From vegetation relevés to applied modelling of plant biodiversity, productivity and wild equid habitats in southern Mongolia – and beyond

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Gutachterinnen und Gutachter
1. PD Dr. Karsten Wesche
2. Prof. Dr. Helge Bruelheide
3. Prof. Dr. Milan Chytrý
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It was started out
as a small book.
Probably about,
oh, … pages.
It had gotten
a little larger in scope.
And the ending,
it kept getting further away.
But the ending was there.
I knew it.
I could almost see it.

Michael Douglas as Grady Tripp in the movie version of Michael Chabon's "Wonder Boys"

Contents

Extended summary

The overall framework of this dissertation was to describe the vegetation of the southern Mongolian Gobi, and to model the relations between plant biodiversity, precipitation and productivity. Based on the relevé data, vegetation maps of all protected areas were processed, which were used as a basis for habitat analysis for the Gobi`s two equid species. Furthermore a thorough analysis of the precipitation variability was performed on a scale of 1) Arid Central Asia based on climate data and 2) on a global scale, where climate data was combined with a literature review. The publications are sorted into five chapters and an appendix.

Within the first chapter vegetation descriptions of the southern Mongolian Gobi are given. Based on some 1418 relevés in total, the syntaxonomic system was amended and partly changed, yet most already existing proposals were confirmed. Vegetation checks were made based on a Braun-Blanquet approach, with standard environmental parameters sampled along in the field. For two subregions more detailed vegetation descriptions were derived, which are based on a sub-selection of the total dataset. The syntaxonomic descriptions were amended by interpretations of the environmental background, which aided a differentiation of the different syntaxonomic units. The riparian vegetation contrasts zonal stands due to the high productivity of the often salt adapted vegetation. Regarding the zonal vegetation an altitudinal zonation of the vegetation was diagnosed within all regions, which reflects a species gradient. A comparably low number of species dominates the vegetation in the semi-deserts and deserts found at a lower altitude above sea level, while a high number of species is widely restricted to the montane environments.

Due to the large area (>200000 km^2) covered by the syntaxonomic overview from chapter 1, the sampling density in the montane sites was sufficient on the given scale, yet a finer sampling was attempted as a basis for chapter 2, in order to gain better insight into the ecosystem which hosts the highest biodiversity. Based on a randomized design 100 plots were placed in the highest peak region of the Dund Saykhan Mountain, which is part of the Gobi Gurvan Saykhan. The region is known for its comparably high plant biodiversity, and many plants are restricted to these mountains within the Gobi region, including several endemics. At first a vegetation description based on the relevés set was made, which offered a finer syntaxonomic system compared the overview given in chapter 1, and amended the descriptions given in previous publications. The higher *Festuca valesiaca* steppes were split into two units, one growing on rocky sites supporting a higher set of species, while the other occurs on lower and gentler slopes, and thus host a lower number of species. The moistest

northern slopes are covered by *Kobresia* mats, which were clarified regarding their syntaxonomic placement in a wider geographical context.

A clear altitudinal gradient was identified by the second paper given in this chapter, which is in line with results from the first chapter on a coarse and medium scale. The main focus in this study was to model all abundant plant species (n=52) and communities (n=5) based on spatial predictors derived from digital elevation models and Landsat transformations. Using logistic regressions the probability of occurrence was modelled, which was validated by AUC values. Significant models were build for about half of the species. Altitude proved as the most valid predictor for the individual species, yet Landsat data contributed also to numerous valid models. Tasseled cap transformations, which compensate for soil parameters, proved as useful remotely sensed predictors, since the vegetation signal is rather low within this arid environment. Thus distribution maps of half of the species could be derived for the working area.

Since rare species were not included in this approach, information on the ecology and distribution of four endemics (*Papaver saichanense*, *Saussurea saichanensis*, *Potentilla ikonnikovii* and *Galitzkya macrocarpa*) of the Gobi Gurvan Saykhan was derived in the sixth paper. While *S. saichanensis* and *P. saichanense* mainly occur on continental Asian mountains. *Potentilla ikonnikovii* has relatives with a mainly East-Asian distribution, and the genus *Galitzkya* is a mainly a Mid-Asian element. Distribution of all species was found to be highly fragmented, yet they are probably not endangered.

Within the third chapter the vegetation mapping procedure, biodiversity modelling and productivity gradients were examined. Landsat based vegetation mapping performed within the framework of this dissertation is exemplary shown for the driest part of the southern Mongolian Gobi, the Great Gobi A strictly protected area, in the seventh paper. Nine habitat types were mapped based on the relevé set described in chapter 1. Overall accuracy of the final map was > 90%; accuracy was higher in the more uniform semi-deserts compared to the more heterogeneous montane sites. In addition further GIS and remote sensing data was discussed in this chapter, which was used in the second part of this chapter (paper 8) to derive spatial information on net primary productivity and precipitation for the southern Mongolian Gobi. Furthermore these datasets were related to data obtained from the set of 1418 vegetation relevés described in chapter one. Principal plant diversity gradients were examined based on altitude, precipitation and productivity data (based on GLOPEM data), and the plant composition of the zonal vegetation was correlated with key environmental parameters. Correlation of plant biodiversity with all environmental predictors was fairly high, with

$r^2 = 0.57$ in a multiple regression, which included a quadratic term for longitude, since a reversed unimodal west-east climatic gradient determines the southern Mongolian Gobi; altitude, precipitation and productivity were partly redundant, yet differences were high enough to justify all three predictors in a multiple regression. The variance of the net primary production related to the average annual precipitation; at sites with more than ~220 mm/a precipitation the median coefficient of variation in productivity data gradually decreased, which indicated a rather gradual shift from a non-equilibrium ecosystem towards an equilibrium ecosystem with increasing moisture. DCA-ordination indicated that the main gradient in plant community composition was closely correlated to environmental variables for altitude, precipitation and net primary production, which within the ordination also correlated to plant biodiversity. This might enable a sound spatial protection scheme for plant biodiversity. Furthermore GIS-derived predictors can be used to enable further ecological analyses.

Within chapter four this was tested by modelling the habitat use of Przewalski's horses *Equus ferus przewalskii* and Asiatic wild asses *Equus hemionus* in the Great Gobi B strictly protected area, which is the only region where sympatric, free-ranging populations of these equids occur. Using a vegetation map it was tested whether Przewalski's horses are primarily adapted to mesic steppes, while Asiatic wild asses typically roam in arid desert steppes and semi-deserts. Based on nine Przewalski's horses and seven Asiatic wild asses habitat use and social structure was assessed using satellite telemetry and direct observations, using generalized linear mixed models with individuals as a random factor. Przewalski's horses had non-exclusive home ranges of 152-826 km², and selected for the most productive plant communities and formed stable harems groups.

Asiatic wild asses instead had non-exclusive home ranges of 4,449-6,835 km², thus showed almost no preference for any plant community and seemed to live in fission-fusion groups. Habitat use and resource selection widely differs between both species, and competition between both species is rather low. The Gobi areas provide a sub-optimal edge habitat for Przewalski's horses, thus only small and isolated pockets of suitable habitat remain for future re-introductions. Asiatic wild asses, on the other hand, demand wide areas to cope with the variable productivity of the Gobi.

Suchlike variability patterns in drylands are long known in ecology, which led to the development of the non-equilibrium (henceforth abbreviated as "NEQ") theory, which states that livestock numbers and thus ecological interactions are widely determined by precipitation variability. A number of overview publications are available, but comparisons often do not have a consistent climatic background data. Within the fifth chapter the NEQ paradigm was tested on a global scale, evaluating published studies against a global precipitation model, which was based on values for variability of the precipitation derived from some 19000 climate stations. The study widely supported the validity of the NEQ paradigm, and discrepancies in several of the published studies are due to an invalid interpretation of the environment or non-comparable precipitation data. The modelled global precipitation variability offers an explanation why authors assumed wrong ecological interactions or misinterpreted the NEQ theory. Based on 58 evaluated studies it is safe to state that grazing degradation is indeed limited to rangelands with a coefficient of variance (CV) of interannual precipitation (IP) <33%, or to non-zonal "equilibrated" zones within NEQ ecosystems. In zonal conditions with a CV of IP >33%, degradation is usually not described based on the evaluated studies. This has a global impact since wide areas of the worlds rangelands are subjected to mismanagement, and the actual rainfall variability should be a key tool to derive land use patterns.

However annual precipitation might still be enhanced as a predictor of climatic variability, since not all precipitation contributes to the actual vegetation growth. Within the second part of this chapter (paper eleven) it was therefore attempted to extract the precipitation of the growth period for a set of climate stations. The analysis focussed on arid and semiarid Central and High Asia; generalized additive models were used to designate the vegetation period for each station and year for several decades. Thereafter annual precipitation and precipitation of the vegetation period were tested regarding mean values against the variability. Total annual and growing season precipitation values were also compared in order to derive valid results for land use, since a threshold determining non-equilibrium ecosystems exists only for annual values. The results confirmed the well known relation of an increasing variability with lower mean precipitation levels. However the precipitation variability does increase dramatically where mean precipitation levels fell below 120 mm, indicating a non linear relation between mean precipitation and variability of the precipitation. This effect is even more pronounced within an analysis focussing on the precipitation of the growing season. This may alter our understanding of non-equilibrium dynamics, as it might indicate a border between regimes with more regular rainfall patterns and those with rather episodic rainfall. This analysis allows for a finer demarcation between rather stable ecosystems in comparison to regions where non-equilibrium dynamics prevail.

Numerous ordinations were made during this dissertation, two of which are included in the publications (chapter three). Since the analysed data originated from semi-arid to arid environments, the data contains a high proportion of absences and only some few co-occurrences. Only DCA ordinations offered an interpretable pattern yet other ordination techniques (CCA, NMDS) are often considered superior. Therefore the appendix paper assessed the trends and patterns in the application of ordination techniques in vegetation science from 1990-2007. Based on an evaluation of five major journals of vegetation science and a search of all ISI-listed ecological journals, a dataset of ordination techniques in vegetation sciences was compiled. Data were analysed using ANCOVAs, Spearman's rank correlations, GLMs, biodiversity indices and simple graphs. The ISI search retrieved hardly half of the papers using ordinations compared to the manual evaluation of five selected journals. Still, both retrieval methods revealed a clearly increasing frequency of ordination applications from 1990 to the present. While CCA was far more frequently detected by the ISI search than any other method, DCA was the most abundantly used method in the manual evaluation. NMDS has increased over the last ten years. Applications such as CA/RA and DCA have increasingly been used in studies published in 'applied' journals, while CCA, RDA and NMDS were more frequently used in journals focusing on more 'basic' research. The application of certain ordination techniques (e.g. CCA, NMDS) was influenced by the available software packages; these constraints may have decreased within recent years; there was also only limited evidence that the choice of methods follows social considerations such as the need to use fashionable methods. Methodological diversity was maintained or even increased over time, which reflects the researcher's need for diverse analytical tools in order to analyse a wide range of questions.

Organisation of the thesis

The herewith presented thesis consists of a set of peer reviewed publications that originated from scientific work conducted in the southern Mongolian Gobi. The author was glad to continue the work started in his diploma thesis, and to bring his scientific input further – and beyond.

The twelve publications/manuscripts were directly adopted from the original papers, thus the formatting and structure might follow the particular guidelines of the journal where the manuscript was published/submitted. The dissertation also includes several later publications, which are cited as "submitted" etc. in some of the earlier publications. The journals where the papers are published/submitted are outlined in the heading of each paper, and a note on the status of the journal is given in brackets. For the heading and contents, short titles of the papers are used.

The general framework of the dissertation ranges from relevé sampling to equid habitat modelling. However, other questions are raised throughout by the author or by other scientists in relation to the original framework of the dissertation, or from new insights and methods gained during its development. For example, a paper using logistic regression models was inspired by a paper on *Narduus stricta* published by Peppler-Lisbach & Schröder in JVS (Peppler-Lisbach, C. & B. Schröder 2004. Predicting the species composition of mat-grass communities (Nardetalia) by logistic regression modelling. *Journal of Vegetation Science* **15**: 623-634). A paper in Science (Gillson, L. & Hoffman, M.T., 2007, Rangeland ecology in a changing world. *Science*, **315**, 53-54.) led to the development of a review on the non-equilibrium theory in rangelands. The dissertation concludes with a synthesis that briefly discusses the outcomes in the context of the literature. A short summary provides a general overview of the dissertation, and an outlook states future potential projects of the authors, which are based upon the results gained within this dissertation. An appendix paper is placed at the end of the work.

The literature cited in the introduction, description of the study site, synthesis and outlook is found at the end of the dissertation, before the appendix.

List of relevant publications of the thesis

1) Plant communities of the working area

von Wehrden H., Wesche K. & Miehe, G. (accepted) Plant communities of the southern Mongolian Gobi. Phytocoenologia.

von Wehrden H., Tungalag & Wesche K. (2006) Plant communities of the Great Gobi B Special Protected Area in south-western Mongolia. Mongolian Journal of Biological Sciences 4(1): 3-17.

von Wehrden H., Wesche K. & Hilbig W. (2006) Plant communities of the Mongolian Transaltay Gobi. Feddes Repertorium 7-8: 526-570.

2) Species distribution within a biodiversity hotspot of the southern Mongolian Gobi

von Wehrden, H. & Zimmermann, H. (in print) Plant communities of the Dund Saykhan summit region, southern Mongolia. Candollea.

von Wehrden, H., Zimmermann, H., Hanspach, J., Ronnenberg, K., Wesche, K. (accepted) Predictive mapping of plant species and communities by using GIS and Landsat data in a southern Mongolian mountain range. Folia Geobotanica.

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.

3) Large scale spatial patterns of plant biodiversity, vegetation and productivity by means of remote sensing data

von Wehrden H., Wesche K. (2007) Mapping the vegetation of southern Mongolian protected areas: application of GIS and remote sensing techniques. Arid Ecosystems 33-34: 130-139.

von Wehrden, H. & Wesche, K. (2007) Relationships between climate, productivity and vegetation in southern Mongolian drylands. Basic and Applied Dryland Research 2: 100-120. [partly related to chapter 5]

4) Application of vegetation maps

Kakzensky, P. Ganbaatar, O., von Wehrden, H. & Walzer, C. (2008) Resource selection by sympatric wild equids in the Mongolian Gobi. Journal of Applied Ecology 45: 1762-1769.

5) Non equilibrium theory

von Wehrden, H., Hanspach, J., Kaczensky, P. & Wesche, K. (manuscript) Testing the global validity of the non-equilibrium theory of rangeland science by evaluating field studies against a common climatic data base.

von Wehrden, H., Hanspach, J., Ronnenberg, K. & Wesche, K. (in prep for resubmission after major revision) Inter-annual climatic variability in Central Asia - a contribution to the discussion on the importance of environmental stochasticity in drylands. Journal of Arid Environments.

Appendix paper) Methodological considerations

von Wehrden, H., Hanspach, J., Bruelheide, H. & Wesche, K. (in print) Pluralism and diversity - trends in the use and application of ordination methods 1990-2007. Journal of Vegetation Science.

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Interdisciplinary work emerges as a precondition for ecology nowadays; therefore the present work would have been impossible without the competent help of my co-authors from a wide array of disciplines.

As a trained geographer, I owe a great debt to G. Miehe, who introduced me to the field of vegetation science, and further. E. J. Jäger helped regarding plant determination and distribution; he was a constant source of both advice and information. W. Hilbig showed me "the different Henrik" and proved that the outer form of a paper is its inner essence. Wilfried Endlicher seeded my interests in the field of remote sensing.

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I would like to dedicate this work to my father and my son, two generations that only met in me.

Introduction

Earlier research on the vegetation of the southern Mongolian Gobi

The southern Mongolian Gobi covers approximately 400 000 km^2, which roughly equals the area of Germany (see Fig. 1).

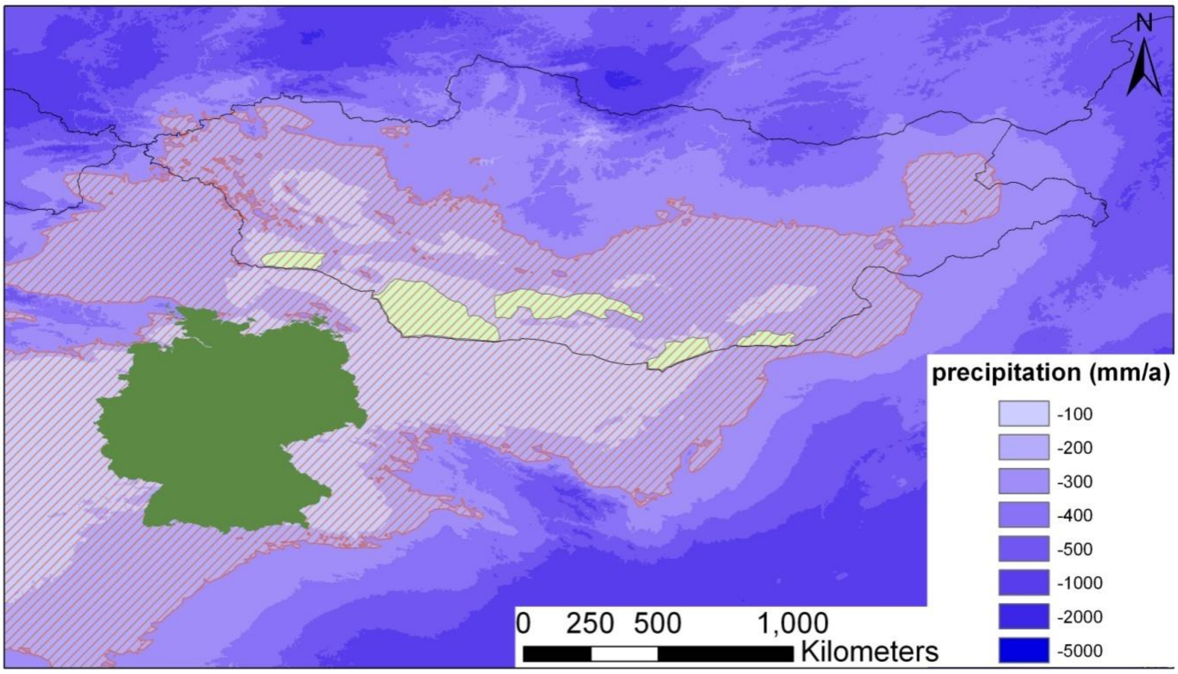

Fig. 1: Overview of Central Asia; the beige areas are the large protected areas found within southern Mongolia, which were the focus regions throughout most of this study. The dashed area represents the region with less than 200 mm of mean annual precipitation. The silhouette of Germany, in green, is outlined for comparison.

Our knowledge of the ecology of this vast ecosystem is sparse. Data on the distribution of most higher plant species is restricted to the scale of four geographic subregions (Grubov, 2001; Gubanov, 1996). Some site descriptions can be found in the Plants of Central Asia volumes (Grubov, 2000a), and detailed data for a limited number of species is available in local studies, including distribution maps (e.g. Dulamsuren et al., 2005; Hilbig et al., 2004).

The first accounts of the vegetation were made by Russian expeditions crossing the area (e.g. summarized by Junatov, 1950); valuable information originates from that time, yet most descriptions are mere pinpricks in an otherwise unknown matrix. During the 1960s a more systematic assessment of the region was started. Ecological field stations were established at numerous locations, and frequent expeditions surveyed the vast drylands of the Mongolian Republic. Vegetation descriptions for a number of sites were produced (e.g. Gunin & Vostokova, 1995; Gunin et al., 1999; Karamysheva & Khramtsov, 1995; Račhkovskaya, 1993; Račhkovskaya & Volkova, 1977; Walter, 1974) and in 1990 the first comprehensive overview of the phytosociology of the entire country was compiled (Hilbig, 1990), which became available in English as well (Hilbig, 1995). The Russian (or formerly Soviet) vegetation surveyors widely favoured the dominance approach to vegetation studies; the German botanists instead mainly adopted the Braun-Blanquet method, and thus classified the vegetation based on the presence of certain character species. In 2000, Hilbig published a formal phytosociological overview of the plant communities of Mongolia, and several other publications have since been compiled (e.g. Hilbig & Tungalag, 2006; von Wehrden, 2005; von Wehrden & Tungalag, 2004; von Wehrden et al., 2006; Wesche et al., 2005).

Countrywide - and thus necessarily coarse-scaled - vegetation maps became available with the production of the Atlas of Mongolia, and other work contributed further maps (e.g. Anonymous, 1990; Gunin et al., 1999; Vostokova & Gunin, 2005). Detailed vegetation maps are still widely lacking, so it remains only vaguely known as to which vegetation types and plant species are actually occurring and being protected within Mongolia's ambitious network of nature reserves. Moreover, the ecology and distribution of vegetation types has as yet hardly been examined on a local or even regional scale (e.g. Miehe, 1998).

Mongolia contains one of the oldest protected areas in the world (Barkmann, 2000), and the democratic government continues the long tradition of nature conservation (Reading et al., 2006). However, the protected areas of the Mongolian Gobi alone currently total about 100000 km^2 (see Fig. 1), ranking them among the largest protected areas recognized by the IUCN (WDPA Consortium, 2004). Recent initiatives attempt inventories of the animal biodiversity (mostly vertebrates, Clark et al., 2005; Stubbe et al., 2007), and a few species are mapped in the Atlas of Mongolia or other publications (e.g. Dulamsuren et al., 2005; Hilbig & Knapp, 1983; Jäger, 2005; Miehe et al., 2007), but detailed distribution data regarding most of the individual plant and animal species are profoundly lacking.

The protected areas of the southern Mongolian Gobi were gazetted in order to protect so-called umbrella species (e.g. Khulan, Ibex, Argali, Wild camel, Gobi bear, Snow leopard), most of which are declining (e.g. Tulgat & Schaller, 1992). Reading et al. (1999) suggested an enlargement of the protected areas within Mongolia and an enhancement of protection measures within existing protected areas, where poaching still threatens wildlife. One precondition for a valid protection regime of the southern Mongolian animal and plant species is the availability of sound spatial data regarding their ecology and distribution. Several surveys were already performed to gather more information (e.g. Reading et al., 1999a), yet much of the data remains unpublished and focuses on wildlife rather than on habitats (e.g. Clark & Javzansuren, 2008).

Surveying plant biodiversity in drylands

The need to understand patterns in plant biodiversity is as old as ecology itself, and continues to puzzle researchers to the present day (e.g. Barthlott et al., 2007; Gaston, 2000; Kier et al., 2005). Low plant biodiversity is a typical feature of almost all drylands worldwide, and biodiversity patterns are often related to productivity gradients (Bai et al., 2007; Breckle, 2006). Knowledge of plant biodiversity for the southern Mongolian Gobi is sparse (Barthlott et al., 2007). A general altitudinal gradient regarding plant species biodiversity has already been described in the first descriptions of the region (e.g. Kozloff, 1902), and several recent publications confirmed this general pattern; however, sound spatial data is lacking. This is surprising as plant biodiversity is considered a general criterion for the designation of protected areas throughout Mongolia (Reading et al., 1999), which renders the foundations for the current reserve network somewhat doubtful.

It is rather trivial that in poorly known regions biodiversity assessments are beneficial even if the given sampling density is low (Gaston & Rodrigues, 2003). Calculations presented by Balmford & Gaston (1999) illustrate that for southern Mongolia a detailed survey is not affordable, because special funding is widely lacking and almost completely dependent on external NGOs (Reading et al., 1999b). Extrapolations based on low density surveys offer an option for generating prediction models on plant biodiversity. Remote sensing plays a key role in this context (Bradley & Fleishman, 2008) because it facilitates the surveying of such vast areas (Gunin et al., 1999).

Such an approach was previously tested based on Landsat data and ground truth data to derive vegetation maps of the Gobi Gurvan Saykhan National park located in the southern Mongolian Gobi (e.g. von Wehrden et al., 2006), which confirmed that remote sensing offers valid tools. So far, no fine-scale vegetation maps for the other reserves in the southern Mongolian Gobi are available. Knowledge regarding plant biodiversity is also virtually absent, with only a few publications giving general remarks (e.g. Wesche et al. 2005). Furthermore, modelling and remote sensing methods facilitate an understanding of the ecological gradients in the working area: the precipitation gradient is mirrored in a productivity gradient (see below), which can be readily assessed by remote sensing products (e.g. MODIS NDVI, GLOPEM).

Habitat mapping of equids

Almost all large mammal species within southern Mongolia are threatened. The Przewalski's Horse *(Equus przewalskii)* suffered due to increasing human pressure and became extinct (in the wild) in the middle of the 20th century, while all other wildlife species are, as yet, still roaming the Central Asian steppes (see outlook). Population numbers of the other equid occurring in the region, the Asiatic Wild Ass (*Equus hemionus*), give reasons for concern. Both equids occur together in the drylands of the southern Mongolian Gobi, where many of Central Asians large mammals have found their last refuge (Zevegmid & Dawaa, 1973). Again, distributions of these species are only known on a coarse scale, and only general accounts of their habitats are available. Moreover, the habitat use of the species has not been examined yet, which is of specific importance regarding the present case where two equids occur together, since horse species sharing the same range are expected to compete for grazing grounds (Chesson & Huntly, 1997). This hypothesis was tested in the south-western Mongolian Gobi, namely the Dzungarian Gobi, where both the reintroduced Przewalski's horse and the Asiatic wild ass roam.

In addition, the reintroduction of the once extinct Przewalski's horse demands the identification of suitable habitat sites, which need to be designated based on sound spatial habitat maps. Furthermore, data on the productivity, as well as altitude and slope layers, are of obvious importance for the horse's biology, and as such were obtained as standard predictors for modelling and interpreting habitat use.

Human land use in drylands - the non-equilibrium theory

Traditional rangeland theory widely regards livestock as the driving factor of rangeland dynamics. In the 1980s the non-equilibrium theory (NEQT) was proposed (Ellis & Swift, 1988; Westoby et al., 1989), which interprets livestock numbers – under dry conditions - as being widely driven by climatic parameters. Consequently, livestock numbers cannot grow indefinitely, but collapse under unfavourable conditions. Thus, the impact of livestock on plant biodiversity and vegetation composition is rather low (on average), and mainly concentrated around wells, springs and key resources (e.g. salt meadows).

In the case of southern Mongolian Gobi, the practical consequences of the non-equilibrium theory are well known and feared by Mongolians. The old nomadic culture has adapted over millennia to the variable semi-arid to arid climate (Fernandez-Gimenez, 1999), although some of the driest sites in the southern Mongolian Gobi were presumably not used until recently by humans and their livestock, when well digging enabled the use of these drier regions as pasture (Fernandez-Gimenez, 2006). Summer precipitation has long been known as a crucial driver of livestock dynamics, and droughts, which are locally called Black Dzuuds (Retzer & Reudenbach, 2005), are common in this ecosystem. Furthermore, excessive winter snow affects livestock numbers as well, thus the so called White Dzuuds (= snow that represents unfavourable conditions for livestock) are likewise a threat to Mongolian livestock (Begzsuren et al., 2004). Some studies assume that non-equilibrium conditions prevail almost throughout the whole country (e.g. Reading et al., 2006). In contrast, field studies for the drier south of Mongolia describe non-equilibrium conditions (Retzer, 2004a; Retzer & Reudenbach, 2005), while a gradient towards more stable precipitation regimes is assumed for the countries central and northern parts (Fernandez-Gimenez & Allen-Diaz, 1999). On a more regional scale, human land use reflects the productivity gradient found in southern Mongolia, as the montane slopes and pediments are used as grazing lands by many families, while the lower surroundings and drier parts support fewer nomads (Bedunah & Schmidt, 2004).

The contradicting opinions reflect the general state of discussion around the non-equilibrium theory. Several reviews of the NEQT are available (e.g. Gillson & Hoffman, 2007; Sullivan & Rohde, 2002; Vetter, 2005), however, none on a globally comparable climate-data basis. The discussion has gained momentum in the last years (Gillson & Hoffman, 2007; Sullivan & Rohde, 2002; Vetter, 2005), but recent reviews have not been data-driven. Instead, authors discuss the various aspects based on the components of different publications which do not necessarily share a common data background. A main question arising from the recent discussions around the NEQT might be the outcome of a combination of the available field data (as derived from publications) with actual climatic data on a globally comparable scale.

Most available studies that examine NEQT dynamics define climatic variability by precipitation, which is in line with the original proposal of the NEQT. However, a recent review suggests a shift in focus toward variability in productivity (Cingolani et al., 2005), which would better catch the underlying dynamics at the consumer level. The variability of productivity may be heavily influenced by the timing of the rainfall (Yu et al., 2004), and this may also affect rain use efficiency (Lehouerou, 1984). Therefore, the question arises as to whether an analysis focussing on the seasonal rainfall distribution would actually better represent vegetation growth patterns and ecosystems dynamics within arid environments.

Methodological implications

Much of the present thesis is based on statistical analysis of relatively large data sets; the selection of a suitable set of methods is not necessarily straightforward. Ordination techniques are well established standard tools within vegetation science, since these methods allow the analysis of gradients in multivariate data. Within recent years, datasets have come to contain an increasing number of relevés, which can hardly be analysed by traditional desk-based methods.

Several reviews and methodological papers and books are available which outline the benefits and drawbacks of the individual methods. A huge number of reviews and methodological papers have compared the performance of different techniques (e.g. Ejrnaes, 2000; Gauch, 1994; Jackson & Somers, 1991; James & McCulloch, 1990; Palmer, 1993; Podani, 2005; van Groenewoud, 1992). Even standard textbooks do not always agree in their evaluation of any given method (McCune et al., 2002; Palmer, 2006; ter Braak & Šmilauer, 2002), which may be partly biased since textbooks often accompany software packages (e.g. PC-Ord, Canoco), and not all packages are able to perform all types of analysis (Gilliam & Saunders, 2003). A well-known example is the ordination method *Detrended Correspondence Analysis* (DCA), which is sometimes recommended as a standard tool and widely applicable technique (Jongman et al., 1995; Kent & Coker, 1992; Lepš & Šmilauer, 2003). Other sources discourage the use of DCA completely or restrict it to certain special cases (Legendre & Legendre, 1998; Podani, 2000; Zuur et al., 2007), the reason being that the detrending process has no proper mathematical justification.

The multivariate data obtained during the course of this dissertation was, however, not easily analysed with alternative methods such NMDS and CCAs, which are however frequently considered to be more powerful and valid (see above). Instead statistical sound and ecologically interpretable results were only derived from CA and DCA ordinations, which are often considered to be outperformed by more recent approaches. There appears to be a wide range of opinions, but the last review summarizing the actual use of particular methods appeared more than 20 years ago (Kent & Ballard, 1988). It therefore seemed natural to review the current set of methods and the respective number of applications in vegetation sciences.

Objectives and aim of the dissertation

This dissertation contains five chapters and an appendix. The first chapter characterises the large protected areas within southern Mongolia with respect to their vegetation. Three of the publications describe the vegetation of different subregions (papers 1, 2, 3; partly paper 4, see below), and provide regional vegetation classifications; the classified vegetation samples also served as ground truth data for the vegetation mapping of each protected area. These maps were not separately published but served as input data for various modelling studies (see below). A comprehensive description of the plant communities of southern Mongolia summarises this data (paper 1).

The second chapter focuses on a detailed survey of one of the mountain regions in order to provide more detailed knowledge of the particular site, which contains the highest plant biodiversity within the study region. Therefore, a more detailed survey of the local vegetation types was conducted (paper 4), which partly follows on from the information in chapter 1. The next step was to test whether distribution models for all abundant plant species can be derived by employing generalized linear modelling techniques. We also tested if Landsat and SRTM data serve as suitable predictors within this environment, as this had previously not been tested for the drylands of Central Asia (paper 5). Since this approach was only performed for abundant plant species, an assessment of distributional and systematic relations of four endemic species typically found within these mountain ranges was made; distribution maps were drawn and the biogeography of the species was discussed (paper 6).

The third chapter addresses methodological issues of the vegetation mapping approach employed here (paper 7). A principal question was to assess the accuracy of the classification. To illustrate, the vegetation classification and the environmental background of the driest region of the working area is described and discussed. In addition it was tested whether there is a relation between plant biodiversity and precipitation within this driest part of the working area. Finally, the available remote sensing datasets for the analysis of the environments of the southern Mongolian Gobi are discussed. As a follow-up, both the plant biodiversity and the productivity of the complete working area are examined (paper 8).

The correlation between plant biodiversity and altitude, precipitation and productivity within this region is also discussed with a view to analysing the species-area relationships of the derived vegetation types as well as the variability in productivity and its dependence on climate. The spatial focus was laid on the southern Mongolia rangelands, asking where the gradual boarder between equilibrium and non-equilibrium dynamics is located, and which temporal trends of rangeland productivity are found within the region.

The last two chapters go beyond the main topic of vegetation surveying in southern Mongolia. The obtained spatial predictors (vegetations maps, productivity, altitude, slope) were employed to model the habitat use of both equids found in the region (fourth chapter). Data originates from several animals (*Equus hemionus* & *Equus przewalskii*) collared in the Great Gobi B SPA as the principal data source. The main question was to quantify the similarities and differences which characterise the habitat use of the two species; thus providing a detailed habitat use analysis of both species (paper 9).

The aim of the following paper was to gain further insight into the NEQT by making a literature review in the fifth chapter (paper 10), which was motivated by experience gained in our working group with Mongolian grazing systems over the last years. The main research question was whether precipitation variability can explain presence or absence of degradation. Data on degradation was compiled from several studies and tested against a globally extrapolated map of precipitation variability; the baseline data was derived from 19,000 climate stations. In order to analyse the relation between mean annual precipitation and interannual variability, a regional analysis of all climate records of Central and High Asia was performed. A recent review (Cingolani et al., 2005) emphasised the necessity to consider the variability of productivity, for which the precipitation variability is a mere surrogate. In order to gain a deeper insight into the rainfall dynamics of these vast drylands, the analysis focused on the precipitation of the vegetation period, which should be a more suitable indicator of variability in productivity. Within the eleventh paper the question was addressed as to whether we can refine standard climatic data in order to gain a more precise insight into the ecologically relevant climatic variability of the Central and High Asian drylands (paper 11).

Two ordination figures are published within this dissertation (chapters 3 & 4) – and many more unpublished plots were generated during the data analyses or presented during conferences. These motivated the appendix paper, which contains a review on the use of ordination techniques within ecology since 1990. Within this chapter the main questions were whether and how the use of ordination techniques changed over the last two decades, and how this pattern is reflected within an ISI-driven search.

Study site

Geology and soil

The southern and south-eastern parts of the Altay mountain chains traverse the southern Mongolian Gobi (see Fig. 2); their chains strike in an east-west direction in accordance with the ongoing strike and slip faulting of the region (Tapponnier & Molnar, 1979). These tectonic processes shaped the typically steep relief of the southern Mongolian mountains (Cressey, 1960); only the eastern steppes and the Alashan Gobi lie below 2000 metres asl. However, the basins with the lower pediments and depressions dominate the area, while the montane environments and riparian ecosystems are much smaller in their spatial extent (Cressey, 1960; Rippington et al., 2006).

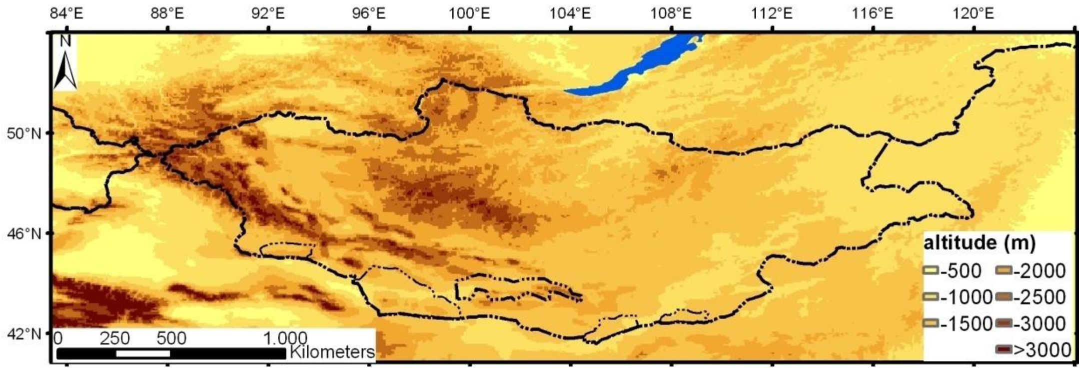

Fig. 2: Topographical map of Mongolia. The dashed lines indicate the protected areas in southern Mongolia, which were in the focus of this dissertation.

Quaternary processes shaped the current surfaces (Lehmkuhl, 1997). In the montane environments, freeze and thaw cycles have eroded the rocks and stones. The pediments and basins are deflated due to the strong winds, and dry drainage lines form networks of lineaments toward the depressions. The beds of these temporary rivers often contrast with their surroundings due to a heterogeneous mosaic of accumulated fine soil material and rather coarse gravel or even smaller rocks.

Burosems and Kastanosems are the dominating soil types, yet at montane slopes, shallower Kastanosems, Parachernosems, and Leptosols occur. Sandy spots are edaphically unique environments and may form weakly developed Arenosols; the temporarily moist depressions contain Solonchaks and Solonetz soils.

Climate

The southern Mongolian Gobi is the easternmost part of the Old World's desert belt (Cressey, 1960). The vegetation period is rather short (3-5 months) and rainfall is predominantly restricted to the summer (Weischet & Endlicher, 2000). Knowledge on the region's climate is sparse, since most of the few operational climate stations are widely restricted to the lowlands. Based on a global extrapolation, the highest peaks within the region may gain about 200 mm/a on average (Hijmans et al., 2005), which is in line with local measurements (Retzer, 2004). The local precipitation is, however, mostly much lower, and the median of the precipitation of the southern Mongolian Gobi (all areas with less than 200 mm/a) is around 120 mm/a (own analysis based on Hijmans et al., 2005). The driest sites in southern Mongolia receive < 35 mm/a.

Two principal climate regimes prevail in the southern Mongolian Gobi. While the eastern part is mainly influenced by monsoonal rains reaching the Mongolian Gobi (Herzschuh et al., 2006), the south-western parts (e.g. the Mongolian part of the Dzungarian basin) gain precipitation from western disturbances (Jäger et al., 1985) that cross the Turranic highlands or the adjacent northern lowlands. The Siberian anticyclone forms the main climatic influence within Central Asia during the winter (Weischet & Endlicher, 2000); by drawing air from north-western directions western Mongolia gains more winter snow compared to other parts of the southern Mongolian Gobi (Hijmans et al., 2005, Morinaga et al., 2003). The persistence of the snow cover is generally low as most snow evaporates quickly, still, snow depths tend to be higher in the western part of the region. The pronounced altitudinal gradients modify the regional precipitation gradients; within any given region, mountain sites receive more than twice as much precipitation compared to the surrounding lowlands (Retzer, 2004).

During the Holocene, the vegetation belts shifted severely, which is indicated by the available pollen records as well as analyses of biogeographical patterns (Herzschuh et al., 2004; Jäger, 2005; Miehe et al., 2007). For the southern Mongolian Gobi, available palynological studies are far from conclusive, but almost certainly not only temperatures, but more importantly the magnitude of the East Asian monsoon, varied during the Holocene (Jiang et al., 2006). Today, climate change is affecting Central Asia, resulting in higher temperatures with overall stable to slightly increasing precipitation rates (Christensen et al., 2004; Shi et al., 2007; Wei, 2005). For instance, the temperature during the last decades has increased at almost all climate stations (see Fig. 3); regarding precipitation patterns, positive trends prevail as well, suggesting an increase in annual precipitation (Fig. 4).

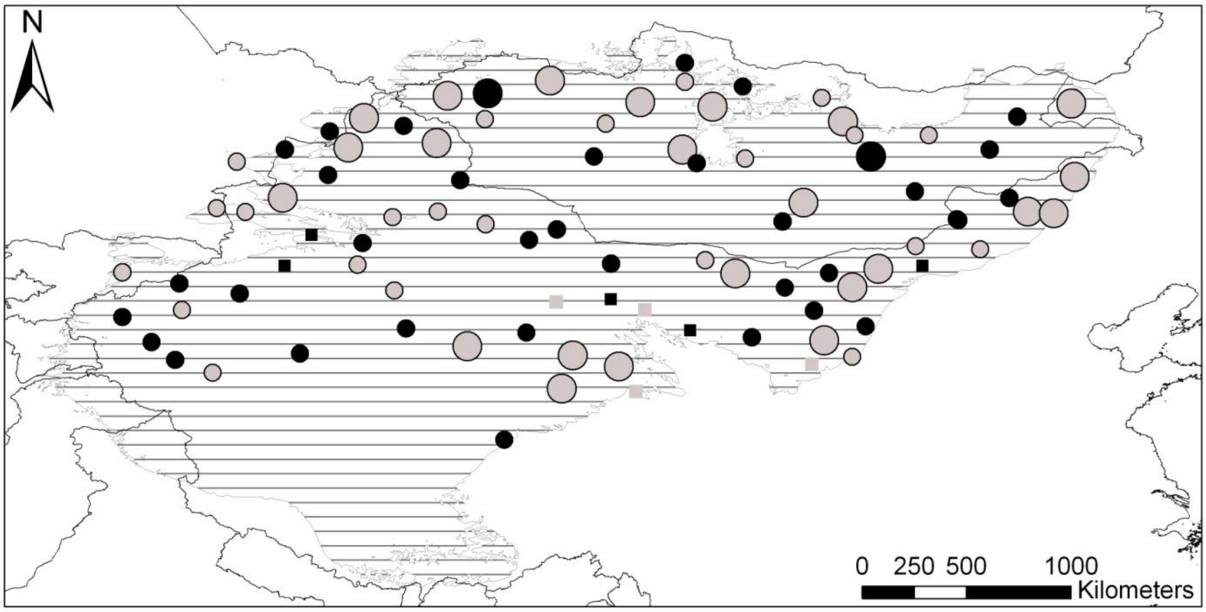

Fig. 3: Temperature trends for the last five decades for climate stations in Central and High Asia (developed by H. von Wehrden; data was processed with the help of J. Hanspach). Small quadrangles show a negative linear trend (=colder temperature), the smaller circles indicate a slightly positive trend (=warmer temperatures), and strongly positive trends are indicated by large circles. Solid black circles indicate significant trends within the linear models, while grey circles indicate non-significant trends. The lined area indicates all regions with average precipitation below 300 mm/a (based on Hijmans et al., 2005).

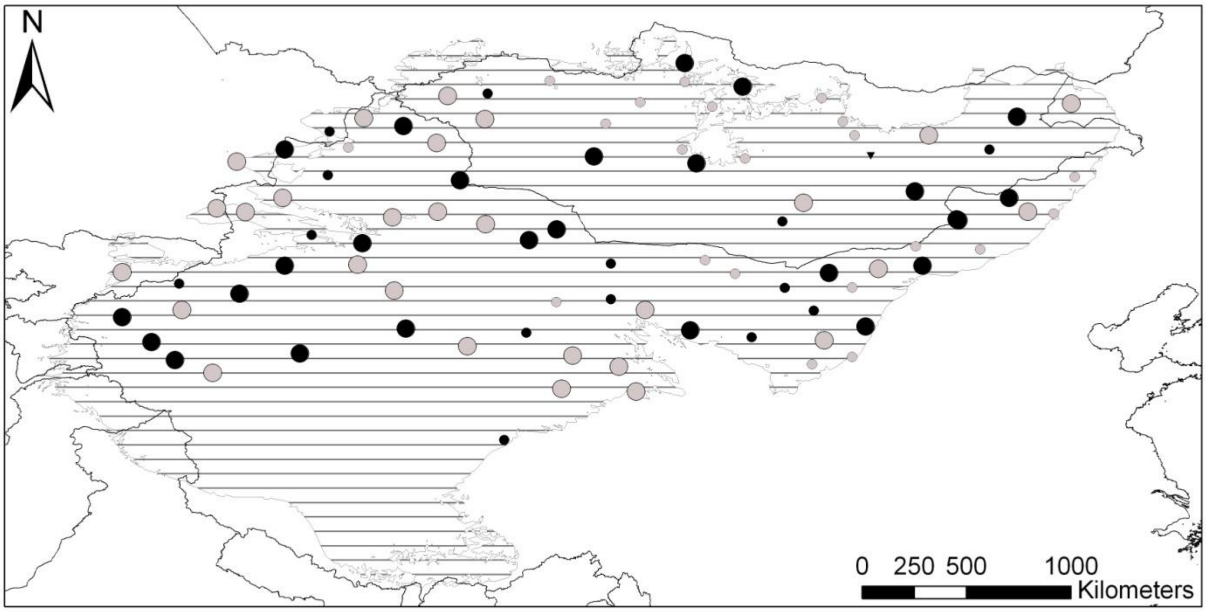

Fig. 4: Precipitation trends for the last five decades for climate stations in Central and High Asia (developed by H. von Wehrden; data was processed with the help of J. Hanspach). Small triangles show a negative linear trend (decreasing annual precipitation), the smaller circles indicate a positive trend (=increasing annual precipitation), and larger circles indicate a strong positive trend. Solid black circles indicate significant trends within the linear models, while grey circles indicate non-significant trends. The lined area indicates all regions with average precipitation below 300 mm/a (based on Hijmans et al., 2005).

Flora

The Gobi province is usually included in the Central Asian desert region (Meusel et al., 1965), and is divided into a western and an eastern subregion/province, thus reflecting the two different climatic regimes mentioned above (see Fig. 5).

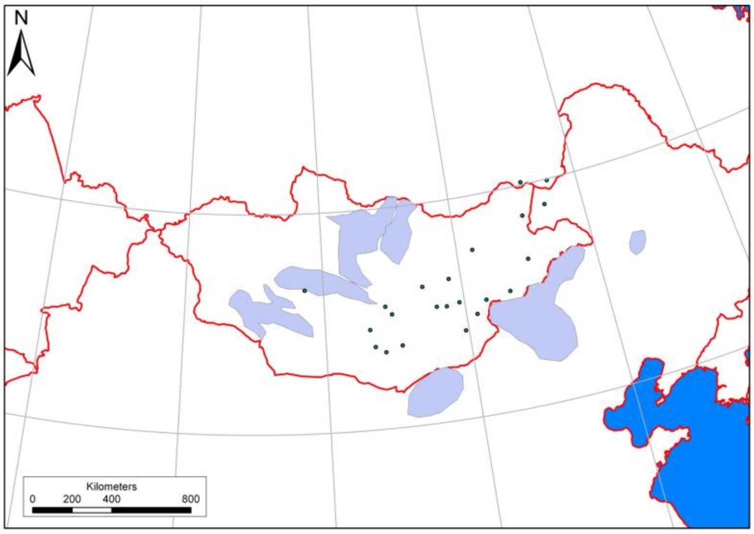

Fig. 5: Distribution of *Astragalus miniatus* as an example of an eastern element in the context of the southern Mongolian flora (own draft; data compiled by E. J. Jäger). Polygons are given where information is only available for specific regions, while points indicate precise locations.

Typical Central Asian elements dominate most of the vegetation; among these are many Chenopodiaceae (*Haloxylon ammodendron*, *Anabasis brevifolia*, *Sympegma regelii*), Tamaricaceae (*Reaumuria songarica*), and Poaceae (e.g. *Stipa glaresoa*, *Stipa gobica*). In the western sub-province, elements of the Aralo-Caspian flora have their easternmost distribution in the Dzungarian Gobi (Jäger et al., 1985; Meusel et al., 1965), e.g. *Nanophyton erinaceum*, *Anabasis aphylla*, *Anabasis elatior*, *Kaschgaria komarovii*; few plants reach as far east as the Transaltay Gobi (e.g. *Halimodendron halodendron*). The eastern sub-province contains a few differentiating elements, e.g. *Ammopiptanthus mongolicus* and *Brachanthemum gobicum*; some species are bound to the east within the southern Mongolian Gobi, yet may be found towards the west outside the Gobi region (e.g. *Salsola passerina*). The central southern Mongolian Gobi, namely the Transaltay Gobi, is relatively poor in species. This is in line with the low levels of precipitation there (von Wehrden & Wesche, 2006): notably drought-adapted elements are restricted to this region within the southern Mongolian Gobi (e.g. *Iljinia regelii*). Despite their relatively limited spatial extent (compared to the pediment regions and basins), the mountain regions host the highest plant biodiversity of the southern Mongolian Gobi (Jäger, 2005); and many relicts (e.g. *Betula microphylla*, *Paeonia anomala*, *Kobresia myosoroides*, *Juniperus sabina*) testify to the different climatic conditions of the past (Miehe et al., 2007). Thus, species with a restricted distribution in the south become more widespread to the north, where many of these species form the zonal vegetation (Grubov, 2001; Gubanov, 1996; Hilbig, 1995). Montane species are restricted to higher ranges (Fig. 6), and several elements show connections to other mountain chains of Central and High Asia (Fig. 7).

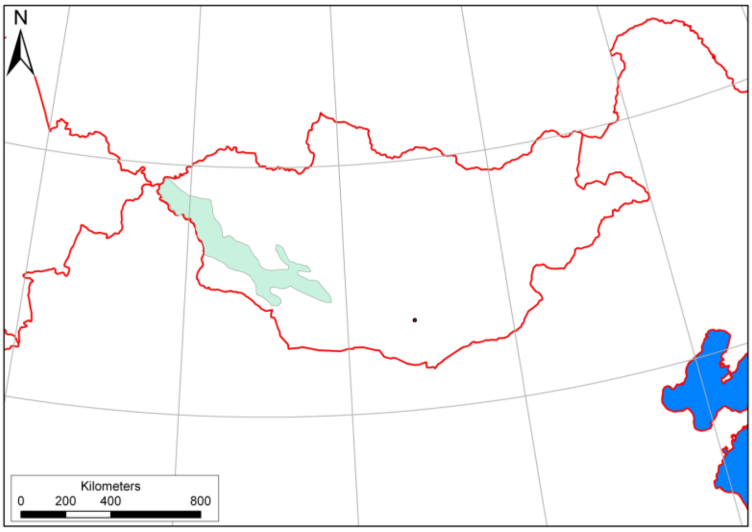

Fig. 6: Distribution of *Saussurea lipschitzii* as an example for a montane element in the context of the southern Mongolian flora (own draft; data compiled by E. J. Jäger). Polygons are given where information is only available for specific regions, while points indicate precise locations.

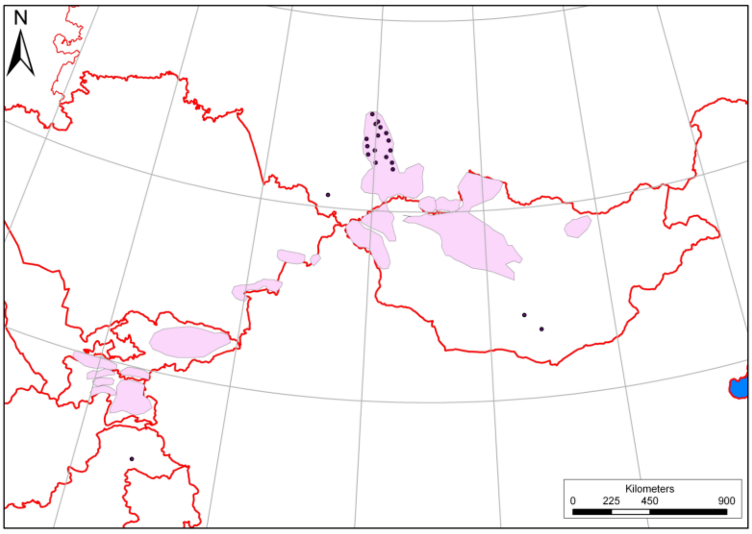

Fig. 7: Distribution of *Androsaceae dasyphylla* as an example of a distribution within Gobi mountain ranges with connections to other montane and alpine mountain chains within Central and High Asia (compare *Stipa sibirica*) (own draft; data prepared by E. J. Jäger). Polygons are given where information is only available for specific regions, while points indicate precise locations.

Only a few endemics are known for the country (Grubov, 1989); but the number of species which are endemic to Central Asia is much higher (Grubov, 2000a). These species can be divided into two groups: The first contains species which are mainly restricted to the mountain chains (see Fig. 6, often also occurring in mountains of neighbouring Russia, Kazakhstan or China, mainly in the Altay), while the other group contains species of the drier lowlands (e.g. *Ammopiptanthus mongolicus, Psammochloa villosa*; species mainly shared with the Chinese part of Central Asia).

Human land use

The Gobi region is an old nomadic ecosystem (Fernandez-Gimenez, 1999). Large populations of wildlife roamed the region over evolutionary time-scales, but the natural grazers have largely been displaced by domestic livestock. Wildlife is often recognized as a grazing competitor by the Mongolian nomads (Retzer, 2004; Wesche et al., 2007; Campos-Arceiz et al., 2004; Lhagvasuren & Milner-Gulland, 1997); this is one reason for the increased hunting pressure within the southern Mongolian Gobi. Regions with comparatively high productivity (e.g. montane environments, oases) experience higher impact from grazing, and these regions often have a higher density of man-made wells, which support more livestock compared to regions without any water sources.

The socialist economy triggered important changes, namely more veterinarian support for herders and the construction of countless wells (Fernandez-Gimenez, 2006). Centralization during socialist times maintained livestock numbers below fixed thresholds. The subsequent political changes leading to capitalism had a severe impact on Mongolian pastoralism, since the free-market economy led to the re-privatization of herds. This has caused livestock numbers to increase over the last two decades (Fernandez-Gimenez, 2006). The desire to maximise income resulted in a higher proportion of goats being introduced into the herds (National Statistical Office of Mongolia, 2001, 2003) in order to maximize cashmere production. However, several successive droughts at the start of the new millennium caused a reduction in livestock numbers (Reading et al., 2006).

Thus, southern Mongolia represents an ideal region where so called *non-equilibrium* conditions prevail: livestock numbers are strongly influenced by climatic variability, and overgrazing is mainly restricted to human settlements and around water sources (Bedunah & Schmidt, 2004; Wesche & Retzer, 2005). The most severe human impact within the semi-deserts and deserts is in almost all cases confined to the oases, many of which have undergone tremendous changes due to agricultural land use (Gunin et al., 1999). Oases in neighbouring Chinese territories are more often severely modified due to agriculture and gardening (Bruelheide et al. 2003), and vegetation degradation probably exceeds levels found in southern Mongolia (Kürschner, 2004).

Altitudinal gradients result in precipitation zonation, which defines productivity gradients in the region (Retzer et al., 2006). Therefore, an altitudinal zonation of the grazing density is often observed as well. Within the resulting zonal vegetation, the lower semi-deserts support far less livestock than the richer montane pastures, which have a higher mean biomass. During winter this pattern may be somewhat reversed, and lower grazing grounds are often used as winter pastures.

Publications of the dissertation

Chapter 1: Plant communities of the working area

Paper 1: Plant communities of the southern Mongolian Gobi. - Phytocoenologia (accepted)

Henrik von Wehrden (Halle), Karsten Wesche (Göttingen) and Georg Miehe (Marburg)
with 27 figures and 8 tables.

Abstract

The present study provides an updated inventory and classification of the plant communities of the Gobi region in southern Mongolia based on a set of 1418 sample plots. The vast Gobi landscape is characterised by a dry climate with mean annual precipitation in the semi-deserts of between 50 and 150 mm, while the highest mountain peaks may receive up to 200 mm/a. The wetter montane regions are composed of extrazonal communities including woodlands and comparatively dense mountain steppes. The surrounding lowlands are characterised by sparse and more diffuse vegetation comprising dry grass steppes and, more commonly, shrub formations. Water surplus sites host various salt-adapted vegetation types which contrast sharply with the surrounding semi-deserts in terms of their high vegetation cover and species richness. In total, 28 associations / communities plus 18 sub-associations / sub-communities or variants are listed. Nine of these are newly described, and the syntaxonomical status of several other units known from literature has been clarified. The distribution of the plant communities is exemplified by six vegetation profiles.

Paper 2: Plant communities of the Great Gobi B Strictly Protected Area. – Mongolia. - Mongolian Journal of Biological Sciences 4(1): 3-17.

Henrik von Wehrden[1,2], Karsten Wesche[2] and Radnaakhand Tungalag[3]

[1] Research Institute of Wildlife Ecology, Savoyen Strasse 1,Vienna, 1160 Austria
[2] Institute of Biology - Geobotany and Botanical Garden, Martin-Luther-University Halle-Wittenberg, 06099 Halle, Germany, E-mail: HenrikvonWehrden@web.de
[3] Faculty of Biology, National University of Mongolia, P.O. Box 377, Ulaanbaatar, Mongolia

Abstract

This paper presents the first syntaxonomical overview of plant communities of the Great Gobi B Strictly Protected Area. Within Mongolia this region represents the south-westernmost protected area and preserves several species listed in the IUCN Red List. Therefore the region is of high importance to the country and moreover for the whole Central Asian eco-zone. Knowledge of the main habitat types is a precondition for nature conservation. Based on 211 vegetation samples collected during the summer of 2003 we derived 16 vegetation units. There are two mountainous communities; eight zonal semi-desert units, and the extra-zonal vegetation is assigned to six communities. The described vegetation units are compared with available descriptions from other Gobi regions.

Paper 3: Plant communities of the Mongolian Transaltay Gobi. - Feddes Repertorium 7-8: 526-570.

von Wehrden, H., Hilbig, W. & Wesche, K.

With one map, twelve figures and 14 tables

Abstract

Here we present the first detailed phytosociological description of the plant communities of the Transaltay Gobi, the driest region within Outer Mongolia. It was originally gazetted as a national park by the Mongolian parliament in 1976, which included also the Dzungarian basin in south-western Mongolia. The status of the Great Gobi A Nationalpark in the Transaltay Gobi, and the Great Gobi B Nationalpark in the Dzungarian Gobi was later raised to the level of Strictly Protected Area. Since the area hosts many endangered wildlife species, we offer an initial vegetation description, which is necessary to understand the habitats of this arid ecosystem. Based on a modified Braun-Blanquet approach we designated eight zonal vegetation units, most of which are impoverished regional variants of vegetation types previously described from adjacent regions; most units contain several sub-units. The altitudinal gradient reflects the climatic regime in the study area; therefore the vegetation distribution follows the precipitation gradient regarding both vegetation cover and diversity. The most important diagnostic species are typical drought-adapted Central Asian elements, namely *Haloxylon ammodendron*, *Ephedra przewalskii*, *Reaumuria songarica* and *Anabasis brevifolia*. Three new associations were designated based on our vegetation data.

The main determinant for the riparian vegetation types is apparently groundwater availability, leading to locally high soil salt contents due to the high evaporation in the region. Poplar stands, reed beds and *Tamarix* stands are the characteristic vegetation types of the oases in the working area.

Chapter 2: Species distribution within a biodiversity hotspot of the southern Mongolian Gobi

Paper 4: Plant communities of the Dund Saykhan summit region, southern Mongolia. - Candollea (in print)

von Wehrden, Henrik [1,2] and Zimmermann, Heike [1]
[1]Martin-Luther-University Halle-Wittenberg, Department of Geobotany and Botanical Garden, Am Kirchtor 1, 06108 Halle/Saale, Germany, E-mail of the corresponding author: HenrikvonWehrden@web.de
[2]Research Institute of Wildlife Ecology, Savoyen Strasse 1, Vienna, 1160 Austria

Abstract

We assessed the vegetation of the summit region of the Dund Saykhan mountain range located in southern Mongolia. The existing literature is set in context to our set of randomly obtained relevés, presenting a detailed description of the montane vegetation of one of the core zones of the Gobi Gurvan Saykhan National Park.

Two new associations and one regional sub-association are described, and the ecology of all associations/communities is related to their occurrence in the study area and the accompanying environmental characteristics. The landscape is dominated by *Festuca valesiaca* steppes; the southern slopes are covered by large juniper patches and, at similarly disturbed sites, *Artemisia santolinifolia* dominance stands are common. In contrast, the northern exposures are covered by a mosaic of dense *Kobresia* mats and *F. valesiaca* rock steppes.

Paper 5: Predictive mapping of plant species and communities by using GIS and Landsat data in a southern Mongolian mountain range. - Folia Geobotanica (accepted)

von Wehrden, Henrik[1,2,*], Zimmermann, Heike[1], Hanspach, Jan[3], Ronnenberg, Katrin[1] & Wesche, Karsten[1]

[1]Martin-Luther-University Halle-Wittenberg, Institute of Biology - Geobotany and Botanical Garden, Am Kirchtor 1, 06108 Halle/Saale, Germany, E-mail: *HenrikvonWehrden@web.de*
[2]Research Institute of Wildlife Ecology, Savoyen Strasse 1, Vienna, 1160 Austria
[3]UFZ, Helmholtz-Centre for Environmental Research - UFZ, Theodor-Lieser-Str. 4, 06120 Halle, Germany
*Corresponding author: Tel +493455526264

Abstract

We assessed presence/absence prediction of plant species and communities in a southern Mongolian mountain range from geospatial data using a randomised sampling approach. One hundred randomised vegetation samples (3 x 3 m) were collected within the 2 x 2 km summit region of the Dund Saykhan range, which forms part of the core zone of the Gobi Gurvan Saykhan National Park in arid southern Mongolia. Using logistic regression, habitat preference models for all abundant species (n=52) and communities (n=5) were constructed; predictors were derived from Landsat 5 imagery and a digital elevation model. Nagelkerkes r^2 was used for an initial data mining, and all significant models were validated by splitting the data and using one half for accuracy assessment based on the AUC (Area Under the receiver operating characteristic Curve)-values. Significant models could be built for half of the species. Altitude proved to be the most important predictor followed by variables derived from Landsat data. The clear altitudinal distribution patterns most definitely reflect precipitation; the overall biodiversity in this arid environment is widely controlled by moisture availability. The chosen approach may prove valuable for applied studies wherever spatial data on species distributions are required for conservation efforts.

Paper 6: Status and distribution of four endemic vascular plants in the Gobi Altay. - Mongolian Journal of Biological Sciences 3: 3-11.

K. Wesche[1], E. J. Jäger[1], H. von Wehrden[1,] R. Undrakh[2]

[1]Institute of 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 (†)
(Contribution no. 265 in the series "Results of the Mongolian-German Biological Expedition since 1962")
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.

Chapter 3: Large scale spatial analyses of patterns of plant biodiversity, vegetation and productivity by means of remote sensing and GIS data

Paper 7: Mapping the vegetation of southern Mongolian protected areas: application of GIS and remote sensing techniques. - Arid Ecosystems vol. 13, 33-34: 136-145.

H. von Wehrden*,**, K. Wesche*

*University of Halle/Wittenberg, Germany, E-Mail: henrikvonwehrden@web.de
**Research Institute of Wildlife Ecology, Savoyen Strasse 1, Vienna, 1160 Austria

Abstract. We present initial results of a vegetation survey of the Great Gobi A Strictly Protected Area. The plant biodiversity within this area is closely related to the average precipitation pattern. Thirteen plant communities were derived, and we chose plots for the nine zonal communities as ground truth data for a supervised classification of Landsat data. Accuracy of the final habitat map was >90%. We additionally give an overview of all remotely sensed data which we compiled to create a complex GIS data base. The GIS can serve as a tool for the protection and conservation of Przewalski Horses and Khulans.

Paper 8: Relationships between climate, productivity and vegetation in southern Mongolian drylands. - Basic and Applied Dryland Research 2: 100-120.

H. von Wehrden[1, 2] & K. Wesche[1]

[1]Institute of Biology - Geobotany and Botanical Garden, Martin-Luther-University Halle-Wittenberg, 06099 Halle, Germany
[2]Research Institute of Wildlife Ecology, Savoyen Strasse 1, Vienna, 1160 Austria
e-mail: HenrikvonWehrden@web.de

Abstract

We assessed the relationship between open-source data on net primary production and precipitation for the southern Mongolian Gobi, and related this information to data obtained from a set of 1418 vegetation relevés sampled in the region. Gradients determining plant community diversity and composition were examined, and the relation between α-diversity and key environmental parameters was tested.

The correlation between net primary production and precipitation within our working area was fairly high (r^2 = 0.66). The variance of the net primary production was related to the average annual precipitation; at sites with more than ~220 mm/a precipitation the median coefficient of variation in productivity data decreased, indicating a rather gradual shift from a non-equilibrium ecosystem towards an equilibrium ecosystem with increasing moisture. A DCA-ordination showed that the main gradient in plant community composition was closely correlated to environmental variables for altitude, precipitation and net primary production. All three parameters were also significant predictors of the species diversity. The final model, which included an additional quadratic term for longitude, predicted local plant biodiversity at r^2 = 0.57.

The results can be directly applied to both resource management and nature conservation within the area. For future studies a closer focus on the characterization on non-equilibrium rangelands based on modelled productivity layers is suggested.

Chapter 4: Application of vegetation maps

Paper 9: Resource selection by wild equids in the Mongolian Gobi. - Journal of Applied Ecology (45), 6: 1762-1769.

P. Kaczensky[1,2], O. Ganbaatar[2,3,4], H. von Wehrden[1,5] and C. Walzer[1,2]

[1] Research Institute of Wildlife Ecology, University of Veterinary Medicine, Austria
[2] International Takhi Group
[3] National University of Mongolia, Faculty of Biology, Department of Zoology, Mongolia
[4] Gobi B Strictly Protected Area Administration, Mongolia
[5] University of Halle, Institute of Biology/Geobotany and Botanical Garden, Germany

Summary

Historically, the overlap zones of wild equids were small in Africa but extensive for Przewalski's horses *Equus ferus przewalskii* and Asiatic wild asses *Equus hemionus* in Asia. Currently the Great Gobi B Strictly Protected Area in south-western Mongolia is the only place where sympatric, free-ranging populations of these equids occur. This provides a unique opportunity to test the hypothesis that Przewalski's horses are primarily adapted to mesic steppes and Asiatic wild asses to arid desert steppes and semi-deserts. Understanding the spatial needs and habitat requirements of these little studied species is a pre-requisite for setting aside and managing protected areas and planning future reintroductions.

From 2001 to 2005 we followed nine Przewalski's horses and seven Asiatic wild asses using satellite telemetry and direct observations to assess differences in their resource selection strategies and social organization.

Przewalski's horses had non-exclusive home ranges of 152-826 km², selected for the most productive plant communities and formed stable harems groups.

Asiatic wild asses had non-exclusive home ranges of 4,449-6,835 km², showed little preferences for any plant community and seemed to live in fission-fusion groups.

Synthesis and applications. Our results provide evidence for different resource selection strategies in two sympatric equid species. Our findings indicate that the Gobi areas provide an edge, rather than an optimal habitat for Przewalski's horses. Consequently only small and isolated pockets of suitable habitat remain for future re-introductions. Asiatic wild asses, on the other hand, need access to large tracts of land to cope with the unpredictable resource distribution of the Gobi. Managers should be aware that protecting habitat where Asiatic wild

asses occur does not necessarily benefit Przewalski's horse restoration, whereas setting aside habitat for the conservation of Przewalski's horses will only locally benefit Asiatic wild asses.

Chapter 5: Non equilibrium theory

Paper 10: Testing the global validity of the non-equilibrium theory of rangeland science by evaluating field studies against a common climatic data base. (manuscript)

von Wehrden, Henrik[1,2] , Hanspach, Jan[3], Kaczensky, Petra[2] & Wesche, Karsten[1,4]

[1]Martin-Luther-University Halle-Wittenberg, Institute of Biology - Geobotany and Botanical Garden, Am Kirchtor 1, 06108 Halle/Saale, Germany, E-mail: HenrikvonWehrden@web.de
[2]Research Institute of Wildlife Ecology, Savoyen Strasse 1, Vienna, 1160 Austria
[3]UFZ Helmholtz-Centre for Environmental Research, Theodor-Lieser-Str. 4, 06120 Halle, Germany
[4]Institute of Plant Sciences – Dept. of Ecology and Ecosystems Research, Georg-August-University Göttingen, Untere Karspüle 2, 37073 Göttingen, Germany

Abstract

1. Arguments supporting and contradicting the non-equilibrium (NEQ) theory of rangeland science have been summarised in a number of overview publications, but comparisons often suffer from inconsistent climatic background data.

2. We tested the NEQ paradigm on a global scale by evaluating published studies against a global precipitation model. The model was based on values for mean precipitation and variability of the precipitation derived from some 19000 climate stations.

3. Our re-evaluation supported the validity of the NEQ paradigm. Discrepancies between the assumed precipitation regime in several of the published studies and our global precipitation model explained why authors observed effects that seemingly contradicted the NEQ theory.

4. As predicted by the NEQ theory, grazing degradation is indeed limited to rangelands with a coefficient of variance (CV) of interannual precipitation (IP) <33%, or to non-zonal "equilibrated" zones within NEQ ecosystems. In zonal conditions with a CV of IP >33%, degradation is usually not reported.

5. Our global precipitation model offers an easy tool to check for rainfall variability, which should be a primary guideline for devising appropriate rangeland management strategies. Studies from dry- but nonetheless relatively stable environments (CV <33%) that undergo degradation prove that wide areas of the world's drylands are vulnerable to mismanagement.

Paper 11: Inter-annual climatic variability in Central Asia - a contribution to the discussion on the importance of environmental stochasticity in drylands. - Journal of Arid Environments (in prep. for resubmission)

von Wehrden, Henrik[1,2,*] , Hanspach, Jan[3], Ronnenberg, Katrin[1] & Wesche, Karsten[1,4]

[1]Martin-Luther-University Halle-Wittenberg, Institute of Biology-Geobotany and Botanical Garden, Am Kirchtor 1, 06108 Halle/Saale, Germany, E-mail: HenrikvonWehrden@web.de
[2]Research Institute of Wildlife Ecology, Savoyen Strasse 1, Vienna, 1160 Austria
[3]UFZ, Helmholtz Centre for Environmental Research - UFZ, Theodor-Lieser-Str. 4, 06120 Halle, Germany
[4]University of Göttingen, Dept. of Ecology and Ecosystems Research, Albrecht-von-Haller-Institute for Plant Sciences, Untere Karspüle 2, 37073 Göttingen, Germany
[*]Corresponding author

Abstract

Drylands are characterised by pronounced climatic fluctuations, especially in regards to precipitation. We tested the relationship between mean precipitation and variability values using monthly data from climate stations in both arid and semi-arid parts of Central and High Asia. Total annual and growing season precipitation values were also compared in order to produce results relevant to land-use. Our study confirmed the well known observation that variability increases with lower overall precipitation levels. The observed correlation indicated that precipitation variability increased dramatically where mean precipitation levels fell below 120 mm. This sheds new light on the transition between regimes with more regular rainfall patterns and those with episodic rainfall. This is fundamental for land management because with episodic rainfall, land-use is thought to be controlled by severe abiotic constraints. We therefore encourage future analysis for other parts of the world to improve our understanding of the relationship between climatic conditions and productivity in drylands.

Synthesis

The results presented here augment the available ecological knowledge on the southern Mongolian Gobi, but also highlight the need for further ecological studies in this vast dryland.
Despite the benchmark works of Hilbig (Hilbig, 1990, 1995, 2000b) and the modifications made within this study, our knowledge on the vegetation of the southern Mongolian Gobi is still far from comprehensive. The established syntaxonomical system provides a relatively sound overview, which is indicated by the relatively minor changes that were necessary in comparison to Hilbig's earlier accounts on a Gobi-wide scale. However, the detailed case studies described above resulted in a deeper understanding regarding certain associations; this indicates that for many communities, more data would certainly result in major new insights. In terms of vegetation description the situation is, however, more dramatic in Inner Mongolia, from where only a few phytosociological data or vegetation descriptions have been published in the international literature (for an example see Kürschner, 2004).
The limited phytosociological knowledge parallels the likewise coarse knowledge on vegetation distribution (e.g. Anonymous, 1990; Gunin & Vostokova, 1995). For the southern Mongolian protected area, the resolution of the available vegetation maps was improved in the course of this dissertation: In the context of Central Asia, these are now virtually the only regions mapped on a reasonably detailed spatial scale (yet see Sha et al., 2008). Our studies confirmed that Landsat is a suitable standard platform for such efforts (Leimgruber et al., 2005), and Landsat images proved reliable, even for the arid rangelands of Central Asia. (von Wehrden et al., 2006).
Modelling biodiversity based on remotely sensed predictors is now commonplace (e.g. Duro et al., 2007; Kerr & Ostrovsky, 2003), and examples of successful applications in the field of plant biodiversity have been published for both drylands (e.g. John et al., 2008) and montane regions (e.g. Levin et al., 2007). Within this dissertation, such an analysis was however performed for the first time for Central Asia on a plant-species data set for a supra-regional scale. Topographical information, climate models and remotely sensed productivity data (e.g. Hijmans et al., 2005; Jarvis et al., 2006; Tucker et al., 2005) proved valuable for modelling plant biodiversity, and were to my knowledge combined for the first time to model biodiversity in an arid environment. My results prove that, given a sufficient predictor resolution, plant biodiversity can be modelled and/or interpreted on at least three spatial

scales; thus the GIS and remote sensing predictors are able to reflect the gradients on a local (2x2 km), regional (tens of thousands km^2) and Gobi-wide scale (hundreds of thousands km^2). In addition to spatial variation, temporal variability is known to control patterns in arid environments, and a variety of studies dealing with rangeland dynamics are available from Inner Mongolia and other parts of arid and semi-arid China (e.g. Christensen et al., 2003; Ho, 2001; Kawamura et al., 2005; Klein et al., 2007; Runnstrom, 2000; Wang et al., 2004; Zhang et al., 2005). Most publications focus on the patterns of productivity/climate on a regional or local scale, yet some studies examine productivity dynamics on a larger scale by remote sensing and/or modelling approaches (e.g. Brogaard et al., 2005; Christensen et al., 2003; Kawamura et al., 2005; Runnstrom, 2000, 2003); these indicate severe degradation in Inner Mongolia and adjacent Chinese regions, and point at to equilibrium conditions, at least for the moister steppe ecosystems, which is in line with unpublished data (remotely sensed productivity variability) processed by the author. For Outer Mongolia, studies on regional (e.g. Fernandez-Gimenez & Allen-Diaz, 2001; Fernandez-Gimenez & Allen-Diaz, 1999; Retzer & Reudenbach, 2005; Stumpp et al., 2005; Wesche et al., 2007) scales undertaken in the Gobi region indicate non-equilibrium conditions; studies on supra-regional scales (Kogan et al., 2004; Leimgruber et al., 2001) are likewise available, yet do not focus on the designation of ecosystem variability. Thus, studies based on field data indicate variable environments; available remote sensing studies do not detect patterns for the arid parts of the Mongolian Gobi (e.g. Yu et al., 2004), which was the focus region for this dissertation. However, the results of this dissertation corroborate other studies (e.g. Al-Bakri & Taylor, 2003; Holm et al., 2003; Ichii et al., 2002; Pickup, 1996; Wessels et al., 2007), which describe a relation between precipitation and productivity within the examined regions. Thus variability patterns accessed by means of remote sensing data (Chen et al., 2004; Paruelo & Lauenroth, 1998; Wessels et al., 2007) have already been analysed in other regions of the world; but studies presented here indicate that GLOPEM data are applicable even in arid environments, which offers new perspectives for further studies.

Results of this dissertation also close a regional gap regarding our understanding of rangeland dynamics in semi-arid to arid regions. The examined relations between the mean precipitation, the CV of the precipitation (both annual sums as well as focussed on the growing season) and the CV of the productivity improve our understanding of the gradual transition zone between rather stable drylands and regions that encounter non-equilibrium dynamics. The data support studies from other regions, where comparable transition zones are known (e.g. Diouf & Lambin, 2001; Reeves et al., 2006; Wessels et al., 2007). Thus, the non-equilibrium theory (e.g. Ellis & Swift, 1988) was largely supported by this dissertation. Numerous reviews on the subject are available (e.g. Illius & O'Connor, 1999; Sullivan & Rohde, 2002; Vetter, 2005), but the climatic thresholds differentiating equilibrium from non-equilibrium ecosystems are still not clear (Gillson & Hoffman, 2007), hence the intense debate surrounding the overall concept (Vetter, 2005). Our review study has at least partly clarified this controversy, since levels of climatic variability seem to distinguish the principal rangeland systems; which was confirmed by the data on degradation included in our analysis. The impact of grazing, with degradation as the ultimate consequence, appears to be widely governed by precipitation variability on a global scale.

The wildlife of the southern Mongolian Gobi has widely been replaced by livestock, which is more spatially aggregated. Moreover, the livestock experience non-equilibrium dynamics, and probably to a greater extent than the wildlife (Retzer & Reudenbach, 2005). Nomads tend only to migrate to different zones during extreme years (Bedunah & Schmidt, 2004), while most large wild herbivores have an inherently higher mobility. This was demonstrated for khulan (Gobi wild ass: *Equus hemionus*) using telemetry data during the course of this dissertation. Herds avoid extreme droughts by conducting long-distance migrations, and relative losses are probably lower than in domestic herds, which often collapse in dry years. Analyses of habitat use of wildlife species by means of telemetry (Ropert-Coudert & Wilson, 2005) and remotely sensed data (McDermid et al., 2005) are common applications nowadays (Aarts et al., 2008; Hulbert & French, 2001; Rushton et al., 2004). Still, to our knowledge no such application has been used for equids, and the results presented here serve as a starting point for habitat analysis of these taxa. Based on the derived ecological data (e.g. vegetation maps, productivity) and habitat-use analysis, suitable sites were already identified in the Dzungarian Gobi where newly introduced Przewalski horses were released (www.takhi.org). Most of the available habitat analyses for other taxa do not test for autocorrelation, and rather few studies account for the unbalanced design and serial pseudo-replication of the datasets (Aarts et al., 2008; Gillies et al., 2006). Thus, the analysis presented here also informs methodological approaches for telemetry studies in general.

A final methodological contribution is presented in the dissertation for the field of statistics. A variety of paper and textbooks dealing with multivariate statistics in ecology are available (e.g. Gauch, 1994; Gilliam & Saunders, 2003; Jackson & Somers, 1991; James & McCulloch, 1990; McCune et al., 2002; Palmer, 1993, 2006; Podani, 2005; ter Braak & Smilauer, 2002; van Groenewoud, 1992, Kent, 2006; Kent & Ballard, 1988). Still, the available literature does not agree on the quality of the different methods, and data-driven reviews on the frequency and abundance of ordination techniques being used were outdated (e.g. Kent & Ballard, 1988). The review of methods employed presented in the dissertation contributes somewhat to this discussion by testing the number of applications for the different ordination methods within vegetation sciences. Our analyses revealed that the complete array of methods was applied throughout all years. This is an important contribution to the question which ordination method is preferable – obviously all are still necessary, and the whole methodological spectrum was applied by the scientists and accepted by the reviewers. Moreover, in recent years the choice of methods was found to be less constrained by the software available than before.

Outlook

The present study can be considered a work in progress as some questions remain unanswered and more questions arose from the insights gained. Moreover, several of the revealed patterns require further examination on a more global scale, and as such, the established methods and ideas shall be applied on broader temporal and spatial scales in the future.

The designated plant communities will be fed into a habitat key, which is currently used to access the habitat connections of the bird species of the southern Mongolian Gobi; this analysis will contain both observations by the author (HVW) and compile data based on the available literature. Distribution maps of all bird species have already been collected with a view to analysing the biogeography of the southern Mongolian avi-fauna.

The distribution of the vegetation types of the southern Mongolian Gobi was mapped for the first time on a reasonably detailed spatial scale, but only for the protected areas and their surroundings. These areas cover only one quarter of the southern Mongolian Gobi, thus for most of the region, fine-scaled vegetation maps are still lacking. Since further mapping would demand tremendous efforts in regards to vegetation sampling, it must be assumed that during the following years no further surveys will be conducted. Based on the available ground-truth data, a vegetation map of the whole region may nonetheless be processed based on MODIS data. This would yield maps at a scale of ~1:250 000, which would enable a medium-scaled habitat analysis for animals roaming outside the protected areas.

Regarding the geographical distribution of most of the plant species, our knowledge is even poorer than for the vegetation. Several studies provide distribution maps for species typically occurring in northern Mongolia, but the distribution of the drier climate flora of the southern Mongolian Gobi still needs to be examined. Therefore, we will use established models (e.g. MAXENT, Phillips & Dudik, 2008) to attempt to derive distribution maps of all the abundant plant species (as included in our dataset) using remotely sensing products and climate data as predictors.

Large proportions of the biodiversity are restricted to the relatively small montane ranges within the southern Mongolian Gobi. These habitats should receive special attention in further studies of both plant and animal life. This would enable the restructuring of boundaries of the protected areas to bring them into line with IUCN categories (e.g. Man and Biosphere). The now available data may help to designate core zones for conservation based on the vegetation and plant biodiversity of the region. This would probably facilitate funding and enable monitoring and help maintain the biodiversity of these sites.

Precipitation variability is the key factor for understanding animal fluctuations within the southern Mongolian Gobi and it is the main factor driving migrations of larger mammals. Therefore, more analysis of the precipitation and its interaction with the productivity would be of benefit to both wildlife and livestock conservation.

Gaining a deeper understanding of spatial and temporal variation in fodder availability may thus have ecological and economic importance and would be crucial in determining any competition between livestock and wildlife. Based on the analyses established within this dissertation, further analyses of the habitat use of equids will be performed on a Gobi-wide scale. However, habitat use of several other endangered mammal species (e.g. Wild camels, Gobi bears, Argalis) has not been examined in detail so far. The available GIS-datasets would facilitate analysis for most of these species as well, with likely benefits for conservation efforts and basic research. This is especially important as processing of the climate data in the course of the present thesis revealed severe climate change within Central and High Asia, with temperature rises of up to 3°C in the last 60 years. These data are of clear relevance for conservation schemes and habitat analyses.

The most severe challenge identified within this study is obtaining further insights into the global framework of the NEQT paradigm. Our studies proved that degradation is sometimes overemphasized in non-equilibrium ecosystems, although most often downplayed because of a misunderstanding of the NEQT. Since more than a third of the globe's terrestrial surfaces are drylands, this could have tremendous implications for land use and management. The climatic variability of each biome in the region has already been modelled, and for drylands, a finer differentiation into regional ecozones will be attempted as well. This should generate further knowledge on climatic variability in the context of regional and local rangeland types, e.g. savannahs, grasslands or semi-deserts.

Regarding the ordination review, parts of the data will be incorporated into a comparison between an ISI (Web of knowledge)™ driven review and a review performed through Google™ Scholar. This analysis should reveal the benefits and drawbacks of both methods as evaluated against the manually revised dataset used in the ordination review.

Short overall summary

The studies presented provide new insights into the ecological characterisation, description and dynamics of the southern Mongolian drylands. Numerous new plant associations/sub-associations/communities have been described, ranging from montane regions and semi-deserts towards oases. Furthermore, the placement of several syntaxonomic units was clarified.

In the course of a detailed case study in the Dund Saykhan mountain range, the ecology of a montane ecosystem, which contains the highest biodiversity in the Gobi desert, was examined by a randomized sampling approach; furthermore the distribution of four endemics was mapped and discussed. The randomized design revealed valid models based on the transformation of Landsat satellite imagery and SRTM altitudinal data for a high proportion of the plant species. The analysis revealed a clear altitudinal gradient of plant biodiversity. A large-scale analysis showed a similar pattern, where plant biodiversity is widely positively correlated with altitude, precipitation and productivity, all of which are highly redundant. This pattern was examined based on simple linear models; however, an indirect ordination (DCA) of the zonal vegetation supported the inferences.

Vegetation maps were derived for all large southern Mongolian protected areas and adjacent areas (~150000 km^2) using all 1518 available vegetation relevés as ground-truth data. The final vegetation maps were combined with other spatial predictors (e.g. altitude based on SRTM data, productivity data derived from GLOPEM) and used for the analyses of movement patterns of *Equus przewalskii* and *Equus hemionus*. Data on migrations obtained from collared animals were used for an analysis of their home ranges. Based on this approach, the habitat preferences of these two equids were modelled. Using a post-hoc test, habitat preference was also quantified based on the vegetation map. While wild asses showed no clear habitat preference, the Przewalski's horses selected more productive riparian vegetation and desert steppe vegetation, which they favoured over semi-desert vegetation types.

Further understanding of the dynamics of the variability of rangelands was gained through analysis of the annual rainfall patterns within Central and High Asia. Based on temperature values, the proportion of the precipitation which falls during the growing season was examined; this revealed a more precise demarcation of the gradual border between equilibrium and non-equilibrium ecosystems and offered further insights into the stochastic dynamics of rangelands. Thus, the variability of the precipitation was pronounced in an analysis that focused on the growing season only. Inter-annual variability increased tremendously at precipitation sums below 120 mm/a, which differentiates climatic regimes with periodic precipitation patterns from areas which endure more episodic rainfall.

The dependence of rangeland dynamics on climatic variability was tested in a global review for which available literature was examined against a global model of the precipitation coefficient of variability. The formerly proposed border of 33% coefficient of variability was confirmed as forming the threshold between degraded, sensitive equilibrium systems and less affected non-equilibrium systems. Degradation in regions with precipitation variability <CV 33% is widely restricted to areas around key resources and water sources. Within equilibrium ecosystems, permanent changes in the ecosystem due to livestock grazing are ubiquitous.

Since numerous ordinations of various datasets were performed within the course of this dissertation, another review with a more methodological focus was compiled in order to put the employed methods into context. From 1990-2007 all papers using ordination techniques within five journals with a focus on vegetation sciences were manually accessed. An additional ISI-driven search found about one third of the references retrieved through the manual search. Of all ordination techniques, DCAs were most abundantly applied. Still, high methodological diversity was maintained throughout all years.

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Appendix

Appendix paper: Methodological considerations

Pluralism and diversity - trends in the use and application of ordination methods 1990-2007. - Journal of Vegetation Science (in print)

von Wehrden, Henrik[1,2,*], Hanspach, Jan[3], Bruelheide, Helge[1] & Wesche, Karsten[4]

[1]Martin-Luther-University Halle-Wittenberg, Institute of Biology - Geobotany and Botanical Garden, Am Kirchtor 1, 06108 Halle/Saale, Germany, E-mail: *HenrikvonWehrden@web.de*, Helge.Bruelheide@botanik.uni-halle.de
[2]Research Institute of Wildlife Ecology, Savoyen Strasse 1, Vienna, 1160 Austria
[3]UFZ, Helmholtz-Centre for Environmental Research - UFZ, Theodor-Lieser-Str. 4, 06120 Halle, Germany, E-mail: *Jan.Hanspach@ufz.de*
[4]Dept. of Ecology and Ecosystems Research, A. von Haller Inst. of Plant Sciences, Untere Karspüle 2, 37073 Göttingen, Germany, E-Mail: *Karsten.Wesche@biologie.uni-goettingen.de*
*Corresponding author: Tel +493455526264

Abstract

Question: What are the trends and patterns in the application of ordination techniques in vegetation science since 1990?

Location: Worldwide literature analysis.

Methods: Evaluation of five major journals of vegetation science; search of all ISI-listed ecological journals. Data were analysed with ANCOVAs, Spearman's rank correlations, GLMs, biodiversity indices and simple graphs.

Results: The ISI search retrieved fewer papers using ordinations than the manual evaluation of five selected journals. Both retrieval methods revealed a clear trend of increasing frequency of ordination applications from 1990 to the present. CCA was far more frequently detected by the ISI search than any other method. Applications such as CA/RA and DCA have increasingly been used in studies published in 'applied' journals, while CCA, RDA and NMDS were more frequently used in journals focusing on more 'basic' research. DCA was overall the most commonly applied method within the five major journals although the number of publications slightly decreased over time. NMDS has increased over the last ten years.

Conclusion: The availability of suitable software packages has facilitated the application of certain techniques such as NMDS. However, choices of ordination techniques are currently less driven by the constraints imposed by the software; there is also only limited evidence that the choice of methods follows social considerations such as the need to use fashionable methods. Methodological diversity has been maintained or has even increased over time and

reflects the researcher's need for diverse analytical tools suitable for a wide range of questions.

Publications of the dissertation

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von Wehrden, H., Hanspach, J., Kakzensky, P. & Wesche, K. (manuscript) Testing the global validity of the non-equilibrium theory of rangeland science by evaluating field studies against a common climatic data base.

von Wehrden, H., Hanspach, J., Ronnenberg, K. & Wesche, K. (in prep. for resubmission) Inter-annual climatic variability in Central Asia - a contribution to the discussion on the importance of environmental stochasticity in drylands.

von Wehrden, H., Hanspach, J., Bruelheide, H. & Wesche, K. (in print) Pluralism and diversity - trends in the use and application of ordination methods 1990-2007.

Contributions to conferences

Bruelheide, H., von Wehrden, H., Hanspach, J., Wesche, K. (2009) Of fashion in vegetation science: How did the use of different ordination methods change between 1990 and 2007? Talk at the IAVS, Crete.

von Wehrden, H., Hanspach, J., Zimmermann, H., Ronnenberg, K., Wesche, K. (2009) Modelling plant distribution in the Gobi Altay: Influence of local topography and overall distribution range. Talk at the AK Biogeography, Bayreuth.

Wesche, K., von Wehrden, H., Bruelheide, H., Hanspach, J. (2009) Trends in the use and application of ordination methods 1990-2007. Talk at the Datenbankentagung, 26.2-28.2 2009 in Greifswald.

von Wehrden, H., Hanspach, J. Kaczensky, P. & Wesche, K. (2008) The non-equilibrium theory – a comparison between existing data and a new climate data set. Talk at the annual GfÖ-meeting 2008: "Biodiversity in an Ecosystem Context" 15.-19. September 2008 in Leipzig.

von Wehrden, H., Hanspach, J. & Wesche, K. (2008) Predictive mapping of plant species based on climatic and remote sensing derived predictors – a drylands perspective from southern Mongolia. Poster at the annual GfÖ-meeting 2008: "Biodiversity in an Ecosystem Context" 15.-19. September 2008 in Leipzig.

Kaczensky, P., Ganbaatar,O., von Wehrden, H., Enksaikhan, N., Lkhagvasuren, D. & Walzer, C. (2008) Przewalski horse re-introduction in the Great Gobi B SPA – from species to ecosystem conservation. Talk at the conference Fundamental and Applied Issues of Ecology and Evolutionary Biology for 20th Anniversary of the Department of Ecology, Faculty of Biology, National University of Mongolia

von Wehrden, H., Walzer, C. & Kaczensky, P. (2008) Conservation of a vast arid ecosystem – Habitat mapping and modelling in southern Mongolia. Talk at the INTA Bariloche, Argentina.

Wesche, K., von Wehrden, H. & Hanspach, J. (2008) Klimatischer Hintergrund, Vorstellung des Phänomens zeitlicher Variabilität, globale Verteilung von Trockengebieten mit stark schwankenden Niederschlägen. Talk at a conference: Beweidungsökologie und –Management in Trockengebieten 2.-3. Februar 2008, Leipzig.

Kakzensky, P. Ganbaatar, O., von Wehrden, H. & Walzer, C. (2007) Similar Species, Same Habitat – Same Use? Talk at the 6th International Zoo and Wildlife Research Conference on Behaviour, Physiology and Genetics, Berlin.

von Wehrden H., Zimmermann, H, Hanspach, J., Ronnenberg, K. & Wesche, K. (2007) Predicting the occurrence of plant species and communities in an arid southern Mongolian mountain range. Poster at the the GFOE, Symposium 05: Spatial Statistics, Marburg.

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.

Wesche, K., Ronnenberg, K. & von Wehrden H. (2007) Ecology of Central Asian desert steppes - Where do we stand? Talk at the meeting of the AK Wüstenökologie, Leipzig.

Hanspach, J., Zimmermann, H., 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.

Stubbe, M., Stubbe, A., von Wehrden, H., Batsajchan, N. & Samjaa, R. (2006) Biodiversität in Raum und Zeit. Talk at the "III. Deutsch-Mongolisches Expertentreffen für biologische Forschung in ariden Gebieten der Mongolei", Ulaanbataar, Mongolia.

von Wehrden, H., Wesche, K., Kaczensky,P. & Walzer, C. (2006) Habitat mapping of the Bactrian Camel (*Camelus bactrianus ferus*) in southern Mongolia. Poster at the international Workshop on conservation and managment of the wild bactrian camel, Ulaanbaatar, Mongolia.

Tsolmon, A., von Wehrden, H. (2006) Habitat mapping of the Wild Bactrian Camel (*Camelus bactrianus ferus*) in southern Mongolia. Proceedings "International Workshop on conservation and managment of the wild bactrian camel". Ulaanbaatar, Mongolia 12-14 October, 2006, pp. 59-60.

Wesche, K., von Wehrden, H. & Ronnenberg, K. (2006) Spatial and temporal variability in plant communities of Mongolian drylands. In: Jiang Pingan, Yu Xinxiao, S.-W. Breckle, Gao Jiaron, M. Veste (eds.) Proceedings of the workshop on "Biodiversity and its role for ecosystem functioning and services in drylands", Urumqi, China, 3.-10.10.2006.

von Wehrden, H. Tsolmon, A. (2006) Vegetation mapping of the 'Great Gobi A' strictly protected area. Paper and talk 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, Ulaanbataar, Mongolia.

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, Ulaanbataar, Mongolia.

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

von Wehrden H. & Wesche K. (2006) Habitat mapping of the Asiatic Wild Ass (*Equus hemionus hemionus*) in southern Mongolia. Poster at the international conference on remote sensing, UlaanBataar, Mongolia.

von Wehrden, H., Wesche, K. (2006) El sur de Mongolia – una corta introducción.Oral presentation at the Univ. Córdoba, Argentinia.

von Wehrden, H., Tsolmon, A., Zimmermann, H., Tuvshin, (2005) Short summary of our fieldwork undertaken during summer 2005, Ulaanbataar, Mongolia.

von Wehrden, H., Wesche, K. (2005) Mapping the vegetation of southern Mongolian protected areas: application of GIS and remote sensing techniques. Talk at the International conference "Ecosystems of Mongolia and frontier areas of adjacent countries: natural resources, biodiversity and ecological prospects", Ulaanbaatar; Mongolia.

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

von Wehrden, H., Wesche, K. (2005) Phytosociological data as ground truth for vegetation mapping in southern Mongolia. Talk at the "WorkshopVegetationsdatenbanken", Halle.

von Wehrden, H. (2005) Vegetation mapping in the Gobi Gurvan Saykhan National Park and the Great GobiB Strictly Protected Area – a comparison of first results. Talk at the international workshop "Ecosystem research in the arid environments of Central Asia: Results, challenges, perspectives ", Ulaanbaatar; Mongolia.

Kaczensky, P., Enkhsaikhan, N., Ganbaatar, O., Samjaa, R., von Wehrden, H. and Walzer, C. (2004) Takhis, khulans, wolves and vegetation-an ecosystem approach for Takhi conservation. Talk at the International workshop on the reintroduction of the Przewalski's horse, Takhin Tal, Mongolia.

Kaczensky, P., Enkhsaihan, N., Ganbaatar, O., Samjaa, R., von Wehrden, H. & Walzer, C. (2004). Takhis, khulans, wolves and vegetation – an ecosystem approach for takhi conservation. Mongolian Journal of Biological Sciences 2(2): 60 (in English with a Mongolian summary).

von Wehrden, H. & Wesche, K. (2002) Mapping of large-scale vegetation pattern in southern Mongolian semi-deserts - an application of LANDSAT 7 data. - Poster on the meeting of the "AK Wüstenökologie der Gesellschaft für Ökologie", Rauischholzhausen, Univ. Giessen.

von Wehrden, H. & Wesche, K. (2002) Mapping of large-scale vegetation pattern in southern Mongolian semi-deserts - an application of LANDSAT 7 data. Poster at the "Jahrestagung der Gesellschaft für Ökologie" (eds T. Peschel, J. Mrzljak & G. Wiegleb), Verhandlungen der Gesellschaft für Ökologie Band 32: 177. TU Cottbus, Cottbus.

Other publications by the author

von Wehrden, H. (manuscript) Habitats of the southern Mongolian Gobi - their Avifauna and its distribution.

Juan Carlos Illera, J. C., von Wehrden & Wehner, J. (manuscript) Habitat of *Saxicola dacotiae* accessed by remote sensing and GIS on the landscape level.

Heklau, H. & von Wehrden, H. (manuscript) Woody anatomical traits of *Krascheninnikovia ceratoides* reflecting the distribution in steppes or semi-deserts in Eurasia and Western North America.

Schindler, S. Poirazidis, K., Papageorgiou, A., Kalivas, D., von Wehrden, H., Kati V. (accepted) Landscape approaches and GIS as a prerequisite for biodiversity management in a Mediterranean forest landscape. In: Andel J, Bicik I, Dostal P, Lipsky Z, Shahneshin SG, Raska P (eds), Landscape modelling: geographical space, transformation and future scenarios, Urban and Landscape Perspectives Series, Springer-Verlag.

Schindler, S., von Wehrden, H., Poirazidis, K., Wrbka, T. & Kati, V. (in prep. for resubmission) Multiscale performance of landscape metrics as indicators of species richness of plants, insects and vertebrates.

Kaczensky, P., Ganbaatar,O., von Wehrden, H., Enksaikhan, N., Lkhagvasuren, D. & Walzer, C. (2007) Przewalski horse re-introduction in the Great Gobi B SPA – from species to ecosystem conservation. Mongolian Journal of Biological Sciences, 5, p. 13-18.

Wesche, K., Assefa, Y., von Wehrden, H. (2008) Temperate Grassland Region: Equatorial Africa (high altitude). In: Peart, B. Life in a Working Landscape: Towards a Conservation Strategy for the World's Temperate Grasslands - Compendium of Regional Templates on the Status of Temperate Grasslands. Conservation and Protection. IUCN / WCPA. Temperate Grasslands Conservation Initiative, Vancouver: 5-21.

von Wehrden, H. (2008) The Giant Hummingbird (*Patagona gigas*) in the Mountains of Central Argentina and a Climatic Envelope Model for its Distribution. The Wilson Journal of Ornithology 120(3):648-651. 2008.

Stubbe, A., Stubbe, M., von Wehrden, H., Batsajchan, N. & Samjaa, R. (2007) Biodiversity in space and time - towards a grid mapping for Mongolia. Exploration into the Biological Resources of Mongolia 10: 391-406.

von Wehrden H. & Wesche K. (2007) Mapping Khulan habitats - a GIS-based approach. Exploration into the biological resources of Mongolia 10: 31-44.

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(3), 261-72.

von Wehrden H. (2005) Vegetation mapping in the Gobi Gurvan Saykhan National Park and the Great Gobi B Special Protected Area - a comparison of first results. Exploration into the biological resources of Mongolia 9: 225-236.

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.

Other conference contributions by the author

Hirsch, H., Zimmermann, H., von Wehrden, H., Renison, D., Ritz, C., Hensen, I. (2009) Where is the European origin of the Rosa rubiginosa, (Rosaceae) invasion in Argentina. Poster at the PopBio conference. 21-24. May 2009, Bern, Switzerland.

Schindler, S., Kati, V., Poirazidis, K. & von Wehrden, H. (2008) The performance of landscape structure variables as predictors of biodiversity. Testing the effect of scale, method of composition sets and taxon under concern. Talk at the Landscape Ecology International Conference Chengdu, China.

Wesche, K., Assefa, Y. & von Wehrden, H. (2008) Temperate Grassland Region: High mountain grasslands of equatorial Africa. Regional Summary Template. Talk at the Temperate Grasslands Conservation Initiative Meeting, Hohhot, China.

Schindler, S., Kati, V., von Wehrden, H., Wrbka, T. & Poirazidis, K. (accpeted) Landscape metrics as biodiversity indicators for plants, insects and vertebrates at multiple scales.

von Wehrden, H.: Anwendung von multivariater Statistik in der Ornithologie. Talk at the „18. Jahrestagung und Mitgliederversammlung 2008 - Ornithologenverband Sachsen-Anhalt e. V. (OSA).

Schindler, S., Kati, V., Poirazidis, K. & von Wehrden, H. (2008) The performance of landscape structure variables as predictors of biodiversity. Testing the effect of scale, method of composition sets and taxon under concern. Talk at the Landscape Ecology International Conference Chengdu, China.

Wesche, K., Yoseph Assefa, Henrik von Wehrden. 2008. Temperate grassland region: Equatorial Africa (High Altitude). Invited Talk at the workshop of the World Temperate Grassland Conservation Initiative / International Grassland and Rangeland Congress, Huhhot, China.

von Wehrden, H., Hanspach, J. Bruelheide, H. & Wesche, K. (2008) Of arches, horseshoes and unheard methodological advice: How popular are different ordination methods in vegetation science. Talk at the university of Córdoba, Argentinia.

von Wehrden, H. & Hellmich, J. (2007). Mapping the display sites of *Chlamydotis undulata fuerteventurae* based on Landsat and GIS. Talk at the GFOE, Symposium 13, Marburg.

reports

Wesche K. & von Wehrden H. (2001) Interim report: Mapping of vegetation units of the Gobi Gurvan Saikhan National Park. Martin-Luther University Halle Wittenberg, Halle.

Wesche K. & von Wehrden H. (2002) Vegetation types of the Gobi Gurvan Saikhan National Park (South Gobi Aimag, Mongolia) - Classification and spatial distribution. gtz - Buffer Zone Development Project, Ulaan Bataar.

von Wehrden H. (2003) Mapping of vegetation units of the Great Gobi B National Park. University of Marburg, Marburg. Interim report for the Przewalski-horse project (www.takhi.org)

von Wehrden H. & Tungalag R. (2004) Mapping of vegetation units of the Great Gobi B National Park. University of Halle, Marburg. Final report for the Przewalski-horse project (www.takhi.org)

von Wehrden H., Tsolmon A., Appel K., & Rüthrich F. (2005) Report for the administration of the Great Gobi A strictly protected area. Martin-Luther University Halle Wittenberg, Halle.

K. Wesche, von Wehrden, H., Ronnenberg, K. & Tuvshin, A. (2006) Monitoring of grazing exclosures and other activities by the Gobi Gurvan Saykhan Research Project in 2005 and 2006. Interim Report, Martin-Luther University Halle Wittenberg, Halle.

Erklärung über den persönlichen Anteil an den Publikationen

The following list shall give an overview of my own contribution to the studies included within this dissertation. This is split into fieldwork, analysis, writing and editing of the publication. I am also very grateful for the corrections and suggestions made by the reviewers, who are acknowledged in the individual publications.

von Wehrden H., Wesche K., Miehe, G. & Miehe, S. (accepted) Plant communities of the southern Mongolian Gobi. Phytocoenologia.

Fieldwork:	**Henrik von Wehrden** (60 %); Georg & Sabine Miehe (15%); Karsten Wesche (15 %); Kathariana Appel, Frank Rüthrich, Adida Tsolmon, Heike Zimmermann (together 10 %)
Analysis:	**Henrik von Wehrden** (90 %); Karsten Wesche (10 %)
Writing the paper:	**Henrik von Wehrden** (80 %, corrections by Karsten Wesche & Georg Miehe)

von Wehrden H., Tungalag, R. & Wesche K. (2006) Plant communities of the Great Gobi B Special Protected Area in south-western Mongolia. Mongolian Journal of Biological Sciences.

Fieldwork:	**Henrik von Wehrden** (80 %); Radnaakhand Tungalag (15%); Karsten Wesche (5 %)
Analysis:	**Henrik von Wehrden** (80 %); Karsten Wesche (20 %)
Writing the paper:	**Henrik von Wehrden** (85 %, corrections by Karsten Wesche)

von Wehrden H., Wesche K. & Hilbig W. (2006) Plant communities of the Mongolian Transaltay Gobi. Feddes Repertorium.

Fieldwork:	**Henrik von Wehrden** (65 %); Werner Hilbig (15%); Karsten Wesche (5 %); Kathariana Appel, Frank Rüthirch, Adida Tsolmon (together 15 %)
Analysis:	**Henrik von Wehrden** (75 %); Werner Hilbig (20 %); Karsten Wesche (5 %)
Writing the paper:	**Henrik von Wehrden** (80 %, corrections by Werner Hilbig & Karsten Wesche)

von Wehrden, H. & Zimmermann, H. (in print) Plant communities of the Dund Sayhan peak region, southern Mongolia. Candollea.

Fieldwork:	Heike Zimmermann (50 %); **Henrik von Wehrden** (40 %); U. Tuvshin (10 %)
Analysis:	**Henrik von Wehrden** (95 %); Heike Zimmermann (5 %)
Writing the paper:	**Henrik von Wehrden** (90%, corrections by Heike Zimmermann)

von Wehrden, H., Zimmermann, H., Hanspach, J., Ronnenberg, K., Wesche, K. (accepted) Predictive mapping of plant species and communities by using GIS and Landsat data in a southern Mongolian mountain range. Folia Geobotanica.

Fieldwork:	Heike Zimmermann (50 %); **Henrik von Wehrden** (40 %); Tuvshin (10 %)
Analysis:	**Henrik von Wehrden** (70 %); Jan Hanspach (25 %); Katrin Ronnenberg, Karsten Wesche & Heike Zimmermann (5 %)
Writing the paper:	**Henrik von Wehrden** (80%, corrections by Jan Hanspach, Katrin Ronnenberg, Karsten Wesche & Heike Zimmermann)

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.

Fieldwork:	Undrakh (50 %); Karsten Wesche (50 %)
Analysis:	Undrakh (40 %); Karsten Wesche (25 %); Eckehart J. Jäger (25 %); **Henrik von Wehrden** (10 %)
Writing the paper:	Karsten Wesche (80%, corrections by **Henrik von Wehrden** & Eckehart Jäger)

von Wehrden H. & Wesche K. (2007) Mapping the vegetation of southern Mongolian protected areas: application of GIS and remote sensing techniques. Arid Ecosystems.

Fieldwork:	**Henrik von Wehrden** (80 %); Karsten Wesche (5 %); Katharina Appel, Frank Rüthrich, Adida Tsolmon (together 15 %)
Analysis:	**Henrik von Wehrden** (95 %); Karsten Wesche (5 %)
Writing the paper:	**Henrik von Wehrden** (90%, corrections by Karsten Wesche)

von Wehrden, H. & Wesche, K. (2007) Relationships between climate, productivity and vegetation in southern Mongolian drylands. Basic and Applied Dryland Research.

Data collection:	**Henrik von Wehrden** (80 %); Karsten Wesche (10 %); Georg & Sabine Miehe (together 10 %)
Analysis:	**Henrik von Wehrden** (90 %); Karsten Wesche (10 %)
Writing the paper:	**Henrik von Wehrden** (85%, corrections by Karsten Wesche)

Kakzensky, P. Ganbaatar, O., von Wehrden, H. & Walzer, C. (2008) Differences in habitat use and social behavior of sympartric Przewalski's horse and Asiatic wild ass Mongolia. Journal of Applied Ecology.

Fieldwork:	**Henrik von Wehrden** (50 %); Petra Kaczensky, Chris Walzer & O. Ganbaatar (50 %)
Analysis:	Petra Kaczensky (50 %); **Henrik von Wehrden** (50 %)
Writing the paper:	Petra Kaczensky (70%, corrections by **Henrik von Wehrden**, Chris Walzer & O. Ganbaatar)

von Wehrden, H., Hanspach, J., Kakzensky, P. & Wesche, K. (manuscript) Testing the global validity of the non-equilibrium theory of rangeland science by evaluating field studies against a common climatic data base. Journal of Applied Ecology.

Data collection:	**Henrik von Wehrden** (95 %); Karsten Wesche & Jan Hanspach (together 5 %)
Analysis:	**Henrik von Wehrden** (80 %); Karsten Wesche & Jan Hanspach (together 20 %)
Writing the paper:	**Henrik von Wehrden** (80%, corrections by Jan Hanspach, Petra Kaczensky & Karsten Wesche)

von Wehrden, H., Hanspach, J., Ronnenberg, K. & Wesche, K. (in prep. for resubmission) Inter-annual climatic variability in Central Asia - a contribution to the discussion on the importance of environmental stochasticity in drylands. Journal of Arid Environments.

Data collection:	**Henrik von Wehrden** (75 %); Jan Hanspach (25 %)
Analysis:	**Henrik von Wehrden** (50 %); Jan Hanspach (50 %)
Writing the paper:	**Henrik von Wehrden** (80%, corrections by Jan Hanspach, Katrin Ronnenberg & Karsten Wesche)

von Wehrden, H., Hanspach, J., Bruelheide, H. & Wesche, K. (in print) Pluralism and diversity - trends in the use and application of ordination methods 1990-2007. Journal of Vegetation Sciences

Data collection:	**Henrik von Wehrden** (95 %); Jan Hanspach (5 %)
Analysis:	**Henrik von Wehrden** (80 %); Jan Hanspach (10 %); Karsten Wesche & Helge Bruelheide (10 %)
Writing the paper:	**Henrik von Wehrden** (80%, corrections by Helge Bruelheide, Jan Hanspach & Karsten Wesche)

Curriculum Vitae

Born 1976 in Duisburg, Germany

1996-2002: University studies in Marburg, Germany (subjects: geography, botany, geology and soil sciences).

2003 diploma: Vegetation mapping of the Gobi-Gurvan-Saykhan National Park using remote sensing and GIS as a basis for nature conservation and resource management

2003-2004: Work in the framework of FWF project P14992 (compiling a vegetation survey)

2004-2005: DAAD scholarship for fieldwork in Mongolia

2006-2008: PhD student within the framework of FWF project P18624

since 2000: Several freelance work as a GIS and conservation consultant

First child Linus Conrad von Wehrden born in 2009

Field trips

1998: short fieldtrip to Tenerife (Canary Islands)

1999: participation in the field course “mapping a subtropical forest”, southern Nepal held by K. Wesche

1999: member of the “Nepal excursion” led by G. Miehe and K. Wesche

2000: fieldtrip to Nepal, visit of the treeline and lowland forests

2001: participant of a DAAD-excursion to Ethiopia

2001: three months fieldwork in southern Mongolia (vegetation samples as ground checks for a vegetation map)

2002: participant in the “Semi-desert mammology expedition” led by I. Stürmer

2003: two month fieldwork in south-western Mongolia (Great Gobi B strictly protected area)

2004: short fieldtrip to Fuerteventura

2004: four month fieldwork in south-western Mongolia (Great Gobi A strictly protected area)

2004: short visit on Fuerteventura (sampling for a habitat map)

2005: four month fieldwork in south-western Mongolia (Small Gobi protected area)

2005/2006: fieldwork in Argentina and Spain

2007: fieldwork in Argentina and Spain

2008: fieldwork in Argentina

Teaching

Assistant in a course for the "Plant identification course - advanced level I" led by Prof. Dr. V. Melzheimer (2x).

Assistant in the "Plant identification course - advanced level II" led by Prof. Dr. V. Melzheimer (2x).
Assistant in the "Harz"-excursion led by Prof. Dr. G. Miehe (several times).
Course multivariate statistics together with PD Dr. K. Wesche (several times).
Introduction into R program/statistics, together with J. Hanspach & H. Zimmermann
Several introductionary lectures on remote sensing and GIS as part of geobotanical and nature-conservation courses, 2004-2008, Halle, Germany
Introduction in R program/statistics, together with H. Zimmermann, 19.2.08 & 21. 2.08, Córdoba, Argentina.
Introduction in R program/statistics, led by H. von Wehrden, J. Hanspach, S. Ebeling and H. Zimmermann. 12.2.2009 – 14.2.2009, Halle, Germany.

Halle (Saale), den

Unterschrift:

Eigenständigkeitserklärung

Hiermit erkläre ich, dass diese Arbeit nicht bereits zu einem früheren Zeitpunkt der Naturwissenschaftlichen Falkultät I – Biowissenschaften der Martin-Luther-Universität Halle-Wittenberg oder einer anderen wissenschaftlichen Einrichtung zur Promotion vorgelegt wurde.

Darüber hinaus erkläre ich, dass ich die vorliegende Arbeit eigenständig und ohne fremde Hilfe verfasst sowie keine anderen als die im Text angegebenen Quellen und Hilfsmittel verwendet habe. Textstellen, welche aus verwendeten Werken wörtlich oder inhaltlich übernommen wurden, wurden von mir als solche kenntlich gemacht.

Im Übrigen erkläre ich, dass ich mich bisher noch nie um einen Doktorgrad beworben habe.

Halle (Saale), den

Unterschrift:

Henrik von Wehrden