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Vegetation ecological features of dry Inner and Outer Mongolia

- M.A. van Staalduinen & Marinus J.A. Werger, Utrecht -

Zusammenfassung

Der Vortrag befasst sich mit Wüsten, Halbwüsten und Trockensteppen im Gobi-Bereich im Süden der Republik Mongolien und im angrenzenden Norden von China, von der Provinz Inner Mongolia bis Gansu. Die natürlichen Bedingungen dieser Gebiete werden erläutert und ihre großräumigen Vegetationstypen kurz in ihrem Zusammenhang dargestellt. Der Bevölkerungsdruck und vor allem die Viehbestände haben in dieser Region in den letzten Jahrzehnten sehr stark zugenommen. Dies hat zu einer sehr verstärkten Desertifikation der Gebiete geführt. Ausgedehnte, heutzutage von Flugsand bedeckte Gebiete trugen bis vor wenigen Jahrzehnten unter viel geringerem Überbeweidungsdruck noch halboffene Vegetationen auf stabilisierten Bodenoberflächen. Der Effekt der Überbeweidung auf die halboffene Vegetation zeigt sich zunächst in einer Änderung des Vegetationsdeckungsgrades und geht dann auch bald mit einer Verschiebung der Artenzusammensetzung einher. Eine der auffälligsten Änderungen in diesem Stadium der Überbeweidung ist die Ersetzung von büschelförmigen *Stipa*-Arten durch das Gras *Leymus chinensis*, das mittels Rhizomen wächst. Auch andere Rhizomgewächse breiten sich unter Überbeweidung aus. Dies hängt damit zusammen, dass *Leymus* im Vergleich zu *Stipa* ein bedeutend höheres kompensatorisches Wachstum in Reaktion auf Abschneiden (Abfressen) hat. Bei noch stärkerer Überbeweidung gehen auch die Rhizomgewächse zurück, werden *Carex duriuscula* oder *Artemisia*-Arten dominant und nimmt der Artenzahl stark ab. Weiter zunehmende Überbelastung der Vegetation führt dann zu mobilen Flugböden.

Area and Climate

The vast dry parts of northern China, in the provinces of Inner Mongolia, Ningxia and Gansu, and of the Republic of Mongolia, are part of the Gobi desert and semi-desert. They are the easternmost extension of a huge dry area that runs from the Atlantic coast of North Africa, through the Near and Middle East and Central Asia, to the border zone of China and Mongolia.

Climate, relief, soils, and vegetation differ dramatically over this huge area. The flora also changes strongly over this area, though there are common elements, which generally become more abundant within the Asian part of this extensive dry land mass (e.g. ZOHARY 1973; WALTER et al. 1983).

In this paper we restrict ourselves mainly to the dry area stretching from Inner Mongolia to Gansu in China and the adjacent dry area in the southern part of Mongolia (fig. 1). This area lies generally at about 900 to 1500 m altitude, and in parts considerably higher. Soils gradually change from the zonal chestnut soils in the true steppe region to the familiar range of brown and yellow semi-desert and desert soils, with increasingly limited development of soil horizons as aridity increases. These soils generally are low in clay and humus contents, and often rich in calcium carbonate, calcium sulphate and sodium chloride. The salts accumulate in the top soil: at the soil surface until the level till where the soil is dried out (usually not more than 30 to 40 cm). Often the soils contain medium to high amounts of pebbly gravel. In the south there are considerable patches of grey, calcareous soils containing loess, locally developing into thick loess deposits. Alluvial soils are common in and near dry riverbeds, and lake salty bottom soils show up in dry lakes and ponds (HU et al. 1992; KARAMYSHEVA & KHRAMTSOV 1995).

Fig. 1: The dry area of southern Mongolia and northern China discussed in this paper (shaded). The Yellow and Yangtze Rivers are shown.

The area, lying far away from the influences of oceans, is strongly continental. This, and its rather high altitude, determine its climate. Strong contrasts occur between summer and winter and also between day and night (WALTER et al. 1983; RIPLEY 1992; FANG 1988; HILBIG 1995; VAN STAALDUINEN 2005). Its climate is largely controlled by the dynamics of the high pressure cell above Siberia, its shift in position being affected by the monsoonal circulation, and there is also an affect of cyclones brought by western winds. Winters are dry and very cold, with temperatures sometimes down to - 49 ^{0} C, and average temperatures of the coldest months (January and February) considerably below zero. Summers are hot with maxima up to about 40 ^{0} C. On average, the temperatures of the hottest month (July) in this dry area are above 20 ^{0} C and the average values increase from the northern part of the area to the south.

Precipitation is low. Total amounts of precipitation in this area vary from ca. 300 mm yr^{-1} to considerably less than 100 mm yr^{-1}. As in most dry areas, the year-to-year variation in rainfall is large and strongly increases with diminishing total average amounts of rainfall per year. Precipitation falls mainly in summer, while snow in winter is generally very little. Less than 10 % of the annual precipitation falls in winter. In spring, when temperatures are rising, there is still very little precipitation and this hampers plant growth. At that time strong western and north western winds blow over Mongolia carrying great loads of dust deep into China. Summers bring 75 % or more of the annual precipitation. It comes in showers and thunderstorms when depressions occur. Because of the great yearly variability in rainfall, drought periods of several weeks or months on end can occur during the growth season.

Autumn sees a drastic decrease in rainfall and a significant drop in temperature. The herbaceous plants often rapidly desiccate aboveground and freeze while standing, leading to a freeze-dried vegetation that can be grazed in winter (VAN STAALDUINEN 2005).

Potential annual evaporation in the Gobi area, with values of 2500 to more than 3000 mm, strongly contrasts with the much lower annual precipitation, and characterize its aridity (cf. FANG 1988).

This area has seen a rather dry climate at least since the middle of the Pleistocene, though the ice ages created relatively short shifts towards wetter weather types (GUNIN et al. 1999; LIU et al. 1999). During the past 10000 years temperatures in northern China and Mongolia have frequently oscillated, with wetter and colder periods replacing somewhat warmer periods (LI in Ed. Com. 1999). According to KHARIN et al. (1999) the general trend of mean annual temperature during the past 5000 years has been a declining one, but LI (in Ed. Com. 1999) states that temperatures have generally been rising during the past 2000 years. Apparently, the area has become considerably drier during the past one or two millennia, since neolithic camps have been found in places that are presently very dry and far removed from recent human settlements (GUNIN et al. 1999). The 20th century has brought a further strong increase in aridisation and desertification due to increased overutilization (overgrazing, extension of marginal agriculture, heavy vehicle transport) of the land.

Flora and Vegetation

A brief history of the floristic exploration of the flora and vegetation of these dry areas of Mongolia and adjacent China is given by BRETSCHNEIDER (1898, 1981) and by HILBIG (1989). Most early plant exploration has been done by Russian botanists starting their research in the early 19th century, later followed by German botanists. Since the thirties of last century important vegetation analyses and mappings in the Chinese part of the area have been carried out by Chinese botanists, particularly by e.g. HOU et al. (1980, HOU 1983) and LI (see Ed. Com. 1999).

The flora of the Sino-Mongolian dry zone is Holarctic and falls in the West and Central Asian Region; within this region it belongs to the Central Asiatic or Gobi Province. The predominant species are Turano-Gobian and Irano-Turanian, but there are clear floristic affinities to the Mongolian Province and, particularly in its tree and shrub species, also some affinities to the Sino-Japanese Region (MEUSEL et al. 1965; HILBIG & KNAPP 1983; WALTER et al. 1983; HILBIG 1995). LAVRENKO (1965) (discussed in ZOHARY 1973) classifies the steppe zone floristically as the Central Asian subregion of the Eurasiatic steppe region, and YUNATOV (in KARAMYSHEVA & KHRAMTSOV 1995) stresses its uniqueness. These authors classify it as the Mongolian Province, and the desert zone to the south of the true steppe zone as the Gobi Province. The loess plateau still further south is considered as yet another floristical province of the Central Asian subregion. ZOHARY (1973) and WALTER et al. (1983) discuss the various plant geographic classifications of Central Asia, including Mongolia, in detail and, following

GRUBOV (1959), they list the characteristic genera of this area. KARAMYSHEVA & KHRAMTSOV (1995) give a more detailed account of the characteristic genera and species of the steppe and desert steppe zones.

The vegetation cover of the very extensive dry and semi-dry Gobi area is highly varied. It gradually changes from well-developed forest steppe in the north, and open woodland in the east, to steppe, desert steppe, and open desert dwarf shrublands to the south and west. Nearly vegetation-less desert occurs in the driest parts, here and there in the southwest. Further south, in China, as rainfall increases again, the vegetation gradually turns into woodland again. These gradual shifts in vegetation cover correspond with gradual declines and increases of rainfall over the huge area. More sudden changes in vegetation cover are related to slope directions in the mountains and hills, and also to the hydrological pattern of the surface, as in all other dry areas.

The length of the potential growing season in the steppe zone is about 150 days per year (JIANG & LI 1988; HU et al. 1992) and for the desert zone it is given as 250 days per year (LI in Ed. Com. 1999), but the realized growth season decreases with increasing aridity. At anyone locality vegetation cover and forage production can vary up to 4-fold between years in correspondence with a similar variability in rainfall. The major land use of the entire area being pasture, this variability strongly constrains the grazing potential as it affects the forage yields. HU et al. (1992), basing themselves on a much earlier report by CHANG (1949) give average forage yields varying from ca. 1500 kg $ha^{-1} yr^{-1}$ on the best watered sandy soils to less than 150 kg $ha^{-1} yr^{-1}$ in dry desert areas and LI (in Ed. Com. 1999) gives values of 200 to 1000 kg $ha^{-1} yr^{-1}$. LI also reports that the forage quality, in terms of C/N ratio, increases as the area gets drier, but states that total forage quantity has decreased by more than 30 % during the past half century.

In the shallow hollows and valleys in the semi-desert vegetation, where run-on concentrates the moisture brought by precipitation or ground water is available near the surface, the natural vegetation originally was dense. But in China, not in Mongolia, most of these stretches of land, especially in the zone with more than 150 mm yr^{-1} of precipitation, have been exploited for agriculture: a variety of short crops is grown for the benefit of the local population.

The driest parts carry desert vegetation, mostly of the ‘diffuse’ pattern (SHMIDA et al. 1986), and locally conditions are so extreme that the vegetation is contracted solely to the dry riverbeds and runnels (sayrs).

The flora of the semi-desert is not at all poor (ZOHARY 1973; HILBIG 1995; KARAMYSHEVA & KHRAMSTOV 1995; GRUBOV 2001) as far as grasses, sedges and dwarf shrubs are concerned, but turns considerably poorer towards the desert zone.

LI (2001) analysed patterns of species diversity in the communities of the Ordos Plateau inside the giant bend of the Yellow River in Inner Mongolia and Shaanxi, and found that moisture availability was the single most natural determinant factor affecting community diversity, and the diversity gradually decreased as site aridity increased. ZHANG et al. (2006) found that temperature characteristics in the Ordos area also significantly contributed to its geographic pattern of floristic diversification.

Large stretches of land support semi-desert vegetation with dwarf shrubs, grasses, bulbous plants and sedges. Many of the prominent and abundant species occur very widespread and make the distinction between desert and semi-desert vague. Bunch grasses are typical and abundant in these steppe areas, though they are generally smaller than the bunch grasses further west in Kazakhstan and the Black Sea steppes.

Next to the bunch grasses also the rhizomatous grass *Leymus chinensis* can be abundant, particularly on sites with slightly better soil moisture conditions. In general, rhizomatous grasses become more common in the higher rainfall fringes to the east of the dry zone (LI in Ed. Com. 1999). And along the gradient of increasing aridity from the north in Mongolia and the east in China to the south west, particularly the number of herbs decreases (KARAMYSHEVA & KHRAMTSOV 1995).

Most of the steppe and desert species, particularly the grasses, sedges, herbs and geophytic species, have relatively shallow root systems, the majority not penetrating deeper than 30 to 60 cm into the soil. A number of desert dwarf shrubs, however, e.g. *Zygophyllum xanthoxylon* and *Nitraria sibirica*, reach 6 m or more into the soil and reach the water resources in those deep layers. The tree *Haloxylon ammodendron* can even reach the water table at 10 m deep below the thick sands and in the first year its seedlings grow roots to nearly 1 m deep (GUNIN et al. 1999).

As the area gets drier, shrubs and dwarf shrubs become more important in the vegetation (KARAMYSHEVA & KHRAMTSOV 1995). Trees are very rare in the driest desert areas, except along large, seasonally dry riverbeds, near springs and in patches with a rather high water table; they also occur in the less extreme semi-desert, and even on deep sands large patches of partly buried trees/bushes of *Sabina vulgaris* can be common.

Though trees are few in species, they can be surprisingly abundant in number of individuals, even in the dry, sandy areas. It may be expected that few tree species occur in these dry, sandy areas, particularly where the soil surfaces are not stabilized. Trees are generally long-lived and start reproducing sexually at a relatively old age. Thus, their risk at being covered by mobile sands and die before they reproduce is considerable, and as a result few species may be expected to be adapted to such a habitat. However, it is surprising that several of those (usually short) tree species that manage to live in such a habitat are so abundant in number of individuals, because population persistence of these long-lived species more strongly depends on survival of individuals and to a lesser extent on sexual reproduction and recruitment. Apparently, some species have overcome this problem and manage to be abundant under these harsh conditions. An example of such a species is *Caragana korshinskii*, which in the west of the Ordos Plateau can grow as small trees of 3-4 m height.

Many grasses and herbs in this dry area reproduce clonally, which is a common feature of semi-dry and dry areas worldwide. However, the Gobi and adjacent dry areas also contain several large shrub and even some tree species that reproduce clonally, particularly on the deep sand areas, such as several species of *Salix* and *Hedysarum* (ZHANG et al. 2002a,b). While clonal reproduction in these species seems to occur regularly, sexual reproduction is successful only in odd, very favourable years. As a consequence, the clonal shrub and tree species tend to show the usual hollow-curve population size (and age?) structures. The non-clonal shrub and tree species, on the contrary, generally have multi-peaked, uneven population size structures, apparently largely made up of cohorts that have been recruited sexually in sporadic, favourable years (DONG & WERGER, pers. obs., WESCHE et al. 2005).

Phytosociologically the vegetation of the huge, dry Gobi area has not yet been fully studied, but important contributions to its floristic classification have been made by Russian and German authors working in Mongolia. Until recently, inventories in the Chinese parts have been mainly published in Chinese and are therefore difficult to consult. The short outline of the main floristic features of the vegetation given here is mainly based on HILBIG (1995) and KARAMYSHEVA & KHRAMTSOV (1995) for Mongolia, and on KÜRSCHNER (2004), HOU et al. (1979) and HU et al. (1992) for the Chinese part.

South of the Mongolian true, dense steppe vegetation, where on average the rainfall amounts to about 300 mm or more per year, the plains, foothills, piedmonts and lower slopes of the mountains become increasingly drier, having averages of 250 to 150 mm of rainfall per year. This area supports a fairly rich, open steppe to semi-desert vegetation of relatively small bunch grasses, dwarf shrubs and herbs in which, along the decreasing rainfall gradient, in which *Stipa krylovii* gives way to widespread vegetation types with *Stipa glareosa, Stipa gobica, Cleistogenes songorica, Caragana leucophloea*, several *Artemisia* spp. and *Allium* spp. as common species. In patches *Allium polyrrhizum* or woody *Convolvulus* spp., *Eurotia ceratoides, Oxytropis aciphylla, Caragana bungei, Brachanthemum gobicum*, or *Amygdalus pedunculata* shrubs dominate, often depending on particular soil or geomorphological conditions, that cause differences in the moisture availability between sites. Several of these species can locally be very abundant, leading to total vegetation cover values of up to 35 %. On different lower mountain slopes and piedmonts plains, vicarious species may dominate similar communities, e.g. an *Amygdalus pedunculata* community in southern Mongolia on granitic soils and a comparable *Amygdalus mongolica* community in the Ya Gan mountains of China. As the climate becomes still drier *Artemisia* spp., *Calligonum mongolicum* (particularly common on aeolian sands and gypsum soils), *Reaumuria soongorica, Nitraria sphaerocephala,* and *Ephedra przewalskii* (particularly common on gravelly to rocky substrates), and several other dwarf shrubs commonly occur. *Sympegma regelii* is common on stoney, rocky substrates, including up-slopes, but also dominates in the desert zone on the north-faced slopes with sandy loamy soils in the Kun Lun Mountains. On slightly salty, sandy or gravelly soils in the semi-desert zone *Zygophyllum xanthoxylon* or *Anabasis brevifolia* are common, and on solonchaks *Kalidium*-dominated communities occur, frequently mixed with, or surrounded by rather narrow belts of *Nitraria* spp., *Achnatherum splendens*, and even *Phragmites australis*. Footslopes and larger dry riverbeds (sayrs) contain several of the above species, and also typically *Astherothamnus centrali-asiaticus* and *Gymnocarpus prezwalskii*.

Locally these communities have been strongly overgrazed and became ruderalized supporting very open stands with *Peganum* spp. and, on solonchaks, also *Lycium ruthenicum*.

In the very dry desert parts of the Gobi, on the gravelly and stoney substrates, more open communities occur with a similar floristic composition as described above, though grasses, except for a few annual species, and *Allium* spp. are scarce. Solonchaks also support similar communities. But the desert areas with deep aeolian sands differ as regards their communities from the semi-desert parts. In the desert parts the deep sands carry *Calligonum mongolicum – Haloxylon ammodendron* communities, often containing also the widespread dwarf shrubs, *Nitraria* spp. and also, in dune valleys and low laying plains, *Phragmites australis*.

Mostly this vegetation has a diffuse distribution pattern, but where sand dunes are very high in these driest parts, the dunes are bare and the vegetation is contracted to the runnels, sayrs, deep valleys and low-lying run-on patches. Where the substrates are more gravelly, and on alluvial plains, that usually are somewhat salty, the *Calligonum mongolicum – Haloxylon ammodendron* communities can form intricate mosaics with stands dominated by *Nitraria sphaerocarpa, Artemisia* spp., *Reaumuria soongorica,* *Ephedra prezwalskii* and other dwarf shrubs, and on stoney substrates *Calligonum* mixes with these species, but *Haloxylon* does no longer occur. *Calligonum mongolicum – Haloxylon ammodendron* communities, though typical of deep sands, can also occur on somewhat loamier soils when these contain gypsum. *Haloxylon ammodendron* is a tree, that can be up to 7 m tall in sayrs and sites where the sands meet alluvial deposits; its apparent height is even increased by wind erosion partly baring its root system and making the tree appear to stand on tall stilts. Mostly *Haloxylon* plants are much smaller and badly damaged, however, as it is an important species for browsing, particularly by the abundant camels, and for fuel.

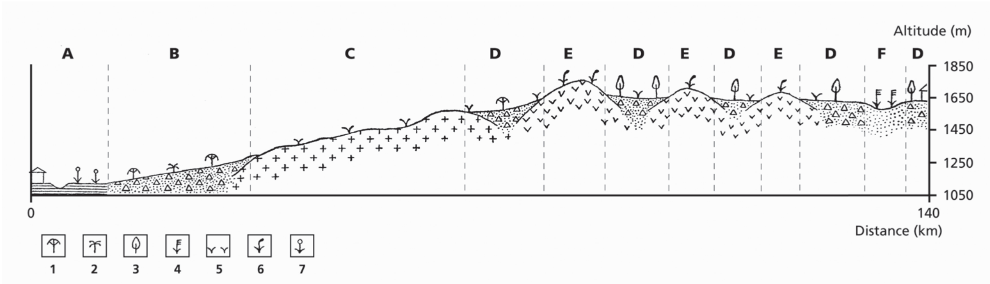

Fig 2: Characteristic sequence of vegetation – substrate associations in a transect of 140 km, rising 600 m in elevation, from the town of Anxi to Malian well in the Hexi Corridor in Gansu Province, China (schematized and modified from HOU et al. 1980).
A: alluvial terrace of the Shule River; B: gravelly and sandy deposit, infrequently flooded; C: eroded granitic substrate; D: gravelly desert soils; E: eroded metamorphic substrate; F: saline lake basin; 1: *Nitraria sphaerocarpa*; 2: *Ephedra przewalskii*; 3: *Haloxylon ammodendron*; 4: *Phragmites australis*; 5: *Reaumuria soongorica*; 6: *Sympegma regelii*; 7: *Alhagi sparsifolia*.

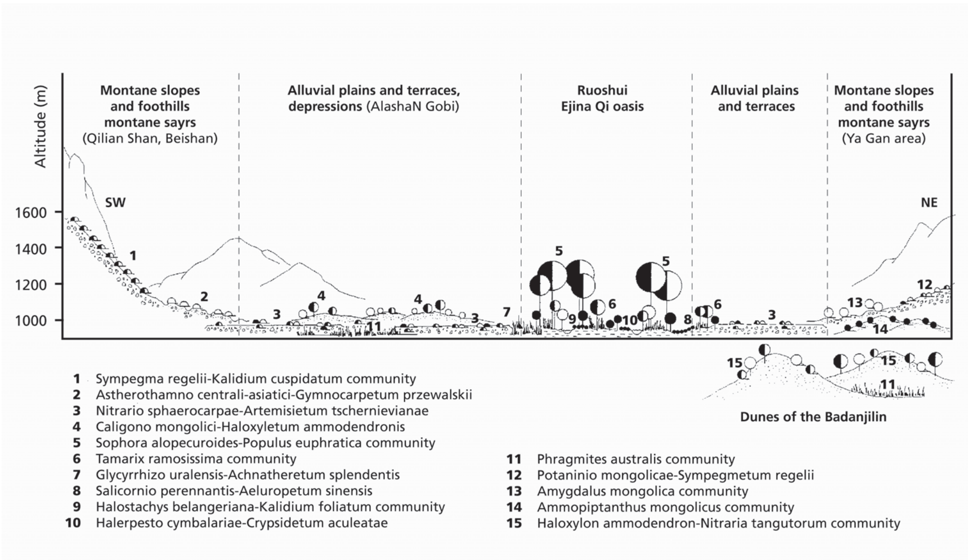

Fig. 3. Schematized, characteristic sequence of vegetation – landform associations in the Alashan Gobi, Inner Mongolia Province, China (from KÜRSCHNER 2004).

Tree species are rare in the true desert parts. However, apart from the *Haloxylon* stands on deep sands, patches of *Salix* spp., *Populus euphratica, Populus diversifolia* and *Elaeagnus angustifolia* woodland occurs along those larger dry river beds where ground water can be reached by its roots. Where these sites are saline woodland patches of *Tamarix* spp., mainly *Tamarix ramosissima*, may also occur. These trees and woodlands are also strongly overused and badly damaged or even eradicated, particularly the *Populus* stands. Most of the remaining stands are very open and strongly ruderalized, containing large dense tussocks of the grass *Achnatherum splendens*, and of the ruderals *Glycyrrhiza uralensis, Sophora alopecuroides, Peganum* spp., etc.

In the semi-desert zone tree species (and tall shrub species) are not many but considerably more than in the desert zone. Here *Ulmus pumila* is common where its roots can reach the water table. Other tree species, mostly on alluvial or loamy substrates, include *Tamarix chinensis*, some *Populus* spp., and *Malus transitoria*, on compact, loess soils *Pinus tabulaeforme* and some *Sabine* spp., while on sands *Caragana microphylla, Sabine vulgaris, Hippophae rhamnoides* and various tall *Salix* spp. are frequent.

Schematic sequences of vegetation – substrate and vegetation – landform associations that are characteristic of the area under discussion are shown in figs 2 and 3.

Grazing, overgrazing and desertification

These dry lands of Mongolia and China have been a pasture land for thousands of years. Wild animals and various species of livestock have grazed the steppes and semi-steppes sustainably during the past 3000 years, but this has changed in the course of the 20th century, and since about 1950 grazing pressure has become heavy. Particularly in the Chinese part of this arid zone the land presently is overpopulated and overstocked considering the natural growth conditions of the vegetation. While in a favourable season the amount of forage might still be sufficient, in winter and spring there is a serious lack of forage (KHARIN et al. 1999; KHARIN 2002; GUNIN et al. 1999; HU et al. 1992; ZHANG 1998; LI in Ed. Com. 1999). Accordingly, in Chinese Mongolia a common saying referring to one's livestock is "strong in summer, fat in autumn, thin in winter, and dead in spring" (LI in Ed. Com. 1999).

KHARIN et al. (1999) show that the numbers of camels, horses, cattle, sheep and goats in Mongolia generally more than doubled between 1918 and 1985 (Table 1) while the human population tripled. From 1985 to 1995 the number of livestock in Mongolia

Table 1: Number of livestock in Mongolia, 1918 - 1985 (from KHARIN et al. 1999)

Year	Camels (*10^3)	Horses (*10^3)	Cows (*10^3)	Sheep (*10^3)	Goat (*10^3)
1918	228.7	1160.5	1078.4	5700.1	148.9
1924	275.0	1339.8	1512.1	8444.8	2204.4
1961	751.7	2889.3	1637.4	10981.9	4732.6
1970	638.5	2317.9	2107.8	13311.7	4204.0
1980	591.5	1985.4	2397.1	14230.7	4568.7
1985	559.0	1971.0	2408.1	14429.8	4298.6

increased another 25 % to circa 28 million head (CBD 1996). When the communist regime fell in 1990, the Mongolian economy crashed, many people became unemployed and left the cities, returning to a nomadic life-style on the steppe (VAN STAAL-

DUINEN 2005). This led to widespread, strong overgrazing, and this is particularly severe in the vicinities of functioning wells and health care centres, as the families of the herdsmen concentrated there.

While in Mongolia population density in 1995 was about 1.2 persons per km^2 and the stocking rate of the rangeland stood at about 1 sheep unit per 2.6 ha, in Inner Mongolia population density stood at 17.7 persons per km^2, the stocking rate at 1 sheep unit per 0.97 ha, and in the loess area of adjacent Gansu at 47 persons per km^2 with a stocking rate of 1 sheep unit per 0.45 ha (LI in Ed. Com. 1999).

HU et al. (1992) state that the number of camels in the Alashan Gobi in China about tripled since 1949 and LI (in Ed. Com. 1999) reports that the number of livestock has at least tripled between 1950 and 1990 in Inner Mongolia and has more than doubled in the other dry Chinese provinces. In the moister eastern fringes of the Chinese steppes, and in the loess plateau, much of the steppe vegetation has been turned into farmland during the past fifty years, producing wheat, maize and potatoes, though not all of this farmland is producing successfully and a fallow system is often used. Locally farmland is irrigated, but a considerable part of that farmland has become salinized. In the remaining parts of the eastern Chinese steppe, cattle raising is the main practice, changing to meat and wool sheep raising in the somewhat drier parts further west, and to fine-fiber goat raising on the loess area and the Ordos Plateau. In the driest parts wool sheep and camel raising is practised. Much of the dry area, particularly the steppe vegetation, has been severely overgrazed in the past decades and the forage productivity has accordingly decreased. Presently the area of overgrazed rangeland in China is still increasing with about one million ha per year and a full one third of the dry Chinese rangelands are heavily overgrazed. As a rule of the thumb, cattle do least damage to the vegetation, sheep more, and goats cause strong damage. Unfortunately, both in the Mongolian and Chinese rangelands, the proportion of goats, to the disadvantage of that of sheep, has rapidly increased in recent years. This makes careful and professional management of the grazing system a top priority.

The most rapid increase in damage to the dry Chinese rangelands occurred during the years of collectivization, but the situation improved after 1985 when the management of the rangelands was returned to herding families. On the Ordos Plateau, for instance, during the years of collectivization an average family had only 20 sheep units, while at the same time the quality of the rangeland deteriorated rapidly. A few years after the collectivization policy had been stopped and the rangelands had been returned to the private management of herding families, an average family had 50 sheep units, the deterioration of the vegetation had ceased, and the production had risen 18 fold. This change in management strongly improved the stability of the grazing/production system on the rangelands (LI in Ed. Com. 1999).

Grazing opens up the vegetation and overgrazing does so severely and soon leads to destruction of the vegetation cover, opening the way for severe soil erosion. Different intensities of grazing also lead to changes in species composition. ZHANG (1998) found in Inner Mongolia that severe grazing reduced the number of perennial species, while the number of annual species increased. Complete protection from grazing resulted in higher cover values of the vegetation but a lower species richness. While extensive grazing allows for high species richness, overgrazing also reduces species numbers. In fact, overgrazing has a much stronger effect on species richness of the vegetation than the natural environmental variation (LI 2001).

GUNIN et al. (1999) showed that the steppe and semi-steppe vegetation is much more affected by overgrazing than the desert vegetation. This is first of all because steppe vegetation is more relentlessly overgrazed than desert vegetation, but also because the bunch grasses of the steppe are more easily destroyed by overgrazing than the hardy desert shrubs and dwarf shrubs. Furthermore, rocky desert plant communities are much more resistant to overgrazing than sandy desert vegetation and quite easily recover. In the sandy desert vegetation overgrazing easily loosens the top soil and thus allows the wind to move the sand and gather into mobile sand deposits, initially stuck against remaining plants or rocks, but gradually accumulating to huge mobile dunes. Constant and strong winds can move these dunes over large distances. The dunes generally move eastward due to prevailing westerly winds (WANG 1961; GUNIN et al. 1999). In Inner Mongolia these shifting dunes become more prominent as one proceeds further westwards into the drier zone. There, presently about 40 % of the approximately 100 million hectares of what was originally sandy steppe has turned into mobile sand dunes (LI in Ed. Com. 1999). Huge effort and much capital is invested in planting tree and shrub shelter belts in an attempt to stop the shifting dunes from overrunning valuable rangeland, farmland and villages. At the same time aeroplanes are used to sow in the bare sands with suitable, often clonally growing species to stabilize the sandy top soils.

Detailed investigations on overgrazing in the steppe communities showed that initially the more compact bunchgrasses, such as *Stipa* spp. and *Koeleria macrantha*, soon decrease in cover and abundance, while the rhizomatous grass *Leymus chinensis* increases, just as some short rozette plants, e.g. *Potentilla acaulis*, and the hardy sedge *Carex duriuscula*. Under more severe and continued overgrazing also *Leymus chinensis* and all other grasses decline as well as the short rozette plants, and finally only a few species remain that are less palatable, such as *Carex duriuscula, Artemisia frigida*, other annual *Artemisia* spp. and some unpalatable weeds (HILBIG 1995; GUNIN et al. 1999; FERNANDEZ-GIMENEZ & ALLEN-DIAZ 2001; Xie & WITTIG 2003; VAN STAALDUINEN 2005).

On a much smaller, patchy scale, but with high frequency, such effects of overutilization of the steppe vegetation are caused by burrowing rodents which are very frequent in the steppe zone. We investigated the effects of the burrowing, grazing and urinating activities of *Marmota sibirica* in the Mongolian steppe and found that grazing favoured *Leymus chinensis* and other rhizomatous species over *Stipa krylovii* and other bunch grasses, and that the heaviest disturbances resulted in bare patches or patches dominated by the annual *Artemisia adamsii*. All these marmot activities led to a decline in species richness of the disturbed vegetation on the mounds, and also to a better forage quality of the mound vegetation as apparent from its higher nitrogen concentration (VAN STAALDUINEN 2005).

The initial shift in dominance from bunch grasses to rhizomatous grasses under overgrazing is observed in many steppe vegetations and has been attributed to a higher grazing tolerance of the rhizomatous species. Rhizomatous species have a much larger below ground storage potential of carbohydrates and buds than bunch grasses. This allows them a strong reallocation of reserves to replace removed plant parts and thus they have a stronger compensatory growth following grazing than the bunchgrasses (DONG & PIERDOMINICI 1995; WANG et al. 2004; VAN STAALDUINEN 2005). We investigated this in a controled, simulated grazing experiment with the bunch grass *Stipa krylovii* and the rhizomatous grass *Leymus chinensis*, replacing grazing by monthly clipping removing 75 - 90 % of the above ground plant mass. *Leymus* showed a much stronger compensatory growth after clipping than *Stipa*, and significantly increased its relative growth rate, while that of *Stipa* decreased. While leaf productivity of *Leymus* under clipping was similar to that in undamaged control plants, leaf productivity of clipped *Stipa* fell to less than half of the controls. The much stronger compensatory growth of *Leymus* compared to *Stipa* could be attributed to its much larger storage capacity of carbohydrates that could be reallocated to growth after clipping, and it explains the higher grazing tolerance of *Leymus* compared to *Stipa* (VAN STAALDUINEN & ANTEN 2005).

In the semi-desert zone relatively small caespitose bunch grasses often are dominant on the more compact soils, but on loess slopes in the southern part of the semi-desert zone the rhizomatous *Phragmites australis* can also be very common in the steppe vegetation, emerging with relatively short shoots. Under increasing grazing pressure the caespitose species are increasingly replaced by rhizomatous species, and under severe overgrazing, or at sites that are strongly disturbed by digging animals, these too give way to ruderal annuals and unpalatable other species. On the loose sandy substrates rhizomatous species are clearly predominant, and include large shrubs, such as *Hedysarum* and *Salix* spp. Very common and typical in loose sands in the semi-desert zone is also the stout and strongly rhizomatous Gobi-endemic grass *Psammochloa villosa*.

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Address of the autores:

Dr. M.A. van Staalduinen & Prof. Dr. Marinus J.A. Werger, Plant Ecology & Biodiversity, Utrecht University, P.O. Box 80084, 3508 TB Utrecht, The Netherlands

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Autor(en)/Author(s): Staalduinen M. A. van, Werger Marinus J. A.

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