Plant survival in southern Mongolian desert steppes - Ecology of communities, interactions and populations

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1. Prof. Dr. Isabell Hensen, Halle
2. Prof. Dr. Jörg Pfadenhauer, München
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Plant survival in southern Mongolian desert steppes - Ecology of communities, interactions and populations

By

K. Wesche

Inst. of Biology - Geobotany and Botanical Garden

Martin-Luther-University Halle-Wittenberg

Germany

"Full many a flower is born to blush unseen
And wastes its fragrance to the desert air"

cited after J. Austen *Emma*

Contents

Organization of the thesis

The present thesis is based on a set of peer-reviewed publications that originated from work carried out in the Gobi Gurvan Saykhan Research Project, which has been coordinated by the author since 2000. Due to copyright regulations, here only the abstracts are given, more details are available from the author on request. Publications have been organised into three chapters which include an overall introduction and summary to highlight the most relevant aspects of the work. Each of these chapters ends with an overview of ongoing and planned research. In addition to the three chapters summarising the publications, there is a general introduction to the topic, the framework of the larger research project, and another chapter on general aspects of the study region. The thesis ends with a general summary.

The appendix gives detailed acknowledgements, a list of degree theses that were compiled in the Gobi Gurvan Saykhan Research Project, a comprehensive list of publications written in the project, a list of grants organised and a CV of the author.

List of publications relevant for the thesis

(notes in brackets indicate the work that was done by K. Wesche)

Chapter 3 - Communities: Flora and vegetation

Wesche K., Miehe S. & Miehe G. (2005) Plant communities of the Gobi Gurvan Sayhan National Park (South Gobi Aimag, Mongolia). *Candollea* **60**: 149-205.
(larger part of field work and data analysis, writing and editing the paper)

Wesche K. & Ronnenberg K. (2004) Phytosociological affinities and habitat preferences of *Juniperus sabina* L. and *Artemisia santolinifolia* Turcz. ex Bess. in mountain sites of the south-eastern Gobi Altay, Mongolia. *Feddes Repertorium* **115**: 585-600.
(idea, data analysis, writing and editing the paper)

von Wehrden H., Wesche K., Reudenbach C. & Miehe G. (2006) Vegetation mapping in Central Asian dry eco-systems using Landsat ETM+. A case study on the Gobi Gurvan Saykhan National Park: *Erdkunde* 60: 261-272.
(idea, main part of field work, editing the paper)

Miehe G., Opgenoorth L., Cermak J., Schlütz F., Jäger E. J., Samiya R. & Wesche K (2007) Montane forest islands and Holocene forest retreat in Central Asian deserts: a case study from the southern Gobi Altay, Mongolia. *Paleogeography, Paleoclimatology, Paleoecology* 250: 15-166.
(part of field work, part of writing and editing the paper)

Chapter 4 - Plant-animal interactions: Impact of livestock and small mammals

Stumpp M., Wesche K., Retzer V. & Miehe G. (2005) Impact of grazing livestock and distance from water points on soil fertility in southern Mongolia. *Mountain Research and Development* **25**: 244-251.
(part of lab work and data analysis, writing and editing the paper)

Wesche K., Nadrowski K. & Retzer V. (in press) Habitat engineering under dry conditions: The impact of pikas (*Ochotona pallasi*) on southern Mongolian mountain steppes. *Journal of Vegetation Science* 18: 665-674.
(idea, main parts of idea, field work, data analysis, writing and editing the paper)

Wesche K., Ronnenberg K. & Retzer V. (submitted) Effects of herbivore exclusion in southern Mongolian desert steppes.
(idea, main parts of idea, field work, data analysis, writing and editing the paper)

Wesche K. & Ronnenberg K. (submitted) NPK-fertilisation increases plant productivity in southern Mongolia desert steppes.
(main parts of idea, field work, data analysis, writing and editing the paper)

Chapter 5 - Populations: Population ecology of selected plant species

Wesche K., Pietsch M., Ronnenberg K., Undrakh R. & Hensen I. (2006) Germination of fresh and frost-treated seeds from dry Central Asian steppes. *Seed Science Research* **16**: 123-136.
(idea, data analysis, writing and editing the paper, large parts of data collection)

Wesche K., Ronnenberg K. & Hensen I. (2005) Lack of sexual reproduction in dry mountain steppe populations of the clonal shrub *Juniperus sabina* L. in southern Mongolia. *Journal of Arid Environments* **63**: 390-405.
(idea, data analysis, writing and editing the paper)

Wesche K., Jäger E. J., von Wehrden H. & Undrakh R. (2005) Status and distribution of four endemic vascular plants in the Gobi Altay. *Mongolian Journal of Biological Sciences* **3**: 3-11.
(idea, field work, analysis of local distribution, writing and editing the paper)

Wesche K., Hensen I. & Undrakh R. (2006) Genetic structure of *Galitzkya macrocarpa* and *G. potaninii*, two closely related endemics of Central Asian mountain ranges. *Annals of Botany* **98**: 1025-1034.
(idea, data analysis, writing and editing the paper, part of data collection)

Wesche K., Hensen I. & Undrakh R. (2006) Range-wide genetic analysis provides evidence for natural isolation among populations of the Central Asian endemic *Potentilla ikonnikovii* Juz. (Rosaceae). *Plant Species Biology* **21**: 155-163.
(idea, data analysis, writing and editing the paper, part of data collection)

1 Introduction: The relevance of research in dry Central Asian grasslands

Why grasslands matter

Among the principal outcomes of the last decade of scientific but also public discussions is an increased awareness of global interdependencies. In economics, the focus has widely been shifted from regional to global aspects, and a similar development has taken place in nature conservation, where local and regional problems have increasingly been overshadowed by global developments such as the widely discussed biodiversity crisis or the complex, partly related issue of climate change (e.g. Araújo *et al.* 2004; Myers 2003; Parmesan & Yohe 2003; Saxon *et al.* 2005).

The rapid decline of global forest cover has attracted tremendous attention, partly because an unknown but certainly large proportion of global biodiversity resides in tropical and subtropical forests, and because they are regarded as being an important buffer system against rising concentrations of carbon dioxide and other atmospheric changes (IPCC 2001, 2005). However, forests are absent from large parts of the terrestrial land surface mostly because of constraints in water availability and, increasingly more so, land use. Much of the earth's surface is in fact covered by grasslands, or rangelands in the broader sense, and global estimates range from 30 - 40% of the terrestrial land surface depending on the methodology employed (White *et al.* 2000). Grasslands tend to give way to forests where conditions become drier (Box 2002; Breckle 2002), but they also often replace forests following human disturbance. An important note is that grasslands have been estimated to store up to a third of the global terrestrial carbon (White *et al.* 2000), and stocks per unit area in Central Asian grasslands are estimated to be larger than in other grassland regions (Ni 2002). These figures have to be treated with caution (Lioubimtseva *et al.* 2005; White *et al.* 2000) but nonetheless clearly show the general importance of grasslands to climate change and land use.

Grasslands host a notable but not disproportionally high fraction of vascular plant diversity (Kier *et al.* 2005), and only a few grassland regions comprise so called biodiversity hotspots (Mittermeier & Robles Gil 2004; Myers *et al.* 2000). Nonetheless, a number of grassland regions have been included in schemes for priority setting in conservation (most notably Olson & Dinerstein 1998; Olson *et al.* 2001). In particular, temperate, mid-latitude grasslands are among the vegetation formations that have suffered the most in terms of extensive habitat conversion, yet the proportion protected in nature reserves is comparatively low. According to these criteria, temperate grasslands rank among the most threatened biomes of all (Hoekstra *et al.* 2005).

If regional climatic conditions become even drier, dense grasslands are typically replaced by (semi-) deserts with much lower vegetation cover (Box 2002). Thus grasslands play a central role in the discussion on desertification (Sheng *et al.* 2000; Veron *et al.* 2006; Yang *et al.* 2005), and this has increasingly been realised as one of the main problems in global land degradation. North American prairies have declined by a mean of 80% since European occupation, and a similar scale has become apparent for northern China (White *et al.* 2000; Yang *et al.* 2005). With respect to the vast spatial extent of grasslands in these mid-latitude regions, any lasting changes at the boundary between grasslands and deserts have supra-regional, if not global, implications.

The situation in Central Asia

Asia hosts more than 10 Mio. km² of grassland in the broadest sense, distributed mainly throughout Russia, China, Kazakhstan and Mongolia. Desertification appears to be particularly severe in Kazakhstan, where large-scale conversion of steppes into agricultural land has led to tremendous changes at practically all levels of the ecosystem (Babaev 1999; Frühauf *et al.* 2004). At least locally, these steppes begin to recover as agriculture de-intensifies (Babaev 1999; Hölzel *et al.* 2002), whereas desertification is an ongoing process in northern China. Again, estimates depend on the method applied, but with an estimated 0.8 to 1.6 Mio. km² of desertified land the problem certainly is huge (Yang *et al.* 2005). This has severe consequences for local land use including tremendously increased wind erosion and transport of dust over long distances (Li *et al.* 2005a; Li *et al.* 2003). Long-distance transport of the outblown material reaches as far as Beijing and even the Pacific, and there is evidence that the frequency of dust storms is on the increase (ESA 2006; Lehmkuhl & Haselein 2000).

Land management in northern China is confronted with open desert vegetation types or even entirely unconsolidated soil substrates at annual precipitation levels being between 180 and 350 mm (e.g. Tengger, Horqin; Li *et al.* 2002; Li *et al.* 2004; Zhang *et al.* 2005). In (Outer) Mongolia, similar precipitation sums are sufficient to sustain relatively dense grass steppes and even forests (Hilbig 1995; Lavrenko & Karamysheva 1993), which are apparently much rarer in China. This highlights the severity of human impact on Chinese steppes. Neighbouring Mongolia hosts more than 1.3 Mio. km² of grasslands (White *et al.* 2000), and these have also been subject to human impact over centuries, if not millennia (Fernandez-Gimenez 1999). However, the still relatively low population densities and differences in land use practice have rendered degradation phenomena much less severe than in adjacent countries, and Mongolian steppes are generally regarded as still relatively intact (Ho 2001; Müller 1999; Müller & Janzen 1997; Sneath 1998).

Human land use in Central Asian steppes is traditionally based on nomadic pastoralism (Fernandez-Gimenez 1999; Fernandez-Gimenez 2000; Scholz 1999) because agriculture is widely impossible outside oases due to low precipitation. Nomads in both Mongolia and northern China used to migrate regularly between summer and winter pastures, but also travelled over hundreds of kilometres in years of excessive drought (Neupert 1999). More recently, people have largely adopted a more sedentary life style in northern China (Ho 2001; Zhu 1993). Russian influence in Mongolia also led to the establishment of permanent settlements, but herds always remained at least partly migratory (Fernandez-Gimenez 1993; Müller 1994; Sneath 1998). After political changes in the early 1990's the extent of nomadism even increased in Mongolia (Janzen 2005; Müller 1999) because soaring unemployment in the cities triggered a search for new sources of income. This, coupled with an even larger increase in the number of goats, has led to concerns about increasing pasture degradation in the Mongolian steppes (Batkhishig & Lehmkuhl 2003; Golovanov *et al.* 2004; Hilbig & Opp 2005; Opp & Hilbig 2003).

Emerging topics for a research project in southern Mongolia

Availability of baseline data

Working in remote regions often has the consequence that the availability of base-line data is limited. Mongolian drylands are certainly not the least well studied, but previously published research on vegetation history and plant community composition is far from comprehensive. In particular, the available accounts of Mongolian vegetation are based on a limited number of samples from southern Mongolian rangelands (e.g. Hilbig 1990, 2000; Karamysheva & Khramtsov 1995), and maps on vegetation patterns have only been available on a relatively coarse scale (Gunin *et al.* 1995; Lavrenko *et al.* 1979; Vostokova & Gunin 2005). Thus, it would have been difficult to decide whether results obtained from a certain study region were representative on a larger spatial context. Therefore the first principal research topic was the provision of new and detailed baseline data on vegetation composition and spatial extent for the chosen study area in southern Mongolia (chapter 3). This was supplemented by new data on the environmental history, which has presumably been strongly influenced by human activities.

Impact of grazing

Given the sheer size of degraded and potentially degradable areas in the region, grazing ecology was given some emphasise during the early stages of preparation for the present thesis (2000, 2001). However, before starting our research we had not anticipated the steep increase in the number of basic and applied studies on Central Asian dryland ecology that have since begun. In terms of plant ecology, grazing ecology has become one of the fastest growing fields of research in Central Asia followed by recruitment and management of selected plant species. Details are discussed in the relevant chapters below, but the general development is highlighted by a simple example of my own, certainly not comprehensive, literature data base (Fig. 1.1). The development was facilitated by an increasing global discussion about desertification phenomena and the consequences of human impact in dry regions (Vetter 2005).

However, most of these studies come from the northern and central parts of Mongolia, or from the heavily degraded regions of China. Data on the relatively intact dry southern Mongolian steppes are still much more limited, and the actual extent of grazing degradation is still under debate. Livestock keeping remains the principal form of land use in the more arid parts of Central Asia, and livestock is widely held responsible for severe degradation phenomena (Katoh *et al.* 1998; Yang *et al.* 2005; Zhao *et al.* 2005).

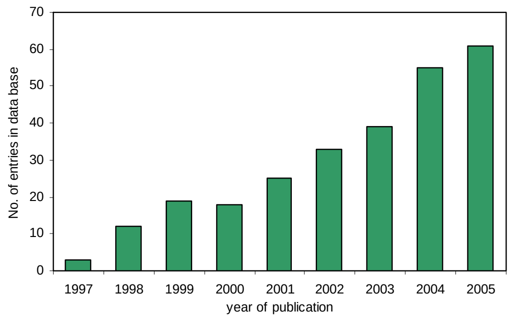

Fig. 1.1: Number of publications on grazing ecology of Mongolian and Chinese steppes consulted during the course of the present research (mostly texts in English).

In Mongolia, the number of animals has increased during the 20th century, and recent years have witnessed a shift from keeping local domestic Bactrian camels towards rearing increasing numbers of goats, which are widely regarded detrimental for pasture quality (Chimed-Orchir 1998; Tsagaan Sankey *et al.* 2006; Vallentine 2001). However, the idea that anthropo-zoogenic degradation represents the main threat all over Central Asia has recently been challenged. Numbers of livestock in Mongolia increased during the 1990's, but collapsed to 1990-levels after a sequence of drought years between 2001 and 2003 (Reading *et al.* 2006; Retzer & Reudenbach 2005). Annual precipitation levels vary tremendously in drylands, and droughts have pronounced effects on both vegetation and livestock. This led grassland ecologists working in Sub-Saharan Africa to formulate the so called "non-equilibrium model of rangeland science" (Ellis & Swift 1988; Wiens 1984). It is based on the assumption that livestock numbers collapse in years of drought and recover much more slowly than vegetation structures. Thus, dynamics of livestock and vegetation conditions are not in equilibrium with each other. The ecosystem is not under top-down control by the herbivores, and grazing degradation is presumed to pose a limited threat in (semi-) arid regions. The theoretical and practical implications of this approach caused a controversial debate (e.g. Illius & Connor 1999; Sullivan & Rohde 2002), revealing the need for more sound studies over a broader range of ecosystems under land use by grazing. Mongolia is ideal in this respect as it offers one of the last reasonably intact nomadic societies, and still relatively intact pastures. We therefore performed a set of descriptive and experimental studies on the impacts of mammalian herbivores in southern Mongolia, which are described in chapter 4.

Plant population ecology

The dynamics of any given plant community are closely related to the population ecology of the principal plant species, but these had hardly been studied in Central Asian plants. Thus, plant population ecology was included as a third general aim during the preparation of the research project. Only over the last few years have publications of some studies on vegetation restoration emerged (Hao *et al.* 2005; Li & Shao 2006; Zhang *et al.* 2005), with germination being one of the main focuses (Li *et al.* 2005b; Nie & Zheng 2005; Tobe *et al.* 2005; Zheng *et al.* 2003). Given that restoration in northern

China is largely concerned with severely degraded lands, most of the tested species are pioneers suitable for growth at early successional stages (Li *et al.* 2006). Mongolian steppes offer important examples in this context, as they still host a number of late-successional species that have rarely been studied so far (e.g. Huang *et al.* 2004; Liu *et al.* 2004). Moreover, recruitment in perennial species is generally less well understood than that of annuals. Perennials constitute the principal life forms in most of the huge northern-hemispheric drylands and sexual recruitment appears relatively rare (Gunin *et al.* 2003; Lavrenko & Karamysheva 1993; Wesche *et al.* 2005). Instead, population survival depends on extensive vegetative, and often clonal, growth. This was anticipated for theoretical reasons (Eriksson 1996; Garcia & Zamora 2003), but empirical evidence and implications are still under debate (Dong & Alaten 1999; Honnay & Bossyut 2005; Li & Ge 2001).

Thus, new studies in this field are of obvious relevance for practical issues, but should also contribute to general theory. Populations of dryland plants have predominantly been studied in (sub-) tropical deserts (Gutterman 1993), while comprehensive data from mid-latitude drylands come mainly from North America (Baskin & Baskin 1998; Whitford 2002). Neither vegetation structures nor plant communities there are directly comparable with the continental Asian drylands (e.g. Lauenroth & Milchunas 1992 vs. Lavrenko & Karamysheva 1993), and the same refers to plant population ecological characteristics. The issue is also of interest to species conservation because the southern Mongolian mountains host several endemic vascular plants with widely isolated populations (Grubov 1989). Thus, the fifth chapter of the thesis describes new data on the population ecology of selected perennial vascular species addressing the aspects discussed above.

The organizational framework of the research project

The range of methodological approaches available for plant ecological research has never been as wide as today, and technical developments have also considerably improved on the simplicity of applications as well as ease of handling. Nonetheless, complex research projects in remote regions rely on close cooperation among several research teams and reliable organizational structures. This was the reason prompting collaborative research in southern Mongolia, which continued a long tradition of scientific cooperation between Mongolia and Germany, especially from the universities of Halle-Wittenberg and Ulaan Baatar (Hilbig *et al.* 2007; Stubbe *et al.* 2005).

The Gobi Gurvan Saykhan Research Project was initiated in 2000 as a joint research effort by the Universities of Ulaanbaatar, Marburg and Halle. The involved scientists represented a field of expertise ranging from remote sensing, biogeography and zoology to plant ecology. The project has been coordinated by the author since 2000. Research teams have visited the drylands of southern Mongolia every summer (and during the winter of 2000/01); these always comprised Mongolian and German colleagues (see the appendix for a list of theses compiled during the GGS Research Project).

Fig. 1.2: Setting of the camp of the Gobi Gurvan Saykhan research project in the footzone of the Dund Saykhan, Gobi Gurvan Saykhan National Park, southern Mongolia (43°36'W, 103°48'E, photo by K. Wesche, 2005).

The project maintains a small camp of gers (Mongolian word for yurt), plus a varying number of smaller tents (Fig. 1.2). Available facilities include a minibus, a solar power unit, satellite phone and thus internet access, in addition to basic research equipment (microscope, balances etc.). Taken together, these facilitated detailed studies on a range of subjects in the direct vicinity of the camp, which also served as a starting point for field surveys that eventually covered all major nature reserves in southern Mongolia (e.g. von Wehrden & Wesche 2005) and also extended into the steppe and forest steppe regions (e.g. Ronnenberg *et al.* 2006; Walther 2006). The present thesis covers only part of the studies conducted in the project, which is still continuing. More information is given in the appendix, which also lists the institutions that have funded the research over the last 6 years.

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2 Study region

Choosing a study site

The Gobi Gurvan Saykhan Research Project is based in a region in southern Mongolia that seemed suitable for several reasons: Mongolia has a relatively intact environment and a stable political situation (Fish 2001; Sneath 1998). The zonation of Mongolian vegetation belts is largely controlled by precipitation patterns which show pronounced latitudinal but also altitudinal gradients (Hilbig 1995; Opp & Hilbig 2003). Thus, we decided on a mountain region, because this offered a wide range of plant communities with varying moisture requirements within a short distance. The main study site in the Gobi Gurvan Saykhan region in southern Mongolia (Fig. 2.1) forms part of a national park, which ensured that the area at least partly represents the original flora and vegetation. Choosing a protected area also facilitated cooperation with local nature conservation authorities.

The landscape is governed by the south-easternmost outpost of the Altay system (Gobi Altay); the relatively moist mountain ranges support a much more dense and species-rich vegetation than the surrounding lowlands. The region hosts a number of rare species including endemic plants (e.g. *Potentilla ikonnikovii*, *Galitzkya macrocarpa*, Gubanov 1996) and endangered mammals (Asiatic wild ass, *Equus hemionus hemionus*; Marco Polo sheep, *Ovis ammon*, Reading *et al.* 1999). About 27 000 km² are included in the Gobi Gurvan Saykhan National Park, which is managed for conservation purposes but nonetheless offers representative examples of traditional land use systems (Bedunah & Schmidt 2000, 2004). The Mongolian name translates to the "Three Beauties of the Gobi" and refers to the rich vegetation in the mountains. Fortunately, large-scale base-line data on the flora and vegetation were available (Gubanov 1996; Gunin *et al.* 1995), and some earlier regional studies and reports helped to detail some of the research questions (Helmecke & Schamsran 1979a, 1979b; Miehe 1996, 1998). All the studies are based around a semi-permanent camp that is situated on the upper pediments of the Dund Saykhan range at 2300 m asl. at 43°36'W, 103°48'E (Fig. 1.2). Various vegetation types including desert steppes, mountain steppes and extrazonal montane communities (see chapter 3) are within walking distance of the camp. Moreover, the neighbouring mountain hosts the most isolated forests of Central Asia and is thus a key-locality for the understanding of environmental changes in the region.

Geology, landforms and soils

Mongolia is situated between relatively stable blocks of Precambrian crust, namely the Central Siberian Craton in the north, and the Tarim Massif and the Sino-Korean Craton in the south (Chain & Koronovskij 1995). Much of central Mongolia belongs to the stable Khangay Dome, which is surrounded by much more dynamic systems (Cunningham 2005, cf. Fig. 2.1). The north is part of the Altay-Sayan Baykal region, while the central and southern parts belong to the Southern Mongolian-

Gobi-Chingan System. The latter dates back to the late Palaeozoic era and has a varied relief with extended basins as well as uplifted mountain ranges running mainly north-east to south-west. The region is still tectonically active, which is related to the ongoing collision of the Indian Plate and the origin of the mighty southern and central Asian mountain ranges that commenced in the Eocene (Chain & Koronovskij 1995).

The geology is accordingly heterogeneous with ancient sediments, metamorphic rocks and plutonites underlying or emerging from Quaternary deposits. The rocky massifs in the Gobi Gurvan Saykhan region are made up of Palaeozoic gabbros as well as tonalites, slates and sandstones, while younger basalts are restricted to smaller spots (Anonymous 1990). Mountain ranges run from WNW to ESE (Fig. 2.1); uplifting took place mainly in the Tertiary but earthquakes still occasionally occur (Carretier *et al.* 2002; Vassallo *et al.* 2005). During the Quaternary, rocks were subjected to heavy weathering and are widely covered with screes. Eroded material accumulated around the steep slopes and Quaternary deposits form the largest part of the park’s surface today. Extensive pediments built up during transition times between glacial and interglacial periods (e.g. ~20 000 yrs. BP, Vassallo *et al.* 2005). The pediment regions extend between 1300 and 2100 – 2300 m asl. and account for > 60% of the national park's area (Table. 2.1). They have a typically low inclination (< 5°) but are often dissected by steep erosion gullies. These so called *Sayrs* have episodic runoff. Therefore, linear erosion is also episodic, while wind deflation is practically a permanent process (Lehmkuhl *et al.* 2003). The second major landform group, the steep mountain slopes, emerge from these pediments and reach up to 2850 m asl, and account for some 30% of the surface. The remaining ca. 6% are covered by moving sand dunes, and basins with salt-marshes and oases.

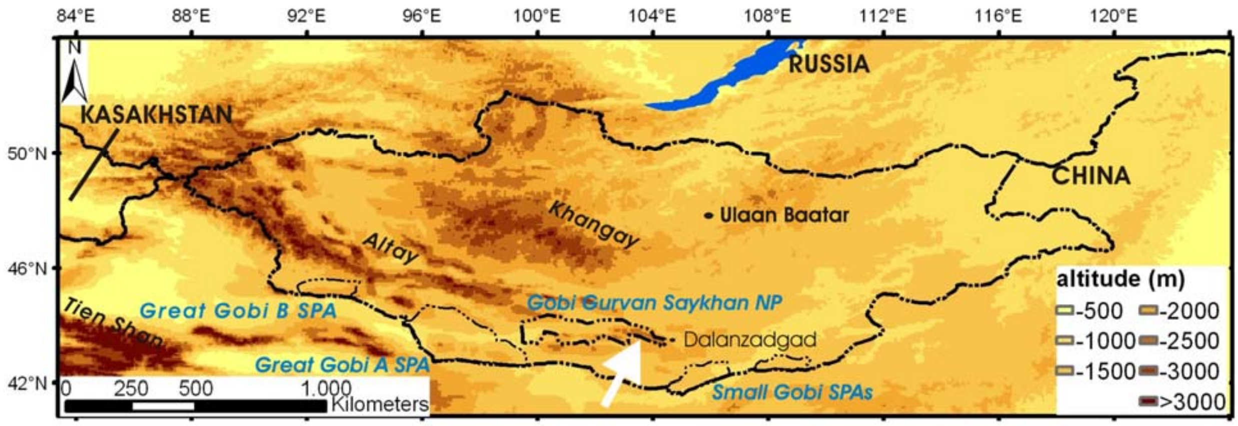

Fig. 2.1: Topography of Mongolia. The arrow points to the main study site in the Gobi Gurvan Saykhan National Park. Dotted lines demarcate the other southern Mongolian nature reserves: Great Gobi B Strictly Protected Area (Dzungarian Gobi), Great Gobi A SPA (Transaltay Gobi) and Small Gobi Strictly Protected Areas A & B (draft von Wehrden & Wesche, based on SRTM data).

The distribution of Mongolian soils shows a clear latitudinal zonation (Haase 1983; Opp 1994; Opp & Hilbig 2003), and precipitation and elevation are among the principal controlling environmental factors in the Gobi (Dai & Huang 2006). On a regional scale, intense weathering and climatic conditions even out the geological differences, and soils show clear altitudinal belts according to the major landforms. In the Gobi Gurvan Saykhan region, the deep Quaternary deposits of the pediments mainly formed Burosems and, under more favourable conditions, Kastanosems. The soil matrix is dominated by sand and silt (unpublished data by Hennig & Wesche). Less inclined sites in the mountain ranges may carry shallow Kastanosems and occasionally Chernosems with a topsoil relatively rich in organic matter content. On scree slopes barely developed Leptosols prevail. At the lowest elevations, weakly developed Arenosols occur in sandy regions, while Solonchaks and Solonetz soils are confined to moist depressions and clay pans.

Tab. 2.1: Extent of altitudinal belts in the Gobi Gurvan Saykhan National Park (GIS-analysis based on SRTM data compiled by H. von Wehrden).

m asl.	km²	m asl.	km²	m asl.	km²	m asl.	km²	m asl.	km²
0 -900	473	-1300	2418	-1700	2329	-2100	1227	-2500	305
-1000	806	-1400	2439	-1800	1845	-2200	1020	-2600	200
-1100	1146	-1500	2712	-1900	1674	-2300	893	-2700	76
-1200	2779	-1600	2510	-2000	1534	-2400	562	-2800	20
								>2800	1

The climate in Mongolia

Mongolia is situated in the mid-latitude regions of the northern hemisphere, and its closest border is more than 600 km away from the nearest ocean. Moreover, huge mountain ranges block most of the inflowing moist air; the main surrounding systems are the Himalayas and the Tien Shan to the south and southwest, the Qin Ling Shan and Da Hinggan Ling / Chingan to the south and south-east, and the Altay-System to the west and north-west. Thus, the Mongolian climate is extremely continental and generally dry.

Paleoecological and geomorphological evidence suggests that the climate of Central Asia has undergone pronounced changes in the Quaternary. Conditions during the last glacial maximum tended to be relatively moist (Herzschuh 2006); after that temperatures have presumably peaked in the middle Holocene. The current extent of glaciers is very limited in southern and western Mongolia, and even Pleistocene glaciations were restricted to the mountain ranges of the Mongolian and Gobi Altay (Klinge 2001; Lehmkuhl 1998). During glaciations, permafrost extended well into the surroundings of the Gobi Altay region (Owen *et al.* 1996), and scattered occurrences of permafrost can still be found in the mountain ranges of the Mongolian and Gobi Altay. They buffer the water supply to the overlying soils and allow growth of some highly isolated forest outposts (Böhner & Lehmkuhl 2005; Miehe *et al.* 2007). This of importance, as general climatic conditions started to get drier in the middle Holocene (Herzschuh 2006; Yang *et al.* 2004) and have been relatively dry since.

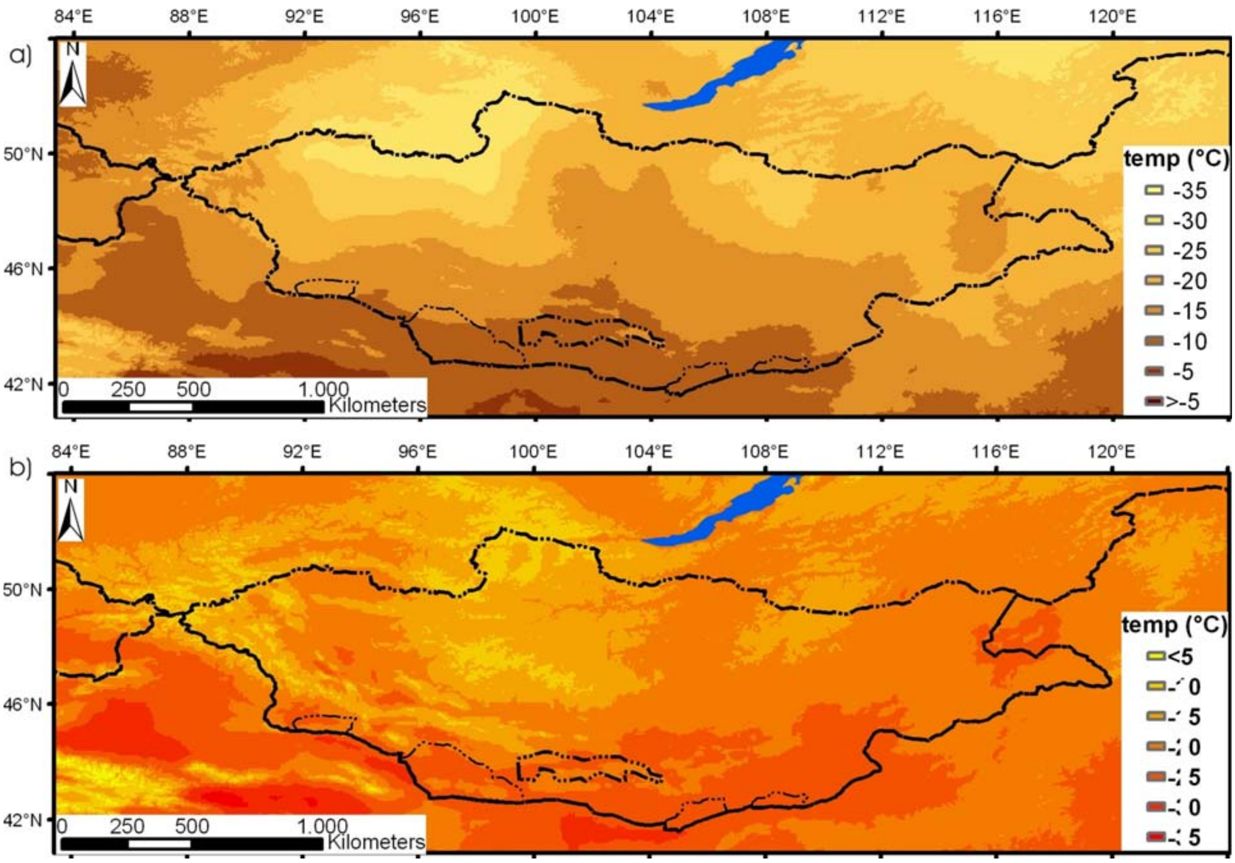

Fig. 2.2: Modelled mean monthly temperatures for Mongolia in a) January, range < -35 to > -5°C; and b) July, range < +5 to < +35°C (Worldclim data by Hijmans *et al.* 2005, draft H. von Wehrden).

Extremely low levels of atmospheric moisture are the main determinants of the current climate in winter. These are related to a high incoming daytime radiation, extreme outgoing radiation at night, and the development of the Central Asian Siberian anticyclone (Barthel 1983; Weischet & Endlicher 2000). Mongolia is thereby exposed to polar air masses, leading to extremely low temperatures in the northern part of the country where daily winter means can be as low as -40°C, while winter mean temperatures in the Gobi generally remain above -20°C (Fig. 2.2a). Cold air accumulates in the extensive basins while mountain sites are less affected, leading to stable temperature inversions on a local scale. In spring, the anticyclone collapses and the planetary west-wind drift gains control of the climate. Temperatures rise steeply, but inflow of cold northern air masses can result in occasional frosts up to May. Moreover, strong winds, especially in the Gobi Altay, make living conditions unpleasant. Western circulations and cyclones moving in various directions control the macroclimate in summer resulting in relatively favourable mean temperatures (> 20°C; Fig. 2.2b) and a frost free period until September.

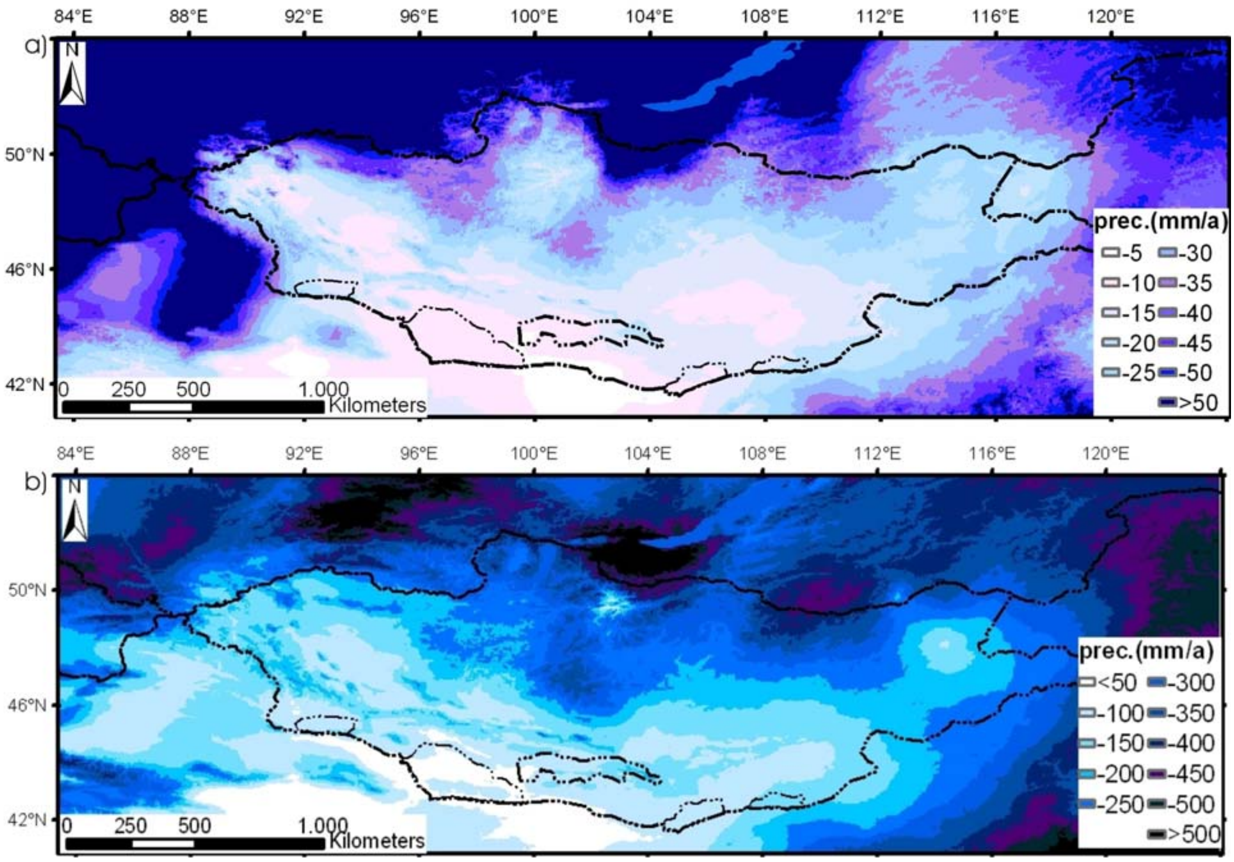

Fig. 2.3: Modelled mean precipitation sums for Mongolia between a) October to March, range < 5 to > 50mm and b) April to September, range < 50 to > 500mm. Note the different intervals of the maps! (Worldclim data by Hijmans *et al.* 2005, draft H. von Wehrden).

Precipitation is low but shows a pronounced seasonal distribution. Winters are usually dry; in the Gobi only the western parts, the south-east, and some mountain ranges receive winter precipitation and have some snow cover (Fig. 2.3a). Most snow evaporates before entering the (frozen) soil. Conditions tend to remain dry until the end of May, thus the onset of the vegetation period is determined by the beginning of the summer rains in June rather than by thermal constraints. More than two thirds of the rains are concentrated in the few summer months. The dynamic causes of the summer rains are still subject to debate (Barthel 1983; Weischet & Endlicher 2000). The relatively high levels in the south-east of the country (Fig. 2.2b) point to influences of the south-eastern Monsoon (Helmecke & Schamsran 1979a). However, considering the high precipitation levels in the north-east, which is - apart from the Dzungarian basin - the only part of Mongolia not sheltered by high mountain ranges, the overall north-south distribution led to the conclusion that most of the rain develops in disturbances that originate in the western wind drift along the northern mountain ranges (Barthel 1983; Weischet & Endlicher 2000). Disturbances intermingle with occasional inflows of monsoonal air masses causing turbulence, the development of frontal systems and the formation of rain clouds. These usually flow into the country from north-easterly directions. The actual precipitation events tend to depend on local convective processes, and rains thus show a tremendous spatial but also temporal variability.

Dalanzadgad in southern Mongolia, for example, has an annual mean of 131 mm; but the coefficient of variation was > 30% between 1936 and 1999. The driest year yielded a mere 52 mm; the wettest, 236 mm (data from the National Meteorological Survey, corrected by Bergius 2002). Summer precipitation (sum: June, July, August) ranges between 31 and 218 mm (mean 90 mm), while winter precipitation is generally low at a mean of 4 mm (sum: December, January, February). However, all parts of the country are subject to occasional inflows of cold air and winter months may receive up to 10 mm of snow which can result in the development of a closed snow cover, particularly so in the western parts of the country. As livestock depends entirely on access to standing biomass even in winter, these occasions regularly result in catastrophic losses (*Zagan Zuud*; "white disease / drought"). Drought seasons in summer are termed *Khar Zuud* ("black disease") and result in even heavier losses of livestock in the Gobi (Begzuren *et al.* 2004).

Recent evidence from Pakistan and northern China suggest that the last century has been the moistest in the last millennium (Sheppard *et al.* 2004; Treydte *et al.* 2006). The available dendrochronological data suggest increasing temperatures in Mongolia but not decreasing precipitation levels (Jacoby *et al.* 1999; Jacoby *et al.* 1996); this is also found in direct measurements and phenological analysis of satellite data (Yu *et al.* 2003). In addition, a 60 year record from the southern Gobi (Dalanzadgad) did not show trends of increasing or decreasing precipitation (Bergius 2002). This is supported by analyses from neighbouring China (Shilong *et al.* 2004; Zheng *et al.* 2006). Aridity may nonetheless become more pronounced as increasing temperatures may result in increasing evapotranspiration (Christensen *et al.* 2004; Li *et al.* 2006). Thus increasing aridity is often anticipated, but available measurements and palynological data for the Gobi show strong fluctuations rather than clear trends (Herzschuh *et al.* 2006; Yu *et al.* 2003).

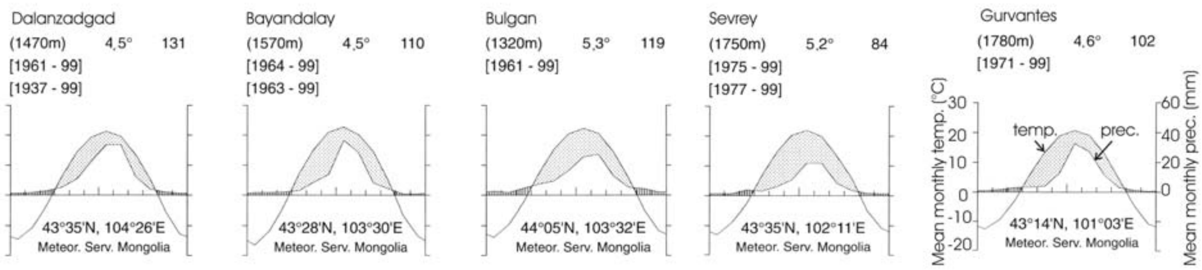

Fig. 2.4: Walter-Lieth Diagrams for the governmental weather stations in the South Gobi, Mongolia (data from the National Meteorological Service, draft C. Enderle, K. Wesche).

Tab. 2.2: Summary of precipitation at the research camp in the Dund Saykhan (Retzer et al. 2006 and own measurements). Figures for the nearest governmental weather station (Bayandalay, 1570 m asl.) are given for comparison (records for 2004 are incomplete).

	Total (mm)					July + August (mm)				
Year	2000/'01	'01/'02	'02/'03	'03/'04	'04/'05	'01	'02	'03	'04	'05
Camp	69	no data	no data	211	125	41	27	94	84	71
Bayandalay	72	79	75	>100	70	18	4	45	>40	38

The local climate in the study area

The Gobi is part of the Asian dryland belt (Cressey 1960). It forms a huge endorheic basin in southern and central Mongolia and northern China, and is thus clearly arid. Conditions in the Gobi Gurvan Saykhan region represent the northern part of the Gobi (Fig. 2.3). The climate is extremely continental with cold winters, warm summers and overall low, but highly concentrated, summer precipitation. The climate becomes drier towards the western ends of the park. Rains in Mongolia tend to be of convective origin (Weischet & Endlicher 2000), and mountains are likely to receive more rains than their surroundings (Helmecke & Schamsran 1979a; Hilbig *et al.* 1988). Unfortunately, none of the governmental weather stations is situated in the mountains as all major settlements lie on the pediment regions. Interpolation models (Begzuren *et al.* 2004; Hijmans *et al.* 2005) suggest that mountains in the eastern part of the Gobi Gurvan Saykhan receive up to 200 mm of rain, or around twice as much as most of the pediment regions. This is corroborated by personal discontinuous measurements from the research camp in the Dund Saykhan (Tab. 2.2). The increase of precipitation levels results in a pronounced altitudinal zonation in plant community composition and productivity (see chapter 3).

Temperatures in the mountains are lower than in the surroundings (Nadrowski & Retzer unpubl.), but conditions during the vegetation period are nonetheless quite warm. Figure 2.4 summarises short-term measurements at the research camp obtained during field campaigns in summer. Sensors were placed at 20 cm above ground and thus approximately reflect conditions experienced by the typical herbaceous plants. Global radiation was high in all years with mean maxima always well above 800 W/m², and absolute maxima at 1200 W/m² and even higher due to re-radiation. This high energy gain is reflected in reasonable warm temperatures that usually reach above 20°C at noon and remain around 10°C at night. Temperatures vary between years as temperatures in moist 2003 (cf. Tab. 2.2) were clearly lower than in the drought year 2001. This is also reflected in the humidity values. Mean relative humidity is below 50% at noon in most years, and does not climb above 60% even at night time. Vapour pressure deficits show a more pronounced daily and interannual variation. They remained below 15 hPa in moist and normal years but climbed above 25 hPa in the dry years of 2001 and 2002.

The figures indicate that plants growing at these sites could potentially lose a substantial amount of water by evapotranspiration. Real levels of saturation deficits should be even higher, as leaves warm up above ambient temperature under the high incoming radiation of a montane climate (Körner 2003). We did not estimate potential evapotranspiration (using e.g. the Penman approach), but crude measurements with Piche evaporimeters suggested that potential evapotranspiration may exceed precipitation in summer by 6 to 10 times. Even if we don't give these figures too much credit we can safely conclude that the site certainly poses relatively arid conditions and can be regarded as an example of a cold montane dryland (Helmecke & Schamsran 1979b). Both the pronounced interannual variability and the diurnal variation are supported by earlier data obtained from short-term measurements in the Gobi Altay (Helmecke & Schamsran 1979a; Hilbig *et al.* 1988).

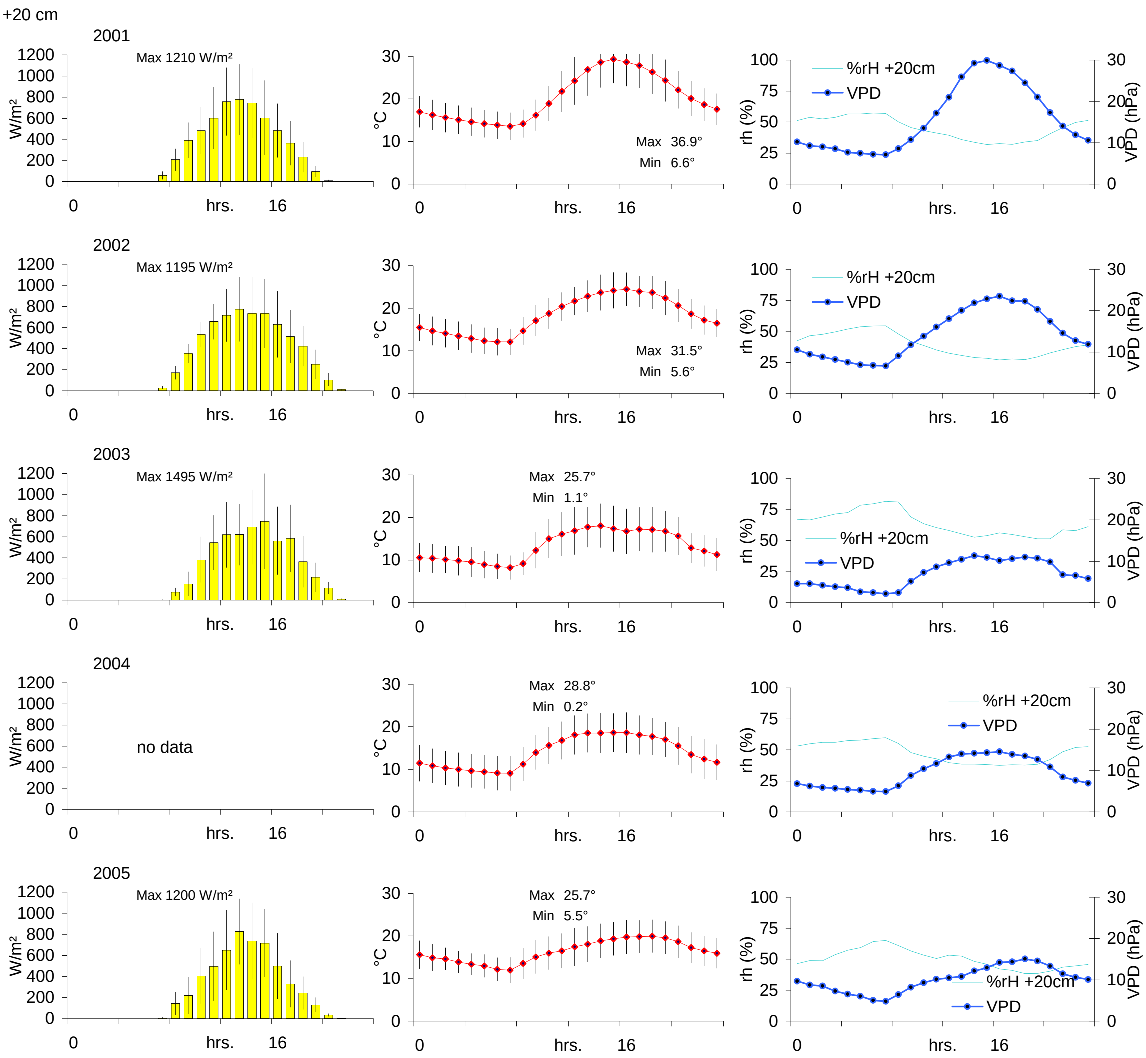

Fig. 2.4: Summary of microclimatic conditions at the Dund Saykhan camp in August: global radiation, temperature, relative humidity and vapour pressure deficits. Figures refer to mean hourly values at 20 cm above ground, error bars for radiation and temperature indicate 1 SD (own measurements, Licor sensors and logger).

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3 Communities: Flora and Vegetation

3.1 Summary: Flora and Vegetation

Introduction

Most ecological work is local, but inferences are usually generalised to a wider context. This is logically questionable (e.g. Chalmers 1994; Ströker 1992) but common practice. Inferences rely heavily on the pragmatic assumption that the obtained results are representative in a wider context, but this can only be assessed if comparable data are available. These were limited for southern Mongolia; moreover, the national park management required detailed information on the status of rare plants and their distribution along with data on the composition of vegetation. Thus, we compiled descriptive data on flora, vegetation history, plant community composition and a vegetation map.

Overview data on flora and vegetation of Mongolia are relatively comprehensive due to continuous efforts by botanists mainly from Mongolia, Russia and Germany. A flora for vascular plants was published in the early 1980s and later translated into English (Grubov 1982, 2001). More recent accounts include the partially completed "Plants of Central Asia" (Grubov 2000ff), and a comprehensive checklist (Gubanov 1996). These volumes, together with scientific expertise and the Mongolia collection (herbarium HAL) available in Halle, Germany, formed a sound base for plant identification. They were indispensable for descriptions of plant communities, but new records were also of interest for conservation purposes, because the Gobi hosts a number of rare and endemic species (Grubov 1989; Ulziikhutag 1989). Thus, surveying the flora constituted a central aim.

International cooperation has yielded an impressive body of publications on Mongolian vegetation (Hilbig 1982, 1988); synthesis volumes are available for major formations (e.g. Lavrenko *et al.* 1991; Rachkovskaya 1993; Yunatov 1974), and coarse-scale maps were also compiled (Lavrenko *et al.* 1979). More recently, some major results and maps were published in English (Gunin *et al.* 1995; Karamysheva & Khramtsov 1995; Lavrenko & Karamysheva 1993; Vostokova & Gunin 2005). In these cases, classification of plant communities was largely based on the dominant species (cf. Alexandrova 1973; Mirkin 1987; Walter 1974) resulting in a relatively high number of units. However, dominance relations can change quickly in a semi-arid region with highly variable precipitation (cf. chapter 2), and differences among communities are not always clear. These are the main reasons why the dominance-approach was criticised (Hilbig 1990b). Phytosociological schemes offer an alternative, where classification is based on the presence of diagnostic species. These are restricted to a given community but not necessarily among its dominant members. This method has also proven successful in Mongolia, and work has culminated in the compilation of country-wide overviews (Hilbig 1990a, 1995, 2000) which have since become the benchmark reference texts on Mongolian vegetation.

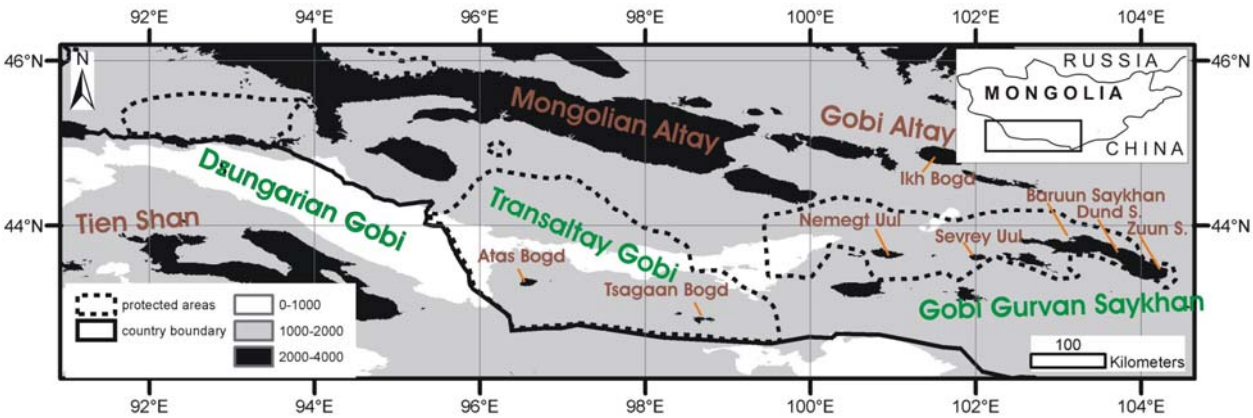

Fig. 3.1.1: Map of south-western Mongolia indicating the distribution of the main mountain chains and the landscape units; dotted lines demarcate protected areas (cf. Fig. 2.1, draft von Wehrden & Wesche, based on SRTM data).

Arid southern Mongolia received considerably less attention by botanists than the central and northern parts of the country (among the few exceptions are Helmecke & Hilbig 1985; Helmecke & Schamsran 1979a, 1979b). Phytosociological surveys conducted in the preparatory phase of the Gobi Gurvan Saykhan Research Project (Miehe 1996, 1998) revealed that the vegetation comprised plant communities not comprehensively described before. Thus, the compilation of a vegetation description for the entire study region (Gobi Gurvan Saykhan National Park and surroundings) became a second major research aim in the project (chapter 3.2). This was amended by detailed small-scale assessments of relatively moist mountain sites, which are of high interest to conservation.

Whether or not results obtained for a certain stand are representative for larger regions depends on the spatial distribution of the given plant community. Regional vegetation maps are the most straightforward source of that kind of information. For the Gobi Gurvan Saykhan region, local maps had been compiled for the semi-deserts south of the Nemegt Uul and around Bulgan (Rachkovskaya 1993; Vostokova & Gunin 2005); and for the Zuun Saykhan (Shurentuya *et al.* 2002; for locations see Fig. 3.1.1). Classification of plant communities was largely based on dominant species, and maps covered only small sections of the park. Available large-scale maps (scale ≥ 1: 1 000 000, Gunin *et al.* 1995; Lavrenko *et al.* 1979) were not detailed enough for the project's purposes, and the national park administration also demanded a medium-scale vegetation map covering the entire region. With respect to the park's vast size (> 27 000 km²), a ground-based survey would have been extremely time-consuming and impractical, so the map was based on satellite imagery.

Current vegetation patterns can not be understood with respect to the present conditions alone as historical events often leave lasting imprints on the vegetation. This is particularly true for regions with strongly fluctuating conditions such as Central Asia (Gunin *et al.* 1999; Ma *et al.* 2004; Tarasov & al. 1998). In a dryland, oscillations of precipitation are of utmost importance in this respect. This is well exemplified by extrazonal occurrences of plant communities in the Gobi Gurvan Saykhan. The summit region of the Zuun Saykhan (Fig. 3.1.1) hosts birch forests and *Kobresia* mats, which are typical of northern and central Mongolia and do not occur in the lowlands of the Gobi (Anonymous

1990; Jäger 2005). Not surprisingly, several of the associated species have severely isolated populations which are of interest to conservation. These occurrences raise the obvious questions as to whether birch forests in the Zuun Saykhan represent remnants of a once more widespread forest cover, and whether the current levels of fragmentation are entirely due to climatic constraints or due to human impact. Thus, the fourth aim of the base-line survey was to obtain new data on the history of climate and vegetation in the eastern Gobi Gurvan Saykhan.

Results and Discussion

New data on the vascular plant flora

We collected > 1300 specimens in the initial phase of the project (2000 and 2001), and travelled more than 4000 km in 2001 alone. This was followed by repeated visits to selected sites in the years 2002 – 2005, yielding a total of well above 3500 specimens. However, though we specifically looked for unknown taxa, we only found a limited number of new records. In fact, these seemed so few that we decided to combine the data from the Gobi Gurvan Saykhan with results from surveys in adjacent regions (Jäger *et al.* in prep). Species were identified using standard literature on Mongolia and adjacent countries (e.g. Krasnoborov 1987ff; Wu & Raven 1994ff), and some taxonomically difficult groups were kindly cross-checked by specialists: Z. Sanchir (all groups), H. Freitag (Chenopodiaceae, Ephedraceae), N. Friesen (*Allium*), J. Soják (*Potentilla*). The demarcation of floristic regions used follows the standard proposal by Grubov (1982), so the Gobi Gurvan Saykhan belongs mainly to the Gobi Altay floristic region, while its southern forelands belong to the Alashan Gobi.

The results are summarised in Tab. 3.1.1. The level of knowledge on the regional flora proved to be very high. We made new records for less than 100 species; most of which were from the Dzungarian Gobi and from the Gobi Altay. The relatively high number in the latter region reflects its varied relief and moisture conditions as well as the survey intensity (main project site). The survey in the Dzungarian Gobi was relatively short at less than 2 months (2003, mainly H. von Wehrden). That region had been poorly visited by botanists before (but see Jäger *et al.* 1985), and especially the mountain ranges along the Chinese-Mongolian border hosted a number of previously unknown populations. Several species were not known for Mongolia - which is explained by the occurrence of winter precipitation that is more typical for Middle Asian regions (and westwards) - making the Dzungarian Gobi, along with its respective biogeographic connections, unique within Mongolia.

Tab. 3.1.1: Summary of newly recorded vascular plant species collected during surveys by K. Wesche, H. von Wehrden, G. & S. Miehe and E. Jäger (2000 – 2005, only certain identifications, Jäger *et al.* in prep).

New ….	Dzungarian Gobi	Transaltay Gobi	Gobi Altay (mainly Gurvan Saykhan)	East Gobi
… for the region only	31	11	32	2
… for Mongolia	1	1	3	-
… to science	1	-	1	-
Total	33	12	36	2

Only two species appeared to be new to science, both of which come from taxonomically difficult groups (*Suaeda* spec. nov, H. Freitag pers. comm.; *Potentilla gobica* Soják 2006), confirming that the Mongolian flora is relatively well known. The chorological analysis of these findings is not yet completed, but records reflect the overall pattern that most of the Mongolian flora comprises taxa with eastern affinities, while only the regions west of some 100°E more commonly host Middle Asian or western Eurasian species, which are adapted to higher levels of winter precipitation (Jäger 2005; Wesche *et al.* 2005a).

Comprehensive description of the (vascular) plant communities (Candollea 2005; 60: 149 – 205)

We sampled some 550 relevés covering all regions of the Gobi Gurvan Saykhan National Park and the adjacent areas employing a modified Braun-Blanquet approach. Selection of sampling sites was subjective but aided by printouts of Landsat satellite images to ensure comprehensive representation of all vegetation units. Manual classification by phytosociological table work yielded 39 communities in 4 major community groups.

Community groups showed a clear altitudinal zonation following the sequence semi-desert scrub, desert steppes and mountain steppes at the upper slopes. Unfortunately, usage of formation names is somewhat inconsistent in Russian and European geobotany (Zemmrich 2005), and we followed an intermediate scheme. True deserts have contracted, as opposed to continuous vegetation and are rare in the study region. Sparse but continuous vegetation on the pediments represents semi-deserts (Ellenberg & Mueller-Dombois 1967). Most plant communities in the Gobi Gurvan Saykhan belong to this class, including both desert steppes (with an appreciable cover of perennial grasses) and semi-desert scrub communities (mostly woody Chenopodiaceae, Tamaricaceae). Mountain steppes have at least partly closed swards and are somewhat similar to the grass steppes of central Mongolia (Hilbig 1995, 2000).

The classification of plant communities confirmed previous studies to a large extent. Though hardly any samples from our study regions were available for the compilation of the nation-wide classification system (Hilbig 1990a, 1995), most samples corresponded to associations described before (Helmecke & Schamsran 1979a; Hilbig 2000). Resemblance was particularly close in extrazonal communities (*Betula microphylla* forests; *Kobresia* mats). Much more widespread in the mountains than those forests or Cyperacee mats are mountain steppes with *Agropyron cristatum* and *Stipa krylovii*, both of which also occur in adjacent parts of the Altay system (Hilbig *et al.* 1988).

The zonal semi-desert vegetation of the Gobi is relatively homogenous over large regions, and most plant communities have been described before including desert steppes with *Stipa glareosa*, *Allium polyrrhizum*, and other semi-deserts with *Anabasis brevifolia* or *Haloxylon ammodendron*. Among the few necessary amendments were a community of dry river beds with *Artemisia sphaerocephala*, and new insights into the altitudinal distribution of *Stipa gobica*. *Stipa gobica* is closely related to *S. glareosa*; both species are extremely widespread in the Gobi and can only be distinguished when flowers / fruits are present. For that reason, they are usually lumped together in vegetation surveys (e.g. Helmecke & Schamsran 1979a, 1979b; Hilbig 1995). Wherever possible, we differentiated between the species and found that *Stipa gobica* prefers sites at slightly higher altitudes (2000 - 2400 m), which are somewhat moister and have a more coarse soil matrix. In contrast, feather grasses found in dry semi-deserts were almost always *S. glareosa*.

Finally, vegetation of azonally moist sites such as saline meadows, oases or surroundings of small springs depends closely on water surplus, and similar communities are found in large parts of the northern hemisphere (e.g. reed beds with *Phragmites communis*, or clay pans with *Salicornia europaea* s.l.).

Of particular relevance are highly isolated stands of the tree *Ulmus pumila,* which are rare but scattered all over the park. This poses the question of the potential extent of dry woodlands in the southern Gobi. Another woody perennial of some interest is the prostrate *Juniperus sabina*, which forms extensive scrub vegetation in the Gobi Altay. Stands represent outposts in the overall species' range but nonetheless host a special flora and fauna. Thus, communities with that species were studied in more detail in a separate project.

Randomised sampling of small-scale vegetation patterns at sites with Juniperus sabina *(Feddes Repertorium 2004, 115: 585-600)*

Phytosociology is widely criticised because of the non-random sampling and the manual, only partly formalised data analysis (Kent & Coker 1992). We tested our approach during a small-scale study on the slopes of the Dund and Zuun Saykhan. We sampled a total of 160 plots in the two study regions; coordinates were randomly chosen but constrained to represent the altitudinal range of *Juniperus sabina*, which was of interest for conservation reasons. The phytosociological classification was compared to a numerical approach (Ward's clustering based on Euclidean distance). The relationships between vegetation and soil conditions were analysed by correlating vegetation data with a set of soil data obtained from lab analyses using constrained multivariate ordination.

The results supported several of the methods applied in the present thesis. The randomly chosen samples could be assigned to the previously described phytosociological units, and even the transitional stands had been described with phytosociological methods before. The bias introduced by deliberate selection of sampling sites in the large-scale survey (Wesche *et al.* 2005b) should therefore be low (at least in the context of mountain steppes). Numerical classification of relevés yielded 7 larger groups, each characterised by a set of largely exclusive species. Several were described as diagnostic species in the previous phytosociological survey indicating a large correspondence between numerical and phytosociological classification. This is supported by studies from other regions (e.g. van der Maarel 1979; Wesche *et al.* 2005c).

Of particular interest was the relation between vegetation patterns and site conditions. The juniper scrub had favourable site conditions with elevated levels of carbon, pH and potassium. Juniper stands also offer grazing refuge and thus safe sites for a number of accompanying plant species. Thus, conservation of stands is of some importance.

The results also have another methodological implication. Canonical Correspondence Analysis revealed that a large fraction of the variation in species composition was related to site parameters such as altitude, exposure, litter cover and inclination. These variables are easily mapped based on digital elevation models and satellite images, indicating that large-scale vegetation mapping may be feasible in the region.

Satellite-based mapping of plant communities in dry steppes (Erdkunde 2006, 60: 261-272)

We employed a supervised classification of LANDSAT ETM+ images; the algorithm was trained with a set of vegetation samples classified along the phytosociological lines explained above. The survey thus comprised four steps: Sampling training regions in the field, classifying the plant communities, and using these data for a maximum likelihood classification of the satellite data. The last step included cross-validation against an independent data set gathered in 1996 (Miehe 1996, 1998).

Central Asian vegetation has been assessed with satellite data before (Burkart *et al.* 2000; Erdentuya 2002; Kawamura *et al.* 2003; Kharin 2004; Kogan *et al.* 2004), but phytosociological units have rarely been mapped with Landsat data there or elsewhere (one of the few examples is Zak & Cabido 2002). However, we were able to map a total of 19 plant communities for the Gobi Gurvan Saykhan National Park at an overall accuracy of above 93%. These represent half of the units compiled on phytosociological grounds (see above), because several communities form small-scale mosaics or occur in only very small stands (e.g. saline meadows, meadow steppes). These were mapped together with other units. Nonetheless, all spatially relevant plant communities could be mapped, giving a reasonably detailed and reliable impression of the park's habitats.

The overall classification accuracy was surprisingly high in view of the overall low vegetation cover. Satellite images provide information on vegetation but also on underlying geology, soil substrates and landform. Signatures are partly mixed and were not disentangled in the present study. We deliberately included this abiotic information, as this has proven to be closely related to plant communities (see above, Wesche & Ronnenberg 2004).

Stands of birch forest in southern Mongolia indicate environmental changes in the second half of the Holocene (Paleogeography, Paleoclimatology, Paleoecology 2007, 250: 150-166)

The *Betula microphylla* forests of the Zuun Saykhan are probably the most isolated forests in the whole of Central Asia. They host a number of regionally rare species but also provide evidence of a once more continuous forest cover. We used a multi-proxy approach and compiled several strains of evidence. A biogeographic analysis (Jäger 2005) was fundamental because several of the isolated plant species are not capable of long-distance dispersal, suggesting that they migrated along the Altay chains at a time when climatic conditions allowed for a more continuous extent of moist mountain vegetation. Connections must have been lost in the late Quaternary, as even the most evolutionary plastic species have not yet evolved morphologically different local varieties or other taxa of lower rank.

We found a piece of wood from a Pinacee that was dated at some 3700 years BP, and this is in line with similar charcoal findings in the Altay, 500 km northwest of the Zuun Saykhan, that were dated between 3500 - 4500 BP (Gunin *et al.* 1999). All studied sites are presently devoid of coniferous forests, which were apparently more widespread in the Sub-Boreal Phase. This is supported by a pollen profile collected by the author in the Zuun Saykhan that implied the absence of coniferous forests during the last approx. 4000 years, while pollen of *Pinus* and *Larix* was somewhat more common before that time (basis of the profile not dated but > 4500 yrs.BP).

Overall, evidence from biogeography, dendro-ecology and palynology implied that sub-boreal forests disappeared from the region around 4000 - 4500 yrs. BP. The main reason for the demise is most certainly climatic with levels of mean annual precipitation estimated to have been at least 100 mm higher than at present. Climatic conditions in the drylands of Central Asia are known for their pronounced fluctuations in the Holocene (Gunin & Slemnev 2000; Herzschuh *et al.* 2004; Ma *et al.* 2004), and forests were at times continuous in the south-western Mongolian mountains (Gunin *et al.* 1999). Today's birch forests depend on extreme water surplus and on moisture buffered by the permafrost layer found under the soil. Once the forest is cleared, the ice will be lost and with it the hydrological buffer, rendering re-colonisation of the site under current climatic conditions impossible. Thus, forests are true remnants (Eriksson 1996, 2000), and sensitive to human impact. This is rather low at present, but charcoal findings imply that fires had played a role in forest dynamics. Whether these were man-made or not cannot be decided with the available methods, but the continuous occurrence of grazing indicators in the pollen profile suggests that the current land use has been practised for at least 2500 years. This is in line with other palynological evidence that also revealed continuous presence of open vegetation over most of Central Asia since 2000 - 3000 yrs. BP (Herzschuh *et al.* 2004; Ma *et al.* 2004).

Conclusions and Outlook

The results of our studies are largely descriptive but also have some methodological implications:

- Though available data on the southern Mongolian flora proved comprehensive, we still found new records for almost 100 species including two new to science and five new for Mongolia
- Available vegetation descriptions proved largely applicable; however, particularly in the context of montane desert steppes with *Stipa gobica*, some amendments were necessary
- Randomised vegetation sampling followed by data analysis with multivariate statistics yielded essentially similar results as the phytosociological approach
- Stands of *Juniperus sabina* offer safe sites with favourable soil conditions; this and other montane communities are closely linked to topographic variables such as aspect or inclination
- Landsat data can be used to map phytosociologically derived plant communities in southern Mongolia; maps of the scale 1: 100 000 – 1: 200 000 give comprehensive baseline data for research and management

- Data derived from biogeography, vegetation science, and paleoecology indicate that coniferous forests were once widespread in the Gobi Altay at levels of precipitation at least 100 mm higher than today. They disappeared from the region 4000 – 4500 BP for climatic reasons, but humans and their livestock may have also interfered

The results suggested that the chosen approaches were feasible, so we are currently extending our studies to neighbouring sites. Research concentrates on the other southern Mongolia nature reserves, which are representative of the entire southern Mongolian Gobi (Fig. 3.1.2). In 2003, we surveyed the Great Gobi B Strictly Protected Area, which represents the Dzungarian Gobi with its relatively high levels of winter precipitation (Fig. 2.3). In 2004, we visited the Great Gobi A Strictly Protected Area in the Transaltay Gobi, which has the driest conditions of all reserves. Finally, the Small Gobi A and Strictly Protected Area were visited in 2005. They represent the conditions in the south-eastern Gobi, where summer rains tend to be higher.

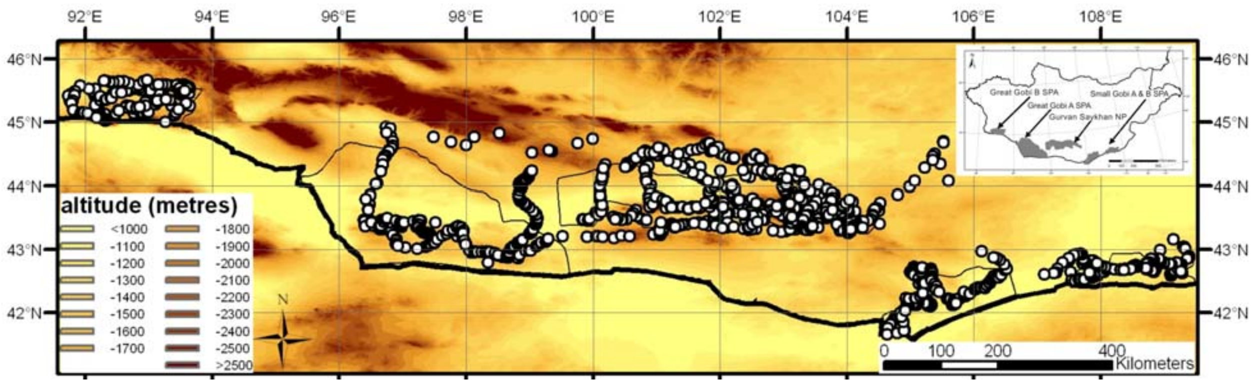

Fig. 3.1.2: Map of southern Mongolian indicating the location of the protected areas (names in insert, cf. Fig. 3.1.1) and the position of vegetation samples taken up to 2006 (von Wehrden & Wesche 2006).

Regional vegetation descriptions were already compiled for the Great Gobi SPA's (von Wehrden *et al.* 2006a,b), data for the south-eastern Gobi are currently being analysed. These surveys indicate that the available country-wide classification system is generally valid (Hilbig 1995, 2000), but conditions differ regionally so amendments will be necessary. The final assessment will depend on a comprehensive synoptic classification of the entire data set gathered during the project (> 1500 relevés). Data analysis is underway and based on both phytosociological and numerical approaches. So far, a mixed approach has proved to be the most feasible, in which diagnostic species chosen from literature (Hilbig 1990a, 1995) are used to configure a numerical classification based on the COCKTAIL-algorithm (Bruelheide 2000; Tichý 2002).

Vegetation classification is paralleled by satellite-based mapping. So far, we have tentative maps for 3 out of the 5 reserves (von Wehrden 2005; von Wehrden & Wesche 2005, 2007). The methods again proved reliable, and maps have already been used in local conservation projects. One example is the selection of a new re-introduction site for the Przewalski horse in Dzungarian Gobi that was aided by our vegetation map (ITG 2006; Kaczensky *et al.* in prep). Cooperation with zoologists seemed promising, so we secured funding in order to finish the comprehensive mapping of the southern Mongolian reserves and to devise a habitat model for the endangered Asiatic Wild Ass (cooperation with C. Walzer & P. Kaczensky, Wien).

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3.2 Abstracts of corresponding publications: Flora and Vegetation

Plant communities of the Gobi Gurvan Sayhan National Park (South Gobi Aimag, Mongolia). - *Candollea* 2005, 60: 149-205.

Karsten Wesche: Institute of Biology - Geobotany and Botanical Garden, Univ. of Halle-Wittenberg, Am Kirchtor 1, 06099 Halle, Germany, Tel. 0049 345 55 26212, karsten.wesche@mailer.uni-halle.de

Sabine & Georg Miehe: Fac. of Geography, Univ. of Marburg, Deutschhausstr. 10, 35032 Marburg, Tel. 0049 6421 2824263 or 0049 6421 31516, miehe@staff.uni-marburg.de

Summary

This paper presents the first detailed description of plant communities in the south-eastern Gobi Altay, covering the terrain of the Gobi Gurvan Sayhan National Park and adjacent areas. Phytosociological classification of 549 relevés yielded 4 community groups with 39 communities. The distribution of communities is largely controlled by water availability, which is generally higher in the mountains. The upper slopes are covered by scrub with *Juniperus sabina* and by various types of mountain steppes with *Stipa krylovii*, while *S. gobica* desert-steppes dominate the upper piedmont areas. With decreasing humidity, *Stipa glareosa-Allium polyrrhizum* desert steppes occur and merge with semi-desertic, very open dwarf-shrublands towards the inter-montane basins and salt pans. *Anabasis brevifolia*, *Salsola passerina*, *Zygophyllum xanthoxylon*, and *Haloxylon ammodendron* are the most characteristic woody constituents of these semi-deserts.

Extra-zonal vegetation types of minor spatial extent concentrate in water-surplus habitats in both extremes of the humidity range: *Betula microphylla* forests, *Helictotrichon schellianum* meadow steppes, and *Kobresia myosuroides* mats are restricted to the moistest slopes in the mountains; they contrast with *Nitraria* scrub, takyr communities, salt meadows, and *Phragmites* reeds in saline habitats of the inter-montane basins.

The steppes have been grazed by both, wild and domestic herbivores for millennia, so all occurring plant species are well adapted to the grazing pressure. No regional grazing indicators could be identified, and grazing appears to be sustainable on the current level. However, rare occurrences of trees (*Populus laurifolia* gallery forest in the mountains, *Populus diversifolia* woodlands, and *Ulmus pumila* stands in the piedmont zones) indicate a certain potential for tree growth at favourable sites in the study area. Further studies are needed to assess whether trees could become more abundant if grazing is strictly controlled.

Keywords

Semi-deserts, grazing impact, Mongolia, phytosociology, steppes, vegetation

Phytosociological affinities and habitat preferences of *Juniperus sabina* L. and *Artemisia santolinifolia* Turcz. ex Bess. in mountain sites of the south-eastern Gobi Altay, Mongolia. - *Feddes Repertorium* 2004, 115: 585-600

K. Wesche & K. Ronnenberg
Institute of Biology - Geobotany and Botanical Garden, Martin-Luther-University Halle-Wittenberg
Corresponding author: K. Wesche, Email: karsten.wesche@botanik.uni-halle.de

Summary

Plant community composition was analysed for 145 relevés, randomly sampled on steep slopes in the Gobi Gurvan Sayhan National Park, southern Mongolia. Cluster analysis designated 7 communities into three main groups, namely mountain steppes, dominance stands of the dwarf shrub *Artemisia santolinifolia*, and scrub composed of *Juniperus sabina*. Multivariate classifications corresponded well to available phytosociological classification schemes. Dense mountain steppes on northern exposures, as well as juniper stands on south- and east-facing scree slopes, had high contents of organic matter and cations in the soil, while stands with disturbance-tolerant species such as *Carex stenophylla*, annuals, or *A. santolinifolia* grew on less favourable soils. Stands of the latter species showed some overlap with *J. sabina* with respect to species composition and site conditions, and specimens of *A. santolinifolia* were present in most relevés of juniper stands. The complete absence of juniper seedlings suggested an apparent potential replacing of ageing specimens of *J. sabina* by *A. santolinifolia.* However, both species were distinct in cluster, ordination and correlation analyses, so this process seems to be still in its infancy.

Vegetation mapping in Central Asian dry eco-systems using Landsat ETM+. A case study on the Gobi Gurvan Saykhan National Park. - *Erdkunde* 2006, 60: 261-272

Henrik von Wehrden[1,] *Karsten Wesche, Georg Miehe, Christoph Reudenbach*

[1]*corresponding author: Henrik von Wehrden, Institute of Biology - Geobotany and Botanical Garden, Univ. of Halle-Wittenberg, Am Kirchtor 1, 06099 Halle, Germany, Tel. 0049 345 55 26264, henrikvonwehrden@web.de*

Summary

This paper presents a vegetation map of the Gobi Gurvan Saykhan National Park, a large protected area in the semi-arid parts of southern Mongolia. The map was compiled in order to provide spatially explicit baseline data that were required for conservation management. The study area was covered by five partly overlapping Landsat ETM+ scenes. Vegetation was sampled at more than 600 sites using a modified Braun-Blanquet approach; locations were selected with the help of unsupervised classifications of the satellite scenes.

Vegetation samples were initially classified with a phytosociological approach yielding four main groups of plant communities: mountain steppes, moist desert steppes of the upper pediments, dry desert steppes and extra-zonal vegetation. These groups comprised a total of 18 plant communities, which were subsequently used for the supervised classification of satellite images. Difficulties were expected due to the sparse vegetation cover typical for semi-deserts and steppe ecosystems, resulting in minor spectral differences among the different communities. However, independent validation of the map yielded an overall accuracy above 93%. Thus, the chosen set of methods proved suitable for the study region, and is currently employed for similar surveys in other southern Mongolian nature reserves.

Montane forest islands and Holocene forest retreat in Central Asian deserts: a case study from the southern Gobi Altay, Mongolia. - *Paleogeography, Paleoclimatology, Paleoecology* 2007, 250: 150-166.

G. & S. Miehe +, L. Opgenoorth +, J. Cermak +, F. Schlütz++, E. J. Jäger +++ , R. Samiya ++++, K. Wesche +++*

+Faculty of Geography, University of Marburg, Deutschhausstr. 10, D-35032 Marburg, Germany; ++ Department of Palynology and Climate Dynamics, A. v. Haller-Institute of Plant Sciences, University of Göttingen, Untere Karspüle 2, D-37073 Göttingen, Germany; +++ Institute of Biology - Geobotany, University of Halle-Wittenberg, Am Kirchtor 1, D-06108 Halle, Germany; ++++ Department of Zoology, Faculty of Biology, Mongolian State University, Ulaan Baatar, P.O. Box 377, Mongolia

**Author for correspondence (e-mail: miehe@staff.uni-marburg.de)*

Abstract

A multi-proxy case study conducted on Central Asia's most isolated mountain forest sheds light on the apparent decline of sub-boreal forest and the incisive environmental shifts from dark taiga to steppe in the Gobi Altay of Southern Mongolia over the last 5000 years.

New vegetation records from the 'Gobi Gurvan Saykhan' (43°30' N / 103°10' E) reveal long distance disjunctions of birch-willow forests as well as of a number of forest plants. Thus the question arises as to whether long-distance dispersal or fragmentation, following climatic changes and human interference, are more plausible explanations for such a pattern. An analysis of the current plant distribution patterns led to the following conclusions, which are corroborated by zoological surveys on the Gobi Altay: During the mid-Holocene climatic optimum, dark taiga forests apparently existed a further approx. 600 km to the southeast of their present range, and pollen analyses and charcoal remains provide evidence of the sub-boreal decline of dark taiga by forest fire. The presence of humans during these environmental changes is highly probable as pollen indicating human presence was found. Thus, it is assumed that humans at least contributed to the sub-boreal forest decline and the spreading of sagebrush and grazing pastures. Moreover, we cannot exclude with certainty that disjunctions of forest flora between the Gobi Altay and the forests of north-eastern Tibet are indicative of migration through the present North China desert, as woodlands may have partly replaced semi-deserts during the moister periods of the Holocene. This multidisciplinary approach implies a mid-Holocene and sub-boreal scenario, which is new for Central Asia and more in accordance with the environmental history of the Holocene in the western Old World's desert belt.

Keywords

Island biogeography, plant migration, boreal forest, Gobi desert, precipitation, climate change, High Asia

4 Plant-animal interactions: Impact of livestock and small mammals

4.1 Summary: Livestock and small mammals

Introduction

Nomadic pastoralism is the traditional form of land use in Central Asia and still represents the overwhelmingly dominant part of the agricultural sector in Mongolia (Janzen 2005). Apart from the driest sites where lack of wells renders livestock-keeping impossible, practically the entire 1.3 Mio. km² of steppes in the country are grazed to some extent; and several plant communities have been severely reduced in abundance due to the anthropo-zoogenic impact (e.g. *Ulmus pumila* forests, Hilbig 1987; Hilbig & Opp 2005).

Grazing degradation has become a major concern over the last decade (Fernandez-Gimenez 2000; Hilbig & Opp 2005; Opp & Khakimov 2001), mainly due to the observation that herds increased tremendously following the collapse of the socialist economy, which forced many unemployed urban dwellers to return to nomadic husbandry (Bedunah & Schmidt 2004; Fernandez-Gimenez & Batbuyan 2004; Müller 1999). Available numbers might underestimate the real size of herds (Reading *et al.* 2006), but according to governmental statistics livestock numbers in Mongolia increased from some 24.8 Mio. in 1989 to 33.8 in 2002 (Janzen 2005). This increase was facilitated by a sequence of moist years, but *Zuud* (drought) conditions at the beginning of the new millennium brought total figures back to levels of the socialist era (Retzer 2004; Retzer & Reudenbach 2005).

Numbers of livestock can be standardised to an estimated daily uptake based on the concept of the traditional Mongolian Sheep Unit (Bedunah & Schmidt 2000: horse ~7kg/d; cattle 6; camel 5; sheep 1 and goat 0.9). When livestock numbers are thus standardised and related to the estimated size of rangelands in Mongolia (White *et al.* 2000), crude estimates of the annual uptake can be obtained. These varied between a mean of 150 kg/ha in 1989 and 200 kg/ha in 1999, but declined to 130 kg/ha in 2002 (Fig. 4.1.1). These figures seem low compared to other mid-latitude rangelands. However, above-ground productivity in dry Central Asia is also low. Reliable country-wide data are not available, and published estimates range widely between 150 and 16500 kg/ha x yr (Kazantseva 2005; Ni 2004; Ojima *et al.* 2000; Zheng *et al.* 2006). The lower value seems rather high for the extensive deserts of southern Mongolia, but the upper value represents untypical water surplus sites. Values for the typical steppes in the area are mostly below 2000 kg/ha x yr (Ni 2004). Estimates based on global patterns of rain use efficiency also suggest a range between 200 and 2000 kg/ha annual net above-ground productivity for Mongolian steppes (30 - 300 mm precipitation, Huxman *et al.* 2004). Our study site in the Gobi Gurvan Saykhan had a measured mean annual productivity of between 200 and 600 kg/ha, and values for moister central and northern Mongolia are certainly higher.

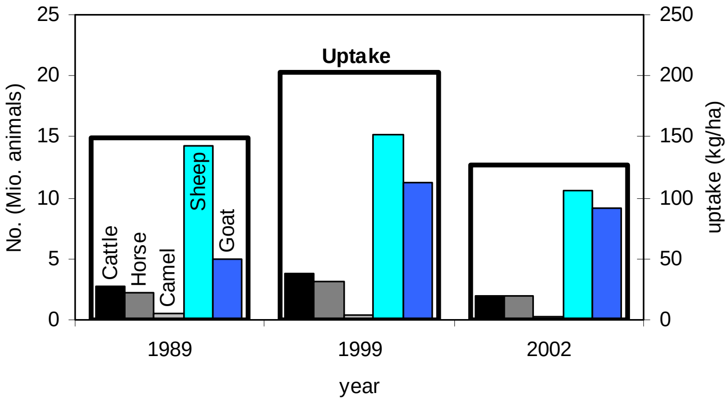

Fig. 4.1.1 Numbers of livestock species in Mongolia (small columns), and estimated annual uptake/ha (broad boxes, data from National Statistical Office of Mongolia, compiled by Janzen 2005).

Admittedly, these are crude and simple estimates, but they sufficiently demonstrate the overall pattern that levels of grazing have not generally increased since the early 1990's. Still, there are differences, even on this crude scale, as developments differed among the five major livestock species. The number of (cashmere) goats has increased particularly strongly, and numbers are still well above those of the 1980's. Their collective uptake almost doubled from an estimated 1.6 Mio. t/year to some 3 Mio. t/year. This is indeed worrying, as goats are expected to affect pasture conditions more detrimentally than other species (Chimed-Orchir 1998; Reading *et al.* 2006; Tsagaan Sankey *et al.* 2006).

Mid-latitude grasslands support large herds of grazers in the absence of domestic livestock (Coupland 1992, 1993; Lavrenko & Karamysheva 1993; Zhu 1993). North-American prairies hosted millions of bison, and steppes of Mongolia (particularly in the east) are still grazed by millions of gazelles (mainly *Procapra gutturosa*, *Gazella subgutturosa*; Leimgruber *et al.* 2001; Lhagvasuren & Milner-Gulland 1997; Milner-Gulland & Lhagvasuren 1998). Among the rarer wild large herbivores are wild camels (*Camelus bactrianus ferus*, Mix *et al.* 2002), wild ass (*Equus hemionus hemionus*, Reading *et al.* 2001), and the few re-introduced Przewalski horses (*Equus przewalskii*, Ganbaatar 2004). All of these species have decreased in number (cf. Schaller 2000), and have some or even most (Bactrian camels) of their remaining populations in the northern Gobi. They certainly had a higher impact on the vegetation before domestic animals were introduced as the current principal competitors (Campos-Arceiz *et al.* 2004).

Unfortunately, no country-wide figures are available on wild ungulates. Therefore, in the initial phase of the research project a survey of wild herbivore density was conducted in the Gobi Gurvan Saykhan (Retzer *et al.* 2006). Figures were standardised to the Mongolian Sheep Unit and compared to densities of domestic livestock. In the pediment regions, uptake of domestic livestock was up to 60 times that of wild ungulates (mainly gazelles; plus Argali sheep, *Ovis ammon*; ibex, *Capra sibirica*), and uptake was a further 6 times higher in the mountains, where wildlife is more frequent. Domestic livestock thus constitutes the overwhelmingly dominant group of ungulates in the region.

Small mammals form the second important group of mammals in drylands of the world (Kinlaw 1999), and pikas (mainly *Ochotona pallasi*, Lagomorpha) are very abundant in the moister mountainous regions of the Gobi. Initial studies in 2000 and 2001 suggest that pikas consume a similar fraction of the biomass as the ungulates (mostly livestock, Nadrowski 2006; Retzer 2004; Retzer & Nadrowski 2002). Moreover, digging activity directly affects some 5 - 10% of the land surface. Thus, unlike wild ungulates, small wild mammals are certainly not negligible in terms of vegetation ecology.

In any case herbivore impact is clearly a cross-cutting issue in grassland ecology and several theoretical frameworks for an assessment of grazing impact are currently being discussed (Cingolani *et al.* 2005; Illius & Connor 1999; Milchunas & Lauenroth 1993), not least because evaluation of the human contribution to ongoing desertification of grasslands is of tremendous political relevance (Sullivan & Rohde 2002; Veron *et al.* 2006). The consequences of herbivory vary between habitats, and evolutionary history and grassland productivity are among the prime controlling factors (Cingolani *et al.* 2005; Olff & Ritchie 1998). The latter is closely coupled to precipitation in dry rangelands. Given the occurrence of wild ungulates, Central Asian rangelands are assumed to have a long evolutionary history of grazing; but precipitation and productivity levels vary among regions (Erdenetsetseg & Erdenetsetseg 2005; Kogan *et al.* 2004; Ni 2004). Variability in precipitation is the central focus of the non-equilibrium theory of rangeland science (NEQT, Ellis & Swift 1988; Vetter 2005), which has become popular among ecologists working in dry rangelands. The theory predicts that herbivore impact should be limited under arid conditions because they are forced to follow the highly variable precipitation and thus fodder availability. Livestock populations collapse in drought years, and - being mostly long-lived mammals - need years to recover while the plants recruit quickly from the seed bank or from surviving buds, rhizomes etc. Thus, development of livestock populations lags behind pasture conditions and should, on average, be too low to cause severe degradation.

Several recent publications emphasised that the NEQT may be too simple, especially when applied to larger spatial and temporal scales (Briske *et al.* 2003; Illius & Connor 1999; Vetter 2005). Moreover, the impact of small mammals remains much less well known (with the possible exception of Northern American prairies, e.g. Fahnestock & Detling 2002; Kerley *et al.* 2004; Scheffer 1956; Stapp 1998). Still, the NEQT is among the most widely discussed theories in grassland ecology, and even alternative views put strong emphasis on grassland productivity in desertification assessments (Veron *et al.* 2006; Vetter 2005). Thus, we concentrated on this approach; notwithstanding the heuristic value of other theoretical frameworks.

Most available evidence comes from subtropical grasslands which are rich in short-lived species (Ellis & Swift 1988; Oba *et al.* 2003; Sullivan & Rohde 2002). In order to formulate a general theory on grasslands evidence from other regions is needed (Vetter 2005). Mongolia represents an ideal country for the testing of the aforementioned assumptions because rangelands there are still relatively intact (Sneath 1998), and the pronounced latitudinal and altitudinal precipitation gradients (see introduction) allow for comparisons under different moisture regimes. The moist northern parts of the country rarely experience severe droughts, so in accordance with the NEQT, livestock numbers remain more or less constantly high, and degradation risks are also accordingly high. With increasing aridity, sites are assumed to experience non-equilibrium conditions; and these should prevail below around 200 mm mean annual precipitation with a coefficient of variation > 30% (Ellis *et al.* 2002; Fernandez-Gimenez & Allen-Diaz 1999). Thus, the entire Gobi should experience non-equilibrium conditions. Since the beginning of the project in 2000, the analysis of livestock statistics in Mongolia has indicated a high dependence of livestock numbers and precipitation levels on the local- (Retzer 2004; Retzer & Reudenbach 2005), as well as the national scale (Fig. 4.1.1). However, hardly any study was based on experimental manipulations, and few studies covered more than one year or two. Moreover, detailed data for our study region were not available (Bedunah 1998; Bedunah & Schmidt 2000).

We employed several methods in testing various predictions of the NEQT. Long-term effects of grazing are most easily assessed with transects radiating away from high impact sites such as wells (Thrash 1998; Turner 1998a). Such gradients are easily found around the research camp, so we performed a transect study with the aim of assessing the relationship between livestock activity and plant community composition (chapter 4.2). This was not an experimental approach, and no data on productivity were obtained as grazing was not excluded. Thus, in cooperation with the national park administration, plots on desert steppes have been fenced-in and monitored since 2000 for changes in community composition, but also partly for standing crop. The aim was to test the assumption of a pronounced interannual variability that rendered effects of grazing exclusion negligible. A more elaborate fencing experiment has been maintained near the camp in order to assess the relative importance of grazing by livestock and small mammals. This was supplemented by a study on effects of small mammals, which assessed whether they have other ecosystem levels impacts in addition to herbivory. Finally, as several results pointed towards an unexpected interaction between animals, vegetation productivity and soil nutrient conditions, we additionally set up a fertilisation experiment.

Results and Discussion

Do plant community composition and soil nutrient contents differ along established grazing gradients? (Mountain Research and Development 2005, 25: 244-251)

The desert steppes on the upper pediments of the Dund Saykhan are among the most valued pastures in the region and have been intensively grazed by horses, sheep and goats in most years. The latter return to their overnight resting places near wells and herder’s camps every night and thus have a limited roaming radius (< 3 km). We laid out transects radiating away from these long-established traditional high impact sites and counted droppings to assess the spatial extent of utilisation belts. The same transects were used to record vegetation composition and collect soil samples.

Results corroborated the idea of decreasing livestock activity along the transects. Numbers of droppings decreased sharply within the first 500 metres around the wells, but there was nonetheless animal activity up to 1500 m distance - where the utilisation belt around the next well was reached. Plant community composition was very homogenous over all plots (less than one species turnover), and neither species richness, nor cover of shrubs or any other group of species was correlated with distance to the well. This contrasted with the soil conditions, where we found increasing levels of carbon, nitrogen (total and NO_3) and particularly phosphate towards the wells.

These results support predictions from the NEQT, as differences in grazing intensity had no impact on community composition. This was certainly not a short-term effect, as wells are stable and sites have been used for decades if not centuries. Virtually all abundant plant species are perennial and survive even drought conditions (Wesche *et al.* 2005). The general lack of grazing impact on the vegetation was also confirmed in similar transect studies from the Gobi (Fernandez-Gimenez & Allen-Diaz 1999, 2001; Knopf *et al.* 2005). Grazing thus has no obvious detrimental effects for composition of the present plant communities, which nonetheless may still be very different from conditions in a hypothetically ungrazed situation. Unfortunately, as is often the case in traditional grazing systems (Veron *et al.* 2006), no untouched rangelands are available for comparison in Mongolia. With respect to the wild ungulates it is doubtful that the vegetation had looked so very different, but in any case the current situation seems to be relatively stable.

The available transect studies also describe a decoupling of soil conditions and plant community composition, and authors usually find increased levels of soil nutrient contents around the high-impact sites. Livestock deposit much of the uptaken nutrients in their faeces (particularly P, Ca, Mg, Barrow 1987; Clark & Woodmansee 1992), which are largely dropped at night. K and N are largely lost with urine, and spatial gradients in soil contents are often less clear. Still, gradients of increasing soil nutrient contents are found in most arid rangelands (Augustine 2003; Tolsma *et al.* 1987; Turner 1998b). This large-scale nutrient dislocation results in a net loss of soil nutrients from the larger part of the grass stands. The problem is aggravated in Mongolia, where livestock droppings are the main source of fuel and are widely collected and burnt. This has been practised for centuries, so there are good reasons to suspect nutrient deficiencies in much of the Mongolian rangelands (Golovanov *et al.* 2004; Slemnev *et al.* 2004). Whether this has consequences for productivity or not was assessed in subsequent studies.

Is grazing exclusion or interannual climatic variability more important for plant community composition and productivity? (Wesche, Ronnenberg & Retzer, submitted)

A set of nine exclosures representing all major types of desert steppe in the Gobi Gurvan Saykhan region was built in 1999, and was monitored annually up to 2005. Records concentrated on plant community composition in fenced-in sites in comparison to adjacent open control sites; records on flowering activity and monitored biomass productivity in ungrazed cages outside and inside the exclosures for the years 2004 and 2005 were also kept. This design was amended by a factorial grazing experiment near the research camp, where we allowed for access to large ungulates alone, pikas alone, both groups, and none of them. Here we concentrated on biomass development and flowering activity.

The results of the large-scale experiment supported most predictions of the NEQT. The mean richness of vascular plant species varied between 10 and 18/100 m² over the years tracking the highly variable precipitation levels. Numbers for the ungrazed controls were similar, and the grazing effect was much less pronounced than the interannual variability. Both factors nonetheless had significant effects, which did however largely disappear when only the perennial species were analysed. Likewise, grazing exclusion did not trigger a directed succession; instead changes in plant community composition tended to follow the precipitation patterns. Grazing exclusion positively affected the number of flowering species, and at least in a moist year sites protected from grazing also had a higher productivity. This was related to accumulation of fine soil matter in the exclosures and marginally significant increases in the levels of phosphate.

The biomass study near the research camp revealed very pronounced variability in following the precipitation pattern, and both livestock and small mammals were about equally as effective grazers consuming between 20 and 60% of the standing crop. Their uptake varied among years but did not fully follow the biomass development, because even the biomass of fully grazed sites varied with precipitation levels, and livestock and small mammal populations indeed showed strong population fluctuations (Nadrowski 2006; Retzer 2004).

This underlines the fact that grazer population dynamics are indeed slower than changes in the vegetation, which is in line with predictions from the NEQT. Pronounced interannual changes vs. comparatively limited effects of grazing exclusion also support the idea that the impact of grazers is limited (Fernandez-Gimenez & Allen-Diaz 1999; Sullivan & Rohde 2002). It is known that recovery after grazing exclusion can take decades (Valone & Sauter 2005), while our study covered only 6 years. However, the results are in line with data on the traditionally established grazing transects discussed above, so we have little reason to question them. Instead, we think the available evidence is sufficient to caution *against* the idea of widespread degradation threat in southern Mongolia.

During the drought of 2001, herders migrated from the study region to the less affected region of central Mongolia (Retzer 2004). Thus, livestock losses were not as pronounced as they would have been if pastoralists had been sedentary; though numbers were still severely reduced. Pikas do not have the option to migrate, and indeed their biomass uptake recovered more slowly than that of livestock herds. This highlights the importance of access to key resources for mediating drought impact (Illius & Connor 2000; Illius *et al.* 2000). Nomads implicitly use such key resources by migrating to less affected areas, while dynamics in the largely sedentary herding systems in northern China appear to be different from Mongolia (Ho 2001; Zheng *et al.* 2006). Thus, the (semi-) migratory lifestyle is a precondition for land use in the area, allowing for apparently relatively stable rangeland conditions, at least on a time scale of some years.

All the same, our study found slight effects of grazing on plant communities. There were about 1 - 2 plant species more on ungrazed sites, and both flowering activity and productivity were higher. There was some evidence that the latter was related to changes in soil conditions. Accumulation of fine soil may beneficially affect hygric properties of the soil, but then the effects on plant productivity should have been more pronounced in a drought year. Instead, we found an effect in the moist year 2003, suggesting that plants benefited from uptake of soil nutrients available in the exclosures. This implies that nutrient limitation is an issue in dry Mongolian steppes, which is also of theoretical interest as hardly any studies are available from semi-desert environments with less than 200 mm precipitation (Hooper & Johnson 1999) where moisture availability should be the overwhelmingly controlling factor (Bal *et al.* 2004; Noy-Meir 1973).

*Is ecosystem engineering by Mongolian pikas (*Ochotona pallasi*) possible under the arid conditions of southern Mongolia? (Journal of Vegetation Science 2007, 18: 665-674)*

The assumed overwhelming effects of water limitation should affect all interactions in drylands (Whitford 2002; Whitford & Kay 1999), including the effects of ecosystem engineers (Jones *et al.* 1994, 1997). Fossorial small mammals alter the availability of resources such as soil nutrients in most drylands of the world (Kinlaw 1999), but unless they influence water availability, they should have limited effects on the vegetation of arid sites. Thus, in addition to grazing we also studied the relationships between vegetation and burrowing activity of the abundant small mammals.

Mongolian pikas (*Ochotona pallasi*) build permanent burrows in the Gobi Gurvan Saykhan, which are easily demarcated in the field due to their different soil structure and vegetation. We sampled vegetation on burrows and on adjacent controls, and correlated the data with results obtained from soil nutrient analysis. The effect of differences in soil nutrients were also studied in a bioassay, where plants were grown in pots filled with burrow and steppe soil. Pots were exposed to ambient temperatures, but received an unlimited water supply. Plant nutrient contents were analysed both for plants growing *in situ* and also in the pot experiment.

The results revealed strong effects of small mammal burrows on plant communities. There were two different types of burrow vegetation, which were clearly differentiated from the adjacent desert steppes. On coarse substrate, dwarf shrub vegetation with *Artemisia santolinifolia* dominated; on finer substrate the grass *Agropyron cristatum* was the dominant species. Annuals were generally more common on burrows, but richness of other plant species showed no uniform pattern. Plant community composition was closely related to soil nutrient contents, with burrows showing higher levels of C, P, nitrate, and K. In contrast, soil moisture tended to be lower on the burrows. Plant biomass production was significantly higher on burrows, particularly so in the moist year of 2003. Increased soil nutrient levels resulted in enhanced growth of radish plants in pots filled with burrow soil. Both radish and native plants growing *in situ* (*Agropyron cristatum*) showed increased contents of C, K and P. The latter grass is of importance for land use as it is one of the preferred fodder species (Jigjidsuren & Johnson 2003).

Allogenic engineering (*sensu* Jones *et al.* 1994, 1997) by small mammals has been frequently described for the North American prairies (Reichman & Seabloom 2002; Stapp 1998; Wilby 2002), but data from arid regions < 200 mm annual precipitation are limited. Some examples from Central Asia describe ecosystem engineering under similarly dry conditions (Breymeyer & Klimek 1983; Smith & Foggin 1999; Weiner *et al.* 1982). These studies are largely descriptive but support the results obtained by the present project. Ecosystem engineering is clearly important for vegetation dynamics even on the relatively dry sites of southern Mongolia.

Results are also of interest to land management. Small mammals are often regarded as pests in Central Asia (Zhong *et al.* 1985), and indeed *Microtus brandtii* detrimentally affects pasture conditions (Samjaa *et al.* 2000; Zhang *et al.* 2003). In contrast, several authors have argued that pikas provide beneficial services for pasture conditions (Komonen *et al.* 2003; Lai & Smith 2003; Smith & Foggin 1999), and this is supported by our findings of enhanced productivity and higher nutrient contents of plants growing on burrows. Small mammals may alter the hygric conditions (Laundre 1993), leading us to expect higher levels of soil moisture on the burrows. Instead, we found lower water content but higher levels of soil nutrients. Thus, the effects were apparently related to higher soil nutrient contents. There was no evidence that phosphorus is brought up by pikas from lower soil horizons, nor are there more legumes on the burrows, which could fix additional nitrogen. Pikas are central place foragers, and thus simply concentrate nutrients on their burrows, which are harvested in the surrounding steppe. Thus working on a smaller scale, pikas counteract large-scale nutrient removal by livestock and dung collection and may play an important, and all together beneficial rather than detrimental, role for pasture conditions. Here the topic of possible nutrient limitations for rangeland productivity emerges again. All studies described above pointed in that direction, but did not provide experimental evidence. This prompted us to conduct a fertilisation study.

Does experimental NPK-fertilisation increase plant growth in dry Mongolian steppes? (*Wesche & Ronnenberg, manuscript*)

No conclusive studies had been available to specify the general hypothesis of nutrient limitation in desert steppes, and only one unreplicated experiment in desert steppes north of the study region (Slemnev *et al.* 2004) found a positive effect of nitrogen fertilisation in combination with irrigation. In the transect study (see above), we found stronger gradients of phosphorus compared to N, suggesting that P might be a crucial factor, but this may have been related to difficulties in estimating available inorganic N with short-term measurements. Thus, we tested the effects of nutrient addition in a randomised block experiment that was run over three years. NPK-fertiliser was added to plots of 1 m²; these were covered by grazing cages to allow monitoring of biomass development. Levels of fertilisation were adopted from previous studies in dry regions (Hooper & Johnson 1999), i.e. we fertilised sites at the equivalent of 10 gN/m² and 20 gN/m² per year (100 kgN/ha and 200 kgN/ha). Fertiliser was dissolved in a limited amount of water (equivalent to 3 mm of rain); controls were also watered. Fertiliser was added in summer 2003, then plots were sampled in July and August 2004. After sampling, plots were again fertilised and a new set of plots was established with the addition of again 10 and 20 gN/m² respectively. These were not harvested in 2004. The four treatments thus comprised plots that were fertilised twice at levels of 10 and 20 gN/m², and plots that were fertilised only once at the respective levels. These and the controls were again sampled in July and August 2005. Records included a list of species and their cover, the number of inflorescences, and a complete sample of the above-ground standing crop. Nutrient contents in the top soil and in plant tissue were analysed with standard methods.

Levels of soil P and N in the control plots were low, while Ca, Mg and even K tended to be moderately high to very high. These cations accumulate near the surface due to the upward directed water flow in such a (semi-) arid environment. Fertilisation increased the levels of total N and available P, and nutrients accumulated in the soil implying a possible long-lasting effect. Standing crop increased almost linearly with fertiliser treatment. Under relatively moist ambient conditions, the addition of 20 gN/m² fertiliser equivalent resulted in an almost threefold increase in productivity; the effect was also apparent, though not significant, after the relatively dry spring / early summer 2005. Fertilised sites also showed a clear increase in flowering activity, while no effects on species richness were detected, possibly as a result of the small sampling units (0.2 m²). The important fodder grass *Agropyron cristatum* (Jigjidsuren & Johnson 2003) benefited more than other species from the fertilisation and, in addition to enhanced growth, also showed higher levels of tissue-N on fertilised sites.

Thus, above-ground standing crop and flowering activity can apparently be constrained by nutrient limitation at a mere 160 mm total annual precipitation. Available meta-analysis (Hooper & Johnson 1999) also failed to corroborate the idea that plants switch between nutrient limitation and water limitation below a certain threshold of precipitation, but so far hardly any experiments have been conducted with below 200 mm total annual precipitation. However, the observed effects are related to the highly continental climate of Mongolia, where the limited rains are almost exclusively concentrated in the largely thermally constrained growth season, resulting in a relatively high level of available moisture per month of growth period. Thus, Mongolian vegetation at 160 mm mean annual precipitation is much denser than e.g. North-American drylands at this rain level (Hilbig 1995; Lauenroth & Milchunas 1992; Lavrenko & Karamysheva 1993).

The results are of applied interest, because we found that the nutrient translocation and withdrawal in southern Mongolian steppes may indeed affect productivity. This implies a pathway for indirect pasture degradation, which has not received much attention in the theoretical debate so far (Fernandez-Gimenez & Allen-Diaz 1999; Sullivan & Rohde 2002; Vetter 2005). Still, nitrogen-use efficiency was low (increases of 2 - 4 g dry matter/gN applied) compared to moister Central Asian steppes (Yuan *et al.* 2006), and we do not imply that Mongolian steppes should be supplemented with chemical fertiliser. However, land use with high levels of livestock may result in slow, but nonetheless relevant, decreases of pasture quality, especially in the long-term. Smaller ungulates that return daily to overnight resting places, such as sheep and the increasing numbers of goats, may be especially relevant as they trigger the most pronounced nutrient dislocation (Stumpp *et al.* 2005). These have increased in numbers, in contrast to camels (Fig. 4.1.1), which is cause for concern in light of the data presented here.

Conclusions and Outlook

The key results of the described studies can be described as follows:

- Neither grazing exclusion nor long established differences in grazing intensity affect plant community composition or species richness
- Effects of interannual climatic variability are much more pronounced, particularly so in short-lived plants
- Mongolian pikas function as ecosystem engineers in the dry Gobi although they hardly change water availability. Instead, effects of burrowing activity on vegetation are related with higher soil nutrient contents
- Grazing exclosures tend to have more fertile soils and a higher biomass productivity
- Studies along grazing gradients, at grazing exclosures, and at small burrows point to increased productivity on sites with higher soil nutrient levels
- A fertilisation experiment yielded direct evidence for nutrient limitation in plant growth, even under the dry ambient climate of the Gobi
- Taken together, results support most predictions of the non-equilibrium theory of rangeland science, but also hint at the importance of potential soil degradation as a rarely discussed pathway of pasture degradation

Overall, our results imply that current levels of land use probably do not lead to heavy and direct grazing degradation, supporting much of the predictions of the non-equilibrium theory. However, we caution against less obvious effects of land use, including the still not comprehensively understood effects of grazing on soil conditions. These are not negligible because we found evidence that soil conditions may influence plant productivity and reproduction, even in dry southern Mongolia, and are an important aspect in desertification assessments (Li *et al.* 2006). Moreover, soil carbon stocks in the vast steppes are of great interest in terms of greenhouse effect and climatic change (Dai & Huang 2006; Li *et al.* 2005; Lioubimtseva *et al.* 2005). Our data also support the general inference that small mammals form an important group of herbivores and most probably compete with livestock for fodder. But, unlike *Microtus brandtii* in northern and central Mongolia, *Ochotona pallasi* apparently does not induce severe degradation of dry rangelands in the Gobi.

Clearly, all these results were obtained from what was essentially one study region, and it would be highly interesting to compare them to effects of livestock and small mammals on moister sites in central and northern Mongolia. Some detailed data have recently become available from Hustai Nuruu in central Mongolia (van Staalduinen 2005), but experimental studies are still limited. At present, we are trying to obtain funding for comparative research projects at several research stations in Mongolia (proposal together with Dr. Stürmer, Dr. Dulamsuren, Göttingen), but this has, as yet, not been decided on.

The system of grazing exclosures in the Gobi Gurvan Saykhan will be maintained and we will continue with our regular sampling. On the local scale, two further directions of research have been implemented. First, we extended the fertilisation experiment, crossing the fertilisation effect in a factorial experiment with artificial irrigation. Experiments were initiated in 2004, and preliminary results confirm that the nutrient effect is largely independent and apparently even stronger than the irrigation / moisture effect (Ronnenberg, unpubl.). Second, we intend to conduct differential fertilisation with N and P in a factorial experiment. Experimental plots will be set up at different altitudes in order to assess effects at different levels of precipitation. The ongoing and planned studies will also focus more closely on the performance of dominant taxa (*Agropyron cristatum*, *Stipa* spp, *Allium* spp.). These will include records on plant population ecology and will supplement the available data described in the next chapter.

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4.2 Abstracts of corresponding publications: Impact of livestock and small mammals

Impact of grazing livestock and distance from water points on soil fertility in southern Mongolia. - *Mountain Research and Development* 2005, 25: 244-251.

Markus Stumpp[1], Karsten Wesche[2], Vroni Retzer[1], Georg Miehe[1]
[1]*Fac. of Geography, Univ. of Marburg, 35032 Marburg, Germany*
[2]*(corresponding author) Inst. of Biology - Geobotany and Botanical Garden, Univ. of Halle, 06099 Halle, Germany, karsten.wesche@botanik.uni-halle.de*

Abstract

The impact of livestock grazing on soil nutrients and vegetation parameters was studied in dry montane steppes of southern Mongolia in order to assess the risk of habitat degradation. Data was collected along transects radiating away from permanent water sources. Dung density counts revealed gradients of livestock activity, but utilisation belts around water sources overlapped indicating that pastoral land use affects the entire landscape. Dung counts corresponded to gradients in soil nutrient parameters (C, N, P), which significantly decreased with distance from the wells. However, no significant correlation was observed for plant species richness and vegetation composition with distance from water source. This indicates that soil parameters and livestock grazing exert a relatively smaller influence on the vegetation than the high interannual variability in precipitation. Therefore, the ecosystem at the study site was found to react in a non-equilibrium way, which suggests that the risk of degradation is low, at least insofar as plant community composition is concerned.

Keywords

Grazing; non-equilibrium dynamics, vegetation, soil, steppe, Mongolia.

Effects of herbivore exclusion in southern Mongolian desert steppes. – *Manuscript*, submitted

Karsten Wesche[1*], *Katrin Ronnenberg*[2], *Vroni Retzer*[3]

[1,2] *Institute of Biology - Geobotany and Botanical Garden, Martin-Luther-University Halle-Wittenberg, 06099 Halle, Germany, E-mail* [1]karsten.wesche@botanik.uni-halle.de, [2]*katrin.ronnenberg@botanik.uni-halle.de;*

[3] *Chair of Biogeography, University of Bayreuth, 95440 Bayreuth, Germany, E-mail* vroni.retzer@uni-bayreuth.de*;*

[*]*Corresponding author*; *Fax +49 345 55 27228*

Abstract

Questions: We assessed the grazing impact and possible associated degradation risks to dry steppe vegetation in southern Mongolia. Following the assumptions of the non-equilibrium theory of rangeland science, we ask whether interannual precipitation variability (mean < 150 mm) has more pronounced effects on vegetation composition, species richness, plant flowering activity, biomass production, and soil nutrient content than grazing.

Location: Desert steppes surrounding the Gobi Altay, southern Mongolia

Methods: The data are mainly based on a set of nine fenced-in exclosures built in 1999 that represent the principal plant communities in the area. Records on species data were kept on an annual basis, supplementary data on flowering activity, biomass production and soil conditions were collected during some of the years. In addition, productivity data from another small-scale exclosure experiment are used.

Results: Plant community composition and species richness showed modest interannual changes over years of varying precipitation levels, grazing effects existed but were comparatively much smaller. There was no evidence of directed succession under grazing exclusion. The number of flowering species and level of plant biomass productivity were higher in the exclosures than on the grazed controls. Of the investigated soil nutrients only phosphorus was just significantly higher inside the exclosures.

Conclusion: The data support most assumptions of the non-equilibrium theory. However, small but significant differences among grazed and ungrazed sites suggest that herbivore impact is not negligible and can specifically alter plant recruitment and ultimately, soil conditions and productivity. We conclude that the original non-equilibrium theory requires some amendment, but emphasise that there is no evidence of extensive range degradation in southern Mongolia.

Keywords

Non-equilibrium theory, vegetation dynamics, degradation, species richness, soil nutrients, productivity

Habitat engineering under dry conditions: The impact of pikas (*Ochotona pallasi*) on vegetation and site conditions in southern Mongolian steppes. - *Journal of Vegetation Science* 2007, 18: 665-674.

Karsten Wesche[1], Karin Nadrowski[2], Vroni Retzer[3]*

[1]*Institute of Biology - Geobotany and Botanical Garden, Martin-Luther-University Halle-Wittenberg, 06099 Halle, Germany, E-mail karsten.wesche@botanik.uni-halle.de;*

[2]*Fac. of Geography, Philipps-University Marburg, 35032 Marburg, Germany, E-mail nadrowski.k@gmx.de;*

[3]*Chair of Biogeography, University of Bayreuth, 95440 Bayreuth, Germany, E-mail* vroni.retzer@uni-bayreuth.de*;*

[*]*Corresponding author; Fax +49 345 55 27228*

Abstract

Question: Does ecosystem engineering by small mammals have a significant influence on vegetation patterns in the arid steppe vegetation of southern Mongolia?

Location: Gobi Altay Mountains, southern Mongolia

Methods: We assessed the impact of the small lagomorph *Ochotona pallasi* on plant community composition, nutrient levels and biomass production in montane desert steppes. Data were derived from vegetation relevés, harvests of above-ground standing crop and a bioassay, followed by analyses of soil and plant nutrient contents.

Results: Although the local climate is arid with < 150 mm annual precipitation, clear evidence of allogenic ecosystem engineering was found. Plant communities on burrows differed from those on undisturbed steppe in that they contained more species of annuals and dwarf shrubs, and a greater abundance of the important fodder grass *Agropyron cristatum*. Biomass production and nutrient concentrations were higher in plants growing on burrow soil. *In situ* measurements and a pot experiment showed that this effect was related to increased levels of soil nutrients (P, K, N) rather than moisture availability.

Conclusions: The study confirms that *O. pallasi* positively influences soil nutrient levels on its burrows, which leads to increased grassland productivity even under dry conditions. Thus, *O. pallasi* does not deteriorate site conditions, and the need for presently applied pest control schemes aimed at this species should be reassessed.

Keywords

allogenic engineer, arid environments, nutrients, plant community composition, soil, small mammals

Effects of NPK fertilisation in southern Mongolian desert steppes. – *Manuscript*, submitted

By K. Wesche[1] & K. Ronnenberg[2]

Institute of Biology - Geobotany and Botanical Garden, Martin-Luther-University Halle-Wittenberg, 06099 Halle, Germany

E-mail [1]karsten.wesche@botanik.uni-halle.de, [2]katrin.ronnenberg@botanik.uni-halle.de

Summary

Water is the decisive factor for plant productivity in drylands, but few studies have been performed on the relative importance of water versus nutrient availability at < 200 mm annual precipitation. Here, we present data for a replicated experiment on the effects of NPK-fertilisation in dry Central Asian steppes. The study site had an annual mean precipitation of some 160 mm and was covered by an intensively grazed montane desert steppe. One year of fertilisation at levels equivalent to 10 and 20 gN/m² increased above-ground mean standing crop in moist year to 1130 and 1490 kg dry mass/ha, compared to the 615 kg/ha from the control. The absolute increase was smaller in a subsequent normal year, but the crop again more than doubled under fertilisation. The effects were also highly significant for the main fodder species *Agropyron cristatum*, which benefited from fertilisation more than other less palatable species and even showed increased levels of foliar N. Fertilisation also enhanced flowering activity on the community level, and soil analyses revealed that nutrients accumulate in the soil. Thus effects should be lasting.

There was no evidence of a switch from nutrient limitation to water limitation under dry conditions, and results imply that a lack of nutrients affects plant growth at well below 200 m annual precipitation. Because predominantly nomadic land use is known to result in nutrient withdrawal, our data raise concerns of a largely unnoticed potential pathway to pasture degradation.

Keywords

Biomass productivity, fertilisation, grazing, soil nutrients, steppes

5 Populations: Population ecology of selected plant species

5.1 Summary: Plant population ecology

Introduction

The data on vegetation composition and ecology presented above revealed that conditions in the Gobi are only partly comparable to other dryland regions. This relates to the specific climate that facilitates the growth of sparse yet continuous vegetation at an annual mean precipitation below 100 mm. Rains in the extremely continental climate are almost exclusively restricted to the short growing season, which is thereby not as arid as might be expected based on annual mean figures. For that reason, results obtained in e.g. tropical or Mediterranean deserts are not necessarily transferable to the Gobi; and even conditions in the North American short grass steppes may differ, as the discussion on ecosystem engineering and fertilisation effects has shown (chapters 4.1). Differences in the ecology of plant communities should relate to differences in the underlying processes on the population level (van der Maarel 2005), but population ecology of Central Asian dryland species had hardly been studied when the present research project was started in the year 2000.

The climate of the Gobi can be described as harsh, but established desert and mountain plants can mediate environmental stress by way of certain adaptations such as extensive root systems (Körner 2003; Kutschera *et al.* 1997). Among the few previously available data were long-term studies from the Gobi on *Stipa gobica* and *S. glareosa*, which suggested that successful sexual regeneration, i.e. sapling establishment, takes place at mean intervals of 7 to 10 years (summarised in Lavrenko & Karamysheva 1993). In contrast, for the typical desert shrub *Haloxylon ammodendron* (Saxaul) reseeding may only be successful every 50 - 100 years (Gunin *et al.* 2003). We did not find seedlings of the typical steppe plants in the first three years of the project, even where grazing was excluded, and seedlings of e.g. the common *Artemisia frigida* were only abundant in the moist year of 2003. So an obvious first topic was germination ecology of the principal species. Plants growing in seasonal climates often have mechanisms to delay germination until climatic conditions are not only favourable for germination but also for establishment (Baskin & Baskin 2001; Fenner & Thompson 2005). We screened seeds of a set of species for their capacity to germinate directly after dispersal, to survive pronounced frost, and also tested a subset for germination success under different germination conditions (chapter 5.2). We thus tested the hypothesis that seed dormancy is commonly found in Central Asian drylands.

For perennials, regular reseeding is much less important than for short-lived species, and an obvious option is survival of unfavourable conditions by vegetative growth. Theoretical considerations suggest that longevity and non-sexual modes of reproduction should be favoured in harsh environments (Eriksson 1996; Garcia & Zamora 2003; Peck *et al.* 1998). Annual plants are abundant in many (sub-)tropical deserts and semi-deserts (e.g. Dallman 1998; Pausas 1999), but they are much less important in mid-latitude drylands (Schmutz *et al.* 1992; Walter 1974), where grasses and shrubs prevail instead. This is also clearly seen in southern Mongolia where we have taken vegetation samples from all principal nature reserves (see chapter 3.1) and collected well above 1400 samples, which included some 465 species that occurred more than once. Among those, less than 20% were short-lived (annual and biennial, see Fig. 5.1.1). Thus, further research concentrated on perennial plants.

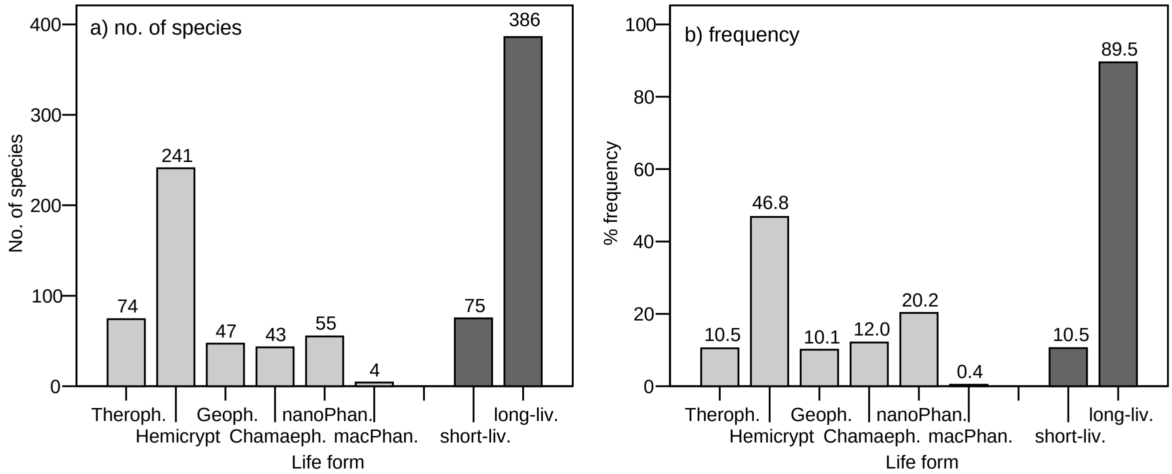

Fig. 5.1.1: Summary of species found in > 1400 vegetation samples from southern Mongolian nature reserves (von Wehrden & Wesche unpubl.) split by Raunkiaer life form (therophytes including biennials, hemicryptophytes, geophytes, chamaephytes, nano-phanerophytes/shrubs, macro-phanerophytes/trees; and summaries for short-lived and perennial plants): a) total no.; b) weighted by number of occurrences.

Many long-lived plants have the capacity for prolonged clonal growth (Honnay & Bossyut 2005; Svensson *et al.* 2005), and indeed clonal growth has recently been described in a number of Central Asian species (Song *et al.* 2002). Clonal plants are also commonly found in mountain and alpine environments (Escaravage *et al.* 1998; Young *et al.* 2002), so we had good reason to expect clonally growing species in the dry and montane environments of the Gobi Altay. We initially chose the prostrate shrub *Juniperus sabina* that was already described as constituting special plant communities and improving site conditions (chapter 3.2). Tentative observations had suggested that sexual recruitment was rare or even absent, so we assessed the relative importance of sexual reproduction vs. survival by clonal growth in *J. sabina*.

Clonal growth was also studied in herbaceous plants. Again, we started with species that were of interest in terms of nature conservation. Mongolia hosts a number of sub-endemic species that are shared with neighbouring Central Asian countries, but there are also some true national endemics (Grubov 1989; Ulziikhutag 1989). They mostly grow in isolated mountain populations, are perennial and are at least potentially capable of clonal growth. We chose endemics known to occur in the Gobi Altay and started with a survey of their distribution. The aims of this approach were twofold: We had to verify their overall distribution and their endemicity status based on an updated review of the available floristic and taxonomical literature. The second aim was an assessment of their local distribution in the study area and their conservation status.

Among the four species surveyed, we chose the two that can be regarded as true endemics of the Gobi Altay, namely *Galitzkya macrocarpa* and *Potentilla ikonnikovii*. We again assessed the importance of clonal growth, particularly so in *G. macrocarpa*. This species colonises as equally extreme sites as the juniper, but has its centre of distribution in the study region. So we tested whether reproductive collapse and exclusive vegetative propagation were really as important as in *J. sabina.*

Populations of *Galitzkya macrocarpa* and *Potentilla ikonnikovii* are exclusively restricted to the mountains, which form an archipelago-like system of relatively moist habitats surrounded by otherwise semi-arid lowlands. Thus, populations are highly fragmented for mainly climatic reasons. Effects of isolation are central issues in conservation biology (Channell & Lomolino 2000; van Dyke 2003), and especially conservation genetics because of the known general relationship between genetic diversity and reproductive fitness (Frankham 2005; Frankham *et al.* 2002; Reed & Frankham 2003). Unfortunately, no data on this topic were available for any Mongolian mountain plant. Thus, the main focus of our studies was subsequently put on possible effects of isolation on genetic structure, which were anticipated based on the spatial isolation of the respective populations. We took range-wide samples of all occurring populations, and compared genetic structure among the two focus species (plus a closely related species), which occupy similar habitats but differ with respect to their dispersal adaptations. We expected a strong spatial genetic structuring and isolation-by-distance, and tested this assumption using molecular fingerprint methods.

Results and Discussion

Is dormancy common in Central Asian dryland species? (Seed Science Research 2006, 16: 123-136)

Germination is among the most well studied aspects in the (vascular) plant ecology of dry rangelands and deserts. Large screenings revealed an impressive variation of patterns (Baskin & Baskin 2001; Gutterman 1993); which is partly related to the need for germination under suitable conditions that allow for seedling establishment, and in the case of annuals, rapid flowering and fruiting. Unfortunately, most of the available studies are from tropical and subtropical deserts. A number of Russian studies concentrated on relatively moist middle and western steppes (Nikolaeva 2001; Nikolaeva *et al.* 1985), while most data for dry mid-latitude environments come from North American (semi-)deserts and steppes (Baskin & Baskin 2001). Seeds in these seasonal environments should ideally germinate at the beginning of the moist season in early summer or spring, allowing for the maximum possible time available for establishment before the harsh winter comes. Not surprisingly, physiological dormancy is the most frequently found germination strategy in cold North American (semi-)deserts (Baskin & Baskin 1998). Studies on Central Asian plants have only commenced in the last few years following large-scale restoration schemes (e.g. Babaev 1999; Zhang *et al.* 2005). Based on the available information and the highly seasonal Gobi climate we expected to find some kind of physiological dormancy, but also anticipated that short-lived and long-lived plants may differ in their germination strategy.

Unfortunately, seeds are not produced in every year due to climatic constraints, so it took several field periods to assemble a representative sample of 26 species covering all principal growth forms found in the study region. Seeds were collected in the field and tested within four weeks after sampling. Sample sizes were not always sufficient to test a range of temperatures, so we selected a regime that corresponded to *in situ* climatic conditions in early or late summer, and which had also proven suitable in tests with a subset of species (Pietsch 2005; Ronnenberg *et al.* 2007; Ronnenberg & Wesche 2005; Wesche & Undrakh 2003). We directly germinated fresh seeds, but also assessed survival capacity during winter by freeze-drying seeds at -18°C and then repeating the germination experiment.

In contrast to our expectations, seeds of most perennial herbaceous and woody species germinated readily without any sign of deep dormancy, and initial germination was usually above 90%. We did not test for conditional dormancy (*sensu* Baskin & Baskin 2004), i.e. possible changes in the range of suitable germination conditions after some dormancy-breaking treatment, but results nonetheless imply that seeds can germinate directly after dispersal providing suitable conditions are met. This contrasted with the results for the short-lived species, where mean germination of fresh seeds was well below 30%. However, almost all species in the Gobi Altay disperse in late summer or autumn and we hardly ever found seedlings at that time, most likely because temperature requirements were not met. Even non-dormant seeds will thus remain quiescent and forced to survive the winter, and our freezing experiment suggested that they are capable of doing so. Seed viability decreased after freezing, but was still well above 60% in all growth forms. Germination was not affected in the perennial species, but significantly increased in several short-lived species. This was again unexpected, because freezing of dried seeds is not a typical form of stratification though it may affect status of non-deeply dormant seeds (Baskin & Baskin 1998). In any case, germination remained below 50% in most short-lived species, so frost can not be regarded as an effective dormancy-breaking treatment.

These results are important for re-seeding schemes in steppe restoration, but also have some theoretical implications. Results emphasise again that data from North American prairies cannot be directly transferred. In Central Asia, most native species apparently have no pronounced dormancy, and this was also supported by a review of some 25 recent publications on the seed ecology of Central Asian species, which mostly also indicated a lack of deep dormancy. Species follow an opportunistic strategy allowing germination whenever climatic conditions are suitable. Most species disperse in August or later, thus germination is usually delayed for thermal reasons until the following spring, a pattern also found in seasonal grasslands of moister regions (Washitani & Masuda 1990). A lack of control mechanisms implies a risk of losing seeds germinating under unfavourable conditions, but this poses no major problem as the described plants are perennial. In contrast, controls should be more rigorous in annual species, and this is what we found in our data set. The principal exceptions are species that are long-lived and disperse in early summer, such as *Ulmus pumila* and some *Stipa* spp.

Such species also germinate readily and germination may occur directly after dispersal implying a need for rapid establishment. Thus, further ongoing studies largely concentrate on these taxa (see outlook below).

Is clonal growth crucial for persistence of Juniperus sabina *in the harsh environment of the Gobi Altay?*

(Journal of Arid Environments 2005, 63: 390-405)

The prostrate *Juniperus sabina* is restricted to mountain sites over the largest part of its western to central Eurasian range (Meusel *et al.* 1965). It is among the most drought-tolerant junipers (Farjon *et al.* 2001), but populations in the Gobi Altay also represent the most climatically extreme sites in its overall distribution range. This supported the impression of severely reduced sexual recruitment (chapter 3.2).

We randomly selected sampling sites and, apart from the plant community data (chapter 3.3), recorded size and sex of individuals and checked for the presence of seedlings. Cones were subjected to a wide range of germination treatments including various temperature regimes, dry and moist storage, frosting and scarification of the entire cones and of the bare seeds. We also took DNA samples from patches of *J. sabina* and used RAPD-fingerprinting to assess whether these were constituted by several genets or not (see also below). The germination data were compared to germination tests for the apparently more actively recruiting *Artemisia santolinifolia*, which colonises similar sites in the study region.

Even after intensive search, we only found one seedling of *J. sabina* in the field. Adult shrubs nonetheless produced thousands of cones, and thus seeds, though only 30% of those were morphologically intact. Only 3 of the > 2500 morphologically intact seeds tested with different treatments in the lab germinated. This corresponded to a low viability according to TTC-tests (always < 8%), suggesting that sexual reproduction is hardly possible under current climatic conditions. Instead, we found abundant evidence of extensive clonal growth and vegetative persistence. Neighbouring patches tended to be of similar sexes suggesting fragmentation of common genets. Patches were always constituted by a single genet, although they were up to 100 m in diameter. We calculated crude age estimates based on data for its current growth rate (tree ring counts and measurements of tagged shoots) under the assumption of radial growth. These implied that establishment of larger genets occurred between some 800 to 3000 years ago. Since then, plants have apparently survived adverse conditions by prolonged clonal growth. This is the time scale of climate changes in the Holocene, and indeed personal (chapter 3.2) and previously published studies suggest that conditions in the Gobi Altay became drier after 4000 - 3000 BP (Gunin *et al.* 1999; Jäger 2005).

Our results support theoretical considerations concerning the survival of remnant populations under adverse conditions (Eriksson 1996; Garcia & Zamora 2003). Species tend to be long-lived and, over short time-spans, sexual recruitment is much less important than clonal growth. This allows for the survival of unfavourable periods, even on the scale of secular trends in climate, i.e. hundreds or even thousands of years. Similar patterns have been described for other junipers (Gumbatov 2001;

Houle & Babeux 1994), and stands of *Populus diversifolia* in Central Asian oases also apparently survive by extended clonal growth (Bruelheide 2003). More recently, further evidence has implied that extensive clonal growth is also important in other Central Asian perennials (Huang *et al.* 2004; Li & Ge 2001; Liang *et al.* 2002; Song *et al.* 2002). In the short run, clonal growth will tend to stabilise the population and, if the species has keystone characteristics, even entire communities (Eriksson 2000). This is the case in *Juniperus sabina,* which provides safe sites and a reasonably constant environment for a number of associated species. The overwhelming importance of clonal growth is not without its dangers due to the fact that prolonged clonal growth eventually results in the fixation of alleles along with reduced adaptive capabilities (Honnay & Bossyut 2005). Thus, stands of *Juniperus sabina* are probably threatened in the long run; and this is indeed the case when in competition with *Artemisia santolinifolia,* which reseeds much more effectively (Ronnenberg & Wesche 2005) and is already invading juniper stands in the study region.

Are restricted-range species in the Gobi Altay true endemics and possibly threatened? (Mongolian Journal of Biological Sciences 2005, 3: 3-11)

We compared the described results on germination and clonal growth of mainly widespread species against data for the four truly Central Asian species *Papaver saichanense, Saussurea saichanensis, Potentilla ikonnikovii* and *Galitzkya macrocarpa*, which are among Mongolia's few endemic species. So far, the available information on Mongolian endemic plants has been limited to taxonomical and coarse distributional data (Grubov 1982, 1989; Gubanov 1996). We updated information on taxonomical status and overall distribution range for the four mountain endemics occurring in southern Mongolia and surveyed their local distribution by visiting most suitable mountain sites between 2000 and 2006. This allowed for a more comprehensive assessment of their conservation status compared to Mongolia's current Red List (Shiirevdamba *et al.* 1997).

Three of the four assessed species proved to be taxonomically stabilised taxa and true national endemics. *Galitzkya macrocarpa* is one of only three species in that Brassicaceae genus. The other two are distributed in north-western China / south-western Mongolia (*G. potaninii*) and northern Kazakhstan. Thus, in the context of the Gobi Altay, *G. macrocarpa* is one of the few species with mid-Asian rather than east-Asian affinities. This is also reflected in its semi-evergreen habit that hints at adaptations to winter rains as they still occur in Middle Asia. *Potentilla ikonnikovii* is a western species within the largely eastern Asian section *Tanacetifoliae* and thus represents the most common biogeographic element in the Mongolian flora (Dulamsuren *et al.* 2005; Jäger 2005). *Saussurea saichanensis*, in contrast, belongs to the exclusively Central Asian section *Glanduligerae*, with its only closely relative being confined to the Himalayas. Finally, *Papaver saichanense* is just a tentative name within the largely unresolved complex of taxa around *Papaver nudicaule*. Samples from the Gobi Altay may represent a separate taxon, which would then be endemic to Mongolia, but at present the available information is not sufficient to draw any conclusions (P. Hanelt, pers. comm.).

On a local scale, we were able to confirm almost all of the previously known populations

(Grubov 2001; Gubanov 1996), and found several new ones (Fig. 5.4.4). Within our sample, *Papaver saichanense* is the rarest species and is apparently restricted to the eastern Gobi Gurvan Saykhan However, with respect to its unknown taxonomic position, its conservation status can not be assessed. *Saussurea saichanensis* is also rare in the Gobi Altay, as we did not find more than 6 populations, but it also occurs in other regions of Mongolia and is certainly the least threatened of the four species. The two remaining species have their overall centre of distribution in the Gobi Altay, where we found some 10 populations of *Potentilla ikonnikovii* and some 15 sites with *G. macrocarpa*.

All species are restricted to mountain slopes and rocky outcrops above 2000 m asl. Because sites are hardly accessible to livestock, populations should not be overly sensitive to human impact. Therefore, none of the three taxonomically clear species can be presently regarded as vulnerable according to standard IUCN criteria (IUCN 2001, 2005), but overall low numbers of populations and fragmented structure of habitats render *Potentilla ikonnikovii* and *G. macrocarpa* potentially sensitive to environmental changes; and especially so if genetic exchange is found to be hampered by spatial isolation.

Do the small- and large scale genetic structures of Galitzkya macrocarpa *and* G. potaninii *populations provide evidence of clonal growth and effects of isolation? (Annals of Botany 2006, 98: 1025-1034)*

The two Central Asian *Galitzkya* species, *G. macrocarpa* and *G. potaninii*, are restricted to remote and scattered mountain populations; moreover, they are perennials and capable of clonal growth. Their genetic structure had not previously been studied; in fact, our study represented the first analysis into the population genetic structure of any plant growing in the (outer) Mongolian Gobi.

We took tissue samples of all visited *G. macrocarpa* populations in the Gobi Altay, but found only *G. potaninii* in the Transaltay Gobi. Both species grow on scree slopes and upright boulders which are exceedingly difficult to access. Thus, sampling of a sufficient number of plants (≥ 10) was not always possible, as was estimating of population sizes. For *G. macrocarpa*, we were able to map one population on a relatively flat slope, and also took individual tissue samples for analysis of the small-scale genetic structure. We used a standard protocol for RAPD-fingerprints to assess genetic structure. Data analysis included genetic measures but, as their application for dominant markers relies on certain assumptions, we also used simple multivariate statistics.

Our results for *G. macrocarpa* did not provide evidence for a predominant importance of clonal growth, as is described for *Juniperus sabina*. The small-scale mapping revealed that more than three quarters of all shoots represent independent genets. Clones occur, but they usually comprise only two to three shoots and may only extend up to a few metres. Thus, *G. macrocarpa* apparently follows a mixed reproductive strategy in which clonal growth ensures survival during detrimental conditions, but where sexual reproduction is the dominant mode of recruitment. Clonal growth is just one option in its mixed reproduction strategy and this has been described for other alpine perennials before (Jones & Gliddon 1999; Linhart & Gehring 2003; Young *et al.* 2002). High levels of clonal diversity combined with limited clonal growth are also known for the alpine *Geum reptans* (Pluess & Stöcklin 2004) and are expected to facilitate long-term survival in the harsh environment.

The presence of sexual recruitment allows for genetic exchange among populations, and this is reflected in the inter-population genetic structure. A Φ_{ST}-value of 0.251 implies that natural isolation has had an impact on population differentiation, but such a figure is commonly found in perennial species with mixed pollination systems (Nybom 2004; Nybom & Bartish 2000); as is the case for *G. macrocarpa*, where self-pollination is possible (Undrakh unpubl.). Moreover, all populations, including the most remote ones, had similar levels of intra-population diversity, which were not related to habitat size. With respect to the overall structure of the species' range, where populations are separated by up to 275 km of unfavourable habitats the Φ_{ST}-value is not overly high. This is also exemplified by a comparison with the Mongolian populations of *G. potaninii* where a Φ_{ST}-value of 0.550 indicates strong isolation of populations, possibly dating back to glacial times.

Galitzkya macrocarpa appears to be well adapted to maintain its genetic diversity over a strongly fragmented range. Seeds are winged and capable of wind dispersal and germinate readily without any treatment. They contribute to genetic exchange, as pollen flow in this insect-pollinated species should not extend over very large distances. We found some evidence for-isolation-by-distance, but populations still shared most bands. Genetic exchange is apparently possible and should facilitate adaptation to potentially changing environments (Honnay *et al.* 2006). This contrasts with results for *G. potaninii*, where the even stronger topographic isolation among populations around the Dzungarian basin results in apparently strongly reduced genetic exchange and loss of diversity in the most remote population in the Dzungarian Gobi. Here, we may expect remnant population dynamics (Eriksson 1996), implying that these populations should be monitored in order to assess potential threats to survival.

Is there evidence for isolation-by-distance in the isolated populations of Potentilla ikonnikovii*?(Plant Species Biology 2006, 21: 151-163)*

We compared the results obtained for the two *Galitzkya* species with a RAPD-based study on another relatively frequently encountered endemic. *Potentilla ikonnikovii* is exclusively restricted to the Gobi Altay where it occupies similar habitats as *Galitzkya macrocarpa*; and indeed both species often grow together. Most suitable mountain ranges are colonised, though the overall number of populations found is slightly lower at 15, compared to 18 for *G. macrocarpa*. We did not assess the small-scale genetic structure as populations of *P. ikonnikovii* tended to be somewhat smaller and harder to access, and sample sizes were more unbalanced than in the *Galitzkya* species. Thus, we had to change the statistical treatment and included a more thorough analysis of the confounding effects of varying sample size on genetic diversity. We employed a resampling procedure to obtain sound estimates of within-population diversity (Leberg 2002), and also subsampled the data in various ways to test the estimates of interpopulation differentiation.

The 92 specimens represented 86 RAPD phenotypes; implying that populations were again largely constituted by different genets. Still, *P. ikonnikovii* follows a mixed strategy because clones nonetheless occurred; indicating a life strategy similar to the *Galitzkya* spp. discussed above. Estimates of within-population diversity were not influenced by sampling intensity and were of the same moderately high level as those for *G. macrocarpa*. Other aspects of genetic structure were, however, clearly different. Peripheral populations showed a much reduced diversity (< 20% of values for the central populations), and the overall Φ_{ST}-value was high at 0.681, corresponding to the high fraction of variance accounted for by differences among mountain ranges (55%, AMOVA). The Φ_{ST}-value remained well above 0.5, even when the most remote population was excluded. The genetic differences were significantly related to spatial distances according to significant Mantel-Tests, so we found evidence for strong isolation-by-distance in *P. ikonnikovii*.

An estimate of the gene flow in *P. ikonnikovii* yields an $N_e m$ of 0.12, much less than the rule-of-thumb-value (Pearse & Crandall 2004; Wang 2004) of one migrant per generation that is widely considered to maintain sufficient genetic exchange among populations. Lack of current gene flow may relate to the low figures of genetic diversity found for peripheral populations, which may represent isolated outposts of a once more continuous range, but may also result from rare long-distance dispersal events and founder effects. In any case, levels of isolation-by-distance are high, and the species' range can be described as severely fragmented (IUCN 2005). So far, we have no evidence of declining populations, and the species can thus not yet be regarded as vulnerable (IUCN 2001). However, low levels of genetic diversity are likely to affect reproductive fitness in the long run (Reed & Frankham 2003). This may be mediated by the capacity to reproduce clonally (see above), but still a more detailed monitoring on the populations dynamics of *Potentilla ikonnikovii* is recommended.

Conclusions and Outlook

The principal results of the described studies may be summarised as follows:

- Unlike in other steppes, dormancy is not the dominant germination strategy in Central Asia; and it hardly occurs in perennial plants, which constitute most of the vegetation
- Clonal growth is an important mode of persistence in the harsh climate of the Gobi, but the extent of vegetative growth vs. sexual recruitment differs among plants of different biogeographical affinities and growth forms
- The Gobi Altay hosts several mountain endemics which have widely isolated populations, but they are nonetheless somewhat more widely distributed than was previously known
- The pronounced isolation of populations has had limited effects on the genetic structure of the wind-dispersed endemic *Galitzkya macrocarpa*, while spatial genetic structure is much more pronounced in *Potentilla ikonnikovii*, which has no special adaptations to long-distance dispersal
- Wind dispersal is apparently not sufficient enough to maintain genetic exchange in the extremely widely isolated population of *G. potaninii* in the Dzungarian Gobi

The data confirm the special importance of perennial life forms in general, but also some characteristics of Central Asian plants in particular. The number of comparable studies on plant population ecology in the region has increased in the last five years, but there are still vast gaps in the understanding. Based on the described results, we have started several new studies in this rapidly growing field of research. The focus on perennial plants was maintained, but we have now included species that are more common in the zonal vegetation of Central Asian drylands.

Seed ecology is still of major interest, because artificial seeding is of utmost importance in restoration schemes. Much of the ongoing programmes concentrate on pioneer species of early successional regeneration stages (e.g. Fang *et al.* 2006; Li *et al.* 2006a; Li *et al.* 2006b), but once these have been completed, the establishment of true pasture species will become a main focus. For such studies, data from the still relatively intact southern Mongolian rangelands will be of interest. Thus, we are continuing to screen dominant species for germination behaviour and ongoing studies are employing various treatments for temperature, osmotic stress and light regimes (Ronnenberg *et al.* 2007).

We chose two characteristic taxa for detailed research on germination ecology, as well as clonal growth and genetic structure. A study has recently been completed on *Ulmus pumila* (Walther 2006), which is the only tree species indigenous to southern and south-eastern Mongolia. Though rare overall, trees locally build extensive woodlands which serve as habitats for a wide range of organisms. Previous surveys and palynological studies imply a possibly more extensive distribution of that elm in Central Asia (Herzschuh *et al.* 2004; Hilbig 1987, 2000), so we performed a detailed study on its population ecology. *Ulmus pumila* proved capable of germination under a wide range of conditions, and germination was indeed also observed directly in the field. However, mortality of seedlings was apparently near 100% under field conditions (mostly due to climatic constraints and small mammal herbivory), so hardly any seedlings were found. Unlike *Juniperus sabina*, clonal growth is not important; instead trees date back to rare events of cohort establishment under unusually favourable conditions. According to dendrological data, these occur during large intervals lasting decades or centuries. Results are currently prepared for publication, and further logical steps would include assessments on a wider geographical range with the possible goal of identifying suitable accessions and methods for woodland restoration in southern Mongolia and northern China, where elm trees were formerly more widespread (e.g. An *et al.* 2002; Chen *et al.* 2002; Katoh *et al.* 1998; Shi *et al.* 2004).

The third major topic is population ecology of the three feather grasses *Stipa krylovii*, *S. gobica* and *S. glareosa*. They are characteristic taxa of most principal steppe vegetation types in Mongolia, and our sampling thus covers a wide hygric range. Tentative genetic results suggest that clonal growth is not the important mode of recruitment. Instead, the majority of plants in all study regions originated from seedling establishment (Ronnenberg unpubl.). Seed viability however, was often low and apparently related to pollination mode. In dry years, cleistogamy prevailed and this leads to higher levels of seed viability (Ponomarev 1961; Ronnenberg *et al.* 2006). In any case, populations nonetheless maintain some genetic exchange, as Φ_{ST}-values among regions are in the expected order of magnitude for wind-pollinated grasses. These studies will be supplemented by a study on the relevance of animal species for seed dispersal.

Finally, a wider perspective is offered by more detailed comparisons to North America, where several Central Asian plants can grow and even become invasive (Ambrose & Wilson 2003; Grant *et al.* 2003; Heidinga & Wilson 2002). Population ecology of North American populations has been studied in some detail (Bai *et al.* 1995; Hansen & Wilson 2006; Sabo *et al.* 1979), but there are no comparative studies on populations in their native range.

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5.2 Abstracts of corresponding publications: Population ecology of selected plant species

Germination of fresh and frost-treated seeds from dry Central Asian steppes. - *Seed Science Research* 2006, 16: 123 – 136.

[1]K. Wesche, [1]M. Pietsch, [1]K. Ronnenberg, [2]R. Undrakh & [1]I. Hensen*

[1]Institute of Biology - Geobotany and Botanical Garden; Martin-Luther-University Halle-Wittenberg; 06099 Halle; Germany

[2]Faculty of Biology; National University of Mongolia, P.O. Box 377; Ulaanbaatar; Mongolia

[*]Corresponding author: karsten.wesche@botanik.uni-halle.de, Tel. 0049 345 55 26212, Fax 0049 345 55 27228

Abstract

We tested germination of fresh and frost-treated seeds for 26 species of southern Mongolian mountain and desert steppes, covering the major growth forms of woody and herbaceous perennials and short-lived species in the region. In the field, germination depends on rains that are largely restricted to the summer months between June and August. Thus, germination tests were performed at alternating conditions of 10°C in darkness and 20°C in light (12 hrs / 12 hrs), which correspond to temperatures at the study site in early and late summer.

Seeds of both woody and herbaceous perennials germinated well under the chosen conditions and apparently did not require stratification or scarification. In contrast, germination of annual species was mostly below 30%, while seed viability was equally high in all three growth forms. Winter conditions, simulated by freezing dried seeds at -18°C, hardly changed seed germination in the perennial species, but several short-lived species responded with increased germination.

Short-lived species are not abundant in the real vegetation, which is governed by perennials. Thus, we conclude that the important species in Mongolian mountain steppes germinate readily without a dormancy-breaking treatment. A review of the available literature revealed that a complete lack of dormancy or presence of at most conditional dormancy, is also widely described for other species of Central Asian deserts and steppes, which is in contrast to data from North American prairies.

Keywords

China, climate, dormancy, germination, Mongolia, steppe

Lack of sexual reproduction in dry mountain steppe populations of the clonal shrub *Juniperus sabina* L. in southern Mongolia. - *Journal of Arid Environments* 2005, 63: 390-405.

Karsten Wesche[A], Katrin Ronnenberg[B], Isabell Hensen[C]
Inst. of Biology - Geobotany and Botanical Garden, University of Halle
Am Kirchtor 1, 06108 Halle, Germany
[A]corresponding author: karsten.wesche@botanik.uni-halle.de, Tel. 0049 345 55 26212, Fax 0049 345 55 27228
[B]katrin.ronnenberg@botanik.uni-halle.de
[C]isabell.hensen@botanik.uni-halle.de

Abstract

The present study describes the reproductive ecology of the prostrate shrub *Juniperus sabina* in dry mountain steppes of southern Mongolia where stands are located at the drought-limit of the species' distributional range. Even though cones are produced in large numbers, the larger part of those collected for the study had incompletely developed embryos, and only 2.5% were viable. In germination experiments only 3 out of 2100 intact seeds germinated, suggesting that germination would be unlikely under field conditions. Correspondingly, nearly no seedlings or saplings were found in the field.

Ample evidence was found for clonal growth. Patches of similar sexes of *J. sabina* were spatially associated in the field. RAPD-fingerprinting demonstrated that patches were constituted by a single genet. As mean current growth rates were between 1.8 and 6.8 cm/yr, we estimated that the largest patches found in the study area had minimum ages of 770 to 2940 years. Thus, establishment of seedlings may have taken place in periods defined by more favourable climatic conditions, whereas dry phases have apparently been survived by clonal growth. This combination of rare sexual reproduction with extended periods of exclusively vegetative reproduction could be a widespread strategy in the harsh conditions of the Central Asian drylands.

Keywords

clonal growth, juniper, Mongolia, mountain steppes, persistence, reproduction

Status and distribution of four endemic vascular plants in the Gobi Altay. - *Mongolian Journal of Biological Sciences* 2005, 3: 3-11.

by K. Wesche[1], E. J. Jäger[1], H. von Wehrden[1,] R. Undrakh[2]
[1]Institute of Biology - Geobotany and Botanical Garden; Martin-Luther-University Halle-Wittenberg; 06099 Halle; Germany
[2]Faculty of Biology, National University of Mongolia, P.O. Box 377; Ulaanbaatar; Mongolia (†)
Corresponding author: Email karsten.wesche@botanik.uni-halle.de; Tel. 0049 345 55 26212; Fax. 0049 345 55 27228

Abstract

The paper presents distributional data on the four vascular plants *Papaver saichanense*, *Saussurea saichanensis*, *Potentilla ikonnikovii* and *Galitzkya macrocarpa*, all of which are restricted to Mongolian mountains. Updated biogeographical data demonstrate that all four are Mongolian endemics. In terms of their taxonomic relationships, *S. saichanensis* and *P. saichanense* belong to a group of species occurring mainly on continental Asian mountains. *Potentilla ikonnikovii* has relatives with a mainly East-Asian distribution, and the genus *Galitzkya* is a predominantly Mid-Asian element.

New maps of the local distribution in the Gobi Altay and adjacent mountains indicate that all species are highly fragmented and are so far only known to occur in less than a dozen localities. We have since discovered new sites and subsequently have little reason to regard the species as threatened, although the overall rarity suggests that some form of rough monitoring is advisable.

Key words

biogeography, distribution, endemism, flora, Gobi-Altay

Genetic structure of *Galitzkya macrocarpa* and *G. potaninii*, two closely related endemics of Central Asian mountain ranges. - *Annals of Botany* 2006, 98: 1025-1034.

K. Wesche[1], I. Hensen[1], R. Undrakh[2]*

[1]Institute of Biology - Geobotany and Botanical Garden; Martin-Luther-University Halle-Wittenberg; 06099 Halle; Germany

[2]Faculty of Biology; National University of Mongolia, P.O. Box 377; Ulaanbaatar; Mongolia

**corresponding author: karsten.wesche@botanik.uni-halle.de; Tel. 0049 345 55 26212; Fax 0049 345 55 27228*

Abstract

Background and Aims: Habitats in mountains are often isolated. Plants growing in these sites face severe dispersal limitations, but also difficulties for recruitment. The focus was laid on the magnitude of genetic differences among populations but also on the size of potentially occurring clones.

Methods: RAPD fingerprints were obtained from 23 populations in southern Mongolia. Sampling covered the entire distribution range of *G. macrocarpa*; samples of *G. potaninii* represent only the Mongolian part of its mainly northern Chinese range.

Key Results: The Mongolian endemic *G. macrocarpa* showed moderately strong population differentiation (Φ_{ST} = 0.251), and limited evidence for isolation by distance. Local genetic diversity was not positively correlated to habitat size, and not reduced in peripheral populations. Clonal growth is possible, but most plants originate from sexual reproduction. In contrast, populations of *G. potaninii* were highly differentiated (Φ_{ST} = 0.550); and the most remote outposts had reduced genetic diversity. In these areas, isolation is expected to date back to glacial times.

Conclusions: Effects of natural fragmentation differ among species. Both are rare, but *G. macrocarpa* appears to be able to maintain genetic diversity over its range. Clonal growth is an option in its mixed reproduction strategy and allows survival under harsh conditions. In contrast, genetic structure in *G. potaninii* gives reason for concerns, and further studies on population dynamics are needed.

Keywords

conservation, clonal growth, fragmentation, endemics, genetic diversity, isolation, Mongolia, mountains

Range-wide genetic analysis provides evidence for natural isolation among populations of the Central Asian endemic *Potentilla ikonnikovii* Juz. (Rosaceae). – *Plant Species Biology* 2006, 21: 155-163.

K. Wesche[1], I. Hensen[1], R. Undrakh[2]*

[1]Institute of Biology - Geobotany and Botanical Garden; Martin-Luther-University Halle-Wittenberg; 06099 Halle; Germany

[2]Faculty of Biology; National University of Mongolia, P.O. Box 377; Ulaanbaatar; Mongolia

[*]Corresponding author: karsten.wesche@botanik.uni-halle.de, Tel. 0049 345 55 26212, Fax 0049 345 55 27228

Abstract

Isolated populations are likely to experience a loss of genetic diversity due to reduced gene flow, and effects of habitat fragmentation are therefore central issues in conservation genetics. Here, we present data on genetic diversity and isolation-by-distance for the rare Central Asian plant *Potentilla ikonnikovii* (Rosaceae), which occurs in naturally fragmented populations. Sampling covered the entire distributional range of this endemic of southern Mongolia, where the species is restricted to archipelago-like mountain systems which emerge from the semi-desert lowlands of the Gobi region. RAPD-analyses revealed modest levels of genetic diversity at both the population and species level. The Φ_{ST} of 0.68 indicates that isolation has strong effects on population genetic structure; most variance is kept among populations rather than within, and the two most remote populations were genetically distinct. Mantel-statistics showed that genetic distance was highly correlated to spatial distance ($R_M > 0.6$). We conclude that the populations of *P. ikonnikovii* are severely isolated in terms of genetic structure. This may lead to reduced fitness, so a crude monitoring scheme is recommended.

Keywords

conservation; endemics; isolation; Mongolia; RAPD-analysis

6 Short summary of the entire thesis

The thesis describes a set of studies performed in the Gobi Gurvan Saykhan National Park in southern Mongolia between 2000 and 2005. Research addressed three main groups of topics, namely the composition, distribution and history of vegetation patterns; interactions of plants with domestic livestock and small mammals; and the population ecology of selected plant species.

We described some 50 plant communities that show a clear altitudinal zonation. The most valued pastures are found in the mountains and their surroundings, where mountain steppes and montane desert steppes prevail. Mapping of plant communities with the aid of Landsat-imagery proved feasible, and confirmed the inferred spatial patterns. Moreover, a multi-proxy paleoecological study showed that the vegetation belts have essentially been similar over the last 3000 years, but before 4000 BP forests including conifers were apparently much more widespread in the Altay and even occurred in the mountains of the study region.

The Gobi Gurvan Saykhan offered ideal conditions to study the effects of livestock and small mammals in a semi-arid environment, where conditions should largely be controlled by water availability. Transect studies following long established grazing gradients along with 6 years of experimental grazing exclusion showed that grazing has only limited effects on plant community composition. Instead, interannual changes in precipitation levels strongly affect plant biomass production and flowering, and varying fodder availability results in changes in the herbivore populations. They recover more slowly after a drought than plants and their impact remains relatively low on average. However, fossorial rodents alter site conditions and have lasting effects as ecosystem engineers, which are mainly related to enhanced soil nutrient conditions and not to water availability. Experimental fertilisation also demonstrated that plant performance suffers from nutrient limitations, even under dry climatic conditions. Livestock removing more nutrients may point to a largely overlooked pathway of pasture degradation.

Relatively stable species composition in plant communities is related to the predominance of perennial species. Longevity has a number of advantages in a harsh semi-arid environment like this. Recruitment from seeds is delayed over several years and decades and indeed perennials showed no indication of dormancy that would delay germination until a more favourable season occurs. Instead, seeds germinate whenever germination conditions are met, and successful recruitment depends on the rare occasions when conditions happen to be suitable for both germination and establishment. Most perennials proved capable of surviving less favourable conditions by clonal growth, and the prostrate *Juniperus sabina* may have done so over Millennia. Instead, several mountain endemics showed small-scale clonal diversity indicating that reseeding is at least occasionally successful. This allows gene flow among highly isolated populations, which depends on dispersal capabilities. However, none of the four endemics assessed seem threatened at the moment. Overall, species of dry Mongolian steppes seem well adapted to the harsh conditions, explaining why vegetation and land use patterns have remained largely stable in this variable and intensively used environment.

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- this is for the three of them -

Appendix: Theses compiled in the Gobi Gurvan Saykhan Research Project (as of summer 2007)

Type	Author	University	Title
Ph.D.	Vroni Retzer	Marburg	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 (December 2003)
	Karin Nadrowski	Marburg	Life history strategy and forage of a dominant small mammal herbivore in a dry steppe (June 2006)
	R. Undrakh	Ulaan Baatar	Population biology of rare and endemic vascular plant species of southern Mongolian mountain steppes (the papers have been published but the promotion could not be finished due to the unexpected and tragic death of Undrakh in 2004)
	Henrik von Wehrden	Halle/Marburg	Composition and spatial distribution of plant communities in southern Mongolian nature reserves (2004 to 2008)
	Katrin Ronnenberg	Halle	Reproduction of widespread *Stipa*-species of Central Asian steppes and semi-deserts (2004 – 2008)
MSc	T. Monkhzuul	Ulaan Baatar	Behaviour of *Ochotona pallasi* in the Gobi Gurvan Sayhan National Protected Park (2003, in Mongolian)
	T. Bolortuya	Ulaan Baatar	Taxanomy and ecology of soil microarthropods of the Mountain Gobi Gurvan Saykhan (2003, in Mongolian)
	J. Cermak	London	Isolated birch forests in southern Mongolia and nomads: A case study for biodiversity conservation (2002, in English)
	C. Oyundari	Ulaan Baatar	Facilitation in southern Mongolian desert steppes: Is *Caragana leucophloea* a nurse plant? (2005 until 2007)
	T. Tsolmon	Ulaan Baatar	Classification of plant communities of the Bordzongijn Gobi, southeastern Mongolia (2005 - 2006)
Diploma	Julia Bergius	Marburg	Untersuchungen zu Klimaschwankungen in der Mongolischen Südgobi (2002, in German)
	Henrik von Wehrden	Marburg	Vegetationskartierung in zentralasiatischen Trockengebieten mittels LANDSAT 7 ETM als Grundlage für Naturschutz und Ressourcenmanagement am Bsp. des Gobi Gurvan Sayhan Nationalparks, Süd-Gobi, Mongolei (2003, in German)
	Lars Opgenoorth	Marburg	Ökologische Untersuchungen an Birken – Weiden – Wald Relikten des Gobi Altai. Eine dendroökologische Studie (2003, in German)
	Katrin Ronnenberg	Halle	Vergleichende populationsbiologische Studien zu *Juniperus sabina* L. und *Artemisia santolinifolia* Turcz. ex Bess. in Gebirgssteppen der südöstlichen Mongolei (2004, in German)
	Matthias Pietsch	Halle	Populationsbiologische Untersuchungen dominanter Schlüsselarten der trockenen Gebirgssteppe des Gobi Altais (Mongolei) (2005, in German)
	Denny Walther	Halle	Populationsbiologische Untersuchungen an *Ulmus pumila* L. in Wald- und Wüstensteppen der Mongolei (2006, in German)
	Christine Blaess	Halle	Der Einfluss von Weidegängern und Kleinsäugern auf die Ausbreitungs- und Keimungsbiologie charakteristischer Arten der süd-mongolischen Gebirgssteppen (2006 - 2007, in German)
	Steffen Heinrich	Halle	Vergleichende Untersuchungen zur genetischen Struktur von *Juniperus sabina* in Mitteleuropa und Zentralasien mit Hilfe von RAPD und Mikro-Satelliten Markern (2006 – 2007, in German)
State exam	Markus Stumpp	Marburg	Vegetationskundliche Transektuntersuchungen zur Weidedegradation in Gebirgssteppen der Süd-Mongolei (2002, in German)
BSc	T. Bolortuya	Ulaan Baatar	Arthropods of the Dzuun Sayhan, eastern Gobi Altay (2002, in Mongolian)
	S. Lhagvasuren	Ulaan Baatar	Small mammals of the Dzuun Sayhan, eastern Gobi Altay (2002, in Mongolian)
	T. Amarjargal	Ulaan Baatar	Selective grazing of pika (*Ochotona pallasi*) in dry mountain steppes of southern Mongolia (2003, in Mongolian)
	D. Enkhjargal	Ulaan Baatar	Differences in vegetation of small mammal burrows (*Ochotona pallasi*) and the surrounding steppe in the Gobi Altay (2003, in Mongolian)
	T. Tsolmon	Ulaan Baatar	Mapping the vegetation of the Transaltay Gobi (2004, in Mongolian)
	C. Oyundari		Flora of the Dund Saykhan (2004, in Mongolian)
	B. Turmandakh	Ulaan Baatar	Relative importance of above- vs. below-ground plant biomass along an altitudinal transect in the Gobi Altay (2006-2007)

Plus additional small research projects by students Tuvshin, Munktur, Zhadaambaa, Bläß, Walther, Beckmann

List of publications and conference contributions by the Gobi Gurvan Saykhan Research Project (as of summer 2007)

Publications

Retzer V. & Nadrowski K. (2002) Livestock and small mammal grazing in the mountain steppe of Gobi Gurvan Saikhan National Park, Mongolia. In: T. Chuluun & D. Ojima (eds.) *Fundamental issues affecting sustainability of the Mongolian steppe*. IISCN, Ulanbataar, Mongolia, pp. 192-197.

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Retzer V. & Reudenbach C. (2005) Modelling the carrying capacity and coexistence of pika and livestock in the mountain steppe of the South Gobi, Mongolia. *Ecological Modelling* **189**: 89-104.

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von Wehrden H. & Wesche K. (2005) Mapping the vegetation of southern Mongolian protected areas: an application of GIS and remote sensing techniques. In: C. Dorjsuren, N. I. Dorofeyuk, P. D. Gunin, Y. I. Drobyshev, S. N. Bazha & L. F. Vasilieva (eds.) *Ecosystems of Mongolia and frontier areas of adjacent countries: natural resources, biodiversity and ecological prospects: Proceedings of the International Conference*. Publishing House "Bembi San", Ulaanbaatar, pp. 232-234.

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Bolortuja T. & Bayartogtokh B. (2005) Ecology of soil microarthropods in Gobi Gurvan Saykhan mountains, southern Mongolia. *Erforschung Biologischer Ressourcen der Mongolei* **9**:53-58.

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V. Retzer. Facts from a year of drought: forage competition between livestock and the Mongolian Pika (*Ochotona pallasi*) and its effects on livestock densities and body condition. *Erforschung Biologischer Ressourcen der Mongolei* **9**:147-161.

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Wesche, K., Nadrowski, K., Retzer, V. & Miehe, G. (2001) Untersuchungen in Gebirgssteppen-Biozönosen des südlichen Gobi Altai. Oral presentation on the M*eeting of the German Society for Geography*, Leipzig.

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Wesche, K. & Undrakh, R. (2003) The population ecology of *Potentilla ikonnikovii*, an endemic plant species of the Gobi Altai. Poster at the *33rd Annual Meeting German Ecological Society* (eds. J. Stadler, I. Hensen, S. Klotz & H. Feldmann), *Verhandlungen der Gesellschaft für Ökologie* Band **33**: 357. Halle.

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Wesche, K. (2003) Die Halbwüsten der südlichen Mongolei – Vegetation unter Wassermangel und Weideeinfluss. Invited talk FB Biologie, Marburg.

Cermak, J., Opgenoorth, L. & Miehe, G. (2004) Isolated birch-willow forests in the Gobi Gurvan Saikhan National Park. Oral presentation at the international workshop "*Ecosystem research in the arid environments of Central Asia*: Results, challenges, perspectives", Ulaanbaatar.

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Retzer V. (2004) Forage competition between livestock and the Mongolian Pika (*Ochotona pallasi*) in the mountain steppes of the South-Gobi. Oral presentation at the international workshop "*Ecosystem research in the arid environments of Central Asia*: Results, challenges, perspectives", Ulaanbaatar.

Reudenbach C. & Retzer V. (2004) Modelling pika and livestock carrying capacity South-Gobi, Mongolia. Oral presentation at the international workshop "*Ecosystem research in the arid environments of Central Asia*: Results, challenges, perspectives", Ulaanbaatar.

Retzer. V. & Reudenbach, C. (2004) Competition, long-term coexistence, and carrying capacity of small mammals and livestock, South-Gobi, Mongolia. Talk at the *34rd Annual Meeting German Ecological Society*, *Verhandlungen der Gesellschaft für Ökologie* Band **34**: Giessen.

Wesche, K. (2004) Das Gobi Gurvan Sayhan Research Project: Beweidungs- und Populationsbiologische Untersuchungen in der südlichen Mongolei. Invited talk at the international expert meeting "*Deutsch-mongolische Zusammenarbeit in der Erforschung der biologischen Vielfalt in der Mongolei*", Internationale Naturschutzakademie, Vilm.

von Wehrden, H., Wesche, K. (2005) Phytosociological data as ground truth for vegetation mapping in southern Mongolia. Oral presentation at the "*Workshop Vegetationsdatenbanken*", Halle.

Wesche, K. (2004) Die Steppen der südlichen Mongolei: Degradierte Kulturlandschaften oder klimatisch bedingte Halbwüsten? Invited talk Regensburger Botanische Gesellschaft, Regensburg.

Miehe, G. (2005) Das Erbe der Steppenvölker Asiens": "Leben und Überleben in kalten Wüsten: Beweidungsbiologische Untersuchungen in der Gobi". Invited talk for an international symposium organised by Deutsche Forschungsgemeinschaft & Kunst- und Ausstellungshalle der Bundesrepublik Deutschland, Bonn.

Wesche, K. (2005) The Gobi Gurvan Saykhan Research Project: Vegetation change in heavily grazed desert steppes of southern Mongolia. Invited talk at the "*2nd Mongolian-German Expert Meeting on steppe ecology*", Ulaanbaatar.

Wesche, K., Schlütz, F., Jäger, E. (2005) How widespread were forests in Central Asia during the Holocene? Evidence from Biogeography, Palynology and Vegetation Science. Oral presentation at the "*Tibet Workshop 2005*", Marburg.

Ronnenberg, K., Wesche, K., Hensen, I. (2005) Reproductive ecology of *Juniperus sabina* – a keystone species in the mountain ranges of southern Mongolia (oral presentation). In: *Progress in plant population biology: contributions to the 18th Annual Conference of the Ecological Society of Germany, Switzerland and Austria, Section Plant Population Biology*, Potsdam, May 2005, S. 50.

Wesche, K. (2005) Überleben von Pflanzenarten in fragmentierten Gebirgssteppen der südlichen Mongolei. Oral presentation at the meeting of the "*AK Biogeographie*", Marburg.

von Wehrden, H., Wesche, K. (2005) Conservation of *Equus hemionus hemionus* in southern Mongolia: A GIS-based approach. Oral presentation at the international "*Asiatic Wild Ass Conference*", Ulaanbaatar.

Wesche, K. (2005) Enclosure studies indicate non-equilibrium dynamics in southern Mongolian rangelands. Oral presentation at the International conference "*Ecosystems of Mongolia and frontier areas of adjacent countries: natural resources, biodiversity and ecological prospects*", Ulaanbaatar.

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Mongolia and frontier areas of adjacent countries: natural resources, biodiversity and ecological prospects", Ulaanbaatar.

Retzer, V. & Reudenbach, C. (2005) Modelling long-term livestock carrying capacity in the South-Gobi, Mongolia. Oral presentation at the International conference "*Ecosystems of Mongolia and frontier areas of adjacent countries: natural resources, biodiversity and ecological prospects*", Ulaanbaatar.

Wesche, K., Retzer, V. (2005) Spatial and temporal changes of community composition indicate non-equilibrium dynamics in southern Mongolian desert steppes (oral presentation). In: *Landscapes, ecosystems and population dynamics, functions and conservation: abstracts of the lectures and posters presented at the 35th Annual Conference of the Ecological Society* in Regensburg, September 19.-23.2005. *Verhandlungen der Gesellschaft für Ökologie* **35**, S. 254.

von Wehrden, H., Tsolmon, A., Zimmermann, H., Tuvshin T. (2005) Short summary of our fieldwork undertaken during summer 2005. Oral presentation at the State University of Ulaanbataar.

von Wehrden, H., Wesche, K. (2006) El sur de Mongolia – una corta introducción. Oral presentation at a the University of Cordoba, Argentinien, 23.2.2006.

Ronnenberg K., Wesche K. & Hensen I. (2006) Effects of different annual precipitation levels on seed viability of two *Stipa*-species of southern Mongolia (poster). In: A. Erfmeier, I. Hensen, D. Prati, H. Auge & W. Durka (eds.) *19th annual conference of the section plant population biology of the ecological society of Germany, Switzerland and Austria* (24 -27 May 2006). Abstracts. Centre for Environmental Research, Martin-Luther-University Halle Wittenberg, Halle, pp. 85.

von Wehrden H., Wesche K. (2006) Khulan protection in southern Mongolia – understanding and mapping of a desert habitat. Invited talk at the Research Institute of Wildlife Ecology, University of Veterinary Medicine, Vienna, Austria.

Retzer V. & Reudenbach, C. (2006): Modelling long-term livestock carrying capacity in the South-Gobi, Mongolia. Talk at the workshop "*Wüstenränder multidimensional*". Bayreuth, 13.-14.01.2006.

von Wehrden, H , Wesche, K., Kaczensky, P., Walzer, C. (2006) Habitat mapping of the Asiatic Wild Ass (*Equus hemionus*) in southern Mongolia. Poster at the *2nd International Conference on Land cover /Land use study using Remote Sensing and Geographic Information System and GOFC-GOLD regional capacity building meeting in Mongolia* (8-9th June 2006)

von Wehrden, H. Tsolmon, A. (2006) Vegetation mapping of the 'Great Gobi A' strictly protected area. Paper for the conference volume of the 2nd International Conference on *Land cover / Land use study using Remote Sensing and Geographic Information System and GOFC-GOLD regional capacity building meeting in Mongolia* (8-9th June 2006)

Wesche, K. (2006) Wüstensteppen in der Süd-Mongolei: (Über-)Lebensstrategien von Pflanzen bei Kälte, Trockenheit und Beweidung. Invited talk Inst. of Geography, Univ. Bayreuth, 27.7.2006.

Wesche, K. (2006) The relation between grazing and plant species diversity in southern Mongolian desert steppes. Invited talk at the Sino-German workshop *Biodiversity and its role on ecosystem functioning*, Urumqi 3.-10.10.2006.

Wesche, K. (2006) Ökologie Mongolischer Trockengebiete – Kenntnisstand und Kenntnislücken. Invited talk at the *DFG-Rundgespräch Trockengebiete*, Bergisch-Gladbach (30.-31.10.2006).

Wesche, K. (2006) Das Gobi Gurvan Saykhan Research Project - Aktivitäten und Perspektiven. Talk at the *III. German-Mongolian Expert Meeting for Biological Research in arid regions of Mongolia*, Berlin, 20.11.2006.

Retzer, V., Reudenbach, C., Wesche, K. 2006. Pastorale Tragfähigkeitsmodellierung in Steppenökosystemen – eine Fallstudie in der südlichen Mongolei Vortrag - Biologisches Kolloquium am Biozentrum Klein Flottbek, Uni Hamburg, Hamburg (06.12.2006).

Bläß, C., Ronnenberg, K., Wesche, K. 2006. Exozoochorous seed dispersal: Seed retention under experimental and natural conditions in Mongolian steppes. Poster on the 5th International Scientific-Practical Conference. Problems of Botany of South Siberia and Mongolia. Barnaul, pp. 329-331.

Ronnenberg, K., Wesche, K. 2006. The effects of NPK-fertilization and irrigation on *Stipa krylovii* and *Stipa gobica* in southern Mongolian desert steppes. Poster on the 5th International Scientific-Practical Conference. Problems of Botany of South Siberia and Mongolia. Barnaul, pp. 332-333.

Nadrowski, K. Life history and ecosystem impact of the Mongolian pika (*Ochotona pallasi pricei*) in a mountain steppe, Mongolia. Talk at the 99.annual meeting of the German Zoological Society, 2006, Münster.

Wesche, K., Ronnenberg, K., von Wehrden H. 2007. Ecology of Central Asian desert steppes - Where do we stand? Vortrag auf der Sitzung des AK Wüstenökologie, Leipzig (23.3.2007).

Ronnenberg, K., Wesche K., Hensen, I. 2007. Experimental evidence for nutrient limitation in growth and reproduction of *Stipa*-species from dry southern Mongolian steppes (Oral presentation). In: U. Becker, T. Becker, R. Brandl, B. Ziegenhagen (Eds.). Proceedings of the GfÖ 37: Abstracts of talks and posters presented at the 37th Annual Conference of the Ecological Society of Germany, Austria and Switzerland in Marburg, Germany, September 10-14, 2007, p. 293.

Bläß, C., Ronnenberg, K., Tackenberg, O. Wesche K., Hensen, I. 2007. Relative importance of zoochory vs. anemo- and hydrochory for seed dispersal in Mongolia (Poster). In: U. Becker, T. Becker, R. Brandl, B. Ziegenhagen (Eds.). Proceedings of the GfÖ 37: Abstracts of talks and posters presented at the 37th Annual Conference of the Ecological Society of Germany, Austria and Switzerland in Marburg, Germany, September 10-14, 2007, p. 474.

von Wehrden, H., Zimmermann, H., Ronnenberg K., Hanspach, J. Wesche K. 2007. Predicting the occurrence of plant species and communities in an arid southern Mongolian mountain range (Poster). In: U. Becker, T. Becker, R. Brandl, B. Ziegenhagen (Eds.). Proceedings of the GfÖ 37: Abstracts of talks and posters presented at the 37th Annual Conference of the Ecological Society of Germany, Austria and Switzerland in Marburg, Germany, September 10-14, 2007, p. 172.

von Wehrden, H. (2007) Posibles aplicaciones de la geografía a la conservación: introducción y ejemplos de proyectos en Mongolia y en las islas Canarias. Talk at the University of Córdoba, Argentina (9.4.07).

Hanspach, J., Zimmermann, Z., Ronnenberg, K. & von Wehrden, H. (2007) Predicting plant species and communities in a southern Mongolian mountain range. Talk at the conference "Vegetationsaufnahme und Florenkartierung - neue Perspektiven, gemeinsame Wege." Bonn, 28.2.-2.3.2007.

Nadrowski, K., Ferreri, M., Schultheiß, R. 2007. Behaviour, habitat and genes – the Mongolian Pika in the Gobi Altai. Talk at the Annual Meeting of Deutsche Zoologische Gesellschaft (DZG), Köln.

Nadrowski, K. What -- if anything -- is a burrowing pika? Evolution of life history strategies in pikas. Talk at the Evolutionary Biology Meeting, 2007, Bayreuth

Funding organised by K. Wesche for the Gobi Gurvan Saykhan Research Project (as of summer 2007)

Summer 2000 - 2004

- together with Prof. Dr. G. Miehe, Univ. Marburg: DFG project "Tier- und weideökologische Untersuchungen zur Tragfähigkeit von Gebirgssteppen-Biozönosen (südlicher Gobi Altai, Mongolei) im Transformationsprozess nomadischer Viehhaltung" (PhD students Karin Nadrowski, Vroni Retzer, plus one post doc for one year).
- accompanied by a grant from the BMZ, application together with Prof. Dr. R. Samyaa, Univ. Ulaan Baatar (Mongolian PhD R. Undrakh, 1 MSc student)
  These parts of the project terminated in autumn 2004

2001

- Short-term contract as a consultant for the gtz, topic: compilation of a vegetation map for the Gobi Gurvan Saykhan National Park

2002

- together with Prof. Dr. I. Hensen, Univ. Halle: travel grants by the DAAD supporting a student excursion to Mongolia
- Organisation of stay of three months for PhD student R. Undrakh in Halle, financed by the DAAD

2003

- Grant by the A.F.W. Schimper foundation to perform fieldwork in Mongolia

2004

- Organisation of the international workshop "Ecosystem research in the arid environments of Central Asia: Results, challenges and perspectives" in Ulaan Baatar (together with Prof. Dr. G. Miehe, Prof. Dr. R. Samyaa); financed by the DFG
- Organisation and supervision of the DAAD-supported fieldwork for PhD student K. Ronnenberg (together with Prof. Dr. I Hensen) on "Population ecology of Mongolian feather grasses (*Stipa* spp.)", further fieldtrips 2005, 2006 (see DFG-grant below)
- Organisation and supervision of the DAAD-supported fieldwork for PhD student H. von Wehrden (together with Prof. Dr. I Hensen) on "Mapping of habitats for the endangered Khulan (*Equus hemionus hemionus*)", further fieldtrip 2005 (see FWF grant below)

from autumn 2004 onwards

- Supervision of the DFG project "Reproduction ecology of widespread feather grasses (*Stipa* spp.) of Central Asian steppes and semi-deserts" (together with I. Hensen). PhD student K. Ronnenberg, duration until 2007

from autumn 2005 onwards

- together with Dr. C. Walzer and Dr. P. Kaczensky (Univ. Wien) grant by the Austrian "Fonds zur Förderung der wissenschaftlichen Forschung (FWF)": "Landscape level research for the conservation of Asiatic wild ass in Mongolia"; responsible for the module on habitat mapping. PhD student H. von Wehrden, duration until 2008.

in review

- Mongolian-German research network "Ecology of forest steppes, grass steppes and semi-deserts in Mongolia"; two international expert meetings have already taken place, financial support is currently decided on by the BMZ in cooperation with the Mongolian government (together with Dr. I. Stürmer, Göttingen; Prof. Dr. R. Samjaa, Ulaan Baatar)

Curriculum Vitae Karsten Wesche

Personal data

Born:	26.01.1970, in Lüchow / Lower Saxony, Germany
Marital status:	unmarried, 2 children
Nationality:	German
Address - office:	Institute of Biology - Geobotany and Botanical Garden; Martin-Luther-University Halle-Wittenberg; Am Kirchtor 1; D 06108 Halle (Saale); Germany, Tel. 0049 345 55 26212; Fax. 0049 345 55 27228; Email karsten.wesche@botanik.uni-halle.de
Address – private:	Graefestr. 17; 06110 Halle; Germany, Tel. 0049 345 2098996

Education

Mai 1989	Abitur (A-level)
June 1989- Oct. ’90	Social services
from Oct. 1990	University studies – biology & soil science; University of Marburg/Germany; 1 semester Univ. of Aberdeen
April 1996	Diploma thesis "*Structure and use of a Sal- (*Shorea robusta*) forest in southern Nepal*"

Working experience

Sep.’96-Jan 2000	Ph.D. thesis, Univ. of Marburg: *"The high-altitude environment of Mt. Elgon (Uganda/Kenya). Climate, vegetation and the impact of fire"*
since June 2000	Postdoctoral researcher / lecturer at the Institute of Geobotany and Botanical Garden, Univ. of Halle-Wittenberg

Research field trips after the Ph.D. thesis

2000	Fieldwork in Ethiopia and southern Mongolia
2001	Addis Ababa, south-eastern Spain, southern Mongolia
2002	Southern Mongolia, Mt. Elgon (Uganda)
2003	Southern and western Mongolia, Bolivia
2004	Bale Mts. (Ethiopia), southern and western Mongolia
2005	Bale Mts. (Ethiopia), central and southern Mongolia
2006	Bale Mts. (Ethiopia), central Kenyan mountains, southern Mongolia, Tien Shan

Activities as editor, reviewer

- Member of the editorial board of *FLORA* (since Jan. 2004)
- Member of the editorial board of *"Exploration into the Biological Resources of Mongolia*"
- Member of the editorial board of "*Mongolian Journal of Biological Sciences*"
- Regular reviews for: *Mountain Research and Development*, *Plant Ecology*, *Journal of Arid Environments*, *Basic and Applied Ecology*, *Basic and Applied Dryland Research*, *Arid Land Research and Management*, *Journal of Vegetation Science*, *Applied Vegetation Science*, *Folia Geobotanica*, *Candollea*

Membership in scientific societies

- Ecological Society of Germany, Austria and Switzerland

- Society for Tropical Ecology, Germany
- International Association for Vegetation Science (IAVS)
- INTECOL
- Floristisch-Soziologische Arbeitsgemeinschaft
- Reinhold-Tüxen-Gesellschaft
- Arbeitsgemeinschaft Geobotanik in Schleswig-Holstein und Hamburg

Principal research interests

- Community- and population ecology of keystone species of southern Mongolian steppes
- Ecology of the tropical treeline ecotone
- Conservation biology of rare plant species in Central Europe
- Analysis of vegetation data by means of multivariate statistics

Signature:

(Karsten Wesche)

Karsten Wesche
Gräfestr. 17
06110 Halle
Tel. 0049 345 2098996

Erklärung zur vorgelegten schriftlichen Leistung

Hiermit erkläre ich an Eides statt,

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