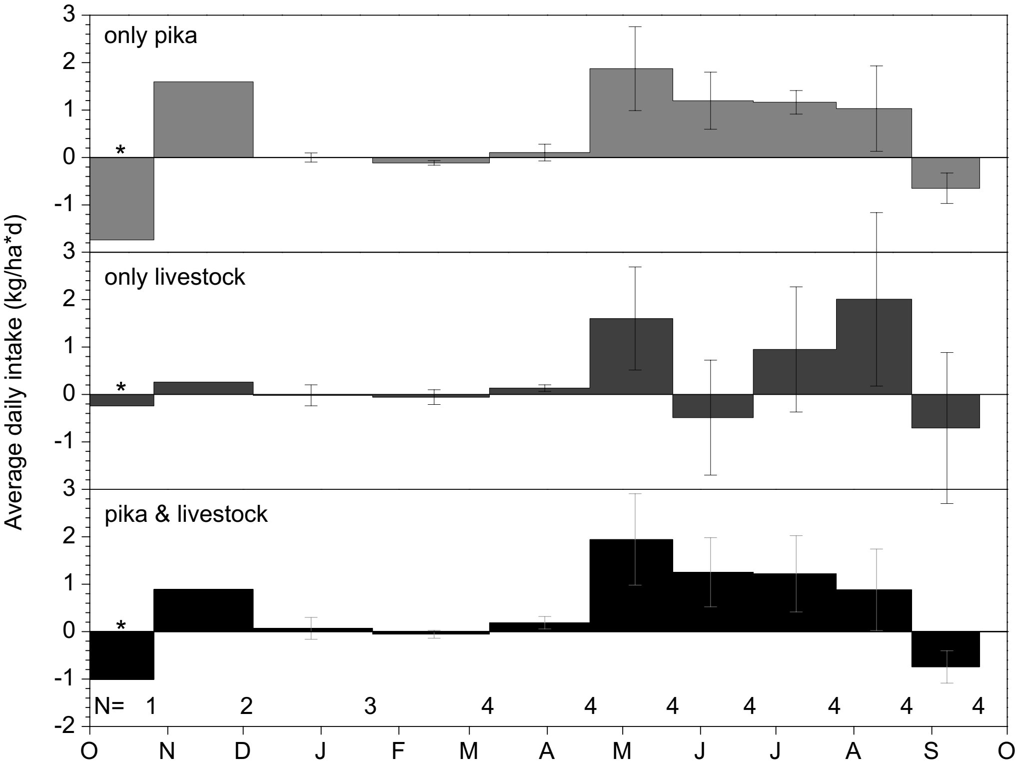


Figure 2.12.: Calculated average daily intake of standing crop by pika (above), livestock (middle), and both the herbivore groups (below), respectively. Error bars indicate standard deviation. N = displays the number of replicates available at each harvest. Values marked with * are questionable, see text for further explanations.

as well as plant growth and plant decay (see the method of calculation in chapter 2.2.7, p. 87). The error bars in the graph indicate the standard deviation of the four replicates of the exclosure experiment, but this does not include errors resulting from previous steps of data processing. The uncertainty of the data is thus even higher than can be shown in the error bars. Negative values of intake are included in figure 2.12, although negative values of intake are unrealistic. These negative values indicate a mixture of mistakes and errors as explained below. Some errors are intrinsic to the measurements, whereas others are due to oversimplification during the calculations (p. 88, see also Sala & Austin 2000).

For the interpretation of the intake data the first negative values from October 2000 should be considered with care, because these were derived from the unreplicated mobile cages (see p. 81) and are not representative. The main difference in the distribution of intake in the course of a year for pika and livestock are found in November and June. In November pika show positive consumption, while livestock's consumption is almost zero. In winter and early spring, from December until mid April, the consumption of both groups is close to zero. Consumption begins to be detectable again for both the herbivore groups with the inset of fresh growth in May. It remains on approximately the same level until the end of August. The only exception is found during June, when no consumption by livestock can be measured. This corresponds to very low livestock numbers in the vicinity of the exclosure experiment (see also figure 2.16, p. 115).

The curve of consumption for both the herbivore groups is remarkably similar to that of pika alone. It, too, resembles all features which distinguish the course of intake by pika from that of livestock: relatively high negative values for October 2000, relatively high consumption in November, and no negative values in June 2001.

In September 2001 both the herbivore groups show negative values of consumption. These are presumably artefacts which result from the assumption that during non-growth conditions a drying-out of vegetation would occur on all plots, which is proportional to the reduction of standing crop measured on treatment *no grazing*. But during this particular period a quite high percentage of the vegetation dried out on treatment *no grazing* while no change in standing crop or even plant growth could be observed on the grazed treatments. Therefore the assumption made above does not hold true in that particular situation. Possibly this is because plants on treatment *no grazing* have already finished their reproductive cycle and thus are actually dying of while those on the grazed treatments were not able to produce diaspores and thus still make use of September rains.

Phytomass harvest by pika Pika in general are well known to harvest plants in autumn for hay storage in their underground burrows for consumption during winter (Guriceva, 1985; Retzer & Nadrowski, 2002). The Mongolian Pika is no exception. Pika's hay-making is supposed to result in a distinctive pattern of intake by pika because they are supposed to be able to take away much more forage than they can digest when it is plentiful and stop consumption during winter when they can live on the stored hay. Guriceva (1985) reported that the Daurican Pika (*Ochotona daurica*) collected 56 kg/ha of hay in the forest-steppe in northern Mongolia.

In contrast to the pika, livestock has to store all its winter supply as body fat and has physiological limits to the maximum amount it can digest per day. In summer when there is plenty of forage, livestock should consume as much phytomass as it can digest. Furthermore, when grazing in winter it should try to derive as many nutrients as possible from the remaining standing crop so that the stored body fat will last as long as possible.

Following this assumptions pika are supposed to remove much more phytomass from the plots during times of high availability (late summer and autumn) and distinctively less during times of low availability (especially winter and early spring). Livestock on the other hand should take up as much phytomass as it can digest during times of high availability and as much as possible under the given constraints (physiology, grazing range, forage availability etc.) in times of low forage availability. Both intake distributions should be detectable in the consumption pattern.

Within this study a peak of consumption in November can be found for pika (fig. 2.12, p. 107). But consumption is zero (negative) in October. Possibly we missed the autumn consumption peak of pika in 2000 because the exclosure experiment was built up only at the beginning of October.

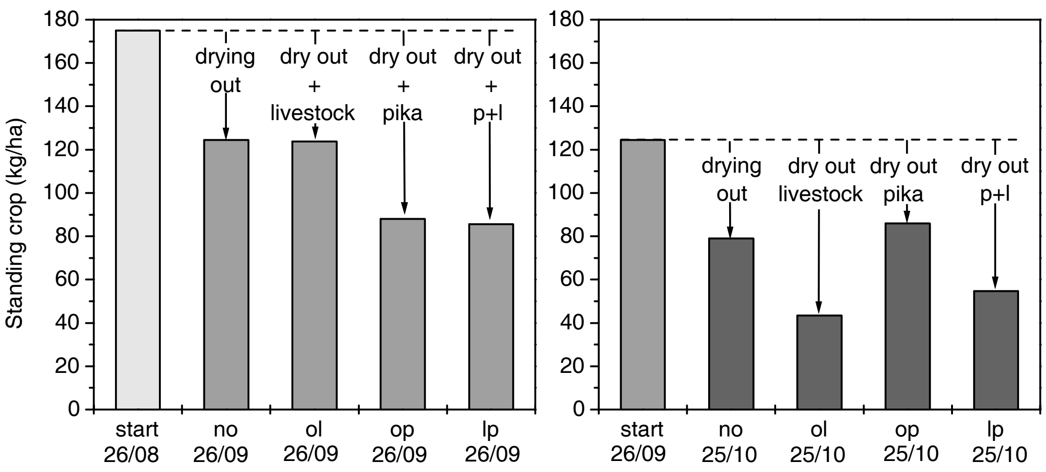


Figure 2.13.: Development of standing crop on the plots of the small mobile cages. In the left panel development from 26/08–26/09/2000 and in the right panel from 26/09–25/10/2000. Treatments abbreviations are: no - *no grazing*, ol - *only livestock*, op - *only pika* and lp - *pika & livestock*.

The data from the unreplicated mobile cages allow a closer look at the development from the end of August to the end of October 2000. Figure 2.13 shows the development of standing crop on the unreplicated mobile cages for the periods 26/08–26/09/2000 and 26/09–25/10/2000. During September the intake on plots which could be entered by pika is much higher than on those not accessible to them. This is an indicator for pika's harvesting activities during that period. The picture for October remains unclear. On the plot accessible to pika only phytomass remains much higher than on the treatments *only livestock* and *pika & livestock*. This is no surprise as these are the same data which result in the negative intake of pika and livestock in October in figure 2.12. Unfortunately no data from the exclosure experiment are available, so no profound statement can be given for this period.

In conclusion, pika show a higher intake in November succeeded by a phase of almost zero intake from January to mid April. In this period pika have to feed on their hay supplies. With the beginning of fresh plant growth pika's consumption of standing crop sets in again and remains at the same level the whole summer. Pika's intake is negative in September which may be partially due to a difficulty in the calculation of consumption, but also shows that during a year of drought pika cannot harvest large amounts of hay.

Livestock shows almost zero consumption from October until mid April. Consumption sets in parallel with the inset of the growing season. Livestock's pattern of consumption is therefore separated into two distinct phases. During summer and possibly autumn they consume large amounts of forage and store the surplus as fat. During winter their grazing is basically ineffective and they mainly have to rely on their stored fat. The difference between the two phases is much more pronounced than was hypothesized. During a summer of drought livestock may have only 3 months during which they have to consume enough forage to sustain them until the next spring.

growing season 2001

04–09/2001	*only livestock*	*only pika*	*pika & livestock*	available
A (kg/ha)	107	148	150	227
A (%)	0.47	0.65	0.66	
B (kg/ha)	143	167	172	227
B (%)	0.63	0.73	0.76	

one year

09/2000–09/2001	*only livestock*	*only pika*	*pika & livestock*	available
A (kg/ha)	105	151	158	279
A (%)	0.38	0.54	0.57	
B (kg/ha)	151	226	211	279
B (%)	0.54	0.81	0.76	

Table 2.17.: Absolute consumption of livestock, pika, and livestock & pika, respectively, in the growing season 2001 (above, 04–09/2001) and during the whole investigation period (below, 09/2000–09/2001) in kg/ha and expressed as a percentage of the available phytomass. A and B indicate two different methods of calculation. A: summing **all** increments of consumption, and B: summing all **positive** increments. See text and chapter 2.2.7 for further explanation.

Annual intake Table 2.17 shows the consumption by both groups in absolute numbers and expressed as percentage of available phytomass. As a comparison, both ways of calculating the intake are shown. Method A shows the values derived from adding up **all** increments and B from adding up all **positive** increments of consumption (see chapter 2.2.7, p. 89). In this particular case the negative values of intake for the last month of the study certainly do not reflect grazing behavior, but a difficulty with the underlying assumptions for calculating intake as mentioned above. So the ”truth” may lie somewhere in the middle of the two values given.

In the growing season 2001 net primary productivity, as measured on treatment *no grazing*, is 184 kg/ha. Additionally, 43 kg/ha still remain over winter. Therefore the available phytomass in (column ”available” in table 2.17) is 227 kg/ha. Of this, after calculation method A, 107 kg/ha are consumed by livestock on treatment *only livestock*, 148 kg/ha by pika on treatment *only pika*, and 150 kg/ha on treatment *pika & livestock*. In September 2000 an additional 51 kg/ha of consumable standing crop were left, so the total available phytomass for the period 09/2000–09/2001 sums up to 279 kg/ha. From these data the percentage of consumed phytomass from the available phytomass can be calculated. During the growing season of 2001, depending on the method of calculation, 66–76 % are consumed by both the herbivore groups (on treatment *pika & livestock*). For the whole investigation period the range of this percentage is similar: 57–76 %.

During the growing season 2001 pika seem to dominate the consumption also on treatment *pika & livestock*. The forage disappearance on the latter treatment is only slightly higher than on treatment *only pika*. Possibly pika consume the maximum amount accessible to them on both treatments. The fact that the disappearance on treatment *pika & livestock* is still slightly higher may be attributed to the additional trampling impact of livestock on this treatment.

For the whole investigation period the consumption of livestock is only slightly different from that in the growing season, because their consumption is confined to the growing season (fig. 2.12, p. 107). The consumption of pika on the other hand is much higher during the whole year due to their intake in November. Pika intake exceeds livestock intake almost by the factor 1.5. Consumption by pika alone is slightly lower than on the plots accessible to both the herbivore groups. It is even higher for the yearly intake calculated by method B. This is probably an artefact from the first unreplicated harvests as the values from the first three harvests with the lowest number of replicates are responsible for this.

Considering all methods and periods of calculation, livestock consumes about half the available phytomass (38–63 %), while pika consume considerably more: 54–81 %. Furthermore, the percentage of consumption by both the groups is similar to that by pika alone: 57–76 %.

Whatever the exact numbers may be, the two methods provide at least a minimum and maximum estimation of the consumption. The following pattern can be detected with either method:

1. **Pika always consume a higher amount of the vegetation than livestock does.** This is true for both methods of calculation and both periods of investigation.

2. **The consumption of pika alone is always more similar to that of *pika & livestock* than to that of livestock alone.** This, too, holds true for both methods of calculation and both periods of investigation.

Competitive advantage of pika The competitive advantage of pika is difficult to measure. In order to give an idea about the approximate level a calculation is presented in table 2.18.

The advantage of pika can be calculated as the proportion of phytomass which can be accessed by pika on treatment *pika & livestock* which cannot be removed by livestock alone (treatment *only livestock*). Depending on the method of calculation of consumption and on the period of time considered, the forage advantage of pika is estimated as 16–22%! The average for the growing season of 2001 ("summer") is 20 %. This indicates that pika have access to a considerable amount of the vegetation which cannot be consumed by livestock.

Average intake by pika The average daily requirement for pika is not known. Table 2.19 attempts to give a first estimation for the daily and yearly intake per pika. It is calculated for two different periods, the summer of 2001, and the whole investigation period ("year") and for two values of pika intake derived from the two methods A and

pika's competitive advantage

period	method	av pm	cons(lp) - cons(l)	adv pika
summer	A	227	43	0.19
summer	B	227	29	0.13
				0.16
year	A	279	53	0.19
year	B	279	61	0.22
				0.20

Table 2.18.: Estimation of pika's competitive advantage in comparison to livestock. The amount of phytomass which pika can consume on pasture shared with livestock but which is not accessible to livestock is calculated by subtracting the phytomass consumed on treatment *only livestock* from that on treatment *only livestock* (cons(lp) - cons(l)). The percentage advantage of pika (adv pika) is then calculated as the proportion of the available phytomass (av pm) which can be accessed by pika only. Again, consumption has been calculated by two different methods A and B (see chapter 2.2.7).

intake by pika

period	method	density #/ha	intake kg/ha	daily intake g/#·d	yearly intake kg/#·y
summer	A	42.5	148	19.5	3.5
summer	B	42.5	167	22.0	3.9
year	A	37.7	151	11.3	4.0
year	B	37.7	226	16.8	6.0
∅				**17.4**	**4.4**

Table 2.19.: Daily and yearly intake per pika calculated from first estimations of pika densities (K. Nadrowski, pers.comm.) and intake figures calculated by two different methods (A and B, see table 2.17). The intake is calculated for two time periods, the summer of 2001 (04-09/2001) and the whole year from 09/2000–09/2001. The last row gives the average value for daily and yearly intake per pika.

B (see above). The last row gives the average for all methods and periods. Because standing crop at the end of the summer of 2001 is extremely low, it can be assumed that consumption is complete for this growing season. This column is therefore labelled "yearly" intake.

Depending on the period investigated and the method used for the calculation of pika intake, daily intake per pika individual ranges between 11.3 and 22.0 g/d. Average individual daily intake is 17.4 g/d. The estimates for the yearly forage requirement – the equivalent to the MSU for livestock – range from 3.5 to 6.0 kg/individual·a, the average is 4.4 kg/individual·a. This number provides a minimum estimate, because the values are derived from a period of drought. Furthermore, pika concentrate on their burrows for foraging, therefore the values derived from the exclosure experiment in the steppe-matrix probably underestimate pika consumption.

2.3.5. Body condition of livestock

The hump-shaped distribution of forage intake by livestock (fig. 2.12, p. 107) results in a distinctive pattern of the body condition of the animals. Figure 2.14 exemplarily shows the body condition scores of female sheep and goats, but the course of the curve would be similar for the other livestock species (own observation). Sheep and goats usually reach their highest fat content in October/November. After this time they burn the stored fat and get thinner and thinner as winter proceeds. During a year with enough forage they than regain the fat until they are fat again in October/November. Figure 2.14 very clearly shows the difficulties livestock experiences during the drought of 2001.

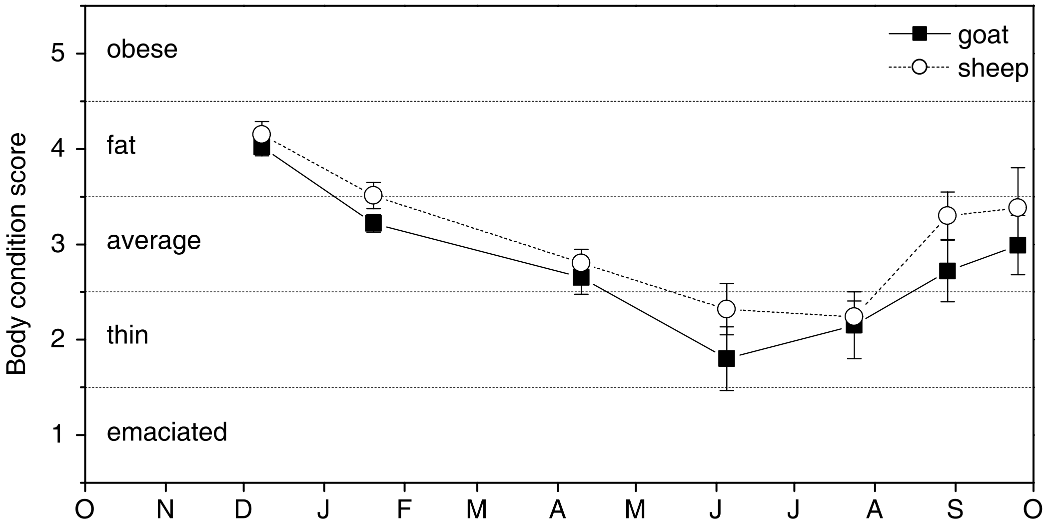


Figure 2.14.: Average body condition score of ten female goats and ten female sheep.

Although in April/May the growing season slowly sets in, the condition of both, sheep and goats, deteriorates between April and June. The condition of sheep deteriorates even further until the end of July. During this time goats are able to gain at least some fat and improve from an average condition of 1.8 to 2.2. The reason for this difference may be that usually only sheep are milked and therefore it is easier for the goats to put on fat again. After July both species show an improvement in the body condition. But the increase is too slow to reach a fat body condition before winter sets in. Both species enter the winter of 2000/2001 in a much worse state than in the previous year. In October 2001 their body condition is worse than in January 2000, but still the whole winter is lying ahead of them.

Under these difficult circumstances it is no surprise that a large fraction of animals did not survive the winter 2001/2002. In Mongolia 2,917,100 animals were lost in 2002 (UB Post, 2003a). Within the study area, the family from which the body condition scoring of sheep and goats was derived, lost 34.1 % of their sheep, 11.7 % of their goats, 36.0 % of their horses and 71.4 % of their cattle.

The fact that the body condition score of goats is always lower than that of sheep is probably an artefact. As no fact sheet for the scoring of goats was available, the

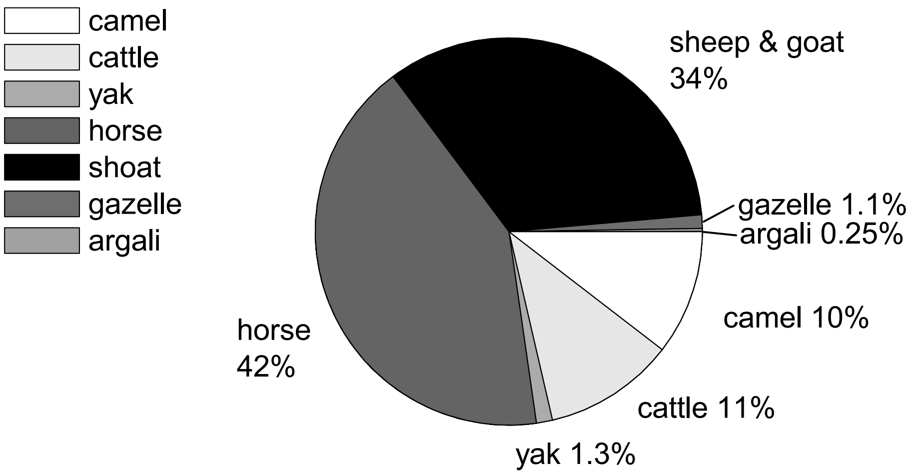


Figure 2.15.: Average composition of large herbivores (livestock and wild herbivores) in the vicinity of the exclosure experiment during the investigation period in MSU.

same scoring method that was used for sheep was also applied to the goats. The graph suggests two inferences on the suitability of the sheep body condition scoring chart for goats. First the results show that this is a suitable method to detect differences in the body condition of goats in the course of a year. But still, as goats have a fat distribution different from that of sheep, the figures may be biased towards lower or higher figures for goats. The data also present a clue for the direction: although goats started into the winter 2001/2002 with a lower score than sheep, a higher percentage of the goats survived. This indicates that the sheep scoring chart underestimates the goats' scores. In order to produce comparable figures the chart has to be adapted to the anatomy of goats.

2.3.6. Dynamics of large herbivore density

The composition of large herbivores around the exclosure experiment is dominated by livestock. Livestock has been observed grazing on the steppe all year round. Figure 2.15 shows the composition of large herbivores calculated in percent MSU of all observations. The most important species are horses making up 42 % and flocks of sheep and goats with 34 %. Camels account for 10 %, they are found more frequently on the lower altitudes, yaks, which prefer higher altitudes, amount to 1.3 % (see also chapter 3.3.4, p. 142), and cattle account for 11 %. The composition of the grazing livestock around the exclosure experiment closely reflects the average composition of the interviewed herders.

Wild large herbivores are extremely rare. Ibexes (*Capra sibirica*) are not sighted at all at this altitude, and gazelles (*Procapra gutturosa*) and wild sheep (*Ovis ammon*) only infrequently. Wild sheep usually live in small groups comprising not more than 5 animals, and gazelles in flocks from only a few individuals up to 150.

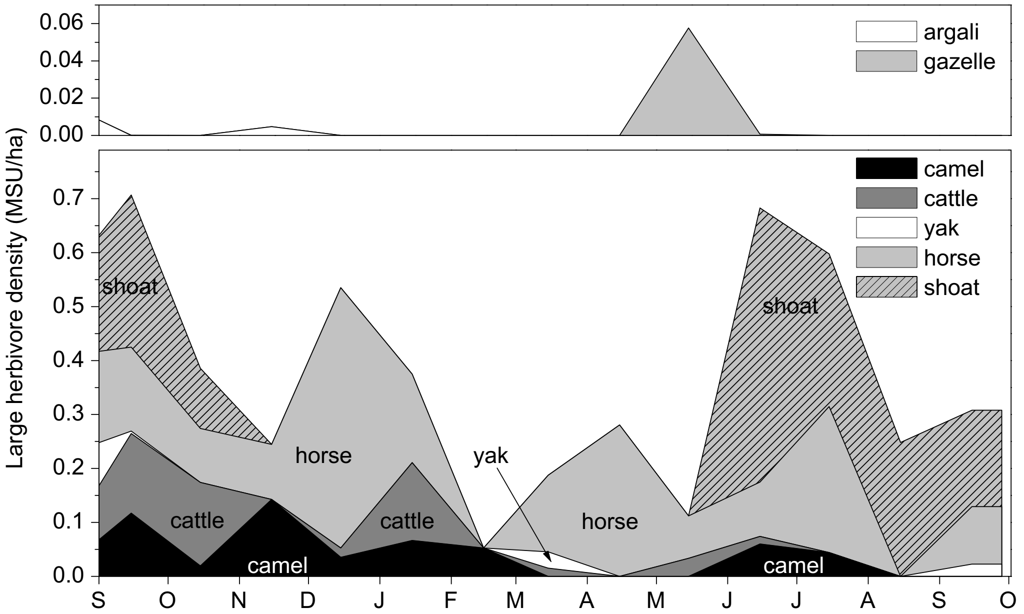


Figure 2.16.: Densities of large herbivores at the exclosure experiment during the investigation period. Livestock in the lower graph and wild large herbivores in the upper graph with an y-axis enlarged 3.5 times in comparison to that of the livestock graph.

The composition of large herbivores derived from observation somewhat misrepresents the densities of wild animals because they have a much greater fleeing distance and thus will be recorded in systematically lower numbers than livestock. But even taking this into account, their number in the investigation area is much smaller than livestock numbers and altogether the grazing impact of wild animals is probably not more than 5 % of the impact caused by large herbivores. The ecosystem is dominated by livestock as the main large herbivore consumer.

The composition and density of large herbivores varies with the season (fig. 2.16). The average density of large herbivores is 0.38 MSU/ha at the upper pediment. The minimum density of 0.05 MSU/ha is reached in February, while the maximum density of 0.71 MSU/ha is recorded in September 2000. A second peak is reached during June 2001, when a sharp increase in the number of shoats led to livestock densities of 0.68 MSU/ha.

Camels are constantly low in numbers, but are missing during times of extremely low forage availability (compare figure 2.11, p. 104 for standing crop) in the spring and autumn of 2001. The pattern of fluctuations in horses and cattle densities are not clear. Yaks seem to descend to altitude of 2300 m only in spring and autumn. The reason for this type of movement is not clear. The density of sheep and goats follows the movement rhythm of the herders. It decreases when the herders move to their winter places further south in October 2000 and increase again when they return to their summer places in May 2001. From the middle of November until the middle of May no shoats are observed at the study site.

2.4. Discussion

In field experiments with focus on forage competition, consumption is rarely measured directly. Most studies are based on indirect indicators such as overlap of habitat or forage species (e.g. Dawson & Ellis, 1996; Van der Wal et al., 1998). Exclosure experiments have frequently been used to quantify the grazing impact by livestock on phytomass (Brathen & Oksanen, 2001; Meurer, 1998; Sturm, 1998), species composition and biodiversity (Hart, 2001; Meissner & Facelli, 1999; Noy-Meir et al., 1989), and on small mammals and birds (Bock et al., 1984; Smit et al., 2001). But only few investigations use exclosure experiments as a method to evaluate the individual and combined impact and especially the competition between two different groups of herbivores, as was done in this study.

Van der Wal et al. (1998) used exclosures of geese to investigate the dietary and habitat overlap between two wild herbivores, hares and geese in a marsh system. Hulbert & Andersen (2001) made use of ”natural exclosure experiments” on Norwegian islands for assessing the forage competition by roe deer and mountain hare, using clip diameter of browsed shoots as an indicator for switches in diet, while not assessing browsed phytomass itself. Ryerson & Parmenter (2001) have described vegetational changes resulting from the exclosure of livestock and prairie dogs, but both groups were excluded at the same time and no references are made to what happened when only one herbivore group was excluded from the area.

Exclosure experiments for studying forage competition between two groups of herbivores which exclude both the herbivore groups are generally rare. Two studies could be found that use an experimental setup designed to exclude prairie dogs and bison individually and combined. The study of Fahnestock & Detling (2002) combines data on the grazing effect by prairie dogs and bison and on the effect of prairie dog colonies (plots on- and off-colonies). The results show that the differences of species composition and diversity, plant nitrogen concentration, and nitrogen mineralization were much greater between on- and off-colony plots than between treatments of different grazing impact. The authors conclude that the effect of the prairie dogs on vegetation and soil properties is larger than that of the bison. But they make no reference to forage competition of both groups.

A study in the same national park by Cid et al. (1991) showed that the exclosure of bison and prairie dogs had only modest effects on plant species composition. The impact of individual grazing of both the herbivore groups on standing crop was similar in both years. But no significant interactions of bison and prairie dogs on plant characteristics could be found. Again this study does not deal with the forage competition of the investigated herbivores.

As the method of exclosure experiments is not widely used to assess forage competition and as no literature focusing on the exclusion of pika could be found, difficulties with the setup and methodological problems are described in detail before the results of the experiment are discussed.

2.4.1. Discussion of the experimental setup

In order to assess the validity of the results derived from the exclosure experiment it has to be evaluated whether the experiment has actually measured what it was intended to. The questions which have to be posed are whether the experimental design worked consistently and whether the methodology used to calculate productivity and consumption is suitable. In more detail:

- Who is grazing? Can the measured impact really be attributed to **livestock** and **pika** grazing?
- Was the exclosure successful? Did they really graze on the plots where they had access to?
- Is the strategy to focus on phytomass as an integrative parameter rather than on single species dynamics an appropriate approach?
- What about neglecting compensatory growth?
- Is the method used to derive ANPP consumption data from standing crop valid?

Who is grazing? The design of the exclosure experiment aimed at the exclusion of pika and livestock respectively, although, of course, all large herbivores (including the wild ones) and all small herbivores (including several other species apart from pika) have been excluded from the fenced-in areas. Nevertheless, for the purpose of this study livestock can be assumed to make up the major share of large herbivores, even if livestock density is probably lower than the 98.5 % of animals observed around the exclosure experiment (fig. 2.15, p. 114) because of the greater fleeing distance of wild animals compared to livestock (see chapter 2.16). It still is reasonable to hold livestock responsible for the main impact caused by large herbivores. The same applies to grazing by small mammals. As unpublished data from K. Nadrowski show, more than 95 % of the biomass of small herbivores consist of the Mongolian Pika. Hence for the terms of the exclosure experiment the distinction of the herbivore groups in "livestock" and "pika" is valid.

Was the exclosure successful? Concerning livestock the question can be answered with a profound "yes". Only on one occasion one fence was not closed correctly, allowing one herd of cattle to intrude into the fenced areas for one night. Fortunately they did not cause severe damage.

During winter also pika exclusion was satisfactory. But in spring problems commenced because juvenile pika were small enough to slip through the mesh which effectively excluded adult ones. So the treatment *only livestock* had to be replaced by smaller mobile cages with finer mesh width not accessible to pika (see chapter 2.2.4, p. 78). Two replicates of treatment *no grazing* suffered from intruding pika as well, but as this could be detected reliably only after the end of the investigation period, here the error was corrected mathematically (chapter 2.2.7, p. 86). Overall the exclosure of pika is much more difficult to realize than the exclosure of livestock but was generally successful as well.

Pika were observed grazing in treatment *only pika*, and livestock has been seen feeding inside treatment *only livestock* at several occasions. These sightings combined with the fact that differences in standing crop between the treatments could be detected, ensures the validity of the assumption that the two herbivore groups grazed where they were supposed to graze. However, whether or not the areas accessible to one group only were grazed as frequently and intensely as the areas which were not fenced, cannot be assessed.

Furthermore, the question whether the fences influenced plant growth within the exclosure experiment has to be addressed. The fences are a barrier in the bare landscape and slow down wind speed. In winter this was obvious when snow cover inside the fence was higher than outside. If this snow melts in spring it might provide additional soil moisture inside the fences and this might falsify the productivity data. Therefore, snow was removed from inside the fences (see p. 79).

It is difficult to prove that this measure was successful, but there are several indicators for it. The vegetation inside the exclosures did not show an earlier greening than the surrounding steppe as other snow accumulating sites such as the area where the surplus snow was deposited or the gullies did. Also the first substantial growth was recorded on all treatments alike between mid April and mid May (see fig. 2.11, p. 104). This speaks against the hypotheses that the fenced treatments could have a higher moisture availability. As neither visual observation nor the data indicate a influence of the fences on plant growth, it can be assumed that the measure was successful.

Whether the fences also acted as a rain trap in summer, is even harder to disprove. But again all facts indicate that they did not. For one, summer rainfall was usually associated with low wind speeds minimizing any potential effect and secondly rainfall in contrast to snow cannot be subject to drift after reaching the ground. Therefore, it seems unlikely that the fences influenced productivity on the treatments this way.

Focus on standing crop The focus on standing crop rather than on the development of phytomass of single species had several practical advantages. Firstly, integrative parameters such as average plant height (although derived from species specific measurement) and vegetation cover could be used for double sampling on standing crop. Secondly, this allowed a higher sampling frequency, more replicates, and a more condensed distribution of sampling dates during one harvest than a more detailed, species-based sampling scheme could.

Furthermore, a species-based sampling scheme would have been much more time-consuming. The number of four replicates and the resolving power of one month are already low and could not have been diminished further without seriously harming the significance of the results.

Livestock in the investigation area consists of six different species of domestic animals. The term ”livestock” summarizes the grazing habits of a mixed flock of animals with distinctively different body sizes, grazing strategies (grazer and browser), forage preferences, and digestive systems. Together, they fill the different niches available for large herbivores in the ecosystem. As the different foraging strategies of different kinds of herbivores were not in the focus of the study, it seems feasible to concentrate on total phytomass. Moreover, mixed animal grazing optimizes the use of different forage resources (Duffy, 2002; Nolan et al., 1999). Besides, the diets of pika and livestock overlap widely and unpalatable species are scarce (see 2.4.4, p. 124). Therefore almost all (except one or two poisonous) are grazed by livestock and pika. As virtually all available phytomass is used as forage it is reasonable to operate with the integrative parameter of standing crop.

Furthermore, the intra- and inter-annual fluctuations in forage availability and quality are probably much higher than the differences between different plant species (Long et al., 1999). Therefore it is feasible to use standing crop as a parameter which is of the same abstract level as the term ”livestock”.

Compensatory growth is the ability of plants to regenerate above-ground leave tissue rapidly after being grazed. Grasslands being cut or grazed with a medium disturbance frequency have been shown to produce higher yields than plots which are not or extremely often disturbed (McNaughton, 1976, 1979). Therefore McNaughton et al. (1996) stress the need to account for compensatory growth effects either by using moveable exclosures or by stimulating growth inside the cages by clipping. Other studies indicate that consumption may be overestimated with this method (Sharrow & Motazedian, 1983). The immobility of the exclosure experiment does not allow for such compensatory growth nor were the plots clipped to simulated grazing. Thus the experimental set up of the exclosure experiment may underestimate growth on the grazed plots.

But analysis of the phenology of important species shows that the phenological status on the grazed plots is not significantly different from that on the ungrazed plot. This indicates that compensatory growth did not have much effect on the phenological status of plants during the growing season of 2001, so probably growth differences are also minor. This may again be a consequence of the drought: the main rain impulse in June allowed only one peak of vegetation growth and whether or not the plants had (treatment *no grazing*) or had not (grazed plots) completed their generative cycle, soil water was not sufficient for continued growth.

Using a model approach, Leriche et al. (2001, p. 114) found that ”the response of ANPP to grazing intensity emerged as a complex result of both positive and negative, and direct and indirect effects of phytomass removal on light absorption efficiency, soil water availability, grass nitrogen status and productivity, and root/shoot allocation pattern”. Consequently, neither the direction nor the quantity of grazing effects on vegetation growth are predictable.

Klötzli (1996) showed that grazing by herbivores has minimal or even no influence on the productivity of grasslands. In a 8-year study in North-Dakota's grasslands, Biondini et al. (1998) also found no consistent effect of herbivore intensity on ANPP. Belsky et al. (1993) conclude that increased growth rates found after grazing or clipping have to be interpreted more accurately as "the results of growth at one end of a spectrum of normal plant regrowth patterns, rather than as overcompensation." Also Painter & Belsky (1993) found that although overcompensation can be encountered in fertile soils during wet periods, it is not a general feature and probably of little ecological importance. Furthermore, Belsky (1986) summarizes his review of more than 40 papers dealing with compensatory growth that "no convincing evidence supports the theory that herbivory benefits grazed plants". Therefore, compensatory growth was not accounted for in this study, as has also not been done by Schulte (2001).

Calculation of productivity and consumption There are different methods available to calculate production and consumption from paired-plot data at different dates. A thorough review and comparison of the different methods was compiled by Singh et al. (1975). Basically two sets of methods can be distinguished. One set uses a single value of standing crop called "standing vegetation at the end of the season", "peak value of standing crop", or "peak value of standing crop subtracting minus value during winter". The second set of methods uses subsequent measurements of standing crop of single species or vegetation and sums up the changes in standing crop over the growing season. These methods further differ from each other as they either include recent dead material and litter in the calculations or neglect them, using all or only statistically significant positive increments to calculate ANPP. Singh et al. (1975, p .225) found all but one method being highly correlated and suggested to use simple calculations, as "complex calculations do not appear to be justified [...] even though more elaborate calculations may be intuitively satisfying".

ANPP was calculated by summing up the positive increments on treatment *no grazing* during the growing season, which is equivalent to "peak standing crop minus winter minimum". For this study this method probably underestimates ANPP, because it dismisses growth after 27/07/01. Growth after this date, which might have occurred, was counterbalanced by the drying out of the vegetation and therefore is not detected in the next harvest. This problem is intrinsic to non-continuous measurements, and cannot be addressed further with the available data. But in this case the errors made through this method seem to be reasonably small for two reasons. Firstly production after July was small due to the lack of rain, and secondly, with the brevity of the growing season in the investigated area, turnover during this time is less important than at sites with longer vegetation periods.

2.4.2. Comparison of large herbivore densities and consumption

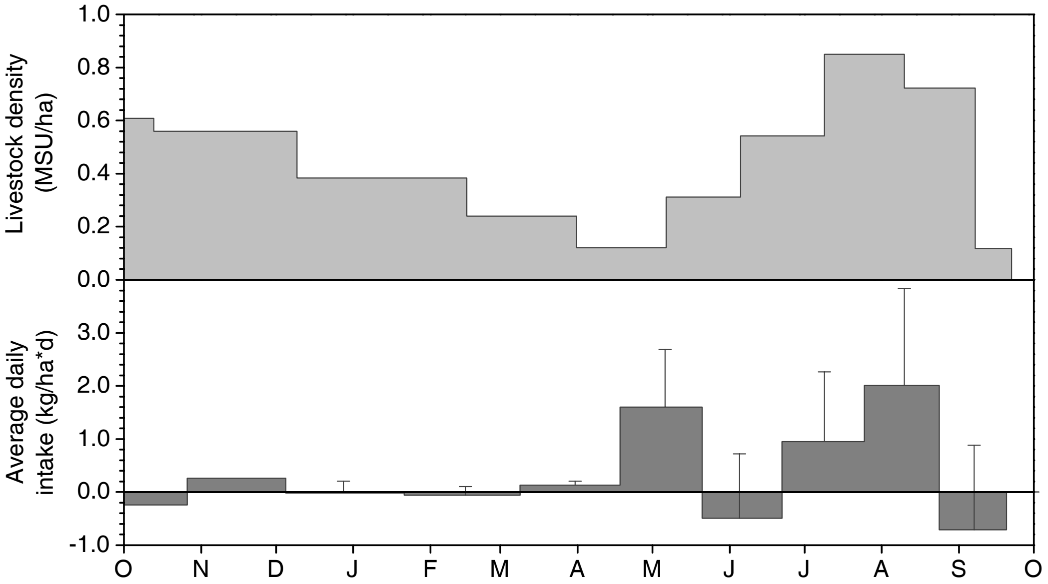


Figure 2.17.: Comparison of livestock densities (in MSU/ha) with calculated consumption by livestock (kg/ha·d) during the investigation period.

McNaughton et al. (1996) suggested to compare values for animal intake with estimates of "how much they *should* have consumed" (p. 974) in order to trace errors made during the calculation. Figure 2.17 shows a comparison of livestock densities (see fig. 2.16, p. 115) with livestock consumption (in kg/ha·d see chapter 2.12, p. 107) during the investigation period. Livestock density is given as MSU/ha, and as 1 MSU is defined as an animal which consumes 1 kg of dry matter per day livestock density is indirectly given as kg dry matter consumed per day and hectare (kg/ha·d). As the same unit is used for the consumption by livestock, the units for both panels are equivalent and the values can be compared directly. The comparison of the numbers not only allows to cross–check and evaluate both methods, but also to draw conclusions on forage availability.

Both data sets allow to sum up the forage consumption for the whole investigation period or the growing season of 2001 (table 2.20). It is better to compare both figures for the period of a whole year, because one MSU consumes 1 kg/d **on average** over the whole year, with a high variability between the seasons. In order to exclude those seasonal fluctuations the Mongolian Sheep Unit is correctly defined as the number of animals of one certain species which consume 365 kg dry matter per year.

For the balance of the whole year 09/2000–09/2001 the values for the consumption derived from animal observations and calculated from the exclosure experiment are relatively similar. Both experiments estimate a consumption of approximately 120–130 kg/ha·a. The fact that the values derived from such widely different experiments such as phytomass harvest and animal observation estimate about the same level of consumption indicates that both methods worked satisfactorily.

consumption (kg/ha)	animal observation	exclosure experiment
year	120	105 (A)–151 (B)
growing season	72	107 (A)–143 (B)

Table 2.20.: Comparison of the consumption by large herbivores derived from animal observations and the exclosure experiment, respectively. Data are shown for the whole year of the exclosure experiment ("year") and the growing season of 2001 in kg/ha.

For the growing season of 2001 the difference between the values from the different databases is much higher. While animal density is equivalent to a consumption of 72 kg/ha, calculated consumption from the exclosure experiment is between 107 and 143 kg/ha (method A and B, respectively). This difference can be explained by the seasonal variation of livestock intake. Livestock has to acquire almost all energy for the whole year during the growing season because of higher availability and much higher nutritional value (Long et al., 1999). Hence, daily consumption during this time must exceed considerably 1 kg/d·MSU.

Depending on the climatic conditions within one specific year the time for fattening is variable. In average years the growing season lasts from May to September. **That means livestock has to meet all energetic requirements for a whole year during maximal five months.** The average daily intake of standing crop during this time must be 12/5 or 2.4 kg/ha·MSU. In 2001 the period with good grazing conditions was even shorter. Already in September the standing crop on treatment *pika & livestock* dropped to 38 kg/ha, a value lower than in January 2001, hence reducing the period of intake to only four months in 2001. The average intake per MSU from May to August 2001 therefore should have been 3 kg/ha·MSU to supply livestock with enough energy to survive until the next summer. But the intake calculated from the exclosure experiment is actually lower: 0.89–1.19 kg/d·MSU (method B/A). This means that livestock can consume only 30–40 % of its forage requirement. This is another indicator for the scarcity of forage and thus the severity of competition for forage during the drought in 2001. Under these conditions animals cannot gain enough fat (compare chapter 2.3.5, p. 113) for the following year.

Another possibility to explain the low consumption of livestock during winter is that the animals may use alternative forage. It is well-known that livestock switches towards woody perennials for forage during times of low forage availability (dry season) in African semi-arid areas (e.g. Meurer, 1993; Müller-Hohenstein, 1999; Sturm, 1998). Within the investigation area such a plant would be basically the small shrub *Artemisia santolinifolia*, which preferably grows in the gullies and on scree slopes in the mountains. An experimental setup to measure the decrease in phytomass during winter for *Artemisia santolinifolia* was destroyed so frequently by grazing livestock that the fragments of the data were not suitable for analysis. Nevertheless, from the observations made during the measurements it can be stated that *Artemisia santolinifolia* was grazed in winter, but not as severely as could be expected if it were be the sole adequate source of forage.

The scarcity of forage was underlined by the fact that during the snow storm on March 3^{rd}, 2001 sheep and goats feeding on horse dung could be observed.

2.4.3. Dynamic of livestock consumption

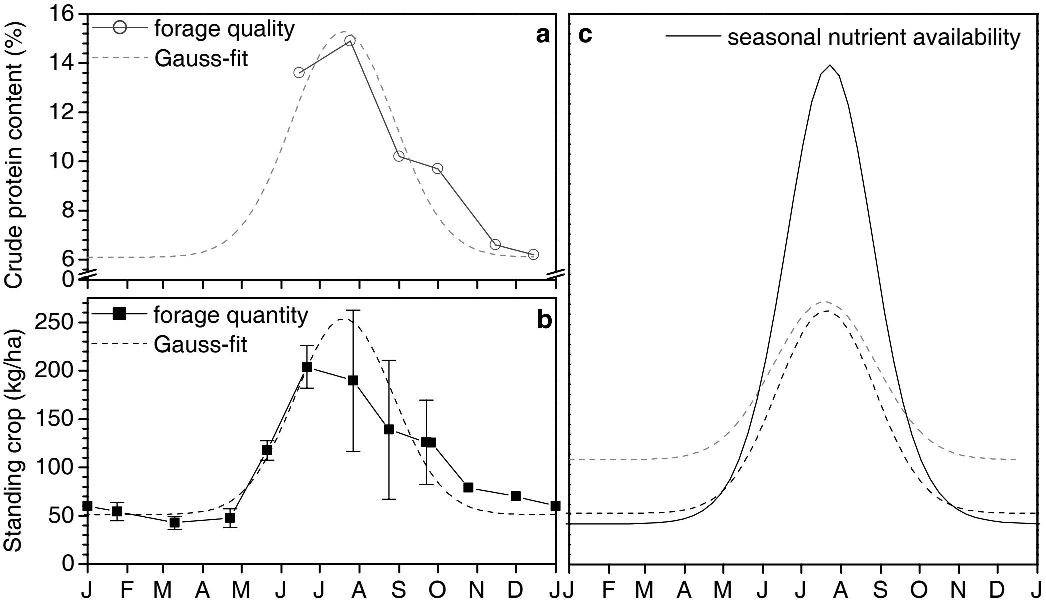


Figure 2.18.: Schematic overview of qualitative (a) and quantitative (b) seasonal forage availability and resulting seasonal nutrient availability (c).

As has been shown before (see chapter 2.12, p. 107), consumption of livestock during the winter months is almost zero. This is surprising as several authors praise the high value of ”witoshi”, the vegetation dried on the site, as winter forage (Barthel, 1983, 1990; Thiel, 1985). Witoshi is said to have a high nutritive value, because it becomes ”shock-frosted” during the first frosts in late September. In this study the remaining standing crop at the end of September 2000 – after a year with average precipitation – was only 49.2 kg/ha. Even if this were preserved well, it just would not be enough to supply only minimum forage throughout the winter. Additionally, this forage is constantly reduced by wind and weather as can be seen on treatment *no grazing* (fig. 2.11, p. 2.11). Therefore forage availability and forage quality both are maximal during the short summer period.

Figure 2.18 shows the seasonal variation in forage quantity (a, standing crop on treatment *no grazing*) and in forage quality (b, content in crude protein in an annual grassland in northern California, data from Rosiere & Torell 1985). A Gaussian curve has been fitted to the data on forage quantity and quality in order to generalize the findings. Although the data on forage quality originate from a different grassland the general development in Mongolia is likely to be similar.

For the seasonal nutrient availability to herbivores both aspects – forage quality and quantity are of immediate importance (Müller-Hohenstein, 1999). Figure 2.18 c shows the idealized course of the nutrient availability during one year (forage quantity multiplied with forage quality). It illustrates very well that the absolute maximum of energy is available during the short summer period. The peak during this time is even more pronounced than for forage quality or quantity alone. Therefore it seems reasonable for livestock to take up most of the yearly energy during this time and store the excess as fat for winter. Following this theory winter grazing is only of minor importance for the nutrition of livestock. This may explain why almost no grazing could be observed in a winter which followed a year of approximately average precipitation.

2.4.4. Competition for forage by pika and livestock

Before competitive effects can be discussed, the three prerequisites mentioned in the introduction (p. 75) have to be analyzed with regard to the potential for competition between the two herbivore groups in the investigation area.

Overlap of habitat The use of mountain-steppe by grazing livestock during the course of the year can be confirmed by the animal observations (fig. 2.15, p. 114, and fig. 2.16, p. 115). Pika are territorial, diurnal and active in winter, thus being present on the investigation area all year round (Nadrowski et al., 2002; Retzer & Nadrowski, 2002). As both the herbivore groups use the forage resources of the mountain-steppe at the same time, this results in an overlap of habitat use.

Overlap in dietary composition has not been investigated directly in this study, but several indicators allow to draw conclusions concerning the dietary preferences of pika and livestock. The most important forage species, *Agropyron cristatum, Stipa krylovii*, and *Stipa gobica*, are browsed intensively by livestock (Stumpp, 2002). The same plants can be found in pika hay-piles (K. Nadrowski, pers. comm.) and pika use the same plants as forage. As pika feed in the vicinity of their burrows (Roach et al., 2001), the composition of the pika's hay-piles closely resembles the vegetation composition around their burrows (Nadrowski, pers.comm., personal observation, Miehe 1998), and livestock has been seen feeding on hay-piles on pika burrows (personal observation). Herders collect or even dig up hay from pika burrows to provide supplementary forage especially for the lambs and kids in spring (interviews and personal observation). They reported that this hay can be used just as it is, which indicates that all plants collected by pika are palatable for livestock as well. This has been reported for stocks of the Daurican Pika (*Ochotona daurica*) as well (Schneider, 1988, p. 315). For a discussion of forage selection and dietary overlap on the basis of the exclosure experiment see page 126.

Limited forage availability Both the above–mentioned points are necessary but not sufficient to indicate the existence of forage competition. As long as enough forage is available, a peaceful coexistence of both the herbivore groups is possible. But the situation in the investigation period is different: during the drought of 2001 primary productivity is extremely low (see p. 104) and is not sufficient to meet the needs of livestock (see p. 121, and p. 100).

Thus all three prerequisites for forage competition between pika and livestock, namely shared habitat, overlapping dietary requirements and limited forage availability are met (De Boer & Prins 1990, cited in Van der Wal et al. 1998; Schoener 1976, 1978, 1983; Tilman 1980).

2.4.5. Interpretation of species heights

The height development of *Allium* spp., *Stipa* spp., and *Agropyron cristatum* can be subdivided into four phases. Each phase is characterized by a distinctive patterns of similarity and dissimilarity between the treatments. The different phases (1-2-3-4) roughly follow a series of grazing impact:

1. **Homogeneity**: no significant differences between any of the treatments. Homogenization can be caused by either

    a) a combination of grazing and drying out. Both processes lead to a minimum height of the vegetation which cannot be reached by any of the herbivores any more. This situation is usually encountered in winter and spring. This process is the prerequisite that all treatments start into the new growing season under similar preconditions. Or by

    b) fast growth of a species which is disdained by all herbivores alike, so that they select against it. Because its height is not influenced by grazing, only by trampling, it can grow the same way on all treatments according to moisture availability.

2. **Intensity effect**: only the treatment *pika & livestock* shows significant difference from the other treatments. This implies that both the herbivore groups have an impact on species height which is too small to cause significant difference between the treatments grazed by only one of the two herbivore groups and the treatment *no grazing*. But these effects accumulate on treatment *pika & livestock* thus making this treatment distinguishably different from all others.

3. **Grazing effect**: treatment *no grazing* is significantly different from all grazed treatments but the latter are not different from each other. This indicates a situation where the grazing impact from the different herbivores is similar on all treatments. This phase is usually followed by the

4. **Treatment effect**: apart from the grazing effect also all (or most) grazed treatments show significant differences from each other. Different herbivore groups have significantly different impact. Due to the longer impact, grazing takes significant effect on species height on all treatments.

After the winter homogeneity *Allium* heights show a grazing effect in spring (table 2.10, p. 97). With the onset of growth caused by the rains in June, homogenization sets in (21/6/ – 27/7/01) while continued grazing leads via a grazing effect in August to a treatment effect at the end of the investigation period (pattern 1a - 3 - 1b - 3 - 4).

The development of *Stipa* is somewhat different (table 2.11, p. 97). A period of inconsistent pattern mixed with homogeneity in winter is followed by a short intensity effect in May, which is in turn replaced by a treatment effect in May and June. In July a grazing effect emerges, which turns into a treatment effect in August and September (pattern 1a - 2 - 4 - 3 - 4).

The pattern of *Agropyron* (table 2.12, p. 97) shows a long homogenous period in winter. An intensity effect can be detected in April, which turns into a grazing effect in May. Subsequently, from June until the end of the observations *Agropyron*-heights exhibit a clear treatment effect (pattern 1a - 2 - 3 - 4).

2.4.6. Lessons on competition learnt from vegetation data

One indicator for the assessment of the competitive strength of pika and livestock can be the similarity or dissimilarity of the different treatments of the exclosure experiment in terms of species height, development of vegetation cover, and standing crop. Vegetation height and biomass have been found to be negatively correlated with grazing intensity (Hickman & Hartnett, 2002).

For the parameters *Agropyron*-height, -cover, and -standing crop, the treatment *pika & livestock* shows a tendency to be more similar to treatment *only pika* than to any of the other treatments. Treatment *no grazing* tends to be more similar to treatment *only livestock* than to treatment *only pika*. For standing crop this can be seen not only in the development on the different treatments (fig. 2.11, p. 104 and table 2.14, p. 105) but also between the different harvest dates (table 2.15, p. 105). This indicates a higher impact resulting from pika grazing than from livestock grazing .

Simulation experiments have shown that among grazing ruminants those "of smaller body size are competitively superior to larger ones due to allometric relationships of bite size and metabolic requirements to body size" (Clutton-Brock & Harvey, 1983, cited in Hulbert & Andersen 2001, p. 499) . This can also be the explanation for the higher grazing impact by pika. Their small size and mouth anatomy allow pika to bite vegetation down to lower heights than livestock and thus to reach and remove more standing crop than livestock possibly can. As the year of the study was one of an extreme drought it is possible that the data represent a special situation and that under different circumstances the impact of pika is not higher than that of livestock.

Forage selection From the observations on plant height and cover development of *Allium*, *Stipa*, and *Agropyron* reported in the chapters 2.3.3, p. 95 and 2.3.3, p. 98 several conclusions can be drawn regarding the preference for the investigated species by pika and livestock, respectively:

1. *Allium* is the species which both herbivore groups, pika and livestock, like least of all. *Allium* is the only species which does not show significant differences in height in June (tables 2.10-2.12, p. 97). This indicates that during times of relatively high forage availability both the herbivore–groups show only low preference for *Allium*. Therefore *Allium* can grow to a height of about 40 mm and even preserve this height without being bitten down. Only in situations of low forage availability (spring and autumn) *Allium* shows a grazing and treatment effect. *Allium polyrrhizum* is reported to be palatable only with sufficient additional species available (Stumpp, 2002), which does not seem to be the case during the drought.

2. *Stipa* is a species preferably consumed by pika and livestock alike. Indicators are the beginning differentiation of the treatments without regular pattern already in spring and the treatment effect in autumn. This concurs with the statement of herders on the palatability of *Stipa* (Stumpp, 2002). The only drawback to the palatability of *Stipa* is that the remaining seeds from the previous year are hard and pointed. When consumed they may prick the animal in the mouth region and cause injuries (Miehe, 1996). This is probably the reason why *Stipa* is consumed with medium preference.

3. *Agropyron* is the favorite species of both herbivores but especially of pika: the treatment begins to take effect earlier in the season and is more pronounced than for the other species indicating the grazing pressure on *Agropyron*. On both treatments which could be entered by pika (*only pika* and *pika & livestock*) *Agropyron*-height throughout the investigation period is lowest and between May and August no significant difference between *Agropyron*-height on treatment *only pika* and that on treatment *pika & livestock* can be found.

   The finding that *Agropyron* is intensively grazed by both the herbivore groups is also supported by the comparison of its growth form under grazing and under protection from grazing. In treatment *no grazing* it grows upright, while in the grazed treatments its leaves creep along the ground. *Agropyron* clearly tries to avoid grazing by escaping the bites of herbivores. The ability to vary growth forms in this way is an important feature for the survival under grazing (see Diaz et al., 2001).

2.4.7. Comparison of consumption; and the winners are ... the pika

The baseline against which competition has to be judged is difficult to determine. The amount of forage needed in order to maintain a healthy body condition all year round can be estimated for livestock by using the Mongolian Sheep Unit and can be compared to the intake calculated from the exclosure experiment (see p. 121). As it is much more difficult to get reliable data on forage requirements for pika, indicators from the exclosure experiment have to be used to evaluate the competitive ability of those animals.

The interpretation of the results of the exclosure experiment in regard to the competition between pika and livestock is difficult because the exclosure method yields integrated

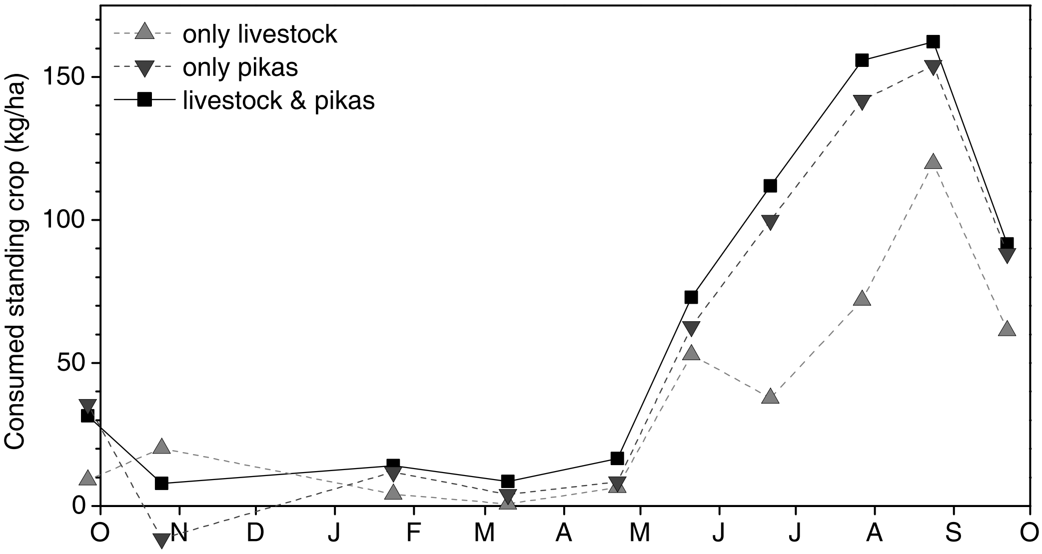


Figure 2.19.: Forage consumed by the different herbivore groups as an indicator for competition. Values are obtained by the subtraction of standing crop on the different grazed treatments from that on treatment *no grazing*.

values for more than one process which cannot be easily separated. For example, it is not possible to distinguish which proportion of the standing crop consumed on treatment *pika & livestock* has been consumed by which herbivore. What can be said is that the difference between treatment *no grazing* and treatment *pika & livestock* at any time is the amount of forage removed by the efforts of both the herbivore groups. Whatever is left on this treatment, is not in the pool of competition – either because it is ”surplus”, at least for one competitor, or because it is inaccessible to both. So the standing crop consumed on treatment *pika & livestock* (fig. 2.19), which is calculated as the difference of standing crop on treatment *no grazing* and that on treatment *pika & livestock* represents the amount of forage which the herbivore groups compete for.

Of course, the seasonal patterns of consumption are similar – low or no consumption in winter and intake concentrated in the summer months. For the whole year the correlation between consumption on treatment *pika & livestock* significantly correlates with grazing on treatment *only livestock* (r^2=0.83, p<0.001) and even more on treatment *only pika* (r^2=0.99, p<0.001). The times relevant to detect differences between the herbivore–groups are those when there is grazing, i.e. the summer months. During the summer of 2001 the consumption by pika on treatment *only pika* follows the curve of consumption of both herbivore–groups very closely on a slightly lower level, while the consumption by livestock follows a different pattern: summer consumption on treatment *only pika* is highly significantly correlated with that on treatment *pika & livestock* (r^2=0.99, p<0.001), while the correlation between consumption on treatments *pika & livestock* and *only livestock* is not significant (r^2=0.51, p=0.18). Hence, the consumption pattern on treatment *only livestock* is controlled by pika. The fact that standing crop on treatment *pika & livestock* during most of the summer is still slightly lower than on treatment *only pika* can be attributed to the additional effect of trampling by livestock

(Farnsworth & Anderson, 2001; Laycock et al., 1972; Pearson, 1975).

Pika seem to be the herbivores with higher competitive power, for two possible reasons. One reason is that they have the advantage of being virtually everywhere all the time. Within the investigated area mountain-steppe seems to be saturated with pika territories (K. Nadrowski, pers. comm.). Secondly, their anatomy allows them to bite certain plants down to lower heights than livestock can (Miehe & Miehe, 2000). Under conditions of limited forage availability, pika possibly consume higher amounts of the forage in competition, and additionally seem to be able to reach forage inaccessible to livestock. This interpretation is supported by findings from a recent modelling approach that shows that smaller grazers are generally competitively dominant over larger ones (Farnsworth et al., 2002).

The ability of pika to access a certain "safe supply" of forage, which is not subject to competition with livestock may be an adaption which allows them to stay and survive droughts on the site, which force livestock to move to better grazing grounds. This may be a prerequisite for the generally successful coexistence of pika and livestock in Mongolian mountain-steppes.

Models have shown that coexistence of competing species is possible, if each species has free access to another resource not in competition, too (Belovsky, 1984; Schoener, 1974 both cited in Van der Wal et al., 1998). In the ecosystem of the mountain-steppes of the South–Gobi this resource for pika is phytomass which is not accessible to livestock, and for livestock, on the other hand, it is the phytomass it can reach by moving to different grazing grounds, which are not accessible to pika.

The question remains how much livestock could additionally stock in the area if pika would be eliminated. The values derived for the annual consumption of one pika being minimum 4.4 kg and approximately 38 pika per hectare (table 2.18, p. 112) result in a total annual consumption of 167 kg/ha. Approximately 20 % of the annual phytomass production is not accessible to livestock (0.20*279 kh/ha= 55.8 kg/ha), therefore reducing the amount to 111 kg/ha which could be used as additional forage for livestock in the absence of pika. This is about the same amount as has been consumed by livestock during the investigation period (see table 2.17, p. 110). this is comparable to values reported by Miehe & Miehe (2000) for the alpine belt in Tibet. This indicates that in a year of drought such as 2001 livestock could consume twice the amount if pika would be absent from the area. Still, forage competition is only one interaction between pika and livestock. Pika can also positively influence livestock as will be discussed in chapter 4, p. 153.

2.5. Summary

The Mongolian Pika and livestock consume the same forage plants within the same habitat and are found to compete for forage at least during times of forage scarcity. Pika are competitively dominant and consume more phytomass than livestock.

Nevertheless, pika and livestock can coexist in the mountain-steppes of the Gobi Gurvan Sayhan. Even a severe drought such as that encountered in the summer of 2001 does not lead to the competitive exclusion of one of the species. The coexistence is possible because both groups have access to a mutually exclusive forage resource. For livestock this is the standing crop in regions with higher rainfall and productivity. This resource is exclusively accessible to livestock because they can move there due to their superior mobility and pika cannot.

Pika forage on a much smaller scale and preferably in the vicinity of their burrows. But on the other hand, pika have the advantage that they can bite down the vegetation to a lower height and can dig for below-ground organs of plants (this feature has not been investigated within the present study). In this way they can exclusively feed on forage that is not available for livestock. In a year of drought both strategies may not be enough to sustain the population levels, but the mechanism of the use of different resources prevents the extinction of one of the herbivores by competitive exclusion.

Livestock and pika use the same strategy to escape starvation during winter. Both use stored energy to supply them during this time. Only the form is different: livestock uses its own body fat to store the energy needed, while pika stock up their hay-supplies to feed on them during winter. Although the means of storage are different, the effect is the same: both groups have to extract as much energy as possible during the short period during which phytomass is available in abundance.

3. Phytomass and animals along an altitudinal transect

3.1. Altitudinal transect

Already the name Gobi Gurvan Sayhan, "Three Beauties of the Gobi", indicates that the ranges represent something beautiful to the people living in their vicinity. Due to higher precipitation the mountains are wetter and greener than their surroundings and therefore attractive for the herders in search of forage for their livestock. The mountains also provide the researcher with an ideal opportunity to explore spatial heterogeneities and serve as an indicator for the consequences of long-term (climatic) changes. Therefore, this chapter serves to expand the view along an altitudinal transect from 2000m to 2800m asl.

Livestock, wild animals, and vegetation communities (Wesche et al., submitted) show distinct patterns of abundance along the altitudinal gradient. The high mountain areas in the park belong to the core zone for protecting wildlife and vegetation. The high-altitude communities such as *Betula microphylla – Salix bebbiana* relict forests and *Kobresia myosuroides* mats are important for the preservation of biotic diversity (Cermak & Opgenoorth, 2003; Miehe, 1996, 1998; Wesche et al., submitted). They are also the habitat of endangered species such as snow leopard and the argali wild sheep (Reading et al., 1996, 1999a; Steinhauer-Burkart, 1999). In this chapter the importance of the mountains for livestock grazing and for the protection of wildlife will be assessed.

Geomorphologically, the transect is split into two parts. The lower altitudes up to 2380 m are gently sloping pediment regions, dissected by erosion gullies. The soils support steppe communities. Semi-desert *Stipa gobica-Allium polyrrhizum* steppes at the lower altitudes up to about 1900 m are replaced by *Sibbaldianthe adpressa-Astragalus laguroides* mountain-steppes (2000 m and 2200 m) and dry mountain-steppes characterized by *Agropyron cristatum, Artemisia frigida* and *Stipa krylovii* on the upper pediment (2300 m) around the research camp (Wesche et al., submitted). Burozems are the dominant soil types in the pediment region (Wesche & von Wehrden, 2002). Frequently found fossil horizons are indicators of over-sedimentation.

At about 2380 m steep rocky slopes emerge from the pediments forming a very heterogenous landscape with high relief energy and differences in exposure (fig. 3.1). Rocky outcrops emerge between the steeper slopes which are covered with scree. Only gentler slopes are completely covered with vegetation, but indicators for solifluction as well as cattle tracks are abundant. The mountain slopes carry chestnut soils ("Castanozems")

Figure 3.1.: Panorama of the southern aspect of the Dund Sayhan. The abrupt transition from gently sloping pediments to steep mountain slopes at about 2380 m is clearly visible. The picture was taken at around 2000 m. The summit reaches 2830 m.

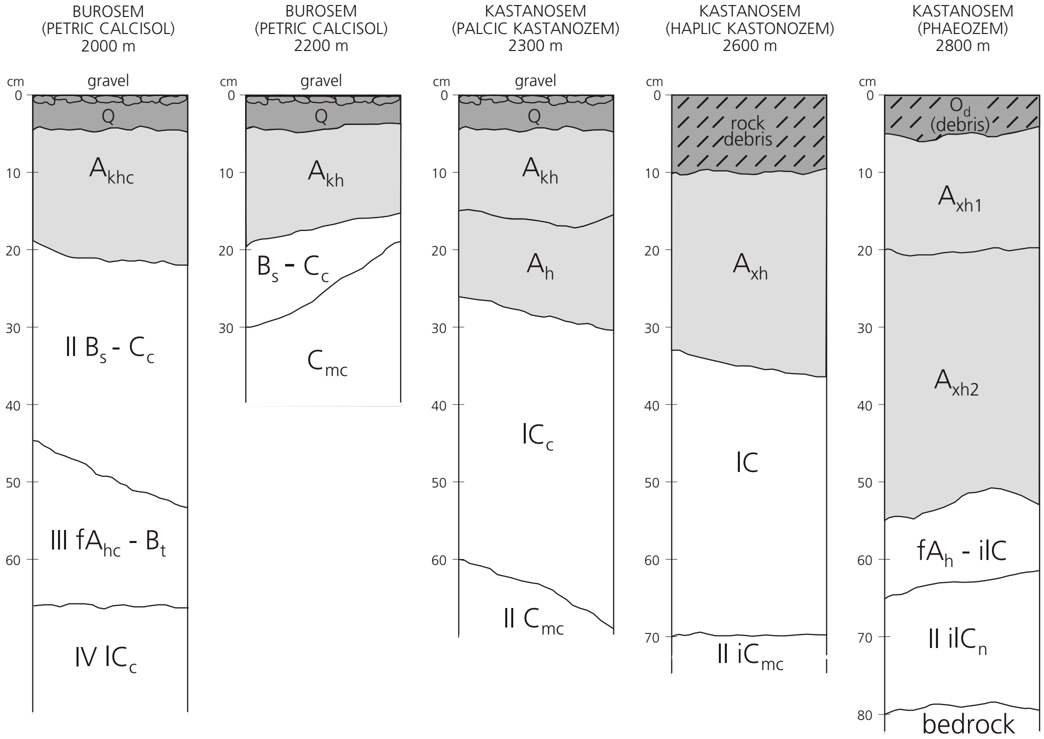


Figure 3.2.: Gradient of soil profiles along the altitudinal transect in the Dund Sayhan. Data from T. Hennig, draft by K. Wesche.

and the ridges Leptosols (Wesche & von Wehrden, 2002). Greater soil depths at higher altitudes indicate more intense weathering processes, probably facilitated by better moisture conditions, higher biotic activity and possibly more intense biopedturbation (fig. 3.2). The amount of scree is much higher on the mountain profiles than in the pediment. Vegetation changes from steppes with *Stipa* spp. towards *Arenaria meyeri-Poa attenuata* steppes which increase in forb-richness with altitude.

3.2. Material and methods

3.2.1. Design

The altitudinal transect is situated on the southern slope of the Dund Sayhan and stretches from 2000 m to the summit region at 2800 m. Every 200 m vertical meters plots for vegetation studies and climatic measurements were established. All plots were situated in steppe vegetation, facing a southerly direction if possible.

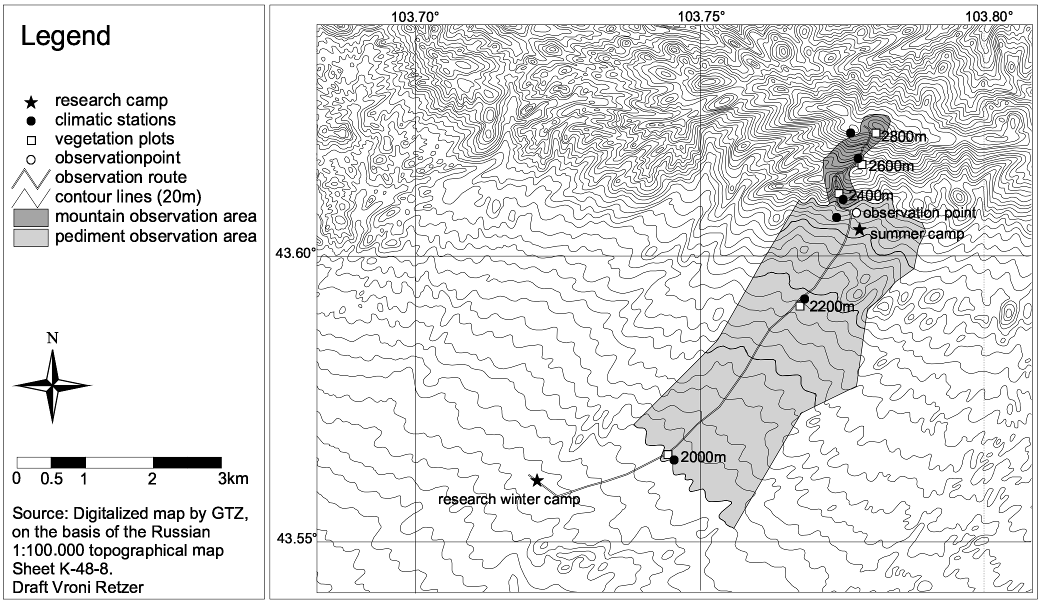


Figure 3.3.: Overview over the altitudinal transect. The locations of the research camps, climatic and vegetation plots, an outline of the animal observation area, and its altitudinal subdivisions, and the observation point and route are indicated.

Figure 3.3 shows the locations of the research camp, the climatic stations and vegetation plots along the altitudinal transect, the observation route and point for animal observations, as well as the subdivisions of the observation area into zones of 200 m in altitude.

3.2.2. Measurement of precipitation

Precipitation was measured using a Hellmann rain gauge with 100 cm^2 catching area (see also p. 77). It was installed about 50 cm above-ground. This height had to be used to prevent the gauges from being tossed over be livestock in search of a scratching post. The gauges were emptied at monthly intervals starting in September 2000. Some oil was added into the gauges to prevent the collected water from evaporating before collection. The amount of rain or snow was weighed, converted into mm precipitation and recorded (see also p. 77).

3.2.3. Vegetation data

For the assessment of vegetation data all plots were situated within grass-dominated steppe vegetation. Four 1-m^2-plots were marked at the corners of a 1-hectare plot on the pediments and of a 1/4-hectare plot in the mountains, respectively. Vegetation sampling was done in a similar manner to that within the exclosure experiment (see p. 80) On each of the 1-m^2-plots the cover of vegetation, earth, stone, dung, litter and snow were estimated directly in percent. Vegetation cover was sub-divided in grass, herb, shrub, moss, and lichen, and the cover of each group was estimated separately. For the most abundant plant species or species groups *Allium* spp., *Stipa* spp., *Agropyron cristatum, Koeleria altaica*, and *Poa attenuata* maximum height was measured for each twenty individuals (or all if less than twenty). The phenological development (table 3.1) of *Allium* spp., *Stipa* spp., *Agropyron cristatum, Koeleria altaica, Arenaria meyeri, Artemisia frigida*, and *Poa attenuata* was recorded using a 12-step scale approach developed by Dierschke (1989, 1995). For every plot an average value per species was assigned.

	for grasses	for herbs
0	without fresh above-ground shoots	without fresh above-ground shoots
1	fresh shoots without unfolded leaves	fresh shoots without unfolded leaves
2	first leaf unfolded	first leaf unfolded (up to 25 %)
3	2-3 leaves unfolded	2-3 leaves unfolded (up to 50 %)
4	beginning stalk development	several leaves unfolded (up to 75 %)
5	stalk partially developed	nearly all leaves unfolded
6	plant fully developed	plant fully developed
7	decay starts	decay starts
8	up to 50 % dried out	up to 50 % dried out
9	more than 50 % dried out	more than 50 % dried out
10	plant dead above-ground	plant dead above-ground
11	no above-ground sign of plant	no above-ground sign of plant

Table 3.1.: Classification scheme used to describe the vegetative phenological development of important plant species, after Dierschke (1989, 1995).

3.2.4. Calculation of standing crop

Along the transect phytomass was not harvested, but estimates of standing crop were calculated from the regression functions for *cover* and *height* found for the exclosure experiment at 2300 m (see equations 2.1-2.2, p. 85). Calculation was done according to that on the exclosure experiment (see p. 87), using vegetation cover and "average height of vegetative tillers of the most important species/groups" as parameters. The "most important species" were different for the mountains due to changes in species cover: *Stipa*-species and *Agropyron cristatum* were replaced by *Koeleria altaica* and *Poa* *attenuata* in the mountains and the *Allium*-genus was represented mainly by *Allium eduardii*.

The extrapolation of data from within one vegetation unit at 2300 m to different units between 2000 m and 2800 m is likely to be a source of error. This could have been minimized by choosing a sampling design which includes phytomass harvests along the transect and skips some sampling on the exclosure experiment. But as variations in time and space were not known beforehand, the more precise information from the exclosure experiment was given precedence. In the context of the project it was more important to get data on the competition between pika and livestock, and data collection had to focus around this central question. Judging from the results of the exclosure experiment the invested sampling effort seems appropriate. Nevertheless also the results from the computed standing crop along the altitudinal transect match the observations made during the investigation period. So the calculations seem to be a reasonable estimation of the distribution of phytomass along the height transect.

3.2.5. Animal observations

For the estimation of animal densities direct observation with binoculars was used. Three different approaches were combined in order to get complete records for the whole transect. For the lower altitudes up to 2400 m data from a observation hill near the summer place and from the drives between the summer- and the winter-camp could be used (see p. 82). Due to the relief visual observation was more difficult in the mountains. In the mountains notes on observed animals were taken each time when passing through Muurin Am, the valley where the climatic transect and the vegetation plots have been located. The records included height (a.s.l.), number, and kind of the observed animal(s), its distance and direction from a known height of the valley bottom, as well as date, and time of the observation. Usually a 360 °-turn was made noting all sighted animals and afterwards a second turn served to look for animals that had been missed.

As the distance from the observation hill increased towards the lower elevations, it is possible that animals at lower altitudes were systematically overlooked during this kind of observations. But neither the data nor observations during drives towards lower elevations supported this concern.

Observations at the lower elevations were easier to accomplish and thus more numerous than in the mountains. 128 observations from the observation hill, 54 during drives, and 28 from trips to the mountain were available for analysis. Moreover, the area observed decreased with increasing height, and was much larger on the pediments than within the mountain range. Areas ranged from 617 ha (between 2000 m and 2100 m) to 158 ha (between 2300 m and 2400 m) on the pediment and from 17 ha to 30 ha for each 100 m in altitude within the mountain range. Thus the data for the mountains are based on a considerably smaller observation area and on a lower number of observations. For these two reasons the observation data for the mountainous area are less reliable than those for the pediments. Thus species compositions are given only for the whole observation period, while for temporal dynamics the data from the mountains and from the pediments are pooled.

All information on animal observation was stored in a database and analyzed with a GIS (see also p. 89). The area actually observed was determined with the help of the GIS and split along the contour-lines. Number and kind of animals or livestock units within another GIS-layer were selected and merged with the altitudinal layers of the observation area in order to determine the number of livestock units within each altitude. Depending on the position of the observer some areas, especially gullies in the pediments were not within the range of vision. Therefore all animals inside these gullies were missed during the observation. But as these structures were too small to be mapped and omitted from the observation area there is a general tendency to overestimate the observed area and to underestimate the number of animals. This implies that the animal densities derived from this data are minimum estimations. But they are comparable with each other.

For the data on species composition all observations during the whole investigation period were analyzed together. For the altitude labelled ”2050 m” all observations between the 2000 m and 2100 m contour-lines were used, for ”2200 m” all between 2100 m and 2300 m, for ”2400 m” all between 2300 m and 2500 m, for ”2600 m” all between 2500 m and 2700 m, and for ”2750 m” all above 2700 m accordingly. This approach was chosen to make the data comparable to precipitation and vegetation data. But it has also one drawback for the altitudinal range around 2400 m. Here, many more sightings from the pediments were grouped together with relatively few observations from inside the mountain range (see above). For this reason the altitude ”2400 m” is much more representative of pediment conditions than of the mountain range. This has to be kept in mind when interpreting those data.

3.3. Results

3.3.1. Precipitation along the transect

The pattern of precipitation within the National Park is not well documented. Especially the effect of altitude on precipitation is not known. All stations of the Mongolian Meteorological Service are situated in the inner-montane basins at about 1400 m reflecting the arid conditions there. The increasing humidity of the mountain ranges is indirectly shown by the distribution of vegetation units (Miehe, 1996, 1998; Von Wehrden & Wesche, 2002; Wesche & von Wehrden, 2002).

The comparison of average precipitation and actual precipitation encountered in 2001 for the weather stations Dalandzadgad and Bayandalay shows an extreme drought during the investigation period (see chapter 2.3.1, p. 91). During this period of drought the data from the transect show a substantial distinction between the pediment and the mountain range (fig. 3.4). While on all plots precipitation is very low during the winter months, the rainfall patterns in summer differ markedly. On the pediments (2000 m and 2200 m) the summer rains fail completely from May to August and only in September some 22 mm to 31 mm of rain were recorded.

The pattern of the mountainous stations is different from the pediments, but very similar at all stations. Here the rains set in in May, and June brings some 40-46 mm, while July and August show no or very low precipitation until in September again up to 52 mm are recorded. The station at 2800 m shows a slightly different pattern. Although situated higher than station 2600 m and station 2400 m the annual precipitation is lower than in both other mountainous stations. This may be caused by the special topographic situation of station 2800 m. As the highest peak of the Dund Sayhan is at 2835 m, the area available for the placement of the gauge was limited. It was located relatively near to the ridge and was therefore exposed to high wind velocities. This may be the cause for increased evaporation and subsequently lower measured precipitation. Still, even this station shows considerably higher precipitation than was recorded on the pediment.

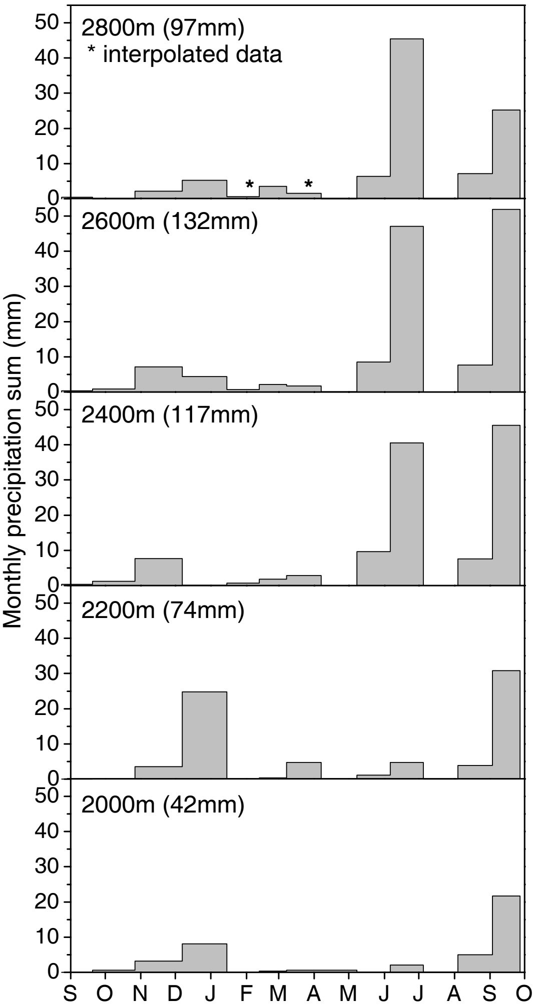


Figure 3.4.: Precipitation along the altitudinal transect during the investigation period. Data were gathered jointly with Karin Nadrowski.

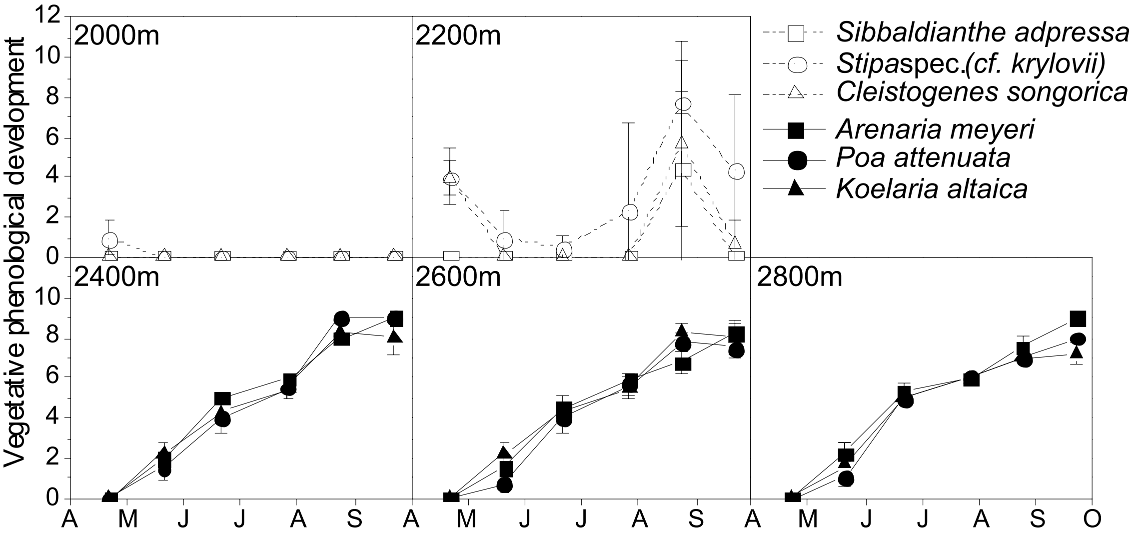


Figure 3.5.: Phenological development of important species (groups) along the altitudinal transect from April to October 2001. Classification after Dierschke (1989, 1995), see table 3.1, p. 135.

When calculating the average increase of the annual precipitation per 100 m in altitude, the special situation of the mountains becomes obvious. While normally the increase ranges between 4.5–8 mm/100m the increase between 2200 m and 2400 m is much higher: 29.5 mm per 100m. This shows that the prominent geomorphological transition goes along with a change in precipitation patterns. Although precipitation is higher in the mountains, the failure of rain in July and August is not normal and indicates below-average precipitation in the mountains as well. The drought of 2001 is of considerable effect along the whole transect, but is less severe in the mountains.

3.3.2. Phenological development

The phenological development of plant species can serve as an indicator for the development of weather conditions (Larcher, 1994). In this study it has been used to assess climatic conditions along the transect. For the phenological development of important plant species along the transect different species had to be chosen, because no species occurs along the whole transect (fig. 3.5). In the mountains the grasses *Poa attenuata,* and *Koeleria altaica*, and the herb *Arenaria meyeri* have been studied. On the pediments the herb *Sibbaldianthe adpressa* and the grasses *Cleistogenes songorica* and *Stipa* spp. which is mostly *Stipa krylovii* mixed with some *Stipa gobica* have been sampled.

Again a distinctively different pattern between mountains and pediments can be observed. Within the mountainous area (2400–2800 m) all species develop synchronously on all altitudes. In late April none of the species shows fresh shoots, but in May, with the first small amounts of precipitation, the plants develop fresh shoots and grow until they reach full development in late July. Signs of decay can be observed in August, and until late September up to 50 % of the plant have dried up. The development is continuous although the rains in June seem to have accelerated the growth of the plants.

The pattern on the pediment is different between the two plots at 2200 m and 2000 m. There, the development is not as continuous as in the mountains. The pattern at 2000 m is simple and the same for all species analyzed: during the whole summer of 2001 plants cannot develop fresh shoots yet alone finish vegetative development.

The situation is different at 2200 m, but again all species behave very similarly. At 2200 m the approximately 5 mm of precipitation which were recorded in March until April 6^{th} obviously are enough to trigger the growth of some fresh shoots of *Stipa* and *Cleistogenes*. In May and June the average phenological development of all plants decreases to almost zero. This of course is not caused by "backward" development, but probably caused by grazing herbivores which select the tasty fresh shoots and leave the dry leftovers from the previous year behind. The late August rains have the main effect on vegetation development. Instantly all three species reach their maximum development phase: *Cleistogenes* is fully developed, while *Sibbaldianthe* is only partially developed and *Stipa* begins decaying. Although September brings more rain, due to grazing the average phenological development stage is decreasing again for all species.

On the plot at 2200 m the standard deviation of phenological development for all species is very high – if any development can be found at all. The reason for this is that in figure 3.3.2 average values from the four investigated 1m^2-plots are given. But the development on the plots was not always homogenous and was even more different between the plots. Thus there were always individuals of all species which did not show any development next to others which started growth and tried to finish their generative cycle. This parallel occurrence of plants which do not initiate growth and others which do is the reason for the high standard deviation. But it may also be an indicator that the abiotic conditions at 2200 m in the summer of 2001 were very near to the limits of plant growth. Only slight differences in precipitation (table 3.2) compared with the plot at 2000 m are enough to stimulate plant development on the plots at 2200 m. These 15 milimeters of precipitation during the growing season are of crucial importance and seem to be the lower limit for plant growth.

	March	April	May	June	July	August	sum
2200 m	5	0	1	5	0	4	15
2000 m	1	1	0	2	0	5	9

Table 3.2.: Monthly precipitation sum (mm) on the plots at 2200 m and 2000 m of the altitudinal transect during the drought in the summer of 2001.

3.3.3. Standing crop along the transect

Figure 3.6 shows the development of standing crop on the transect under grazing. Therefore, it is comparable to treatment "*pika & livestock*" of the exclosure experiment. Vegetation growth patterns follow very closely the patterns observed by the distribution of precipitation along the transect (fig. 3.4). Here the distinctive partitioning into a mountain and a pediment zone can be observed as well. The pediment does not exhibit any substantial vegetation growth during the whole summer of 2001.

Standing crop on the plots at 2000 m and 2200 m varies between 21 kg/ha and 43 kg/ha. These amounts are so low that they can barely be harvested by any herbivore (fig. 2.11, p. 104, and fig. 2.12, p. 107). On the pediments the drought hits extremely hard: practically no phytomass is available for grazing livestock or wild herbivores.

The situation is different in the mountains. Vegetation growth sets in with the first rains in May reaching maximum standing crop in June with 200 kg/ha at 2600 m and 320 kg/ha at 2800 m. At these two altitudes standing crop decreases again as soon as August. At 2400 m, however, the maximum of 260 kg/ha is reached not before August, but afterwards declines, too. This fast decrease of standing crop on all plots in the mountains indicates a relatively high grazing pressure in comparison to the available phytomass.

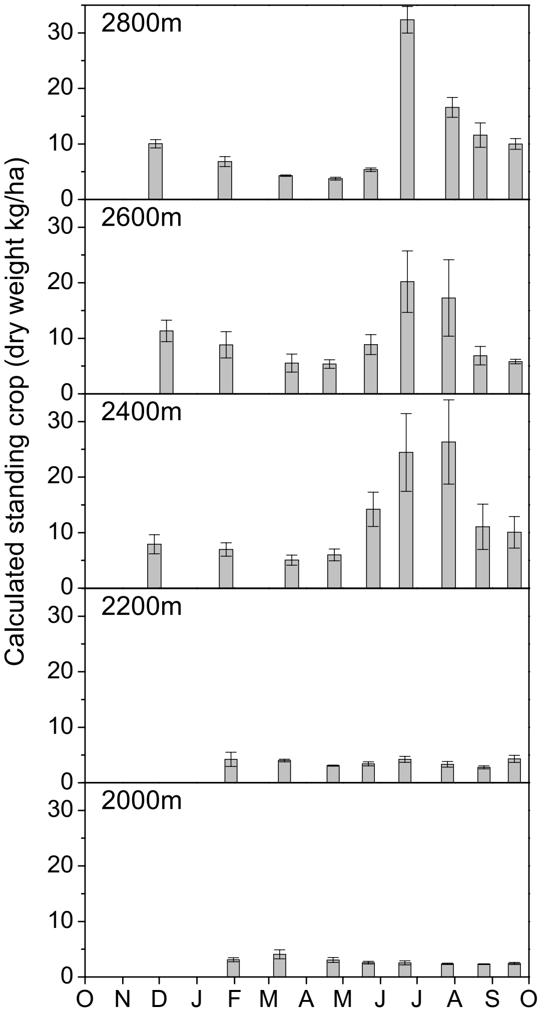


Figure 3.6.: Estimated standing crop along the altitudinal transect (kg/ha). Standard deviations are given for the four plots per altitude.

At the end of the investigation period in September standing crop on all plots in the mountains is approximately the same or even less than in November 2000. At this time of the year 2000, after two more months without growth but continued grazing, more phytomass was left than in September 2001 just at the end of the growing season. This indicates that the forage resources for herbivores are already depleted at this time and again underlines the severity of the drought in the summer of 2001. It supports the impression that the mountains hold a reserve of phytomass for grazing livestock, but cannot compensate for the failure in phytomass production at lower altitudes.

3.3.4. Distribution of animals along the transect

Species composition along the transect

The distribution of livestock and wild herbivores along the transect during the investigation period shows a distinct altitudinal zonation (fig. 3.7). The data basis are livestock densities given in livestock units (MSU) because that resembles the consumption of the different species more closely than simple livestock numbers (see chap. 2.2.7, p. 89). The impact of livestock is generally much higher than that of wild herbivores.

Here again the difference between pediments and mountains is evident, although the transition is more gradual than the pattern observed from precipitation and vegetation. For the interpretation of this data it has to be noted that due to the method used to separate the different altitudinal belts, the altitude of "2400 m" basically represents the situation on the upper pediment, and not that in the mountains (see chapter 3.2.5, p. 137).

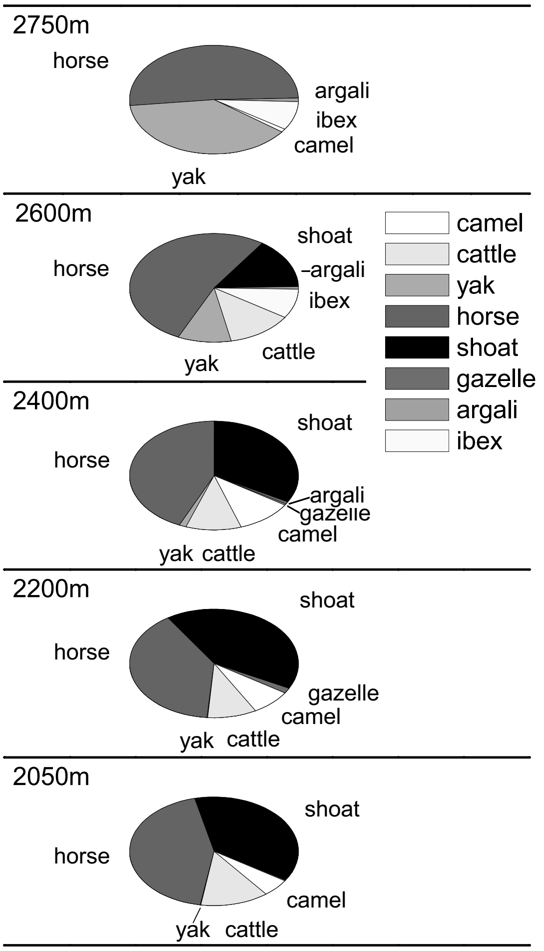


Figure 3.7.: Average species composition of livestock and wild herbivores along the altitudinal transect during the investigation period. Proportions are given in livestock units, MSU (see chapter 2.2.7, p. 89).

Horses are dominant along the whole transect. They are the only species which does not show a clear preference for any altitude. They account for up to 52 % of the grazing impact in the mountains and more than 40 % on the pediments. The other livestock species are more restricted. Cattle as well as the small stock are preferably found on the pediments, but also go up into the mountains up to 2600 m but never climb to the summit region (2750 m). While the proportion of cattle is constantly about 10 % from 2050 m up to 2600 m, sheep and goats seem to be confined to the pediments, with a share of 33–41 % there, and only 15 % at 2600 m.

Camels and yaks are restricted to their desert-steppe and mountain habitat, respectively. While camels are confined to the lower elevations, yaks occur only in the summit regions. Camels constitute 5–11 % of the grazing herbivores on the pediment and are only rarely observed in the mountains. Yaks on the other hand prefer the high mountains and make up 10 % at 2600 m and more than 1/3 at the summit region. Especially in autumn and winter they are occasionally seen at lower altitudes.

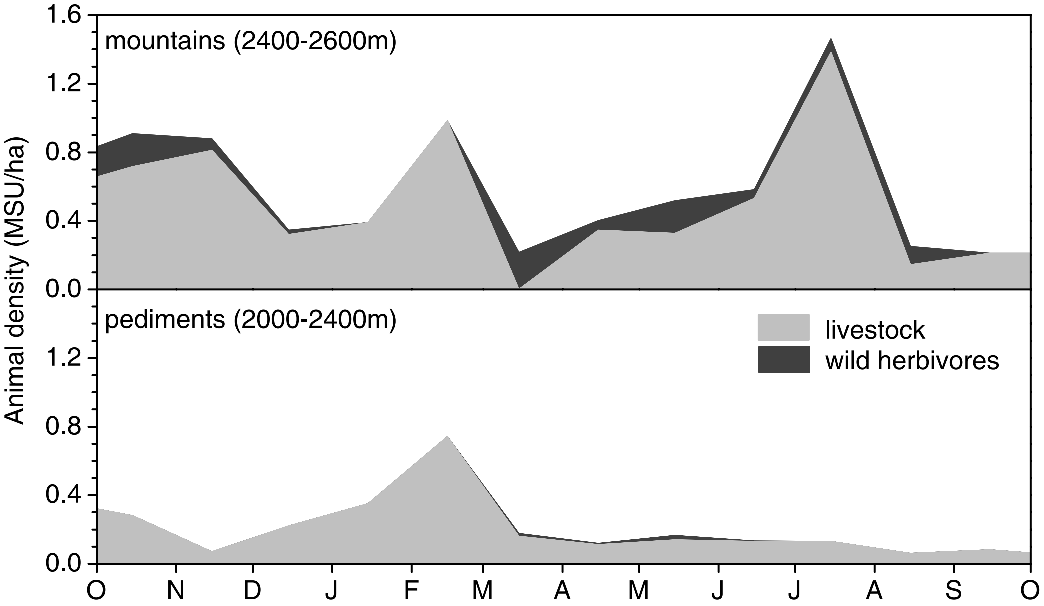


Figure 3.8.: Densities of wild animals (black) and livestock (grey) during the investigation period within the mountains and on the pediments.

The distribution of wild herbivores is also very distinctive. Gazelle are observed only at the pediments in low densities of 1-2 % on average with the center of distribution around 2200 m. Wild sheep (argali) and ibex have a similar distribution centered in the mountains. Argali make up 1 % and the more numerous ibex 10 %. The rare and endangered argali (Finch, 1996) use the mountains as habitat during summer, but descend to the upper ends of the pediments in winter (see also Huffman, 2003): ibex on the other hand have only been observed in the mountains. This habitat distribution is typical: ibex generally prefer the more rugged terrain within the mountains and argali are found on hillier terrain (Hess, 1988; Reading et al., 1999a,b; Valdez, 1988).

Comparison of livestock and wild herbivores

As the data base for observations within the mountains is less comprehensive than that from the pediments, data have been pooled as a comparison of the temporal dynamics. Figure 3.8 shows the average density of livestock and wild herbivores during the investigation period. Although the density of wild animals probably underestimates the real number (see chapter 3.2.5, p. 136) because they have a greater fleeing distance than livestock, it is safe to state that livestock accounts for the main share of the grazing impact encountered along the whole transect.

During the whole investigation period animal densities are lower on the pediments than in the mountains. This may not be the usual pattern, but related to the untypically dry conditions, when more forage is available in the mountains. On the pediments livestock densities are relatively high during winter, which is probably due to the fact that many herders had their winter camps around 1900 m. From the middle of March onwards herders move towards their summer-places, probably moving some flocks of sheep and goats out of vision. Livestock densities on the pediment remain low during summer and even diminish at the end of summer. This is paralleled by the lack of forage on the pediments which forces livestock and herders to seek better pasture on the northern side of the Dund Sayhan and in the mountains.

The main share of wild animals on the pediments is made up of migrating gazelle herds which moved through the area in spring. Argali were observed occasionally at the upper end of the pediment during winter.

In the mountains herbivore densities decrease in winter compared with the autumn of 2001. This is probably due to the higher snow cover inside the mountain range which makes the area less accessible. Herbivore densities increase again in February reducing the leftover phytomass (fig. 3.6). After a sharp drop in March especially the livestock densities increase constantly until July reaching 1.5 MSU/ha when herders move their herds towards and into the mountain range. Afterwards livestock densities drop to about 0.2 MSU/ha, when herders move their animals to grazing grounds far away. The distribution of livestock can be explained by the herders' moving strategies and phytomass availability, but the dynamics of wild herbivores need more thorough investigation to allow interpretation.

3.4. Discussion

3.4.1. Mountains as a reserve for livestock during drought

Precipitation along the altitudinal transect As shown above, precipitation was much higher in the mountains than on the pediment area (fig. 3.4, p. 138). During the summer of 2001 this effect was very pronounced, yielding approximately 3 times more precipitation at 2600 m than at 2000 m. In order to assess the positive impact of the enhanced precipitation on the forage production during a normal year the extent of the increased precipitation in the mountains during a normal year has to be known. But the observed precipitation gradient may not be linearly extrapolated for wetter years. As no measurements exist, this has to be logically derived from the measurements available and the knowledge on the generation of precipitation in the Gobi Gurvan Sayhan.

During the summer of 2001 the mountain tops of the Dund Sayhan were regularly covered with convective clouds. Weather observations indicate that most rainfalls in the mountains were caused by convective rainfall events often in combination with thunderstorms. This kind of precipitation is sort of self-induced: once rain falls, it already provides the moisture to form new clouds, which may result in rain again. In wetter years, a higher proportion of the rains is expected to be derived from advection currents and thus to be more evenly distributed along the different altitudes in the park, too. The percentage of convective rains is likely to be lower in an average year, and therefore the slope of the observed gradient from the pediment to the mountains should be more gentle during a year of average precipitation than observed in 2001. The difference between precipitation on the pediments and in the mountains is certainly also relevant in years with average precipitation, but it will not be as extreme as could be shown during this particular investigation period. The factor of more than 3 times higher precipitation at 2600 m in comparison with 2000 m can be assumed to be a maximum increase during a year of drought.

Shurentuja et al. (2002) regressed average rainfall at three stations within the Gobi Gurvan Sayhan National Park with altitude and found a 12 mm increase in mean annual precipitation per 100 m shift in altitude. As stated before the stations are situated in the lower elevations of the park (1192–1462 m), and do not include a single station within the mountain ranges. The specific processes of increased convection within the mountains can therefore not be detected by this method and the regression function cannot be applied to the higher elevations. A calculation of the increase in precipitation per 100 m in altitude from our data shows that on the pediment the increase is between 4.5 and 8 mm/100m and that it is much higher between 2200 m and 2400 m with 29.5 mm/100m. The increase between 2400 m and 2600 m again is about the same as on the pediment (7.5 mm/100m) (see also 3.3.1, p. 138). If the average slope from our data on the pediment (6.4 mm/100m) is extrapolated to the stations 2400 m and 2600 m the predicted amount of precipitation is 84 mm and 71 mm only, which account for 64 % and 61 % of the measured amount, respectively. This indicates that it is not possible to apply the regression function from the stations at lower altitudes to the mountains.

Therefore we can conclude that rainfall is not constantly higher in the mountains, but super-proportionally higher during times of low precipitation. This higher amount of precipitation enables a higher phytomass production which turns the mountains into even more valuable pastures for herders and their livestock (fig. 3.6, p. 141). This effect further increases the importance of the mountains as reserves during drought.

Calculation of standing crop The application of the same regression functions which were found at 2300 m to the whole transect with different vegetation types is critical. The estimations presented are probably more reliable for the pediments because vegetation composition there is more similar to that at the exclosure experiment. But as only an approximation is needed, this approach is suitable anyway. The most important thing is the trend in vegetation development, which can be clearly seen in the data, even if some of the absolute numbers may not be totally accurate. Also other studies showed that the same regression function could be applied to 141 different species and during different seasons (Huennecke et al., 2001), so the error caused by using the same regression functions seems to be within reasonable limits. Furthermore, three test harvest samples from 2600 m show that the regression function applied underestimates phytomass production in the mountains rather than overestimates it. Still phytomass production is estimated to be much higher in the mountains than in the pediments.

The mountains as pastures for livestock The shift of livestock from the pediments to the mountains in the course of the year 2001 (fig. 3.8, p. 143) indicates the intensity of the grazing pressure in the mountains. Possibly due to this shift the altitudinal zonation of livestock is not as distinct as might be expected (fig. 3.7, p. 142). This again may be a sign that livestock which usually prefers grazing on the pediments intrudes into the mountains in search of better pasture during the drought of 2001. For example, camels were seen grazing up to 2700 m and herds of small livestock were driven up to 2750 m by the children herding them.

Reading et al. (1996) also reported that people in interviews stated that the density of herders and their livestock within the mountains has been much higher than usual in the spring of 1996 due to the unusually dry winter. The same phenomenon has also been observed in Africa, where mountains were used as refugia for cattle during "bad periods" in the Rift-valley of north-western Kenya (Coppock et al., 1986).

During periods of extreme drought as those encountered in the summer of 2001, even the forage resources in the mountains are not sufficient to satisfy the needs of livestock. As a consequence herders have to reduce livestock densities. While many move to better pasture grounds far away, the remaining ones spread over the region.

The herders' ability to exploit such spatial and temporal heterogeneities by moving their herds, which allows them to use the available land in an optimal way. Opportunistic management strategies all over the world have been found to allow higher livestock densities in non-equilibrium grazing systems than management at constant densities would (e.g. Behnke et al., 1993; Fynn & O'Connor, 2000; Sullivan & Rohde, 2002).

3.4.2. Implications for nature conservation

The Gobi Gurvan Sayhan mountain ranges are of special value to most of the user groups within the national park. For herders they represent a forage reserve for livestock during dry years and observation-points to observe their freely roaming large animals. For nature conservationists and the park administration they are habitat for endangered fauna and flora, and foreign tourists because of their scenic beauty (see Saffery, 2000, for the discussion of tourism and conservation issues in the National Park). As the number of tourists is still low and tourism was not in the focus of this study, only the interests of the first two groups will be discussed here. As could be shown above, mountains are an attraction for livestock in bad years, therefore conflicts between pastoralism and the protection of rare plant species and wildlife are predetermined.

Within this study no data on vegetation composition and the influence of livestock on vegetation has been investigated. However, Wesche et al. (submitted) have found that the grazing impact on high altitude vegetation has no strong influence on its biodiversity and that all open vegetation units are extremely well adapted to permanent grazing. The situation is different for the remains of forest vegetation. Cermak et al. (2004) demonstrated the importance of the remaining birch-salix forests in the Dzuun Sayhan for biodiversity conservation and how they are threatened by livestock grazing. The forests possibly are a self-preserving system in special topographic situations, which decelerate snow melt until summer and thus have a higher moisture availability during the growing season than the surrounding steppe. This makes them especially vulnerable to human impact. Once destroyed it is not likely that these forests can reestablish under present day climate and grazing pressure (Cermak et al., 2004; Opgenoorth, 2003). Seedlings outside the forests were found primarily where grazing pressure was very low (Miehe, 2003). It seems that the impact of livestock grazing on vegetation is critical mainly for the forest remains, but not for the open vegetation units in the mountains.

The dynamics of plant-herbivore interactions may change from more non-equilibrium dynamics on the pediments to more equilibrium dynamics in the mountains. This is indicated by the gradient in rainfall observed and especially by the fact that inter-annual variation seems to be more explicit on the lower elevations than in the mountains. The same gradient within different altitudes could be shown by Fernandez-Gimenez & Allen-Diaz (1999) in an area about 250 km north-west of the Gobi Gurvan Sayhan. Assuming this, the change in plant-herbivore interactions can be transferred to the Gobi Gurvan Sayhan, the high mountain vegetation may be endangered by constant grazing in high densities.

It was not in the immediate focus of this study to assess the impact of livestock on wild large herbivores, but some conclusions can be drawn from the distribution and migration behavior of animals observed along the transect. In a situation of severe drought, as encountered in the summer of 2001, forage competition between wild herbivores and livestock in the mountains is likely to occur, though it is hard to prove only on the basis of the existing data of this study. Forage competition between pika and large wild herbivores cannot be assessed on the basis of the data presented here.

Livestock and wild herbivores share the same habitat in the mountains, and livestock intrudes into the mountains especially under bad conditions (see chapter 3.3.4, p. 143), so there is an overlap of the habitats of both groups. The second prerequisite for forage competition (see chapter 2.1, p. 75), dependency on the same resources, could not be shown explicitly in this study. Schaller (2000) has shown in Tibet that livestock in fact competes with wild herbivores for the same forage species, and animal and plant species there are similar to those found in the Gobi Gurvan Sayhan. Forage competition with domestic sheep is regarded as the main reason for the decreasing numbers of argali (Reading et al., 1999b; Valdez, 1988). Also Valdez (1988) stresses the variability of forage resources used by argali. So it seems plausible to assume an overlap in resource use also within the investigation area. The third condition "limited availability of resources" is met during the investigation period along the whole transect (see chapter 3.3.3). Considering all these pieces of evidence, it is very likely that forage competition between wild herbivores and livestock exists in the summer of 2001, although its extent is still unclear. Further research will be necessary to clarify this matter.

The presence of forage competition with livestock has more implications especially for argali and ibex. Like all wild animals in the Gobi Gurvan Sayhan which depend on the mountain habitat they are restricted to a relatively small habitat which is separated from other suitable habitat (Maroney, 2003; Mongolian Atlas, 1990) – a typical island biogeographical situation (Lomolino, 2000; McArthur & Wilson, 1967). On their way to a suitable habitat in other Altai mountains in the north-west they have to cross flat areas of steppe which is adverse terrain for them and is inhabited by human herders. This makes migrations difficult.

The increasing stress on wild herbivores in the mountains during drought therefore is twofold:

1. The competition with livestock for forage gets more severe than under normal conditions.

2. Wildlife is likely to be disturbed more frequently by herders searching for their livestock, and people herding their livestock in the mountains.

Furthermore, the competition for water may be intensified as during drought conditions some herders move to springs which previously have been used only infrequently and were exclusively available to wildlife (own observation and interviews).

Nevertheless argali and ibex are not in immediate danger, they have coexisted with grazing livestock for thousands of years. But the increasing grazing pressure may intensify stress on the animals and possibly may cause their numbers to fall below a critical number to sustain the populations. Pressure is higher on argali, whose habitat overlaps more with livestock grazing ranges (Reading et al., 1996, 1999a,b). Moreover, their number in the park is lower than that of ibex. Reading et al. (1999a) estimate their number at 3257±1071 animals within the park's 5.200 km^2 of mountain habitat. That is a density of about 0.57 animals/km^2. Ibex populations are much higher. Their number was estimated to be around 12,166 in 1995 and about 19,290 animals in 1996 (Reading et al., 1999a). Population numbers of ibex are higher, but population structure indicates that the reproductive capacity (higher percentage of yearlings and females) of argali is higher (Reading et al., 1996), possibly making up for the lower numbers. Ibex reproduction was significantly greater in 1995 than in 1994 and 1996 (Reading et al., 1996). The annual precipitation measured in Dalandzadgad was also greater in 1995 (175 mm) than in 1994 (135 mm) and 1996 (157 mm) (data from the Meteorological Service, Mongolia). This might be an indicator that ibex reproduction is triggered by precipitation. But this is not much more than speculation and should be investigated further, especially under changing rainfall regime under global change.

A further threat for argali as well as for ibex is poaching (Reading et al., 1996, 1999a). Ibex poaching was observed especially in the Dund Sayhan by Reading et al. (1999a) but the situation is probably similar in the other high mountain ranges.

The consequences of livestock pressure on predators was not in the primary focus of this study. But as argali and ibex are the main prey species of snow leopard (Reading et al., 1999a), strong populations of both species are a prerequisite for the conservation of this endangered species (Reading et al., 1996). If argali and ibex densities are high enough to feed the predators, the depredation on livestock may be reduced. And reduced depredation in turn may change the attitude of Mongolian herders towards the snow leopard, who now regard it as a danger to their livestock. Possibly in the long run this may result in decreasing poaching pressure. But this is a long way to go and conflicts are foreseeable if livestock numbers increase and livestock uses mountain habitat more frequently.

The importance of the reputation of a certain species among the locals, can be seen at the example of the gray wolf. This predator frequently is perceived to increase in the area and as a threat for livestock and human safety (Reading et al., 1996, 1999a). Khuukhenduu & Bidbayasakh (2001) have found that 60 % of the hair found in wolf scats was from livestock, about one third from wild ungulates and the remaining about 7 % from small mammals.

According to Tungalagtuya Khuukhenduu, President of the Mongolian Gray Wolf Center, and the wildlife biologist Badamjavin Lhagvasuren, it is allowed to hunt wolves, even within the National Park throughout the year (personal communication). But wolf numbers actually observed are low. Reading et al. (1999a) found even fewer signs of wolf presence than of snow leopard. During the field work I found tracks of (probably) one single snow leopard and one pack of about four wolves in the Dund Sayhan mountains and observed one juvenile wolf next to the road passing between the Dzuun and Dund Sayhan ranges. Nevertheless wolf attacks on livestock have been reported several times by our neighbors.

Acknowledging the Mongolian tradition of communal land tenure and seeing the efficiency of grazing exclosures within the park (Wesche & Nadrowski, 2000) it seems neither technically nor socially feasible to establish zones which are free from livestock grazing (see also Wesche et al., submitted). Moreover, the herders' knowledge about the park, its borders, and regulations is very limited (Reading et al., 1996). What is possible, and what is being tried by the park administration supported by the GTZ, is to raise awareness of conservation issues among the inhabitants of the park. But probably these efforts will show only limited success, because the problem is most severe when herders struggle to ensure the survival of their herds, which are usually the only way to earn their livelihood.

This assumption is underlined by observations made during the field work: the "Special Protection Zone" in the Gobi Gurvan Sayhan mountains has been marked with yellow iron posts in the summer of 2001. But neither the meaning of those posts was known to local herders, nor are they of any hinderance for grazing livestock. The local ranger Sorinsombold, although he had put up the posts and knew about their meaning, even built a new well in a mountain valley in order to use this place – inside the core zone – as a winter shelter.

So the only further measure which seems feasible and within the power of the park administration is to encourage early movement in years of drought. Possible actions include the support of information on regions with good pasture quality. Already nowadays the walkie-talkies of the national park rangers have been used to exchange information on pasture quality within the park.

3.5. Summary

The mountain ranges of the Gobi Gurvan Sayhan are of special importance to herders and nature conservation. They are islands of higher precipitation and higher primary productivity in an ocean of semi-desert and therefore offer valuable pasture for the herders' livestock. Furthermore, they are the habitat of scarce and endangered flora and fauna of the park.

This setting provides the base of the dilemma encountered during a period of drought such as in 2001. When forage is scarce, herders use the mountains as pastures for their livestock more intensively than under normal circumstances. This is nothing else than an opportunistic management of heterogenous resources. During such a difficult time the park regulations even allow an use of the core areas for livestock grazing.

But this may have detrimental influence on the protected wild herbivores such as argali and ibex. Forage competition with livestock during drought intensifies the stress they face and may drive the populations closer to local extinction. Migration to other habitat to avoid the stress as well as recolonization after potential local extinction is difficult because other suitable habitat is far away and separated by semi-deserts which offer low habitat quality for the animals.

The likeliness of local extinctions can not be predicted from the data presented but they indicate a severe problem when two objectives of the park – protection of wildlife as well as long-term sustainable land use by nomadic herders – collide with each other.

4. Pika within the mountain-steppe ecosystem - indicators for pika as ecosystem engineers?

4.1. Introduction

The initial question of this study was whether pika can be regarded as pests. The question of forage competition between pika and livestock has been assessed in chapter 2. But apart from that small mammals can have much more direct and indirect influence on their biotic and abiotic environment (see e.g. Jones et al., 1994; Kotliar et al., 1999; Lawton, 1994; Miller et al., 2000; Stapp, 1998; Whitford & Kay, 1999; Zhang et al., 2003a). The changes pika induce on their environment affect livestock as well and therefore are of special relevance to herders. This chapter focuses on the effects of pika on the vegetation of their burrows, explores some of the mechanisms which may induce these changes, and assesses the consequences they have for grazing livestock.

The perception of small mammals by humans depends very much on the role the human observer plays within the ecosystem in question. Within the Gobi Gurvan Sayhan National Park this includes mainly the role as herders and within the present study the role as ecologist. For herders the reference point against which they will judge a small mammal, is its influence on their livelihoods by forage competition with livestock.

Relatively independent of these ratings are scientific categories used to describe the influence of species on their environment. They sort species according to the kind and intensity of influence they have on their biotic and abiotic environment. Two popular concepts have to be named in this context: the concept of ”keystone species” and that of ”ecosystem engineers”. Keystone species have been introduced by Paine (1969) as species which modify the species composition and physical appearance of complex systems by their activity. Removal of keystone species causes massive changes in species composition especially along the trophic links. Keystone species have also been used as an indicator of rangeland health (Krogh et al., 2002). The concept of ecosystem engineers on the other hand tries to separate trophic from engineering effects and focuses on the mechanisms of interactions. Ecosystem engineers are defined as ”organisms that directly or indirectly modulate the availability of resources [other than themselves] to other species” (Jones et al., 1994, p. 373). Jones et al. (1994) integrate keystone species into their concept of ecosystem engineers, because ”critical effects frequently involve engineering” (p. 380). They divide ecosystem engineers into allogenic and autogenic engineers. Autogenic engineers "change the environment via their own physical structures" while allogenic engineers "change the environment by transforming living or non-living materials from one physical state to another [...]" (p. 374). Jones et al. (1994) suggest six criteria to quantify the impact of engineers:

1. life time per capita activity of individual,
2. population density,
3. spatial distribution of the population,
4. duration of population presence at a site,
5. durability of the constructs, artefacts, and impacts in the absences of the original engineer,
6. number and types of resource flows that are modulated and number of other species dependent upon these flows.

There has been some controversy on the semantics and meanings of ecosystem engineering, especially on whether engineering is an activity carried out with intent (Jones et al., 1997; Power, 1997a,b). There have also been warnings that it may become trivialized by applying the concept to any case (Reichman & Seabloom, 2002a,b; Wilby, 2002). Within this study the concept is used to provide a framework to assess the impacts of pika on their abiotic environment and the feedbacks these environmental modifications have on livestock.

For example the prairie dog, another small mammal living in colonies in the prairies of North-America, has long been known to influence vegetation and soil properties. On its burrows it alters chemical and physical soil properties (Whicker & Detling, 1988), nutrient dynamics (Coppock et al., 1983a), biodiversity (Kotliar et al., 1999; Miller et al., 1994), vegetation structure (Bangert & Slobodchikoff, 2000), vegetation composition (Bonham & Lerwick, 1976), and increases phytomass (Fahnestock & Detling, 2002). These effects lead to a preferred selection of prairie dog colonies as habitat by bison (Coppock et al., 1983b). Due to their effect on the faunal and floral biodiversity of the system they have been labelled a keystone species (see reviews by Kotliar et al., 1999 and Stapp, 1998) and because of their modification of processes ecosystem engineers as well (Whicker & Detling, 1988).

So which effects do Mongolian Pika have on their abiotic and biotic environment and especially on livestock? The green pika burrows within the surrounding steppe-matrix[1] are one of the most striking feature within the mountain-steppes of the national park

---

[1] A note on terminology: the term "steppe" appears in two different connotations in this chapter. Firstly it is the zonal grass-dominated mountain-steppe vegetation, and secondly it is used to differentiate burrows from their surroundings. So when burrows are compared to their surroundings on a smaller scale, "steppe" is opposite to "burrow" throughout this chapter. To eliminate this terminological difficulty the "steppe, which is no pika burrow" will be called steppe-matrix.

Figure 4.1.: The Mongolian Pika, *Ochotona pallasi*, (left) and one of their burrows (right). The pika is watching for predators. The burrow shows a contracted vegetation, fresh mounds, and heaps of livestock (horse) dung. The picture is from August 2001.

are (fig. 4.1). Pika burrows can be easily visually differentiated from the surrounding steppe. The distinguishing criteria are

- frequent occurrence of holes, stones, and bare soil as immediate results from pika's burrowing activities, and
- the same plant species, which occur also in the steppe are of darker green, seem more vital, and grow in more congregated patches on the burrow.

These observations indicate that pika indirectly influence vegetation development on their burrows by modifying water and/or nutrient availability by their activities. The proposed mechanisms are the following: pika may influence nutrient distribution by their behavior of collecting hay and livestock dung and by defecation on their burrows. All three activities lead to a nutrient flux from the steppe-matrix towards the burrow. This should result in a higher nutrient concentration and availability on the burrows.

Water availability may be modified by pika as well. It is possible that the loosening of the soil by digging may increase the infiltration capacity on the burrows. Karin Nadrowski (pers. comm.) proposed a mechanism which could increase soil humidity on the burrows: during high intensity rains the infiltration capacity on the steppe-matrix is quickly exceeded and surface runoff can be observed. This is typical for semi-arid and arid regions (Schultz, 1995). The surface flows then run into the entrances of pika burrows and thus is led deeper into the soil where it can infiltrate slowly and build up a water reservoir under the burrows (see also Miehe, 1996). This mechanism is supposed to increase water availability on the burrows until the reservoir is emptied.

The hypotheses how pika act as ecosystem engineers therefore are:

1. pika improve nutrient availability on their burrows through nutrient concentration
    a) by collecting hay and
    b) livestock dung,
    c) and by deposing faeces and urine on the burrow they inhabit.
2. They also improve the water availability for plants growing on their burrows by two mechanisms:
    a) Their digging activity increases the infiltration capacity on the burrows and
    b) the burrows act as "water traps" during surface runoff.
3. The combined increased water and nutrient availability enables higher plant productivity on the burrows than in the steppe-matrix.

This chapter attempts to sort pika along the pest – neutral – beneficial categories from a herder's point of view and to investigate first indicators for pika's possible role as ecosystem engineers. As many of these mechanisms are relatively difficult to investigate, some have been investigated directly, while others have been tested only indirectly. For example, the digging activity of pika was not quantified, but was indirectly documented by the description of pika burrows in terms of coverage with entrances, mounds, etc. Hay collection of pika is well-known (Guriceva, 1985; Kaetzke & Traglauer, 1998; Schneider, 1988), and was obvious in the investigation area and was not quantified either. The same is true for pika's defecation pattern.

The collection of livestock dung and its concentration on pika burrows has been assessed by collecting dung, and estimating the amount found on and off burrows. The supposed result of these processes – increased nutrient availability on the burrows – has been tested on soil profiles on burrows and in the steppe-matrix by Thomas Hennig. The hypothesized higher water availability on the burrows was not tested itself, but the result, water content under burrows and under the steppe-matrix was investigated in the soil profiles by Thomas Hennig.

The feedback of these modifications on the vegetation which is of special relevance to livestock was investigated as well. Data on the phenological development, vegetation cover and height on pika burrows were collected parallel to the exclosure experiment (see chapter 2). In order to compare productivity of vegetation on burrows with the results from the exclosure experiment on the steppe, small cages were established on the burrows. Additionally samples of below-ground biomass on and off burrows were taken.

4.2. Material and methods

4.2.1. Study area

All experiments took place in the surroundings of the exclosure experiment at about 2350 m. Pika density there is about 30 individuals/ha (Nadrowski et al., 2002).

4.2.2. Characteristics of pika burrows

In order to assess the intensity of pika's influence on the landscape level, information on the structure and density of the burrows was needed. Therefore burrows around each of the four exclosures from the exclosure experiment were mapped on four areas ranging from 0.23–0.62 ha. Altogether 25 burrows were investigated and the following parameters were noted: area of burrow, number of entrances, and percentage cover of entrances, mounds, bare soil, stones, and vegetation, the latter divided into grass, herbs, and shrubs.

4.2.3. Collection of dung

The (re-)distribution of nutrients by livestock dung was assessed by collecting livestock dung on marked 1 ha-plots adjacent to the four exclosures. Initially all dung was removed at the beginning of March 2001. Afterwards dung was collected in regular intervals of about one month. The amount of dung found on burrows and within the steppe-matrix was counted during collection and converted into percent. Collection was limited to the dung of the large herbivores, camels, horses, cattle and yaks for practical reasons. All dung was completely removed from the area, which ensured that all dung encountered during the next collection must have been deposited in the meantime. After collection its weight and volume was quantified. Both parameters were closely correlated ($r^2=0.93$, $p<0.001$). Therefore volume was chosen for the calculations, because this parameter is less biased by rainfall preceding collection.

4.2.4. Soil properties

To evaluate the changes in soil properties caused by pika, soil pits were dug on two different pediments in pika burrows, and in the steppe-matrix. The profiles were described by their horizons following Haase (1983), AG Bodenkunde (1994), and WRB (FAO, 1998). Soil color, structure, and texture were estimated in the field. The water content was measured in situ with a Theta-sonde from Delta-T-Devices. As the sonde broke during the field-work these values are only partially available. For further laboratory analysis representative samples were taken from within each horizon. Each sample was air-dried in the field and again prior to analysis in an oven at 105 ° C. The soil was then crushed and passed through a sieve with 2 mm mesh width.

Chemical analysis was carried out in the laboratories of the Geobotanical Institute at the University of Halle. It closely followed the methods outlined in Schlichting et al. (1995). All standard soil parameters were analyzed, but only for the parameters presented the exact methods are described. The soluble NO_3^- and NH_4^+ fraction was extracted by shaking 20 g of the soil with 100 ml of 1 M KCl–solution for 60 min, and filtering the resulting suspension. After that NO_3^- as well as NH_4^+ contents were measured photometrically with an Eppstein-photometer. The soluble P-fraction was extracted by shaking 2 g of the soil with 100 ml double-lactate solution for 90 min, and filtering the resulting suspension. Again phosphorus content was measured photometrically and PO_4^- calculated from it.

For the analysis of C and N, 20 mg extremely finely ground soil was packed together with ca. 40-60 mg wolfram-oxide in tin foil and analyzed with a CNS-analyzer (Jenoptik). The wolfram-oxide does not participate in the reaction, but was used in order to minimize the impact of the high calcium-content on the analyzer's cores. The C/N-value can be easily calculated from the C and N values. The photometrical measurement of P and N was carried out by the Agricultural Institute/University of Halle. Soil sampling and all other analyzes were performed by Thomas Hennig.

For the comparison of C-, and N-content, C/N ratio, phosphate, nitrate and ammonium concentrations, profiles from T. Hennig's series named x.Or23 were chosen, because this series offered the highest number of comparable samples in the two uppermost horizons. Within this study results of the nutrient concentrations from the two uppermost horizons are presented. These were chosen because root biomass is concentrated in this depth (see Borisova & Popova, 1985) and it therefore is important for the nutrient resorption of the vegetation. The horizons investigated in all profiles were the Q-horizon (after Haase, 1983), a loose sand/silt layer with low humus content. This horizon is characteristic for Burozems. Additionally the Ah-horizon, a mineral horizon with humus accumulation (3–6 % in Mongolian soils), was analyzed (Haase, 1983).

Because the Theta-sonde broke during the course of the study no data of the water content for the same series of profiles was available. For the comparison of water content therefore another series, named 1.OrX, had to be used.

4.2.5. Standing crop

Sampling of vegetation height, cover and above-ground biomass was carried out parallel to the exclosure experiment (table 2.1, p. 78). Next to each exclosure a 1-m^2 plot was established on a pika burrow. These plots were not fenced. With respect to the grazing treatment the plots on pika burrows thus correspond to treatment *pika & livestock* of the exclosure experiment. Data collection on vegetation cover and height on the 1-m^2 plots on burrows was identical to that within the exclosure experiment (see chapter 2.2.4, p. 80). The plots on the pika burrows were integrated into the double-sampling scheme, but were never actually harvested. Therefore all data on standing crop are based on calculations via the regression functions derived from the exclosure experiment (p. 85) .

4.2.6. Phenology of important forage plants

On the same plots where vegetation height and cover were assessed also the phenological development of important forage plants was recorded. Data collection followed the scheme suggested by Dierschke (1989, 1995). It was identical on the exclosure experiment and on the adjacent plots on pika burrows. Because of their abundance and importance for grazing herbivores, the following plants were chosen for the phenological studies: *Allium* spp. *(= A. prostratum* and *A. polyrrhizum)*, *Stipa* spp. *(=S. krylovii* and to a lesser extent *S. gobica)*, *Agropyron cristatum*, and *Artemisia frigida.* The methodology applied was equivalent to that on the transect. For a more detailed description of the method see chapter 3.2.3 and table 3.1 on page 135.

4.2.7. Below-ground biomass

To assess the influence of pika burrows on the below-ground biomass on the pika burrows, below-ground biomass was investigated with four replicates on pika burrows and in the adjacent steppe-matrix. Samples were collected from four different pediments, each one in the vicinity of the exclosures of the exclosure experiment. All samples were exactly 8 cm in depth and about 10 x 15 cm in surface area. The precise length and width was measured for each sample and sample volume calculated.

Above-ground biomass was removed and then the block was soaked with water to loosen the earth. The roots were then washed at least three times by means of a 2 mm sieve (see Long et al., 1989). After washing, the roots were dried to constant weight on the ger stove just as any above-ground biomass sample (see chapter 2.2.4, p. 80). As long as the drying temperature is constant the choice of the exact drying temperature does not have a significant influence on the results (Lieth, 1968). Separation into living and dead phytomass was not possible under field conditions and therefore was omitted (Biondini et al., 1998; Van der Maarel & Titlyanova, 1989).

4.2.8. Productivity of pika burrows

To evaluate primary production on pika burrows without grazing, two small exclosures, about 30 cm in diameter, excluding pika and livestock were put up in the spring of 2001. They were established on different pika burrows within Karin Nadrowski's pika investigation area in the vicinity of the exclosure H4 (table 2.2, p. 79).

The cages were smaller than those used in the exclosure experiment. They had to be adapted to the conditions on the burrows. Their average size was about 0.35 m^2 so that they would fit between the numerous entrances of a burrow. The size of every cage was exactly determined prior to harvest. To omit edge effects some 5 cm from the edge of the cages were not used for the harvests. The cages were placed on the vegetation patches of the burrows. The experiment was set up in the spring of 2001 before vegetation growth set in.

The small cages were harvested on July 12th, 2001. Further harvest later in the year was planned, but due to the lack of rain (fig. 2.5, p. 92) no growth was recorded afterwards. The standing crop found at this date was therefore assumed to be the ANPP on the burrows in the summer of 2001. The results from this experiment are compared with the data from the treatment *no grazing* of the exclosure experiment. As no data for the middle of July were available from the exclosure experiment, the data closest to the harvest on the small cages were taken. But as the small cages were sampled just in the middle of two sampling-events at the exclosure experiment both the available data sets were about two weeks before or after July 12th. Therefore it was tested (SPSS, t-test for independent samples) whether the mean standing crop on grazed and ungrazed plots differed significantly between both dates. As the means of end of June and end of July were not significantly different, neither for grazed (p=0.358) nor for ungrazed (p=0.720) plots, both data sets were combined and compared with the samples from the pika burrows.

Calculation of productivity The data on above-ground productivity from the small exclosure cages cannot be used directly for estimating the productivity on pika burrows. The problem is the placement of the cages on the burrows. The cages were not placed randomly, but had to be concentrated on the patchy vegetation for two reasons: due to the low numbers of cages available random placement was technically not feasible, and secondly a sufficient amount of vegetation had to be protected from grazing to enable the measuring of any effect. This led to the fact that the percentage of vegetation cover was higher in the cages than on the whole burrow. Therefore the cages are not representative for the vegetation cover of the burrows. To make the data comparable with the big exclosure experiment the data from the burrows had to be converted into ANPP-figures corresponding to the average vegetation cover on burrows "outside" the cages.

The four parameters "vegetation cover inside cage (%)", "vegetation cover outside cage (%)", "ANPP inside cage (kg/ha)", and "area (ha)" are derived from the experiment (table 4.5). They are the basis for calculating the ANPP per hectare steppe on the different microsites using the following equations:

1. calculation of the ANPP inside the cages per percent vegetation cover and hectare:

$$\text{ANPP inside cage (kg/ha*\%)} = \frac{\text{ANPP inside cage (kg/ha)}}{\text{vegetation cover inside cage (\%)}} \tag{4.1}$$

2. Calculation of the ANPP outside the cage per hectare of the specific microsite by using the productivity per % vegetation cover as transfer factor:

$$\begin{aligned}&\text{ANPP outside cage (kg/ha)} = \\ &\qquad \text{ANPP inside cage (kg/ha*\%)} \cdot \text{vegetation cover outside (\%)}\end{aligned} \tag{4.2}$$

3. This last step of the calculations gives the productivity of the burrows and in the steppe-matrix in kg/ha. Therefore now the factor by which productivity on burrows is modified (increased or decreased) in comparison with the steppe-matrix can be calculated as:

$$\text{factor}_{B-M} = \frac{\text{ANPP outside cage (kg/ha) [on burrows]}}{\text{ANPP outside cage (kg/ha) [in steppe-matrix]}} \tag{4.3}$$

4. Now the area of burrows within the steppe has to be taken into account to calculate the productivity on the 7 % of the area covered with burrows and on the 93 % of the area covered with steppe-matrix:

$$\begin{aligned}&\text{ANPP burrow (kg/ha steppe)} = \\ &\qquad \text{area burrow(\%)} \cdot \text{ANPP burrow outside cage (kg/ha)}\end{aligned} \tag{4.4}$$

$$\begin{aligned}&\text{ANPP steppe-matrix (kg/ha steppe)} = \\ &\qquad \text{area -matrix (\%)} \cdot \text{ANPP steppe-matrix outside cage (kg/ha)}\end{aligned} \tag{4.5}$$

5. This is the basis for calculating the productivity of the steppe by summing up the production on the burrows and the production in the steppe-matrix:

$$\begin{aligned}&\text{ANPP steppe (kg/ha Steppe)} = \\ &\qquad \text{ANPP burrow (kg/ha Steppe)} + \text{ANPP steppe-matrix (kg/ha Steppe)}\end{aligned} \tag{4.6}$$

6. Finally the factor by which burrows modify productivity within the steppe in comparison with sole steppe-matrix can be calculated as:

$$\text{factor}_{S-M} = \frac{\text{ANPP steppe (kg/ha)}}{\text{ANPP steppe-matrix (kg/ha)}} \tag{4.7}$$

4.2.9. Statistical methods

Basic calculations such as statistical mean and standard deviations were performed using the standard routines of the software programs Origin 6.0 or Excel 97. The software program SPSS 10.07 and its functions were used to investigate the significance of means. The t-test routine for independent samples was used to calculate the significance of differences in mean values for standing crop, the cover of vegetation, earth, stone, grass, herb, and shrub in the steppe-matrix in comparison with the burrows. It was also used for the comparison of C-, and N-contents, C/N ratio, phosphate, nitrate and ammonium concentrations in soil profiles between burrows and the steppe-matrix as well as between the different layers of one site. Only for the comparison of the below-ground biomass, the dependent t-test was used, because here the samples from burrows and steppe-matrix were collected in direct vicinity from each other. The significance of p-values is indicated as follows: $p \leq 0.001$ ***; $p \leq 0.01$ **; $p \leq 0.05$ * higher values of p are indicated as not significant (n.s.).

4.3. Results of the comparison between pika burrows and steppe-matrix

4.3.1. Burrow characteristics

As described in the introduction pika burrows can easily be distinguished from the surrounding steppe-matrix with the bare eye. Although the same species often build up the vegetation communities on the burrows and in the steppe-matrix, the differences are obvious. Apart from the simple feature of burrow entrances, cover of vegetation, earth and stones as well as the proportions of grass, herbs and shrub within the vegetation vary between steppe-matrix and burrows.

Burrows cover 7–12 % of the steppe at this altitude. Table 4.1 shows characteristics of pika burrows: the mean area of the burrows, the number of entrances per burrow, and the mean cover of entrances and mounds. The area per burrow varies from 4.5 to 108 m^2 thereby showing a high standard deviation. The average burrow has 36.7 entrances which cover 11.4 % of the burrow's area. About 4.8 % are covered with mounds. Mounds consist of bare earth and originate in the digging activity by pika. In the subsequent data mounds are included in the value for "earth cover".

Characteristics of pika burrows

	area (m^2)	entrance (#)	entrances (%)	mounds (%)
mean	32.4	36.7	11.4	4.8
sd	23.5	17.2	2.6	3.1
min	4.5	7	7	1
max	108	81	18	12

Table 4.1.: Characteristics of pika burrows in the investigation area: mean, standard deviation, minimum and maximum for burrow-area, the number of entrances per burrow, and the cover of entrances and mounds.

The number of entrances per burrow (r^2=0.64, $p<0.0001$) is significantly positive and the percentage of mounds (r^2=0.27, p=0.008) significantly negative correlated with the size of the burrow. The correlation between the number of entrances and burrow size indicates the usefulness of entrances to delimit burrows from the steppe-matrix.

The percentage of mounds (r^2=0.27, p=0.008) is significantly negative correlated with the size of the burrow. Possibly the significant decrease in mound cover with increasing burrow area is an indicator for the limited digging capacity per pika. As Karin Nadrowski's data (in prep.) show, pika are highly territorial and therefore generally only one adult pika inhabits and defends one burrow. When its burrow's size increases this individual's digging capacity may be exceeded and the percentage of mound cover may decrease.

While the number of entrances increases significantly with burrow size, the cover of entrances shows no correlation with burrow size (r^2=0.06, p=0.203). Burrow size also

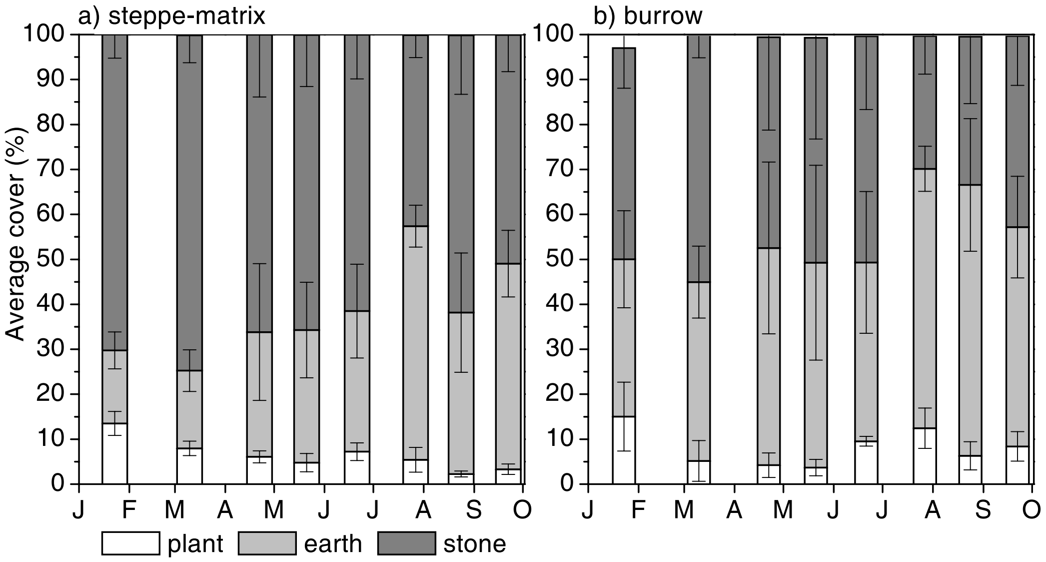


Figure 4.2.: Comparison of the cover development for earth, stones and vegetation in the steppe-matrix (a) and on burrows (b). Values are means for N=4, error bars mark the standard deviations.

does not significantly influence the cover of earth (r^2=0.08, p=0.165), stones (r^2=0.01, p=0.590), and vegetation (r^2=0.00, p=0.896).

These data indicate that pika need and create a certain density of entrances per area, thus the number of entrances increases linearly with burrow size. This is possibly an adaption to predators: pika minimize the distance from any given point on their burrow to the next entrance, in order to be able to escape predators. On the other hand their influence on vegetation, earth, and stone cover does not change with burrow size.

The proportions of cover with plants, earth and soil on burrows and in the steppe-matrix are shown in figure 4.2. On average, stones and earth together cover more than 90 % on both microsites. Cover of earth is higher and stone cover lower on the burrows than in the steppe-matrix. During 2001 average stone cover on the burrows is 44 % and average earth cover 47 %.

In contrast to that, average stone cover within the steppe-matrix is 61 % and average earth cover 31 %. These differences are not significant for each single investigation date. But over the whole growing season earth cover is significantly higher (p=0.003) and stone cover significantly lower (p=0.001) on the burrows in comparison with the steppe-matrix. The reason for this is probably pika's habit of arranging the stones on the burrow in heaps. It is yet unclear what purpose these heaps serve, but by doing so pika rearrange the stones on their burrows and concentrate them on a few spots. Therefore the same or even higher amount of stones on a burrow covers less area than in the steppe-matrix.

Vegetation cover is generally lower on the burrows than in the steppe-matrix in late winter and spring (March–May). During the growing season this trend is reversed. Vegetation cover during the growing season is significantly (p=0.01) higher on the burrows.

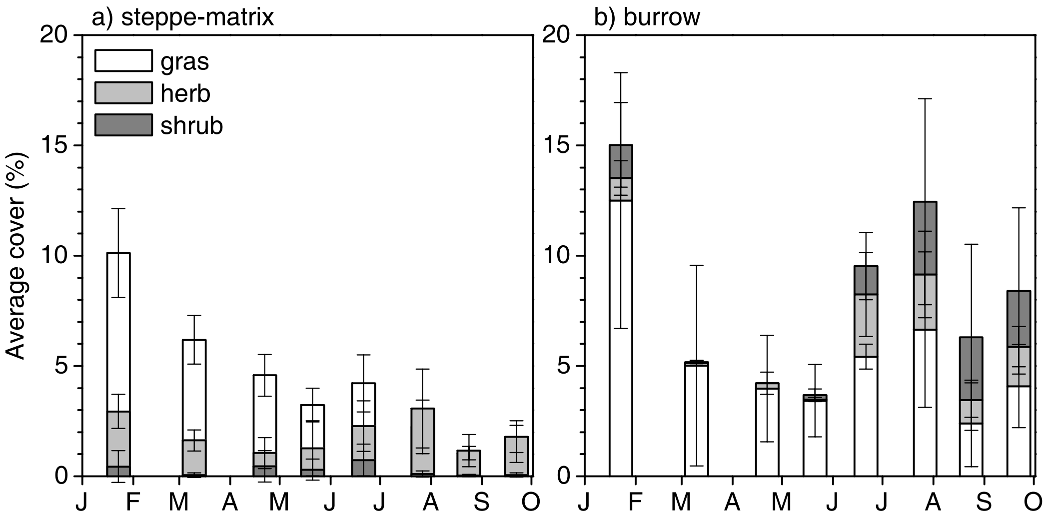


Figure 4.3.: Comparison of the development of vegetation cover divided into grass, herb and shrub on the steppe-matrix (a) and on burrows (b). Values are means for N=4, error bars mark the standard deviations.

The proportions of grass, herb and shrubs in the vegetation of the steppe-matrix and the burrows are shown in figure 4.3 for the year 2001. On pika burrows the percentage of herbs in the vegetation cover is lower and the percentage of grasses and shrubs higher than in the steppe-matrix. During the growing season average grass, herb and shrub cover on pika burrows were 4.3, 1.4 and 1.7 %, respectively. The corresponding values for the steppe-matrix were 2.8 % grass, 1.8 % herbs, and 0.3 % shrubs. The differences within one harvest date are only significant for grass cover at the end of August (p=0.044). For the whole growing season the differences in grass (p=0.012) and shrub (p=0.028) cover are significant.

4.3.2. Dung distribution

The redistribution of nutrients via dung is important for nutrient cycling in grazed semi-arid ecosystems (Augustine, 2003). Figure 4.4 shows the distribution of livestock dung on pika burrows and in the steppe-matrix. Values are given as average monthly deposition between two sampling dates. The average amount of dung collected per hectare follows the densities of large livestock observed in the investigation area in the previous period. Dung collection therefore also can be used to estimate grazing pressure. An average of 0.18 MSU/ha deposit a volume of 4.8 l of dung per hectare. If this dung were distributed by chance, only 7.4 % of it should be found on a pika burrow. But a much higher percentage is found there: table 4.2 lists the factor by which the burrows are enriched with livestock dung. On average, the volume of dung found on the burrows exceeds 67 times the volume which should be deposited there by chance.

Two mechanisms can explain this distribution pattern of livestock dung: for one thing, dung may be deposited preferably near or on burrows, because livestock prefers them for grazing in comparison with the steppe-matrix. Another explanation is that dung is

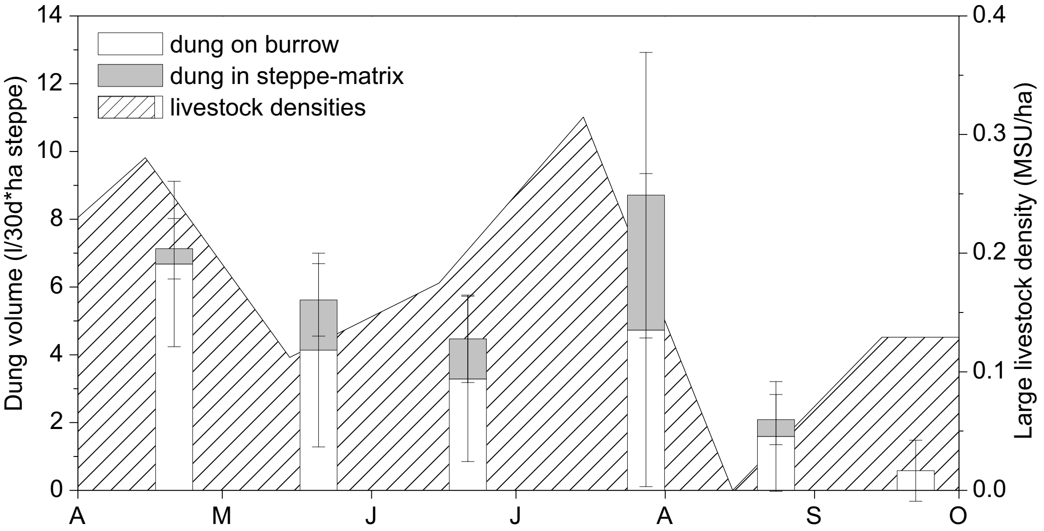


Figure 4.4.: Distribution of livestock dung on pika burrows and in the steppe-matrix for the vegetation period April to September 2001. As a comparison densities of large livestock in MSU/ha are given on the right y-axis.

redistributed actively by pika and concentrated on their burrows. Livestock dung dries very fast under the Mongolian climate. So it is easily possible for pika to move the dried dung patches towards their burrows.

Why pika behave like this has not been investigated yet. But it could be observed that pika use the dung as building material for closing their burrow entrances in winter. It may also be used for weighing down collected hay to prevent it from being driven away by the wind. Nothing is known about the amounts of dung which pika actively transport towards their burrows. But from the data presented it can be concluded that during six consecutive months pika actively concentrate dung on their burrows.

dung concentration on burrows

date	burrow (l)	steppe-matrix (l)	factor
21/04/01	6.68	0.45	202
21/05/01	4.14	1.48	38
21/06/01	3.29	1.18	38
28/07/01	4.73	3.98	16
24/08/01	1.59	0.50	43
22/09/01	0.58	0.00	n.p.
mean	3.50	1.26	67

Table 4.2.: Dung concentration on the burrows in comparison to the steppe-matrix. The factor by which burrows are enriched with dung is calculated using the fact that pika burrows cover only 7.4 % of the steppe-matrix. For the last date no enrichment-factor can be calculated because no dung is found in the steppe-matrix at all (division through zero).

The enrichment-factor cannot be generalized for other years, because the investigations date from only one year of drought with relatively low densities of livestock and subsequently low densities of dung. As we know almost nothing about what pika use the dung for, it is not possible to judge when their need for dung may be satisfied and under which circumstances they refrain from further dung transport towards their burrows. In wetter conditions a higher percentage of the dung may stick to the ground so that it cannot be moved by pika. Therefore we presume that the observed enrichment-factors are more likely to represent the upper limit of the scale than average conditions. Both mechanisms, livestock defecation on burrows, and pika's collecting activity, work together and create this distinct distribution pattern. The individual importance of the single mechanisms cannot be evaluated yet. But they subsequently result in a concentration of nutrients on the burrows.

4.3.3. Soil properties

The results of the soil analysis show that calcium and magnesium are available in abundance, while the levels of potassium and sodium are approximately sufficient. This holds true for all profiles and depths. The critical elements which may limit plant growth are phosphorous and nitrogen. Table 4.3 shows the mean levels of C, N, C/N, phosphate, nitrate, and ammonium for the two uppermost horizons of three profiles in pika burrows and two burrows in the steppe-matrix. These profiles were chosen because here the most complete data for two layers of the same depth from one pediment were available. The Q-, and Ah–horizons show the highest content of roots and are of immediate importance for the nutrient availability for all herbaceous plants.

Nutrient concentrations on burrows and steppe-matrix

a) Q-horizon. 3 cm	burrow (n=2)	steppe (n=3)	factor	p-value
C (%)	3.7 ± 0.7	1.9 ± 0.02	1.92	**0.041**
N (%)	0.41 ± 0.07	0.27 ± 0.01	1.54	n.s.
C/N	9.0 ± 0.6	7.3 ± 0.3	1.24	**0.033**
PO_4^- (mg/kg)	135.7 ± 61.9	42.5 ± 28.1	3.20	n.s.
NO_3^- (mg/kg)	190.6 ± 102.2	7.8 ± 0.3	24.59	n.s.
NH_4^+ (mg/kg)	9.6 ± 1.6	3.6 ± 0.9	2.65	**0.018**

b) Ah-horizon. 10 cm	burrow (n=2)	steppe (n=3)	factor	p-value
C (%)	1.8 ± 0.3	1.7 ± 0.01	1.06	n.s.
N (%)	0.26 ± 0.03	0.25 ± 0.01	1.04	n.s.
C/N	6.8 ± 0.4	6.7 ± 0.2	1.02	n.s.
PO_4^- (mg/kg)	20.2 ± 10.2	7.6 ± 1.9	2.66	n.s.
NO_3^- (mg/kg)	68.5 ± 54.5	3.1 ± 0.6	22.10	<**0.001**
NH_4^+ (mg/kg)	5.7 ± 4.0	3.0 ± 0.00	1.91	n.s.

Table 4.3.: Comparison of soil properties of pika burrows and the steppe-matrix. Data are mean and standard deviations for samples from pika burrows and the steppe-matrix. The upper part a) gives the values in the uppermost Q-horizon and the lower part b) those in the Ah-horizon. The column "factor" shows the enrichment of each parameter on the burrows compared with the steppe-matrix. Levels of significance for an unpaired t-test are given for the comparison of the means between burrow and steppe-matrix. Data by Thomas Hennig.

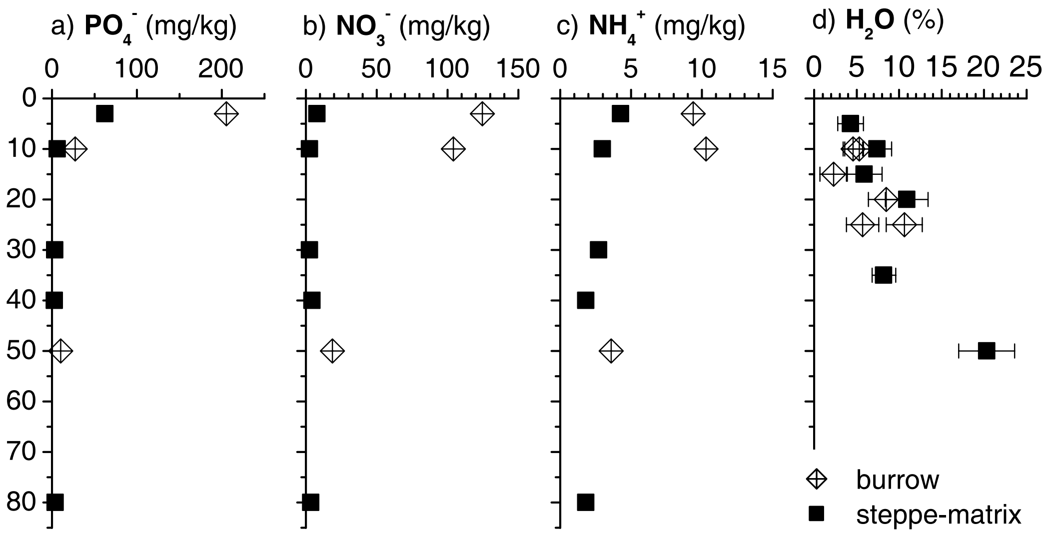


Figure 4.5.: Comparison of the distribution of the a) phosphat-, b) nitrate-, and c) ammonium-concentration in reference profiles on a pika burrow and in the steppe-matrix from one pediment. The distribution of water content with profile depth is shown in part d) for three profiles on pika burrows and for two profiles in the steppe-matrix from a different pediment. Data by Thomas Hennig.

All parameters are higher on the burrows in both horizons (see column "factor"). The C-content in the Q-horizon of the burrows is almost twice as high as in the steppe–matrix, while N-content is 1.5 times higher. This results in a higher C/N ratio in the Q-layer on the burrow (9.0) than in the steppe-matrix (7.3). In the Ah-layer the differences in C, and N content are much smaller. In this horizon no significant difference between burrow and steppe-matrix can be detected. This is a consequence of the changes with the horizons on the burrow. In the steppe-matrix only the C–content decreases significantly between the two layers, whereas C–, and N–content, as well as the C/N ratio decrease between the two layers on the burrow. The C/N ratios are lower in the deeper soil layer on both sites and indicate a good decomposition ability of the litter. Hence it follows that the Q-horizon is enriched with C and N in comparison with the steppe-matrix and in comparison with the Ah-horizon on the burrows. Still the enrichment with C is higher than that with N resulting in a higher C/N ratio.

The concentrations of phosphate, nitrate, and ammonium in both layers are much higher on the burrow than in the steppe-matrix. In the Q-horizon the concentration of phosphate is 3.2 times, the concentration of nitrate 24.5 times, and the concentration of ammonium 2.7 times higher on the burrow. The differences are slightly less distinct in the Ah than in the Q-horizon. Due to the low number of samples the differences are not always significant, but for all three parameters and both horizons all values on the burrows are higher than within the steppe-matrix. These results show that the soil of pika burrows is enriched with C, N, phosphate, nitrate and ammonium. The higher variability in the concentrations of phosphate and nitrate in the samples on pika burrows indicates a higher heterogeneity of these elements on pika burrows.

The distribution of phosphate, nitrate, and ammonium in the layers of two representative profiles on a burrow and in the steppe-matrix respectively is shown in figure 4.5. The distribution of all three ions is similar. The values remain higher on the burrow than in the steppe-matrix, but the differences are most pronounced in the uppermost horizons. In a depth of 40–50 cm the concentrations of phosphate, nitrate, and ammonium are only slightly higher on the burrow. The effect of nutrient enrichment on the burrows is therefore limited to the upper soil layers. As these are the region of highest biological activity and root density, the enhanced nutrient availability in this zone is of tremendous importance for vegetation productivity.

Figure 4.5 d) shows the mean values and standard deviations of measurements of the water content on three burrow and two steppe profiles, which were repeated 10 times. Although it is difficult to compare the different horizons in different profiles, there is no obvious difference between the water content of the burrows and the steppe-matrix. Water content seems to be actually lower under the burrows. This may be caused by the air circulation through the burrow system which dries the soil out.

On the burrows in the uppermost 3 cm of the Q-horizon a higher content of C and N, and a higher C/N ratio than in the steppe-matrix can be found (table 4.3). These are indicators for humus enrichment on the burrows. These effects are only relevant at the surface, as for C and N almost no difference between burrow and steppe-matrix can be detected in the 10 cm-deep Ah-horizon. The concentrations of phosphate, nitrate and ammonium are much higher on the burrow in both horizons.

The investigation of nutrient parameters shows that pika improve nutrient availability on their burrows, an effect which is especially pronounced for the concentrations of phosphate, nitrate and ammonium in the upper soil layer. No evidence could be found to support the hypothesis of higher water availability on the burrows - on the contrary water availability tends to be lower on the burrow. A possible explanation for this is that digging by pika might improve the infiltration capacity of the burrows (Wesche, K., pers.comm.), but that this is of no relevance in a year of drought: when almost no rain falls which could infiltrate into the soil, even an enhanced infiltration capacity cannot improve the moisture content.

4.3.4. Productivity of burrows

Already the first visual impression of the green vegetation on pika burrows indicates that the burrows may be more productive than the steppe–matrix (see also Wesche et al., 2003). The data from the exclosure experiments indeed show significantly higher standing crop on burrows. This is true for grazed areas (fig. 4.6a) and for ungrazed areas as well (fig. 4.6b). Due to the low number of samples the standard error is very high for the data from the burrow but nevertheless the differences are significant.

Under protection from grazing maximum standing crop on burrows is 1180 kg/ha compared with 220 kg/ha in the steppe-matrix. The maximum of standing crop therefore is more than 5 times higher on the burrows than in the steppe-matrix. The same can

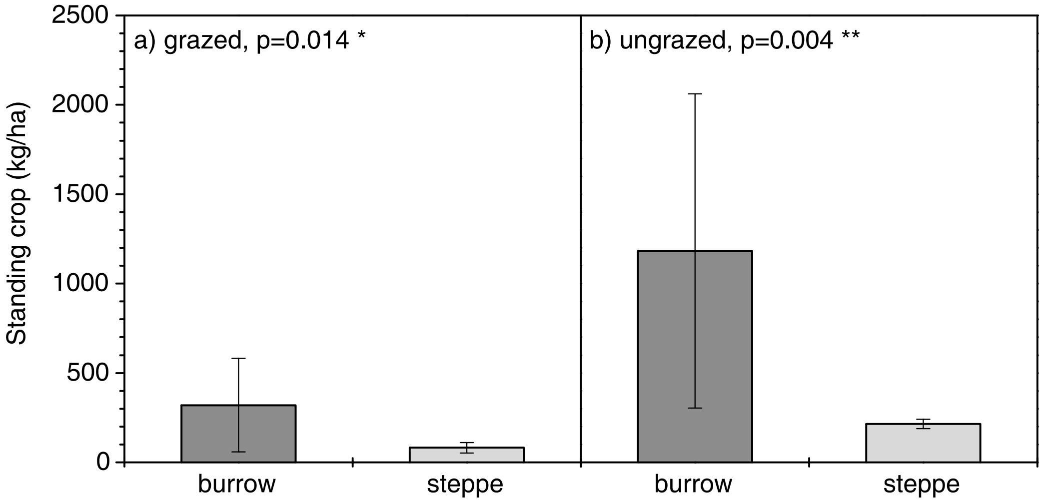


Figure 4.6.: Comparison of standing crop on pika burrows (n=2) and in the steppe-matrix (n=8) under grazing (a) and protected from grazing (b). Note that the scale is ten times enlarged in comparison with figure 2.11 showing standing crop on the exclosure experiment.

be found even under grazing. Here the peak standing crop reaches 320 kg/ha on the burrows and 82 kg/ha in the steppe-matrix and therefore is about 4 times higher on the burrows. This indicates that the additionally produced phytomass on the burrows is not used immediately by either livestock or pika.

The below-ground biomass under burrows is higher than in the surrounding steppe-matrix, too (table 4.4). But here the difference is not significant (p=0.27, two-tailed).

below-ground biomass (kg/m^2)	mean	standard error	N
steppe-matrix	1115	577	4
burrow	1648	658	4

Table 4.4.: Below-ground biomass on pika burrows and the steppe-matrix.

The results on above-ground productivity as shown in figure 4.6 are not suitable for extrapolation. The problem is that the cages were not placed randomly on the burrows but deliberately put on the vegetated areas. This was technically necessary, but resulted in a vegetation cover that was higher inside than outside the cages. Production figures from the burrows therefore had to be corrected to match average vegetation cover outside the cages (see chapter 4.2.8, p. 159).

Data from different sources were combined in this calculation in order to assess whether pika burrows as a whole still are more productive than the steppe-matrix. The principle is to compute the productivity per percent vegetation cover in the cages and transfer it to the whole burrow area. The productivity of the whole burrow is calculated by multiplying the productivity per percent vegetation cover derived from within the cages with the vegetation cover of the whole burrow. The way of this calculation is described

a) grazed	burrow	matrix	steppe	factor
vegetation cover inside cage (%)	24.7	6.3		
vegetation cover outside cage (%)	10.9	6.3		
ANPP inside cage (kg/ha)	292.0	48		
ANPP inside cage (kg/ha·%)	11.8	7.6		
ANPP outside cage (kg/ha)	129.1	47.6		**2.71**
area (%)	0.07	0.93	1.00	
ANPP (kg/ha steppe)	9.6	44.1	53.6	**1.13**

b) ungrazed	burrow	matrix	steppe	factor
vegetation cover inside cage (%)	48.8	12.6		
vegetation cover outside cage (%)	*22.6*	12.6		
ANPP inside cage (kg/ha)	1154.0	184		
ANPP inside cage (kg/ha·%)	23.7	14.6		
ANPP outside cage (kg/ha)	535.0	184.4	210.5	**2.90**
area (ha)	0.07	0.93	1.00	
ANPP (kg/ha Steppe)	39.8	170.7	210.5	**1.14**

Table 4.5.: Parameters used to calculate the productivity on burrows and in the steppe-matrix a) under grazing, and b) protected from grazing and subsequently the factor by which productivity is enhanced on the burrows. Note that the vegetation cover outside cage (%) on burrows is estimated. See text for details.

in detail in the methods section 4.2.8, p. 159. Table 4.5 shows the parameters for the grazed and ungrazed treatments, respectively.

These calculations estimate a maximum standing crop under grazing of 129.1 kg/ha on burrows and of 47.6 kg/ha in the steppe-matrix. Thus the "corrected" standing crop on grazed burrows is still by the factor 2.7 higher than on the steppe-matrix. This results in an increase of 13 % of standing crop in the steppe due to pika burrows.

The calculation of ANPP under protection from grazing is more problematic because the parameter "vegetation cover outside cage (%)" is not known for burrows. As it is technically not feasible to fence off a whole burrow including all entrances, it is necessary to approximate the missing value. To estimate this parameter we have to rely on indicators. These are

1. In the steppe-matrix vegetation cover is about 2 times higher under protection from grazing than under grazing.
2. The vegetation cover inside the cages on burrows is about 2 times higher under protection from grazing than under grazing.
3. Under grazing vegetation cover outside the cages is 1.7 times higher on burrows than in the steppe-matrix.

The average vegetation cover outside the cage on ungrazed pika burrows when applying these indicators is 22.6 %. This value is inserted in table 4.5, and written in italics.

Production without grazing on pika burrows therefore is 535 kg/ha and in the steppe-matrix 184 kg/ha. ANPP is 2.9 times higher on the burrows and this increases the overall production of the steppe by 14 %. This is a rough estimation only as explained above, but it seems to be reasonable. Even under the most conservative calculation, when we assume the vegetation cover on burrows without grazing to be the same as in the steppe-matrix, production on the burrows is still enhanced by the factor 1.62, resulting in a 5 % plus of production in the steppe.

Productivity per percent vegetation cover is higher on the burrows, and burrows have been shown to carry a higher cover of vegetation than the steppe-matrix does (fig. 4.2, and fig. 4.3). Thus we can conclude that the size of the effect is still not known exactly, but a proper context is established, which shows that pika burrows indeed are more productive than the surrounding steppe-matrix.

4.3.5. Plant development

Figure 4.7 shows the phenological development of *Allium* spp., *Stipa* spp., and *Agropyron cristatum* on burrows and in the steppe-matrix under grazing. The phenological development of plants is not necessarily linear under grazing. Grazing herbivores disturb growth by removing phytomass and as a reaction the plant may grow new shoots, which of course have to start their development anew. Therefore grazing may alter the phenological status of the grazed plant species.

The development of *Allium* spp. is most rapid, that of *Stipa* spp. intermediate and that of *Agropyron cristatum* the slowest of the three investigated species (figure 4.7). The plants are presumably best digestible for livestock when they are in a young, growing state, because during senescence the plant relocates proteins into seeds and below ground (Larcher, 1994). As the plant is fully developed at development stage 6 (table 3.1) the most preferable stages are values next to 6 or lower.

Two general tendencies can be observed for all three species:

1. at the beginning of the vegetation period phenological development seems to be faster on the burrows. Especially the high valued forage plant *Agropyron cristatum* starts growth on pika burrows already in March, while no growth can be detected in the steppe-matrix at this time. *Agropyron cristatum* and *Stipa* spp. are further developed on the burrow in May, *Agropyron cristatum* and *Allium* spp. in June. These findings are supported by repeated observations of livestock (especially cattle) focusing on pika burrows for grazing in spring. They deliberately went from one burrow to the next without grazing the area in between.

2. Species on the burrows remain in a ”better” state towards the end of the vegetation period. They tend to get senescent more slowly on pika burrows than in the steppe-matrix. Therefore they probably provide a better digestibility and thus a higher forage quality on the burrows. From August on *Allium* spp. is continually in a more preferable state on the burrows, while this applies to *Agropyron cristatum* and *Stipa* spp. only in August.

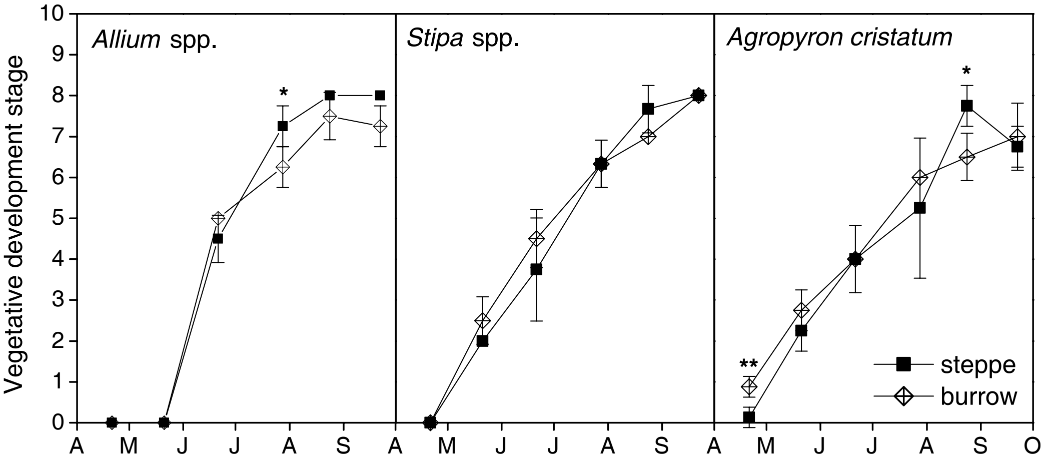


Figure 4.7.: Comparison of the phenological development of three important forage species on pika burrows and in the steppe-matrix under grazing. Values are means of the four replicates of the exclosure experiment, error bars indicate the standard deviation. Significant differences are indicated by stars.

Only few of these differences are statistically significant, these are marked in figure 4.7. This is a problem of the low number of samples which are obtained by estimating the average phenological development over one 1 m^2-plot. It would be preferable to estimate phenological development of e.g. ten or twenty individuals as it has been done for the plant height estimation.

Nevertheless, we can conclude that pika burrows support an earlier inset of vegetation growth in spring which is statistically significant for *Agropyron cristatum* (p=0.005), but the tendency can be seen for *Allium* spp., and *Stipa* spp. as well. This early growth provides valuable forage especially for emaciated livestock in the most critical time of the year.

4.4. Discussion

4.4.1. The function of pika in the ecosystem

As described in the introduction to this chapter (p. 153), pest and ecosystem engineer are labels from two different categories and therefore it does not make sense to ask whether they are pests **or** ecosystem engineers. The question of the function of pika within the ecosystem has to be dealt with under both different aspects. The first aspect will be whether they are ecosystem engineers sensu Jones et al. (1994). Secondly pika's direct and indirect influence on livestock is summarized in order to evaluate the function of pika from a herder's point of view.

Table 4.6 summarizes the main direct (1–4) and indirect effects (5–11) pika potentially have on their abiotic and biotic environment as proposed in the introduction. This is the basis to evaluate pika's possible status as ecosystem engineers and to assess their impact on livestock.

Investigation methods of pika activities

	pika activity		investigation method
1	digging	y	burrow characteristics, observation
2	collecting hay	y	observation, literature
3	collecting dung	y	dung collection, observation
4	defecation on burrows	y	observation

	results of pika activity		
5	nutrient concentration on burrow	y	consequence of 1-4
6	increase infiltration capacity	?	not yet investigated
7	burrows as water traps	?	not yet investigated
8	higher water availability	n	2001 lower water content on burrows
9	higher nutrient availability	y	soil analysis
10	changes in phenological development	y	phenological observations
11	higher plant productivity	y	small cages

Table 4.6.: List of proposed and observed pika activities and their effects on biotic and abiotic environmental parameters as investigated in this study. The third column indicates whether the proposed effect could be shown (y=yes, n=no, ?=not directly investigated) and with which method of investigation (fourth column).

Are pika ecosystem engineers?

According to the definition by Jones et al. (1994) pika are allogenic ecosystem engineers, because they modulate the availability of nutrients and thus influence primary productivity and plant phenological development (table 4.6). Through the concentration of nutrients on their burrows they modulate the temporal and spatial distribution of phytomass. This has a feedback effect on the forage availability of other herbivores, including livestock.

Although it is relatively simple to show the effects of altered nutrient availability on the burrows and its feedback on primary productivity, it is extremely difficult to quantify the impact. This can be done only by a relative description using the six criteria Jones et al. (1994) proposed to quantify the impact of engineers (see introduction, p. 153):

1. **Life time per capita activity of individual organism:** From our observations the digging activity of a single pika is not extremely high. They seem to repair and extend their burrows slowly. The burrows are used constantly. They do not abandon them and dig new ones frequently, as the Brandt's vole does.

2. **Population density:** Average population density is around 30 pika per hectare (Nadrowski et al., 2002).

3. **Spatial distribution of the population:** The Mongolian Pika is characteristic for the mountainous areas of the Gobi Gurvan Sayhan National Park (Kaetzke & Traglauer, 1998; Mongolian Atlas, 1990; Retzer & Nadrowski, 2002). In the Dund Sayhan they do not occur in regions lower than 2200 m (Nadrowski et al., 2002).

4. **Length of time the population has been present at a site:** This question is hard to answer. According to interviews with the herders they must have been there at least for 1-2 human generations. But this is an extremely conservative minimum estimate. As Central Asia is the center of origin for lagomorphae and therefore also pika (Schneider, 1988; Thenius, 1980), they may have inhabited the area for thousands of years.

5. **Durability of the constructs, artefacts, and impacts in absences of the original engineer:** Few cases of uninhabited burrows can be observed in the Dund Sayhan. Therefore any statement on the persistence of burrows remains speculative. On the lower limit of the present distribution of pika some areas with slightly altered vegetation approximately the size of a pika burrow can be seen. But it is not known whether these structures have indeed been created by pika, and if so, when they were abandoned. In the summit region of the Nemegt Uul there are uninhabited pika burrows (K. Nadrowski, pers. comm.). But here also nothing is known about the time when pika became extinct there, and for how long the burrows have persisted.

6. **The number and types of resource flows that are modulated, and the number of other species dependent upon these flows:** This question can be preliminarily answered by the facts presented in this study. Pika at least modulate nutrient distribution and by doing so increase the phytomass on their burrows and the time of availability (Wesche et al., 2003). Practically all other herbivores within the ecosystem can make use of that, but none depends on it.

As the Mongolian Pika has not been investigated more intensively, quantifying its impacts remains somewhat vague. Further studies may contribute to a better understanding of the quantitative effects of pika, but for now it seems safe to conclude that the Mongolian Pika has considerable impact on the mountain-steppes within the Gobi Gurvan Sayhan National Park.

Are pika pests?

After clarifying pika's status as ecosystem engineers, their impact on the herders via their livestock has to be evaluated. Here the different positive and negative indirect impacts of pika on livestock have to be weighed against each other. Therefore any judgement will be biased by the emphasis which is assigned to every single of these influences. In order to classify pika's status more objectively they are compared with three other (groups) of herbivorous small mammals which inhabit steppe ecosystems. These are the prairie dogs (*Cynomys* spp.), because they have been intensively investigated in North America, and two other species which have their center of distribution in the steppes of Central Asia, the Brandt's vole (*Microtus brandti*) and the Daurican Pika (*Ochotona daurica*). All these species have been or still are considered to be pests and all are or have been subject to eradication programs with poisoned baits.

Six aspects which can be used as criteria to evaluate the status of these species are:

1. An estimation of the area directly affected by the digging activities of the small mammals (burrows, colonies), which serves as indicator for the severity of the impact caused by the species considered.

2. The forage competition with livestock or other large herbivores, most frequently derived from the evaluation of species overlap in the dietary composition of the large and the small mammal.

3. The influence of the small mammal on the productivity of the vegetation in the area of their immediate influence (burrow, colony). This is especially difficult to assess as most studies only measure standing crop under grazing but not productivity inside fenced plots.

4. The change in phenological plant development on burrows or colonies of the small mammals. This detail seems to have escaped the attention of other scientists as no previous studies focusing on this subject could be found for any of the four species.

5. The devastation by digging, especially caused by frequent reestablishment of burrows and abandonment of old ones, determines the degree of disturbance by small mammals. A high disturbance rate should be detrimental to the establishment of perennial plant cover and therefore decrease productivity.

6. The tendency of the species to mass population outbreaks. This is just one reference to the importance of the population ecology of these species for their impact on the ecosystem. This aspect will be dealt with further in a PhD-thesis by K. Nadrowski.

Table 4.7 compares the Brandt's vole, prairie dogs, the Daurican Pika and the Mongolian Pika under these aspects. The Brandt's vole, prairie dogs, and the Daurican Pika share two common features which probably are the main reasons why they are regarded as pests. This is their abundance – all of them inhabit considerable areas – and the dietary overlap with livestock. These two features seem sufficient to consider a species as a pest. The Mongolian Pika fits very well into this blueprint.

However, this line of thought disregards other, less obvious, interactions with large herbivores. For example it is often believed that the presence of herbivorous small mammals automatically reduces the forage availability for livestock. But the possibility that small mammals may act as "gardeners" on their burrows, and may actually increase forage production, is often overlooked. Many studies measure a lower amount of standing crop on burrows or colonies and generalize from these data that productivity is lower at these sites. But sites with lower actual standing crop may still have a higher productivity, because standing crop is a function of both, productivity and consumption. Exclosures of all herbivores on burrows would be necessary to answer this question. But no such experiment conducted on the burrows of the Brandt's vole or the Daurican Pika, or on colonies of prairie dogs could be found in the literature.

Before the Mongolian Pika will be classified as a pest, the main reasons for the classification shall be summarized for the three species which serve as comparison. The perception of the Brandt's vole at large is a strictly negative one. Apart from forage competition this is especially related to its potential for massive population outbreaks and their habit of devastating the landscape by constantly digging new burrows (Samjaa et al., 2000; Shi et al., 2002; Zhang et al., 2003c). The Brandt's vole seems to benefit from overgrazing, possibly because in a less densely vegetated environment it can spot predators more easily (Samjaa et al., 2000).

The perception of the Daurican Pika is based on the forage competition with livestock (Shi et al., 2002; Zhang et al., 2003b,c), although other authors do not regard them as competitors for livestock (Guriceva, 1985). It has been proposed that their density increases with grazing impact, too (Zhong et al., 1985a). But a recent study to the contrary shows that their density actually decreases with grazing impact (Komonen et al., 2003). These differences result in different judgments on their status. While many authors regard the Daurican Pika as a pest (Zhang et al., 2003c), others perceive them as neutral with respect to livestock growth and even hint that they may play a role as keystone species (Komonen et al., 2003). Further investigations seem to be necessary to clarify this matter.

species feature	Brandt's vole *Microtus brandti*	Prairie dogs *Cynomys* spp.	Daurican Pika *Ochotona daurica*	Mongolian Pika *Ochotona pallasi*
area affected	1.6-10 %^{b}, 5.6/ha^{a}	6-12 %^{j,m}	7 %? (26.5/ha)^{i}	7-12 %^{u,w} (-33/ha)^{w}
forage competition	yes^{a,b,c}	yes^{j}	yes^{f,g,h}, no^{e,i}	yes^{v,u}
effect on plant productivity	decrease^{b,d}	decrease^{j,k}, none^{l}	increase^{r}	increase^{u,t}
effect on plant development	?	?	?	earlier^{u}
devastation by digging	high^{e}	medium^{k}	low^{i}?/high^{t}	low^{u,w}
population outbreaks	frequent^{b,f}	not reported	not reported	not likely^{w}
poisoned?	yes^{f,g,h}	formerly yes^{n}	yes^{f,g,h}	yes?^{x}
perception today	pest^{b,f,h}	keystone^{j,m,o,p,q}	pest^{h,s}-neutral^{i}	no pest^{u}

Table 4.7.: Review of the indirect impact of four small mammal species on livestock used to assess their possible status as pests. References: a) Wang et al. (2001), b) Samjaa et al. (2000), c) Zhong et al. (1999) in Shi et al. (2002), d) Zhong et al. (1985b) in Wang et al. (2001), e) Guriceva (1985), f) Shi et al. (2002), g) Zhang et al. (2003b), h) Zhang et al. (2003c), i) Komonen et al. (2003), j) Krueger (1986), k) Coppock et al. (1983a), l) Whicker & Detling (1988), m) Coppock et al. (1983b), n) Miller et al. (1994), o) Stapp (1998), p) Kotliar et al. (1999), q) Fahnestock & Detling (2002), r) Tsendzhay (1985) cited in Smith & Foggin (1996) s) Zhong et al. (1985a), t) Miehe (1996, 1998), u) this study, v) Wesche et al. (2003), w) Nadrowski, K. unpublished data, x) Smith & Foggin (1996).

North American prairie dogs are an especially well investigated example for the change in the perception of a small mammal in the eyes of humans. They were classified as pests and subsequently the main target of eradication programs over the last century (Kotliar et al., 1999). These efficiently reduced the numbers of e.g. the black-tailed prairie dogs by 98 %, so that they are now a designated candidate for listing under the Endangered Species Act (Winter et al., 2002).

After the eradication of a considerable amount of the population, investigations on the prairie dogs and their interactions with their biotic and abiotic environment intensified. Nowadays they are considered to play a keystone role in the North American prairie (see Kotliar et al., 1999; Stapp, 1998, and references therein). They have been shown to influence plant species diversity, functional composition of the vegetation and nutrient dynamics and ameliorate biological activity on their colonies (Coppock et al., 1983a), and thus may also qualify as ecosystem engineer. As a result they facilitate grazing of large herbivores (bison and pronghorn) on their colonies (Coppock et al., 1983b; Krueger, 1986): "during midsummer, prairie dog towns were one of the most frequently used habitats by bison parkwide" (Coppock et al., 1983b, p. 10).

According to the data available the Mongolian Pika fits between prairie dogs and the Daurican Pika. Its burrowing intensity is low. Mongolian Pika on the one hand compete for forage with livestock. But on the other hand approximately 20 % of all vegetation grows on pika burrows and about 11.5 % is forage which grows only because of the good growing conditions on the burrows (table 4.5, p. 170). So a considerable amount of pika's forage grows on its own burrows, and provides forage for livestock there as well (Wesche et al., 2003). The same relationship has been shown for prairie dogs and bison (Detling, 1998).

Also the earlier development of vegetation on the burrows in spring is of an importance which should not be underestimated. During this time of the year livestock is weakest and the rate of death is highest. Any additional forage at this point may save an animal until the rains set in and it may recover from a bad year. To summarize, the Mongolian Pika cannot be regarded as a pest, because its detrimental effects on livestock are counterbalanced by beneficial ones.

The function of pika

Pika's known and proposed impact on the water and nutrient availability on their burrows and subsequently on plant productivity are summarized in figure 4.8. This model of pika's influence still includes several hypotheses which require further studies.

It was hypothesized that pika increase the water availability in two ways. By building a burrow they create a structure which may act as water trap for runoff water during high intensity rains. Their digging activity also loosens the earth and thus may increase infiltration capacity on the burrows. All these proposed features did not take effect in the summer of 2001 due to the lack of sufficient rain. On the contrary, the burrows showed a tendency to lower water content than the steppe-matrix (fig. 4.5 d), p. 167). This can be explained with the improved air circulation through the tunnel system of the

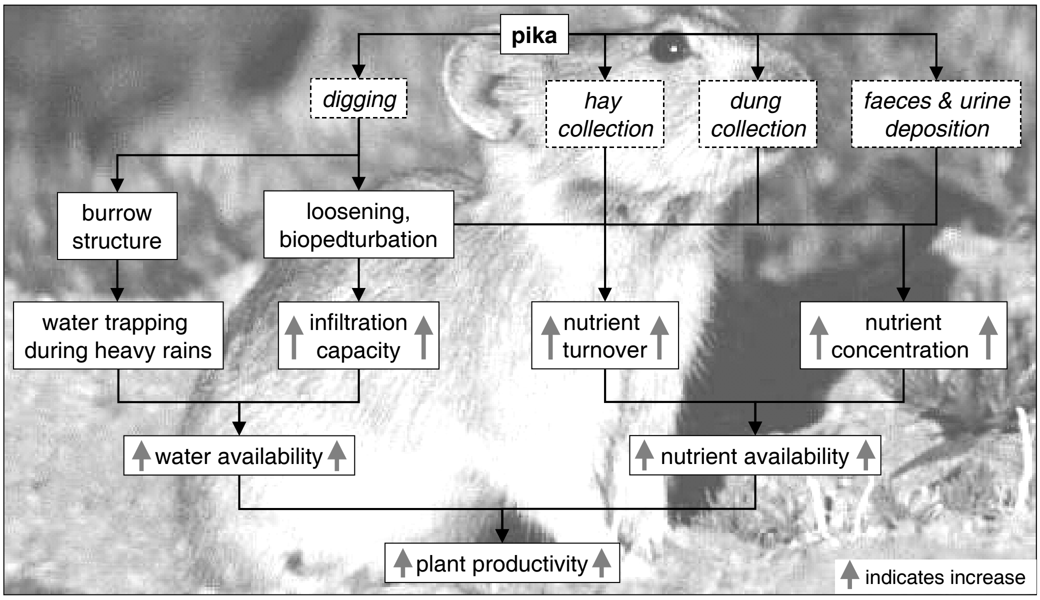


Figure 4.8.: Model of the effects of pika activities on the nutrient and water availability on their burrows.

burrows which leads to a drying out of the soil in comparison with the steppe-matrix. Depending on the predomination of either effect, air-circulation or better infiltration, water availability on the burrows is either always lower or it shows much more extreme inter-annual fluctuations: drier in drought years and wetter in average to wet years. Further investigations into this point are carried out by K. Wesche and coworkers.

On the other hand extraordinarily strong rains also have negative impact on pika. When high surface runoff occurs after heavy rains, the burrows can get filled with water so that pika either drone or are forced to leave their burrows and are easy catch for any predator. Miehe (1996) reports that after a torrential rain in 1996 pika density was reduced so effectively that compared with the formerly ubiquitous whistling of the animals the steppe appeared absolutely silent.

Apart from the effect on water availability, biopedturbation by digging may also have positive effects on the decomposition of litter, because it improves the abiotic conditions for decomposers. This makes pika burrows microsites of intensified biological activity. Three other activities of pika lead to a concentration of nutrients on the burrows: hay making, dung collection and the deposition of faeces on the burrow all result in a transfer of nutrients from the steppe-matrix towards the burrow.

Many of these interactions could not be investigated directly yet, but similar mechanisms have been reported by Tsendzhay (1985, cited in Smith & Foggin 1996). Further investigations will clarify these questions. Especially a quantification of the effects on nutrient and water availability would help in assessing pika's status as ecosystem engineers.

4.4.2. Open questions

Dynamics of burrow creation and decay

At the moment next to nothing is known about the mechanisms of burrow creation or destruction. The dynamic of burrow densities has not been investigates previously. As the number of burrows per hectare play an important role in the control of the population size, it is important to obtain more information on the question which parameters regulate the densities of burrows. Possible parameters are the "diggability" of the substrate, the occurrence of hiding-places, and phytomass production around the burrow.

Moreover, it would be interesting to determine whether the limiting factor in different altitudes is abiotic, as mentioned above, or biotic, caused by social interactions of pika themselves. Density dependent biotic parameters include social stress caused by territorial behavior and higher mortality caused by the transmission of parasites and diseases. The altitudinal transect with increasing precipitation and plant productivity with altitude provides an excellent setup for investigating these kinds of question because the factors may change along the transect.

The observation of pika activities has shown that the activities of pika are very much confined to the immediate surroundings of their burrow (Monkhzul, unpublished data, in Retzer & Nadrowski, 2001). This includes hay collection, dung collection, and defecation as well as their digging activities. The clear differentiation between burrow and steppe-matrix is therefore basically self-induced. Burrows probably remain constantly in the same place because of the explicit territoriality pika show (Nadrowski et al., 2002; Schneider, 1988). This in turn allows the accumulation of the impact of many generations of pika on one burrow. This may be the reason why the differences between burrow and steppe-matrix are so clearly visible.

Vegetation on burrows

The evidence of the phenological development of important forage species on and off the burrows suffers from methodological weaknesses (see chapter 4.3.5, p. 171). A better experimental setup is needed to answer this question in detail. Instead of estimating the average phenological development of one species on 1 m^2, repeated values from e.g. 20 individuals on and off the burrows would be needed. Also the sampling should take place at a higher frequency than once a month.

Further and thorough investigations on the botanical composition on pika burrows are on the way. They will answer to which extent pika influence species composition and diversity. Possibly pika burrows also are a suitable habitat for other animals. They provide nesting places for birds such as the Isabelline wheatears (*Oenanthe isabellina*) or snow finches (K. Wesche, pers. comm.) as has already been shown for the burrows of Daurican Pika (Smith & Foggin, 1996). No literature could be found on the effects of the Mongolian Pika on other animals, thus leaving much space for further research.

What is the limitation? Nutrient versus water limited ecosystem

As has been shown above, pika burrows are more productive than the steppe-matrix, and plants on pika burrows start their phenological development earlier in the year. Especially higher productivity is believed to be related to higher water availability in arid ecosystems or to higher nutrient availability in more humid ecosystems (see Hooper & Johnson, 1999). The limiting factor determines vegetation growth, and in semi-arid regions this is mainly believed to be the availability of water. For arid ecosystems it has frequently been shown that plant production responds directly to plant available moisture (e.g. Jingyun Fang et al., 2001; Lauenroth & Sala, 1992; Milchunas et al., 1994; Sala et al., 1988b).

In this context pika burrows serve as a sort of natural experiment. As proposed above, they may have a higher water availability during many years, but in 2001 water availability was not higher on burrows than in the steppe-matrix. Nevertheless plant productivity was higher on the burrows. The higher plant productivity can therefore only be attributed to the higher nutrient availability on the burrows, but not to higher moisture availability. This is in agreement with the findings of Hooper & Johnson (1999) who in a literature review show that primary productivity under semi-arid to sub-humid conditions (200-1100 mm APPT) is co-limited by water and nitrogen availability. The results from this study support these findings and show that even in an even drier ecosystem during an extremely dry year phytomass production is not only triggered by water availability but also co-limited by nutrient availability. This also indicates that the steppe-matrix is nutrient deficient. Furthermore, this may explain the relatively low values for the rain use efficiency of the steppe-matrix as derived from the exclosure experiment (see chap. 2.3.3, p. 101ff).

4.5. Summary

Pika change the environment on their burrows by digging, hay and dung collection, and defecation. This results in a higher productivity of the burrows in comparison with the surrounding steppe-matrix. This in turn, has important consequences for the forage availability for livestock. The burrows offer the first fresh forage in early spring and produce more phytomass than the surrounding steppe-matrix.

The effects of pika presence on livestock are therefore more complex than simple forage competition and therefore pika should not be regarded as a pest. Further research is necessary to assess the positive and negative effects of pika for herders. However, it is certain today that pika play an important role in the mountain-steppes of the Gobi Gurvan Sayhan and can be regarded as ecosystem engineers sensu Jones et al. (1994).

5. Model of pika and livestock carrying capacity

5.1. Introduction

As presented in the previous chapters, the field data provide valuable information on the interactions among pika, livestock, and herders and on the function of pika in the ecosystem. But although the field work extended for more than a year, the data are only representative for the special situation in 2001 – a year of extreme drought. Therefore the findings cannot be extrapolated to other years with a different rainfall regime. A mere extension of the investigation period cannot solve this problem either, as every other year of investigation would face the same difficulty: any given year represents only the special situation of the specific year and in a non-equilibrium system no single state is characteristic for the system, but the variation of states is the fundamental characteristic (see also chapter 1.2.4, p. 34).

Ecological modelling offers a possibility to bypass this dilemma: models can be based on the understanding of processes rather than on simple linear extrapolation of figures from a limited period of time (Jørgensen, 1988). Especially the mismatch between observation times and the scale of changes on the ecosystem make it difficult to understand the long-term dynamics (Wiegand & Jeltsch, 2000; Wiegand et al., 1995). Ecosystem processes can be observed, and are valid, under any given situation – also under a year of drought. Process-orientated modelling makes use of this knowledge. If the processes are understood correctly and implemented in the model, modelling can provide an estimation for the parameters under multiple states (such as a time-series), all of those never could be investigated directly in the field due to the lack of time and manpower (Fishwick, 1995). Secondly process-orientated models remain valid even under changing external conditions such as climate change or transformation. Both situations, the extension in time and changing external conditions, belong to the classical applications of models (Bossel, 1994). Furthermore, such models provide a sound framework to identify trends of pasture development and to develop appropriate management strategies White et al. (1996).

In this study the data from the previous chapters plus data from Karin Nadrowski et al. (2002) are used in order to test the results from the field and to achieve a better understanding of the system. With the help of the model the findings from the investigation period can be generalized. This makes it possible to assess long-term carrying capacity, as well as the impact of transformation and possible threats of climate change.

The model comprises data from the poorly represented, less intensive pastoral systems which should be studied more intensively to achieve a synthesis of global change effects on pasture and rangeland production as has been called for by Campbell & Smith (2000).

This chapter is based on a manuscript compiled in cooperation with C. Reudenbach (Retzer & Reudenbach, submitted).

5.1.1. Field data collection

The field data for this study were gathered within the mountain-steppe of the Gobi Gurvan Sayhan National Park in southern Mongolia (see chap. 1.4, p. 53ff). Data were collected during the investigation period from June 2000 to September 2001, and again in June and July 2002 (Nadrowski et al., 2002).

The data on pika were gathered using a regular live-trapping scheme with Sherman-traps and observation of the animals on 1 ha near the research station in about monthly intervals. Data from the trapping were used for the calculation of pika numbers and their reproductive potential. Burrow creation and decay was followed on one marked burrow over two consecutive years Nadrowski, K., unpublished data). Data on burrow densities and burrow area were recorded by mapping and measuring out more than 40 burrows (p. 162). Livestock densities were observed from an elevated observation point (p. 82).

The production of phytomass was assessed by means of an exclosure experiment (see chapter 2.3.3, p. 101). Data collection took place in approximately monthly intervals. This experiment was used to calculate pika requirement, pika's competitive advantage, rain use efficiency of the vegetation, and the amount of phytomass which could be harvested by the scientist, but was not accessible to the animals (30 kg/ha). Similar exclosure experiments on pika burrows were used to assess the influence of pika's digging activity on vegetation productivity (p. 168). Additionally, information was gathered from interviews with local herders and by participatory observation.

Basically all data on pika, pika burrows, and pika behavior were collected by Karin Nadrowski, whereas data on vegetation productivity, forage competition, and livestock densities were collected by the author unless otherwise indicated. Further information was acquired from the literature, especially an array of statistical yearbooks on the Mongolian agriculture provided useful information on the development of the livestock sector (National Statistical Office of Mongolia, 1996, 1998, 2000, 2001, 2002). The precipitation data for Dalandzadgad from 1937-2002 were derived from the Meteorological Service of Mongolia. The data up to 1999 can be found in Bergius (2002), those for 2000-2002 were obtained directly from the Meteorological Office in Dalandzadgad within the project. Long-term precipitation data for the period 1651-1995 which were reconstructed from tree ring studies in northern Mongolia could be used for validation and to check the long-term stability of the model system (Pederson et al., 2001b).

5.2. Modelling technique

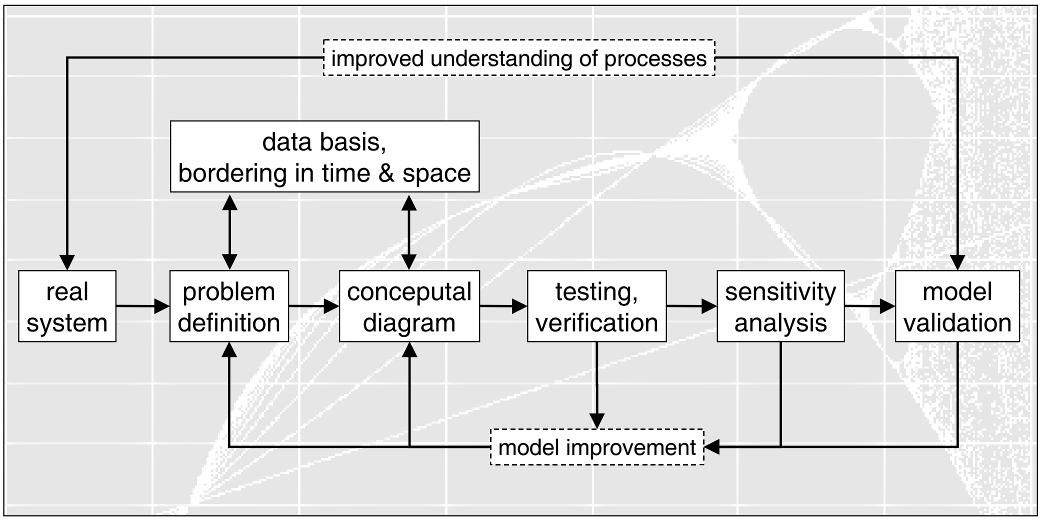


Figure 5.1.: Flow chart showing the iterative modelling procedure. Adapted from Jørgensen (1988) and Bossel (1994).

Models are nothing else but simplified images of the environment. Actually what we see every day is a model of ”reality”. As we are not able to process all information alike we have to pick the most relevant information and concentrate on that within any given situation. The same is true for models: the focus of the model determines which parameters are important and have to be incorporated (Jørgensen, 1988).

Building models therefore is always a simplification of the real system, and the crucial point is to identify the processes relevant to the system and implement them in a logically right and valid way. Modelling is the art of selecting the appropriate parameters from an infinite number of possible parameters and resisting the temptation of including any other than those necessary in the model. With other words the model has to be as complex as necessary but as simple as possible (Bossel, 1994).

The modelling procedure is always an iterative process (Jørgensen, 1988). Figure 5.1 shows a flow chart-model of the different steps of model creation. First of all, the problem has to be defined as accurately as possible. This results in a conceptual model, e.g. a word model or a box chart diagram, which depicts the main interactions within the model. An important element in the model formulation is the delimitation in time, space and focus. The model aim and the conceptual model have to be adjusted and readjusted in the process of model creation according to the quality of available data. If data of good quality are not available, it is advisable to keep the model more simple than to rely on insufficient data. After a setup of the first model this has to be tested and then analyzed for sensitivity. Each of these steps can uncover weaknesses of the model, which make further adjustments necessary, and afterwards the steps of testing and sensitivity analysis are performed over and over again. Last but not least, the model is validated against an independent data set (Bossel, 1994; Jørgensen, 1988).

5.2.1. Problem definition & conceptual diagram

The following questions which arose from the fieldwork served as guidelines to define the aims of the model and to focus the model by delimiting it from other desirable features:

1. How strong is the impact of competition between pika and livestock for both sides? Is the coexistence of pika and livestock in the long-term possible?

2. Are the high numbers of livestock after the transformation only a result of a series of relatively good years, or did the herding strategies change?

3. What can we learn about the long-term carrying capacity of the system?

4. May the model be used as a tool to investigate potential impacts of climate change on the carrying capacity?

The model should be capable of projecting the dynamics and the interaction of the densities of small wild (pika) and large domestic herbivores (livestock) which are qualitatively and quantitatively valid.

The most important parameters are the production of phytomass, and the consumption of phytomass by small and large herbivores. The semi-arid mountain steppe of the Gobi Gurvan Sayhan National Park is driven mainly by non-equilibrium dynamics (see chapter 1.3.3, p. 52). Therefore the development of phytomass is directly dependent on the annual precipitation (Sala, 2001; Sullivan & Rohde, 2002; Wu et al., 1996). As semi-arid systems typically have a short 1-year energy cycle, no phytomass is carried over from the previous year (Schultz, 1995, p. 274f). The population density of pika (*Ochotona pallasi*) is restricted by their territorial behavior (Chapman & Flux, 1990; Nadrowski et al., 2002; Schneider, 1988), reproduction rate (Nadrowski, unpublished data, Schneider, 1988; Smith et al., 1990), their specific competitive advantage (Hulbert & Andersen, 2001, see p. 111), and forage availability. Predation on pika is not explicitly included in the model, but summarized under the variable territoriality death, because pika without burrow are easily caught by predators. Pika burrows are more productive than the surrounding steppe and increase overall productivity (see p. 168 and Wesche et al., 2003).

The different kinds of livestock are not modelled separately but are converted into livestock units (Mongolian Sheep Units). The densities of domestic herbivores are mainly controlled by the management decisions of the herders. Herders follow an opportunistic management strategy: they try to optimize (= maximize numbers, while minimizing losses) their livestock numbers by adapting their migration strategies to forage availability (Illius et al., 1998; Dean & Macdonald, 1994; Ward et al., 1998). Livestock numbers are further regulated by the reproduction rate (Abel & Blaikie 1990; Georgiadis et al. 2003; Livingstone 1991; Scoones 1990, in Scoones 1993b), slaughter rate, and death of starvation (Dean & Macdonald, 1994; Georgiadis et al., 2003; Scoones, 1993a). The factor of water availability for livestock can be neglected because a sufficient number of

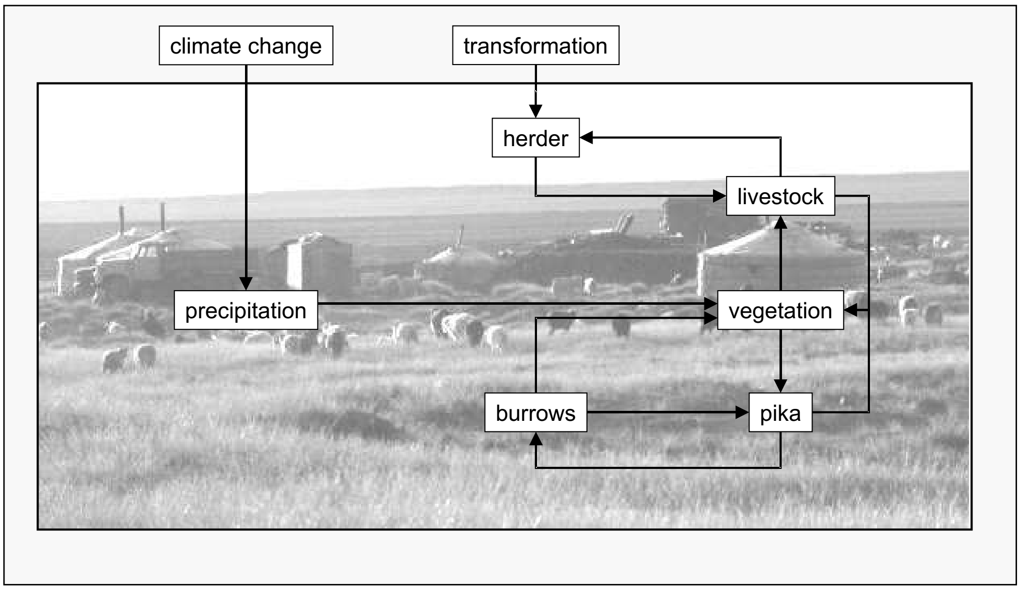


Figure 5.2.: Conceptual model as a box diagram. The inner frame marks the border of the model. The model may give some answers on the impact of the outside variables climate change and transformation.

wells and springs is available within the investigation area (Schmidt, 2000). The role of livestock diseases is regarded a minor one and therefore not modelled explicitly.

Livestock and pika have different foraging strategies: while pika can exploit a higher percentage of the available phytomass on the site due to their smaller size (Farnsworth et al., 2002; Hulbert & Andersen, 2001), livestock can avoid severe forage shortages by movement to better pastures. Figure 5.2 shows the graphical illustration of the conceptual word model as a box diagram.

5.2.2. Resolution in time and space

The timely and spatial resolution has to be adapted to the available data. Within the field work of this study most data were available in monthly intervals. But as most other necessary data such as precipitation and livestock figures for calibration and validation are mainly available on an annual basis, the timely resolution was set to 1 year. This has important consequences for the structuring of the model: it implies that all processes which operate on a shorter time scale have to be included as balanced variables.

As the main objective of the model is to understand the situation of competition in an arid mountainous area, the model was not constructed spatially explicit, but the model area was standardized to one hectare. This is an appropriate spatial dimension because most data from the field work were available per hectare, and other data sources could easily be converted if necessary. The model thus does not include any gradients such as the altitudinal gradient in precipitation and is not spatially explicit.

5.2.3. Sensitivity and validation of the model

The validity of the model is assumed to be met under qualitative aspects, when over a period of 50 years a stable system can be reproduced. Stability in this context does not mean constant population numbers but that firstly, the population numbers vary within reasonable numbers and secondly, that none of the populations becomes extinct. Quantitative validity is met when the population densities and phytomass production under drought conditions are close to those observed during the field campaign. Furthermore the balance of migrating and remigrating livestock was analyzed in order to implement a sound opportunistic migration strategy.

Sensitivity analysis of the critical parameters was performed and used to improve the implementation of the model. Monte Carlo simulations (=multivariate sensitivity simulations), were used to perform the sensitivity analysis. If not specified otherwise 1000 simulation runs were made when one parameter was varied, and correspondingly more if more parameters were included in the sensitivity test. Parameters were generally varied according to a random uniform distribution. The results of the most critical parameters and an interpretation of the reaction of pika and livestock densities to changes in these parameters will be presented in the discussion (chapter 5.4, p. 199).

The model was validated with the modified long-term precipitation data derived from tree rings in northern Mongolia (Pederson et al., 2001b). As the level of precipitation is much higher there, the absolute data could not be used. Therefore the data were transformed to match the average annual precipitation in Dalandzadgad.

5.3. Model description

This chapter will explain the set-up of central sub-models: the precipitation and phytomass dynamics, the implementation of competition, and the dynamics of the regulation of the populations of pika and livestock.

The model simulates the functional response of competition between two groups of herbivores. Basically the model is driven by the precipitation dynamics which produce a specific amount of vegetation biomass each year. Then vegetation biomass is split up between the two groups of herbivores. Apart from the forage in competition both the groups have mutually exclusive access to some forage. Pika have an ubiquitous competitive advantage, due to their smaller size and the possibility to dig for below-ground phytomass (own observation), while the large herbivores benefit from the optimization strategies of pasture management by the Mongolian herders.

The model was constructed under the following assumptions:

- All used variables and constants are standardized to the area of one hectare (ha) and the time of one year (yr).
- There are no explicit spatial or temporal activities of the actors.
- All simulated stocking rates of livestock are expressed in numbers of Mongolian Sheep Units (MSU).

Tables 5.1–5.4 provide all variables and constants used in the model.

5.3.1. Production of vegetation biomass

The ecosystem of the mountain-steppe in southern Mongolia is assumed to behave basically as a non-equilibrium system (see Behnke et al., 1993; Fernandez-Gimenez & Allen-Diaz, 1999; Sullivan, 1996). This implies that vegetation growth is triggered by precipitation. Therefore the production of vegetation biomass is considered as a linear function of the annual precipitation (Sims & Singh, 1978; Sullivan & Rohde, 2002). As pika burrows are covered with denser vegetation and are more productive than the steppe-matrix, the area has to be split into two zones of productivity: burrow area (B_A) and steppe-matrix area (S_A). Net area fraction of burrow and steppe vegetation is determined by:

$$B_A = B * b \tag{5.1}$$

$$S_A = 1 - B_A \tag{5.2}$$

Pika burrows are by the factor bV more productive than the steppe-matrix (p. 170). Therefore overall rain use efficiency RUE is calculated from the rain use efficiency derived from the field experiments for the steppe-matrix ($rueS$, p. 101) by:

$$RUE = rueS * (S_A + B_A * bV) \tag{5.3}$$

A constant amount of vegetation biomass per hectare can be harvested by the human researcher but cannot be consumed by any of the herbivores (v, p. 104). This amount of phytomass has to be subtracted from the produced phytomass in order to get the available or net vegetation biomass production V:

$$V = RUE * R - v \tag{5.4}$$

5.3.2. Competition

As outlined in chapter 2, pika and livestock show different strategies of optimizing their forage supply. This results in a specific forage demand and acquisition strategies of both consumers. The core idea of the implementation of competition is therefore based on the forage demand of pika (p. 112) and livestock (MSU), respectively. It can be expressed as the potential consumption ratio (PCR): the ratio of forage demand and net vegetation biomass. In order to derive a dimensionless characterization it is standardized according to:

$$PCR = \frac{F_P + F_L - V}{V} \tag{5.5}$$

The average PCR ($=\overline{PCR}$) of the last two years is then:

$$\overline{PCR} = \frac{PCR_t + PCR_{t-1}}{2} \tag{5.6}$$

PCR is used as a binary decision whether or not both populations have access to a sufficient amount of forage to satisfy their needs. Hunger and therefore also competition will occur if PCR is greater than zero. Consequently animals will starve if other adaptation opportunities such as hay stocking or migration prove inefficient to make up for the missing forage. Due to a coarse classification of the observed and statistically derived numbers of herbivores the following conditions were implemented.

The starvation process of the pika population is initiated if:

$$PCR > 0 \tag{5.7}$$

and that of livestock if:

$$\overline{PCR} > 0 \tag{5.8}$$

In general, this condition can be interpreted as a rough implementation of the different metabolism of both the herbivore groups. Livestock can partially rely on stored body fat from last year, and therefore can cope with some adverse conditions. Therefore major losses of stock are associated with bad conditions during a single year than with 2-year droughts (Illius et al., 1998; Patterson & Power, 2002). Pika on the other hand do not store energy as body fat and need constant access to forage. The special characteristics of the single processes which results from the competition, such as migration, starvation, etc. are discussed in the separate sections of livestock management and pika dynamics.

5.3.3. Livestock management: migration and remigration

The model concept is highly related to the assumption that successful opportunistic pasture management has been practised for centuries. Economically spoken this is an optimization strategy comparable to a cost-function-analysis. Basically the simulated livestock management strategy takes two features into account: the maximization of the average stocking rate and the minimization of livestock losses. The typical problem of modelling such decisions is that one can only use a set of parameters which is also available to real herders. The main constraint for constant stocking rates is the extreme variability of precipitation and therefore forage availability in non-equilibrium ecosystems. Furthermore, the knowledge about the precipitation dynamics of the previous years is the most reliable information herders can use for their management activities.

The herders' decision-making module comprises two single cores. The first controls the migration decision (leaving the 1-ha), the second one remigration (returning towards the model hectare). While the migration module is based on the standardized PCR, the remigration module has to be more sophisticated and basically uses a weighted running average of precipitation for the last three years to estimate future forage availability. The decisions on migration and remigration are based on different variables in order to avoid an auto-correlation. The decision to remigrate is made early in the year. Available phytomass is estimated based on the precipitation of the previous years and is compared to the forage demand of the actual stocking rate (= potential livestock deficit). If there is more available phytomass, additional livestock can remigrate. The migration decision, on the other hand, is a reaction to the real forage competition observed during the year.

Generally, herders have the intention to stay where they have traditional pasture rights. As a result they remigrate with a higher priority than they migrate.

The fundamental processes for livestock dynamics are migration, remigration, reproduction, starvation, and slaughtering. Due to the fact that the model has a timely resolution of one year, the following basic assumption regarding the timing of the processes are made:

- Migration is the first response to lack of forage.
- Starvation takes place if insufficient forage availability cannot be balanced any more by energy stored as body fat.
- Slaughtering affects all livestock, migrating, or not, except those that died of starvation.

- Remigration is only possible if the estimation of forage availability indicates a surplus when compared to the forage needs of the already stocking livestock.

Migration Each time when forage is not sufficient ($PCR > 0$) herders have to decide whether or not they migrate their livestock towards another pasture. Migration in terms of the model means that the livestock number per ha decreases. It is implemented as follows:

1. If $-1 < PCR < 0$ forage is sufficient and there is no need to migrate away.
2. On the other hand if $0 \leq PCR < 1$ forage supply is insufficient and herders start migrating.

In order to meet the assumed trend to minimize migration activities, an empirically determined linear relationship is implemented for the factor of livestock migration mL with a somehow arbitrary upper threshold of 0.9 which has a tendency to minimize migration activities. The intensity of herders' migration wish (mH) is then derived from:

$$mH = a(mH) + PCR * s(mH) \tag{5.9}$$

The forage deficit (F_d) is calculated from the actual demands of small and large herbivore populations according to:

$$F_d = V - (P * fP + L * fL) \tag{5.10}$$

In order to simulate the fact that herders do not have exact knowledge of future precipitation and phytomass production, forage deficit is multiplied with a normally distributed Gauss filter function (table 5.3, gF_d) in order to add statistical uncertainty. The number of migrating livestock is then finally derived from:

$$L_m = \frac{gF_d}{fL} * mH \tag{5.11}$$

Remigration As mentioned above, the calculation of the remigration of livestock is based on different assumptions. During late spring herders outside the simulated area decide whether they stay (outside) or whether they want to remigrate (immigrate into the model-hectare). The basic assumption is that external herders only want to remigrate if there is sufficient forage for both, the livestock already on the plot, and the remigrating livestock. If herders decide to remigrate the remigrating livestock is added to the numbers of livestock already in the area. This implementation results in a decoupling of the migration and remigration controls avoid artificial feedback between both the processes.

In order to decide about remigration, a priori estimation of available forage (V_e) is performed using a normalized three years running average of precipitation (R_3). In a second step the intensity of the herders' wish to remigrate is derived from a linear relationship depending on the normalized rainfall. Finally the number of remigrating livestock (L_r) is determined by multiplying this herders' remigration wish (rH) with the deficit of livestock with respect to the estimated available biomass (V_e) and livestock already in the area (L). Equation 5.14 summarizes the calculation rule for remigration.

Vegetation biomass in the actual year is estimated according to:

$$V_e = R_3 * RUE - fP * P - v \tag{5.12}$$

And the intensity of the herders' remigration wish according to:

$$rH = a(Hr) + \frac{R_3 - R}{r} * s(Hr) \tag{5.13}$$

The number of remigrating livestock (L_r) is then calculated as:

$$L_r = \frac{V_e - fL * L}{fL} * rH \tag{5.14}$$

Reproduction The main process of increase in livestock is the reproduction of the animals. As no correlation of reproduction with precipitation parameters such as precipitation of this year, precipitation of last year, or mean precipitation of this and last year could be found, reproduction of livestock is implemented using the Mongolian statistics of livestock reproduction rates since 1939. Each time step a random Gauss normally distributed reproduction rate (rpL) based on the statistical moments derived from these figures (table 5.3 presents the coefficients) is applied to the actual total number of livestock (L):

$$L_{rp} = rpL * L \tag{5.15}$$

Slaughtering The slaughter rate is implemented similarly to the reproduction rate. For the slaughtering of livestock no simple correlation with precipitation parameters, human or livestock population density could be found either. Therefore, a random Gauss normally distributed slaughter rate (slL) with the parameters derived from the Mongolian statistics on agriculture (table 5.3) is applied:

$$L_{sl} = slL * L \tag{5.16}$$

Starvation Livestock dies of starvation – if it did not migrate away or was slaughtered anyway – if the mean PCR of two subsequent years, $\overline{PCR}$, is positive:

$$\overline{PCR} > 0 \wedge L - (L_m + L_{sl}) > 0 \tag{5.17}$$

If the conditions are met, starvation of livestock is calculated according to the following equation.

$$L_{st} = stL * L \tag{5.18}$$

Within the model it is assumed that almost no livestock dies of old age because the herders try to maximize the output from their herds and therefore slaughter old animals before they can dy a natural death. The number of animals dying from diseases actually is low and therefore not integrated explicitly in the model.

Livestock numbers Therefore the integral number of livestock at each time step is derived from:

$$\frac{\Delta L}{\Delta t} = \frac{L + L_r + L_{rp} - L_{sl} - L_{st} - L_m}{t} \tag{5.19}$$

5.3.4. Pika's population dynamics

The dynamical patterns of the population of pika was implemented in agreement with the following field observations:

1. Due to their territorial behavior, the maximum number of pika is a functional relation of the number of available burrows (= territories).
2. Under average conditions pika always reproduce a sufficient number of juveniles to "refill" any empty burrows.
3. Pika have a competitive advantage in obtaining and storing forage in comparison to livestock.
4. Burrow creation and decay is a very slow process, within two years changes are barely visible.

According to these observations pika minimum population is primarily determined by the factor of forage availability, while the maximum number is controlled by the number of available territories. Therefore the crucial point in modelling the population dynamics of pika are the implementation of their forage advantage and burrow dynamics.

Pika's forage advantage Pika's competitive forage advantage consists of two different features: pika graze more efficiently and additionally can extend this advantage into the next year as they store hay for winter. Therefore pika's total forage advantage (fP_{at}) is split into two: the grazing advantage (V_{ag}) and the advantage gained by storing this forage as hay (V_{ah}). Moreover, pika's competitive advantage is subsequently used to calculate pika's minimum population density (P_m):

$$\begin{aligned} V_{ag} &= V * fP_{at} * (1 - fP_{ah}) && (5.20) \\ V_{ah} &= V_{t-1} * fP_{ah} * fP_{at} && (5.21) \\ P_m &= \frac{V_{ag} + V_{ah}}{fP} && (5.22) \end{aligned}$$

Reproduction of pika With respect to the second assumption (p. 189) pika's net reproduction rate (rP) is calculated depending on the precipitation conditions of the previous two years (R_2) and the ratio of female pika in the population (p) according to equation:

$$rP = (a(rP) + s(rP) * R_2) * p \tag{5.23}$$

This linear relationship of precipitation and birthrate is derived from the conversion of the absolute field observations into a net birthrate. The benefit of this approach is that natural death by aging can be neglected. The resulting number of juvenile pika (P_j) can then be derived from:

$$P_j = rP * P_{t-1} \tag{5.24}$$

Territoriality and starvation The field observations confirm that the Mongolian Pika shows a strong territorial behavior. Every adult pika needs a burrow (= territory) to survive predator attacks and the winterly cold. The number of available burrows (B) therefore limits the adult pika population over winter.

Due to the timely resolution of one year all those processes, which in reality come one after another, run parallel. Therefore the number of burrows of the previous year (B_{t-1}) has to be used in the calculation to uncouple these processes. In order to translate the field observations into model terminology, pika which do not die a natural death, die either because they do not have any protection or of starvation. In the model the first routine calculated is that for pika which die of predation or exhaustion when they have no territory (= territoriality death, P_{td}). Later on, those occupying a territory can die of starvation (= death by starvation, P_{sd}) if forage is insufficient ($PCR > 0$):

$$\begin{aligned} P_{td} &= B_{t-1} - P_j \quad \text{if:} && (5.25) \\ PCR > 0 &\wedge P_m + P_{td} > P && (5.26) \end{aligned}$$

The number of pika dying of starvation is calculated according to:

$$P_{sd} = P - P_{td} - P_m \tag{5.27}$$

Here again, dying of old age can be neglected, because this cause of death is summarized in the net birthrate, and furthermore it can be assumed that old individuals dy first under the hardships of lack of forage and territorial pressure from younger and fitter individuals.

Pika's population density The integral change of pika population is then derived from summarizing all the single processes in time:

$$\frac{\Delta P}{\Delta t} = \frac{P_j - (P_{td} + P_{sd})}{t} \tag{5.28}$$

Burrows The number of burrows (B), as already mentioned above, is important because it sets the upper limit of the adult pika population. Unfortunately the knowledge on the burrow digging behavior of pika is almost zero. In order to avoid artefacts it was assumed that the number of burrows observed in the field is representative for the current long-term local phytomass production. Therefore the number of burrows is modelled dynamically but somehow arbitrarily fixed within narrow margins. It is assumed that only juvenile pika contribute to the digging of new burrows while adult pika preserve the burrow they inhabit but do not dig new ones. Therefore, burrow decline only if they are uninhabited. The change of burrows Δ B is derived from:

$$\frac{\Delta B}{\Delta t} = \frac{nB * P_j - dB * B_e}{t} \tag{5.29}$$

Initial values

Variable	Description	Dimension	Value
B_i	number of burrows per hectare	dmnl	30
P_i	pika	MPU	30
L_i	livestock	MSU	0.4
R	annual precipitation of Dalandzadgad	mm	data
t	time	yr	

Table 5.1.: Initial values used to start the model run.

Constants

Constant	Description	Dimension	Value
b	average burrow area	ha	0.00324
dB	factor of empty burrows decaying	dmnl	0.0005
nB	factor of burrows built per juvenile pika	dmnl	0.001
vB	factor of higher productivity on burrows	dmnl	2.9
fL	forage intake (dry phytomass) per year and livestock	kg	365
stL	factor of livestock starvation	dmnl	0.4
p	ratio of female pika	dmnl	0.6
fP	forage intake by pika	kg	5
fP_{ah}	percentage of pika's total forage advantage realized by hay stocking	dmnl	0.1
fP_{at}	pika's total competitive forage advantage	dmnl	0.21
r	mean precipitation of time series	mm	131
$rueS$	rain use efficiency of the steppe-matrix, which is production of dry phytomass per mm precipitation	kg/yr/ha	3.22
v	constant of vegetation biomass not available	kg	30
$s(c)$	slope of constant c linear relationship	dmnl	1
$a(c)$	factor of constant c linear relationship	dmnl	0.7

Table 5.2.: Constant values used within the model. Note: some values may differ slightly from the values calculated in the previous chapters because preliminary values had to be used for model development.

Parameters of the Gauss function

Variable	Minimum	Maximum	Mean	Standard deviation
gF_d	$F_d - 0.5 * F_d$	$F_d + 0.5 * F_d$	F_d	50
rpL	0.15	0.4	0.3039	0.0414
slL	0.2	0.36	0.284	0.032

Table 5.3.: Parameters of the Gauss normally distributed filter functions

Runtime variables

Variable	Description	Dimension	Value
B	number of burrows	dmnl	rt
B_A	area covered with burrows	ha	rt
B_e	number of empty burrows	dmnl	rt
F_L	potential forage demand of actual livestock population	kg	rt
F_P	potential forage demand of actual pika population	kg	rt
F_d	forage deficit	kg	rt
mH	intensity of herders' migration wish	dmnl	rt
rH	intensity of herders' remigration wish	dmnl	rt
L	number of livestock	MSU	rt
L_m	number of migrating livestock	MSU	rt
L_r	number of remigrating livestock	MSU	rt
L_{rp}	number of born ("reproduced") livestock	MSU	rt
L_{sl}	number of slaughtered livestock	MSU	rt
L_{st}	number of starving livestock	MSU	rt
mL	factor of livestock migration	dmnl	rt
rL	reproduction rate of livestock	dmnl	rt
slL	livestock slaughter rate	dmnl	rt
stL	livestock starvation rate	dmnl	rt
P	number of pika	MPU	rt
P_{ag}	vegetation biomass exclusively available for pika	kg	rt
P_{ah}	vegetation biomass exclusively available for pika as hay from the previous year	kg	rt
P_j	juvenile pika	MPU	rt
P_m	pika minimum population sustained by their competitive forage advantage	MPU	rt
P_{st}	number of starving pika	MPU	rt
P_{td}	pika mortality due to territoriality constraints	MPU	rt
rP	reproduction rate of pika	dmnl	rt
PCR	standardized potential consumption ratio	dmnl	rt
R_n	average of the previous n years precipitation: $\sum_{t=0}^{n} \frac{R_t}{n}$	mm	rt
RUE	rain use efficiency of the vegetation (=production of dry phytomass per mm precipitation)	kg/yr	rt
S_A	area with steppe vegetation	ha	rt
V	net vegetation biomass	kg	rt

Table 5.4.: Runtime variables calculated during the model run.

5.4. Implications of the model

For the discussion of the model and the implications derived from the model, attention is primarily directed to the three most important aspects:

1. The intensity of the competition between pika and livestock and the implications of the competition for both groups.
2. The control of livestock dynamics by herders, implications on the long-term carrying capacity and the possible impact of transformation on livestock densities.
3. And the suitability of the model to project changes in long-term carrying capacity induced by climate change.

5.4.1. Competition between pika and livestock

The first and seemingly most trivial result of the model is that both groups can coexist although they feed on the same forage plants. Pika can escape the competition with livestock by their ability to remove deeper parts of the plant and by storing hay over winter. The competitive advantage of 20 % of the available phytomass, as calculated from the field studies for the investigation period, was used in the model (table 2.18, p. 112). This competitive forage advantage directly influences the number of pika.

Table 5.5 shows the effect of different levels of pika's forage advantage on the densities of pika and livestock. Up to about 30 % the advantage directly affects pika and livestock densities: pika can consume more, and translate this into higher densities, while livestock numbers are reduced due to the competitive disadvantage they face. From about 30 % upwards pika cannot convert further increasing competitive advantage into higher population densities, because then the number of pika is limited by the availability of burrows.

effect of pika's competitive advantage		
advantage	pika (#/ha)	livestock (MSU/ha)
0 %	12.8	0.89
10 %	19.4	0.81
20 %	**26.4**	**0.73**
30 %	31.9	0.66
40 %	34.9	0.64
50 %	36.7	0.62
100 %	37.3	0.60

Table 5.5.: Comparison of the effects of different levels of pika's forage advantage (pika adv) on mean densities of pika and livestock. The 20 % advantage used in the model is marked bold.

Figure 5.3 shows the effects of varying pika advantage on pika density. The different grey scales correspond to the confidence bands of the sensitivity simulations. When pika have a high competitive advantage they can use it to occupy all available burrows. The higher their advantage, the more frequently pika numbers are limited by the number of available territories (burrows). Further increase in competitive advantage therefore

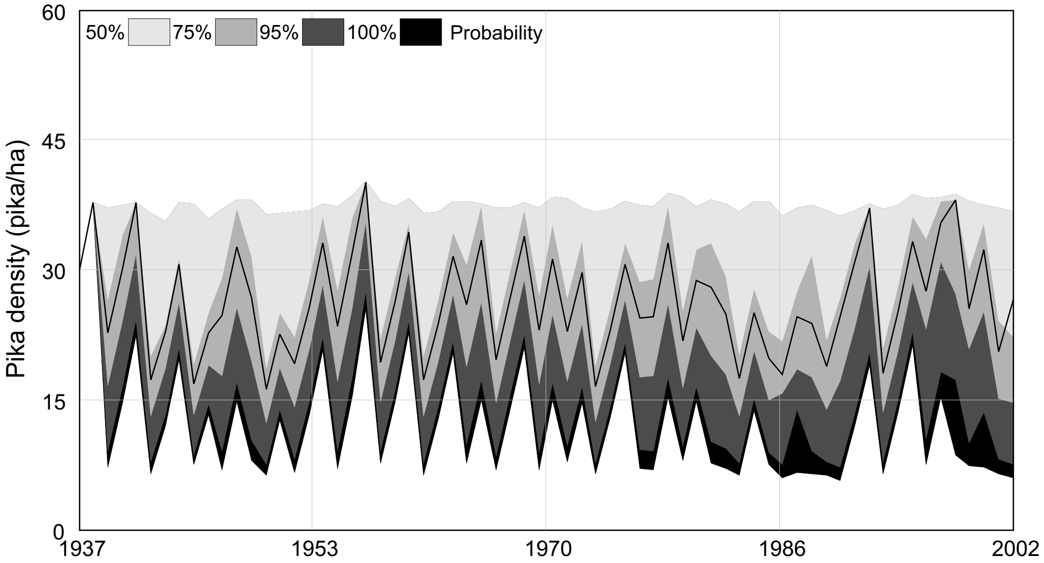


Figure 5.3.: Sensitivity testing of the effect of variable pika's competitive advantage on the density of pika. Pika advantage was varied between 0 % and 100 %. The black line marks the run with the standard parameter set.

pays off only in increasingly seldom situations when the forage availability is low and free territories are available.

When their competitive advantage is lower – such as in the standard parameter set – pika numbers are limited by forage availability. Consequently, pika density only seldom (in 1941, 1957, 1992, 1998), or even never reaches the maximum population as indicated by the number of available territories.

The reverse of course is true for livestock densities as indicated in table 5.5. A reduction of pika's competitive advantage from 20 % to 10 % would allow the average density of livestock to increase by 11 % and a total absence of the advantage would allow 24 % higher average stocking rates for livestock. On the contrary, a further increase of pika's competitive advantage even up to 100 % would only result in maximal another 17 % lower average stocking rates of livestock.

Anyway, the decrease of pika's competitive advantage does not directly lead to an increase in livestock density. The interactions within the model are complex, and the numbers presented in table 5.5 are only part of the changes caused by different levels of pika's competitive advantage. Especially the migration-remigration balance for livestock changes, too. The migration and remigration decision bases are adjusted to the standard situation of the model. In a scenario where pika do not have any competitive advantage this leads to a constantly large influx of additional livestock, which in turn results in higher livestock numbers. This constant influx of livestock towards the area indicates an unbalanced system. Herders' management decisions would have to be readjusted in a system without a competitive advantage of pika. Therefore, the numbers presented in table 5.5 show the effect of the competition in the model, but cannot be expected to be realized as pika's advantage cannot be manipulated by the herders.

Neither can it be expected to realize the increase in livestock numbers mentioned in table 5.5 by consequent eradication programs. A model run without the presence of pika shows that under the absence of competition average livestock density is 10 % higher than under the standard parameters (pika present, 20 % competitive advantage). This result seems to justify poisoning programs for the small mammal. But apart from conservational reasons also the bad efficiency is an argument against poisoning programs. Due to their high reproductive potential the pika population can rapidly regain the density levels before the action. The effect of improved forage availability for livestock therefore is only temporary. As the density of pika is limited by the number of available territories, no mass-outbreak of the Mongolian Pika with negative impacts on the vegetation can be expected. The effect of eradication programs therefore is expected to be very limited.

Pika's competitive advantage therefore has been found to be at a sensible level. The implementation of pika's competitive advantage in the model as a fixed percentage of the available phytomass is a relatively simple way and seems not totally satisfactory. The factor used in the model has been derived from a situation of severe competition and therefore may overestimate the average competitive advantage of pika.

Pika's advantage consists of the phytomass which is between the lowest possible biting height of pika and the lowest possible biting height of livestock, e.g. between 1 cm and 2 cm for *Agropyron cristatum* (fig. 2.8, p. 98). But the percentage of phytomass in the critical height does not necessarily remain constant – neither throughout the growing season, nor between years with different precipitation and vegetation growth.

Additionally, pika have the ability to dig up roots and below-ground storage organs of perennial plants. The amount of below-ground phytomass consumed by pika also varies with the available above-ground phytomass. The more above-ground phytomass is available, the less below-ground phytomass is consumed, and vice versa (personal observation). As the consumption of below-ground phytomass seems to at least partially substitutes inadequate above-ground phytomass availability this would also warrant a fixed amount of forage assigned as pika's competitive advantage. The implementation as a percentage was nevertheless preferred because this corresponds much better to the dynamic nature of the model, and does not cause numerical problems in cases when the produced phytomass is lower than the guaranteed advantage of the pika.

The consumption pattern of pika therefore would justify an own sub-model or model, but as our knowledge of it is very limited the implementation in the model was made rather simple as recommended by Bossel (1994). Further field experiments would be necessary to improve this part of the model. But whether these efforts would really pay off in an increased performance of the model remains doubtful.

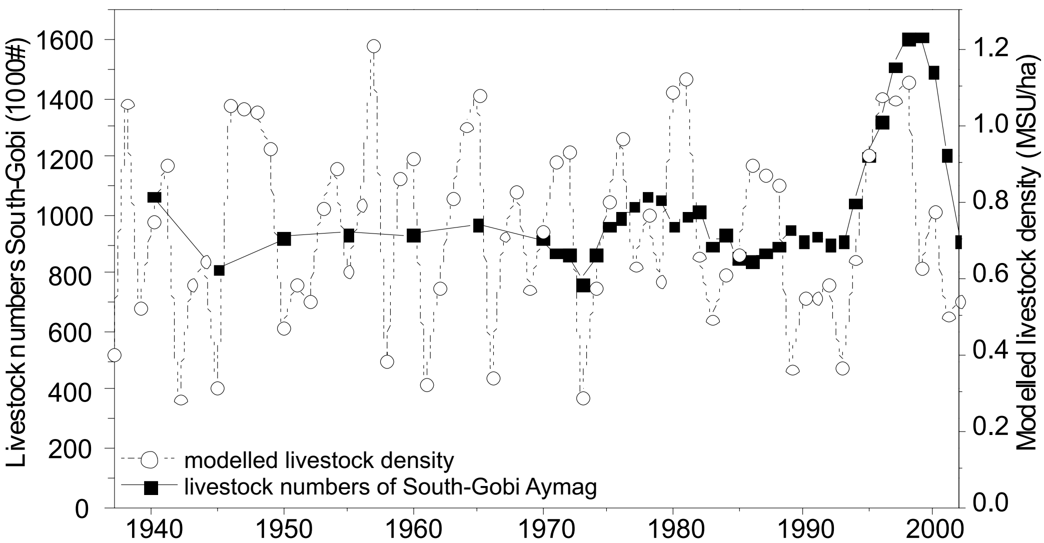


Figure 5.4.: Comparison of the development of livestock population of the South-Gobi Aymag and of the model run. Data from the (National Statistical Office of Mongolia, 1996, 1998, 2000, 2001, 2002, 2003).

5.4.2. Transformation and livestock carrying capacity

Figure 5.4 shows a comparison of the development of the livestock numbers in the South-Gobi Aymag and the projected development of livestock densities on the "virtual model hectare". Of course the numbers cannot be compared directly with each other. Generally, the livestock numbers of the South-Gobi Aymag fluctuate much less than those of the model. The explanation is simple: as the aymag covers an area of 1,654,000 km^2, migration within the aymag due to spatial variation of precipitation can level out many of the extremes of the 1 ha model plot (see fig. 1.3, p. 37). Unfortunately from 1935 to 1970 data on aymag level are available only in 5-years intervals. This makes the curve look relatively static in comparison with the years succeeding 1970. But there is no reason to believe that inter-annual variations were less during this time.

The migration pattern and decision-making of herders was tested by sensitivity analysis. Figures 5.5 and 5.6 show the effects of varied migration decisions on pika and livestock densities, respectively. The livestock density with the standard parameter set of the model (solid line) on average shows higher values of livestock densities than are achieved by random migration decisions. This confirms the fact that the implementation in the model allows herders to keep as large livestock numbers as possible. The migration and remigration decisions therefore are "intelligently" implemented in the model. "Stupid" random migration decisions on average result in much lower livestock numbers.

Figure 5.5 also shows that even by applying more sophisticated migration methods the available phytomass cannot be exploited much more effectively and that the implemented migration pattern already realizes high returns from the available resources. It furthermore indicates that although the early 1990s can support relatively high livestock numbers, the precipitation pattern alone cannot explain the observed increase in livestock numbers as observed after the transformation (fig. 5.4). Even a better op-

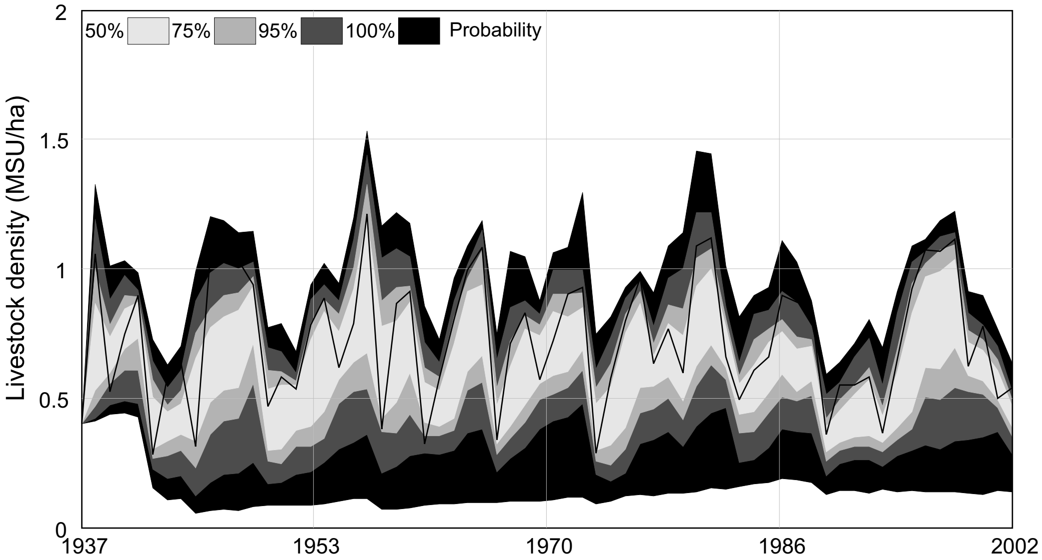


Figure 5.5.: Sensitivity test of the effect of random herder decisions on livestock migration on livestock density. Migration and remigration minimum and maximum each was varied between 0 and 1. The black line marks the run with the standard parameter set.

timization of the migration pattern does not leave much margin to increase livestock numbers much further (fig. 5.5). Therefore we have to conclude that herders changed their grazing strategies after the transformation and took a greater risk by stocking the pastures with higher livestock numbers than traditionally.

Under the new situation, after the collapse of the socialistic state and the infrastructure in the urban centers many of the now unemployed former state workers switched back to earn their livelihoods as herders. This increased the pressure on the pastures and was implemented in the model as increasing willingness to remigrate while ignoring possible risks. Figure 5.7 shows the effects of increasing remigration willingness. From 1990 on remigration willingness was randomly varied between 100–300 % of the "traditional" willingness in case remigration was advisable. If herders had no intention to remigrate at all, this was not affected. on livestock density beginning in 1990, and figure 5.8 shows the effect on the livestock losses by starvation.

The model displays the characteristic course of both parameters, which has also been observed in Mongolia: supported by a series of years of good rainfall, livestock numbers can be increased to levels never recorded before. But when this spell of good weather ends in 1999 and is followed by another series of three "bad years" in a row, the high-risk strategy takes its toll, and starvation losses dramatically reduce livestock numbers to the level before the transformation.

The series of rainfall events in the 1990s is an exception to the long-term distribution of precipitation intensities: it is characterized by above-average precipitation levels with relatively low inter-annual variability. Within the period from 1993–1997, precipitation was continually above-average in Dalandzadgad. Since the beginning of recordings this was the first time that five subsequent years received above-average precipitation.

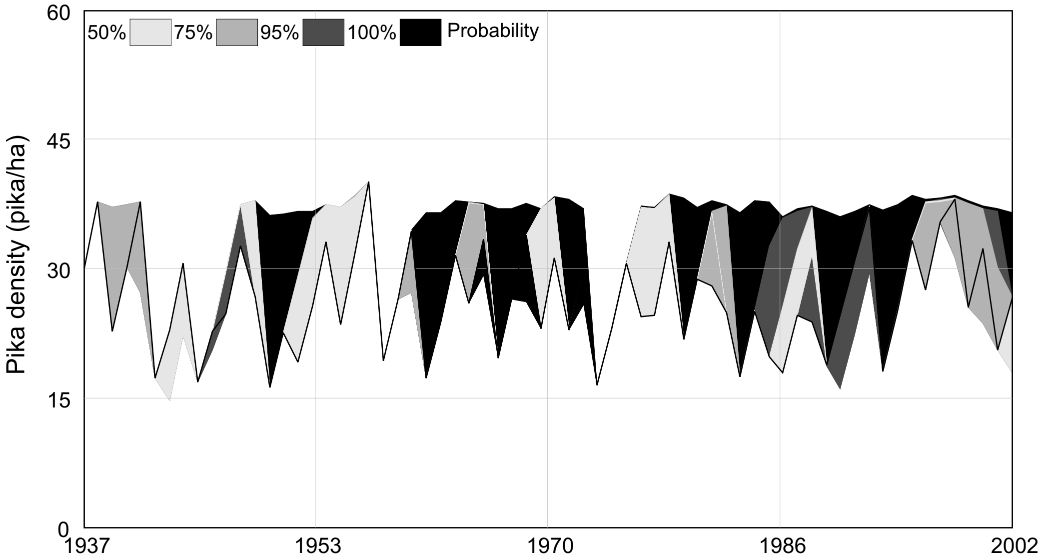


Figure 5.6.: Sensitivity test of the effect of random herder decisions on livestock migration on pika density. Migration and remigration minimum and maximum each was varied between 0 and 1. The black line marks the run with the standard parameter set.

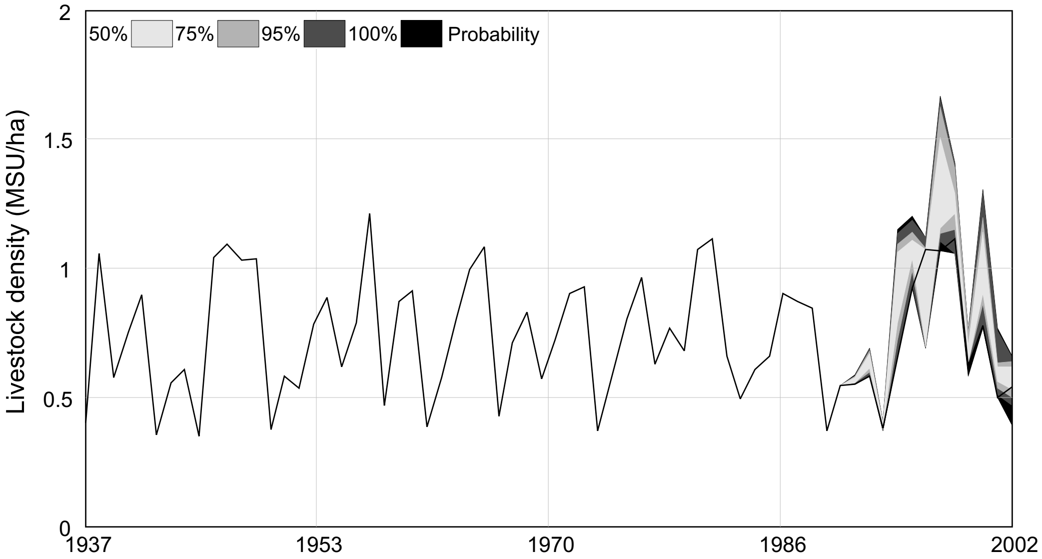


Figure 5.7.: Sensitivity test of the effect of increased pressure under transformation beginning in 1990 on livestock density. The black line marks the run with the standard parameter set.

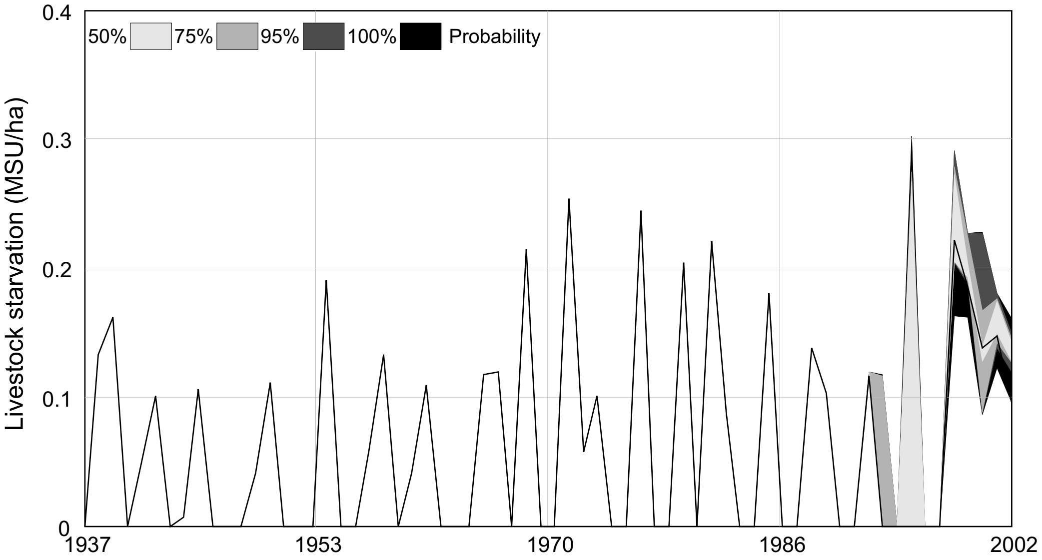


Figure 5.8.: Sensitivity test of the effect of increased pressure under transformation beginning in 1990 on the starvation of livestock. The black line marks the run with the standard parameter set.

Extreme events occurred extraordinarily seldom: in the decades preceding the 1990s, years with more than 40 % deviation from the average occurred at least twice, on average 3.6-times, and maximal 6-times per decade! During the 1990s the deviation of the precipitation of the actual year was constantly less than 40 % of the mean annual precipitation. This makes the 1990s the decade with the lowest inter-annual variation in precipitation since the beginning of the recordings.

In 1998 and 1999 the period of above-average precipitation ended. In both years a slightly below average precipitation was recorded (-5 % and -9 %). The years 2000–2002 all received well below-average precipitation (-24 %, -35 %, and -41 %, respectively). Again five subsequent years of below-average precipitation in a row have not been recorded previously.

The precipitation data show that the situation in the 1990s was much more an equilibrium situation than previously (see chapter 1.2.4 for an explanation of non-equilibrium and equilibrium dynamics). Especially the absence of years of well below-average precipitation allow the building up of high livestock numbers. In non-equilibrium systems such years are sort of a "reset" which efficiently decreases livestock numbers below-average carrying capacity (Behnke et al., 1993; Biot, 1993). In the absence of such resets livestock numbers can grow continually for five years (see also Desta & Coppock, 2002, for an example from Ethiopia). The growth then is halted by average conditions in 1998 and 1999. Finally the risk of stocking a non-equilibrium system according to equilibrium conditions takes its toll: the increased livestock numbers cannot be maintained in the bad situation of 2000–2003 and a high proportion of livestock starves.

The impact of continuing transformation pressure may result in higher fluctuations of livestock numbers, as has been recorded between 1990 and 2002. The question is, which effect such fluctuation may have on the pastures. Certainly, carrying capacity cannot be enhanced without considerable human efforts – and even if these efforts will be under-taken, they are not sure to have the desired positive effects. If grazing continues to be managed the way it was from 1990 to 2003 the grazing impact on the Mongolian pasture may show extreme variabilities in the course of one decade. It cannot be predicted yet whether the system can or cannot cope with such stress. It is possible that the system breaks down into a lower state (see Schulte, 2001). More research is needed to identify possible indicators for such a collapse and to develop new management strategies under the free market economy in Mongolia. Still, as long as the pattern of precipitation does not change substantially and the system remains a basically non-equilibrium system, no detrimental impact on the vegetation is expected.

The consequence of the observed and simulated pattern for the long-term carrying capacity is clear: the relatively good distribution of precipitation in the 1990s allowed a large number of Mongolians to escape the hardships of a collapsing state by living self-sufficiently of their herds. But it cannot be expected that the carrying capacity can be expanded much beyond what has been realized already in the 1930s–1980s. This also means that the number of people living on herding in Mongolia cannot increase in the long-term, either. The increasing population of Mongolia cannot live subsist on the pastoral economy but has to rely on other means for their livelihood. **Pastoral nomadism could absorb a part of the shock from the transformation, but will not feed a substantially higher number of people in future.**

5.4.3. Climate change

By changing the precipitation input parameters the effects of climate change projections on the precipitation patterns in Mongolia can be implemented and investigated relatively easily with the presented model. The effect of changing temperature on vegetation is not implemented directly but can be considered via its effect on the rain use efficiency of the vegetation. However, no feedback of changing temperatures on livestock energy balance has been integrated in the model, yet (Bolortsetseg & Tuvaansuren, 1996).

As shown above, the distribution of the precipitation also is crucial to the functioning of the system. The 1990s were an exception of the previous recordings, although it cannot be distinguished whether this happened by chance, or whether it may be the first sign of changed precipitation patterns caused by climate change. If phases of good precipitation, as observed in the 1990s, get more frequent, this will alter the dynamics driving the Mongolian pastoralism towards a more equilibrium system. This implies that livestock numbers will be much more frequent near the ”actual carrying capacity” and much more seldom clearly below it. Under such conditions the questions of potential overgrazing and regulations of pasture use in order to avoid degradation become much more important than previously.

5.5. Summary

The presented model is capable of simulating pika and livestock density reactions to variable precipitation input. The results of the model show that pika and livestock can coexist in the long-term. Pika's small size, which allows them access to forage which is not accessible to livestock, gives them a competitive advantage. The quantity of this advantage has distinct effects on the density of livestock. Nevertheless coexistence of pika and livestock therefore is possible in future. Eradication programs in all likelihood do not make sense.

The 1990s do not indicate that the long-term carrying capacity of Mongolia's non-equilibrium systems is much higher than previously realized. This period represents an exceptional situation of low inter-annual precipitation variability. Simultaneously herders increased their herds at a high rate and had to take a greater risk of losses than in previous times. Under the favorable circumstances this strategy resulted in large short-term increases in livestock numbers. But in less favorable years the stock was rapidly reduced to the former level. Average long-term carrying capacity cannot be efficiently increased beyond the numbers observed between 1930 and 1990.

Still it remains unclear which effects "equilibrium phases" of relatively good weather conditions such as in the early 1990s may have even on an otherwise more non-equilibrium system. The model strictly is designed for predominant non-equilibrium conditions, as no feedback from livestock densities to vegetation properties is implemented, and cannot be applied to equilibrium situations.

The presented model can be used as the basis for assessing the impact of changes in precipitation as projected by climate change scenarios (Batima & Dagvadorj, 2000; Batima et al., 2002). But it yet does not include the effects of increasing temperature on vegetation growth and livestock energy turnover (Bolortsetseg & Tuvaansuren, 1996).

6. Synthesis

Forage competition between pika and livestock

When the turnover from predominant wild herbivore grazing to grazing by domestic livestock took place in the South-Gobi is still unclear. Moreover, it is even more difficult to determine gradual changes in the proportions of wild and domestic herbivores. Today, however, livestock account for the majority of large herbivores grazing in the Gobi Gurvan Sayhan National Park. Forage competition between pika and livestock and the consequences for livestock carrying capacity therefore are also of economical importance.

In the South-Gobi, a non-equilibrium system triggered mainly by precipitation, years with above-average rainfall generally provide plenty of forage for both competitors because large herbivore densities are usually below the actual possible carrying capacity (see chap. 1.2.4, p. 34ff for more information on the regulation of non-equilibrium systems). Therefore, years with above-average precipitation are not suitable for studying forage competition. On the contrary, years of below-average precipitation, when forage is scarce, provide the best setting for a work about forage competition. For this reason it was good luck for the author (though not for the herders) that the summer of 2001 encountered a severe drought.

During the drought of 2001 forage competition between pika and livestock is severe. Pika consume up to 1.5-times more phytomass than livestock does, and this amount not even includes the even higher proportion they may use on their burrows. Pika are competitively dominant when they graze on the same area together with livestock.

Nevertheless, both groups of herbivores can coexist in the long-term. Even a severe drought such as that encountered in the summer of 2001 and the associated competition for forage does not lead to the competitive exclusion of one of the species. The reason is that both groups have access to a mutually exclusive forage resource. Pika have the ability to bite down forage plants to lower heights than livestock possibly can. Additionally, they can dig for roots and other subterranean storage organs of perennial plants during times of low forage availability. These abilities secure pika competitive dominance on the shared pastures. Livestock, on the other hand, is moved to better pastures by the herders whenever possible and there it has access to forage which is out of reach for pika. Although both strategies are not sufficient to maintain the population at the level of average years during droughts, the resource partitioning apparently prevents the extinction of one of the herbivores by competitive exclusion.

The extreme seasonal differences of the Mongolian climate lead to equally extreme seasonal differences in forage availability. With the inset of the summer rains in May or

June plant growth begins and already at the end of September standing crop is too low again to provide substantial forage. The logical consequence is that both the herbivore groups have to satisfy their nutrient requirements during this period of four or maximal five months and store enough energy to survive winter until rain sets in again in next spring. Livestock stores this energy as body fat while pika harvest plants, dry them, and store the hay inside their burrows. This allows both to extract as much energy as possible during the short period during which phytomass is abundant.

The different strategies of surviving winter again indicate an advantage of pika compared to livestock. When there is plenty of forage the maximum amount livestock can consume is restricted by their digestive capacity. Pika, on the other hand, are not restricted by their digestive capacity because they can store surplus as hay. Still, they may be restricted by the time available for hay-making but has not been investigated yet.

The function of pika in the ecosystem

Although forage competition between pika and livestock can be severe during a drought, the effects of pika presence on livestock are more complex. In order to evaluate pika's role, other aspects of pika presence have to be taken into account, too.

Pika modulate their steppe environment by digging burrows, hay-making, and dung-collection. This has profound effect on resource flows within the system. For one, pika's activities such as their defecation pattern and their habit of collecting dry livestock dung lead to an enrichment with nutrients (phosphate, nitrate, ammonium) in the soil of the uppermost horizons on their burrows. In comparison with the steppe-matrix burrows therefore offer a higher nutrient availability for the vegetation.

Exactly how pika burrows influence water availability is not yet clarified. Two mechanisms were proposed which both lead to a higher moisture availability on pika burrows. Firstly, infiltration capacity is enhanced on the burrows because the soil is loosened by biopedturbation. Secondly, the tunnels of the burrows allow surface runoff to infiltrate deeply into the soil, and thus lead to a higher moisture availability. But in a year of drought, when almost no surface runoff could be observed, the soil under the pika burrows was actually drier than under the steppe-matrix. Therefore, the hypothesis has to be modified. In a year of drought pika burrows air circulating through the tunnel system dries out the burrow. However, when there is much rainfall, the second mechanism proposing that the tunnels act as water traps during times of surface runoff may still be effective. The combination of those two effects implies that pika burrows generally provide a more extreme habitat in terms of moisture availability than in the steppe-matrix: higher in rainy years and lower in dry years.

Although water availability on the burrows was not higher in 2001, phytomass productivity was nevertheless. This indicates that pika burrows provide better growing conditions for the vegetation than the surrounding steppe-matrix. The fact that this can be achieved without higher moisture availability indicates that the steppe-matrix is deficient in nutrients. Even under the extremely dry conditions in the year of study (65.4 mm precipitation from January to September 2001) plant growth is co-limited by water and nutrient availability.

In order to evaluate the impact of forage competition by pika on livestock the productivity effect of pika burrows has to be taken into account as well. The presence of pika burrows increases phytomass availability in the steppe by 13 %. This forage is at least potentially also available for livestock. The question which part of the phytomass on pika burrows is consumed by which herbivore has not been investigated yet. But several species of livestock have repeatedly been observed grazing preferably on pika burrows. Furthermore, in spring pika burrows provide the first fresh shoots of *Agropyron cristatum*, the most highly regarded forage plant. In April and May this species is further developed on pika burrows than in the steppe-matrix. This additional source of forage in early spring cannot be valued by its quantity alone. As this is the season with the highest mortality of livestock, already small amounts of additional forage may save an animal from dying of starvation.

In order to classify the Mongolian Pika's status as pest, both features, forage competition and phytomass availability on its burrows, have to be considered. Other aspects such as the area affected by pika, the devastation caused by their burrowing, and the likeliness of population outbreaks additionally have to be taken into account. Although the Mongolian Pika inhabits considerable area of the mountain-steppe in the Gobi Gurvan Sayhan they are not likely to show mass population outbreaks and they cause only minor devastation by digging. Summarizing all the evidence, the Mongolian Pika cannot be regarded a pest. Furthermore, the modulation of the environment classifies it as an ecosystem-engineer sensu Jones et al. (1994).

Conservation in the mountain ranges of the Gobi Gurvan Sayhan

The dilemma of nature conservation in the mountain ranges of the Gobi Gurvan Sayhan is their importance for livestock grazing during years of drought. Due to their higher precipitation and phytomass productivity they are valuable pastures for herders' livestock during dry years. Although the park regulations allow this use of the core zone only in especially bad situations, this increases the pressure on the protected flora and fauna as 80 % of the large herbivores observed in the mountains are livestock.

The effect of high livestock densities in the mountains on the populations of wild herbivores is difficult to assess. But in all likeliness, increased forage competition and more frequent disturbance by humans add to the stress of low forage availability and thus contradict the aim of the park to conserve healthy populations of wildlife. Further studies are required to assess the risk more precisely but the conflict has been shown and will be difficult to resolve as possibilities to mediate between the interests of herders and nature conservationists are marginal. Herders have used the mountains as pasture for their livestock for a long time and nature conservationists have almost no means of keeping livestock outside the mountains. Even if livestock would be banned from the mountains such a regulation cannot effectively be controlled in a country without fences.

Furthermore harsh actions of this kind only would set the herders against the national park administration. The other way of offering incentives such as hay for herders staying outside the mountains is probably too expensive and again the effectiveness cannot be controlled.

The problem may not seem so dramatic as relatively large populations of ibex and argali have survived in the mountains of the Gobi Gurvan Sayhan until today. But what might endanger the populations is the combination of increased livestock densities and changing management strategies after the transformation with recent multiple year droughts which have not been observed previously.

Model of livestock and pika carrying capacity

The field data from the drought in the summer of 2001 cannot be linearly extrapolated to years with different annual precipitation. This a general problem of investigations in non-equilibrium systems with high inter-annual variability. In such an environment there is no single characteristic state but the sole and unique characteristic is the variability of states. Therefore, also investigations during a year of average precipitation cannot be extrapolated to different years. In this respect, it may even be regarded good luck that a period of drought could be observed because processes such as forage competition may gain importance especially in such years (see above).

However long and whichever single year is investigated, has no influence on the fact that every observation is connected only to a single combination of circumstances such as annual precipitation, history of livestock density, etc. None of the settings which could be possibly studied allows to extrapolate the results linearly to a longer period of time because it ignores the variability of the system and the complex interactions between precipitation, productivity, herders' decisions, livestock population, and pika densities. In order to derive a prediction of the long-term carrying capacity of the study area, a modelling approach had to be used which takes all these interactions into account.

The model presented simulates the reactions of pika and livestock densities to variable precipitation input. The results show that pika and livestock can coexist in the long-term. They also indicate that the increase in livestock densities after the transformation in 1990 has been caused by a change of the herders' strategy. In the 1990s herders took a greater risk to maximize their livestock numbers while ignoring the risk of potentially high losses in bad years. The increase in livestock numbers was facilitated by a series of years with above-average precipitation in the early 1990s. But this series of good years alone is not sufficient to explain the observed increase in livestock numbers. Beginning in 1998 a series of years with below-average precipitation caused the breakdown of livestock numbers to approximately the level before the transformation. The model indicates that long-term carrying capacity has already been reached in socialistic times and cannot be increased further without measures to supply additional forage during times of drought, although this is not even an adequate solution (see below).

For modelling the interactions of precipitation, pika population, and livestock densities a non-equilibrium ecosystem was assumed. Therefore, no feedback of herbivore densities on the productivity of the vegetation was integrated in the model. However, at least two scenarios are thinkable which may lead to a violation of the assumption of dealing with a non-equilibrium ecosystem. One is the future development of precipitation patterns. In the last twenty years precipitation extremes tend to deviate less from the mean as previously and years with above-average and below-average precipitation do not alternate as frequently anymore as from 1940 to 1980. This indicates that the precipitation pattern tends to get less variable and therefore allows for a more equilibrium balance between precipitation, primary production, and livestock density. A second factor which drives the system towards a more equilibrium one is the supply of additional fodder and hay for livestock when forage is scarce. Certainly, any attempt of this kind is reasonable for the herders involved, but it makes the system more vulnerable to degradation because it reduces the effect of extreme droughts. Such droughts are a ”reset” which reduce livestock densities to very low population levels and therefore give the vegetation a rest period to recover from grazing. A lower frequency or lower intensity of such ”resets” increase the likeliness of negative feedbacks of livestock densities to vegetation and soil. Still, the latter scenario is not supposed to have great impact on the ecosystem as long as the amounts of fodder and hay used do not increase significantly from today’s level.

Nevertheless, it is important to keep in mind that any impulse which drives the ecosystem nearer to equilibrium also is likely to increase the problem of degradation. At the moment the main protection against degradation of the pastures is the non-equilibrium behavior of the ecosystem which only seldom allows livestock densities to reach levels high enough to have a degrading impact on the vegetation. Prerequisite for the protection and sustainable use of the pastures remains the opportunistic management of the resources while employing a high mobility migration scheme. Therefore, the pastures should remain common property in order to allow for this high mobility pastoralism. The consequences of abandoning such a management can be observed across the border in the province of Inner Mongolia in China.

Conclusion

The mountain-steppe of the Gobi Gurvan Sayhan is well suited to grazing as all the major forage species are adapted to herbivory by having their reproductive organs below or close to the ground. This is the consequence of a selection process lasting for millennia which resulted in a set of plant species which cannot easily be damaged by herbivores. This and the non-equilibrium dynamic of the system are the prerequisites that the ecosystem supported nomadic pastoralism for such a long time and also can support it in future.

The effects of the Mongolian Pika on livestock and carrying capacity are complex. This includes forage competition with livestock, but also reaches much further than that. Mongolian Pika inhabit large areas of mountain-steppe and permanently modulate the environment on their burrows thus creating small micro-sites with special abiotic conditions. Hence, they increase the heterogeneity of the ecosystem. Being omnivorous herbivores, they compete with livestock for forage, but apart from that they do not influence carrying capacity for livestock negatively. The study demonstrates the importance of including complex interactions when evaluating the role of small mammals in steppe-ecosystems.

However, for the future it is crucial that a opportunistic livestock management strategy is applied. The information gained by herders in constant search for better pasture, and the exchange of this information among herders, results in a collective memory about the available forage resources. This absolute knowledge of the whole area is the precondition for an optimal utilization.

Acknowledgements

The study was carried out under the framework of the memorandum about joint Mongolian–German research on the mountain-steppes of the Gobi Gurvan Sayhan signed in 1999 between the biological faculty of the Mongolian National University, Ulaanbaatar and the institute of the Department of Geography of the Philipps-University, Marburg. A three year programme was jointly funded by the German Science Foundation and the German Ministry for Economic Co-operation and Development. The GTZ-project ”Nature Conservation and Bufferzone Development” funded two gers and a walkie-talkie.

For many suggestions and support during this research I want to thank my supervisor, Prof. Dr. Georg Miehe. Prof. Müller-Hohenstein on short notice discussed the concept of the study before my rush-off to Mongolia. Karin Nadrowski, Karsten Wesche, and Christoph Reudenbach were constant partners in hard and extended discussions on pika, livestock, and the like.

During the field work in Mongolia Prof. Samyaa helped not only in organizing legal requirements for scientific work in Mongolia, but also with many other things. The team at the research station, Undrakh, Monkhzul, Enkhjargal, Biche, and Dolgion provided a great introduction to the Mongolian way of life and the language. The GTZ-team around Dr. Sabine Schmidt with Amagalanbaatar, Chimgee, and Myadak and the staff of the Gobi Gurvan Sayhan National Park office, Rafjir and Dogermaa were always helpful with the provision of information as well as logistical support. Our neighbors at the research camp, especially Otshir, Agwan, and Batsaikhan and their families, welcomed us, were interested in us and our work, and helped us in many ways. The rangers Sorensonbold and Bayarsaikhan shared their knowledge on the park with us.

Furthermore, I want to thank Pera Haumann for sharing her knowledge of livestock body condition scoring, Prof. Opp for offering part of the meteorological data to our disposal, Matthias Pietsch for the recording of phytomass data in 2002, and Henrik von Wehrden for his assistance in compiling the map of the Gobi Gurvan Sayhan National Park.

Numerous other people were involved in the creation process of this work. Some of them know this while others are unaware of it. Nevertheless, I also want to thank many people not named here for inspiring my thoughts, giving me strength and laughter, and distracting me.

Three people, Karsten Wesche, Jan Axmacher, and Carsten Neßöver, already undertook the lengthy task of reading this thesis. Their valuable comments improved the manuscript considerably.

Without meeting Karin Nadrowski in 2000 I never would have started this PhD-thesis. Her excitement and commitment are unequalled and carried me away to Mongolia.

I am grateful to my parents who not only helped starting the project off early, by lending me money when the funds of the DFG were not yet available, but also made their spontaneous resolution come true and visited me in the South-Gobi. Later on, my mother read this study cover to cover (2–times thanks to the German Postal Service losing the first copy) in order to improve the English. Apart from that I also want to thank both for their constant support and love.

Special thanks go to Sandra. Several times during the last year her love prevented me from becoming insane and gave me the strength to continue.

Vroni Retzer
November 2003, Marburg, Germany

A. Appendix

Animal species cited

Wild large mammals

English name	Scientific name	Mongolian	CITES	MRB
Siberian Ibex	*Capra sibirica*	Yangir		
Wild Sheep	*Ovis ammon*	Argali	*	*
Black-tailed Gazelle	*Gazella subgutturosa*			*
Mongolian Gazelle	*Procapra gutturosa*			
Wild Ass (Khulan)	*Equus hemionus*	Khulan	*	
Bactrian Camel	*Camelus bactrianus ferus*			*
Gobi Bear	*Ursus arctos*		*	*
Wild boar	*Sus scrofa*			*
Daurican Pika	*Ochotona daurica*	Ochdoi		
Mongolian or Pallas' Pika	*Ochotona pallasi*	Uchir Ochdoi		
Tolai Hare	*Lepus tolai*			
Gobi Jerboa	*Allactaga bullata*			
Mongolian Gerbil	*Meriones unguiculatus*			
Polecat	*Mustela eversmanni*			
Snow Leopard	*Uncia uncia*	Irvis	*	*
Gray Wolf	*Canis lupus*			
Eurasian Lynx	*Lynx lynx*		*	
Manul Cat	*Felis manul*	Manuul	*	
Red Fox	*Vulpes vulpes*			
Corsac Fox	*Vulpes corsac*			
Przewalski's wild horse	*Equus przewalskii*	Takhi	*	*
Asiatic waipiti or elk	*Cervus elaphus*			

Table A.1.: List of wild mammals which occur in the Gobi Gurvan Sayhan National Park and have been mentioned in the text. The last two rows give the conservation status, whether the species is listed in The CITES-convention or the Mongolian Red Book (MRB). This list is by no means comprehensive! Sources: Bedunah & Schmidt, 2000; Finch, 1998; Reading et al., 1999a; Steinhauer-Burkart, 1999

Domestic large mammals (livestock)

English name	Scientific name	Mongolian
Cattle	*Bos taurus*	Uchir
Yak	*Bos grunniens*	Sarlig
Camel	*Camelus bactrianus*	Temee
Horse	*Equus caballus*	Adoo
Sheep	*Ovis aries*	Khon
Goat	*Capra hircus*	Yamaa

Table A.2.: Domestic mammals which occur in the Gobi Gurvan Sayhan National Park and have been mentioned in the text. Sources: Bedunah & Schmidt, 2000; Lensch et al., 1996; Steinhauer-Burkart, 1999

Further small mammals

English name	Scientific name
Plateau Pika	*Ochotona curzoniae*
Black–footed ferret	*Mustela nigripes*
Black-tailed prairie dog	*Cynomys ludovicianus*
Brandt's vole	*Microtus brandti*
Pocket gopher	*Thomomys* spp., *Geomys* spp.
Guinea pigs	*Cavia* spp.
Marmots	*Marmota* spp.
Voles	*Microtus* spp.

Table A.3.: Small mammals cited in the text, but not investigated within the study. The information is put together from the various sources cited in the text.

Birds

English name	Scientific name	CITES	MRB
Imperial Eagle	*Aquila heliaca*	*	
Bearded Vulture (Lammergeyer)	*Gypaetus barbatus*	*	
Griffon Vulture	*Gyps fulvus*	*	
Himalayan Vulture	*Gyps himalayensis*	*	*
Cinereous Vulture	*Aeqypius monachus*	*	
White-tailed(Sea) Eagle	*Haliaeetus albicilla*	*	*
Black Kite	*Milvus migrans*	*	
Imperial Eagle	*Aquila heliaca*	*	
Greater Spotted Eagle	*Aquila clanga*	*	
Golden Eagle	*Aquila chrysaetos*	*	
Steppe Eagle	*Aquila rapax*	*	
Long-legged Buzzard	*Buteo rufinus*	*	
Upland Buzzard	*Buteo hemilasius*	*	
Northern Harrier	*Circus cyaneus*	*	
Peregrine Falcon	*Falco peregrinus*	*	
Lesser Kestrel	*Falco naumanni*	*	
Merlin	*Falco columbarius*	*	
Red-footed Falcon	*Falco vespertinus*	*	
Northern Hobby	*Falco subbuteo*	*	
Saker Falcon	*Falco cherrug*	*	
Long-eared Owl	*Asio octus*	*	
Little Owl	*Athene noctua*	*	
Eagle Owl	*Bubo bubo*	*	
Isabelline wheatears	*Oenanthe isabellina*		
White-Wing Snow Finch	*Montifringilla nivalis*		
Piere David's Snow Finch	*Pyrgilauda davidiana*		

Table A.4.: List of bird species in the Gobi Gurvan Sayhan National Park. The table lists the endangered species which occur in the park (CITES and Mongolian Red Book (MRB)), and all other species if directly mentioned in the text. It is not a comprehensive list of all bird species occurring in the park. Sources: Reading et al., 1999a; Finch, 1998.

Vegetation data

plot information				cover						bm	height				phenology						
ID	date	plot	tre	gra	her	shr	veg	ear	sto	bm	al_h	st_h	ag_h	po_h	al_p	st_p	ag_p	po_p	ar_p	cl_p	si_p
36	09/03/01	H3	l	20.0	0.3	0.2	20.5	29.3	50.0	8.1	4.9	29.7	14.8								
37	09/03/01	H3	p+l	7.3	2.0	0.0	9.5	20.0	70.3	1.7	5.1	22.4	10.2								
38	09/03/01	H3	p	11.5	0.3	0.1	11.8	20.2	67.0	4.0	7.2	23.4	10.6								
39	09/03/01	H3	no	11.0	0.5	1.0	12.5	27.3	60.0	5.2	5.4	27.8	14.3								
40	09/03/01	H3	bur	4.3	0.3	0.0	4.5	35.3	60.0			12.7	8.3								
41	09/03/01	H1	p	7.0	0.0	0.0	7.0	32.5	60.0	2.4		23.4	9.8								
42	09/03/01	H1	no	10.5	0.3	0.2	11.0	26.8	62.0	5.8	10.2	18.7	9.0								
43	09/03/01	H1	p+l	7.0	2.0	0.0	9.1	20.7	70.0	3.2	7.6	30.3	9.4								
44	09/03/01	H1	l	9.5	0.5	0.5	10.5	14.3	75.0	6.8	7.7	20.3	7.0								
45	09/03/01	H1	bur	0.9	0.1	0.0	1.0	49.0	50.0		6.0	13.7	7.8								
46	09/03/01	H2	p+l	5.0	1.0	0.2	6.2	10.6	83.0	2.3	7.4	11.8	8.0								
47	09/03/01	H2	l	5.0	2.0	0.8	7.8	25.0	67.1	5.1	10.0	23.2	9.4								
48	09/03/01	H2	bur	9.9	0.0	0.1	10.0	35.0	54.8				6.6								
49	09/03/01	H2	p	7.0	1.0	0.0	8.0	32.0	59.9	4.6	5.2	21.7	9.8								
50	10/03/01	2000	p+l	3.0	5.5	0.2	8.7	8.3	83.0			26.6									
51	10/03/01	2000	p+l	11.0	2.0	0.0	13.0	10.0	76.6		10.8	30.7									
52	10/03/01	2000	p+l	1.7	2.3	1.0	5.0	22.0	72.8			19.6									
53	10/03/01	2000	p+l	3.0	2.0	0.0	5.0	15.0	79.9			22.0									
54	09/03/01	H2	no	6.0	0.0	4.0	10.0	29.0	60.8	4.2	10.7	27.0	8.6								
55	14/03/01	2200	p+l	6.5	3.0	0.5	10.0	25.0	64.3		15.4	25.0									
56	14/03/01	2200	p+l	7.5	0.5	1.0	9.0	31.0	59.8		12.6	25.1	12.3								
57	14/03/01	H4	l	9.5	1.5	2.0	13.0	35.0	51.9		7.7	23.9	12.3								
58	14/03/01	H4	p+l	5.5	1.5	0.0	7.0	17.9	75.0		11.1	19.5	15.6								
59	14/03/01	H4	p	12.0	2.5	2.5	17.0	20.0	62.8		7.8	20.9	14.0								
60	14/03/01	H4	no	10.8	6.0	0.3	17.0	32.0	50.8		8.3	29.4	15.1								
61	14/03/01	2200	p+l	9.0	1.8	0.3	11.0	17.0	71.8		8.0	22.0	10.9								
62	14/03/01	2200	p+l	6.8	1.5	2.0	10.3	29.4	60.0		11.2	27.4	13.4								
63	14/03/01	2200	bur	0.3	1.0	0.1	1.4	20.0	78.6			11.4	12.4								
64	14/03/01	2200	bur	2.8	0.0	0.0	2.8	10.0	87.1			10.5	7.1								
65	15/03/01	2800	bur	11.0	4.0	0.1	15.1	20.0	64.9				10.2	12.9							
66	15/03/01	2800	p+l	8.5	3.5	0.0	12.0	10.0	77.9				11.7	18.7							
67	15/03/01	2800	p+l	10.0	4.0	0.0	14.0	22.9	63.0				13.8	16.4							
68	15/03/01	2800	p+l	8.0	7.0	0.0	15.0	15.0	69.9				10.2	17.2							
69	15/03/01	2800	bur	13.9	5.0	0.1	19.0	20.0	60.9				9.4	15.3							
70	15/03/01	2800	p+l	10.0	3.0	0.2	13.2	21.3	65.3				9.3	20.2							
71	20/03/01	2600	p+l	17.0	3.0	5.0	25.0	50.0	24.7				24.1	21.6							
72	20/03/01	2600	p+l	7.0	5.0	1.0	13.0	34.0	52.9				26.8	17.1							
73	20/03/01	2600	p+l	6.0	1.5	0.5	8.0	47.9	44.0				21.8	20.7							
74	20/03/01	2600	bur	7.0	0.0	4.0	11.0	65.0	6.0				9.2								
75	20/03/01	2600	p+l	13.0	3.5	0.5	17.0	64.5	18.0				18.4	16.5							
76	20/03/01	2400	bur	5.0	0.1	5.5	10.6	38.4	50.7				10.2	19.4							
77	20/03/01	2400	p+l	15.0	1.3	1.8	19.0	15.9	65.0				21.8	19.4							
78	20/03/01	2400	p+l	9.0	0.1	1.5	10.6	9.3	80.0				24.1	20.3							
79	20/03/01	2400	bur	4.5	0.1	2.4	7.0	39.0	54.0				9.6	17.8							
80	20/03/01	2400	p+l	7.0	0.3	0.8	8.0	21.0	70.9				23.7	18.3							
81	20/03/01	2400	p+l	9.5	5.5	2.0	17.0	28.0	54.9		20.7		15.3	20.6							
82	23/01/01	H1	no	19.0	1.0	0.0	20.0	20.0	60.0		8.0	18.0	11.1								
83	04/12/00	H1	l	19.0	0.5	0.5	20.0	30.0	50.0	5.9		36.3	18.1								
84	23/01/01	H1	l	17.0	3.0	1.0	21.0	15.0	64.0		7.2	29.2	10.7								
85	04/12/00	H1	p	14.9	0.0	0.1	15.0	28.0	40.0	3.7	8.6	31.1	18.7								
86	23/01/01	H1	p	14.0	1.0	0.0	15.0	23.0	62.0		3.6	23.2	10.2								
87	11/10/00	H1	p+l	18.0	2.0	0.0	20.0	15.0	64.0	9.5	14.6	34.3	20.8								
88	29/11/00	H1	p+l	13.0	2.0	0.0	15.0	34.0	50.0	3.9	6.6	39.1	14.8								
89	23/01/01	H1	p+l	13.0	4.0	0.0	17.0	20.0	63.0		7.9	26.7	11.4								
90	26/01/01	H1	bur	7.0	0.1	0.0	7.1	50.0	42.9		5.3	10.0	11.2								
91	26/01/01	H2	l	4.0	3.5	2.5	10.0	40.0	50.0		10.8	17.9	9.1								
92	26/01/01	H2	p	10.0	4.0	0.0	14.0	38.0	48.0		6.6	14.8	7.1								
93	11/10/00	H2	p+l	10.5	6.0	3.0	19.5	18.0	60.5	6.2	19.0	36.9	14.0								
94	26/01/01	H2	p+l	8.5	2.3	0.3	11.0	19.0	70.0		7.5	12.1	8.6								
95	12/10/00	H2	bur								12.8	20.7	16.6								
96	23/01/01	H3	l	20.0	4.5	0.5	25.0	23.0	52.0	6.6	8.8	20.6	22.3								
97	05/12/00	H3	p	15.5	2.3	0.3	18.0	22.0	60.0		13.9	28.5	14.6								
98	22/01/01	H3	p	12.0	1.9	0.1	14.0	16.0	70.0	3.2	8.5	21.7	9.3								
99	12/10/00	H3	p+l	12.5	3.5	0.0	16.0	13.0	70.0	4.9	24.2	27.6	17.4								
100	05/12/00	H3	p+l	17.0	2.0	0.0	19.0	34.0	47.0		6.2	27.7	10.8								
101	23/01/01	H3	p+l	9.0	3.0	0.0	12.0	15.0	73.0	3.2	5.1	21.0	8.1								
102	23/01/01	H3	bur	9.0	1.0	0.0	10.0	30.0	60.0		4.5	13.9	6.6								
103	05/12/00	H4	no	15.0	5.5	1.5	22.0	24.0	54.0		20.4	28.8	17.2								
104	22/01/01	H4	no	14.0	7.0	2.0	23.0	17.0	60.0	6.0	11.8	26.1	13.2								
105	05/12/00	H4	l	12.0	1.3	3.8	17.0	33.0	50.0		10.7	29.6	13.7								
106	22/01/01	H4	l	10.0	3.0	2.0	15.0	15.0	70.0	4.0	10.3	22.4	10.7								
107	05/12/00	H4	p	12.0	2.0	5.0	19.0	20.0	61.0		15.4	22.4	15.3								
108	22/01/01	H4	p	9.0	4.0	4.0	17.0	20.0	63.0	4.4	9.2	27.7	11.5								
109	12/10/00	H4	p+l	8.5	3.5	5.0	17.0	14.0	68.0	4.8	12.1	34.0	16.0								
110	05/12/00	H4	p+l	14.0	5.0	6.0	25.0	25.0	50.0		14.7	23.3	14.5								
111	22/01/01	H4	p+l	10.0	2.5	1.5	14.0	11.0	75.0	2.5	10.2	15.7	12.7								

continued on next page

continued from previous page

plot information				cover						bm	height				phenology						
ID	**date**	**plot**	**tre**	**gra**	**her**	**shr**	**veg**	**ear**	**sto**	**bm**	al_h	st_h	ag_h	po_h	al_p	st_p	ag_p	po_p	ar_p	cl_p	si_p
112	05/12/00	H4	bur								5.1	30.9									
113	22/01/01	H4	bur	14.0	2.0	4.0	20.0	25.0	45.0		7.1	24.4	11.4								
114	28/11/00	2800	p+l	29.0	2.0	1.0	32.0	17.0	50.0					23.7							
115	24/01/01	2800	p+l	20.0	2.5	0.0	22.5	17.0	60.5				18.7	20.0							
116	28/11/00	2800	p+l	29.0	5.0	1.0	35.0	14.0	50.0				20.6	21.1							
117	24/01/01	2800	p+l	20.0	3.0	1.0	24.0	16.0	60.0				13.8	18.2							
118	28/11/00	2800	p+l	28.0	6.5	0.5	35.0	13.0	50.0					24.0							
119	24/01/01	2800	p+l	25.0	3.0	1.0	29.0	21.7	49.0				20.5	20.9							
120	28/11/00	2800	p+l	29.0	0.9	0.1	30.0	8.5	60.0				37.0	22.8							
121	24/01/01	2800	p+l	18.0	2.0	0.0	20.0	15.0	64.9				21.6	22.9							
122	24/01/01	2800	bur	22.0	3.5	0.5	26.0	24.0	50.0				10.2	15.6							
123	28/11/00	2800	bur	29.0	7.9	0.1	37.0	22.0	39.0				18.9	22.3							
124	24/01/01	2800	bur	14.0	15.0	1.0	30.0	25.0	45.0		7.9		13.5	20.2							
125	28/11/00	2800	bur	19.0	10.9	0.1	30.0	9.0	60.0				18.9	22.3							
127	26/09/00	SC	p+l	13.0	8.0	1.0	22.0	27.0	50.0	8.6	35.7	37.8	27.6								
128	26/09/00	SC	no	8.0	14.0	3.0	25.0	20.0	53.0	12.4	53.9	44.6	30.4								
129	26/09/00	SC	l	13.0	10.0	2.0	25.0	20.0	54.0	12.4	38.9	53.0	25.5								
130	26/09/00	SC	p	16.0	5.0	1.0	22.0	45.0	30.0	8.8	32.2	40.3	22.7								
131	27/09/00	SC	p+l								19.8	23.1	20.0								
132	24/10/00	SC	p	20.0	1.5	0.5	22.0	18.0	58.5	8.6	24.0	52.1	19.6								
133	25/10/00	SC	p+l	12.5	3.5	4.0	20.0	25.0	53.0	5.5	17.7	37.6	19.4								
134	25/10/00	SC	l	16.0	0.5	1.5	18.0	20.5	60.0	4.3	16.7	27.9	16.6								
135	25/10/00	SC	no	13.0	2.0	1.0	16.0	18.0	65.0	7.9		22.9	19.0								
136	18/04/01	H2	p	9.0	0.5	5.0	14.5	13.0	70.4	5.1	10.3	20.1	14.2		0	0	0				
137	18/04/01	H2	no	5.0	2.5	6.5	14.0	15.0	71.0	2.4	12.0	23.2	11.9		0.5	0.5	0.5				
138	19/04/01	H2	l	7.0	1.0	1.5	9.5	10.4	80.0	3.7	9.6	17.5	14.2		0	0	0.2				
139	19/04/01	H2	p+l	5.0	1.5	0.3	6.8	18.0	75.2	1.8	9.0		10.1		0	0	0				
140	19/04/01	H2	bur	6.0	0.0	0.0	6.0	30.0	63.4				8.4				1				
141	19/04/01	H4	l	8.0	2.0	2.0	12.0	16.0	72.0	4.8	10.5	24.3	16.4		0	0	0				
142	19/04/01	H4	p+l	4.5	1.5	1.5	7.5	12.5	80.0	2.6	9.2	15.6	15.5		0	0	0				
143	19/04/01	H4	p	11.0	3.5	3.5	18.0	18.0	64.0	5.7	10.6	23.5	16.9		0	0	0				
144	19/04/01	H4	no	13.5	6.0	0.5	20.0	18.0	61.9	8.9	13.1	28.6	18.2		0	0	0				
145	19/04/01	H4	bur	6.0	1.0	0.0	7.0	74.6	17.0			16.3	10.5			0	1				
146	20/04/01	2600	p	10.0	5.2	0.8	16.0	33.6	50.0		10.1		11.9	10.8	1		0	0			
147	20/04/01	2600	no	10.0	10.0	0.4	20.4	40.0	39.3		11.5		10.4	10.0	0	0	1	0			
148	20/04/01	2600	l	10.0	7.0	1.0	18.0	22.0	59.8		12.3		17.3	16.9	0		0	0			
149	20/04/01	2600	bur	19.8	0.2	0.0	20.0	35.0	44.7				12.0	11.6			0	0			
150	20/04/01	2600	p+l	12.0	5.2	0.8	18.0	20.0	61.9		13.8		16.0	14.6	0		0	0			
152	20/04/01	2600	p+l	15.5	4.0	3.5	23.0	40.0	36.7				17.2	16.2			0	0			
153	20/04/01	2600	p+l	7.0	4.0	0.2	11.2	52.0	36.8				20.3	18.7			0.2	0			
154	20/04/01	2600	bur	11.0	0.1	3.0	14.1	73.8	12.0				15.3				1				
155	20/04/01	2600	p+l	19.5	4.0	0.5	24.0	57.0	18.6				16.3	15.4			0	0			
156	23/04/01	2000	p+l	1.5	5.2	0.0	6.7	13.0	80.3			19.3				0					
157	23/04/01	2000	p+l	1.8	1.2	0.0	3.0	12.0	85.0		9.0	18.1			0	0					
158	23/04/01	2000	p+l	4.5	0.4	0.0	4.9	18.0	77.0		10.5	19.8			0	0		0			
159	23/04/01	2000	p+l	0.8	1.5	0.1	2.3	12.0	85.7		6.4	15.9			0	0					
160	23/04/01	2200	p+l	2.0	4.5	0.3	6.8	25.9	67.0		10.0	16.2	7.5		0	0	0				
161	23/04/01	2200	p+l	4.7	0.5	0.2	5.4	38.0	56.6		11.8	8.5	12.0		1	0.5	1				
162	23/04/01	2200	p+l	4.0	0.6	1.5	7.1	43.0	49.9		10.1	13.3	9.9		0	0	0				
163	23/04/01	2200	p+l	5.5	0.5	0.2	6.2	23.7	70.0		10.5	15.9	9.6		0	0	0				
164	23/04/01	2200	bur	0.5	1.5	0.1	2.1	12.9	85.0		8.7	13.4	9.7		0	0	0				
165	23/04/01	2200	bur	2.3	0.0	0.0	2.3	22.0	75.7			10.2	8.7			0	0				
166	24/04/01	2400	bur	11.5	0.5	10.0	22.0	28.0	50.0				12.6	13.3			0	0			
167	24/04/01	2400	p+l	22.0	2.0	1.5	27.5	8.5	64.0				19.9	14.6			0	0			
168	24/04/01	2400	p+l	17.0	5.5	2.5	25.2	24.3	50.5		14.6		16.3	21.7	0		0	0			
169	24/04/01	2400	bur	5.3	0.2	2.5	8.1	28.0	63.9				12.2	15.5			0	0			
170	24/04/01	2400	p+l	12.0	0.0	1.0	13.3	20.4	66.0		8.8		23.0	18.4	0		0	0			
171	24/04/01	2400	p+l	17.0	0.0	1.7	18.8	10.2	71.0				18.8	21.4			0	0			
172	24/04/01	H3	no	9.0	0.2	1.3	10.5	34.0	54.5		9.7	20.6	15.9		1	1	1				
173	24/04/01	H3	p	4.7	0.6	0.0	5.3	40.0	54.7		9.2	15.7	13.4		1	0	0				
174	24/04/01	H3	bur	2.7	0.0	0.0	2.7	40.0	57.1			12.3	7.7			0	0.5				
175	24/04/01	H3	l	10.0	1.5	0.5	12.0	40.0	47.9		11.3	24.3	17.5		1	0	1			0	
176	24/04/01	H3	p+l	5.5	0.0	0.0	5.5	35.0	59.5		8.9	16.2	9.6		0	0	0.5				
177	24/04/01	H1	l	10.0	1.0	1.2	12.2	32.0	55.6		8.1	22.2	12.2		0	0	0				
178	24/04/01	H1	no	12.0	0.5	1.2	13.7	39.0	47.3		8.9	21.9	15.9		0	0	1				
179	24/04/01	H1	p	3.0	0.0	0.0	3.0	47.0	50.0			21.8	9.5			0	1				
180	24/04/01	H1	p+l	3.3	1.2	0.0	4.5	45.5	50.0			16.0	8.5	16.1		0	0	0			
181	24/04/01	H1	bur	1.2	0.0	0.0	1.2	48.6	50.0			18.5	7.3			0	1				
182	25/04/01	2800	bur	6.8	2.0	0.3	9.0	23.0	67.5				9.3	15.7			0	0			
183	25/04/01	2800	p+l	7.5	1.5	0.0	9.0	9.7	81.0				12.0	13.2			0	0			
184	25/04/01	2800	p+l	8.5	3.0	0.5	12.0	19.0	68.8					14.9				0			
185	25/04/01	2800	bur	5.0	3.0	0.0	8.0	30.0	61.8				8.1	8.5			0	0			
186	25/04/01	2800	p+l	8.0	3.0	0.5	11.5	23.0	65.5				12.6	12.1			0	0			
187	25/04/01	2800	p+l	6.5	4.0	0.3	10.8	29.0	60.1				11.2	13.0			0	0			
192	21/05/01	H4	l	6.5	1.5	1.0	9.0	18.0	72.9	5.6	10.2	26.2	20.1		0	2	2		1	0	
193	21/05/01	H4	p+l	3.5	3.0	1.0	7.5	27.0	65.5	2.8	8.6	21.2	17.5		0	2	2		1	0	
194	21/05/01	H4	no	11.0	1.2	0.6	12.8	22.0	64.8	8.7	12.9	28.3	19.2		0	2	2		1		
195	21/05/01	H4	p	4.5	3.5	1.3	9.3	15.7	74.3	5.8	9.0	26.0	23.8		0	1	2		1	0	
196	21/05/01	H4	bur	4.6	0.0	0.6	5.2	70.0	22.3			20.1	10.5			2	2		1		
197	21/05/01	H3	no	12.5	0.5	2.0	15.0	20.0	63.0		9.3	29.2	20.0		0	2	2				
198	21/05/01	H3	p	3.5	0.5	0.0	4.0	30.0	65.9		7.4	22.7	13.8		0	1	0				

continued on next page

continued from previous page

plot information				**cover**						**bm**	**height**				**phenology**						
ID	**date**	**plot**	**tre**	**gra**	**her**	**shr**	**veg**	**ear**	**sto**	**bm**	al_h	st_h	ag_h	po_h	al_p	st_p	ag_p	po_p	ar_p	cl_p	si_p
199	21/05/01	H3	l	8.2	0.6	1.0	9.8	30.0	59.5		11.8	29.1	21.0		0	2	2		0	0	
200	21/05/01	H3	p+l	3.5	0.2	0.0	3.7	26.2	70.0		7.0	20.0	17.0		0	2	3			0	
201	21/05/01	H3	bur	2.3	0.2	0.0	2.5	37.3	60.0			26.3	14.8			2	3				
202	21/05/01	H1	p+l	3.8	1.3	0.0	5.1	44.7	50.0			22.2	17.2	14.9		2	2	0	1		
203	21/05/01	H1	bur	1.8	0.0	0.0	1.8	55.0	43.2			22.6	10.4			3	3				
204	21/05/01	H1	l	6.0	1.0	0.5	7.5	40.0	52.4		8.6	26.1	16.4		0	1	2		1	0	
205	21/05/01	H1	no	13.0	0.5	1.2	14.7	35.0	50.2		9.2	29.7	25.2		0	2	3				
206	21/05/01	H1	p	3.0	0.0	0.0	3.0	68.0	28.7			28.6	14.9			2	3				
207	22/05/01	2000	p+l	0.6	0.8	0.0	1.4	23.6	75.0			15.1				0				0	0
208	22/05/01	2000	p+l	0.4	0.4	0.0	0.8	17.1	82.0		9.6	14.1			0	0				0	0
209	22/05/01	2000	p+l	1.1	0.3	0.0	1.3	22.0	76.5			18.8				0				0	
210	22/05/01	2000	p+l	0.2	0.6	0.0	0.8	19.1	80.0		10.0	14.9			0	0				0	0
211	22/05/01	2200	p+l	1.3	2.5	0.3	4.1	21.0	74.7		9.9	16.3			0	0				0	0
212	22/05/01	2200	p+l	3.0	0.2	0.3	3.5	32.0	64.1		11.3	17.1	14.2		0	1	1			0	
213	22/05/01	2200	p+l	2.0	0.1	0.3	2.4	42.0	55.6		9.6	17.2	13.0		0	1	0			0	
214	22/05/01	2200	p+l	2.4	0.2	0.3	2.9	22.1	75.0		8.4	15.6	11.1		0	0	0			0	0
215	22/05/01	2200	bur	0.3	1.0	0.0	1.3	20.0	78.6			16.8	11.1			1	0		2	0	
216	22/05/01	2200	bur	1.3	0.2	0.0	1.5	18.5	80.0		8.6	18.0	10.0		0	1	0			0	2
217	22/05/01	H2	p	6.2	0.1	0.3	6.6	50.2	42.0	4.8	10.6	24.2	18.1		0	3	3			0	
218	22/05/01	H2	no	5.0	1.7	5.5	12.3	27.0	59.7	6.6	19.2	38.1	22.9		0	2	2			0	
219	22/05/01	H2	l	1.5	1.9	0.4	3.8	16.2	80.0	2.7	8.3	13.8	13.6		1	2	1		1	0	
220	22/05/01	H2	bur	5.1	0.0	0.2	5.3	20.0	74.6			17.1	12.4			3	3			0	
221	22/05/01	H2	p+l	2.1	0.5	0.2	2.9	20.0	77.1	2.1	8.6	13.6			0	2	2		1	0	2
222	24/05/01	2800	bur	5.0	1.8	0.2	7.0	20.1	72.9				10.1	10.8			2	1	2		
223	24/05/01	2800	p+l	4.5	1.3	0.0	5.8	20.0	74.1			10.4	25.6	20.1		2	3	1	3		
224	24/05/01	2800	p+l	5.5	1.8	0.0	7.3	25.0	67.4				11.9	17.2			1	1	2		
225	24/05/01	2800	p+l	4.0	3.3	0.0	7.3	28.7	63.9				13.5	15.3			1	1	2		
226	24/05/01	2800	bur	5.0	3.7	0.0	8.7	30.0	60.9				19.5	15.5			2	1	2		
227	24/05/01	2800	p+l	2.7	3.3	0.0	6.0	39.0	54.9					14.5				1	2		
228	24/05/01	2600	p+l	6.5	3.0	0.4	9.9	40.0	50.0		25.0		25.2		2		1	1	1		
229	24/05/01	2600	bur	7.4	0.3	0.0	7.7	27.0	65.0				14.8	13.9			1	0	3		
230	24/05/01	2600	p+l	6.0	6.1	0.3	12.4	50.3	37.0		23.4		20.7	17.9	2		1	0	2		
231	24/05/01	2600	no	2.0	7.6	0.7	10.3	40.0	49.1		24.5		23.1	16.8	1		1	0	2		
232	24/05/01	2600	p	5.5	4.5	0.3	10.3	44.0	45.2		20.2		15.7	14.9	2		1	0	2		
233	24/05/01	2600	l	4.0	4.8	0.4	9.2	45.0	45.8		24.0		24.4	17.6	2		2	1	2		
234	24/05/01	2600	p+l	8.5	0.8	0.3	9.6	63.0	26.5				21.6	19.4			1	1	2		
235	24/05/01	2600	bur	5.5	0.1	5.5	11.1	75.0	13.6				17.6				3				
236	24/05/01	2600	p+l	6.0	1.8	0.3	8.1	50.0	41.5				18.2	15.8			1	1	1		
237	26/05/01	2400	bur	6.9	0.0	10.2	17.2	25.0	56.8			25.1	18.2	20.2		1	1	1			
238	26/05/01	2400	p+l	15.0	0.8	2.5	19.6	10.2	70.0		22.8		30.2	20.9	2		3	2	2		
239	26/05/01	2400	p+l	10.5	7.5	4.0	22.3	17.4	60.0		14.4		22.8	19.7	0		2	1	2		
240	26/05/01	2400	bur	3.8	0.0	4.6	8.7	23.0	68.2		33.0		29.7	18.6	2		3	1			
241	26/05/01	2400	p+l	11.0	0.3	1.0	12.5	10.0	77.3		18.0		27.4	21.0	1		2	2	2		
242	26/05/01	2400	p+l	13.5	0.7	2.0	16.5	8.0	75.4		12.4		23.4	20.8	1		2	1	2		
243	20/06/01	H1	l	6.0	2.7	2.5	11.2	38.5	50.0	11.4	35.2	50.1	27.1		5	5	4		4		
244	20/06/01	H1	no	11.5	1.6	2.0	15.1	34.7	50.0	20.4	23.3	72.6	35.3		4	5	5		6		
245	20/06/01	H1	p	5.7	0.5	0.3	6.5	35.0	58.5	11.7	28.7	52.8	26.2		4	5	5				
246	20/06/01	H1	p+l	5.0	1.5	0.2	6.7	45.0	48.3	7.5	27.9	54.4	20.0		4	4	4		4		
247	21/06/01	2000	p+l	0.6	0.3	0.0	0.9	14.1	85.0		7.6	16.3			0	0				0	0
248	21/06/01	2000	p+l	1.2	0.0	0.5	1.7	18.1	80.0			18.7				0				0	
249	21/06/01	2000	p+l	0.3	0.2	0.3	0.7	17.2	82.1			13.7				0				0	0
250	21/06/01	2000	p+l	0.3	0.3	0.1	0.6	13.4	86.0			16.1				0				0	0
251	21/06/01	2200	bur	0.3	1.6	0.4	2.3	10.0	87.7		20.3	23.5			4	3			2	0	2
252	21/06/01	2200	bur	2.0	0.5	0.1	2.5	11.9	85.5		21.0	22.2	11.9		4	2	1			2	4
253	21/06/01	2200	p+l	0.8	2.1	1.2	4.1	33.0	62.4		14.8	18.5			2	2					0
254	21/06/01	2200	p+l	1.9	0.6	0.4	2.9	52.0	43.1		19.5	13.6	12.5		2	1	1				
255	21/06/01	2200	p+l	1.5	0.6	1.4	4.3	65.0	30.7		16.4	20.9	13.0		3	3	0			0	
256	21/06/01	2200	p+l	2.2	2.0	0.3	4.5	28.0	67.3		20.0	21.2	14.1		3	0	0			0	0
257	21/06/01	H1	bur	5.0	5.5	0.1	10.6	45.0	44.4		48.7		15.5		5		4	5			
258	21/06/01	H2	bur	5.5	1.2	3.1	9.8	25.0	64.9		43.4		15.9		5		4				
259	21/06/01	H2	p+l	2.3	1.1	1.4	4.8	28.0	67.2		31.9	11.0	15.3		4	2	4		3	4	
260	21/06/01	H2	l	2.3	2.5	9.0	13.8	22.0	63.7		31.4	36.5	19.8		4	4	2			2	
261	21/06/01	H2	no	5.8	2.0	7.5	15.3	19.2	65.0		34.1	38.1	26.3		4	4	4			4	
262	21/06/01	H2	p	3.8	3.2	1.6	9.1	20.9	69.5		32.3	22.3	13.7		4	4	3			2	
263	21/06/01	H4	bur	5.0	2.8	2.0	9.8	59.7	30.0		38.4	33.9	11.6		5	4	3		3		
264	21/06/01	H4	p+l	5.0	3.2	1.3	9.5	20.0	70.5		33.8	36.1	19.3		5	4	4		4		
265	21/06/01	H4	l	5.8	2.2	4.5	12.5	22.5	65.0		29.2	44.9	23.2		5	5	4		5		
266	22/06/01	H3	bur	6.2	1.8	0.0	8.0	29.5	62.0		42.7	29.9	16.5		5	5	5				
267	22/06/01	H3	p+l	4.6	3.3	0.0	7.9	32.1	60.0	8.7	38.0	49.8	17.4		5	5	4		3	3	
268	22/06/01	H3	l	2.5	9.0	1.3	12.8	36.7	50.0	19.1	39.3	57.1	35.3		5	5	5		4	3	
269	22/06/01	H3	p	3.5	2.1	0.5	6.1	39.0	54.9	8.4	30.2	41.0	15.3		5	4	4		2		
270	22/06/01	H3	no	9.7	2.8	2.5	15.0	30.0	54.3	22.3	34.8	47.4	28.7		5	5	5			3	
271	22/06/01	2400	bur	8.0	5.0	11.7	24.7	37.0	37.7		63.2		28.8	23.7	5		5	3			
272	22/06/01	2400	p+l	12.5	3.2	4.0	21.2	30.6	48.0		41.5		30.1	26.4	4		5	5	5		
273	22/06/01	2400	p+l	10.0	10.0	5.0	26.0	30.0	43.7		54.3		28.9	28.7	4		4	4			
274	22/06/01	2400	bur	4.5	0.1	5.0	9.9	49.1	41.0		43.0		38.5	23.3	4		5	4			
275	22/06/01	2400	p+l	7.5	2.4	1.0	11.2	38.8	50.0		55.0		36.7	28.1	4		4	4	5		
276	22/06/01	2400	p+l	11.2	1.3	4.0	16.7	13.0	70.3		50.0		37.3	28.1	4		4	3	5		
277	22/06/01	H4	p	7.0	2.3	2.2	11.5	33.4	55.0		39.0	42.3	25.6		4	5	4		3		
278	22/06/01	H4	no	5.0	7.2	0.8	13.0	46.0	40.8		38.0	58.8	27.1		5	5	5		4		
279	23/06/01	2800	bur	5.0	14.0	0.1	19.1	14.0	66.9		41.3		35.7	28.4	5		5	5	5		

continued on next page

continued from previous page

plot information				**cover**						**bm**	**height**				**phenology**						
ID	**date**	**plot**	**tre**	**gra**	**her**	**shr**	**veg**	**ear**	**sto**	**bm**	al_h	st_h	ag_h	po_h	al_p	st_p	ag_p	po_p	ar_p	cl_p	si_p
280	23/06/01	2800	p+l	9.5	11.0	0.0	20.5	13.0	66.4				50.6	37.0			5	5	6		
281	23/06/01	2800	p+l	20.0	5.0	0.1	25.1	20.0	54.9		55.6		33.5	35.3	5		5	5	5		
282	23/06/01	2800	bur	12.0	21.0	0.0	33.0	33.7	33.0				64.3	39.8			5	5	5		
283	23/06/01	2800	p+l	9.0	19.0	1.5	29.5	17.5	53.0				32.5	28.4			5	5	5		
284	23/06/01	2800	p+l	7.0	13.0	0.2	20.2	10.0	69.7		51.2		40.3	40.2	5		5	5	5		
285	23/06/01	2600	p+l	7.5	2.5	1.5	11.5	29.0	59.3		52.7		35.2	27.6	6		5	5	5		
286	23/06/01	2600	p+l	9.0	6.0	1.0	16.0	40.0	43.7		63.0		33.4	25.9	5		4	4	4		
287	23/06/01	2600	p+l	8.0	10.5	1.5	20.0	44.6	35.0		61.1		25.1	26.0	5		5	4	4		
288	23/06/01	2600	bur	1.0	18.0	0.0	19.0	40.0	40.9		59.8		31.1	20.3	5		5	3	5		
289	23/06/01	2600	p+l	11.0	2.0	0.8	13.8	60.3	25.0				31.3	25.2			4	3	5		
290	23/06/01	2600	bur	5.1	1.6	10.0	16.7	10.0	73.0		51.9		31.5		4		4				
291	23/06/01	2600	no	5.5	12.0	4.0	21.5	28.1	50.0		64.1		39.6	30.0	5		5	4	5		
292	23/06/01	2600	l	10.5	12.5	0.8	23.8	38.0	38.0		69.1		36.4	30.6	5		5	4	5		
293	23/06/01	2600	p	7.5	7.0	2.5	17.0	50.0	32.8		69.1		39.0	31.3	5		4	4	4		
298	26/07/01	H4	l	7.0	5.0	4.0	16.0	47.0	37.0	18.8	35.0	39.1	29.2		8	7	7		6	6	
299	26/07/01	H4	no	6.2	7.0	1.0	14.2	38.0	47.8	14.6	42.4	51.1	31.7		7	7	7		6		
300	26/07/01	H4	p	5.2	3.5	2.0	10.7	39.3	50.0	13.6	41.3	44.4	18.8		7	7	7		7		
301	26/07/01	H4	p+l	3.7	5.5	0.3	9.5	50.5	40.0	8.2	38.1	39.1	14.1		7	7	7		7	7	
302	26/07/01	2000	p+l	0.3	0.7	0.1	1.1	18.9	80.0			13.8				0				0	0
303	26/07/01	2000	p+l	0.5	0.1	0.0	0.5	25.0	74.5		14.7	13.6			0	0				0	0
304	26/07/01	2000	p+l	0.5	0.0	0.2	0.7	30.0	69.1			16.2				0				0	
305	26/07/01	2000	p+l	0.3	0.1	0.1	0.5	39.5	60.0			11.2				0				0	0
306	26/07/01	2200	bur	0.3	0.9	0.5	1.7	15.0	83.3		23.6	21.4			7	7	0		4	4	2
307	26/07/01	2200	bur	1.1	0.3	0.0	1.4	18.5	80.0		20.9	15.1			7	4	0			0	3
308	26/07/01	2200	p+l	0.6	1.3	1.0	2.9	50.0	46.7		17.8	19.7	13.7		8	7	0				0
309	26/07/01	2200	p+l	0.6	0.2	0.5	1.2	52.0	46.2		14.6	15.0	11.7		8	7	0			0	
310	26/07/01	2200	p+l	1.5	0.6	0.5	2.7	72.0	25.3		18.9	26.6	6.3		8	6	0			2	
311	26/07/01	2200	p+l	1.6	0.9	0.2	2.7	22.3	75.0		17.3	20.4	13.3		9	0	0			0	0
312	27/07/01	2400	bur	11.5	9.5	14.0	35.0	32.0	32.5		37.3		37.0	23.5	7		6	5			
313	26/07/01	H4	bur	7.8	3.0	3.0	13.8	60.9	25.0		56.1	59.1	27.8		6	6	6		4		
314	27/07/01	2400	p+l	4.0	16.0	3.5	26.2	15.1	58.5		29.2		30.7	24.6	4		6	5	6		
315	27/07/01	2400	p+l	11.0	11.5	6.0	28.6	31.0	40.1		40.3		41.0	28.9	6		6	6	6		
316	27/07/01	2400	bur	5.0	0.8	9.0	15.0	45.0	40.0		67.1		33.7	18.0	6		6	5			
317	27/07/01	2400	p+l	9.0	4.0	1.2	14.4	31.6	54.0		37.5			29.9			5	6			
318	27/07/01	2600	p+l	8.5	3.0	1.5	13.0	40.1	46.3		29.5		36.9	24.5	6		6	6	6		
319	27/07/01	2400	p+l	13.0	1.0	5.0	19.1	20.0	60.9				41.2	32.9			5	5	6		
320	27/07/01	2600	p+l	10.0	2.5	0.5	13.0	66.0	20.0				41.6	26.8			6	5	6		
321	27/07/01	2600	p+l	8.5	7.0	2.5	18.0	21.6	60.0		61.1		39.5	26.9	6		6		6	6	
322	27/07/01	2600	bur	14.5	1.0	0.0	15.5	46.3	38.0		51.0		28.9	19.5	7		6	5	6		
323	27/07/01	2600	bur	5.6	0.2	15.0	20.8	64.2	15.0		60.6		25.8		7	6	6				
324	27/07/01	2600	p+l	5.5	2.0	1.5	9.0	43.6	47.0		44.5		24.6	20.1	6		6	6	6		
325	27/07/01	2600	no	5.0	11.0	2.0	18.0	41.0	40.4		57.7		44.7	30.2	6		6	6	6		
326	27/07/01	2600	l	11.0	6.5	2.0	19.5	40.3	40.0		33.5		39.8	27.7	6		6	6	6		
327	27/07/01	2600	p	8.5	5.5	2.5	16.5	45.0	38.0		67.9		40.3	28.6	6		6	6	6		
328	27/07/01	H3	no	10.5	0.7	1.0	12.2	43.0	43.3		41.5	49.8	33.5		7	7	6			6	
329	27/07/01	H3	p	1.3	2.1	0.1	3.5	56.3	40.0		42.2	38.4	8.9		7	6	5			4	
330	27/07/01	H3	l	7.5	2.5	0.4	10.4	39.1	50.0		43.3	32.5	31.4		7	6	6			6	
331	27/07/01	H3	p+l	2.0	2.6	0.0	4.6	55.4	40.0		40.4	44.6	9.3		7	6	5		4		
332	27/07/01	H3	bur	10.0	1.5	0.0	11.5	50.5	38.0		53.0	46.9	19.7		7	7	6				
333	28/07/01	H2	no	1.7	2.8	4.0	8.5	21.0	70.0	16.3	45.7	17.8	14.6		7	5	5			6	
334	28/07/01	H2	p	1.0	4.6	0.2	6.0	39.9	54.0	8.9	38.2	28.8	7.3		7	6	4			6	
335	28/07/01	H2	l	1.2	2.8	7.0	11.0	18.9	70.0	26.2	40.6	38.1	21.2		7	6	6			6	
336	28/07/01	H2	p+l	0.8	3.0	0.1	3.9	46.0	50.0	3.6	39.0		7.3		7		3		4	5	
337	28/07/01	H2	bur	7.1	0.5	10.0	17.6	61.4	20.0		48.5	53.4	34.0		6	6	6				
338	28/07/01	H1	l	6.0	4.2	0.1	10.3	49.4	40.0		39.3	44.4	23.4		8	7	6		6		
339	28/07/01	H1	no	11.0	1.0	3.5	15.5	42.3	42.0		36.8	72.2	37.4		6	6	7				
340	28/07/01	H1	p	3.5	0.8	1.0	5.3	60.0	34.4		44.7	35.9	17.0		8	6	6				
341	28/07/01	H1	p+l	2.5	1.2	0.0	3.7	56.0	40.0		36.0	31.3	16.4		8	6	6		4		
342	28/07/01	H1	bur	1.7	5.0	0.2	6.9	58.0	35.0		33.6		24.9		6		6				
343	30/07/01	2800	p+l	4.0	10.0	0.0	14.0	10.0	75.9				38.2	24.3			6	6	6		
344	30/07/01	2800	p+l	3.5	12.0	0.8	16.3	22.0	61.5				23.6	24.2			6	6	6		
345	30/07/01	2800	bur	7.5	21.5	0.5	29.5	37.3	33.0				17.3	23.6			6	6	6		
346	30/07/01	2800	p+l	5.5	11.0	1.0	17.5	15.0	67.5		38.4			21.1	6			6	6		
347	30/07/01	2800	p+l	3.5	10.0	0.5	14.0	25.0	60.8		60.0		15.1	19.1	6		6	6	6		
350	22/08/01	2800	p+l	6.0	7.0	0.0	13.0	8.0	78.9				36.0	23.4			7	7	8		
351	22/08/01	2800	p+l	4.0	7.2	0.3	11.5	10.0	78.2					24.2				7	8		
352	22/08/01	2800	bur	5.0	5.8	0.2	11.0	30.0	53.7				20.4	19.4			7	7	7		
353	22/08/01	2800	p+l	4.0	7.0	0.5	11.5	20.4	68.0				20.6	18.8			7	7	7		
354	22/08/01	2800	p+l	3.0	8.0	0.5	11.5	22.0	66.4				24.7	24.2			7	7	7		
355	22/08/01	2600	p+l	3.7	0.8	0.6	5.1	50.0	44.6		20.9		20.2	19.9	7		7	8	7		
356	22/08/01	2600	p+l	3.8	2.2	0.1	6.1	43.5	50.0		11.6		22.1	19.4	7		8	7	7		
357	22/08/01	2600	bur	5.5	0.6	0.0	6.1	53.6	40.0		34.3		19.0	13.2	7		8	9	6		
358	22/08/01	2600	no	2.5	7.0	0.3	9.8	45.0	44.5		30.3		40.2	32.4	7		7	7	6		
359	22/08/01	2600	l	3.3	6.5	0.3	10.1	39.4	50.0		12.9		41.6	19.7	7		9	9	7		
360	22/08/01	2600	p	5.4	2.6	0.1	8.1	55.0	36.4		32.1		19.9	20.8	7		6	8	6		
361	22/08/01	2600	p+l	6.1	0.8	0.7	7.6	61.4	30.0		35.5		27.0	19.1	7		7	8	7		
362	22/08/01	2600	p+l	6.0	0.8	0.3	7.0	65.9	26.0		30.5		22.7	21.4	7		9	8	6		
363	22/08/01	2600	bur	2.8	0.0	8.5	11.3	73.0	14.7				22.0				7				
364	23/08/01	H3	p+l	0.9	2.2	0.0	3.1	30.0	66.8	6.0	39.6	41.8	7.4		8	7	7		6	6	
365	23/08/01	H3	l	5.7	2.5	0.6	8.8	31.7	59.0	14.6	46.6	49.2	30.0		8	7	7		6	6	
366	23/08/01	H3	p	0.6	2.2	0.1	2.9	60.0	36.6	6.4	43.7	28.8	7.4		8	7	7			0	

continued on next page

continued from previous page

plot information				cover						bm	height				phenology						
ID	**date**	**plot**	**tre**	**gra**	**her**	**shr**	**veg**	**ear**	**sto**	**bm**	al_h	st_h	ag_h	po_h	al_p	st_p	ag_p	po_p	ar_p	cl_p	si_p
367	23/08/01	H3	no	5.2	1.0	0.4	6.6	40.4	50.0	14.4	47.0	53.6	23.0		8	7	8			7	
368	23/08/01	H3	bur	5.3	0.7	0.1	6.1	42.8	51.0		30.6	46.5	16.4		8	7	7				
369	23/08/01	H2	no	1.0	3.0	0.8	4.8	20.0	74.5		50.0	27.0	12.1		9	8	8		8	6	
370	23/08/01	H2	p	0.7	2.8	0.2	3.6	54.2	42.0		42.9	12.1	7.2		8	7	7			9	
371	23/08/01	H2	bur	1.5	0.2	9.0	10.7	59.0	30.0		23.5		13.4		7		6			6	
372	23/08/01	H2	l	0.9	2.5	2.2	5.6	29.2	65.0		31.2	34.0	10.5		8	7	8		7	6	
373	23/08/01	H2	p+l	1.4	0.6	0.1	2.1	20.0	77.8		31.0		8.0		8		8		8	6	
374	24/08/01	H1	l	1.4	1.0	0.1	2.5	41.5	55.0	4.5	31.5	35.0	11.0		8	7	8		8		
375	24/08/01	H1	no	9.6	0.7	3.0	13.3	35.2	51.0	31.4	45.3	68.0	35.7		8	8	8		6		
376	24/08/01	H1	p	1.1	0.3	0.1	1.5	50.0	48.0	2.7	31.1	18.6	9.6		8	7	7				
377	24/08/01	H1	p+l	0.7	0.8	0.0	1.5	48.1	50.0	2.4	27.0	11.5	8.3		8	8	8		8		
378	24/08/01	H1	bur	1.8	1.5	0.1	3.4	60.4	36.0		25.7		12.3		7		7		6		
379	24/08/01	2400	bur	3.9	8.0	8.5	20.4	25.0	54.4		19.8		31.7	18.1	7		7	9			
380	24/08/01	2400	p+l	8.7	1.8	1.8	13.3	12.0	74.0		20.1		23.7	24.9	7		8	9	8		
381	24/08/01	2400	p+l	5.7	0.4	1.2	7.3	7.5	85.0		9.7		30.7	27.2	7		8	9	8		
382	24/08/01	2400	p+l	5.5	5.0	3.0	13.8	25.5	60.0		33.2		35.7	27.1	7		8	9	8		
383	24/08/01	2400	bur	1.7	0.2	7.0	8.9	46.1	45.0		20.1		19.7	17.1	7		8	9			
385	24/08/01	2400	p+l	4.3	1.3	0.9	6.7	20.0	73.0				31.2	27.3			9	9	8		
386	25/08/01	H4	no	5.4	4.7	0.0	10.1	29.7	60.0		29.1	55.1	28.7		9	8	9		7	7	
387	25/08/01	H4	p	1.3	3.2	0.1	4.6	33.0	61.4		37.7	37.9	14.5		8	7	8		7		
388	25/08/01	H4	bur	1.0	1.9	2.2	5.1	78.8	15.0		34.7	43.0	18.1		8	7	6		6		
389	25/08/01	H4	p+l	1.2	1.1	0.0	2.3	45.5	52.0		39.3	31.1	12.1		8	8	8		6	7	
390	25/08/01	H4	l	2.8	2.1	1.5	6.3	46.5	47.0		33.6	24.2	22.2		8	7	9		6		
391	25/08/01	2200	bur	0.2	0.5	0.7	1.4	20.4	78.0		22.6	13.7	12.4		8	9	7		7	0	8
392	25/08/01	2200	bur	0.7	1.1	0.1	1.8	18.1	80.0		27.1	15.5	10.6		8	9	9			8	9
393	25/08/01	2200	p+l	0.7	0.7	0.3	1.6	45.2	53.0		20.6	15.6	12.2		8	9	0			10	9
394	25/08/01	2200	p+l	0.6	0.6	0.3	1.7	58.3	40.0		21.7	28.2	8.0		8	8	0			6	
395	25/08/01	2200	p+l	0.6	0.2	0.2	1.0	48.8	50.0		16.4	19.6	5.5		8	8	9			0	
396	25/08/01	2200	p+l	0.6	0.2	0.2	1.0	48.8	50.0		25.9	19.0	13.2		8	8	0			7	0
397	25/08/01	2000	p+l	0.1	0.3	0.1	0.5	15.0	84.5			21.1				0				0	0
398	25/08/01	2000	p+l	0.2	0.1	0.0	0.3	19.7	80.0			18.0				0				0	0
399	25/08/01	2000	p+l	0.4	0.0	0.2	0.5	24.4	75.0			18.2				0				0	
400	25/08/01	2000	p+l	0.3	0.2	0.2	0.6	19.4	80.0			13.7				0				0	0
407	19/09/01	2000	p+l	0.2	0.2	0.2	0.6	9.4	90.0		29.2	25.0			5	2				0	0
408	19/09/01	2000	p+l	0.2	0.1	0.0	0.3	12.7	87.0		28.5	22.9			6	1				0	0
409	19/09/01	2000	p+l	0.4	0.1	0.3	0.7	19.1	80.0		24.5	24.2			6	1				0	
410	19/09/01	2000	p+l	0.1	0.1	0.2	0.3	12.7	87.0		26.9	11.6			6	0				0	0
411	19/09/01	2200	bur	0.2	2.8	1.0	4.0	5.8	90.0		36.8	20.0			6	4	6		5		4
412	19/09/01	2200	bur	0.3	2.6	0.1	3.0	11.9	85.0		34.9	14.1	10.1		6	2	2				4
413	19/09/01	2200	p+l	0.3	2.1	0.2	2.6	20.4	77.0		32.2	14.6	8.3		6	2	0			3	0
414	19/09/01	2200	p+l	0.7	2.0	0.6	3.6	30.4	66.0		27.9	25.1			6	4				4	
415	19/09/01	2200	p+l	0.4	1.6	1.0	3.0	40.0	56.0		27.6	27.0	9.8		6	5	4			4	
416	19/09/01	2200	p+l	0.5	1.5	0.5	2.5	17.3	80.0		30.9	28.8			6	5				5	0
417	19/09/01	2400	bur	7.2	5.0	8.0	20.2	23.0	56.6		15.5		34.6	15.9	7		8	8			
418	19/09/01	2400	p+l	9.2	4.6	2.5	17.5	12.0	70.2		18.6		21.5	19.8	7		8		9		
419	19/09/01	2400	p+l	8.0	0.6	1.0	9.8	10.2	80.0		8.0		28.4	19.8	8		7		9		
420	19/09/01	2400	p+l	5.0	0.6	1.2	6.9	12.1	81.0				22.6	25.5			9	9	9		
421	19/09/01	2400	bur	3.2	0.3	7.0	10.5	40.0	49.4		9.5		21.8	15.7	8		9	10			
422	19/09/01	2400	p+l	6.2	7.5	3.1	17.2	47.6	35.0		12.3		23.6	14.4	8		8	9	9		
424	20/09/01	2800	p+l	4.5	5.5	0.0	10.0	20.0	70.0				28.6	23.7			7	8	9		
425	20/09/01	2800	p+l	5.5	3.8	0.5	9.8	20.0	70.0				28.6	22.4			8	8	9		
426	20/09/01	2800	bur	5.2	2.9	1.2	9.3	30.0	59.0				21.0	18.8			7	8	9		
427	20/09/01	2800	p+l	5.0	3.5	0.6	9.1	15.7	75.0				23.2	20.9			7	8	9		
428	20/09/01	2800	p+l	4.7	5.2	0.3	10.2	12.8	77.0				29.0	22.8			7	8	9		
429	20/09/01	2600	p+l	3.5	2.2	0.3	6.0	18.0	75.7		16.8		22.7	22.7	8		7	7	8		
430	20/09/01	2600	p+l	2.8	2.4	0.3	5.4	19.5	74.9		19.8		25.5	23.9	7		7	7	8		
431	20/09/01	2600	p+l	2.8	1.7	0.5	5.0	64.0	30.8		23.2		21.2	23.0	7		7	8	8		
432	20/09/01	2600	bur	0.0	7.7	0.0	7.7	31.4	60.0				24.6	26.8			8	8			
433	20/09/01	2600	p+l	3.5	0.9	0.3	4.7	74.8	20.0				21.8	20.3			7	8	9		
434	20/09/01	2600	bur	3.7	0.1	7.0	10.8	78.5	10.0		14.1		24.9		7		7				
435	20/09/01	2600	no	6.2	5.9	0.0	12.1	42.0	45.7	17.0	13.1		41.3	32.5	7		8	8	8		
436	20/09/01	2600	l	6.5	3.0	0.1	9.6	15.0	75.2	17.9	16.3		37.9	31.0	7		8	8	8		
437	20/09/01	2600	p	3.8	1.6	0.0	5.4	34.1	60.0	8.4	5.9		22.2	22.1	7		7	8	8		
438	21/09/01	H4	p+l	2.4	2.4	0.2	5.0	49.8	45.0	4.6	40.5	26.7	17.1		8	8	7		9	9	
439	21/09/01	H4	l	3.7	3.6	2.0	9.3	50.6	40.0	12.2	39.6	35.8	30.6		8	8	8		7	10	
440	21/09/01	H4	no	4.7	3.3	1.0	9.0	47.0	43.0	14.3	50.5	66.5	36.3		8	8	8		8	10	
441	21/09/01	H4	p	1.5	4.0	0.0	5.5	39.0	55.0	5.4	41.5	32.9	22.0		8	8	8		9	8	
442	21/09/01	H4	bur	1.8	2.8	2.0	6.6	65.7	27.0	8.7	41.5	38.9	20.9		7	8	8		9		
443	21/09/01	H2	p+l	0.4	2.3	0.0	2.6	37.4	60.0	3.4	36.9		13.2		8		7		8	7	
444	21/09/01	H2	l	0.5	2.5	3.8	6.8	33.1	60.0	10.6	38.9	32.6	11.6		8	8	7		8	9	
445	21/09/01	H2	no	0.7	3.8	0.2	4.7	35.1	60.0	5.8	50.7	22.4	17.9		8	7	7		8	7	
446	21/09/01	H2	p	0.7	2.1	0.1	2.8	35.0	61.9	4.6	35.0	20.4	10.4		8	8	7			8	
447	21/09/01	H2	bur	4.1	1.2	8.0	13.3	44.0	42.5		61.1		21.1		7		7				
448	22/09/01	H3	no	6.3	0.7	1.0	8.0	45.0	45.5		40.7	52.5	30.9		8	9	8				
449	22/09/01	H3	p	1.0	2.3	0.1	3.4	50.0	46.5		44.9	32.9	19.8		8	8	8				
450	22/09/01	H3	p+l	1.5	1.7	0.0	3.2	53.8	43.0		41.8	25.6	19.8		8	8	7			7	
451	22/09/01	H3	l	2.2	1.3	0.3	3.8	59.0	37.0		44.7	43.7	20.9		8	8	7			8	
452	22/09/01	H3	bur	6.4	0.9	0.0	7.3	42.0	50.5		48.2	32.2	17.2		8	8	7				
453	23/09/01	H1	bur	4.1	2.3	0.1	6.5	43.4	50.0	8.1	38.8	27.1	16.0		7	8	6				
454	23/09/01	H1	l	1.4	0.9	0.2	2.5	55.0	42.0	4.9	34.9	35.3	15.8		8	9	7		8		
455	23/09/01	H1	no	7.0	1.2	0.6	8.8	40.0	50.7	11.8	40.2	52.1	32.3		8	8	9				

continued on next page

continued from previous page

plot information				cover						bm	height				phenology						
ID	**date**	**plot**	**tre**	**gra**	**her**	**shr**	**veg**	**ear**	**sto**	**bm**	al_h	st_h	ag_h	po_h	al_p	st_p	ag_p	po_p	ar_p	cl_p	si_p
456	23/09/01	H1	p	1.7	0.4	0.0	2.1	38.0	59.8	2.5	29.0	23.4	11.7		7	8	7		8		
457	23/09/01	H1	p+l	1.6	0.8	0.0	2.4	42.0	55.6	3.2	29.2	17.9	18.5		8	8	6		8		
458	25/01/01	2600	bur	22.0	1.0	0.0	23.0	40.0	37.0				18.6	17.7							
459	25/01/01	2600	p+l	37.0	4.0	4.0	45.0	20.0	35.0				24.6	19.4							
460	25/01/01	2600	p+l	23.0	6.0	1.0	30.0	25.0	45.0		34.8		20.6	21.4							
461	25/01/01	2600	p+l	16.0	5.0	1.0	22.0	35.0	43.0				19.5	20.6							
462	25/01/01	2400	bur	15.0	1.0	7.0	23.0	20.0	56.5				13.4	19.5							
463	25/01/01	2400	p+l	17.0	4.0	2.0	23.0	15.0	62.0				20.5	18.8							
464	25/01/01	2400	p+l	17.0	1.0	2.0	20.0	10.0	70.0				20.9	23.5							
465	25/01/01	2400	p+l	16.0	1.0	1.0	18.0	28.0	53.0				17.5	23.2							
466	25/01/01	2400	bur	10.0	0.5	3.5	14.0	50.6	35.0				10.7	16.0							
467	25/01/01	2400	p+l	14.0	13.0	4.0	32.0	26.0	42.0		19.5		19.5	23.2							
469	29/01/01	2200	p+l	4.0	0.3	3.0	7.3	20.0	12.8		10.9	20.6	6.5								
470	29/01/01	2200	p+l	10.0	1.0	1.0	12.0	10.0	67.0		10.3	19.5	12.1								
471	29/01/01	2200	p+l	10.0	7.0	5.0	22.0	18.0	60.0		13.0	26.6	13.7								
472	29/01/01	2200	p+l	8.0	0.5	0.5	9.0	12.0	14.0		12.4	17.1	9.4								
473	31/01/01	2200	bur	1.5	3.5	2.5	7.5	12.5	80.0		10.3	15.4	11.7								
474	31/01/01	2200	bur	5.0	0.8	0.2	6.0	13.9	80.0		12.8	11.6	9.3								
475	31/01/01	2000	p+l	4.0	2.5	0.5	7.0	13.0	30.0		8.8	21.4									
476	31/01/01	2000	p+l	0.1	0.4	0.0	0.5	0.2	0.4			38.5									
477	31/01/01	2000	p+l	0.8	1.9	0.2	2.8	4.0	18.2			31.9									
478	31/01/01	2000	p+l	3.2	0.2	0.0	3.4	2.6	14.0		9.5	39.4									
479	07/12/00	2600	p+l	14.0	12.0	2.0	28.0	22.0	50.0				24.6	21.7							
480	07/12/00	2600	p+l	36.0	3.0	1.0	40.0	30.0	30.0				26.5	22.0							
481	07/12/00	2600	bur	12.0	1.0	8.0	21.0	55.0	23.5				12.8	23.8							
482	07/12/00	2600	p+l	29.0	8.0	8.0	45.0	12.0	42.0				23.5	25.6							
483	07/12/00	2600	p+l	19.0	15.0	1.0	35.0	18.0	47.0		35.8		25.8	28.1							
484	24/01/01	2600	p+l	28.0	2.0	0.0	30.0	45.0	25.0					17.2							
485	24/01/01	2600	bur	0.0	0.0	3.5	3.5	16.0	20.5				0.0	0.0							
486	27/11/00	2400	p+l	26.5	0.5	3.0	30.0	6.0	32.0				25.5	30.8							
487	27/11/00	2400	p+l	19.8	0.0	0.2	20.0	10.0	70.0				31.8	24.8							
488	27/11/00	2400	p+l	15.0	0.0	3.0	18.0	2.0	15.0				25.7	26.8							
489	27/11/00	2400	p+l	16.0	0.0	2.0	18.0	2.0	80.0				26.6	23.0							
490	27/11/00	2400	bur	10.0	0.1	5.0	15.0	10.0	20.0				27.4	24.7							
491	29/11/00	2400	bur	8.0	2.0	8.0	18.0	2.0	20.0				26.3	20.6							

Table A.5.: List of data on vegetation cover, standing crop, and species height and phenology. ID= sample number, date, plot: altitude or exclosure (see table 2.2, p. 79), tre= treatment (p+l=*pika & livestock* , l=*only livestock* , p=*only pika* no=*no grazing* , bur= pika burrow); cover (%) of grass (gra), herbs (her), shrubs (shr), vegetation (veg), earth (ear), and stone (sto); standing crop (bm = dry weight in g/m^2; average maximum height (see p. 84) (mm) of *Allium* spp. (al$_h$), *Stipa* spp. (st$_h$), *Agropyron cristatum/Koeleria altaica* (ag$_h$), and *Poa attenuata* (po$_h$); vegetative phenological development (see p. 135) of *Allium* spp. (al$_p$), *Stipa* spp. (st$_p$), *Agropyron cristatum/Koeleria altaica* (ag$_p$), *Poa attenuata* (po$_p$), *Arenaria meyeri* (ar$_p$), *Cleistogenes songorica* (cl$_p$), and *Sibbaldianthe adpressa* (si$_p$).

List of plant species
Agropyron cristatum (L.) Beauv.
Allium eduardii Stearn
Allium polyrrhizum Turcz.
Allium prostratum Trev.
Arenaria meyeri Fenzl
Artemisia frigida Willd.
Cleistogenes songorica Roshev.
Koeleria altaica (Domin) Krylov
Poa cf. attenuata Trin.
Sibbaldianthe adpressa (Bunge) Juz.
Stipa gobica Roshev.
Stipa krylovii Roshev.

Table A.6.: List of plant species studied in the course of the research in the field.

Data of animal observations

*

continued from previous page

date	time	ID	kind	#	° East	° North
01/09/2000	08:40	21	horse	8	103.764577	43.615808
01/09/2000	08:40	21	horse	1	103.755812	43.573000
01/09/2000	08:40	21	horse	6	103.774173	43.588007
01/09/2000	08:40	21	sheep & goat	500	103.755812	43.573000
01/09/2000	08:40	21	sheep & goat	200	103.768341	43.583866
01/09/2000	19:07	22	horse	4	103.774616	43.615985
01/09/2000	19:07	22	horse	3	103.774173	43.606541
01/09/2000	19:07	22	horse	5	103.774173	43.580593
01/09/2000	19:07	22	horse	3	103.748467	43.555877
01/09/2000	19:07	22	yak	2	103.774173	43.616040
01/09/2000	19:07	22	cattle	19	103.774173	43.615669
01/09/2000	19:07	22	cattle	2	103.774413	43.615808
01/09/2000	19:07	22	sheep & goat	300	103.774173	43.578740
02/09/2000	12:00	23	horse	1	103.770780	43.619084
02/09/2000	12:00	23	horse	10	103.783039	43.619354
02/09/2000	12:00	23	horse	2	103.774173	43.634342
02/09/2000	12:00	23	sheep & goat	50	103.770780	43.619084
02/09/2000	12:00	23	sheep & goat	300	103.774173	43.601908
02/09/2000	12:00	23	sheep & goat	350	103.785190	43.590123
02/09/2000	18:26	24	horse	2	103.774173	43.580593
02/09/2000	18:26	24	horse	14	103.770501	43.607246
02/09/2000	18:26	24	sheep & goat	300	103.774173	43.585227
03/09/2000	10:00	25	horse	3	103.775826	43.611955
03/09/2000	10:00	25	horse	8	103.774173	43.588007
03/09/2000	10:00	25	horse	4	103.774173	43.590787
03/09/2000	10:00	25	horse	3	103.764992	43.594404
03/09/2000	10:00	25	horse	4	103.769084	43.610893
03/09/2000	10:00	25	horse	5	103.774173	43.580593
03/09/2000	10:00	25	horse	4	103.777566	43.619084
03/09/2000	10:00	25	cattle	26	103.761320	43.585842
03/09/2000	10:00	25	sheep & goat	300	103.777566	43.619084
03/09/2000	10:00	25	sheep & goat	17	103.774173	43.617661
03/09/2000	10:00	25	sheep & goat	55	103.762658	43.615808
03/09/2000	10:00	25	sheep & goat	550	103.768895	43.615808
03/09/2000	19:41	26	horse	2	103.774173	43.597274
03/09/2000	19:41	26	sheep & goat	300	103.774173	43.601908
04/09/2000	17:40	28	horse	9	103.771419	43.609387
04/09/2000	17:40	28	horse	1	103.767388	43.609255
04/09/2000	17:40	28	horse	2	103.762382	43.607835
04/09/2000	17:40	28	cattle	30	103.770501	43.607246
04/09/2000	17:40	28	sheep & goat	50	103.774173	43.597274
04/09/2000		27	horse	12	103.776572	43.615808
04/09/2000		27	cattle	15	103.774173	43.601908
04/09/2000		27	sheep & goat	500	103.757210	43.599426
04/09/2000		27	sheep & goat	300	103.771235	43.608959
05/09/2000	09:00	29	horse	9	103.777497	43.617661
05/09/2000	09:00	29	cattle	30	103.768665	43.602966
05/09/2000	09:00	29	sheep & goat	500	103.785030	43.605324
05/09/2000	09:00	29	sheep & goat	300	103.774173	43.592641
06/09/2000	09:00	30	camel	12	103.764625	43.593548
06/09/2000	09:00	30	horse	3	103.777905	43.612204
06/09/2000	09:00	30	horse	7	103.771235	43.608959
06/09/2000	09:00	30	horse	1	103.774173	43.588007
06/09/2000	09:00	30	horse	1	103.774173	43.586154
06/09/2000	09:00	30	sheep & goat	300	103.764992	43.594404
06/09/2000	16:54	31	camel	2	103.763156	43.590123
06/09/2000	16:54	31	horse	6	103.771294	43.615808
06/09/2000	16:54	31	horse	1	103.774173	43.585227
06/09/2000	16:54	31	horse	3	103.776548	43.613515
06/09/2000	16:54	31	horse	3	103.779451	43.615808
06/09/2000	16:54	31	horse	2	103.775133	43.615808
06/09/2000	16:54	31	cattle	16	103.779451	43.615808
06/09/2000	16:54	31	sheep & goat	300	103.767563	43.600397
07/09/2000	09:00	32	horse	2	103.774173	43.585227
07/09/2000	09:00	32	cattle	21	103.766496	43.615808
07/09/2000	09:00	32	sheep & goat	300	103.764258	43.592692
07/09/2000	09:00	32	sheep & goat	400	103.767563	43.600397
07/09/2000	09:00	32	gazelle	1	103.768895	43.615808
07/09/2000	18:00	33	horse	8	103.777052	43.615808
07/09/2000	18:00	33	cattle	20	103.775373	43.615808
07/09/2000	18:00	33	sheep & goat	300	103.774173	43.609784
07/09/2000	18:00	33	sheep & goat	600	103.774173	43.588007
08/09/2000	09:30	34	camel	5	103.776209	43.617774
08/09/2000	09:30	34	camel	18	103.776572	43.615808
08/09/2000	09:30	34	horse	2	103.774173	43.604688
08/09/2000	09:30	34	horse	2	103.774173	43.606541
08/09/2000	09:30	34	cattle	14	103.774173	43.574107
08/09/2000	09:30	34	sheep & goat	300	103.774173	43.599127
08/09/2000	19:00	35	camel	18	103.779451	43.615808
08/09/2000	19:00	35	horse	5	103.774173	43.601908
08/09/2000	19:00	35	sheep & goat	300	103.774173	43.588007
09/09/2000	09:30	36	camel	4	103.777532	43.615808
09/09/2000	09:30	36	camel	1	103.772477	43.614170
09/09/2000	09:30	36	camel	25	103.774131	43.613492
09/09/2000	09:30	36	horse	2	103.769084	43.610893
09/09/2000	09:30	36	sheep & goat	600	103.774173	43.581057
09/09/2000	09:30	36	sheep & goat	300	103.768665	43.602966
09/09/2000	09:30	36	sheep & goat	550	103.774173	43.599127
09/09/2000	19:00	37	horse	7	103.774173	43.588007
09/09/2000	19:00	37	sheep & goat	300	103.774173	43.589860
09/09/2000	19:00	37	sheep & goat	550	103.757210	43.599426
10/09/2000	10:00	38	camel	13	103.779451	43.615808
10/09/2000	10:00	38	horse	7	103.774173	43.588007
10/09/2000	10:00	38	sheep & goat	550	103.763995	43.605979
10/09/2000	10:00	38	sheep & goat	300	103.774173	43.599127
11/09/2000	09:30	39	camel	6	103.774173	43.613028
11/09/2000	09:30	39	camel	5	103.772704	43.612383
11/09/2000	09:30	39	camel	4	103.778971	43.615808
11/09/2000	09:30	39	horse	4	103.766031	43.607945
11/09/2000	09:30	39	horse	7	103.774173	43.583374
11/09/2000	09:30	39	cattle	15	103.767456	43.615808
11/09/2000	09:30	39	sheep & goat	300	103.767388	43.609255
11/09/2000	19:15	40	camel	8	103.774173	43.617661
11/09/2000	19:15	40	camel	7	103.774173	43.610711
11/09/2000	19:15	40	camel	5	103.764992	43.594404
11/09/2000	19:15	40	camel	1	103.771786	43.610243
11/09/2000	19:15	40	horse	9	103.774173	43.610711
11/09/2000	19:15	40	sheep & goat	300	103.774173	43.599127
12/09/2000	09:40	41	camel	11	103.778426	43.616532
12/09/2000	09:40	41	camel	4	103.778011	43.615808
12/09/2000	09:40	41	camel	5	103.774173	43.608394
12/09/2000	09:40	41	camel	5	103.761320	43.585842
12/09/2000	09:40	41	horse	5	103.760219	43.583274
12/09/2000	09:40	41	horse	7	103.774173	43.588007
12/09/2000	09:40	41	sheep & goat	300	103.763891	43.591836
12/09/2000	18:20	42	horse	5	103.774173	43.588007
12/09/2000	18:20	42	horse	2	103.763995	43.605979
12/09/2000	18:20	42	cattle	25	103.776572	43.615808
12/09/2000	18:20	42	cattle	9	103.768895	43.615808
12/09/2000	18:20	42	sheep & goat	250	103.759471	43.603895
12/09/2000	18:20	42	camel	5	103.767930	43.601253
12/09/2000	18:20	42	horse	8	103.748467	43.555877
12/09/2000	18:20	42	horse	3	103.774173	43.589860
12/09/2000	18:20	42	horse	2	103.764992	43.594404
14/09/2000	14:00	43	camel	16	103.774829	43.617550
14/09/2000	14:00	43	horse	6	103.774173	43.585227
14/09/2000	14:00	43	horse	3	103.780958	43.609255
14/09/2000	14:00	43	sheep & goat	400	103.766094	43.596972
14/09/2000	14:00	43	sheep & goat	80	103.774173	43.597274
14/09/2000	14:00	43	sheep & goat	200	103.787065	43.603358
15/09/2000	07:35	44	camel	10	103.784351	43.605979
15/09/2000	07:35	44	horse	4	103.777052	43.615808
15/09/2000	07:35	44	horse	1	103.757210	43.599426
15/09/2000	07:35	44	horse	5	103.785698	43.611198
15/09/2000	07:35	44	sheep & goat	350	103.774173	43.585227
15/09/2000	19:30	45	camel	10	103.763995	43.605979
15/09/2000	19:30	45	horse	20	103.791136	43.599426
15/09/2000	19:30	45	horse	6	103.770102	43.611876
16/09/2000	08:30	46	camel	3	103.762638	43.604668
16/09/2000	08:30	46	camel	11	103.772400	43.616517
16/09/2000	08:30	46	horse	13	103.776009	43.611527
16/09/2000	08:30	46	sheep & goat	350	103.774173	43.585227
17/09/2000	10:00	47	horse	9	103.774173	43.585227
17/09/2000	10:00	47	horse	5	103.776209	43.613842
17/09/2000	10:00	47	cattle	3	103.776376	43.610671
17/09/2000	10:00	47	sheep & goat	350	103.761320	43.585842
18/09/2000	12:45	48	camel	16	103.783623	43.614199
18/09/2000	12:45	48	camel	6	103.779314	43.603822
18/09/2000	12:45	48	horse	9	103.768503	43.616774
18/09/2000	12:45	48	horse	2	103.774173	43.578740

continued on next page

continued from previous page

date	time	ID	kind	#	° East	° North
18/09/2000	12:45	48	sheep & goat	100	103.779990	43.612565
18/09/2000	12:45	48	sheep & goat	250	103.773439	43.614096
18/09/2000	12:45	48	sheep & goat	30	103.762658	43.615808
18/09/2000	16:10	49	camel	2	103.753817	43.596150
18/09/2000	16:10	49	camel	6	103.774173	43.611175
18/09/2000	16:10	49	horse	12	103.774173	43.585227
18/09/2000	16:10	49	horse	3	103.767456	43.615808
18/09/2000	16:10	49	cattle	8	103.770393	43.615164
18/09/2000	16:10	49	cattle	15	103.774173	43.616966
18/09/2000	16:10	49	sheep & goat	350	103.776376	43.610671
19/09/2000	08:30	50	camel	6	103.782315	43.607945
19/09/2000	08:30	50	camel	1	103.757210	43.599426
19/09/2000	08:30	50	horse	5	103.756442	43.608715
19/09/2000	08:30	50	horse	4	103.760219	43.583274
19/09/2000	08:30	50	cattle	9	103.756531	43.598771
19/09/2000	08:30	50	sheep & goat	350	103.774173	43.585227
19/09/2000	11:30	51	horse	7	103.774173	43.585227
19/09/2000	11:30	51	horse	4	103.778947	43.604678
19/09/2000	11:30	51	horse	4	103.776572	43.615808
19/09/2000	11:30	51	horse	2	103.753782	43.607651
19/09/2000	11:30	51	sheep & goat	300	103.755508	43.597143
19/09/2000	11:30	51	sheep & goat	150	103.750424	43.592873
19/09/2000	11:30	51	sheep & goat	250	103.754669	43.608006
19/09/2000	11:30	51	sheep & goat	80	103.763891	43.591836
19/09/2000	18:20	52	camel	12	103.763995	43.625637
19/09/2000	18:20	52	camel	6	103.761959	43.604013
19/09/2000	18:20	52	horse	10	103.774173	43.585227
19/09/2000	18:20	52	horse	3	103.774173	43.610248
19/09/2000	18:20	52	horse	2	103.770335	43.615808
20/09/2000	07:30	53	camel	7	103.757210	43.599426
20/09/2000	07:30	53	camel	10	103.776878	43.616759
20/09/2000	07:30	53	horse	4	103.779931	43.615808
20/09/2000	07:30	53	horse	4	103.774173	43.608394
20/09/2000	07:30	53	horse	5	103.747031	43.589597
20/09/2000	07:30	53	horse	16	103.757210	43.599426
20/09/2000	07:30	53	horse	3	103.768066	43.609911
20/09/2000	07:30	53	sheep & goat	250	103.774173	43.585227
21/09/2000	07:30	54	camel	5	103.774173	43.609321
21/09/2000	07:30	54	horse	7	103.771052	43.608531
21/09/2000	07:30	54	cattle	28	103.758382	43.578993
21/09/2000	07:30	54	sheep & goat	250	103.774173	43.585227
21/09/2000	19:00	55	camel	5	103.748388	43.590908
21/09/2000	19:00	55	horse	17	103.774173	43.583374
21/09/2000	19:00	55	horse	4	103.774173	43.609321
21/09/2000	19:00	55	sheep & goat	350	103.758382	43.578993
22/09/2000	09:00	56	horse	9	103.766031	43.607945
22/09/2000	09:00	56	horse	3	103.779681	43.602966
22/09/2000	09:00	56	cattle	4	103.767563	43.600397
22/09/2000	09:00	56	sheep & goat	300	103.774173	43.585227
22/09/2000	12:00	57	camel	1	103.750424	43.592873
22/09/2000	12:00	57	horse	4	103.788567	43.615808
22/09/2000	12:00	57	horse	7	103.764992	43.594404
22/09/2000	12:00	57	horse	4	103.783673	43.606634
22/09/2000	12:00	57	horse	5	103.779601	43.610566
22/09/2000	15:30	58	horse	5	103.774173	43.601908
22/09/2000	15:30	58	horse	12	103.773071	43.618376
22/09/2000	15:30	58	horse	5	103.774173	43.610248
22/09/2000	15:30	58	horse	5	103.780890	43.615808
22/09/2000	15:30	58	horse	6	103.771459	43.618429
22/09/2000	15:30	58	cattle	8	103.763995	43.605979
22/09/2000	15:30	58	sheep & goat	200	103.780280	43.609911
23/09/2000	14:30	59	horse	1	103.788567	43.615808
23/09/2000	14:30	59	horse	8	103.774173	43.585227
23/09/2000	14:30	59	horse	1	103.768503	43.614842
23/09/2000	14:30	59	horse	2	103.787744	43.602702
23/09/2000	14:30	59	horse	4	103.774173	43.585227
23/09/2000	18:30	60	horse	10	103.774173	43.585227
23/09/2000	18:30	60	horse	2	103.764673	43.606634
23/09/2000	18:30	60	horse	6	103.775191	43.614825
23/09/2000	18:30	60	cattle	4	103.763997	43.606644
23/09/2000	18:30	60	sheep & goat	300	103.774173	43.588007
25/09/2000	07:45	61	horse	5	103.778947	43.604678
25/09/2000	07:45	61	horse	3	103.776209	43.613842
25/09/2000	07:45	61	horse	3	103.779601	43.610566
25/09/2000	07:45	61	yak	4	103.779931	43.615808
25/09/2000	07:45	61	cattle	12	103.764421	43.611907
25/09/2000	07:45	61	cattle	35	103.761959	43.604013
25/09/2000	07:45	61	sheep & goat	300	103.774173	43.585227
26/09/2000	07:45	62	camel	3	103.738711	43.601623
26/09/2000	07:45	62	horse	5	103.761281	43.603358
26/09/2000	07:45	62	horse	15	103.760602	43.602702
26/09/2000	07:45	62	horse	2	103.776009	43.611527
26/09/2000	07:45	62	horse	2	103.738711	43.601623
26/09/2000	07:45	62	yak	5	103.768745	43.610566
26/09/2000	07:45	62	cattle	8	103.750424	43.592873
26/09/2000	07:45	62	cattle	24	103.761959	43.604013
26/09/2000	07:45	62	sheep & goat	350	103.774173	43.585227
27/09/2000	08:10	63	camel	2	103.738210	43.581078
27/09/2000	08:10	63	horse	11	103.756546	43.574712
27/09/2000	08:10	63	horse	2	103.740246	43.583044
27/09/2000	08:10	63	horse	1	103.762658	43.615808
27/09/2000	08:10	63	cattle	3	103.756546	43.574712
27/09/2000	08:10	63	cattle	21	103.782152	43.612616
27/09/2000	08:10	63	sheep & goat	350	103.774173	43.585227
27/09/2000	10:00	64	horse	7	103.760219	43.583274
27/09/2000	10:00	64	horse	2	103.782315	43.607945
27/09/2000	10:00	64	cattle	2	103.766031	43.607945
27/09/2000	10:00	64	cattle	8	103.783039	43.612262
27/09/2000	10:00	64	sheep & goat	350	103.774173	43.585227
28/09/2000	10:00	65	horse	4	103.773439	43.614096
28/09/2000	10:00	65	horse	5	103.774173	43.608394
28/09/2000	10:00	65	horse	6	103.762658	43.615808
28/09/2000	10:00	65	horse	4	103.778244	43.611876
28/09/2000	10:00	65	cattle	8	103.759484	43.581562
28/09/2000	10:00	65	cattle	2	103.773071	43.613240
28/09/2000	10:00	65	sheep & goat	350	103.774173	43.589860
28/09/2000	10:00	65	sheep & goat	350	103.774173	43.578740
28/09/2000	11:30	66	horse	3	103.776376	43.610671
28/09/2000	11:30	66	horse	5	103.762658	43.615808
28/09/2000	11:30	66	horse	5	103.771798	43.613515
28/09/2000	11:30	66	horse	6	103.765741	43.617613
28/09/2000	11:30	66	horse	1	103.774173	43.597274
28/09/2000	11:30	66	cattle	8	103.759484	43.581562
28/09/2000	11:30	66	sheep & goat	350	103.753817	43.596150
28/09/2000	13:00	67	camel	1	103.740246	43.583044
28/09/2000	13:00	67	horse	6	103.772137	43.617774
28/09/2000	13:00	67	horse	2	103.769766	43.605534
28/09/2000	13:00	67	horse	3	103.789527	43.615808
28/09/2000	13:00	67	horse	12	103.766194	43.619000
28/09/2000	13:00	67	sheep & goat	300	103.745385	43.615808
28/09/2000	13:00	67	sheep & goat	220	103.774173	43.613491
29/09/2000	10:00	68	horse	1	103.774173	43.585227
29/09/2000	10:00	68	horse	3	103.785698	43.611198
29/09/2000	10:00	68	sheep & goat	400	103.747031	43.589597
29/09/2000	10:00	68	sheep & goat	400	103.771459	43.613187
29/09/2000	18:00	69	cattle	5	103.769740	43.614035
29/09/2000	18:00	69	cattle	4	103.774173	43.612101
29/09/2000	18:00	69	sheep & goat	350	103.774173	43.589860
29/09/2000	18:00	69	horse	5	103.774173	43.610248
02/10/2000	13:30	70	horse	2	103.773620	43.585232
02/10/2000	13:30	70	horse	1	103.774377	43.616005
02/10/2000	13:30	70	cattle	18	103.766829	43.598685
02/10/2000	13:30	70	sheep & goat	380	103.767388	43.609255
02/10/2000	16:15	71	camel	3	103.750424	43.592873
02/10/2000	16:15	71	horse	1	103.768415	43.615808
02/10/2000	16:15	71	horse	1	103.774173	43.586154
02/10/2000	16:15	71	sheep & goat	380	103.760219	43.583274
02/10/2000	17:30	72	camel	3	103.757210	43.599426
02/10/2000	17:30	72	cattle	22	103.774173	43.617661
02/10/2000	17:30	72	cattle	15	103.771459	43.613187
02/10/2000	17:30	72	sheep & goat	250	103.760953	43.584986
03/10/2000		73	camel	2	103.747031	43.589597
03/10/2000		73	horse	1	103.752460	43.594839
03/10/2000		73	sheep & goat	300	103.782315	43.607945
05/10/2000	09:50	74	sheep & goat	400	103.748467	43.555877
05/10/2000	09:50	74	sheep & goat	200	103.774173	43.585227
05/10/2000	12:50	75	horse	10	103.770780	43.612532
05/10/2000	12:50	75	horse	10	103.770627	43.617227
05/10/2000	12:50	75	horse	8	103.766829	43.598685
05/10/2000	12:50	75	sheep & goat	220	103.774173	43.609321
05/10/2000	12:50	75	sheep & goat	400	103.766094	43.596972
05/10/2000	19:00	76	horse	2	103.770627	43.617227
05/10/2000	19:00	76	cattle	7	103.776209	43.617774
06/10/2000	10:00	77	horse	10	103.733461	43.576491
06/10/2000	10:00	77	sheep & goat	200	103.774173	43.577813
06/10/2000	10:00	77	sheep & goat	400	103.755812	43.573000
06/10/2000	10:00	77	sheep & goat	60	103.774173	43.588007
06/10/2000	10:00	77	sheep & goat	250	103.759484	43.581562
06/10/2000	13:00	78	horse	10	103.755812	43.573000
06/10/2000	13:00	78	horse	2	103.768745	43.610566

continued on next page

continued from previous page

date	time	ID	kind	#	° East	° North
06/10/2000	13:00	78	sheep & goat	200	103.748467	43.555877
06/10/2000	13:00	78	sheep & goat	400	103.763156	43.590123
06/10/2000	13:00	78	sheep & goat	50	103.753817	43.596150
06/10/2000	17:00	79	horse	7	103.770645	43.612401
06/10/2000	17:00	79	horse	2	103.781370	43.615808
06/10/2000	17:00	79	cattle	21	103.774173	43.611175
06/10/2000	17:00	79	sheep & goat	200	103.764992	43.594404
06/10/2000	17:00	79	sheep & goat	300	103.770780	43.612532
07/10/2000	09:00	80	horse	2	103.774173	43.608394
07/10/2000	09:00	80	sheep & goat	250	103.774173	43.585227
07/10/2000	13:00	81	camel	1	103.774173	43.615762
07/10/2000	13:00	81	camel	3	103.781850	43.615808
09/10/2000	15:00	82	camel	2	103.774365	43.615808
09/10/2000	15:00	82	camel	1	103.776209	43.617774
10/10/2000	13:30	83	horse	6	103.777478	43.608103
10/10/2000	13:30	83	horse	17	103.784351	43.605979
11/10/2000	12:00	84	camel	3	103.775530	43.617119
11/10/2000	12:00	84	horse	8	103.761320	43.585842
11/10/2000	12:00	84	horse	10	103.774173	43.612101
11/10/2000	12:00	84	sheep & goat	350	103.752140	43.564438
14/10/2000	11:00	86	horse	3	103.771459	43.618429
14/10/2000	11:00	86	horse	6	103.774173	43.592641
14/10/2000	11:00	86	horse	2	103.766829	43.598685
14/10/2000	11:00	86	cattle	1	103.774173	43.592641
14/10/2000	11:00	86	cattle	25	103.759484	43.581562
14/10/2000	11:00	86	sheep & goat	350	103.748467	43.555877
14/10/2000	11:00	86	sheep & goat	350	103.713104	43.556833
14/10/2000	13:00	191	wild sheep	12	103.770106	43.618620
26/10/2000	12:00	190	horse	12	103.775407	43.628217
26/10/2000	12:00	190	horse	5	103.774190	43.629656
26/10/2000	12:00	190	ibex	5	103.773022	43.627770
13/11/2000	17:00	85	horse	3	103.770780	43.612532
13/11/2000	17:00	85	cattle	22	103.747031	43.589597
13/11/2000	17:00	85	cattle	9	103.774173	43.569473
20/11/2000		192	horse	11	103.760480	43.600295
20/11/2000		192	horse	2	103.752573	43.584340
20/11/2000		192	cattle	2	103.763299	43.595713
21/11/2000	11:10	194	horse	11	103.772167	43.620261
21/11/2000	11:10	194	horse	2	103.772747	43.612145
21/11/2000	11:10	194	horse	9	103.745376	43.584340
21/11/2000	11:10	194	wild sheep	7	103.775863	43.618620
21/11/2000	13:00	195	horse	11	103.773607	43.619559
21/11/2000	13:00	195	wild sheep	7	103.775863	43.618620
21/11/2000	15:20	87	camel	6	103.710585	43.560005
21/11/2000	15:20	87	horse	15	103.754952	43.594128
21/11/2000	15:20	87	horse	14	103.752093	43.584340
21/11/2000	15:20	87	horse	4	103.748673	43.575116
21/11/2000	15:20	87	horse	2	103.710105	43.560005
21/11/2000	15:20	87	cattle	3	103.720636	43.561203
21/11/2000	15:20	87	cattle	17	103.724255	43.562305
21/11/2000	15:20	87	sheep & goat	500	103.712028	43.559811
22/11/2000	13:00	196	camel	5	103.729230	43.567465
22/11/2000	13:00	196	horse	5	103.784800	43.615050
22/11/2000	13:00	196	horse	2	103.782481	43.616975
22/11/2000	13:00	196	horse	7	103.762628	43.594128
22/11/2000	13:00	196	horse	2	103.751113	43.594128
22/11/2000	13:00	196	horse	4	103.758790	43.594128
22/11/2000	13:00	196	horse	2	103.783962	43.620545
22/11/2000	13:00	196	horse	2	103.780562	43.616975
22/11/2000	13:00	196	horse	13	103.786111	43.619237
22/11/2000	13:00	196	sheep & goat	200	103.737951	43.563408
22/11/2000	13:00	196	wild sheep	7	103.783034	43.615948
22/11/2000	16:00	197	horse	12	103.769318	43.619237
22/11/2000	16:00	197	horse	3	103.758899	43.618003
22/11/2000	16:00	197	horse	16	103.790909	43.619237
22/11/2000	16:00	197	cattle	5	103.710105	43.560005
22/11/2000	16:00	197	sheep & goat	280	103.717782	43.560005
22/11/2000	16:00	197	sheep & goat	280	103.710631	43.556918
22/11/2000	16:00	197	wild sheep	6	103.769318	43.619237
22/11/2000	16:00	197	wild sheep	4	103.761370	43.616975
22/11/2000	16:00	197	wild sheep	3	103.774666	43.612145
27/11/2000	12:15	198	camel	1	103.761232	43.612145
27/11/2000	12:15	198	horse	12	103.766168	43.616975
27/11/2000	12:15	198	sheep & goat	280	103.709672	43.556918
27/11/2000	12:15	198	sheep & goat	250	103.717782	43.560005
28/11/2000	10:30	199	camel	62	103.724517	43.563408
28/11/2000	10:30	199	camel	5	103.764249	43.616975
28/11/2000	10:30	199	horse	2	103.763289	43.616975
28/11/2000	18:00	201	camel	5	103.757601	43.600295
28/11/2000	18:00	201	horse	16	103.787279	43.616975
28/11/2000	18:00	201	horse	2	103.777446	43.606652
28/11/2000		88	ibex	3	103.773927	43.629487
28/11/2000		200	yak	9	103.777080	43.643137
29/11/2000	10:30	202	camel	1	103.761689	43.584340
29/11/2000	10:30	202	camel	40	103.764249	43.616975
29/11/2000	10:30	202	horse	2	103.751133	43.584340
29/11/2000	10:30	202	horse	2	103.764522	43.618604
29/11/2000	10:30	202	horse	2	103.779602	43.616975
29/11/2000	10:30	202	cattle	3	103.756891	43.584340
01/12/2000	10:25	203	camel	10	103.750654	43.584340
01/12/2000	10:25	203	camel	4	103.761689	43.584340
01/12/2000	10:25	203	camel	24	103.754722	43.600295
01/12/2000	10:25	203	camel	2	103.761621	43.608917
01/12/2000	10:25	203	camel	9	103.772648	43.606652
01/12/2000	10:25	203	camel	5	103.780562	43.616975
01/12/2000	10:25	203	horse	4	103.779530	43.618003
01/12/2000	10:25	203	cattle	8	103.765931	43.606652
01/12/2000	15:45	204	camel	4	103.775168	43.618486
01/12/2000	15:45	204	camel	5	103.774173	43.597274
01/12/2000	15:45	204	camel	9	103.761844	43.603465
01/12/2000	15:45	204	camel	2	103.748255	43.584340
01/12/2000	15:45	204	horse	2	103.761366	43.603570
01/12/2000	15:45	204	horse	13	103.780446	43.602486
01/12/2000	15:45	204	cattle	2	103.774508	43.597277
04/12/2000	17:00	206	camel	50	103.714903	43.560005
04/12/2000	17:00	206	horse	22	103.784262	43.612145
04/12/2000	17:00	206	horse	1	103.772940	43.613148
04/12/2000	17:00	206	sheep & goat	560	103.714903	43.560005
04/12/2000		205	camel	7	103.755375	43.606652
04/12/2000		205	camel	8	103.760173	43.606652
04/12/2000		205	camel	2	103.766890	43.606652
04/12/2000		205	camel	8	103.776486	43.606652
04/12/2000		205	camel	13	103.782244	43.606652
04/12/2000		205	camel	4	103.775555	43.619237
04/12/2000		205	horse	5	103.770828	43.612145
04/12/2000		205	horse	12	103.780962	43.615050
04/12/2000		205	horse	10	103.777683	43.616975
04/12/2000		205	cattle	5	103.710105	43.560005
04/12/2000		205	cattle	15	103.760480	43.600295
04/12/2000		205	wild sheep	3	103.772025	43.618620
05/12/2000		207	camel	11	103.712985	43.560086
05/12/2000		207	camel	50	103.707753	43.556918
05/12/2000		207	camel	2	103.779124	43.607762
05/12/2000		207	horse	6	103.771925	43.616975
05/12/2000		207	horse	2	103.758353	43.612145
05/12/2000		207	horse	22	103.774567	43.606652
05/12/2000		207	cattle	7	103.763052	43.606652
05/12/2000		207	cattle	4	103.772885	43.616975
05/12/2000		207	sheep & goat	280	103.708712	43.556918
05/12/2000		207	sheep & goat	280	103.706793	43.556918
06/12/2000	12:30	209	camel	6	103.747962	43.582513
06/12/2000	12:30	209	camel	4	103.753720	43.582513
06/12/2000	12:30	209	camel	3	103.756184	43.586406
06/12/2000	12:30	209	camel	3	103.767127	43.616975
06/12/2000	12:30	209	camel	5	103.753113	43.586406
06/12/2000	12:30	209	horse	2	103.758254	43.606652
06/12/2000	12:30	209	horse	23	103.777113	43.617599
06/12/2000	12:30	209	cattle	3	103.760173	43.606652
06/12/2000	12:30	209	sheep & goat	200	103.756599	43.582513
06/12/2000		210	camel	5	103.766642	43.603465
06/12/2000		210	camel	12	103.774117	43.601880
06/12/2000		210	camel	3	103.768204	43.599144
06/12/2000		210	camel	4	103.756707	43.592253
06/12/2000		210	camel	5	103.755180	43.590362
06/12/2000		210	horse	4	103.777705	43.610073
06/12/2000		210	horse	22	103.779464	43.612145
06/12/2000		210	horse	2	103.737993	43.569278
07/12/2000	13:30	89	horse	15	103.770150	43.631870
07/12/2000	13:30	89	yak	9	103.770150	43.631870
07/12/2000		211	camel	7	103.748922	43.582513
07/12/2000		211	camel	4	103.745367	43.568371
07/12/2000		211	camel	2	103.754038	43.588472
07/12/2000		211	camel	3	103.754700	43.590362
07/12/2000		211	camel	4	103.767284	43.619891
07/12/2000		211	horse	2	103.744547	43.575116
07/12/2000		211	cattle	10	103.736469	43.565436
11/12/2000	11:30	212	horse	4	103.770571	43.625122
11/12/2000	11:30	212	yak	4	103.771470	43.624107
15/12/2000	12:00	208	horse	12	103.752093	43.584340
15/12/2000	12:00	208	horse	10	103.736907	43.567465

continued on next page

continued from previous page

date	time	ID	kind	#	° East	° North
15/12/2000	12:00	208	horse	28	103.717782	43.560005
15/12/2000	12:00	208	horse	12	103.765278	43.600295
15/12/2000	12:00	208	horse	2	103.758790	43.594128
15/12/2000	12:00	208	horse	12	103.758790	43.594128
15/12/2000	12:00	208	horse	13	103.758790	43.594128
15/12/2000	12:00	208	sheep & goat	250	103.736907	43.567465
15/01/2001	10:30	90	camel	7	103.740745	43.567465
15/01/2001	10:30	90	camel	5	103.748734	43.584340
15/01/2001	10:30	90	camel	2	103.766030	43.612145
15/01/2001	10:30	90	horse	3	103.751159	43.588472
15/01/2001	10:30	90	horse	10	103.780424	43.612145
15/01/2001	10:30	90	cattle	8	103.749467	43.586406
15/01/2001	10:30	90	cattle	2	103.770076	43.600295
15/01/2001	10:30	216	horse	10	103.772282	43.633870
15/01/2001	10:30	216	horse	8	103.773242	43.633870
15/01/2001	10:30	216	horse	5	103.776120	43.633870
16/01/2001	11:20	91	camel	2	103.707753	43.556918
16/01/2001	11:20	91	camel	1	103.734988	43.567465
16/01/2001	11:20	91	camel	5	103.740037	43.575116
16/01/2001	11:20	91	camel	2	103.764011	43.606652
16/01/2001	11:20	91	horse	3	103.751639	43.588472
16/01/2001	11:20	91	cattle	2	103.743250	43.577035
16/01/2001	11:20	91	sheep & goat	150	103.703010	43.553589
16/01/2001	11:20	91	sheep & goat	150	103.700131	43.553589
16/01/2001	11:20	91	sheep & goat	150	103.707753	43.556918
22/01/2001	11:20	92	camel	2	103.749214	43.584340
22/01/2001	11:20	92	camel	5	103.776486	43.606652
22/01/2001	11:20	92	camel	17	103.766575	43.618003
22/01/2001	11:20	92	camel	1	103.764656	43.618003
22/01/2001	11:20	92	camel	6	103.714065	43.558807
22/01/2001	11:20	92	camel	1	103.748255	43.584340
22/01/2001	11:20	92	camel	2	103.769116	43.600295
22/01/2001	11:20	92	camel	6	103.713106	43.558807
22/01/2001	11:20	92	horse	1	103.707753	43.556918
22/01/2001	11:20	92	horse	3	103.722528	43.562305
22/01/2001	11:20	92	horse	3	103.751613	43.584340
22/01/2001	11:20	92	horse	11	103.776745	43.610073
22/01/2001	11:20	92	horse	5	103.762447	43.599144
22/01/2001	11:20	92	horse	5	103.755911	43.594128
22/01/2001	11:20	92	horse	5	103.768487	43.615050
22/01/2001	11:20	92	horse	2	103.750174	43.584340
22/01/2001	11:20	92	cattle	16	103.764649	43.615050
23/01/2001	10:50	93	camel	3	103.711495	43.556918
23/01/2001	10:50	93	camel	3	103.754952	43.594128
23/01/2001	10:50	93	camel	3	103.765672	43.596003
23/01/2001	10:50	93	camel	5	103.771995	43.600295
23/01/2001	10:50	93	camel	1	103.773365	43.616975
23/01/2001	10:50	93	camel	21	103.772501	43.616975
23/01/2001	10:50	93	horse	3	103.752553	43.594128
23/01/2001	10:50	93	horse	3	103.747295	43.584340
23/01/2001	10:50	93	horse	7	103.748315	43.586406
23/01/2001	10:50	93	horse	10	103.765576	43.596003
23/01/2001	10:50	93	horse	3	103.735729	43.571238
23/01/2001	10:50	93	horse	2	103.770028	43.610073
23/01/2001	10:50	93	horse	5	103.765374	43.600295
23/01/2001	10:50	93	horse	8	103.770062	43.614152
23/01/2001	10:50	93	horse	3	103.764011	43.606652
23/01/2001	10:50	93	cattle	10	103.764011	43.606652
23/01/2001	10:50	93	sheep & goat	250	103.776003	43.604503
23/01/2001	10:50	93	sheep & goat	170	103.708308	43.558807
24/01/2001	10:30	94	camel	8	103.766467	43.594128
24/01/2001	10:30	94	camel	4	103.774567	43.606652
24/01/2001	10:30	94	camel	4	103.757763	43.592253
24/01/2001	10:30	94	camel	19	103.777931	43.614152
24/01/2001	10:30	94	horse	7	103.755682	43.600295
24/01/2001	10:30	94	horse	3	103.765805	43.599144
24/01/2001	10:30	94	horse	3	103.759750	43.594128
24/01/2001	10:30	94	horse	5	103.766275	43.594128
24/01/2001	10:30	94	horse	4	103.732892	43.568371
24/01/2001	10:30	94	horse	9	103.775047	43.606652
24/01/2001	10:30	94	horse	4	103.756811	43.604503
24/01/2001	10:30	94	horse	3	103.765230	43.610073
24/01/2001	10:30	94	horse	6	103.753032	43.594128
24/01/2001	10:30	94	cattle	16	103.765931	43.606652
24/01/2001	10:30	97	yak	3	103.775161	43.637080
24/01/2001	10:30	97	yak	11	103.775242	43.635359
24/01/2001	10:30	97	yak	2	103.778098	43.634853
25/01/2001		96	camel	4	103.735468	43.567465
25/01/2001		96	camel	7	103.742665	43.567465
25/01/2001		96	horse	3	103.763151	43.612145
25/01/2001		96	horse	5	103.747547	43.586406
25/01/2001		96	horse	6	103.744416	43.584340
25/01/2001		96	horse	8	103.742665	43.567465
25/01/2001		96	cattle	11	103.769765	43.604503
25/01/2001		96	cattle	23	103.759617	43.597993
25/01/2001		96	wild sheep	1	103.777446	43.606652
25/01/2001		98	yak	0	103.777080	43.633870
26/01/2001	11:00	99	camel	1	103.746335	43.584340
26/01/2001	11:00	99	camel	2	103.707753	43.556918
26/01/2001	11:00	99	camel	1	103.771036	43.600295
26/01/2001	11:00	99	camel	2	103.765507	43.594128
26/01/2001	11:00	99	camel	2	103.759770	43.584340
26/01/2001	11:00	99	horse	5	103.750680	43.588472
26/01/2001	11:00	99	horse	5	103.757579	43.590362
26/01/2001	11:00	99	horse	20	103.751113	43.594128
26/01/2001	11:00	99	horse	5	103.749214	43.584340
26/01/2001	11:00	99	horse	5	103.751133	43.584340
26/01/2001	11:00	99	cattle	3	103.746815	43.584340
26/01/2001	11:00	99	cattle	10	103.765931	43.606652
26/01/2001	11:00	99	cattle	22	103.780155	43.615948
26/01/2001	11:00	99	sheep & goat	150	103.761235	43.588472
29/01/2001		100	camel	1	103.764548	43.594128
29/01/2001		100	camel	3	103.715742	43.561203
29/01/2001		100	camel	7	103.707753	43.556918
29/01/2001		100	horse	11	103.773707	43.612145
29/01/2001		100	horse	2	103.765070	43.612145
29/01/2001		100	horse	17	103.763052	43.606652
29/01/2001		100	horse	5	103.753763	43.600295
29/01/2001		100	horse	31	103.751113	43.594128
29/01/2001		100	horse	12	103.753859	43.597993
29/01/2001		100	horse	3	103.751901	43.584340
29/01/2001		100	horse	16	103.754700	43.590362
29/01/2001		100	cattle	14	103.751133	43.584340
29/01/2001		100	cattle	19	103.752803	43.600295
29/01/2001		100	sheep & goat	4	103.712071	43.556918
30/01/2001	11:30	95	camel	7	103.766487	43.584340
30/01/2001	11:30	95	camel	1	103.770441	43.606652
30/01/2001	11:30	95	horse	8	103.757877	43.588472
30/01/2001	11:30	95	horse	5	103.752599	43.588472
30/01/2001	11:30	95	horse	5	103.747801	43.588472
30/01/2001	11:30	95	horse	1	103.750577	43.606652
30/01/2001	11:30	95	horse	3	103.777545	43.612145
30/01/2001	11:30	95	horse	26	103.735594	43.569278
30/01/2001	11:30	95	horse	13	103.744922	43.588472
30/01/2001	11:30	95	cattle	20	103.744922	43.588472
30/01/2001	11:30	95	cattle	15	103.747801	43.588472
30/01/2001	11:30	95	cattle	16	103.749110	43.580687
30/01/2001	11:30	95	sheep & goat	300	103.766487	43.584340
31/01/2001		101	camel	2	103.723487	43.562305
31/01/2001		101	camel	7	103.707753	43.556918
31/01/2001		101	camel	4	103.731192	43.565436
31/01/2001		101	camel	10	103.731276	43.569278
31/01/2001		101	camel	8	103.754972	43.584340
31/01/2001		101	camel	6	103.761941	43.586406
31/01/2001		101	horse	5	103.751133	43.584340
31/01/2001		101	horse	7	103.764114	43.588472
31/01/2001		101	horse	3	103.757397	43.588472
31/01/2001		101	horse	13	103.733548	43.567465
31/01/2001		101	horse	21	103.730973	43.568371
31/01/2001		101	cattle	18	103.759770	43.584340
31/01/2001		101	cattle	12	103.764011	43.606652
31/01/2001		101	sheep & goat	150	103.767175	43.590362
02/02/2001		102	camel	6	103.723557	43.563408
02/02/2001		102	camel	4	103.737498	43.568371
02/02/2001		102	camel	3	103.776486	43.606652
02/02/2001		102	horse	2	103.771238	43.601880
02/02/2001		102	horse	6	103.735947	43.567465
02/02/2001		102	horse	7	103.761133	43.606652
02/02/2001		102	horse	4	103.763151	43.612145
02/02/2001		102	horse	1	103.744792	43.580687
02/02/2001		102	horse	57	103.736907	43.567465
02/02/2001		102	horse	2	103.736619	43.567465
02/02/2001		102	horse	19	103.701441	43.555030
02/02/2001		102	horse	7	103.738128	43.571238
02/02/2001		102	cattle	4	103.737993	43.569278
02/02/2001		102	cattle	10	103.746335	43.584340
02/02/2001		102	cattle	15	103.737786	43.568371
02/02/2001		102	sheep & goat	200	103.736554	43.569278
02/02/2001		102	sheep & goat	170	103.728547	43.563408
02/02/2001		103	yak	16	103.776120	43.633870

continued on next page

continued from previous page

date	time	ID	kind	#	° East	° North
12/02/2001	10:00	106	camel	3	103.708712	43.556918
12/02/2001	10:00	106	camel	5	103.775284	43.616975
12/02/2001	10:00	106	camel	8	103.714929	43.558807
12/02/2001	10:00	106	horse	3	103.737784	43.573198
12/02/2001	10:00	106	horse	10	103.737210	43.568371
12/02/2001	10:00	106	horse	2	103.733852	43.568371
12/02/2001	10:00	106	horse	5	103.708712	43.556918
12/02/2001	10:00	106	horse	2	103.747295	43.584340
12/02/2001	10:00	106	horse	6	103.765070	43.612145
12/02/2001	10:00	106	horse	12	103.764548	43.594128
12/02/2001	10:00	106	horse	7	103.753428	43.580687
12/02/2001	10:00	106	horse	3	103.756307	43.580687
12/02/2001	10:00	106	horse	9	103.762195	43.588472
12/02/2001	10:00	106	horse	4	103.758226	43.580687
12/02/2001	10:00	106	horse	26	103.750680	43.588472
12/02/2001	10:00	106	cattle	13	103.751822	43.590362
12/02/2001	10:00	106	cattle	3	103.751997	43.584340
12/02/2001	10:00	106	sheep & goat	150	103.708712	43.556918
12/02/2001	10:00	106	gazelle	12	103.757099	43.590362
13/02/2001	15:20	105	camel	25	103.729230	43.567465
13/02/2001	15:20	105	camel	5	103.742205	43.582513
13/02/2001	15:20	105	horse	2	103.753209	43.586406
13/02/2001	15:20	105	horse	13	103.769164	43.599144
13/02/2001	15:20	105	horse	12	103.761487	43.599144
13/02/2001	15:20	105	horse	42	103.746841	43.588472
13/02/2001	15:20	105	horse	17	103.758103	43.586406
13/02/2001	15:20	105	horse	11	103.746335	43.584340
13/02/2001	15:20	105	horse	11	103.748922	43.582513
13/02/2001	15:20	105	horse	21	103.750980	43.597993
13/02/2001	15:20	105	cattle	21	103.744416	43.584340
13/02/2001	15:20	105	sheep & goat	350	103.738826	43.567465
13/02/2001	15:20	105	sheep & goat	200	103.759770	43.584340
08/03/2001	17:50	104	horse	19	103.754326	43.588472
08/03/2001	17:50	104	horse	6	103.748757	43.612145
08/03/2001	17:50	104	horse	12	103.756871	43.594128
08/03/2001	17:50	104	horse	2	103.760874	43.596003
08/03/2001	17:50	104	horse	7	103.759702	43.608917
08/03/2001	17:50	104	horse	10	103.756335	43.606652
08/03/2001	17:50	104	yak	8	103.763289	43.616975
08/03/2001	17:50	104	yak	3	103.774874	43.600295
08/03/2001	17:50	104	cattle	15	103.756871	43.594128
08/03/2001	17:50	104	cattle	9	103.767949	43.612145
08/03/2001	17:50	104	gazelle	55	103.765278	43.600295
12/03/2001		107	camel	3	103.708712	43.556918
12/03/2001		107	camel	6	103.724063	43.562305
12/03/2001		107	horse	4	103.769116	43.600295
12/03/2001		107	horse	9	103.770828	43.612145
12/03/2001		107	horse	6	103.778664	43.610073
12/03/2001		107	horse	3	103.761232	43.612145
12/03/2001		107	horse	1	103.734988	43.567465
12/03/2001		107	horse	10	103.762399	43.600295
12/03/2001		107	cattle	4	103.768087	43.616975
12/03/2001		107	cattle	4	103.767949	43.612145
12/03/2001		107	sheep & goat	280	103.714470	43.556918
12/03/2001		107	sheep & goat	280	103.712071	43.556918
12/03/2001		107	gazelle	50	103.767879	43.601880
14/03/2001	9:35	108	camel	1	103.714470	43.556918
14/03/2001	9:35	108	horse	9	103.769868	43.612145
14/03/2001	9:35	108	horse	1	103.730274	43.563408
14/03/2001	9:35	108	horse	3	103.740392	43.569278
14/03/2001	9:35	108	horse	12	103.753137	43.578861
14/03/2001	9:35	108	horse	7	103.758491	43.616975
14/03/2001	9:35	108	horse	10	103.760480	43.600295
14/03/2001	9:35	108	horse	1	103.778405	43.606652
14/03/2001	9:35	108	sheep & goat	560	103.714470	43.556918
14/03/2001	9:35	108	gazelle	17	103.751133	43.584340
14/03/2001	9:35	108	gazelle	39	103.754972	43.584340
14/03/2001	14:45	109	horse	9	103.777545	43.612145
14/03/2001	14:45	109	horse	10	103.766171	43.605542
14/03/2001	14:45	109	yak	13	103.779601	43.621050
14/03/2001	14:45	109	sheep & goat	280	103.749299	43.578861
14/03/2001	14:45	109	sheep & goat	240	103.757267	43.580687
14/03/2001	14:45	109	sheep & goat	280	103.737210	43.568371
14/03/2001	14:45	109	sheep & goat	40	103.717878	43.560005
15/03/2001	9:30	111	camel	1	103.708712	43.556918
15/03/2001	9:30	111	horse	2	103.758739	43.614152
15/03/2001	9:30	111	horse	3	103.761232	43.612145
15/03/2001	9:30	111	horse	7	103.769213	43.597993
15/03/2001	9:30	111	horse	2	103.752512	43.575116
15/03/2001	9:30	111	horse	1	103.766589	43.611109
15/03/2001	9:30	111	sheep & goat	280	103.708712	43.556918
15/03/2001	9:30	111	gazelle	17	103.758103	43.586406
15/03/2001	18:30	113	camel	2	103.749694	43.584340
15/03/2001	18:30	113	horse	6	103.771440	43.603465
15/03/2001	18:30	113	horse	5	103.761844	43.603465
15/03/2001	18:30	113	sheep & goat	280	103.708712	43.556918
15/03/2001	18:30	113	gazelle	25	103.758790	43.594128
15/03/2001		112	yak	7	103.775128	43.638103
15/03/2001		112	yak	8	103.766689	43.620545
15/03/2001		112	ibex	14	103.772561	43.627052
19/03/2001		110	camel	3	103.710227	43.558807
19/03/2001		110	horse	2	103.766487	43.584340
19/03/2001		110	horse	3	103.765027	43.594128
19/03/2001		110	gazelle	41	103.763588	43.594128
20/03/2001	9:30	114	camel	1	103.708424	43.556918
20/03/2001	9:30	114	camel	3	103.711187	43.558807
20/03/2001	9:30	114	horse	1	103.714903	43.560005
20/03/2001	9:30	114	horse	12	103.768487	43.615050
20/03/2001	9:30	114	horse	4	103.716822	43.560005
20/03/2001	9:30	114	horse	5	103.768007	43.615050
20/03/2001	9:30	114	sheep & goat	560	103.708712	43.556918
20/03/2001	9:30	114	sheep & goat	1	103.717302	43.560005
20/03/2001	9:30	114	gazelle	41	103.759617	43.597993
25/03/2001		117	sheep & goat	200	103.732151	43.565436
25/03/2001		117	gazelle	35	103.772648	43.606652
25/03/2001		117	camel	6	103.731671	43.565436
25/03/2001		117	camel	3	103.772648	43.606652
26/03/2001		118	camel	6	103.731671	43.565436
26/03/2001		118	camel	3	103.760709	43.594128
26/03/2001		118	horse	15	103.752890	43.619891
26/03/2001		118	gazelle	10	103.764415	43.597993
07/04/2001	12:30	116	horse	4	103.770919	43.624041
07/04/2001	12:30	116	yak	0	103.777080	43.633870
10/04/2001	11:20	115	horse	17	103.765070	43.612145
10/04/2001	11:20	115	horse	2	103.708158	43.555030
10/04/2001	11:20	115	sheep & goat	280	103.711187	43.558807
10/04/2001	11:20	115	sheep & goat	280	103.719580	43.561203
20/04/2001	17:00	120	horse	1	103.769399	43.604678
20/04/2001	17:00	120	horse	8	103.767388	43.609255
20/04/2001		119	cattle	4	103.775212	43.629009
20/04/2001		119	ibex	1	103.772466	43.626532
21/04/2001	18:00	121	sheep & goat	100	103.728285	43.562305
21/04/2001	18:00	121	sheep & goat	100	103.709672	43.556918
21/04/2001	18:00	121	gazelle	4	103.737867	43.567465
21/04/2001	19:30	122	camel	1	103.713510	43.556918
21/04/2001	19:30	122	sheep & goat	200	103.713510	43.556918
21/04/2001	19:30	122	gazelle	10	103.749299	43.578861
21/04/2001	19:30	122	gazelle	4	103.740392	43.569278
21/04/2001	19:30	122	gazelle	11	103.756803	43.592253
23/04/2001	12:30	123	horse	4	103.771366	43.615050
23/04/2001	12:30	123	horse	3	103.742311	43.569278
23/04/2001	12:30	123	horse	3	103.768335	43.614152
23/04/2001	12:30	123	horse	10	103.774804	43.616975
23/04/2001	12:30	123	horse	4	103.771846	43.615050
23/04/2001	12:30	123	horse	2	103.761844	43.603465
23/04/2001	12:30	123	horse	1	103.776185	43.611109
23/04/2001	12:30	123	sheep & goat	150	103.744365	43.571238
23/04/2001	12:30	123	sheep & goat	20	103.730712	43.565436
23/04/2001	12:30	123	gazelle	4	103.751325	43.584340
23/04/2001	12:30	123	gazelle	120	103.761156	43.596998
24/04/2001	9:30	124	horse	15	103.777710	43.613416
24/04/2001	9:30	124	horse	18	103.770134	43.606390
25/04/2001		125	horse	7	103.773634	43.625352
25/04/2001		125	ibex	10	103.772680	43.628677
25/04/2001		126	horse	10	103.771246	43.583497
25/04/2001		126	horse	15	103.778491	43.610839
25/04/2001		126	horse	2	103.779319	43.611638
25/04/2001		126	horse	5	103.765008	43.565614
25/04/2001		126	sheep & goat	150	103.774173	43.588007
25/04/2001		126	sheep & goat	50	103.763380	43.570661
30/04/2001	13:15	128	horse	2	103.737291	43.567465
30/04/2001	13:15	128	horse	4	103.782343	43.612145
30/04/2001	13:15	128	horse	17	103.784163	43.606652
30/04/2001	13:15	128	sheep & goat	30	103.750174	43.584340
30/04/2001	14:00	127	horse	9	103.763995	43.605979
30/04/2001	14:00	127	horse	5	103.777845	43.607246
30/04/2001	14:00	127	sheep & goat	100	103.767563	43.600397
04/05/2001		130	horse	13	103.774633	43.610731
04/05/2001		130	horse	1	103.775251	43.613230
04/05/2001		130	horse	5	103.782678	43.614360

continued on next page

continued from previous page

date	time	ID	kind	#	° East	° North
04/05/2001		130	horse	10	103.753817	43.596150
04/05/2001		130	cattle	5	103.774173	43.597274
04/05/2001		130	gazelle	4	103.778923	43.611221
04/05/2001		130	gazelle	12	103.778923	43.611221
04/05/2001		130	gazelle	24	103.776423	43.610690
05/05/2001	11:00	131	gazelle	150	103.765278	43.600295
08/05/2001	11:00	129	horse	2	103.768157	43.626007
08/05/2001	11:00	129	horse	2	103.770717	43.629160
08/05/2001	11:00	129	horse	2	103.776475	43.629160
08/05/2001	11:00	129	ibex	13	103.775907	43.631870
08/05/2001		132	horse	2	103.769742	43.610331
08/05/2001		132	gazelle	40	103.750904	43.602834
08/05/2001		132	gazelle	23	103.770037	43.610696
08/05/2001		132	gazelle	10	103.764514	43.601979
08/05/2001		132	gazelle	45	103.771353	43.612059
08/05/2001		132	gazelle	4	103.770392	43.612955
08/05/2001		132	gazelle	12	103.770392	43.612955
08/05/2001		132	gazelle	40	103.755269	43.601545
08/05/2001		132	gazelle	50	103.757288	43.603068
08/05/2001		132	camel	5	103.769742	43.610331
08/05/2001		132	horse	3	103.771018	43.609561
08/05/2001		132	horse	7	103.774173	43.592641
08/05/2001		132	horse	14	103.763617	43.598152
08/05/2001		132	horse	3	103.774173	43.609321
08/05/2001		132	horse	4	103.779463	43.612616
10/05/2001	15:00	133	camel	6	103.768005	43.608709
10/05/2001	15:00	133	horse	2	103.774675	43.610269
10/05/2001	15:00	133	horse	2	103.760602	43.602702
10/05/2001	15:00	133	horse	7	103.768669	43.608217
10/05/2001	15:00	133	horse	8	103.777478	43.608103
10/05/2001	15:00	133	cattle	1	103.771340	43.600293
10/05/2001	15:00	133	cattle	4	103.780280	43.609911
10/05/2001	15:00	133	cattle	1	103.768665	43.602966
10/05/2001	15:00	133	sheep & goat	200	103.760875	43.610489
10/05/2001	15:00	133	sheep & goat	100	103.760602	43.602702
10/05/2001	15:00	133	gazelle	12	103.767388	43.609255
17/05/2001	17:00	134	horse	2	103.777771	43.609789
17/05/2001	17:00	134	cattle	8	103.776799	43.608841
17/05/2001	17:00	134	sheep & goat	200	103.758452	43.605177
17/05/2001	17:00	134	sheep & goat	40	103.768119	43.607458
18/05/2001	19:45	135	camel	5	103.762178	43.595744
18/05/2001	19:45	135	camel	2	103.770235	43.605358
18/05/2001	19:45	135	horse	2	103.761837	43.601610
18/05/2001	19:45	135	horse	8	103.772918	43.601960
18/05/2001	19:45	135	horse	15	103.770840	43.597556
18/05/2001	19:45	135	horse	3	103.772204	43.610583
18/05/2001	19:45	135	cattle	10	103.769640	43.596846
18/05/2001	19:45	135	sheep & goat	8	103.769206	43.597906
18/05/2001	19:45	135	sheep & goat	5	103.761281	43.603358
18/05/2001	19:45	135	sheep & goat	10	103.753817	43.596150
18/05/2001	19:45	135	sheep & goat	5	103.750691	43.605234
18/05/2001	19:45	135	gazelle	10	103.762178	43.595744
18/05/2001	19:45	135	gazelle	25	103.777997	43.616131
19/05/2001	13:30	136	camel	8	103.767936	43.605375
19/05/2001	13:30	136	camel	5	103.772500	43.597345
19/05/2001	13:30	136	horse	2	103.777052	43.610993
19/05/2001	13:30	136	horse	3	103.767219	43.590745
19/05/2001	13:30	136	horse	10	103.764238	43.580003
19/05/2001	13:30	136	cattle	3	103.778923	43.611221
19/05/2001	13:30	136	gazelle	15	103.775129	43.615727
20/05/2001		137	camel	1	103.771174	43.599381
20/05/2001		137	camel	2	103.765480	43.584479
20/05/2001		137	horse	2	103.776251	43.616966
20/05/2001		137	horse	4	103.765480	43.584479
20/05/2001		137	horse	2	103.773636	43.615040
20/05/2001		137	cattle	1	103.775092	43.613370
20/05/2001		137	cattle	4	103.778006	43.594818
20/05/2001		137	sheep & goat	10	103.748267	43.585992
22/05/2001	12:30	138	yak	0	103.777080	43.633870
24/05/2001	11:00	139	yak	1	103.775517	43.627538
24/05/2001	11:00	139	yak	4	103.778786	43.631870
24/05/2001	11:00	139	cattle	4	103.770606	43.624107
24/05/2001	11:00	139	ibex	5	103.775515	43.625453
24/05/2001	11:00	139	ibex	15	103.770241	43.628628
24/05/2001	11:00	139	ibex	4	103.775515	43.633794
26/05/2001		140	camel	1	103.773337	43.606576
26/05/2001		140	camel	1	103.768957	43.597010
26/05/2001		140	camel	2	103.764327	43.589684
26/05/2001		140	gazelle	41	103.770441	43.612204
01/06/2001	14:20	141	camel	1	103.774173	43.611175
01/06/2001	14:20	141	camel	5	103.762702	43.616777
01/06/2001	14:20	141	camel	1	103.754981	43.583706
01/06/2001	14:20	141	horse	6	103.778328	43.613491
01/06/2001	14:20	141	horse	6	103.777751	43.610874
01/06/2001	14:20	141	horse	2	103.764238	43.580003
01/06/2001	14:20	141	cattle	2	103.771547	43.608841
01/06/2001	14:20	141	cattle	1	103.768437	43.616293
01/06/2001	14:20	141	sheep & goat	120	103.780280	43.609911
03/06/2001	13:00	142	horse	1	103.768687	43.624107
03/06/2001	13:00	142	horse	1	103.773434	43.628436
03/06/2001	13:00	142	horse	2	103.775833	43.634565
03/06/2001	13:00	142	yak	4	103.772955	43.625080
03/06/2001	13:00	142	gazelle	1	103.773080	43.628304
03/06/2001	16:00	143	camel	1	103.775824	43.613531
03/06/2001	16:00	143	camel	1	103.772931	43.611332
03/06/2001	16:00	143	camel	1	103.769238	43.610129
03/06/2001	16:00	143	horse	4	103.777566	43.619084
03/06/2001	16:00	143	horse	8	103.750183	43.575681
03/06/2001	16:00	143	horse	4	103.777953	43.615164
03/06/2001	16:00	143	cattle	2	103.777953	43.615164
03/06/2001	16:00	143	sheep & goat	4	103.777455	43.607100
03/06/2001	16:00	143	sheep & goat	150	103.772082	43.592729
03/06/2001	16:00	143	sheep & goat	30	103.753896	43.573814
03/06/2001	16:00	143	gazelle	1	103.770780	43.612532
06/06/2001	13:20	144	horse	2	103.772539	43.625775
06/06/2001	13:20	144	cattle	3	103.772447	43.620545
06/06/2001	13:20	144	wild sheep	3	103.768884	43.622075
06/06/2001	13:20	144	gazelle	1	103.776188	43.632525
06/06/2001	18:00	145	camel	2	103.675750	43.538693
06/06/2001	18:00	145	camel	7	103.724996	43.563408
06/06/2001	18:00	145	camel	1	103.742665	43.567465
06/06/2001	18:00	145	camel	1	103.779464	43.612145
06/06/2001	18:00	145	camel	4	103.764971	43.606652
06/06/2001	18:00	145	camel	9	103.758973	43.607762
06/06/2001	18:00	145	horse	3	103.787879	43.624107
06/06/2001	18:00	145	horse	3	103.774666	43.612145
06/06/2001	18:00	145	horse	7	103.762092	43.606652
06/06/2001	18:00	145	horse	3	103.765070	43.612145
06/06/2001	18:00	145	horse	2	103.771846	43.615050
06/06/2001	18:00	145	cattle	2	103.761636	43.596998
06/06/2001	18:00	145	sheep & goat	200	103.778105	43.611109
06/06/2001	18:00	145	gazelle	4	103.671725	43.534167
06/06/2001	18:00	145	gazelle	12	103.675689	43.535728
06/06/2001	18:00	145	gazelle	3	103.717302	43.560005
06/06/2001	18:00	145	gazelle	3	103.757553	43.610073
06/06/2001	18:00	145	gazelle	15	103.754246	43.615948
06/06/2001	18:00	145	gazelle	5	103.768111	43.610202
06/06/2001	20:00	213	ibex	4	103.774202	43.626702
07/06/2001	10:30	146	camel	9	103.770481	43.603465
07/06/2001	10:30	146	camel	2	103.760885	43.603465
07/06/2001	10:30	146	camel	2	103.744365	43.571238
07/06/2001	10:30	146	camel	1	103.733069	43.567465
07/06/2001	10:30	146	camel	1	103.703914	43.556918
07/06/2001	10:30	146	cattle	10	103.748255	43.584340
07/06/2001	10:30	146	gazelle	1	103.753017	43.586406
07/06/2001	10:30	146	gazelle	6	103.754230	43.588472
07/06/2001	10:30	146	gazelle	4	103.755468	43.590362
10/06/2001	19:50	147	camel	1	103.771079	43.581651
10/06/2001	19:50	147	horse	17	103.757763	43.572267
10/06/2001	19:50	147	cattle	3	103.773337	43.606576
10/06/2001	19:50	147	sheep & goat	170	103.782259	43.609256
10/06/2001	19:50	147	gazelle	4	103.772840	43.608507
10/06/2001	19:50	147	gazelle	12	103.769951	43.600591
10/06/2001	19:50	147	gazelle	16	103.769250	43.602746
10/06/2001	19:50	147	gazelle	10	103.770235	43.605358
10/06/2001	19:50	147	gazelle	5	103.758646	43.604914
16/06/2001	13:00	148	cattle	1	103.778244	43.611876
16/06/2001	13:00	148	sheep & goat	60	103.779601	43.610566
21/06/2001	11:00	149	camel	1	103.753805	43.577035
21/06/2001	11:00	149	camel	3	103.774096	43.608917
21/06/2001	11:00	149	camel	1	103.776106	43.612145
21/06/2001	11:00	149	camel	1	103.769447	43.615050
21/06/2001	11:00	149	camel	5	103.756611	43.592253
21/06/2001	11:00	149	camel	10	103.773914	43.600295
21/06/2001	11:00	149	horse	3	103.757267	43.580687
21/06/2001	11:00	149	gazelle	3	103.761258	43.596003
21/06/2001	16:30	150	camel	1	103.774173	43.592641
21/06/2001	16:30	150	camel	1	103.772082	43.592729
21/06/2001	16:30	150	camel	1	103.770007	43.592992
21/06/2001	16:30	150	camel	1	103.771089	43.612259

continued on next page

continued from previous page

date	time	ID	kind	#	° East	° North
21/06/2001	16:30	150	camel	5	103.768709	43.596115
21/06/2001	16:30	150	sheep & goat	20	103.778971	43.607783
21/06/2001	16:30	150	sheep & goat	3	103.781637	43.608600
22/06/2001	15:00	151	camel	7	103.769250	43.602746
22/06/2001	15:00	151	camel	2	103.765968	43.594038
22/06/2001	15:00	151	camel	2	103.770840	43.597556
22/06/2001	15:00	151	camel	9	103.774173	43.611175
22/06/2001	15:00	151	camel	5	103.773086	43.603807
22/06/2001	15:00	151	horse	2	103.776925	43.619604
22/06/2001	15:00	151	horse	4	103.782777	43.615081
22/06/2001	15:00	151	sheep & goat	50	103.779677	43.608217
22/06/2001	15:00	151	sheep & goat	25	103.780958	43.609255
22/06/2001	15:00	151	sheep & goat	10	103.785964	43.607835
22/06/2001	15:00	151	sheep & goat	70	103.781839	43.615420
22/06/2001	15:00	151	sheep & goat	70	103.780316	43.616854
23/06/2001	12:00	152	horse	2	103.771086	43.624107
23/06/2001	12:00	152	horse	4	103.770717	43.629160
23/06/2001	12:00	152	yak	3	103.777080	43.638504
23/06/2001	12:00	152	cattle	5	103.770076	43.626007
23/06/2001	12:00	152	ibex	2	103.774846	43.620545
24/06/2001	16:00	153	camel	1	103.760602	43.602702
24/06/2001	16:00	153	camel	3	103.747121	43.625317
24/06/2001	16:00	153	camel	1	103.770840	43.597556
24/06/2001	16:00	153	camel	1	103.750183	43.575681
24/06/2001	16:00	153	horse	4	103.774842	43.608423
24/06/2001	16:00	153	horse	1	103.774842	43.608423
24/06/2001	16:00	153	sheep & goat	60	103.780227	43.607458
24/06/2001	16:00	153	sheep & goat	80	103.780280	43.609911
26/06/2001	8:00	155	camel	1	103.769116	43.600295
04/07/2001	15:00	156	camel	1	103.766238	43.600295
04/07/2001	15:00	156	camel	4	103.752825	43.586406
04/07/2001	15:00	156	camel	1	103.758657	43.597993
04/07/2001	15:00	156	camel	2	103.718689	43.562305
04/07/2001	15:00	156	camel	5	103.722702	43.558807
04/07/2001	15:00	156	camel	2	103.720227	43.556918
04/07/2001	15:00	156	horse	4	103.761770	43.615050
04/07/2001	15:00	156	horse	6	103.780424	43.612145
04/07/2001	15:00	156	horse	2	103.703914	43.556918
04/07/2001	15:00	156	cattle	1	103.732193	43.563408
04/07/2001	15:00	156	cattle	6	103.719652	43.556918
04/07/2001	15:00	156	sheep & goat	200	103.780983	43.611109
04/07/2001	15:00	156	gazelle	1	103.722702	43.558807
05/07/2001		154	camel	1	103.772885	43.616975
05/07/2001		154	horse	6	103.773339	43.626007
05/07/2001		154	yak	2	103.777176	43.633870
05/07/2001		154	ibex	3	103.774555	43.629160
05/07/2001		154	ibex	7	103.775470	43.632449
09/07/2001	16:00	157	camel	4	103.758188	43.584157
09/07/2001	16:00	157	camel	3	103.767190	43.584082
09/07/2001	16:00	157	horse	8	103.775970	43.611512
09/07/2001	16:00	157	horse	6	103.779221	43.605813
09/07/2001	16:00	157	horse	7	103.772340	43.605769
09/07/2001	16:00	157	horse	1	103.774173	43.613028
09/07/2001	16:00	157	horse	11	103.757618	43.584432
09/07/2001	16:00	157	sheep & goat	90	103.777417	43.616647
09/07/2001	16:00	157	sheep & goat	10	103.788512	43.614596
10/07/2001	9:00	158	camel	2	103.774173	43.617661
10/07/2001	9:00	158	camel	4	103.773002	43.602884
10/07/2001	9:00	158	camel	2	103.774173	43.592641
10/07/2001	9:00	158	camel	1	103.764577	43.599757
10/07/2001	9:00	158	horse	8	103.773173	43.610332
10/07/2001	9:00	158	sheep & goat	50	103.778026	43.610494
10/07/2001	9:00	158	sheep & goat	350	103.783289	43.615808
11/07/2001	14:00	159	camel	3	103.782284	43.599010
11/07/2001	14:00	159	camel	1	103.765968	43.594038
11/07/2001	14:00	159	camel	4	103.758762	43.583893
11/07/2001	14:00	159	camel	3	103.769378	43.615646
11/07/2001	14:00	159	camel	2	103.771774	43.615808
11/07/2001	14:00	159	camel	3	103.775173	43.610332
11/07/2001	14:00	159	horse	12	103.769495	43.579016
11/07/2001	14:00	159	horse	9	103.772783	43.616168
11/07/2001	14:00	159	sheep & goat	17	103.788348	43.613394
11/07/2001		160	horse	13	103.777353	43.630649
12/07/2001	18:00	161	camel	2	103.773352	43.613631
12/07/2001	18:00	161	camel	1	103.757888	43.600081
12/07/2001	18:00	161	camel	1	103.768008	43.582041
12/07/2001	18:00	161	camel	2	103.771834	43.597412
12/07/2001	18:00	161	camel	3	103.780054	43.611043
12/07/2001	18:00	161	camel	1	103.760717	43.580105
12/07/2001	18:00	161	horse	9	103.773155	43.616791
12/07/2001	18:00	161	horse	2	103.766675	43.574740
12/07/2001	18:00	161	horse	17	103.769448	43.616613
12/07/2001	18:00	161	cattle	14	103.764238	43.580003
12/07/2001	18:00	161	sheep & goat	11	103.786104	43.605064
12/07/2001	18:00	161	sheep & goat	70	103.783444	43.607747
14/07/2001	16:00	162	camel	1	103.778953	43.615404
14/07/2001	16:00	162	camel	2	103.795204	43.614031
14/07/2001	16:00	162	horse	8	103.775539	43.610885
14/07/2001	16:00	162	horse	1	103.779752	43.601004
14/07/2001	16:00	162	horse	2	103.781125	43.614009
14/07/2001	16:00	162	sheep & goat	10	103.785964	43.607835
14/07/2001	16:00	162	sheep & goat	10	103.788512	43.614596
15/07/2001	18:00	163	camel	8	103.770174	43.593905
15/07/2001	18:00	163	camel	2	103.764983	43.591425
15/07/2001	18:00	163	horse	8	103.775339	43.609420
15/07/2001	18:00	163	horse	1	103.772918	43.601960
15/07/2001	18:00	163	horse	3	103.770498	43.612830
15/07/2001	18:00	163	sheep & goat	9	103.780821	43.612101
15/07/2001	18:00	163	sheep & goat	1	103.781131	43.612675
19/07/2001	11:30	164	camel	5	103.774173	43.590787
19/07/2001	11:30	164	horse	4	103.762686	43.585330
19/07/2001	11:30	164	horse	12	103.771674	43.602119
19/07/2001	11:30	164	sheep & goat	7	103.782034	43.610493
23/07/2001	18:00	165	horse	3	103.771898	43.625712
23/07/2001	18:00	165	horse	5	103.776187	43.629160
23/07/2001	18:00	165	yak	6	103.775723	43.632559
23/07/2001	18:00	165	sheep & goat	140	103.777434	43.632370
24/07/2001		166	camel	2	103.771413	43.585343
24/07/2001		166	horse	2	103.778971	43.615808
24/07/2001		166	sheep & goat	90	103.780743	43.617157
24/07/2001		166	sheep & goat	2	103.781370	43.603770
24/07/2001		166	sheep & goat	20	103.761837	43.601610
27/07/2001	14:00	167	horse	2	103.778165	43.630246
27/07/2001	14:00	167	horse	1	103.775440	43.628700
27/07/2001	14:00	167	horse	5	103.776875	43.629027
27/07/2001	14:00	167	horse	1	103.776604	43.631224
27/07/2001	14:00	167	ibex	3	103.772449	43.621379
30/07/2001	9:00	168	camel	1	103.772866	43.630072
30/07/2001	9:00	168	horse	6	103.780439	43.633870
30/07/2001	9:00	168	horse	2	103.776373	43.631183
30/07/2001	9:00	168	horse	2	103.775600	43.630829
30/07/2001	9:00	168	horse	2	103.776705	43.630072
30/07/2001	9:00	168	yak	1	103.772333	43.618003
30/07/2001	9:00	168	yak	25	103.780107	43.635014
30/07/2001	9:00	168	ibex	10	103.779734	43.633742
30/07/2001	9:00	168	ibex	3	103.778945	43.633028
30/07/2001		169	horse	2	103.771246	43.583497
30/07/2001		169	sheep & goat	5	103.780387	43.616333
30/07/2001		169	sheep & goat	13	103.781839	43.615420
04/08/2001		170	camel	1	103.673578	43.535728
04/08/2001		170	camel	3	103.689080	43.541959
04/08/2001		170	camel	6	103.707198	43.555030
04/08/2001		170	camel	2	103.705538	43.552148
04/08/2001		170	camel	11	103.749904	43.565436
04/08/2001		170	horse	3	103.740308	43.565436
04/08/2001		170	horse	1	103.719221	43.560005
04/08/2001		170	horse	25	103.708712	43.556918
04/08/2001		170	horse	4	103.715429	43.556918
04/08/2001		170	horse	8	103.694969	43.543978
04/08/2001		170	horse	20	103.677967	43.538615
04/08/2001		170	horse	5	103.709267	43.558807
04/08/2001		170	sheep & goat	200	103.679528	43.535728
04/08/2001		170	sheep & goat	200	103.758281	43.534167
04/08/2001		170	sheep & goat	150	103.679594	43.534167
04/08/2001		170	sheep & goat	200	103.677675	43.534167
04/08/2001		170	sheep & goat	200	103.675755	43.534167
04/08/2001		170	gazelle	40	103.673866	43.535728
11/08/2001	11:00	171	camel	2	103.748624	43.562896
11/08/2001	11:00	171	horse	5	103.770409	43.574265
11/08/2001	11:00	171	horse	1	103.745385	43.567655
11/08/2001	11:00	171	horse	8	103.769155	43.560418
11/08/2001	11:00	171	sheep & goat	5	103.764201	43.610248
11/08/2001	11:00	171	sheep & goat	80	103.770814	43.610190
22/08/2001	9:15	172	horse	3	103.765730	43.620545
22/08/2001	9:15	172	horse	2	103.771051	43.625122
22/08/2001	9:15	172	wild sheep	3	103.777614	43.633227
22/08/2001	9:15	172	ibex	2	103.777281	43.632816
23/08/2001		173	horse	2	103.755428	43.563235
23/08/2001		173	cattle	1	103.759271	43.562101
23/08/2001		173	cattle	11	103.770080	43.583615

continued on next page

continued from previous page

date	time	ID	kind	#	° East	° North
24/08/2001	14:00	174	horse	2	103.770409	43.574265
24/08/2001	14:00	174	sheep & goat	250	103.770780	43.612532
28/08/2001	15:00	176	camel	1	103.759271	43.562101
30/08/2001	17:00	177	camel	7	103.771831	43.589959
30/08/2001	17:00	177	horse	3	103.768265	43.600133
30/08/2001	17:00	177	horse	2	103.767508	43.579303
30/08/2001	17:00	177	horse	2	103.771831	43.589959
30/08/2001	17:00	177	horse	2	103.777226	43.618757
03/09/2001	15:00	178	camel	8	103.703914	43.556918
03/09/2001	15:00	178	camel	1	103.725392	43.567465
03/09/2001	15:00	178	horse	2	103.708712	43.556918
03/09/2001	15:00	178	horse	2	103.701508	43.552148
03/09/2001	15:00	178	horse	2	103.751133	43.584340
03/09/2001	15:00	178	horse	7	103.734988	43.567465
03/09/2001	15:00	178	yak	2	103.767527	43.615050
03/09/2001	15:00	178	cattle	6	103.708712	43.556918
03/09/2001	15:00	178	sheep & goat	300	103.767855	43.614152
05/09/2001	10:30	179	horse	4	103.745298	43.578803
05/09/2001	10:30	179	horse	2	103.762910	43.595352
05/09/2001	10:30	179	horse	10	103.764327	43.589684
05/09/2001	10:30	179	cattle	7	103.759175	43.581687
07/09/2001	15:15	180	camel	1	103.774173	43.608394
07/09/2001	15:15	180	horse	7	103.764327	43.589684
07/09/2001	15:15	180	cattle	4	103.763665	43.551738
11/09/2001	16:15	181	camel	1	103.769729	43.580856
11/09/2001	16:15	181	horse	14	103.766427	43.562582
17/09/2001	17:00	182	camel	1	103.765008	43.565614
17/09/2001	17:00	182	horse	11	103.773504	43.608423
17/09/2001	17:00	182	horse	8	103.754304	43.544198
17/09/2001	17:00	182	horse	4	103.775423	43.608963
17/09/2001	17:00	182	horse	8	103.771740	43.610769
17/09/2001	17:00	182	cattle	12	103.751676	43.564626
17/09/2001	17:00	182	cattle	3	103.769495	43.579016
18/09/2001	11:00	183	horse	2	103.763282	43.595166
18/09/2001	11:00	183	horse	1	103.771246	43.583497
18/09/2001	11:00	183	yak	4	103.779371	43.609147
18/09/2001	11:00	183	cattle	4	103.773336	43.592655
18/09/2001	11:00	183	cattle	12	103.761676	43.547361
18/09/2001	11:00	183	cattle	3	103.762175	43.588511
19/09/2001	18:15	184	horse	2	103.766193	43.579550
19/09/2001	18:15	184	horse	11	103.764157	43.546982
19/09/2001	18:15	184	horse	2	103.769729	43.580856
19/09/2001	18:15	184	horse	4	103.773838	43.597277
19/09/2001	18:15	184	cattle	8	103.773269	43.599150
20/09/2001	14:00	185	yak	1	103.771633	43.623742
26/09/2001	12:30	187	horse	3	103.753131	43.549342
26/09/2001	12:30	187	horse	4	103.771129	43.617179
26/09/2001	12:30	187	cattle	14	103.742986	43.563643
26/09/2001		188	horse	17	103.706793	43.556918
26/09/2001		188	horse	4	103.775357	43.615948
26/09/2001		188	horse	9	103.771787	43.612145
26/09/2001		188	horse	4	103.768487	43.615050
26/09/2001		188	horse	4	103.736469	43.565436
26/09/2001		188	cattle	8	103.697252	43.553589
26/09/2001		188	cattle	5	103.709727	43.553589
26/09/2001		188	sheep & goat	100	103.694023	43.552148
28/09/2001		189	horse	3	103.771160	43.560282
28/09/2001		189	horse	3	103.776666	43.617198
28/09/2001		189	horse	4	103.773494	43.616463
28/09/2001		189	horse	4	103.772734	43.618216
28/09/2001		189	yak	3	103.737210	43.568371

Table A.7.: List of sightings of large herbivores. The list gives the date, time, ID (= observation sample number), kind of animal sighted (kind), number of animals (#), and the calculated longitude (° East) and latitude (° North) of the animal or group of animals .

Assorted field data

Precipitation along the altitudinal transect

date	2000m	2200m	2400m	2600m	2800m
24/08/00	setup	setup	setup	setup	setup
20/09/00	0.0	0.0	0.3	0.3	0.4
27/10/00	0.6	0.1	1.2	0.8	0.0
07/12/00	3.2	3.6	7.7	7.1	2.1
15/01/01	8.1	24.8	0.1	4.4	5.2
12/02/01	0.0	0.1	0.7	0.7	*
08/03/01	0.3	0.3	1.8	2.2	3.5
07/04/01	0.6	4.7	2.8	1.7	*
08/05/01	0.6	0.1	0.0	0.1	0.0
06/06/01	0.0	1.1	9.7	8.6	6.3
05/07/01	2.1	4.7	40.6	47.1	45.4
04/08/01	0.1	0.0	0.0	0.0	0.0
03/09/01	5.0	3.9	7.6	7.7	7.1
27/09/01	21.7	30.8	45.5	51.9	25.2

Table A.8.: Monthly precipitation data from the altitudinal transect. Precipitation (mm) since the last sampling date is given. Missing values are marked *.

Daily precipitation at the research camp

date	loc	prec. (mm)	date	loc	prec. (mm)
27/06/00	sc	4.46	21/03/01	wc	0.13
02/07/00	sc	1.26	05/04/01	wc	2.01
03/07/00	sc	5.26	08/04/01	wc	0.74
06/07/00	sc	10.10	29/04/01	sc	0.16
07/07/00	sc	8.42	13/05/01	sc	0.07
14/07/00	sc	1.58	14/05/01	sc	2.63
26/07/00	sc	0.74	22/05/01	sc	0.58
01/08/00	sc	5.26	25/05/01	sc	0.53
06/08/00	sc	5.26	26/05/01	sc	0.49
07/08/00	sc	3.16	04/06/01	sc	0.58
08/08/00	sc	8.42	09/06/01	sc	1.89
09/08/00	sc	15.78	15/06/01	sc	0.42
10/08/00	sc	10.52	16/06/01	sc	1.37
17/08/00	sc	4.21	17/06/01	sc	10.52
21/08/00	sc	7.36	26/06/01	sc	0.15
18/09/00	sc	0.00	27/06/01	sc	0.90
30/09/00	sc	0.01	30/06/01	sc	9.15
09/10/00	sc	0.94	01/07/01	sc	2.21
27/10/00	wc	1.25	02/07/01	sc	0.74
08/11/00	wc	0.13	06/07/01	sc	1.40
17/11/00	wc	2.89	18/07/01	sc	0.74
18/11/00	wc	1.99	21/07/01	sc	1.05
19/11/00	wc	0.05	28/07/01	sc	0.12
21/11/00	wc	0.13	29/07/01	sc	0.28
12/12/00-13/01/01		no records	06/08/01	sc	1.07
24/01/01	wc	0.25	11/08/01	sc	3.26
04/02/01	wc	0.06	15/08/01	sc	0.58
05/02/01	wc	0.13	27/08/01	sc	2.71
12/02/01	wc	0.25	28/08/01	sc	0.18
15/02/–21/02/01		no records	02/09/01	sc	0.01
22/02/01	wc	2.51	08/09/01	sc	1.10
23/02/01	wc	0.84	11/09/01	sc	1.05
26/02/01	wc	0.00	12/09/01	sc	1.16
02/03/01	wc	0.13	14/09/01	sc	3.68
05/03/01	wc	0.13	15/09/01	sc	0.15
07/03/01	wc	0.17	22/09/01	sc	6.00
13/03/01	wc	1.13	30/09/01	sc	end

Table A.9.: Daily precipitation data from the research camp, loc indicates the location of the camp, sc= summer camp, wc= winter camp. Periods of sampling gaps are marked as "no records".

Below-ground biomass data

plot	H1	H2	H3	H4	H1	H2	H3	H4
date	03/08/01	03/08/01	30/08/01	30/08/01	03/08/01	29/08/01	30/08/01	30/08/01
steppe/burrow	steppe	steppe	steppe	steppe	burrow	burrow	burrow	burrow
bgbm (g)	12.5	30.1	20.5	12.9	14	37.7	49.6	28.9
area (m^2)	0.01725	0.0154	0.0198	0.01727	0.015525	0.0234	0.0198	0.01837
depth (cm)	8	8	8	8	8	8	8	8
bgbm (g/m^2)	724.6	1954.5	1035.4	747.0	901.8	1611.1	2505.1	1573.2

Table A.10.: Below-ground biomass (bgbm) data sampled in the steppe-matrix and on pika burrows in summer 2001.

Data on pika burrow productivity

ID	date	plot	steppe/burrow	var	scr (g/m^2)
246	21/06/01	H1	steppe	l+p	9.5
259	21/06/01	H2	steppe	l+p	5.1
267	21/06/01	H3	steppe	l+p	11.0
264	21/06/01	H4	steppe	l+p	11.2
496	12/07/01	27	burrow	l+p	50.4
499	12/07/01	11	burrow	l+p	13.5
341	27/07/01	H1	steppe	l+p	5.4
336	27/07/01	H2	steppe	l+p	5.0
331	27/07/01	H3	steppe	l+p	6.8
301	27/07/01	H4	steppe	l+p	11.5
244	21/06/01	H1	steppe	no	23.5
261	21/06/01	H2	steppe	no	18.4
270	21/06/01	H3	steppe	no	20.1
278	21/06/01	H4	steppe	no	19.5
498	12/07/01	30	burrow	no	180.4
502	13/07/01	13	burrow	no	56.1
339	27/07/01	H1	steppe	no	26.7
333	27/07/01	H2	steppe	no	20.5
328	27/07/01	H3	steppe	no	22.4
299	27/07/01	H4	steppe	no	21.4

Table A.11.: Phytomass data used to compare the productivity of pika burrows and steppe-matrix. ID= sample number, date, plot, burrow or steppe, var= grazing treatment(p+l=*pika & livestock*, no= *no grazing*), and standing crop (=scr in g/m^2).

Dung distribution data

date	plot	mass (kg)	volume (l)	% on burrow
24/04/01	H1	0.8	5.2	100
19/04/01	H2	2.1	11.9	85
24/04/01	H3	0.85	4.7	100
19/04/01	H4	1	6.7	100
21/05/01	H1	0.45	4.1	40
22/05/01	H2	1.95	10.2	80
21/05/01	H3	0.4	4.1	100
21/05/01	H4	0.45	4.1	65
20/06/01	H1	1.4	7.3	60
21/06/01	H2	0.9	4.4	70
22/06/01	H3	0.4	5.7	100
21/06/01	H4	0.05	0.46	0
30/07/01	H1	2.1	13.7	70
28/07/01	H2	0.55	2.1	50
30/07/01	H3	1.4	8.6	90
26/07/01	H4	1.1	10.4	5
24/08/01	H1	0.01	0.06	100
23/08/01	H2	0.6	3.5	100
23/08/01	H3	0.75	3.9	60
25/08/01	H4	0.15	0.9	50
23/09/01	H1	0	0	
21/09/01	H2	0	0	
22/09/01	H3	0.5	1.9	100
21/09/01	H4	0.1	0.4	100

Table A.12.: Data on dung distribution: mass (kg/ha) and volume (l/ha) on 1-hectare plots next to the exclosures H1-H4 and estimated percentage of dung found on pika burrows (% on burrow).

Soil nutrient data on pika burrows and the steppe-matrix

steppe-matrix

	horizon	depth (cm)	grain size	C (%)	N (%)	C/N	PO_4^- (mg / kg)	NO_3^- (mg / kg)	NH_4^+ (mg / kg)
1. Or 23	Q	3	Sl4	3.35	0.36	9.4	205.0	124.5	9.4
	Ah	10	Lt2	1.65	0.26	6.4	27.3	104.1	10.3
	Krot.	50	Sl2	1.94	0.27	7.2	10.3	18.6	3.6
2. Or 23	Q	3	sl4	4.49	0.49	9.2	85.9	308.3	8.1
	Ah	5-10	Lt2	1.65	0.24	6.9	24.8	5.8	3.2
	Ah	10-20	Lt2	4.09	0.41	9.9	21.5	85.9	4.8
	Krot.	40	Sl2	3.79	0.33	11.6	7.0	5.3	17.7
4. Or 23	Q	3	Sl4	3.24	0.39	8.3	116.2	139.1	11.2
	Ah	10	Lt2	2.13	0.29	7.2	8.4	95.7	3.5
	Ah	30	Lt2	2.02	0.27	7.4	2.9	118.3	2.1

pika burrow

	horizon	depth (cm)	grain size	C (%)	N (%)	C/N	PO_4^- (mg / kg)	NO_3^- (mg / kg)	NH_4^+ (mg / kg)
3. Or 23	Q	3	Sl4	1.94	0.28	7.0	62.3	8.0	4.3
	Ah	10	Lt2	1.72	0.26	6.6	6.2	2.7	3.0
	A/C	30	Ls3	2.82	0.27	10.6	3.4	2.7	2.7
	C	40	Ls2	3.72	0.18	20.2	3.1	4.4	1.8
	C	80	Ls3	2.45	0.09	26.9	3.7	3.5	1.8
5. Or 23	Q	3	Sl4	1.91	0.26	7.5	69.2	7.5	3.0
	Ah	10	Lt2	1.70	0.25	6.8	8.9	3.5	3.0

Table A.13.: Data on soil nutrient concentrations on burrows and in the steppe-matrix. All profiles have been classified as Kastanozems, or calcic Kastanozem after WRB. The description of the horizons and grain size follow AG Bodenkunde (1994). Data are from T. Hennig.

Measurements of water content (%) in soil profiles

profile	horizon	depth	mean	sd	1	2	3	4	5	6	7	8	9	10
2.Or 1	Ah	10 cm	**7.4**	**1.7**	3.7	8.7	7.2	9.6	8.4	7.7	8.9	6.1	7.3	6.4
steppe	A/C	20 cm	**10.9**	**2.5**	6.5	11.4	12.3	11.3	14.3	8.7	8.6	14.4	9.7	11.8
	C	50 cm	**20.3**	**3.3**	20.8	19.7	21	17.2	23.9	19.6	23.6	14.2	18.4	24.7
1.Or 2	Q/A	5 cm	**4.3**	**1.5**	5.6	7.7	4.9	3.7	3.9	2.9	3.1	4.3	4	2.5
steppe	Ah	15 cm	**5.9**	**2.1**	4.7	3.7	6.8	5.4	5.3	3.9	7.7	6.9	10.5	4.1
	A/C	35 cm	**8.2**	**1.4**	9.7	11	7.2	8.4	8.1	6.3	9	7.7	7.1	7.5
2.Or 3	Ah1	15 cm	**2.3**	**1.6**	1.9	0.2	2.2	3.3	2.5	1.4	2.7	1.7	0.9	5.9
burrow	Ah2	25 cm	**5.7**	**1.9**	4.4	3.5	3.4	3	6.3	7.2	7.8	7.7	7.2	6.9
2.Or 4	Ah1	10 cm	**4.6**	**1.2**	5.1	6.2	4	5.1	3.3	2.5	4.6	4.7	6.3	
burrow	Ah2	20 cm	**8.5**	**2.1**	8.1	12	5.5	8.7	8.3	7.1	10.1			
2.Or 5	Ah	10 cm	**5.3**	**1.7**	5.6	4.7	3.4	3.7	4.5	7.8	7.9	4.4	3.9	7.2
burrow	Ah	25 cm	**10.6**	**2.1**	9.4	13.2	11.6	10.1	11.4	9.9	13.5	9	7	

Table A.14.: Data on the water content (%) measured in soil profiles on pika burrows and the steppe-matrix. The description of the horizons follows AG Bodenkunde (1994). Data from T. Hennig. Mean (mean) and standard deviation (sd) of the measured values are given in bold. The single values follow in the rows labelled 1–10.

Picture copyright

- Background picture for figure 5.1, p. 185 from `http://www.ph.surrey.ac.uk/ugrad/courses/finance2`,
- Background picture for figure 1.1, p. 31 by Steve Dinsmore from `http://faculty.fullerton.edu/pstapp/`
- all other pictures by Vroni Retzer

Software

Access 97 Database management software, © 1989-1997 Microsoft

ArcView GIS 3.2 Geographic information system, © 1992-1999 Environmental Systems Research Institute, Inc.

CoralDraw 8 Vector-based drawing program, © 1988-1998 Corel Corporation.

Excel2Latex Converter for Excel tables to LaTeX-code, freeware, © 1996-2001 by Joachim Marder, http://www.jam-software.com/software.html

Ghostview Postscript-previewer, freeware, © 1993-2002 Ghostgum Software Pty Ltd.

jpeg2ps Converter for JPEG compressed images to PostScript Level 2, freeware, © 1994-2002 Thomas Merz (tm@pdflib.com)

LaTeX 2$_{\varepsilon}$ Type setting programm, public domain software, MiKTeX–Distribution 2.1, 2002, download: ftp.dante.de/systems/win32/miktex

MapInfo Geographic information system

Microcal Origin 6.0 Data analysis & technical graphics, © 1991-2000 Microcal Software Inc.

Microsoft Excel 97 Spreadsheet and analysis program, © 1985-1996 Microsoft

Microsoft Word 97 Word processer, © 1983-1997 Microsoft

Microsoft Powerpoint 97 Presentation program, © 1987-1997 Microsoft

SPSS 10.0.7 Statistic program, © 1989-1999 SPSS Inc.

VensimPLE Plus Graphic simulation environment, © 1988-2000 Ventana Systems Inc.

WinEdt Text-editor, shareware, © 1993-2002 A. Simonic

YAP Yet Another Previewer, © C. Schenk, http://www.snafu.de/~cschenk/miktex

Glossary

The following sources were used to compile this glossary: National Statistical Office of Mongolia & Worldbank, 2001; Library of Congress, n.d.; UNDP, 2000; Mirriam-Webster, 2003

Am valley (Mongolian).

ANPP Above-ground Net Primary Productivity.

APPT Annual Precipitation (after Sala, 2001).

Argal Dung used as fuel. Preferably from cattle and yaks, also from camel - rarely from horses.

Argali Wild sheep, *Ovis ammon* (Mongolian).

Altai Or Altay. Mountain system in Central Asia between Mongolia and China, and between Kazakstan and Russia.

Aymag Province (Mongolian). The largest sub-national administrative unit established in 1921. Aymags are sub-divided into soums(→). Traditionally, an aymag was a tribe. There are 22 aymags in Mongolia, four of those are independent municipalities.

Bag Small (Mongolian). Also the name for the fourth- and lowest level of Mongolian state administration.

Barun West, western (Mongolian)

Bayan Luck, lucky or ”rich in” (Mongolian)

Bayan Bag Lucky small unit (Mongolian). The name of the bag(→) in which the research station was located.

Bayandalay Lucky Ocean (Mongolian). Name of the soum(→) in which the study took place.

Bayankhongor Name of Bayankhongor Aymag and of its capital city. The aymag is directly in the north-west of Umnugov Aymag.

Brigad Socialist name for the lowest unit of Mongolian administration which sometimes still is used instead of bag(→).

Carrying Capacity Controversial term - originally meaning a certain stocking rate which allowed for maximum output of beef without damaging the rangeland

Dund Middle (Mongolian)

Dundgov Middle Gobi (Mongolian). Aymag(→) north of Umnugov. The capital is Mandalgov(→).

Dzud A general term denoting weather conditions which prevent livestock from obtaining sufficient forage from open grazing. Environmental disaster due to climatic and or weather conditions. For example, drought in the summer (black dzud), frozen snow cover in the winter (white dzud), etc. It also refers to a combination of different natural disasters.

Dzuun East, eastern (Mongolian)

Els Sand (Mongolian).

Ger Tent, yurt (Mongolian). The round, felt-covered tent which is a mobile home for the Mongolian Nomads.

Gobi Arid pasture land (Mongolian). Source of the name ”Gobi desert”.

Gobi Gurvan Sayhan ”Three Beauties of the Gobi” (Mongolian) name of the mountain ranges west of Dalandzadgad(→). They consist of the Dzuun, Dund, and Barun Sayhan, and the Bayan Tsagaan range.

Gobi Gurvan Sayhan National Park National Conservation Park which includes and is named after the ”Three Beauties of the Gobi(→)” mountain range.

GTZ Gesellschaft für Technische Zusammenarbeit (German). The GTZ is a government-owned corporation for international cooperation with worldwide operations” (see www.gtz.de/english/).

Gurvan Three (Mongolian).

Hashaa Exclosure (Mongolian). Fenced exclosure around a ger(→) or enclosure for livestock used for the night during winter. It is built with stone walls or wooden fences as a protection against the wind and cold.

Herders Semi-nomadic economic and social group whose primary activity is herding livestock. They would relocate in different areas following different seasons but will tend to relocate around the same area in each of the seasons. Inhabitants of remote areas will have as primary activity herding. 35–40% of the Mongolian population are herders.

Khongoryn Els The singing sands (Mongolian). The largest accumulation of sand in the Gobi Gurvan Sayhan National Park. The dunes are 6–12 km wide, more than 100 km long, and up to 200 meters high.

Khot Ail Herding camp of several cooperating households. These units are often but not necessarily based on kin relations. It has a loose internal structure and flexible composition from year to year. It also has a social role as the smallest local community. The size of khot ails varies according to the season and ecological zones and might be composed from a single household to up to five households.

Khulan Asiatic wild ass (Mongolian).

Mandalgov Capital of the Dundgov or Middle-Gobi Aymag.

Muur Riding horse (Mongolian).

Muurin Am Valley of the horses (Mongolian). Name of the valley in the Dund Sayhan along which the altitudinal transect was installed.

Negdel Mongol term for a herding collective in socialist times. It comprises agricultural stations and herding camps of one soum(→).

Nemegt Uul Mountain range in the western part of the Gobi Gurvan Sayhan National Park. Its summit reaches an altitude of 2769 m.

RUE Rain use efficiency. After Le Houerou (1984) The amount of kilograms of aboveground dry phytomass which is produced over 1 ha in 1 year per mm of precipitation (kg/ha·mm).

Sayhan Beautiful, beauty (Mongolian)

Saxaul Woody species of the open semi-desert. It can reach up to 5 m in height. Its leaves are grazed by camels and its dense wood is good firewood.

Soum District. Second-level administrative unit, subdivision of an aymag. The term, the root of which means arrow, derives from a Qing Dynasty (1644-1911) hereditary military unit of about 100 families. A soum consists of several bags(→).

South-Gobi Name of an aymag(→) in central south Mongolia. The aymag's capital is Dalandzadgad(→).

Sustainability way of use, which preserves natural resources (please refer to the literature for more detail).

Three Beauties of the Gobi see Gobi Gurvan Sayhan(→)

Tsagaan White (Mongolian)

Ulaan Red (Mongolian)

Ulaanbaatar Red Hero (Mongolian). The Mongolian capital.

Ulaangom Capital of the Uvs Aymag in north-western Mongolia.

Uul Mountain (Mongolian)

Umnugov South-Gobi (Mongolian). Name of the Aymag(→) in central south Mongolia. The aymag capital is Dalandzadgad(→).

Witoshi Vegetation dried on the site, used as winter forage.

WWF World Wide Fund For Nature. Globally active non-governmental nature conservation organization (see www.panda.org).

Xur Dung from sheep and goats, inside a hashaa(→) which is compacted by trampling and cut like peat and used as fuel (Mongolian).

Yol lammergeyer (Mongolian).

Yolin Am The valley of lammergeyers (Mongolian). A steep gorge in the Dzuun Sayhan mountain range, about 45 km west of Dalandzadgad. It is famous for the long persistence of the winterly ice sheet on the valley floor into summer, and therefore a tourist attraction.

Bibliography

Abel, N. & Blaikie, P., 1990; *Land degradation, stocking rates and conservation policies for the communal rangelands of Botswana and Zimbabwe.* No. 29a in Pastoral Development Network Paper. Overseas Development Institute, 25 pp.

AG Bodenkunde, 1994; *Bodenkundliche Kartieranleitung.* Schweizerbart'sche Verlagsbuchhandlung, Hannover, 4^{th} edn., 392 pp.

Anonymous, 1997; Law of Mongolia on Land fees. English translation available at `www.investmongolia.com/law35.pdf`. Last visited 20.11.2002.

Anonymous, 2002; Law of Mongolia on land. English translation available at `www.investmongolia.com/law28.pdf`. Last visited 20.11.2002.

Archer, S. & Detling, J., 1986; Evaluation of potential herbivore mediation of plant water status in a North-American mixed-grass prairie. *Oikos*, **47**, 287–291.

Asian Disaster Reduction Center, 2003; Natural Disasters in Mongolia 1901-2000. `www.adrc.or.jp/databook_20th/MNG.pdf`. Last visited 09.07.2003.

Augustine, D., 2003; Long-term, livestock-mediated redistribution of nitrogen and phosphorus in an East African savanna. *Journal of Applied Ecology*, **40**, 137–149.

Baas, S., Reynolds, S., & Batello, C., 2000; Rangeland Management and Conservation. Lessons learned from a planner's point of view. *Freiburger Geographische Hefte*, **60**, 103–118.

Baker, K., 2000; Environmental Equilibrium and Non-equilibrium. In: K. M. Baker (ed.), *Indigenous Land Management in West Africa - An Environmental Balancing Act*, pp. 1–38. Oxford University Press, Oxford.

Bangert, R. & Slobodchikoff, C., 2000; The Gunnison's prairie dog structures a high desert grassland landscape as a keystone engineer. *Journal of Arid Environments*, **46**, 357–369.

Bartels, G., Norton, B., & Perrier, G., 1993; An examination of the carrying capacity concept. In: R. H. Behnke, I. Scoones, & C. Kerven (eds.), *Range Ecology at Disequilibrium. New Models of Natural Variability and Pastoral Adaption in African Savannas*, pp. 89–103. Overseas Development Institute, London.

Barthel, H., 1983; Die regionale und jahreszeitliche Differenzierung des Klimas in der

Mongolischen Volksrepublik (The Regional and Seasonal Differences in the Climate of the Mongolian People's Republic, in German). *Studia Geographica*, **34**, 1–91.

Barthel, H., 1990; *Mongolei - Land zwischen Taiga und Wüste.* VEB H. Haack, Gotha, 220 pp.

Bastian, O., 2000; Mongolei - Transformation und Umwelt in Zentralasien. *Geographische Rundschau*, **52**, 17–23.

Batima, P. & Dagvadorj, D., 2000; *Climate change and its impact in Mongolia.* National Agency for Meteorology, Hydrology and Environmental Monitoring, Ulaanbaatar, 227 pp.

Batima, P., Dagvadorj, D., Oyun, R., & Chuluun, T., 2002; Potential impact of climate change and V&A assessment for grassland ecosystem and livestock sector in Mongolia. `www.aiaccproject.org/meetings/Trieste_02/trieste_cd/Additional_material/AS06.ppt`. Last visited 02.07.2003.

Batkhishig, O., 2000; Influence of overgrazing for the soils cover in Mongolia. *Berliner Geowissenschaftliche Abhandlungen A*, **205**, 26–31.

Batkhishig, O. & Lehmkuhl, F., 2003; Degradation und Desertifikation in der Mongolei. *Petermanns Geographische Mitteilungen*, **147**(5), 48–49.

Bayarsayhan, C., Kurushin, R., Molnar, P., Olziybat, M., Bayasgalan, A., & Enhtuvshin, B. e., 1996; 1957 Gobi-Altay, Mongolia, earthquake as a prototype for southern California's most devastating earthquake. *Geology*, **24**(7), 579–582.

Bazargur, D., 1995; *Rechenschaftsbericht über die im National Park "Gobi Gurvan Saikhan" durchgeführten sozio-ökonomischen und geographischen Forschungen (Original in Mongolian).* gtz Nature Conservation and Buffer Zone Management Project, Ulaanbaatar, 35 pp. Unpublished report.

Bazargur, D., 1998; *Geography of pastoral animal husbandry.* Mongolian Academy of Science Institute of Geoecology, 63 pp.

Bazargur, D., 2000; Social and economic development by establishing an axis-oriented centralised infrastructure. *Berliner Geowissenschaftliche Abhandlungen A*, **205**, 163–164.

Bazargur, D., Shiirevadja, C., & Chinbat, B., 1993; *Territorial Organisation of Mongolian Pastoral Livestock Husbandry in the Transition to a Market Economy*, vol. 1 of *Policy alternatives for livestock development in Mongolia (PALD).* Institute of Development Studies at the University of Sussex Brighton, UK and Institute of Agricultural Economics, Zaisan, Ulaanbaatar 36, Mongolia, Brighton, Ulaanbaatar, 14 pp.

Bedunah, D., 1998; *Livestock Management Issues for the Gobi Gurvan Saikhan National Conservation Park.* gtz Nature Conservation and Buffer Zone Management Project, Ulaanbaatar, 37 pp. Unpublished report.

Bedunah, D., 2001a; *Development of participatory pasture management and monitoring in Gobi Gurvan Saikhan National Park: Identification of traditional methods for monitoring pasture use.* gtz Nature Conservation and Buffer Zone Management Project, Ulaanbaatar, 11 pp. Unpublished report.

Bedunah, D., 2001b; *Suggested stocking rate of Khankhongor and Khurmen Sum areas in Gobi Gurvan Saikhan National Conservation Park.* gtz Nature Conservation and Buffer Zone Management Project, Ulaanbaatar, Mongolia, 6 pp. Unpublished report.

Bedunah, D. & Schmidt, S., 2000; Rangelands of Gobi Gurvan Saikhan National Conservation Park, Mongolia. *Rangelands*, **22**(4), 18–24.

Behnke, R. & Scoones, I., 1993; Rethinking range ecology: Implications for rangeland management in Africa. In: R. H. Behnke, I. Scoones, & C. Kerven (eds.), *Range Ecology at Disequilibrium. New Models of Natural Variability and Pastoral Adaption in African Savannas*, pp. 1–30. Overseas Development Institute, London.

Behnke, R., Scoones, I., & Kerven, C., 1993; *Range Ecology at Disequilibrium. New Models of Natural Variability and Pastoral Adaption in African Savannas.* Overseas Development Institute, London, 248 pp.

Belovsky, G., 1984; Moose and snowshoe hare competition and a mechanistic explanation from foraging theory. *Oecologia*, **61**, 150–159.

Belsky, A., 1986; Does herbivory benefit plants: a review of the evidence. *American Naturalist*, **127**, 870–892.

Belsky, A., Carson, W., Jensen, C., & Fox, G., 1993; Overcompensation by plants: herbivore optimization or red herring? *Evolutionary Ecology*, **7**, 109–121.

Bergius, J., 2002; *Untersuchungen zu Klimaschwankungen in der Mongolischen Südgobi.* Diploma thesis, FB Geographie, Philipps-Universität, Marburg. Unpublished.

Biondini, M., Lauenroth, W., & Sala, O., 1991; Correcting estimates of net primary production: Are we overestimating plant production in rangelands? *Journal of Range Management*, **44**(3), 194–198.

Biondini, M., Patton, B., & Nyren, P., 1998; Grazing intensity and Ecosystem Processes in a northern Mixed-Grass Prairie, USA. *Ecological Applications*, **8**(2), 469–479.

Biot, Y., 1993; How long can high stocking densities be sustained? In: R. H. Behnke, I. Scoones, & C. Kerven (eds.), *Range Ecology at Disequilibrium. New Models of Natural Variability and Pastoral Adaption in African Savannas*, pp. 153–172. Overseas Development Institute, London.

Blench, R., 2001; *"You can't go home again" Pastoralism in the new millennium.* Overseas Development Institute, London, 104 pp.

Bock, C., Bock, J., Kenney, W., & Hawthorne, V., 1984; Response of birds, small mammals, and vegetation to livestock exclosure in a semidesert grassland site. *Journal of Range Management*, **37**, 239–242.

Bolortsetseg, B. & Tuvaansuren, G., 1996; The potential impacts of climate change on pasture and cattle production in Mongolia. *Water, Air, & Soil Pollution*, **92**(1-2), 95–105.

Bonham, C., 1989; *Measurements of Terrestrial Vegetation.* John Wiley and Sons, New York, 338 pp.

Bonham, C. & Lerwick, A., 1976; Vegetation Changes Induced by Prairie Dogs on Shortgrass Range. *Journal of Range Management*, **29**(3), 221–225.

Borisova, I. & Popova, T., 1985; Biogeozönologische Untersuchungen der Steppenwüsten und Wüstensteppen der nördlichen Gobi. *Feddes Repertorium*, **96**(5-6), 409–423.

Bork, E. & Werner, S., 1999; Viewpoint: implications of spatial variability for estimating forage use. *Journal of Range Management*, **52**, 151–156.

Bossel, H., 1994; *Modellbildung und Simulation. Konzepte, Verfahren und Modelle zum Verhalten dynamischer Systeme.* Vieweg, Braunschweig, Wiesbaden, 2^{nd} edn.

Brantigham, P., Haizhou, M., Olsen, J., Xing, G., Madsen, D., & Rhode, D., in press; Speculation on the timing and nature of Late Pleistocene hunter–gatherer colonization of the Tibetan Plateau. *Chinese Science Bulletin.*

Brantigham, P., Olsen, J., & Schaller, G., 2001; Lithic assemblages from the Chang Tang Region, Northern Tibet. *Antiquity*, **75**, 319–327.

Brathen, K. & Oksanen, J., 2001; Reindeer reduce biomass of preferred plant species. *Journal of Vegetation Science*, **12**, 473–480.

Brentjes, B., 1988; *Die Ahnen Dschingis-Chans.* VEB Deutscher Verlag der Wissenschaften, Berlin, 218 pp.

Briske, D., Fuhlendorf, S., & Smeins, F., 2003; Vegetation dynamics on rangelands: a critique of the current paradigms. *Journal of Applied Ecology*, **40**(4), 601–614.

Butler, L., Cropper, J., Johnson, R., Norman, A., & Shaver, P., 1997; *National Range and Pasture Handbook.* United States Department of Agriculture (NSDA), Natural Resources Conservation Service (NRCS), Grazing Lands Technology Institute (GLTI), ca. 500 pp. Online: `www.glti.nrcs.usda.gov/technical/publications/nrph.html` last visited 02.09.2003.

Campbell, B. & Smith, D., 2000; A synthesis of recent global change research on pasture and rangeland production: reduced uncertainties and their management implications. *Agriculture Ecosystems & Environment*, **82**(1-3), 39–55.

Carrier, W. & Czech, B., 1996; Threatened and endangered wildlife and livestock interactions. In: P. R. Krausman (ed.), *Rangeland Wildlife*, pp. 39–47. The Society for Range Management, Denver, Colorado.

Catchpole, W. & Wheeler, J., 1992; Estimating plant biomass: A review of techniques. *Australian Journal of Ecology*, **17**, 121–131.

Cermak, J., 2002; *Isolated Birch Forests in Southern Mongolia and Nomads: A Case Study for Biodiversity Conservation.* Master, King's College.

Cermak, J. & Opgenoorth, L., 2003; Dynamics of forest islands in the Govi Altay: microclimate and human impact. *Berliner Paläobiologische Abhandlungen*, **2**, 28.

Cermak, J., Opgenoorth, L., & Miehe, G., 2004; Isolated Mountain Forests in Central Asian Deserts. A Case Study from the Gobi Altay, Mongolia. In: *Holtmeier–Festschrift*, p. 28. Manuscript submitted.

Chang, K., 1986; *The archaeology of ancient China.* Yale University Press, New Haven, Conneticut, 450 pp.

Chapman, J. A. & Flux, J. A. C. (eds.), 1990; *Rabbits, hares and pikas: status survey and conservation action plan.* IUCN, Gland, Switzerland, 168 pp.

Cid, M., Detling, J., Whicker, A., & Brizuela, M., 1991; Vegetational responses of a mixed-grass prairie site following exclusion of prairie dogs and bison. *Journal of Range Management*, **44**(2), 100–105.

Clutton-Brock, T. & Harvey, P., 1983; The functional significance of variation in body size among mammals. *Special publication / The American Society of Mammalogists*, **7**, 632–663.

Cooper, L., 1993; Patterns of mutual assistance in the Mongolian pastoral economy. *Nomadic Peoples*, **33**, 153–162.

Coppock, D., Detling, J., Ellis, J., & Dyer, M., 1983a; Plant–Herbivore Interactions in a North American Mixed–Grass Prairie. I. Effects of black–tailed prairie dogs on intraseasonal aboveground plant biomass and nutrient dynamics and plant species diversity. *Oecologia*, **56**, 1–9.

Coppock, D., Detling, J., Ellis, J., & Dyer, M., 1983b; Plant–Herbivore Interactions in a North American Mixed–Grass Prairie. II. Responses of Bison to Modification of Vegetation by Prairie Dogs. *Oecologia*, **56**, 10–15.

Coppock, D., Ellis, J., & Swift, D., 1986; Livestock feeding ecology and resource utilization in a nomadic pastoral system. *Journal of Applied Ecology*, **23**, 573–583.

Crawford, R., 1996; Konkurrenz in Pflanzengesellschaften. In: C. Brunold, A. Rügesegger, & R. Brändle (eds.), *Streß bei Pflanzen*, pp. 269–294. Paul Haupt Verlag, Bern.

D'Arrigo, R., Jacoby, G., Frank, D., Pederson, N., Cook, E., & Buckley, B., 2000; 1738 Years of Mongolian Temperature Variability. *Scientific Journal of the Faculty of Biology, National University of Mongolia*, **11**(164), 10–15.

Dasch, D. & Tschimedregsen, L., 1996; *Forschungsbericht der pflanzengeographischen*

Untersuchungen im komplexen Schutzgebiet Gobi-Gurvan-Saichan (German translation, original in Mongolian). gtz Nature Conservation and Buffer Zone Management Project, Ulaanbaatar, 25 pp. Unpublished report.

Dawson, T. & Ellis, B., 1996; Diets of mammalian herbivores in Australian arid, hilly shrublands: seasonal effects on overlap between euros (hill kangaroos), sheep and feral goats, and on dietary niche breadths and electivities. *Journal of Arid Environments*, **34**, 491–506.

De Boer, W. & Prins, H., 1990; Large herbivores that strive mightily but eat and drink as friends. *Oecologia*, **82**, 264–274.

De Leeuw, P. & Tothill, J., 1990; The concept of rangeland carrying capacity in sub-Saharan Africa myth or reality. *Pastoral Development Network Paper*, **29b**, 20.

De Leeuw, P. & Tothill, J., 1993; The concept of rangeland carrying capacity in Sub-Saharan Africa - myth or reality. In: R. H. Behnke, I. Scoones, & C. Kerven (eds.), *Range Ecology at Disequilibrium. New Models of Natural Variability and Pastoral Adaption in African Savannas*, pp. 77–88. Overseas Development Institute, London.

Dean, W. & Macdonald, I., 1994; Historical changes in stocking rates of domestic livestock as a measure of semi-arid and arid rangeland degradation in the Cape Province, South Africa. *Journal Arid Environments*, **26**(3), 281–298.

DeAngelis, D. & Waterhouse, J., 1987; Equilibrium and Nonequilibrium Concepts in Ecological Models. *Ecological Monographs*, **57**(1), 1–2.

Dee Mack, W., 1996; Grassland enclosures: Catalyst of land degradation in Inner Mongolia. *Human Organization*, **55**(3), 307–313.

Defosse, G. & Bertiller, M., 1991; Comparison of four methods of grassland productivity assessment based on *Festuca pallescens* phytomass data. *Journal of Range Management*, **44**(3), 199–203.

Denzau, G. & Denzau, H., 1999; *Wildesel*. Jan Thorbecke Verlag, Stuttgart, 221 pp.

Desta, S. & Coppock, D., 2002; Cattle population dynamics in the southern Ethiopian rangelands, 1980–97. *Journal of Range Management*, **55**(5), 439–451.

Detling, J., 1998; Mammalian herbivores: ecosystem-level effects in two grassland national parks. *Wildlife Society Bulletin*, **26**(3), 438–448.

Diaz, S., Noy-Meir, I., & Cabido, M., 2001; Can grazing response of herbaceaous plants be predicted from simple vegetative traits? *Journal of Applied Ecology*, **38**, 497–508.

Dierschke, H., 1989; Symphänologische Aufnahme- und Bestimmungsschlüssel für Blütenpflanzen und ihre Gesellschaften in Mitteleuropa. *Tuexenia*, **9**, 477–484.

Dierschke, H., 1995; Phänologische und symphänologische Artengruppen von Blütenpflanzen Mitteleuropas. *Tuexenia*, **15**, 523–560.

Dube, O. & Pickup, G., 2001; Effects of rainfall variability and communal and semi-commercial grazing on land cover in southern African rangelands. *Climate Research*, **17**(2), 195–208.

Duffy, J., 2002; Biodiversity and ecosystem function: the consumer connection. *Oikos*, **99**, 201–210.

Dyson-Hudson, R. & Dyson-Hudson, N., 1980; Nomadic Pastoralism. *Annual Review of Anthropology*, **9**, 15–61.

Ellis, J., 1995; Climate variability and complex ecosystem dynamics: implications for pastoral development. In: I. Scoones (ed.), *Living with Uncertainty, New Directions in Pastoral Development in Africa*, pp. 37–46. Intermediate Technology Publications, London, UK.

Ellis, J. & Chuluun, T., 1993; Cross-country survey of climate, ecology and land use among Mongolian pastoralists. In: *Conference on Grassland Ecosystems of the Mongolian Steppe 4.–7. November 1993*. Wingspread Center, Racine, WI, USA.

Ellis, J. & Swift, D., 1988; Stability of African pastoral ecosystems: Alternate paradigms and implications for development. *Journal of Range Management*, **41**(6), 450–459.

Enkh-Amgalan, not dated; Strategies to combat Dzud. unpublished.

Fagerstone, K. & Ramey, C., 1996; Rodents and Lagomorphs. In: P. R. Krausman (ed.), *Rangeland Wildlife*, pp. 83–132. Society for Range Management, Denver, Colorado.

Fahnestock, J. & Detling, J., 2002; Bison-prairie dog-plant interactions in a North American mixed-grass prairie. *Oecologia*, **132**(1), 86–95.

FAO, 1998; *World reference base for soil resources.* World Soil Resources Reports 84. Rome, 88 pp.

Farnsworth, K. & Anderson, A., 2001; How simple grazing rules can lead to persistent boundaries in vegetation communities. *Oikos*, **95**(1), 15–24.

Farnsworth, K., Focardi, S., & Beecham, J., 2002; Grassland-herbivore interactions: How do grazers coexist? *American Naturalist*, **159**(1), 24–39.

Ferguson, L., 2003; The Apples and Oranges of Rangeland Terminology. `www.cnr.uidaho.edu/range456/hot-topics/range-terms.htm`. Last visited 02.09.2003.

Fernandez-Gimenez, M., 1997; *Landscapes, livestock and livelihoods: social, ecological, and land-use change among the nomadic pastoralists of Mongolia.* Phd thesis, University of California, Berkeley. Unpublished.

Fernandez-Gimenez, M., 1999; Sustaining the steppes: a geographical history of pastoral land use in Mongolia. *The Geographical Review*, **89**(3), 315–342.

Fernandez-Gimenez, M. & Allen-Diaz, B., 1999; Testing a non-equilibrium model of rangeland vegetation dynamics in Mongolia. *Journal of Applied Ecology*, **36**(6), 871–885.

Fernandez-Gimenez, M. & Allen-Diaz, B., 2000; Vegetation change along gradients from water sources in three grazed Mongolian ecosystems. *Plant Ecology*, **00**, 1–18.

Finch, C., 1996; *Mongolia's Wild Heritage.* Mongolian Ministry for Nature and Environment (MNE), United Nations Development Programme (UNEP), Global Environment Facility (GEF), World–Wide Fund for Nature (WWF), Boulder, Colorado, 1–42 pp.

Finch, C., 1998; Mongolia's Wild Heritage - Biological diversity, protected areas, and conservation in the land of Chingis Khan. `www.un-mongolia.mn/archives/wildher/`. Last visited 03.09.2003.

Fish, M., 2001; The Inner Asian anomaly: Mongolia's democratization in comparative perspective. *Communist and Post-Communist Studies*, **34**(3), 323–338.

Fishwick, P., 1995; Computer Simulation: The Art and Science of Digital World Construction. `www.cis.ufl.edu/~fishwick/introsim/paper.html`. Last visited 06.06.2003.

Forkert, F., 1993; Zu einigen aktuellen Problemen der sozial–ökonomischen Entwicklung in der Mongolei. *Die Erde*, **124**, 313–322.

Fowell, S., Hansen, B., Peck, J., Khosbayar, P., & Ganbold, E., 2003; Mid to late Holocene climate evolution of the Lake Telmen Basin, North Central Mongolia, based on palynological data. *Quaternary Research*, **59**(3), 353–363.

Frank, D. & McNaughton, S., 1992; The ecology of plants, large mammalian herbivores, and drought in Yellowstone National Park. *Ecology*, **73**(6), 2043–2058.

Fynn, R. & O'Connor, T., 2000; Effect of stocking rate and rainfall on rangeland dynamics and cattle performance in a semi-arid savanna, South Africa. *Journal of Applied Ecology*, **37**, 491–507.

Georgiadis, N., Hack, M., & Turpin, K., 2003; The influence of rainfall on zebra population dynamics: implications for management. *Journal of Applied Ecology*, **40**(1), 125–136.

Grubov, V., 2001; *Key to the vascular plants of Mongolia. Volume I & II.* Science Publishers, Plymouth, 817 pp.

Grunert, J., Lehmkuhl, F., & Walther, M., 2000; Paleoclimatic evolution of the Uvs Nuur Basin and adjacent areas (Western Mongolia). *Quaternary International*, **65/66**, 171–192.

Guevara, J., Gonnet, J., & Estevez, O., 2002; Biomass estimation for native perennial grasses in the plain of Mendoza, Argentina. *Journal of Arid Environments*, **50**(4), 613–619.

Gunin, P. & Slemnev, N., 2000; Geobotanical findings on the desiccation of arid landscapes of Central Asia. In: G. Miehe & Z. Yili (eds.), *Environmental Changes in High Asia*, vol. 135 of *Marburger Geographische Schriften*, pp. 140–155.

Gunin, P., Vostokova, E., & Dorofeyuk, N., 1999; *Vegetation dynamics of Mongolia.* Geobotany 26. Kluwer Academic Publishers, Dordrecht, Boston, 238 pp.

Guriceva, N., 1985; Die Beeinflussung der Steppenvegetation im östlichen Changai durch bodenbewohnende Nagetiere. *Archiv für Naturschutz und Landschaftsforschung*, **25**(1), 47–56.

Haase, G., 1983; Beiträge zur Bodengeographie der Mongolischen Volksrepublik. *Studia Geographica (Brünn)*, **34**, 231–347.

Hardin, G., 1968; The Tragedy of the Commons. *Science*, **162**, 1243–1248.

Hart, R., 2001; Plant biodiversity on shortgrass steppe after 55 years of zero, light, moderate and heavy cattle grazing. *Plant Ecology*, **155**, 111–118.

Hary, I., Schwartz, H., Pielert, V., & Mosler, C., 1996; Land degradation in African pastoral systems and the destocking controversy. *Ecological Modelling*, **86**(2-3), 227–233.

Hess, R., 1988; Sibirischer Steinbock. In: *Grzimeks Enzyklopädie Säugetiere, Band 3*, pp. 527–528. Kindler.

Hickman, K. & Hartnett, D., 2002; Effects of grazing intensity on growth, reproduction, and abundance of three palatable forbs in Kansas tallgrass prairie. *Plant Ecology*, **159**, 23–33.

Hilbig, W., 1990; Pflanzengesellschaften der Mongolei. *Erforschung biologischer Ressourcen der Mongolischen Volksrepublik*, **8**, 5–146.

Hilbig, W., 1995; *The vegetation of Mongolia.* SPB Academic Publishing, Amsterdam, 258 pp.

Hilbig, W., 2000a; Forest distribution and retreat in the forest steppe ecotone of Mongolia. In: G. Miehe & Z. Yili (eds.), *Environmental Changes in High Asia*, vol. 135 of *Marburger Geographische Schriften*, pp. 171–187.

Hilbig, W., 2000b; Kommentierte Übersicht über die Pflanzengesellschaften und ihre höheren Syntaxa in der Mongolei. *Feddes Repertorium*, **111**(1–2), 75–120.

Hilbig, W. & Tschuluunbaatar, S., 1989; Naturschutz in der Mongolischen Volksrepublik. *Archiv für Naturschutz und Landschaftsforschung*, **29**, 45–56.

Ho, P., 2001; Rangeland degradation in north China revisited? A preliminary statistical analysis to validate Non-Equilibrium Range Ecology. *Journal of Development Studies*, **37**(3), 99–133.

Hobbs, N. & Carpenter, L., 1986; Viewpoint: animal-unit equivalents should be weighted by dietary differences. *Journal of Range Management*, **39**(5), 470.

Holling, C., 1973; Resilience and stability in ecological systems. *Annual Review of Ecology and Systematics*, **4**, 1–23.

Hooper, D. & Johnson, L., 1999; Nitrogen limitation in dryland ecosystems: Responses to geographical and temporal variation in precipitation. *Biogeochemistry*, **46**, 247–293.

Huennecke, L., Clason, D., & Muldavin, E., 2001; Spatial heterogeneity in Chihuahuan Desert vegetation: implications for sampling methods in semi-arid ecosystems. *Journal of Arid Environments*, **47**, 257–207.

Huffman, B., 2003; The Ultimate Ungulate Page. `www.ultimateungulate.com`. Last visited 03.04.2003.

Hulbert, I. & Andersen, R., 2001; Food competition between a large ruminant and a small hindgut fermentor: the case of the roe deer and mountain hare. *Oecologia*, **128**(4), 499–508.

Humphrey, C. & Sneath, D., 1999; *The end of nomadism?: Society, state and the environment in Inner Asia*. White Horse Press, Cambridge, 355 pp.

Illius, A. & Connor, T., 1999; On the relevance of nonequilibrium concepts to arid and semiarid grazing systems. *Ecological Applications*, **3**, 798–813.

Illius, A., Derry, J., & Gordon, I., 1998; Evaluation of strategies for tracking climatic variation in semi-arid grazing systems. *Agricultural Systems*, **57**(3), 381–398.

Jacoby, G. & D'Arrigo, R., 2000; Mongolian tree–ring and 20th century warming. *Scientific Journal of the Faculty of Biology, National University of Mongolia*, **11**(164), 1–9.

Jacoby, G., D'Arrigo, R., Pederson, N., Buckley, B., Dugarjav, C., & Mijidorj, R., 2000; Temperature and precipitation in Mongolia based on dendroclimatic investigations. *Scientific Journal of the Faculty of Biology, National University of Mongolia*, **11**(164), 5–9.

Jäkel, D. & Grunert, J., 2003; Die Wüsten Zentralasiens. *Petermanns Geographische Mitteilungen*, **147**(5), 26–33.

Janzen, J., 1999; Einführende Gedanken zum Thema "Räumliche Mobilität und Existenzsicherung". *Abhandlungen - Anthropogeographie Institut für Geographische Wissenschaften FU Berlin*, **60**, 1–11.

Janzen, J., 2000; Present state of development and perspectives after ten years of transformation. *Berliner Geowissenschaftliche Abhandlungen A*, **205**, 149–152.

Janzen, J. & Bazargur, D., 1999; Der Transformationsprozeß im ländlichen Raum der Mongolei und dessen Auswirkungen auf das räumliche Verwirklichungsmuster der mobilen Tierhalter. *Abhandlungen - Anthropogeographie Institut für Geographische Wissenschaften FU Berlin*, **60**, 47–81.

Janzen, J. & Bazargur, D., 2003; Wandel und Kontinuität in der mobilen Tierhaltung der Mongolei. *Petermanns Geographische Mitteilungen*, **147**(5), 50–57.

Jätzold, R., 1984; Steppengebiete der Erde: Bedingungen und Möglichkeiten. *Praxis Geographie*, **11**, 10–15.

Jingyun Fang, Shilong Piao, Zhiyao Tang, Changhui Peng, & Wei Ji, 2001; Interannual Variability in Net Primary Production and Precipitation. *Science*, **293**, 1723.

Johnson, P., Johnson, C., & West, N., 1988; Estimation of phytomass for ungrazed crested wheatgrass plants using allometric equations. *Journal of Range Management*, **41**, 421–425.

Jones, C., Lawton, J., & Shachak, M., 1994; Organisms as ecosystem engineers. *Oikos*, **69**(3), 373–386.

Jones, C., Lawton, J., & Shachak, M., 1997; Ecosystem engineering by organisms: why semantic matters. *Trends in Ecology and Evolution*, **12**(7), 275.

Jørgensen, S., 1988; *Fundamentals in ecological modelling*, vol. 9 of *Developments in Environmental Modelling.* Elsevier, Amsterdam, Oxford, New York, Tokyo, 2^{nd} edn., 391 pp.

Kaetzke, P. & Traglauer, A., 1998; *Ochotona im Gurvan Saichan Park.* Bayreuth, 11 pp. Unpublished.

Karamysheva, Z. & Khramtsov, V., 1995; The steppes of Mongolia. *Braun-Blanquetia*, **17**, 5–79.

Katoh, K., Takeuchi, K., Jiang, D., Nan, Y., & Kou, Z., 1998; Vegetation restoration by seasonal exclosure in the Kerqin Sandy Land, Inner Mongolia. *Plant Ecology*, **139**(2), 133–144.

Kay, R., 1997; Responses of African livestock and wild herbivores to drought. *Journal of Arid Environments*, **37**(4), 683–694.

Khuukhenduu, T. & Bidbayasakh, E., 2001; Wolves in Mongolia – Wolf Depredation in Mongolian Park is a Fact of Life. *International Wolf*, **11**(3).

Kinlaw, A., 1999; A review of burrowing by semi-fossorial vertebrates in arid environments. *Journal of Arid Environments*, **41**(2), 127–145.

Kleiböhmer, C., Heuwieser, W., Bergmann, J., & Ochsmann, A., 1998; Untersuchungen zur Erlernbarkeit und Genauigkeit der Körperkonditionsbeurteilung (BCS) beim Rind. *Der Praktische Tierarzt*, **79**(1), 50–61.

Klötzli, F., 1996; Verbiss. In: C. Brunold, A. Rügesegger, & R. Brändle (eds.), *Streß bei Pflanzen*, pp. 295–307. Paul Haupt Verlag, Bern.

Komonen, M., Komonen, A., & Otgonsuren, A., 2003; Daurian pikas (Ochotona daurica) and grassland condition in eastern Mongolia. *Journal of Zoology*, **259**, 281–288.

Kotliar, N., Baker, B., & Whicker, A., 1999; A Critical Review of Assumptions About the Prairie Dog as a Keystone Species. *Environmental Management*, **24**(2), 177–192.

Kripalani, R. & Kulkarni, A., 2001; Monsoon rainfall variations and teleconnections over South and East Asia. *International Journal of Climatology*, **21**, 603–616.

Krogh, S., Zeisset, M., Jackson, E., & Whitford, W., 2002; Presence/absence of a keystone species as an indicator of rangeland health. *Journal of Arid Environments*, **50**(3), 513–519.

Krueger, K., 1986; Feeding relationships among bison, pronghorn, and prairie dogs: an experimental analysis. *Ecology*, **67**(3), 760–770.

Kurushin, R., Bayasgalan, A., Ölziybat, M., Enhtuvshin, B., Molnar, P., & Bayarsayhan, C. e., 1997; *The Surface Rupture of the 1957 Gobi-Altay, Mongolia, Earthquake*, vol. 320 of *Special papers*. The Geological Society of America, Boulder, 143 pp.

Larcher, W., 1994; *Ökophysiologie der Pflanzen*. Ulmer, Stuttgart, 5 edn., 394 pp.

Lattimore, O., 1962; *Nomads and commissars: Mongolia revisited*. Oxford University Press, New York, 238 pp.

Lauenroth, W. & Sala, O., 1992; Long term forage production of North American shortgrass steppe. *Ecological Applications*, **2**, 397–403.

Launchbaugh, K., not dated; A short course on rangelands. `www.cnr.uidaho.edu/range/wirange/What-is-Range.pdf`. Last visited 02.07.2003.

Lavrenko, E., Iunatov, A., Aleksandr, A., & Dashniam, B., 1979; Karta rastitel'nosti Mongol'skoi Narodnoi Respubliki (Vegetation Map of Mongolia, in Russian).

Lawton, J., 1994; What do species do in ecosystems? *Oikos*, **71**, 367–374.

Laycock, W., Buchanan, H., & Krueger, W., 1972; Three methods of determining diet, utilization, and trampling damage on sheep ranges. *Journal of Range Management*, **25**, 352–356.

Lchagwasuren, L., 1996; *Ergänzung zu "Biological Assessment of Three Beauties of the Gobi National Conservation Park, Mongolia II"*. gtz Nature Conservation and Buffer Zone Development Project, Ulaanbaatar, 9 pp. Unpublished report.

Le Houerou, H., 1984; Rain use efficiency: a unifying concept in arid-land ecology. *Journal of Arid Environments*, **7**, 213–247.

Lehmkuhl, F., 2003; Late Quarternary climate change and aeolian sedimentation in the Altai region (Mongolia and Russia). *Berliner Paläobiologische Abhandlungen*, **2**, 70–72.

Lehmkuhl, J. & Haselein, f., 2000; Quaternary palaeoenvironmentalchange on the Tibetan Plateau and adjacent areas (Western China and Western Mongolia). *Quaternary International*, **65/66**, 121–145.

Lensch, J., Schley, P., & Zhang, R.-C., 1996; *Der Yak (Bos grunniens) in Zentralasien.* Duncker und Humboldt, Berlin, 268 pp.

Leriche, H., LeRoux, X., Gignoux, J., Tuzet, A., Fritz, H., & Abbadie, L., 2001; Which functional process control the short-term effect of grazing on net primary production in grasslands. *Oecologia*, **129**, 114–124.

Leyhausen, P., Grzimek, B., & Zhiwotschenko, V., 1988; Pantherkatzen und Verwandte. In: *Grzimeks Enzyklopädie Säugetiere, Band 3*, pp. 1–10. Kindler, München.

Library of Congress, n.d.; Glossary - Mongolia. `http://memory.loc.gov/frd/cs/mongolia/mn_glos.html`. Last visited 3.10.2003.

Lieth, H., 1968; The determination of plant dry-matter production with special emphasis on the underground parts. In: F. E. Eckardt (ed.), *Functioning of terrestrial ecosystems at the primary production level. Proceedings of the Copenhagen Symposium*, vol. V of *Natural Resources Research*, pp. 179–186. Unesco.

Liu, X. & Chen, B., 2000; Climatic warming in the Tibetan Plateau during recent decades. *International Journal of Climatology*, **20**(14), 1729–1742.

Livingstone, I., 1991; Livestock Management and "Overgrazing" among Pastoralists. *Ambio*, **20**(2), 80–85.

Lomolino, M., 2000; A call for a new paradigm of island biogeography. *Global Ecology and Biogeography*, **9**, 1–6.

Long, R., Apori, S., Castro, F., & Orskov, E., 1999; Feed value of native forages of the Tibetan Plateau of China. *Animal Feed Science and Technology*, **80**, 101–113.

Long, S., E., G., Imbamba, S., Kamnalrut, A., Piedade, M., & Scurlock, J., 1989; Primary productivity of natural grass ecosystems of the tropics: A reappraisal. *Plant and Soil*, **115**, 155–166.

Malyshev, L., 2000; Floristic division on the quantitative basis: Baikalian Siberia, Tuva and Outer Mongolia. *Flora*, **195**, 330–338.

Maroney, R., 2003; *Argali (Ovis ammon) conservation in Western Mongolia and the Altai-Sayan.* Master thesis, University of Montana. Unpublished.

Mauch, C., 2000; Füttern nach Noten. *Bioland*, **1**, 12–14.

McArthur, R. & Wilson, E., 1967; *The Theory of Island Biogeography.* Goldmann, München, 201 pp.

McGinnies, W., 1979; General description of desert areas. In: D. W. Goodall & R. A. Perry (eds.), *Arid–land ecosystems: structure, functioning and management*, vol. 1, pp. 5–19. Cambridge University Press, Cambridge.

McNaughton, S., 1976; Serengeti migratory wildebeest: facilitation of energy flow by grazing. *Science*, **191**, 92–94.

McNaughton, S., 1979; Grazing as an optimization process: grass-ungulate relationships in the Serengeti. *American Naturalist*, **113**, 691–703.

McNaughton, S., 1984; Grazing lawns: animals in herds, plant form, and coevolution. *The American Naturalist*, **124**(6), 863–886.

McNaughton, S., Milchunas, D., & Frank, D., 1996; How can net primary productivity be measured in grazing ecosystems? *Ecology*, **77**, 974–977.

Mearns, R., 1993; Territoriality and land tenure among Mongolian pastoralists: variation, continuity and change. *Nomadic Peoples*, **33**, 73–103.

Mearns, R., 1996; Community, collective action and common grazing: the case of post-socialist Mongolia. *Journal of Development Studies*, **32**(3), 297–339.

Meissner, R. & Facelli, J., 1999; Effects of sheep exclusion on the soil seed bank and annual vegetation in chenopod shrublands of South Australia. *Journal of Arid Environments*, **42**, 117–128.

Meteorological Service Mongolia, 1937-2002; Climate data of the Gobi Gurvan Sayhan National Park. Data were derived from various sources: directly from the Service, from Prof. Opp, University of Marburg, and as cited in Bergius (2002).

Meurer, M., 1993; *Geo- und weideökologische Untersuchungen im Mogod-Bergland Nordwest-Tunesiens unter besonderer Berücksichtigung der kleinbäuerlichen Ziegenhaltung*, vol. 29 of *Erdwissenschaftliche Forschung*. Steiner, Stuttgart, 334 pp.

Meurer, M., 1998; *Geo- und weideökologische Untersuchungen in der subhumiden Savannenzone NW-Benins*, vol. 1 of *Karlsruher Schriften zur Geographie und Geoökologie*. Institut für Geographie und Geoökologie, Karlsruhe, 279 pp.

Meusel, H., Jäger, E., Bräutigam, S., Knapp, H.-D., Rauschert, S., & Weinert, E., 1992; *Vergleichende Chorologie der zentraleuropäischen Flora. Bd. III Text und Kartenband*. G. Fischer, Jena, Stuttgart, 686 pp.

Miehe, G., 2003; Ecosystems of High Asia under human impact - new perspectives. *Berliner Paläobiologische Abhandlungen*, **2**, 83–84.

Miehe, G. & Miehe, S., 2000; Environmental changes in the pastures of Xizang. In: G. Miehe & Z. Yili (eds.), *Environmental Changes in High Asia*, vol. 135 of *Marburger Geographische Schriften*, pp. 282–311.

Miehe, S., 1996; *Vegetationskundlich–ökologische Untersuchungen, Auswahl und Einrichtung von Dauerprobeflächen für Vegetationsmonitoring im Nationalpark Gobi-Gurvan-Saikhan*. gtz Nature Conservation and Buffer Zone Development Project, Ulaanbaatar, 74 pp. Unpublished report.

Miehe, S., 1998; *Ansätze zu einer Gliederung der Vegetation im Nationalpark Gobi–Gurvan–Saikhan*. gtz Nature Conservation and Buffer Zone Development Project, Ulaanbaatar, 86 pp. Unpublished report.

Milchunas, D., Forwood, J., & Lauenroth, W., 1994; Productivity of long-term grazing treatments in response to seasonal precipitation. *Journal of Range Management*, **47**, 133–139.

Miller, B., Ceballos, G., & Reading, R., 1994; The Prairie Dog and Biotic Diversity. *Conservation Biology*, **8**(3), 677–681.

Miller, B., Reading, R., Hoogland, J., Clark, T., Ceballos, G., & List, R., 2000; The role of prairie dogs as a keystone species: response to Stapp. *Conservation Biology*, **14**(1), 318–321.

Milner, C. & Hughes, R., 1968; *Methods for the Measurement of the Primary Production of Grassland*, vol. 6 of *IBP Handbook*. Blackwell, Oxford, 70 pp.

Mirriam-Webster, 2003; Mirriam-Webster online Dictionary. `www.webster.com/cgi-bin/dictionary`. Last visited 15.09.2003.

Mix, H., 2000; *Gazelle populations and wildlife management in the area of Gobi Gurvan Saikhan National Park*. gtz Project Nature Conservation and Bufferzone Development, Berlin, 16 pp. Unpublished report.

Mongolian Atlas, 1990; *Mongolskaya Narodna Respublika Nacionalny Atlas*. Akademiya Nauk, Ulaanbaatar, 144 pp.

Müller, F.-V., 1994; Ländliche Entwicklung in der Mongolei: Wandel der mobilen Tierhaltung durch Privatisierung. *Die Erde*, **123**, 213–222.

Müller, F.-V., 1999; Die Wiederkehr des mongolischen Nomadismus. Räumliche Mobilität und Existenzsicherung in einem Transformationsland. *Abhandlungen - Anthropogeographie Institut für Geographische Wissenschaften FU Berlin*, **60**, 11–46.

Müller, F.-V., 2003; Die Wirtschaftsentwicklung der Mongolei - Geschichte und Gegenwart externer Abhängigkeiten. *Petermanns Geographische Mitteilungen*, **147**(5), 64–71.

Müller, F.-V. & Bold, B.-O., 1996; Zur Relevanz neuer Regelungen für die Weidelandnutzung in der Mongolei. *Die Erde*, **127**(1), 63–82.

Müller, F.-V. & Janzen, J., 1997; Die ländliche Mongolei heute. *Geographische Rundschau*, **49**, 272–278.

Müller-Hohenstein, K., 1993; Auf dem Weg zu einem neuen Verständnis von Desertifikation – Überlegungen aus der Sicht einer praxisorientierten Geobotanik. *Phytocoenologia*, **23**, 499–518.

Müller-Hohenstein, K., 1999; Weideökologisches Management - Erfahrungen in der Dritten Welt. *Geographische Rundschau*, **51**(5), 275–279.

Murzaev, E., 1954; *Die Mongolische Volksrepublik: Physisch-geographische Beschreibung (The Mongolian People's Republic: Physical Geographic Description)*. VEB geographisch-kartographische Anstalt, Gotha, 523 pp.

Nachtigall, C. & Suhl, U., 2002; *Der Regressionseffekt – Mythos und Wirklichkeit.* 2. Lehrstuhl für Psychologische Methodenlehre und Evaluationsforschung Friedrich-Schiller-Universität, Jena, 11 pp.

Nadrowski, K., Retzer, V., & Miehe, G., 2002; Small mammal and livestock grazing: Can the Mongolian Pika (Ochotona pallasi) be considered a "rodent pest"? *Verhandlungen der Gesellschaft für Ökologie*, **32**, 149.

National Statistical Office of Mongolia, 1996; *Agriculture in Mongolia 1971-1995 A statistical Profile.* National Statistical Office of Mongolia, Ulaanbaatar, 519 pp.

National Statistical Office of Mongolia, 1998; *Mongolian Statistical Yearbook 1998.* `http://nso.mn/yearbook/1998/index.asp`. Last visited 30.01.2003.

National Statistical Office of Mongolia, 2000; *Mongolian Statistical Yearbook 1999.* National Statistical Office of Mongolia, Ulaanbaatar, 221 pp.

National Statistical Office of Mongolia, 2001; *Mongolian Statistical Yearbook 2000.* National Statistical Office of Mongolia, Ulaanbaatar, 136 pp.

National Statistical Office of Mongolia, 2002; *Mongolian Statistical Yearbook 2001.* National Statistical Office of Mongolia, Ulaanbaatar, 301 pp.

National Statistical Office of Mongolia, 2003; *Mongolian Statistical Yearbook 2002.* National Statistical Office of Mongolia, Ulaanbaatar, 323 pp.

National Statistical Office of Mongolia, not dated; UN common country indicators Mongolia. `www.un-mongolia.mn/undp/nat-stat-office.htm`. Last visited 07.02.2002.

National Statistical Office of Mongolia & Worldbank, 2001; *Mongolia, Participatory Living Standards Assessment 2000.* Paris, 37 pp.

Nauheimer, H., 1991; Der Umgang mit dem Mangel. Produktionsstrategien in Trockengebieten und Trockenzeiten. In: F. Scholz (ed.), *Nomaden - mobile Tierhaltung: zur gegenwärtigen Lage von Nomaden und zu den Problemen und Chancen mobiler Tierhaltung*, pp. 213–232. Das Arabische Buch, Berlin.

Neupert, R., 1999; Population, nomadic pastoralism and the environment in the Mongolian plateau. *Population and Environment*, **20**, 413–440.

Nolan, T., Pulina, G., Sikosana, J., & Connolly, J., 1999; Mixed animal type grazing research under temperate and semi-arid conditions. *Outlook on Agriculture*, **28**(2), 117–128.

Nowak, R., 2003; Walker's Mammals of the World Online, version 5.1. `www.press.jhu.edu/books/walkers_mammals_of_the_world/`. Last visited 07.08.2003.

Noy-Meir, I., 1973; Desert ecosystems: Environment and producers. *Annual Review of Ecology and Systematics*, **4**, 25–51.

Noy-Meir, I., Gutman, M., & Kaplan, Y., 1989; Responses of mediterranean grassland plants to grazing and protection. *Journal of Ecology*, **77**, 290–310.

Oba, G., Stenseth, N., & Lusigi, W., 2000; New perspectives on sustainable grazing management in arid zones of Sub-Saharan Africa. *BioScience*, **50**, 35–51.

Oba, G., Weladji, R., Lusigi, W., & Stenseth, N., 2003; Scale-dependent effects of grazing on rangeland degradation in northern Kenya: A test of equilibrium and non-equilibrium hypotheses. *Land Degradation & Development*, **14**(1), 83–94.

Opgenoorth, L., 2003; *Ökologische Untersuchungen an Birkenweiden–Waldrelikten des Gobi Altai*. Diploma thesis, FB Geographie, Philipps-Universität, Marburg. Unpublished.

Opp, C., 1994; Böden und Bodenprozesse in der Mongolei. *Geowissenschaften*, **12**, 267–273.

Opp, C., 1996; Die Mongolische Republik - Natur und Lebensräume im Wandel. *HGG–Journal*, **10**, 13–28.

Opp, C. & Hilbig, W., 2003a; The impact of overgrazing on natural pastures in Mongolia and Tyva. *Berliner Paläobiologische Abhandlungen*, **2**, 96–98.

Opp, C. & Hilbig, W., 2003b; Verbreitungsregeln von Böden und Pflanzengesellschaften im nördlichen Zentralasien unter besonderer Berücksichtigung des Uvs-Nuur-Beckens. *Petermanns Geographische Mitteilungen*, **147**(5), 16–23.

ORNL DAAC, 2002; Estimation of NPP for Grasslands. `www.daac.ornl.gov/NPP/html_docs/grassland.html`. Last visited 03.06.2003.

Ososkova, T., Gorelkin, N., & Chub, V., 2000; Water resources of Central Asia and adaptation measures for climate change. *Environmental Monitoring and Assessment*, **61**(1), 161–166.

Owen, L., Richards, B., & Rhodes, E., 1998; Relic permafrost structures in the Gobi of Mongolia: age and significance. *Journal of Quaternary Science*, **13**(6), 539–549.

Paine, R., 1969; A note on trophic complexity and community stability. *American Naturalist*, **103**, 91–93.

Painter, E. & Belsky, A., 1993; Application of herbivore optimization theory to rangelands of the western United States. *Ecological Applications*, **3**, 2–9.

Pamo, E., 1998; Herders and wildgame behaviour as a strategy against desertification in northern Cameroon. *Journal of Arid Environments*, **39**, 179–190.

Pastor, J., Moen, R., & Cohen, Y., 1997; Spatial heterogeneities, carrying capacity, and feedbacks in animal–landscape interactions. *Journal of Mammalogy*, **78**(4), 1040–1052.

Paton, D., Nunez-Trujillo, J., Diaz, M., & Munoz, A., 1999; Assessment of browsing biomass, nutritive value and carrying capacity of shrublands for red deer (*Cervus* *elaphus* L.) management in Monfrague Natural Park, (SW Spain). *Journal of Arid Environments*, **42**, 137–147.

Patterson, B. & Power, V., 2002; Contributions of forage competition, harvest, and climate fluctuation to changes in population growth of northern white– tailed deer. *Oecologia*, **130**(1), 62–71.

Pearson, H., 1975; Herbage disapperance and grazing capacity determinations of southern pine-bluestem range. *Journal of Range Management*, **28**, 71–73.

Pederson, N., Jacoby, G., D'Arrigo, R., Cook, E., Buckley, B., & Dugarjav, C., 2001a; Hydrometeorological reconstructions for Northeastern Mongolia Derived from Tree Rings: AD 1651–1995. *Journal of Climate*, **14**(5), 872–881.

Pederson, N., Jacoby, G., D'Arrigo, R., Cook, E., Buckley, B., & Dugarjav, C., 2001b; Hydrometeorological reconstructions for Northeastern Mongolia Derived from Tree Rings: AD 1651-1995: Urgun Nars annual precipitation data. `ftp://ftp.ngdc.noaa.gov/paleo/treering/reconstructions/mongolia/urgun_nars_precip.txt`.

Pflaumbaum, H., 1995; Niederschlagsvariabilität und weidewirtschaftliche Tragfähigkeit im Sahel. *Regensburger geographische Schriften*, **25**, 95–102.

Pickup, G., 1996; Estimating the effects of land degradation and rainfall variation on productivity in rangelands: An approach using remote sensing and models of grazing and herbage dynamics. *Journal of Applied Ecology*, **33**(4), 819–832.

Potkanski, T., 1993; Decollectivisation of the Mongolian Pastoral Economy (1991–1992): Some Economic and Social Consequences. *Nomadic Peoples*, **33**, 123–135.

Power, M., 1997a; Ecosystem engineering by organisms: why semantic matters - Reply from M. Power. *Trends in Ecology and Evolution*, **12**(7), 275–276.

Power, M., 1997b; Estimating impacts of a dominant detritivore in a neotropical stream. *Trends in Ecology and Evolution*, **12**(2), 47–49.

Pucheta, E., Cabido, M., Diaz, S., & Funes, G., 1998; Floristic composition, biomass, and aboveground net plant production in grazed and protected sites in a mountain grassland of central Argentinia. *Acta Oecologia*, **19**(2), 97–105.

Rachkovskaya, E., 2001; Anthropogenic Transformation of Desert Ecosystems in Mongolia. In: S. W. Breckle, M. Veste, & W. Wucherer (eds.), *Sustainable Land Use in Deserts*, pp. 275–280. Springer, Berlin, Heidelberg, New York.

Reading, P., Amgalanbaatar, S., Lkhagvasuren, L., & Enkhbileg, D., 1996; *Biological Assessment of the Three Beauties of the Gobi National Conservation Park II.* gtz Nature Conservation and Buffer Zone Development Project, Ulaanbaatar, 21 pp. Unpublished report.

Reading, R., 1997; *Aerial Survey of Gobi Gurvansaikhan National Conservation Park,* *Mongolia.* gtz Nature Conservation and Buffer Zone Development Project, Ulaanbaatar, 17 pp. Unpublished report.

Reading, R., Amgalanbaatar, S., & Lhagvasuren, L., 1999a; Biological Assessment of Three Beauties of the Gobi National Conservation Park, Mongolia. *Biodiversity and Conservation*, **8**, 115–137.

Reading, R., Mix, H., Lhagvasuren, B., & Blumer, E., 1999b; Status of wild Bactrian camels and other large ungulates in south–western Mongolia. *Oryx*, **33**(3), 247–255.

Reichman, O. & Seabloom, E., 2002a; Ecosystem engineering: a trivialized concept? *Trends in Ecology and Evolution*, **17**(7), 308.

Reichman, O. & Seabloom, E., 2002b; The role of pocket gophers as subterranean ecosystem engineers. *Trends in Ecology and Evolution*, **17**(1), 44–49.

Retzer, V. & Nadrowski, K., 2001; *Final report of the research camp of the universities Marburg and Ulaanbaatar for the field period June 2000 - September 2001.* gtz Nature Conservation and Buffer Zone Management Project, Dalandzadgad, Mongolia, 19 pp. Unpublished report.

Retzer, V. & Nadrowski, K., 2002; Livestock and small mammal grazing in the Mountain Steppe of Gobi Gurvan Saikhan National Park of Mongolia. In: T. Chuluun & D. S. Ojima (eds.), *Fundamental Issues Affecting Sustainability of the Mongolian Steppe*, pp. 192–197. IISCN, Ulaanbaatar.

Retzer, V. & Reudenbach, C., submitted; Modelling the carrying capacity and coexistence of pika and livestock in the mountain steppe of the South Gobi, Mongolia. *Ecological Modelling.*

Roach, W., Huntly, N., & Inouye, R., 2001; Talus fragmentation mitigates the effects of pikas, Ochotona princeps, on high alpine meadows. *Oikos*, **92**(2), 315–324.

Robinson, S., Milner-Gulland, E., & Alimaev, I., 2003; Rangeland degradation in Kazakhstan during the Soviet era: re-examining the evidence. *Journal of Arid Environments*, **53**(3), 419–439.

Rodin, L., 1979; Productivity of desert communities in central Asia. In: D. W. Goodall & R. A. Perry (eds.), *Arid–land ecosystems: structure, functioning and management*, vol. 1, pp. 273–289. Cambridge University Press, Cambridge.

Rosiere, R. & Torell, D., 1985; Nutritive Value of Sheep Diets on Coastal California Annual Range. *Hilgardia*, **53**(1), 1–19.

Runnström, M., 2003; Rangeland development of the Mu Us sandy land in semiarid China: An analysis using landsat and NOAA remote sensing data. *Land Degradation & Development*, **14**(2), 189–202.

Ryerson, D. & Parmenter, R., 2001; Vegetation change following removal of keystone herbivores from desert grasslands in New Mexico. *Journal of Vegetation Science*,

12(2), 167–180.

Saffery, A., 2000; Mongolia's Tourism Development Race: Case Study from the Gobi Gurvansaikhan National Park. In: P. M. Godde, M. F. Price, & F. M. Zimmermann (eds.), *Tourism and development in mountain regions*, pp. 255–274. CABI.

Sala, O., 2001; Productivity of temperate grasslands. In: J. Roy, B. Saugier, & H. A. Mooney (eds.), *Terrestrial Global Productivity*, pp. 285–300. Academic Press, San Diego.

Sala, O. & Austin, A., 2000; Methods of estimating aboveground net primary production. In: O. E. Sala, R. B. Jackson, H. A. Mooney, & R. W. Howarth (eds.), *Methods in Ecosystem Science*, pp. 31–43. Springer, New York.

Sala, O., Biondini, M., & Lauenroth, W., 1988a; Bias in estimates of primary production: an analytical solution. *Ecological Modelling*, **44**, 43–55.

Sala, O., Parton, W., Joyce, L., & Lauenroth, W., 1988b; Primary production of the central grassland region of the United States. *Ecology*, **69**(1), 40–45.

Samjaa, R., Zöphel, U., & Peterson, J., 2000; The impact of the vole Microtus brandti on Mongolia steppe ecosystems. In: G. Miehe & Z. Yili (eds.), *Environmental Changes in High Asia*, vol. 135 of *Marburger Geographische Schriften*, pp. 346–360.

Scarnecchia, D., 1986; Viewpoint: Animal-unit equivalents cannot be meaningfully weighted by indices of dietary overlap. *Journal of Range Management*, **39**(5), 471.

Schaller, G., 2000; *Wildlife of the Tibetan Steppe*. The University of Chicago Press, Chicago, 373 pp.

Schlichting, E., Blume, H., & Stahr, K., 1995; *Bodenkundliches Praktikum*, vol. 81 of *Pareys Studientexte*. Blackwell Wissenschaft, Berlin & Hamburg, 2^{nd} edn., 295 pp.

Schlütz, F., 2003; Grazing on salty ground - Palynological results from the Gobi Altai, Mongolia. *Berliner Paläobiologische Abhandlungen*, **2**, 103.

Schmidt, S., 1995; Mongolia in transition. The impact of privatization on rural life. *Bielefelder Studien zur Entwicklungssoziologie*, **62**, 240.

Schmidt, S., 2000; Wächter der Drei Schönheiten. *Akzente*, **4**, 38–41.

Schmidt, S., 2002; *Nature Conservation and Bufferzone Development and Integrated Prevention of Desertification; Project Implementation 1998-2002 in Mongolia's Southern Gobi Region*. gtz Nature Conservation and Buffer Zone Management Project, Ulaanbaatar, 45 pp. Unpublished report.

Schneider, E., 1988; Pfeifhasen oder Pikas. In: *Grzimeks Enzyklopädie Säugetiere, Band 3*, pp. 314–324. Kindler, München.

Schoener, T., 1974; Competition and the form of habitat shift. *Theoretical Population Biology*, **6**, 265–307.

Schoener, T., 1976; Alternatives to Lotka-Volterra competition: models of intermediate complexity. *Theoretical Population Biology*, **10**, 309–333.

Schoener, T., 1978; Effects of density restricted food encounter on some single–level competition models. *Theoretical Population Biology*, **13**, 365–381.

Schoener, T., 1983; Field experiments on interspecific competition. *American Naturalist*, **122**, 240–285.

Scholz, F., 1991; Von der Notwendigkeit gerade heute über Nomaden und Nomadismus nachzudenken. In: F. Scholz (ed.), *Nomaden - mobile Tierhaltung: zur gegenwärtigen Lage von Nomaden und zu den Problemen und Chancen mobiler Tierhaltung*, pp. 7–37. Das Arabische Buch, Berlin.

Scholz, F., 1994; Nomadismus - Mobile Tierhaltung. *Geographische Rundschau*, **46**(2), 72–78.

Scholz, F., 1995; *Nomadismus- Theorie einer sozio-ökologischen Kulturweise.* Erdkundliches Wissen 118. Stuttgart.

Scholz, F., 1997; Gedanken zu einer These über die Entstehung des Nomadismus als sozioökologische Kulturweise. *Petermanns Geographische Mitteilungen*, **141**(3), 187–196.

Scholz, F., 1999; Nomadismus ist tot. *Geographische Rundschau*, **51**(5), 248–255.

Scholz, F. & Janzen, J., 1982; Nomadismus - ein Entwicklungsproblem? Einleitung. *Abhandlungen des Geographischen Instituts Antropogeographie*, **33**, 2–8.

Schroeder, F.-G., 1998; *Lehrbuch der Pflanzengeographie.* Quelle & Meyer, Wiesbaden, 1^{st} edn., 459 pp.

Schulte, A., 2001; *Weideökologie des Kaokolandes – Struktur und Dynamik einer Mopane–Savanne unter pastoralnomadischer Nutzung.* Phd thesis, Universität Köln.

Schultz, J., 1995; *Die Ökozonen der Erde: Die ökologische Gliederung der Geosphäre.* Verlag Eugen Ulmer, Stuttgart, 2^{nd} edn., 535 pp.

Schwartz, H., 1980; Understanding the ecology of a nomadic system of livestock production. *Impact of Science on Society*, **30**(4), 279–288.

Scoones, I., 1990; *Livestock populations and the household economy: A case study from Southern Zimbabwe.* Ph.D. thesis, University of London. Unpublished.

Scoones, I., 1993a; Why are there so many animals? Cattle population dynamics in the communal areas of Zimbabwe. In: R. H. Behnke, I. Scoones, & C. Kerven (eds.), *Range Ecology at Disequilibrium. New Models of Natural Variability and Pastoral Adaption in African Savannas*, pp. 62–76. Overseas Development Institute, London.

Scoones, I., 1993b; Why are there so many animals? Cattle population dynamics in the communal areas of Zimbabwe. In: R. H. Behnke, I. Scoones, & C. Kerven (eds.), *Range Ecology at Disequilibrium. New Models of Natural Variability and Pastoral Adaption in African Savannas*, pp. 62–77. Overseas Development Institute.

Sharrow, S. & Motazedian, I., 1983; A comparison of three methods for estimating forage disappearance. *Journal of Range Management*, **36**(4), 469–471.

Shi, D., Wan, X., Davis, S., Pech, R., & Zhang, Z., 2002; Simulation of lethal control and fertility control in a demographic model for Brandt's vole Microtus brandti. *Journal of Applied Ecology*, **39**(2), 337–348.

Shurentuja, Banzragch, Ellis, J., Ojima, D., Detling, J., & Chuluun, T., 2002; Herbaceous forage variability and carrying capacity in the Gobi Three Beauty Mountains National Park of Mongolia. In: T. Chuluun & D. Ojima (eds.), *Fundamental Issues Affecting Sustainability of the Mongolian Steppe*, pp. 177–191. IISNC, Ulaanbaatar, Mongolia.

Sims, P. & Singh, J., 1978; The structure and function of ten western North American grasslands: III. Net primary production, turnover and efficienceie of energy capture and water use. *Journal of Ecology*, **66**(2), 573–597.

Singh, J., Lauenroth, W., & Milchunas, D., 1983; Geography of grassland ecosystems. *Progress in physical Geography*, **7**, 46–80.

Singh, J., Lauenroth, W., & Steinhorst, R., 1975; Review and assessment of various techniques for estimating net aerial primary production in grasslands from harvest data. *The Botanical Review*, **41**(2), 181–232.

Smit, R., Bokdam, J., den Ouden, J., Olff, H., Schot-Opschoor, H., & Schrijvers, M., 2001; Effects of introduction and exclusion of large herbivores on small rodent communities. *Plant Ecology*, **155**(1), 119–127.

Smith, A. & Foggin, J., 1996; The Plateau Pika is a keystone species for biodiversity on the Tibetian Plateau. In: J. Peter, S. Wang, & Y. Xie (eds.), *Conserving China's Biodiversity (II)*, pp. 211–221. China Environmental Science Press, Beijing.

Smith, A., Formozov, A., Hoffmann, R., Zheng, C., & Erbajeva, M., 1990; The Pikas. In: J. A. Chapman & J. A. C. Flux (eds.), *Rabbits, hares and pikas: status survey and conservation action plan*, pp. 14–60. IUCN, Gland, Schweiz.

Sneath, D., 1993; Social relations, networks, and social organization in post–socialist rural Mongolia. *Nomadic Peoples*, **33**, 193–207.

Sneath, D., 1998; State Policy and Pasture Degradation in Inner Asia. *Science*, **281**(21), 1147.

Snyman, H., 1998; Literature review: Dynamics and sustainable utilization of rangeland ecosystems in arid and semi–arid climates in southern Africa. *Journal of Arid Environments*, **39**, 645–666.

Sommer, M., 1998; Die Bärentrauben-Lärchenwälder im Charchiraa-Gebirge (Mongolei).

Feddes Repertorium, **109**(1-2), 129–138.

Sommer, M. & Treter, U., 1999; Die Lärchenwälder der Gebirgswaldsteppe in den Randgebirgen des Uvs Nuur Beckens. *Die Erde*, **130**(2), 173–188.

Stapp, P., 1998; A Reevaluation of the Role of Prairie Dogs in Great Plains Grasslands. *Conservation Biology*, **12**(6), 1253–1259.

Steinhauer-Burkart, B., 1999; *Gobi–Gurvansaikhan National Park.* Eco–Nature, Neckargmünd, 64 pp.

Stumpp, M., 2002; *Vegetationskundliche Transektuntersuchungen zur Weidedegradation in Gebirgssteppen der Süd–Mongolei.* Examensarbeit, FB Geographie, Philipps-Universität, Marburg. Unpublished.

Sturm, H.-J., 1998; Weideökologische Grundlagen der Tierhaltung in der Sudanzone am Beispiel der Fulbe in Nord-Benin. In: M. Meurer (ed.), *Geo- und weideökologische Untersuchungen in der subhumiden Savannenzone NW-Benins*, Karlsruher Schriften zur Geographie und Geoökologie, pp. 87–115. Institut für Geographie und Geoökologie, Karlsruhe.

Sturm, H.-J., 1999; Weidewirtschaft in Westafrika. *Geographische Rundschau*, **51**(5), 269–274.

Suiter, J., 1994; Body condition scoring of sheep and goats; Farmnote 69/1994. `www.agric.wa.gov.au/agency/pubns/farmnote/1994/f06994.htm`. Last visited 22.01.2003.

Sullivan, S., 1996; Towards a non-equilibrium ecology: perspectives from an arid land. *Journal of Biogeography*, **23**, 1–5.

Sullivan, S., 1998; The impacts of people and livestock on topographically diverse open wood- and shrub-lands in arid north-west Namibia. *Global Ecology and Biogeography*, **8**, 243–256.

Sullivan, S. & Rohde, R., 2002; On non–equilibrium in arid and semi–arid grazing systems. *Journal of Biogeography*, **29**, 1595–1618.

Suttie, J., not dated; Country Pasture/Forage Resource Profiles: Mongolia. `www.fao.org/ag/AGP/AGPC/doc/Counprof/mongol1.htm`. Last visited 26.05.2003.

Tarasov, P., Dorofeyuk, N., & Metel'tseva, E., 2000; Holocene vegetation and climate changes in Hoton–Nur basin, northwest Mongolia. *Boreas*, **29**(2), 117–126.

The South Gobi National Protected Areas' Administration, not dated; The Gobi Gurvansaikhan National Park: National Park Rules & Regulations. Unpublished leaflet.

Thenius, E., 1980; *Grundzüge der Faunen- und Verbreitungsgeschichte der Säugetiere.* Gustav Fischer Verlag, Stuttgart, 2 edn., 375 pp.

Thiel, E., 1985; *Die Mongolei: Land, Volk und Wirtschaft der Mongolischen Volksre-*

publik, vol. 13 of *Veröffentlichungen des Osteuropa-Institutes München.* Isar-Verlag, München, 495 pp.

Thompson, J. & Meyer, H., 1994; Body condition scoring of sheep. `http://eesc.orst.edu/agcomwebfile/edmat/ec1433.pdf`. Last visited 02.06.2003.

Tilman, D., 1980; Resources: a graphical–mechanistic approach to competition and predation. *American Naturalist*, **116**, 362–393.

Treter, U., 1996; Gebirgs-Waldsteppe in der Mongolei. *Geographische Rundschau*, **48**(11), 655–661.

Tsendzhay, D., 1985; *The role of the Daurian pika (Ochotona daurica Pallas, 1776) in the biogeocenosis of Eastern Khangai. Abstract of Candidate degree thesis.* Ph.D. thesis, National University of Mongolia, Ulaanbaatar, Mongolia. Unpublished.

Tumurjav, M. & Tsolmon, J., 2000; The Mongolian nomads and nomadic animal husbandry. *Berliner Geowissenschaftliche Abhandlungen A*, **205**, 165–166.

UB Post, 2003a; Economic and Social Situation in Mongolia – as for the end of 2002. *UB Post*, **349**, 5.

UB Post, 2003b; Khovd: Third case of bubonic plague confirmed in western province. *UB Post*, **379**, 1.

UB Post, 2003c; Plague outbreak in Zavkhan aimag. *UB Post*, **377**, 1.

UN–Mongolia, 2001; Historical Dzud: Losses to livestock production caused by drought and zud. `www.un-mongolia.mn/archives/disaster/historical_dzud/index.html`. Last visited 30.04.2003.

UNDP, 2000; Remote Area Access to Information - A Project to Broaden and Deepen Rural Peoples Access to Information. `http://www.un-mongolia.mn/reports/files/access_to_information.pdf`. Last visited 03.09.2003.

Undrakh, R., Wesche, K., & Jamsran, Z., 2003; Pryrodnie usloviya, istoriya i cultura zapadnoiI Mongolijn i soopredelennikh regionov - The distribution of some rare plants in the Gobi-Altai in Russian. In: *Thezisi docladov VI mejdunarodnoi nauchnoi conferentsii, 18.-22.9.2003, Khovd, Mongolia.*, p. 135. lzd. Tomskogo universiteta, Tomsk.

Valdez, P., 1988; Riesenwildschaf oder Argali (Ovis ammon). In: *Grzimeks Enzyklopädie Säugetiere, Band 3*, pp. 550–554. Kindler, München.

Van der Maarel, E. & Titlyanova, A., 1989; Above–ground and below-ground biomass relations in steppes under different grazing conditions. *Oikos*, **56**, 364–370.

Van der Wal, R., Kunst, P., & Drent, R., 1998; Interactions between hare and brent goose in a salt marsh system: evidence for food competition? *Oecologia*, **117**(1-2), 227–234.

Von Wehrden, H., 2003; *Vegetationskartierung in zentralasiatischen Trockengebieten mittels Landsat 7 ETM als Planungsgrundlage für Naturschutz und Ressourcenmanagement des Gobi Gurvan Saikhan Nationalparks, Südgobi, Mongolei.* Diploma thesis, FB Geographie, Philipps–Universität, Marburg. Unpublished.

Von Wehrden, H. & Wesche, K., 2002; Mapping of large-scale vegetation patterns in arid environments - applicability of LANDSAT 7 data in southern Mongolian deserts. *Verhandlungen der Gesellschaft für Ökologie*, **32**, 177.

Walter, H., 1990; *Vegetation und Klimazonen.* Ulmer, Stuttgart, 6th edn., 382 pp.

Walther, M., 1999; Befunde zur jungquartären Klimaentwicklung rekonstruiert am Beispiel der Seespiegelstände des Uvs Nuur Beckens (NW-Mongolei). *Die Erde*, **130**, 131–150.

Walther, M., 2003; Holocene climate change in Mongolia. *Berliner Paläobiologische Abhandlungen*, **2**, 122–124.

Wang, G., Zhou, Q., Zhong, W., & Wang, D., 2001; Comparative food preference of Microtus brandti and Ochotona daurica in grasslands of Inner Mongolia, China. *Mammalian Biology*, **66**(5), 312–316.

Ward, D., Ngairorue, B., Kathena, J., Samuels, R., & Ofran, Y., 1998; Land degradation is not a necessary outcome of communal pastoralism in arid Namibia. *Journal of Arid Environments*, **40**, 357–371.

Ward, D., Saltz, D., & Olsvig-Whittaker, L., 2000; Distinguishing signal from noise: Long-term studies of vegetation in Makhtesh Ramon erosion cirque, Negev desert, Israel. *Plant Ecology*, **150**(1-2), 7–26.

Watson, R., Zinyowera, M., & Moss, R., 1997; *IPCC Special Report on The Regional Impacts of Climate Change – An Assessment of Vulnerability.* Cambridge University Press, UK, 517 pp.

Weischet, W. & Endlicher, W., 2000; *Regionale Klimatologie – Teil 2: Die Alte Welt.* Teubner, Stuttgart, Leipzig, 625 pp.

Wesche, K., Miehe, S., & Miehe, G., submitted; Plant communities of the Gobi Gurvan Sayhan National Park (South Gobi Aimag, Mongolia). *Phytocoenologia.*

Wesche, K. & Nadrowski, K., 2000; *Maintanance conditions of grazing exclosures in GGS National Park.* gtz Nature Conservation and Buffer Zone Development Project, Dalandzadgad, 7 pp. Unpublished report.

Wesche, K., Nadrowski, K., Enkhjargal, D., & Undrakh, R., 2003; Small mammal burrows as special habitats in southern Mongolian mountain steppes. *Verhandlungen der Gesellschaft für Ökologie*, **33**, 356.

Wesche, K. & Undrakh, R., 2003; The Population Ecology of Potentilla Ikonnikovii, an Endemic Plant Species of the Gobi Altai. *Verhandlungen der Gesellschaft für*

Ökologie, **33**, 357.

Wesche, K. & von Wehrden, H., 2002; *Vegetation types of the Gobi Gurvan Saikhan National Park (South Gobi Aimag, Mongolia) – Classification and spatial distribution.* gtz Nature Conservation and Buffer Zone Development Project, Ulaanbaatar, 62 pp. Unpublished report.

Westoby, M., Walker, B., & Noy-Meir, I., 1989; Opportunistic management for rangeland not at equilibrium. *Journal of Range Management*, **42**(4), 266–274.

Whicker, A. & Detling, J., 1988; Ecological Consequences of Prairie Dog Disturbances. *BioScience*, **39**(11), 778–785.

White, D., Howden, S., & Nix, H., 1996; Modelling agricultural and pastoral systems under environmental change. *Ecological Modelling*, **86**(2-3), 213–217.

Whitford, W. & Kay, F., 1999; Biopedturbation by mammals in deserts: a review. *Journal of Arid Environments*, **41**(2), 203–230.

Wiegand, T. & Jeltsch, F., 2000; Long-term dynamics in arid and semiarid ecosystems – synthesis of a workshop. *Plant Ecology*, **150**(1-2), 3–6.

Wiegand, T., Milton, S., & Wissel, C., 1995; A simulation model for a shrub ecosystem in the semi-arid Karoo, South Africa. *Ecology*, **76**(7), 2205–2211.

Wiegert, R. & Evans, F., 1964; Primary production and the disappearance of dead vegetation on an old field. *Ecology*, **45**, 49–63.

Wiens, J., 1984; On understanding a Non-Equilibrium World: Myth and Reality in Community Patterns and Processes. In: D. R. Strong, D. Simberloff, L. G. Abele, & A. B. Thistle (eds.), *Ecological Communities: Conceptual Issues and the Evidence*, pp. 439–458. Princeton University Press, Princeton, New York.

Wilby, A., 2002; Ecosystem engineering: a trivialized concept? *Trends in Ecology and Evolution*, **17**(7), 307.

Winter, S., Cully, J., & Pontius, J., 2002; Vegetation of prairie dog colonies and non–colonized short–grass prairie. *Journal of Range Management*, **55**(5), 502–508.

Wu, H., Li, B., Stoker, R., & Li, Y., 1996; A semi-arid grazing ecosystem simulation model with probabilistic and fuzzy parameters. *Ecological Modelling*, **90**(2), 147–160.

Wünnemann, B., 2003; Lakes in arid northwestern China: responses to climate and environmental changes. *Berliner Paläobiologische Abhandlungen*, **2**, 129–133.

Wünnemann, B., Pachur, H.-J., Jijun, L., & Hucai, Z., 1998; Chronologie der pleistozänen und holozänen Seespiegelschwankungen des Gaxun Nur/Sogo Nur und Bajan Hu, Innere Mongolei, Nordwestchina. *Petermanns Geographische Mitteilungen*, **142**, 191–206.

WWF, 1993; *Mongolische Südliche Gobi - Vorschlag zur Einrichtung eines Nationalen komplexen Schutzgebietes.* World–Wide Fund for Nature, 41 pp. Unpublished report.

Xiao, X., Ojima, D., Parton, W., Chen, Z., & Chen, D., 1995; Sensitivity of Inner Mongolia grasslands to climate change. *Journal of Biogeography*, **22**, 643–648.

Yatagai, A. & Yasunari, T., 1995; Interannual variations of summer precipitation in the arid/semi-arid regions in China and Mongolia: Their regionality and relation to the Asian summer monsoons. *Journal of the Meteorological Society of Japan*, **73**(5), 909–923.

Zhang, Y., Zhang, Z., & Liu, J., 2003a; Burrowing rodents as ecosystem engineers: the ecology and management of plateau zokors Myospalax fontanierii in alpine meadow ecosystems on the Tibetan Plateau. *Mammal Review*, **33**(3-4), 284–294.

Zhang, Z., Pech, R., Davis, S., Shi, D., Wan, X., & Zhong, W., 2003b; Extrinsic and intrinsic factors determine the eruptive dynamics of Brandt's voles Microtus brandti in Inner Mongolia, China. *Oikos*, **100**(2), 299–310.

Zhang, Z., Zhong, W., & Fan, N., 2003c; Rodent problems and management in the grasslands of China. In: G. Singleton, L. Hinds, C. J. Krebs, & D. M. Spratt (eds.), *Rats, Mice and People: Rodent Biology and Management*, vol. 96 of *ACIAR Monograph*, pp. 316–319. Australian Centre for International Agricultural Research, Canberra, Australia.

Zhong, W., Wang, M., & Wan, X., 1999; Ecological management of Brandt's vole (Microtus brandti) in Inner Mongolia, China. In: G. Singleton, L. Hinds, H. Leirs, & Z. Zhang (eds.), *Ecologically–Based Rodent Management*, vol. 59 of *ACIAR Monograph*, pp. 199–214. Australian Centre for International Agricultural Research, Canberra, Australia.

Zhong, W., Zhou, Q., & Sun, C., 1985a; The basic characteristics of the rodent pests on the pasture in Inner Mongolia and the ecological strategies of controlling. *Acta Theriologica Sinica*, **5**, 241–249.

Zhong, W., Zhou, Q., & Sun, C., 1985b; Habitat selection of Microtus brandti and its relationships with vegetation conditions. In: I. M. G. E. R. Station (ed.), *Research on Grassland Ecosystems*, pp. 147–153. Beijing.