Erforsch. biol. Ress. Mongolei (Halle/Saale) 2005 (9): 133–146

Is degradation a major problem in semi-desert environments of the Gobi region in southern Mongolia?[1]

K. Wesche & V. Retzer

Abstract

This paper tests predictions derived from the non-equilibrium theory of rangeland science. Data were collected in livestock enclosures situated in the relatively moist desert steppes of the Gobi Gurvan Saykhan region of southern Mongolia from 2000 to 2003. Plant community composition and species' richness in enclosures showed clear differences between years, but these were equally strong in ungrazed controls. Thus, changes were mainly attributed to differences in precipitation between years as opposed to grazing, as no significant effects thereof were detected. This was also confirmed by data on above-ground standing biomass. This changed tremendously over the years, with differences between various grazing regimes (factorial combination of grazing by livestock and small mammals) being smaller than interannual changes.

The results support the idea that on a local scale desert steppes experience non-equilibrium dynamics with water availability being far more important than livestock impact. As a result, it can be presumed that the danger of anthropo-zoogenic degradation is small. However, a nomadic way of life appears to be a crucial precondition for sustainable land use of these environments, thus, further aspects than precipitation data alone need to be taken into account when assessing the dynamics of the ecosystem.

Keywords steppes, degradation, Mongolia, grazing, vegetation, enclosures, interannual variation, non-equilibrium ecosystem, small mammals

Introduction

Mongolia is one of the most important grassland regions of the world. Its territory covers about 1.3 Mio. km^2 of grass-dominated steppes, which is about 2.5 % of the world's total grasslands area (White et al., 2000). The country is part of the vast central Asian steppe region and many of its neighbors have equally large or even larger grassland areas. Mongolian steppes are usually considered relatively intact, in comparison to China or Kazakhstan for example where human land use has been responsible for large-scale degradation (Babaev, 1999; Sneath, 1998). However, Mongolian steppes are by no means pristine environments, as nomadic pastoralism has been the principal land use practice for centuries (Fernandez-Gimenez, 1999).

Political changes over the last 15 years have had tremendous effects on the country's economy, and subsequently, as pastoral land use is still the main source of income, on the grazing systems in the region. In urban centers, rapid population growth and a lack of suitable employment opportunities have resulted in an increasing number of herder families and even stronger increases in the number of livestock (Müller, 1999). On a nationwide scale, livestock numbers remained essentially stable throughout the larger part of the twentieth century but showed some 30 % increase in its last decade (1990: 24.5 Mio. head of livestock, 1999: 33.5 Mio., quoted from Retzer, 2004).

For the Gobi Gurvan Saykhan National Park in the South Gobi Aymag, livestock density, in terms of Mongolian Sheep Units, increased from 0.82 Mio. units in 1990 to 1.45 Mio. units in 1998 (Bedunah & Schmidt, 2000). Moreover, trends differed among species as herds of Cashmere goats increased particularly strongly while numbers of the highly drought-adapted

[1]Results of the Mongolian-German Biological Expedition since 1962, No. 245.

Bactrian camels decreased. Not surprisingly, human pressure on steppes increased in many parts of Mongolia, and various authors describe severe degradation phenomena as being a result thereof (Batjargal, 1998; Batkhishig & Lehmkuhl, 2003; Opp, 2001; Opp & Hilbig, 2003).

Intensified pastoral land-use and associated pasture degradation has been reported from various tropical and extra-tropical drylands of the world, but the view which holds local herders as being the principal destructive force has been challenged in the last 10 years, particularly so in Africa (Ellis & Swift, 1988; Ward et al., 1998). The discussion on the dynamics of rangeland ecosystems is still vivid (cf. Illius & Connor, 1999; Sullivan & Rohde, 2002), but two principal lines of thought have been most widely discussed: The traditional so called 'equilibrium theory' of rangeland science assumes that climatic conditions are essentially stable and that vegetation is in a largely stable equilibrium with the climate. Under such conditions, livestock is the main ecological factor controlling ecosystem changes in grasslands. Being so dominant, livestock is also held responsible for being the driving force behind pasture degradation (Fernandez-Gimenez & Allen-Diaz, 1999). In contrast, the 'non-equilibrium theory' emphasizes the overwhelmingly important role played by abiotic conditions especially by the precipitation patterns. Non-equilibrium conditions are widely assumed to be very common in semi-arid to arid regions, where water is the limiting factor for plant growth. As variability of precipitation often increases with increasing aridity of the climate (Sullivan & Rohde, 2002), interannual changes in precipitation patterns are particularly strong in drylands, and both plant and livestock communities there would be expected to experience major fluctuations in numbers reflecting these ever-changing moisture conditions.

These two views have fundamental implications for management and politics as non-equilibrium environments are often regarded as being insensitive to livestock impact, simply because numbers of livestock collapse in drought years and are not able to recover as fast as the fast growing plant species (Ellis & Swift, 1988). The latter are either long-lived perennials, surviving adverse conditions in a state of dormancy, or are annuals capable of rapid development after rain. None of these two strategies can be followed by livestock, as ungulates typically reproduce at rates of one to a few offspring per year. Thus, dynamics of herbivore numbers should lag behind the forage availability, and therefore be unable to exert control on plant resources.

However, real ecosystems often follow an intermediate pattern (Wiens, 1984); so both theories have been criticized as being rather extreme positions and there have been calls for a unifying theory on rangelands that incorporates both equilibrium and non-equilibrium aspects (Briske et al., 2003; Fernandez-Gimenez & Allen-Diaz, 1999). Generally, non-equilibrium characteristics are becoming progressively more important with increasing dryness of the sites, while equilibrium conditions and widespread overgrazing are typical for environments with relatively reliable precipitation. Several thresholds have been proposed, but most authors expect that environments with less than 200 mm annual precipitation and a coefficient of variation larger than 30 % in interannual precipitation are better described by non-equilibrium models (Fernandez-Gimenez & Allen-Diaz, 1999; Illius & Connor, 1999).

Clearly, this discussion is of fundamental importance, as the entire Gobi part of Mongolia, i.e. some 40 % of the country, is covered by dry desert steppes and deserts that receive less than 200 mm annual precipitation. Under such conditions, a non-equilibrium approach predicts the following patterns:

1. plant biomass and community composition is closely coupled with precipitation levels and shows high interannual variation

2. in comparison to these interannual changes triggered by irregular precipitation, differences between grazed and ungrazed sites are small

3. numbers of livestock and other herbivores are driven by forage (i.e. biomass) availability and show strong interannual variations in line with biomass levels

4. recovery of livestock numbers after population collapses in periods of forage shortage (Mongolia 'Zud') is slower than recovery of pastures, so livestock numbers in following, possibly more favorable years are often too low to exploit forage resources completely.

This leads to a further hypothesis:

5. edaphic conditions should have no, or only minor impacts on plant communities, because water rather than nutrient availability is the decisive factor for biomass development.

Thus, if predictions of the non-equilibrium theory hold true, large parts of the country should be, at most, weakly threatened by pasture degradation due to overgrazing.

We tested these ideas in the desert steppes of southern Mongolia. In a previous study, we demonstrated that plant community composition is hardly influenced by livestock activity in the area (confirming hypothesis 2, Stumpp et al., in press). Gradients of livestock density radiating away from permanent and traditionally used water sources were not reflected in diversity, in species composition, nor in the lifeform spectra of the respective plant communities. Thus, impact of livestock activity on plant community composition was found to be weak, which is in line with the non-equilibrium model. This was also supported by the fact that soil nutrients had strong gradients paralleling gradients of animal activity, yet plant community composition was completely decoupled from these edaphic conditions (see hypothesis 5 above, Stumpp et al., in press). This evidence was somewhat indirect, since we did not actively manipulate grazing levels but rather used already established gradients. However, the advantage was that these had presumably persisted over longer periods of time, so lack of effects could not be attributed to the limited duration typically found in experimental studies.

Retzer (2004) reports observations on livestock numbers in the study area that support hypothesis no. 3. She demonstrates that livestock numbers show indeed large inter-annual fluctuations in line with the precipitation driven biomass availability. In an additional theoretical study, Retzer and Reudenbach (in review) developed a model which shows that the dynamics of biomass and livestock numbers can be described using the above-mentioned non-equilibrium assumptions, in particular hypotheses no. 3 & 4.

The present paper now turns back to the first two hypotheses and includes data on two manipulative experiments that had been followed over a period of four and five years. Community composition under various grazing regimes and the evolution of biomass are illustrated over a period comprising drought years (2001) as well as years with above-average precipitation (2003).

Study area

The studies were performed in the Gobi Gurvan Saykhan National Park, South Gobi Aymag (figure 1). The region is characterized by the easternmost outposts of the Gobi Altay ranges that are surrounded by extensive pediments. The upper parts of these pediments are intensively grazed and are covered with relatively moist desert steppes dominated by *Stipa gobica, S. glareosa, Agropyron cristatum* and *Allium polyrrhizum* (Wesche et al., in review).

The climate is semi-arid, and precipitation is subject to pronounced interannual changes. Bayandalay Sum, located at some 1500 m asl. south of the so called Dund Saykhan range, reports a long-term annual mean (37 years) of 110 mm precipitation (Meteorological Service Mongolia). Mountains receive more rain as two years of short term-measurements along an altitudinal transect suggest that precipitation at 2300 m asl. fluctuates around 130 mm and is well above 160 mm at 2600 m asl. (Wesche, unpublished; Retzer, 2004). Coefficients of variation are high at 30–38 % for the governmental weather stations, and 2001 was a year of almost zero summer precipitation in Bayandalay, while 2002 was an average year. The interannual variability is equally pronounced in the mountains as short-term measurements on the upper pediments of the Dund Saykhan range suggest (table 1). Thus, conditions throughout the entire region clearly fulfil climatic criteria for the non-equilibrium environments described before.

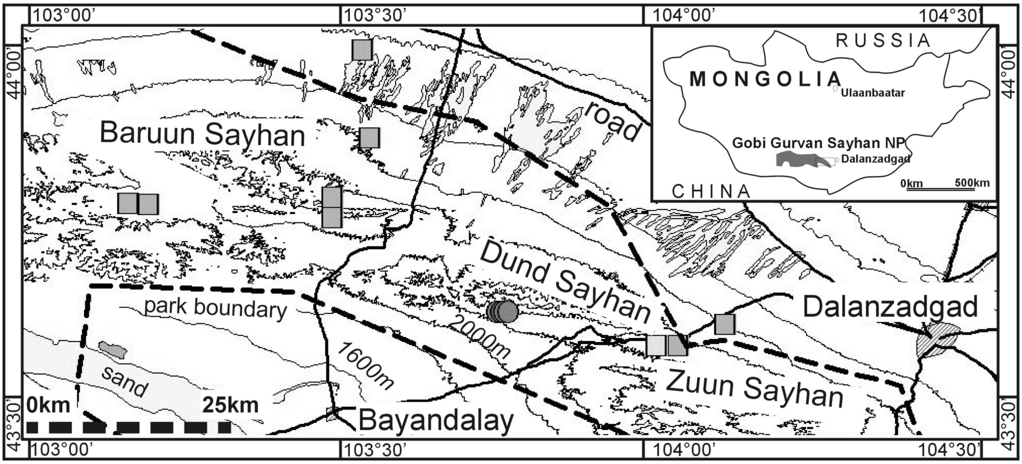

Figure 1: Location of the study sites in the Gobi Gurvan Saykhan region, southern Mongolia. The large enclosures (grey rectangular symbols) are distributed throughout the entire eastern part of the Gobi Gurvan Saykhan National Park, the small enclosures (grey dots) are situated near the research station in the southern Dund Saykhan (draft K. Wesche, GIS coverage provided by the GTZ Buffer Zone Development Project).

Methods

The study is based on two enclosure experiments. One is situated in the surroundings of the research station of the Gurvan Saykhan Research Project (southern Dund Saykhan range, 43°36' N, 103°46' E) at 2300 m asl. In 2000, four blocks of four grazing treatments were set up as part of a general grazing study (Retzer, 2004), and had been maintained for a total of 4 years by the time of writing (summer 2004). The following treatments were implemented: no grazing; grazing by livestock only; grazing by pikas (*Ochotona pallasi*) only and; grazing by both livestock and pikas. Plots are relatively small ($< 100\,m^2$, hereafter called 'small enclosures', see figure 1), vegetation composition and structure is recorded on $1\,m^2$ plots within the fenced-off areas twice each summer (July and August). Additionally, all standing biomass is oven-dried and respective weights are recorded.

The other experiment comprises a total of nine large enclosures ($400\,m^2$, hereafter referred to as 'large enclosures', figure 1), which exclude large herbivores including livestock, but not small mammals. Sites for enclosures were selected and first sampled in 1996, fences were built three years later and monitoring commenced in 2000. These large enclosures are distributed throughout the desert steppes of the entire Gobi Gurvan Saykhan region (six around the Baruun Saykhan, two in the eastern Dund Saykhan, one east of the Züün Saykhan range, figure 1). Records are kept on an annual basis and comprise data on species' composition and cover on large plots ($10 \times 10\,m^2$) within the enclosures. For comparison, a control was always sampled outside the fences. This allows data analysis as a paired-design. Where applicable, we used standard non-parametric statistics to test whether effects are random or not (Wilcoxon Test, U-Test, Kruskal Wallis-Test, or Friedman Test, Sokal & Rohlf, 1995). Detrended Correspondence Analysis was used to assess multivariate community data because detrending produces meaningful distances within the ordination space (Jongman et al., 1995). Statistics were calculated using the software PCORD 3.15 and SPSS 12.0 (McCune & Mefford, 1997; SPSS Inc., 2003).

Results

Species composition – large enclosures

At the beginning of the experiment (2000, one year after enclosures had been built), median species richness was almost equal inside and outside the enclosures (12 vs. 11 species per 100 m^2). Over the years, richness inside the enclosures increased (figure 2) and reached a median of 18 in 2003. However, this was not an effect of grazing exclusion, as the same trend was observable on the grazed controls. Median richness there was also 18, and differences between enclosures and controls were not significant (figure 2).

Species richness is only one simple aspect of the essentially multivariate community data, which are conveniently analyzed with ordinations. DCA ordination of species presence data (figure 3) showed similar trends as the richness data. Differences between 1996 (initial record) and 2003 were pronounced, as plots moved between 0.5 and 2 multivariate standard deviations in the ordination space. This corresponds to a species' turnover of 0.1 to 0.5 on any given plot within these three years (Jongman et al., 1995), which illustrates minor changes overall. Moreover, changes on the controls (figure 3) were as equally large as they were within the enclosures, further implicating that inter-annual changes, presumably in precipitation levels (see table 1), are more important than the grazing regime.

Table 1: Precipitation and piche evaporation (+20 cm above ground) at the research station of the Gobi Gurvan Saykhan Research Project, Dund Saykhan (2300 m asl.). Data for 2001 Retzer & Nadrowski, unpublished.

Time		**Rain (mm)**	**Piche (mm)**
2001	- July	4.7	390
	- Aug.	0.0	371
2002	- July	27.3	383
	- Aug.	0.0	402
2003	- July	31.8	292
	- Aug.	62.2	331

Nonetheless, enclosures effectively excluded livestock. This is evident from the cover of litter, which differed between fenced-in areas and the controls. In 2003, median cover inside the fenced areas was 4 % (interquartile range 4.0–9.5 %), while litter in the controls covered a mere 0.2 % (interquartile range 0.2–0.7 %). This difference was highly significant (Wilcoxon Test for 2003. $p < 0.001$, $n = 9$). Clearly, dead biomass accumulated on the surface within the fenced-off areas, indicating that grazing levels were strongly reduced within the enclosures. Visual impressions suggest that fine soil material is trapped by this biomass, but soil analysis have not yet been performed. However, even if topsoil conditions have changed within the enclosures, consequences for community composition are still minor as vegetation did hardly differ between fenced-in areas and the controls.

Biomass development & intake – small enclosures

Because community composition remained unchanged by grazing in the large enclosures, records in the small enclosures concentrated on growth data only. Data were collected for standing biomass in July and August, but for simplicity only those for August will be discussed as patterns are similar for July.

In August 2001, ungrazed plots showed a median standing crop of 193 kg/ha (figure 4). This was the maximum standing crop of this year (Retzer, 2004). Livestock alone consumed about 122 kg/ha (which is equivalent to 63 % of the standing crop on ungrazed plots), while pika alone harvested some 148 kg/ha (77 %), and both livestock groups together consumed 156 kg/ha (81 %, see also Retzer, 2004, 2005). Joint intake of the two herbivore groups was in the same order of magnitude in 2002 (70 %) but dropped to 49 % in 2003. However, the relative importance of

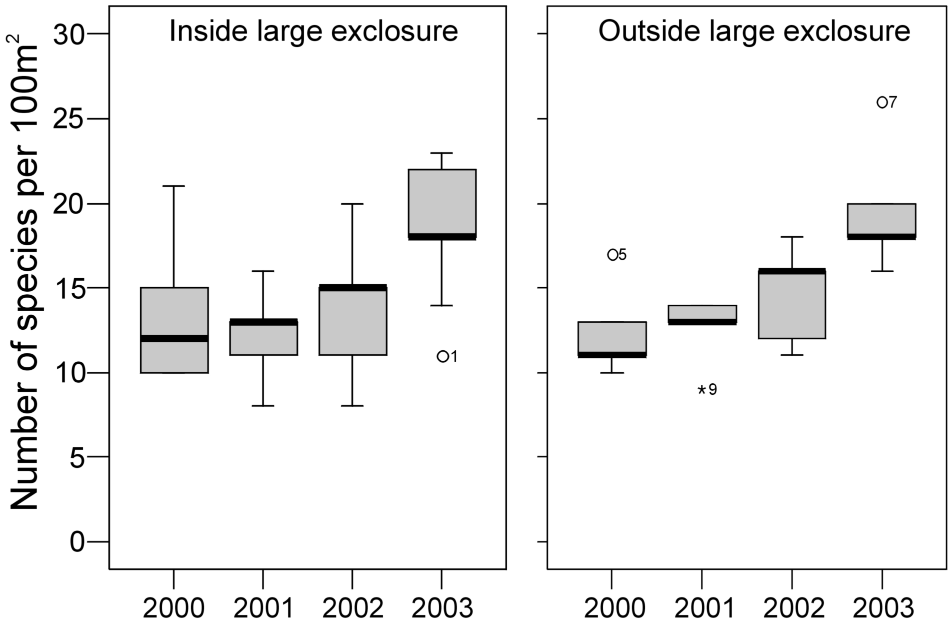

Figure 2: Box and Whisker Plots (showing median and interquartile ranges) for species numbers in large enclosures distributed in desert steppes around the Gobi Gurvan Saykhan ranges. Interannual changes are pronounced but differences between enclosures and ungrazed controls are not significant (Wilcoxon Test for 2003: $p = 0.167$, $n = 9$).

pikas and livestock varied over the years, as pikas alone consumed a mere 26 % of the biomass in 2002, while livestock alone grazed 42 %. This reversed again in 2003, with pikas being the slightly more important group again at 25 % grazing impact, and livestock removing only 22 %.

However, absolute values differed tremendously between years. Joint consumption in 2002 was 130 kg/ha, thus comparable to 2001, but 199 kg/ha in 2003. Ungrazed plots showed a similar trend, with standing crop in 2001 and 2002 being almost equal (193 vs. 185 kg/ha), whereas values more than doubled in 2003 (408 kg/ha). Spring conditions were relatively moist in 2003, and differences in biomass were significant on all treatments (Friedman Test, $p = 0.04$, $n = 4$). Herbivores tracked this development and increased their intake, but not to full extent as they harvested well below 50 % of the standing crop in 2003. Differences among grazing treatments were significant in 2001 (Kruskal Wallis Test, $p = 0.01$, $n = 4$), but the variation within the grazing treatments was huge in 2003, so effects were not significant (Kruskal Wallis Test, $p = 0.156$, $n = 4$).

The overwhelming dominance of interannual changes was also apparent for the presence of flowers on the plots (figure 5). In the dry years 2001 and 2002, numbers of flowers on all plots were relatively low, although they showed a weak tendency to be higher on the ungrazed plots. Spring conditions varied among years with precipitation levels being particularly high in 2003, so numbers of inflorescences differed significantly between years (Friedman Test, $p < 0.01$ for each July and August, $n = 4$). Effects of grazing were less clear, and differences between grazing regimes in July 2003 were not significant (Kruskal Wallis Test, $p = 0.278$, $n = 4$). Thus, reproductive activity of plants was also more strongly affected by climatic variability than by grazing levels.

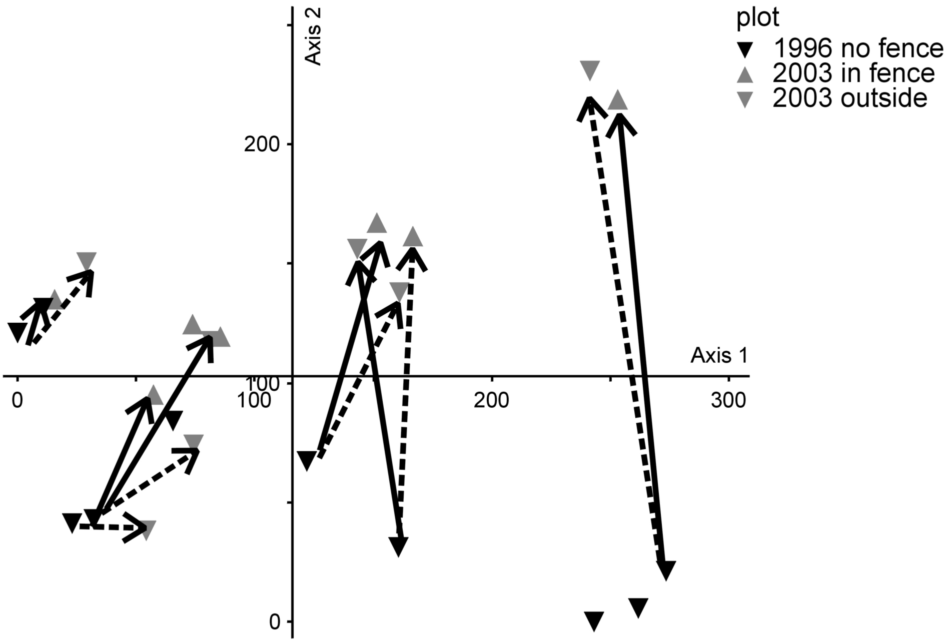

Figure 3: Detrended Correspondence Analysis of community data gathered on the enclosures and the respective controls. Arrows indicate changes over time inside enclosures (→) and on control plots (--→) between 1996 and 2003 in the ordination space (DCA, n > 1 p/a-transformed, detrending by segments, rare species downweighted, axis 1 Eigenvalue 0.43, axis 2 EV 0.22).

Discussion

The Gobi Gurvan Saykhan region is a non-equilibrium ecosystem

The results support the idea of non-equilibrium dynamics being present in the rangelands around the Gobi Gurvan Saykhan as the hypotheses stated in the introduction were confirmed. Plant species richness on the large enclosures (figure 2) as well as plant community composition (figure 3) showed pronounced interannual changes (hypothesis 1), whereas differences between enclosures and fully grazed controls were negligible (hypothesis 2). All dominant species are perennials (genera *Stipa, Agropyron, Allium*) and survive conditions of heavy drought (Wesche et al., in review), so changes in vegetation composition remained small overall and were caused by the presence or absence of a few short-lived species such as *Salsola collina* s.l. Inside the enclosures, there was a clear increase in the overall cover of litter and this is presumably associated with changes in the edaphic conditions as the dead matter reduces wind speed at ground level and therefore acts as a trap for wind-transported fine soil material. However, these changes appear to be irrelevant for plant community composition at least within the 5 years of exclusion, either because soil conditions are relatively unimportant (see hypothesis 5) or because perennial plants react too slowly. As our previous study on long-established grazing gradients (Stumpp et al., in press) also suggests that soil conditions have hardly any impact on vegetation, we expect that changes due to soil accumulation will remain limited in the large enclosures, even if monitoring continues over extended periods of time.

Data from growth parameters also correspond to predictions from non-equilibrium theory. Biomass on the small enclosures changes tremendously from year to year (figure 4) with values doubling under moist conditions. Expressed in absolute figures, changes in biomass between

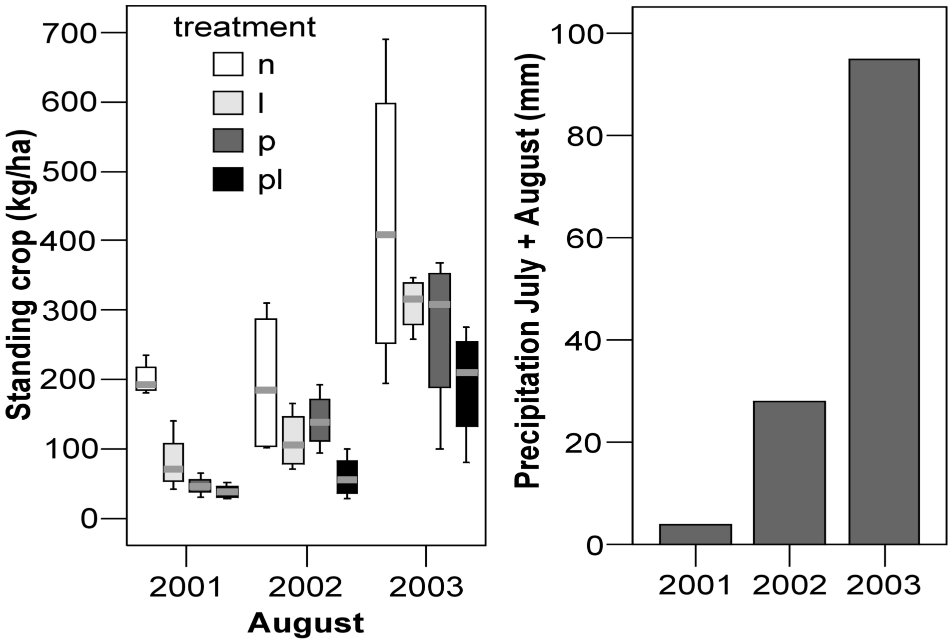

Figure 4: Development of standing above-ground biomass for the small enclosures and sum of precipitation for July and August of the respective years in the surroundings of the station of the Gurvan Saykhan Research Project in the Dund Saykhan. The white columns give mean biomass figures (+ 1 standard deviation) under ungrazed conditions, the other columns refer to various grazing treatments (n = no grazing, l = livestock only, p = pika only, pl = grazing by pika and livestock, data for 2001 from Retzer, 2004).

years are larger than differences between various grazing regimes in any given year. Nonetheless, grazing has a clear impact on standing crop. Impact of climatic conditions on plants' flowering activity was even stronger than on biomass production, figures in the wetter year of 2003 were an order of magnitude higher than in 2001 and 2002. According to this parameter, grazing regime had no impact at all (figure 5).

During this study, we did not formally record livestock numbers, so only indirect evidence is available for testing predictions on herbivore population dynamics (cf. hypothesis 3). However, detailed observations by Retzer (2005) clearly demonstrated that livestock densities around the research station showed high seasonal and interannual variability with figures in September 2001, after a severe drought, being less than half as high as those in September 2000. The physical conditions of livestock decreased steadily from autumn 2000 throughout the drought of summer 2001 and were lower in autumn 2001 than in spring indicating that livestock lost, instead of gained, weight during the summer of 2001 (Retzer, 2004). Such figures are not available for the following years, but we have conducted non-formal observations on livestock densities for the region. Most herders had to leave the Gobi Gurvan Saykhan during late summer 2001 and were forced to migrate to regions less severely affected by the 'Zud', e.g. to the Middle Gobi Aymag. Some remained there until 2002, others soon returned and stayed in the Dund Saykhan range throughout 2002 and 2003. However, in 2003 many families preferred to spend the summer on the northern slopes of the Dund Saykhan as pasture conditions were more suitable there. Thus, on a local scale, livestock densities are indeed not stable and are driven by forage availability. This confirms, that livestock is a reacting, rather than acting, force in the non-equilibrium environments of the southern Gobi. This explains why its impact on the vegetation is much

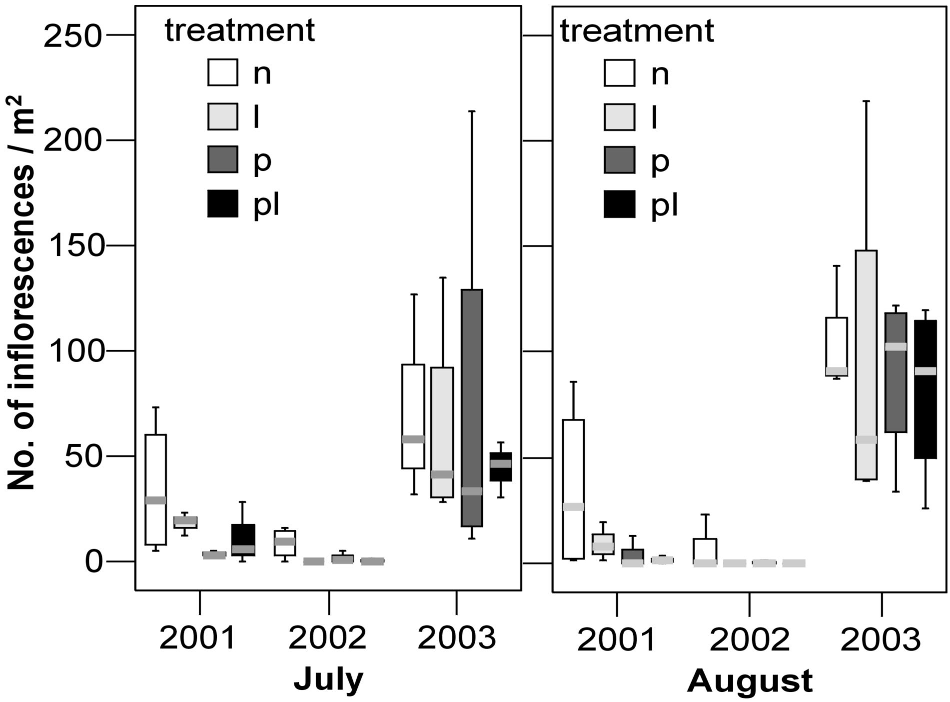

Figure 5: Density of inflorescences in the small enclosures around the research station. Numbers refer to total numbers of inflorescences across all species, data are given for the years 2001 (Retzer 2004), 2002 and 2003, and for the four grazing treatments.

smaller than changes triggered by precipitation levels.

The desert steppes studied by our group are located in the wetter, eastern parts of the Gobi Gurvan Saykhan region where higher altitudes expose them to higher precipitation levels than the surrounding lowlands (Wesche et al., in review). Much of the rangelands of southern Mongolia are desert steppes which are drier than our study region (cf. Gunin & Vostokova, 1995; Hilbig, 1995), therefore the relative importance of precipitation levels versus livestock impact can be expected to be even higher than in the example described here. Thus, at least for the drier southern parts of Mongolia, the widely held notion of large-scale anthropo-zoogenic degradation needs rethinking. The animals are, to a large extent, not driving but driven factors and what seems to matter more is the precipitation. To this extent, therefore, any attempt at supplying recommendations for rangeland management solely on the basis of presumed anthropo-zoogenic degradation will be ill-advised.

The situation is certainly different in the moister parts of Mongolia where more reliable precipitation allows more stable pasture conditions and therefore higher livestock numbers (Fernandez-Gimenez & Allen-Diaz, 1999, 2001). There, livestock poses a serious threat in terms of habitat degradation (e.g. Opp, 2001; Opp & Hilbig, 2003; Hilbig & Opp, 2005). Nonetheless, the overall control exerted by the abiotic resources is also found on a nationwide scale. As described above, total livestock numbers increased tremendously in the last decade of the 20th century. However, the severe winters ('White Zud') of 2000 and 2001, plus summer drought in 2001, triggered a collapse in livestock numbers throughout large parts of the country (Statistical Office of Mongolia, quoted in Retzer, 2004). For entire Mongolia, numbers dropped to approximately the same level as they had been in 1990, and have essentially remained there in the last years. This indicates that there is indeed a nationwide carrying capacity that is more or less controlled by abiotic conditions.

Short-comings of the non-equilibrium theory

Although much younger than the equilibrium model with its implied stability, non-equilibrium thinking in itself is more than 20 years old (Wiens, 1984; Ellis & Swift, 1988). Not surprisingly, criticism is emerging and recent publications on theory in rangeland ecology describe patterns which cannot be easily explained with non-equilibrium dynamics alone (Ho, 2001; Oba et al., 2003). Addressing these, several authors have adopted an intermediate position recognizing that ecosystems usually possess characteristics of both non-equilibrium and equilibrium systems (Briske et al., 2003; Fernandez-Gimenez & Allen-Diaz, 1999), a view already proposed by Wiens (1984).

Even the case of the relatively moist desert steppes of the Gobi Gurvan Saykhan presented above provides evidence that dynamics may not be as straightforward as previously suggested. One point are the figures on herbivore consumption (figure 4). Non-equilibrium theory predicts that herbivore numbers recover more slowly after a collapse in population than does plant biomass (hypothesis 4). As a consequence, much of the standing crop in favorable years is not consumed because the number of consumers is simply too low (Retzer, 2004).

Pikas (*Ochotona pallasi*) showed this pattern in the southern Dund Saykhan. They alone consumed about 77 % (148 kg/ha) of the biomass in 2001, but lack of forage resulted in shrinking populations during the following winter. As a consequence, pikas consumed a mere 26 % (47 kg/ha) of the standing crop in 2002, indicating that numbers had not recovered. Indeed, pika numbers in 2002 were merely half as high as in 2001 (Nadrowski, pers. comm.). In 2003, median figures of consumption had more than doubled (101 kg/ha). However, this was less than a quarter of the standing crop on the ungrazed plots, indicating that pika populations recovered much more slowly than did the biomass. Livestock showed somewhat similar dynamics (figure 4). Livestock alone consumed a median of 63 % (122 kg/ha) in 2001, thus clearly less than the pikas. This changed in 2002, when livestock consumed 42 % in 2002 (78 kg/ha). In 2003, livestock consumed a mere 22 % (91 kg/ha) in 2003. The overall dynamics can be explained with non-equilibrium theory (i.e. numbers were not able to follow the steep increase in standing crop of 2003). The relatively high figures in 2002 are less easily explained as this was the only year when livestock consumed more than the pikas. Apparently, livestock populations did not collapse as seriously as did the pika populations, and they were able to maintain relatively high numbers after the drought of 2001.

The reason lies in the availability of special sites that allow survival of populations under severe conditions. Such reserves have been termed 'key resource areas' by Illius & Connor (1999), who concluded that their presence would allow livestock populations to remain high under adverse conditions. Thus, they can exert continuously high grazing pressure, suggesting that degradation might even occur under non-equilibrium climatic conditions. In our case, such key resource areas were not available in the Gobi Gurvan Saykhan region, but in the neighboring, less-drought affected Middle Gobi Aymag. Numerous herders migrated to these regions in late summer 2001 and were able to rescue at least part of their animals through this nomadic behavior. Losses were still severe (up to 50 % as revealed in non-formal interviews), but not as severe as for those herders that did not migrate.

This points to the importance of scale in the discussion. At regional scales, conditions in dry environments will almost always correspond to the non-equilibrium model (Sullivan & Rohde, 2002). On larger scales, even dry ecosystems often experience equilibrium dynamics (Illius & Connor, 1999; Oba et al., 2003), and this is also supported by the rather stable nationwide livestock numbers in Mongolia described above. In fact, migration is a strategy which mitigates the adverse effects of strongly changing environmental conditions by facilitating migration to less severely affected sites, thereby stabilizing living conditions of livestock. Thus, conditions actually experienced by livestock are less unstable than suggested by regional climatic data; providing herders are willing to migrate. Fortunately, Mongolia is one of the few countries where nomadism has been revived rather than abated in the last few decades (Janzen & Bazargur, 1999; Scholz, 1999), and management certainly should support migration of herders as a precondition for sustainable land use.

There is evidence that precipitation is the most important, but not the only important, variable in drylands. A world-wide analysis suggests that site history also influences the magnitude of grazing impact (Milchunas & Lauenroth, 1993); and this is likely to have some importance in Mongolian steppes as these have been subject to human impact over centuries (Fernandez-Gimenez & Allen-Diaz, 1999). Vegetation types which are intolerant to grazing have presumably long been replaced by grazing-tolerant species, making the observed tolerance to grazing of the current vegetation a rather trivial observation (Stumpp et al., in press).

Moreover, evidence for non-equilibrium conditions depends on the variables analyzed. Hypothetically, if biomass data alone had been monitored, conditions would have emerged as being strongly unstable, and even more so if numbers of flowers had been analyzed. However, if community composition is assessed, changes between years are not nearly as pronounced as they are in the case of biomass data. Plant community composition tracks changes in climatic conditions only to a limited extent; a result also confirmed by studies in neighboring Bayankhongor Aymag (Fernandez-Gimenez & Allen-Diaz, 1999, 2001) and in Inner Mongolia (Ho, 2001). On the other hand, other factors commonly not regarded by non-equilibrium theory exert influence such as the sedentary as opposed to nomadic habit of herders in Inner Mongolia (China), or the importance of plant lifeform, as perennials typically dominating in steppes show slow dynamics (Lavrenko & Karamysheva, 1993).

Moreover, precipitation is the overwhelmingly important, but not the only important environmental variable. Heavy disturbance in the direct vicinity of winter grazing areas triggers changes in community composition (Hilbig, 1995; Stumpp et al., in press). Furthermore, the mounds from burrows of small mammals host a clearly different vegetation from the surrounding steppe (Hilbig, 1995; Wesche et al., 2003), and shrubs are preferentially found on disturbed soils (Ronnenberg et al., in review). Soil nutrient levels probably have some impact on biomass production, as both availability of nitrogen and phosphorus is higher on burrows of Ochotona pallasi resulting in a higher plant productivity (this is not a moisture effect, Wesche et al., 2003). The relevance of nutrients was also confirmed by in situ NPK-fertilization of the desert steppes of the Dund Saykhan. Plots fertilized with the equivalent of 20 g nitrogen (per m^2 & year) had a standing crop almost three times as high as on non-fertilized controls (ambient precipitation 160 mm/year, Wesche unpublished). Thus, the overall dominance of the precipitation pattern is mediated by several site conditions, presumably including, to a small extent, grazing.

Conclusion

An important lesson learnt from the present example is that the non-equilibrium theory, in its simplest form, is not able to explain all patterns observed in desert steppes of southern Mongolia. Clearly, other factors also deserve attention. This supports the general notion that the non-equilibrium, and the equilibrium models form two extremes on a theoretical gradient, with real ecosystems functioning at intermediate levels (Briske et al., 2003; Fernandez-Gimenez & Allen-Diaz, 1999).

However, under conditions of low, rather unreliable precipitation, non-equilibrium theory is far better suited to describe dynamics on a regional scale than the traditional equilibrium model. This includes the overall notion that degradation by livestock is apparently much less severe than often anticipated by rangeland ecologists. This was clearly confirmed by the studies described above and should deserve more attention by managers, donors, and politicians concerned with the fate of the southern Mongolian steppes.

Finally, a need emerges for sound experiments that test the still rather theoretical inferences made in the present paper. In particular, clear indicators for degradation need to be defined. These could concentrate for example on lower productivity of open grazed lands in comparison to enclosures, rather than on simple notions of erosion, which is an intrinsic factor in drylands all over the globe, even under zero grazing impact. Such indicators should be monitored over several years including both above and below average biomass, thus capturing the full dynamics of these ecosystems.

Acknowledgements
This manuscript benefited from support during all stages of the preparation. Thanks go to S. Schmidt from the (formerly) GTZ-run Buffer Zone Development Project in the Gobi Gurvan Saykhan National Park, which maintains the large enclosures. The national park administration and the Mongolian government kindly granted permission to do the work. M. Pietsch, H. von Wehrden, D. Enkhjargal and T. Amarjargal assisted in data collection. K. Nadrowski provided information on pika densities. Fieldwork would not have been possible without the other members of the Gobi Gurvan Saykhan Research Project, notably R. Samjaa and R. Undrakh. We received financial support from DFG, DAAD, A.F.W. Schimper-Stiftung and GTZ. V. Clausnitzer checked the text for scientific content, and D. McCluskey corrected our English.

References

Babaev, A.G. (1999, Editor): Desert problems and desertification in Central Asia. Springer, Berlin, Heidelberg, New York.

Batjargal, Z. (1998): Desertification in Mongolia. Rala Report 200, 107–113.

Batkhishig, O. & Lehmkuhl, F. (2003): Degradation und Desertifikation in der Mongolei. Petermanns Geographische Mitteilungen 147: 48–49.

Bedunah, D. & Schmidt, S.M. (2000): Rangeland of Gobi Gurvan Saikhan National Conservation Park, Mongolia. Rangelands 22: 18–24.

Briske, D.D., Fuhlendorf, S.D. & Smeins, F. (2003): Vegetation dynamics on rangelands: a critique of the current paradigms. Journal of Applied Ecology 40: 601–614.

Ellis, J.E. & Swift, D.M. (1988): Stability of African pastoral ecosystems: Alternate paradigms and implications for development. Journal of Range Management 41: 450–459.

Fernandez-Gimenez, M.E. (1999): Sustaining the steppes: a geographical history of pastoral land use in Mongolia. The Geographical Review 89: 315–342.

Fernandez-Gimenez, M.E. & Allen-Diaz, B. (1999): Testing a non-equilibrium model of rangeland vegetation dynamics in Mongolia. Journal of Applied Ecology 36: 871–885.

Fernandez-Gimenez, M. & Allen-Diaz, B. (2001): Vegetation change along gradients from water sources in three grazed Mongolia ecosystems. Plant Ecology 157: 101–118.

Gunin, P.D. & Vostokova, E.A. (1995): Ecosystems of Mongolia (Map). Moscow, 15 sheets [in Russian].

Hilbig, W. (1995): The vegetation of Mongolia. SPB Academic Publishing, Amsterdam.

Hilbig, W. & Opp, Ch. (2005): The effects of anthropogenic impact on plant cover and soil cover in Mongolia. Erforschung biologischer Ressourcen der Mongolei 9: 163–177.

Ho, P. (2001): Rangeland degradation in north China revisited? A preliminary statistical analysis to validate Non-Equilibrium Range Ecology. Journal of Development Studies 37: 99–133.

Illius, A.W. & Connor, T.G.O. (1999): On the relevance of nonequilibrium concepts to arid and semiarid grazing systems. Ecological Applications 3: 798–813.

Janzen, J. & Bazargur, D. (1999): Der Transformationsprozeß im ländlichen Raum der Mongolei und dessen Auswirkungen auf das räumliche Verwirklichungsmuster der mobilen Tierhalter. Abhandlungen – Anthropogeographie, Institut für Geographische Wissenschaften FU Berlin 60: 46–79.

Jongman, R.H.G., ter Braak, C.J.F. & van Tongeren, O.F.R. (1995): Data analysis in community and landscape ecology. University Press, Cambridge.

Lavrenko, E.M. & Karamysheva, Z.V. (1993): Steppes of the former Soviet Union and Mongolia. In. *Natural Grasslands. Ecosystems of the world 8b.* Edited by Coupland, R.T. Elsevier, Amsterdam, London, New York, Tokyo: 3–59.

McCune, B. & Mefford, M.J. (1997): PC-ORD. Multivariate Analysis of Ecological Data. MJM Software, Gleneden Beach, Oregon.

Milchunas, D.G. & Lauenroth, W.K. (1993): Quantitative effects of grazing on vegetation and soils over a global range of environments. Ecological Monographs 63: 327–366.

Müller, F.-V. (1999): Die Wiederkehr des mongolischen Nomadismus, Räumliche Mobilität und Existenzsicherung in einem Transformationsland. Abhandlungen – Anthropogeographie, Institut für Geographische Wissenschaften FU Berlin 60: 11–46.

Oba, G., Weladji, R.B., Lusigi, W.J. & Stenseth, N.C. (2003): Scale-dependent effects of grazing on rangeland degradation in northern Kenya: A test of equilibrium and non-equilibrium hypotheses. Land Degradation & Development 14: 83–94.

Opp, C. (2001): Analysis of socio-economic and climate change in Mongolia in the 20th century – effects on pasture ecosystems. In: *Change and sustainability of pastoral land use systems in temperate and central Asia.* Edited by Chuluun, T. & Ojima, D. Ulaanbaatar, Mongolia: 27.

Opp, C. & Hilbig, W. (2003): The impact of overgrazing on natural pastures in Mongolia and Tyva. Berliner Paläobiologische Abhandlungen 2: 96–98.

Retzer, V. (2004): Carrying capacity and forage competition between livestock and a small mammal, the Mongolian Pika (*Ochotona pallasi*) in a non-equilibrium ecosystem, South-Gobi, Mongolia. Görich & Weiershäuser Verlag, Marburg.

Retzer, V. (2005): Facts from a year of drought: forage competition between livestock and the Mongolian Pika (*Ochotona pallasi*) and its effects on livestock densities and body condition. Erforschung biologischer Ressourcen der Mongolei 9: 147–161.

Retzer, V. & Reudenbach, C. (in review): Modelling pika and livestock competition and carrying capacity in a highly variable arid environment. Ecological Modelling.

Ronnenberg, K., Wesche, K. & Hensen, I. (in review): Germination ecology of the dwarf shrub *Artemisia santolinifolia* from the Gobi Altay.

Scholz, F. (1999): Nomadismus ist tot. Geographische Rundschau 51: 248–255.

Sneath, D. (1998): State policy and pasture degradation in Inner Asia. Science 281: 1147–1148.

Sokal, R.M. & Rohlf, F.J. (1995): Biometry. W.H. Freeman & Co., New York.

SPSS Inc. (2003): SPSS for Windows 12.0, SPSS Inc., Chicago.

Stumpp, M., Wesche, K., Retzer, V. & Miehe, G. (in press): Impact of Grazing Livestock and Distance from Water Points on Soil Fertility in Southern Mongolia. Mountain Research and Development.

Sullivan, S. & Rohde, R. (2002): On non-equilibrium in arid and semi-arid grazing systems. Journal of Biogeography 29: 1595–1618.

Ward, D., Ngairorue, B.T., Kathena, J., Samuels, R. & Ofran, Y. (1998): Land degradation is not a necessary outcome of communal pastoralism in arid Namibia. Journal of Arid Environments 40: 357–371.

Wesche, K., Miehe, S. & Miehe, G. (in review): Plant communities of the Gobi Gurvan Sayhan National Park (South Gobi Aimag, Mongolia). Candollea.

Wesche, K., Nadrowski, K., Enkhjargal, D. & Undrakh, R. (2003): Small mammal burrows as special habitats in southern Mongolian mountain steppes. Verhandlungen der Gesellschaft für Ökologie 33: 356.

White, R.P., Murray, S. & Rohweder, M. (2000): Pilot analysis of global ecosystems. Grassland ecosystems. World Resource Institute, Washington.

Wiens, N. (1984): On understanding a non-equilibrium world: myth and reality in community patterns and processes, In: *Ecological communities: Conceptual issues and processes.* Edited by Strong, D.R., Simberloff, D., Abele, L. & Thistle, A.B. Princeton University Press, Princeton: 339–457.

Karsten Wesche
Institute of Geobotany and Botanical Garden
Martin-Luther-University Halle-Wittenberg
Kirchtor 1
D-06099 Halle, Germany
wesche@botanik.uni-halle.de

Vroni Retzer
Philipps-University Marburg
Department of Geography
Deutschhausstr. 10,
D-35032 Marburg, Germany
vroni.retzer@gmx.de