# Vegetation-Ecological Investigations of Rangeland Ecosystems in Western Mongolia

## *- The Assessment of Grazing Impact at Various Spatial Scale Levels -*

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# 1 Introduction

## 1.1 Scientific rationale and objectives of the study

The transformation process towards market economy in Mongolia at the beginning of the nineties has lead to tremendous changes in the pastoral economy. In consequence of the privatisation of former state-owned cooperatives between 1991 and 1993, mobile pastoralism experienced an important revival, which has led to a considerable increase in herders and livestock. The proportion of cooperative members, formerly employed outside the animal production sector, obtained private livestock as all members of the cooperatives and joined their nomadic relatives as so-called ‚new nomads' in the steppes (MÜLLER 1995, 1999). Economic and social infrastructure in rural areas collapsed and lead to a reduced mobility among the herders and their concentration near administrative centres. The loss of appropriate grazing areas due to missing technical service of wells in peripheral regions without accessible water formerly supplied by the cooperatives is an additional consequence of the privatisation. Thus, beside higher average livestock densities the transformation process causes moreover a higher variation in livestock densities of peripheral areas compared to areas adjacent to urban centres. Furthermore, the privatisation caused the cancellation of grazing regulations, which formerly were implemented by the cooperatives (BATKHISHIG and LEHMKUHL 2003; JANZEN 2005; JANZEN and BAZARGUR 1999, 2003; MEARNS 1993; own observations 1999-2005). For several areas in Mongolia in particular near big cities and main road corridors of the country, consequences of increased grazing pressure such as the decline in vegetation cover, the rise of unpalatable weed species, loss of soil moisture and moreover, the deflation of humus layer and other forms of soil erosion have been documented (ADYASUREN et al. 2002, HILBIG and OPP 2005, MÜLLER and BOLD 1996, MÜLLER and JANZEN 1997, OPP and HILBIG 2003). The diversity of plant species in areas near town centres has fallen by more as 80 percent (MINISTRY FOR NATURE AND THE ENVIRONMENT OF MONGOLIA et al. 1999). According to STUBBE (1997), 25 percent of Mongolia's pastures are threatened by degradation; according to TSEVEENJAV and BLACKBURN (2001), 40 percent of the total land area is degraded.

In contrast to these economic constraints, natural hazards such as droughts or cold winters with heavy snowfall can reduce livestock numbers. Three consecutive years from 1999 to 2002 with harsh winters followed by summer droughts resulted in a loss of livestock from 33.6 million to 26.1 million (cf. also Fig. 3). However, as long as incentives for short-term profits from high livestock numbers exist, Mongolia's pastures land will be continuously threatened by overgrazing and degradation (BATKHISHIG and LEHMKUHL 2003, JANZEN and BAZARGUR 2003, JANZEN 2005).

Targeted scientific examinations of grazing influences in extreme arid ecosystems worldwide and in Mongolia revealed that grazing influences are of much lower impact than often anticipated by ecologists (ELLIS and SWIFT 1988, FERNANDEZ-GIMENEZ and ALLEN-DIAZ 1999, HOMEWOOD and RODGERS 1987, STUMPP et al. 2005, WESCHE and RETZER 2005, VETTER 2005). Since the mid-1980s, when sufficient data on the interference of grazing, climatic variability and vegetation dynamics of Africa's arid regions became available, researchers have challenged the previously common view that pastoral ecosystems used as commons are generally overstocked and mismanaged (BEHNKE and SCOONES 1993, ELLIS and SWIFT 1988, HOMEWOOD and RODGERS 1987). Rangeland dynamics has since been the object of much controversy. Prominent topics of the debate are the influences of rainfall variability, herbivory and vegetation dynamics in arid and semi-arid pastoral systems, especially in Africa and Australia (VETTER 2005). The main divide runs between two models of ecosystem dynamics. The equilibrium model, referring to grazing-sensitive systems with low rainfall variability, regards livestock density as the primary driver of vegetation dynamics (ILLIUS and O'CONNOR 1999). Basing on the succession model of vegetation dynamics (CLEMENTS 1916), it emphasises internal ecosystem regulation and stability (BRISKE 2003, GRIME 1979, 2002, HOLLING 1979, MAY 1977). The non-equilibrium model, referring to grazing-resilient systems with high climatic variability, suggests that, since food supply can never be exceeded by grazing demand, vegetation dynamics is decoupled from livestock density and primarily determined by stochastic abiotic factors (BEHNKE and SCOONES 1993, ELLIS and SWIFT 1988, SULLIVAN and ROHDE 2002). It focuses on external factors with highly variable occurrence as rainfall and disturbances as drivers of ecosystem behaviour (BEHNKE and SCOONES 1993, ELLIS and SWIFT 1988, FERNANDEZ-GIMENEZ and ALLEN-DIAZ 1999). The equilibrium model allows applying carrying capacity concepts, including optimal management strategies to pastoral systems where rainfall and hence forage production are predictable. The non-equilibrium model on the other hand, is based on a state-and-transition dynamics of vegetation showing abrupt discontinuous and irreversible transitions between discrete states (ALLEN-DIAZ and BARTOLOME 1998, WESTOBY 1980). It rejects the concept of carrying capacity and supports mobile stocking regimes for systems with high climate variations and hence unpredictable primary production (BEHNKE and SCOONES 1993, ELLIS and SWIFT 1988, WESTOBY et al. 1989). In the controversy over the two models, little attention has been paid to the differences in climate, the associated differences in vegetation structure, and the land use regimes of the examined regions. Furthermore, the two models were considered as mutually exclusive (SULLIVAN and ROHDE 2002).

Against the backdrop of the risks of overgrazing and degradation in Mongolia, it is pivotal for sustainable resource use and conservation policy of the country to understand the impacts of grazing on the country's arid ecosystems, and to identify the relevance of both concepts. Their applicability to Mongolia has been tested in few studies (FERNANDEZ-GIMENEZ and ALLEN-DIAZ 1999, 2001; STUMPP et al. 2005; WESCHE 2005; WESCHE and RETZER 2005).

In the steppe zone of Mongolia, grazing degradation series have been described regarding changes in vegetation composition and proportions of single species, increasing proportions of species with low palatability, changes in aboveground biomass production and life form composition by BABAEV and SARANTUYAA (1995), DANZHALOVA (2005), FERNANDEZ-GIMENEZ and ALLEN-DIAZ (1999, 2001), GOLUBEVA and POLYANSKYA (1990), GUNIN et al. (2002), and TSERENDASH and ERDENEBAATAR (1993). GORSHKOVA and GRINEVA (1977) gave detailed information about grazing influence on growth structure, age classes, period of seed maturity and content of P and K of plant communities for the steppes in the Transbaikal region. These studies were repeated by MIRKIN et al. (1988) in the forest steppe of the eastern Khangay Mountains.

In contrast to semi-arid steppe ecosystems, FERNANDEZ-GIMENEZ and ALLEN-DIAZ (1999, 2001) found no consistent changes in vegetation attributable to grazing gradients in arid desert steppe communities of Mongolia. They suppose that grazing has a lesser effect on vegetation than patchiness in soil parameters and interannual variation in precipitation in this arid ecosystem and ascribe vegetation changes mainly to differences in precipitation instead of grazing. These results are confirmed by WESCHE and RETZER (2005) and WESCHE (2005), who found larger differences in vegetation cover between the years than between the years than between grazed plots and ungrazed enclosure control plots in southern desert steppe of Mongolia.

However, all results indicate that neither of the models describes the dynamics of desert steppes and dry steppes sufficiently; but the empirical data better conforms to the non-equilibrium model (FERNANDEZ-GIMENEZ and ALLEN-DIAZ 1999, WESCHE and RETZER 2005).

Recent Studies have shown that one ecosystem can display characteristics of the equilibrium model as well as characteristics of the non-equilibrium model and the detection of grazing effects in arid ecosystems depends significantly on the scale of observation that is applied (OBA et al. 2003). Therefore, a scale-sensitive synthesis of the two models has been called for (BRISKE et al. 2003, OBA et al. 2003, VETTER 2005). Beside the temporal scale level of rangeland dynamics and the spatial scale level of ecosystem properties, in the assessment of grazing effects the local in-situ processes has to be considered: grazing modifies vegetation in species composition and in aboveground and belowground vegetation structure directly through trampling and defoliation, and indirectly via soil compaction and redistribution of soil nutrients. It may cause fertilisation or nutrient depletion, and furthermore changes in soil microbial processes (AUGUSTINE and MCNAUGHTON 1998; GRIME 1979, 2002, MCNAUGHTON 1985; MILCHUNAS et al. 1988; OLFF et al. 1999; VAN DER MAAREL and TITLYANOVA 1989; WEAVER 1930, 1950). These direct and indirect effects can interact with or be overlaid by the structure of food web of the ecosystem. (For more details, see 2.7.5.) Moreover, also variable climatic occasions, heterogeneity of abiotic site conditions or disturbance events can interact with these direct and indirect effects of grazing. All these interactions can either determine or blur the patterns of grazing (CHASE et al. 2000, ELLIS and SWIFT 1988, SANKARAN and MCNAUGHTON 2005). Resulting patterns of direct and indirect grazing effects on vegetation are integrated in various concepts of herbivory and species diversity (CHASE et al. 2000; GRIME 1979, 2002; HUSTON 1979; OKSANEN et al. 1981; OLFF et al. 1999; PROULX and MAZUMDER 1998; SANKARAN and MCNAUGHTON 2005; TILMAN 1988) representing the equilibrium model introduced above.

A lot of research has been conducted on the effects of grazing on vegetation during the last century, but relatively few has included effects on soil conditions. To date, there is a lack of understanding of how abiotic factors regulate rangeland systems and which types of rangelands are mainly controlled by abiotic environment and which are mainly controlled by biotic factors. The reaction of rangeland vegetation to grazing in its dependency on abiotic environment is not fully understood (COMMITTEE ON SCHOLARLY COMMUNICATION WITH THE PEOPLE'S REPUBLIC OF CHINA (U.S.) 1992, FERNANDEZ-GIMENEZ and ALLEN-Diaz 2001, KNOLL and HOPKINS 1959). The few studies available for Mongolia mostly describe grazing impacts on plant communities. No previous study on grazing influences in Mongolia considered the effect of spatial scale in its investigation approach.

To reduce this lack of knowledge against the background of increased threats to grazing resources in Mongolia, a landscape ecological study was carried out on the relationship and mutual dependence of environmental and site-ecological conditions with vegetation and the assessment of grazing impacts on vegetation and site conditions in western Mongolia at three different spatial scale levels. Following objectives are addressed in detail:

**Chapter 2**

At the spatial scale level of vegetation formations:

- Identification of the main environmental and site-ecological factors determining vegetation composition in three different vegetation formations placed along an altitudinal gradient in western Mongolia.
- Based on the main environmental and site-ecological factors determining vegetation composition, plant communities are identified as grazing-mediated communities, which are primarily controlled in their species composition by grazing.
- Comparison of the identified vegetation-determining factors of examined vegetation formations along the altitudinal gradient.
- Detections of patterns of grazing influences on soil and vegetation and their change within these vegetation formations along an altitudinal gradient.
- Assessment of the role of vegetation-determining factors in the formation of grazing patterns.

- Detection of relevant components of herbivory concepts as a basis for the assignment of examined rangelands to models of ecosystem dynamics.

**Chapter 3**

At the spatial scale level of population of the dwarf semi-shrub *Artemisia xerophytica*:

- The effect of grazing on stand density, aboveground biomass, individual plant weight and the proportion of flowering plants of *Artemisia xerophytica* along a gradient of decreasing grazing intensity.
- To distinguish between grazing effects and edaphic influences, selected soil parameters were analysed and correlated with cover values of *Artemisia xerophytica*.

**Chapter 4**

At three spatial scale levels of landscape, plant communities, and plant population:

- The impact of grazing at the landscape level on ecological factors, which were identified as the primary drivers of vegetation development in Chapter 2.6 and the identification of grazing-mediated plant communities.
- The impact of grazing at community level on vegetation structure and soil nutrients within three different communities of desert steppe.
- The influence of grazing at population level on selected characteristics of the dwarf semi-shrub *Artemisia xerophytica*.
- The comparison of grazing effects at different spatial scale levels.
- Validate and improve the non-equilibrium concept as an explanation approach of different susceptibility to grazing of arid and humid ecosystems.

In each chapter, the sampling design with sampled data and methods of analysis are presented separately. Raw data as vegetation relevés for each vegetation formation and soil profiles with soil samples are included in the Appendices I-V.

Transcription of Russian and Mongolian geographical terms and Russian literature in the references follows the Romanisation table for Cyrillic letters according to ENCYCLOPAEDIA BRITANNICA INC. (1997).

## 1.2 The investigation area

### 1.2.1 Geographical region

The investigation area (Fig. 1) located in the western Mongolian province of Khovd extends from the Argalant Mountains within the Great Lake Basin to the Tumtiyn Nuruu Mountain Range of the Mongolian Altai (48°00’ N, 91°05’ E and 48°23’ N, 93°10’ E). It constitutes a transition from the Great Lake Basin landscapes in the east to those of the Mongolian Altai in the west. It covers an altitudinal gradient of 1150 - 3050 m a.s.l. cutting across the different vegetation belts of desert steppe, mountain steppe and alpine vegetation.

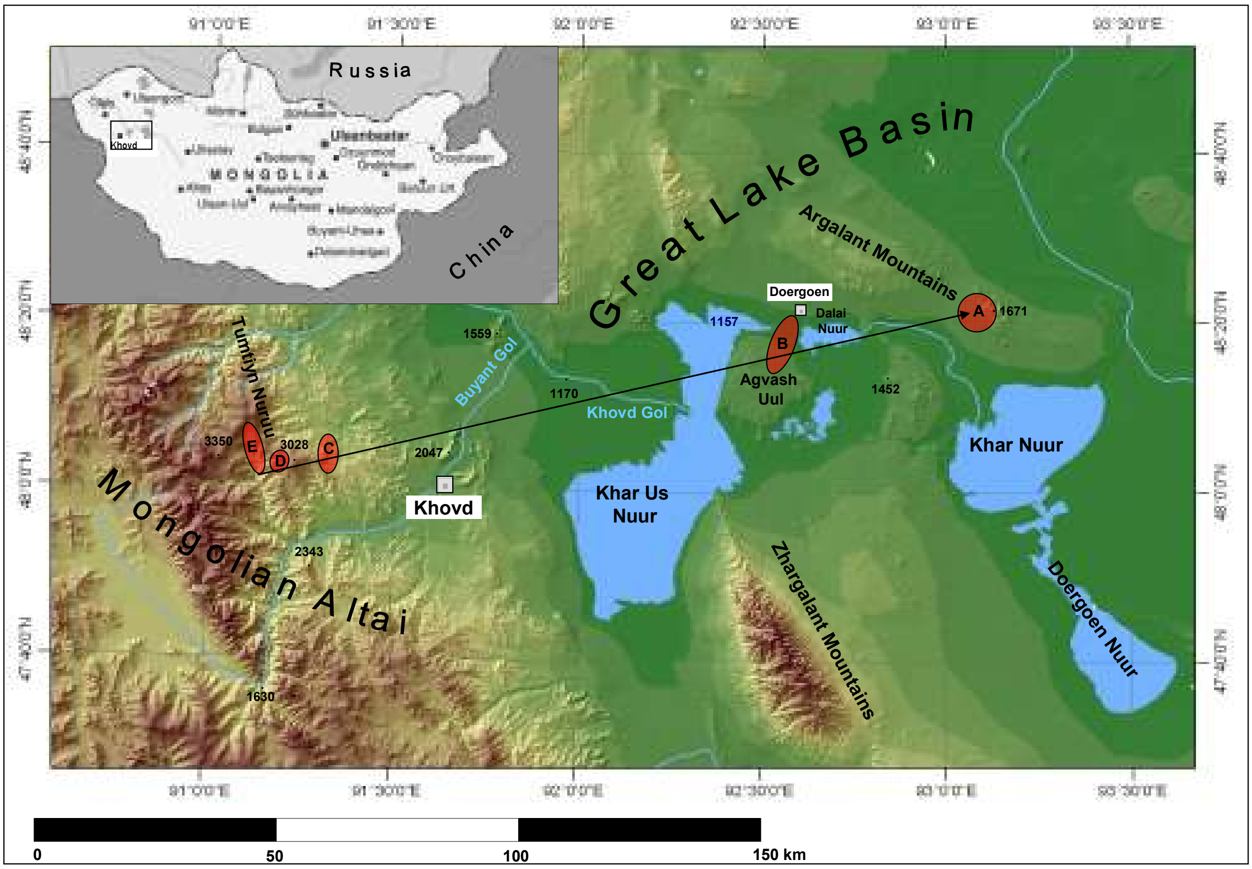
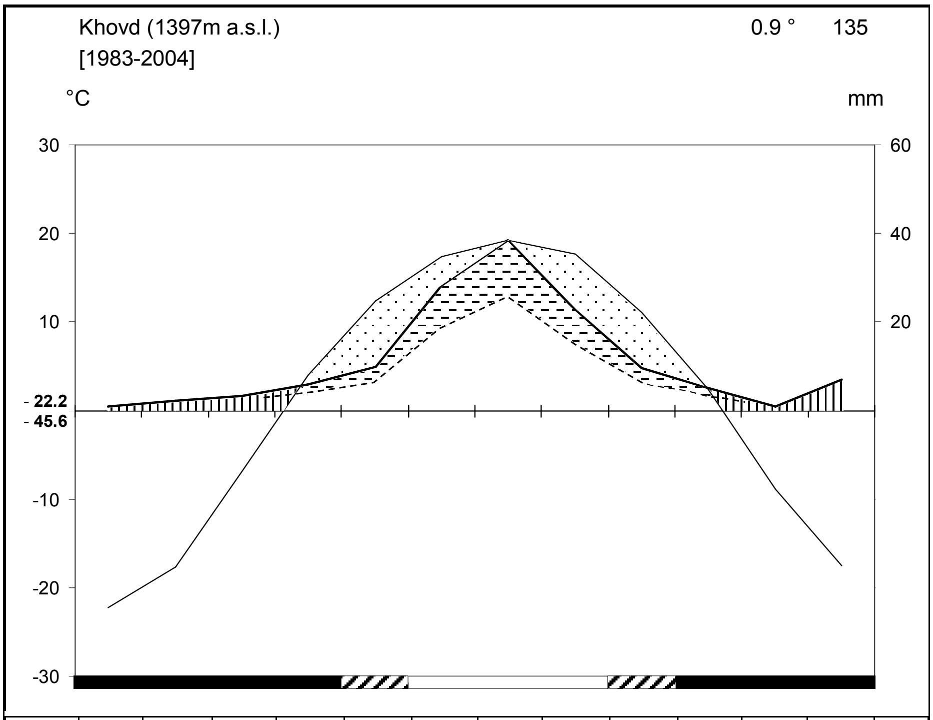


Fig. 1: Map of investigation area in southwestern part of the Great Lake Basin and eastern portion of Central Mongolian Altai. (Study areas are indicated in red and distinguished by capital letters. Sources: Tibet Family, Tours and Travel 2006; Kretschmer 2004, modified.)

The investigation area covering the northern slopes of Mongolian Altai, hydrographically belongs to the drainless basin of Inner Asia which is regionally fed by the Khovd Gol and other rivers from the Mongolian Altai and Khangay. A set of larger and smaller lakes in the western part of the Great Lake Basin forms a network of interconnected freshwater lakes without discharge that ends in the saline Doergoen Nuur lake. The lake areas are surrounded by softly undulating pediments of individual mountain ranges of Argalant Mountains and Zhargalant Mountains that are considered to be a part of the Mongolian Altai system (MURZAEV 1954). The extended pediment area is interspersed with salt pans, small hills and dry river valleys sporadically bearing water (in Russian: sayr). After 10-30 km to west, the pediment area merges into a steeply inclined mountain foreland and later into the Mongolian Altai mountain ranges. The mountainous area consists of separate ridges in latitudinal arrangement divided by intermountain depressions or connected by saddles (GUNIN et al. 1999). The surface is covered with gravelly and rocky erosion debris predominantly consisting of granite and slate rock (MURZAEV 1954).

### 1.2.2 Climate

The investigation area is located in a sheltered position (Tannu Ola Mountains north, Khangay Mountains east, Gobi Altai south and Mongolian Altai west) and is characterized by extremely continental climate. The Pacific monsoon effects can only be traced up to 110-120° E, without ever reaching the investigation area (GUNIN et al. 1999). The stable Siberian anticyclone forms long, cold, and dry winters with mean January temperatures of -22 °C. The climatic factors, relevant for plant growth, are provided in a climate diagram (in Fig. 2).



| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | **Year** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **°C** | -22.2 | -17.6 | -6.9 | 4.0 | 12.4 | 17.4 | 19.2 | 17.6 | 11.1 | 2.4 | -8.9 | -17.6 | **0.9** |
| **mm** | 0.9 | 2.2 | 3.4 | 6.0 | 9.8 | 28.3 | 38.6 | 22.8 | 9.7 | 5.1 | 0.9 | 6.9 | **134.6** |

Fig. 2: Climate diagram according to WALTER (1955) of climate station Khovd situated in the centre of the investigation area within northern desert steppe belt (Source: CLIMATE STATION KHOVD 1983-2004).

Frost periods with mean monthly temperatures below 0 °C lasts from October through April. First and last frosts appear in May and September. Frostfree periods with mean monthly temperatures above 0° C are only found in June, July and August. Winter precipitation is low, failing to create an isolating snow cover. As a rule, the soil remains deeply frozen, except for thin top layers where melting occurs during the short summer period. In winter, extensive temperature inversions involving warm airmass in lower mountain regions superimposed above cold airmass in the plains, lead to relatively warm conditions on the winter pastures at approx. 2000 m a.s.l. (BARTHEL 1983). In spring, high atmospheric pressure conditions are replaced by the influence of the westerly wind zone. Westerly winds bring warm and humid airmass, but rarely make it across the mountain barriers of Mongolian Altai (BARTHEL 1983, GUNIN et al. 1999). Summers are short and warm at mean July temperatures of 19 °C. About 70-90 percent of annual precipitation occurs in summer, even though quantities may vary considerably over the years. For example, mean annual precipitation in the desert steppe lowlands amounts to 135 mm, but only 78 mm occurred in 2002 as opposed to 223 mm in 2003 (CLIMATE STATION KHOVD 1983-2004). Since low precipitation is accompanied by high evaporation rates, the seasons from mid-April through mid-October is generally characterized by arid conditions and summer drought. Dependending on summer precipitation quantities, the summer drought may be interrupted by wet weather conditions in July, the month with heaviest rainfall. Despite substantial evaporation and due to the coincidence of rainy and warm season, the natural process of soil salinization is prevented, thereby causing calcium carbonates and soluble salts to leach out of the top soil layers (HAASE 1983). From mid-October to mid-April, mean monthly temperature drops below 0 °C. According to the aridity index applied by Walter (1955), this period is considered humid, even during very low winter precipitation[1]. The spring and autumn transition seasons are very short. Major daily and annual temperature fluctuations are typical of the region’s continental climate (numerical values of climate data taken from CLIMATE STATION KHOVD 1983-2004, located at center of investigation area in northern desert steppe belt at 1400 m a.s.l.; BARTHEL 1990, GUNIN et al. 1999).

The choosen altitudinal gradient across the investigation area reveals a aridity gradient shifting from (a) arid conditions involving 62 mm mean annual precipitation in the desert steppe lowlands between Lakes Khar Nuur and Khar Us Nuur, (b) via 135 mm in the northern desert steppe lowlands around Khovd city, through (c) 325 mm in the mountain steppe belt, up to (d) 350 mm humid conditions in the alpine belt (CLIMATE STATION DOERGOEN 1985-2004, CLIMATE STATION KHOVD 1983-2004, CLIMATE STATION KHOVD a, b). Following the climatologic rule - the lower the long-term mean annual precipitation, the higher the

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[1] The index of aridity by WALTER (1955) is based on mean monthly temperatures in discrete proportion to monthly precipitation for easy world-wide comparison of commonly available climate data. It makes no distinction between higher daily temperatures with arid conditions caused by high evaporation rates and low overnight temperature with humid conditions during wintertime. HAASE (1983) considers winter frost periods as arid conditions, while WALTER (1955) thinks they imply humid conditions. Application of the aridity index by WALTER (1955) is discussed and criticised by LAUER (1960).

precipitation variability over the years (BLÜTHGEN and WEISCHET 1980, SULLIVAN and ROHDE 2002) - the decreasing aridity gradient established in the study is associated with a decreasing year-to-year precipitation variability. In addition, the altitudinal gradient is accompanied by decreasing vegetation period durations expressed by the sum of mean temperature hours above 10° C. The vegetation periods range from (a) 1500 – 2000 hours per year in desert steppe, via (b) 700 – 1000 hours per year in mountain steppe, up to (c) 500 – 1000 hours per year in the alpine belt (CLIMATE STATION KHOVD a, b).

### 1.2.3 Soil and vegetation

Within the investigation area, three typical vegetation formations of Western Mongolia were chosen as study sites comprising desert steppe, mountain steppe, and alpine vegetation. (An overview of plant communities with corresponding soil types of each vegetation formation is given in Fig. 5.)

#### *Desert steppe*

Vegetation zone of desert steppe, within the investigation area situated between 1150 m and 1460 m a.s.l., is divided according to Russian and Mongolian vegetation classification in desert steppe s.l. and northern desert steppe[2] (cf. ZEMMRICH 2005). The northeastern study areas of Argalant Mountains and Agvash Uul (cf. Fig. 1: A & B) belong to desert steppe s.l. While this sub-belt is considered as the transition from Eurasian steppe zone to Central Asian desert zone in southward direction by EVSTIFEEV and RACHKOVSKAYA (1976), LAVRENKO (1978), RACHKOVSKAYA (1977, 2001) and RACHKOVSKAYA and VOLKOVA (1977), it is explicitly referred to Central Asian desert zone by Grubov (1990). In western European literature on vegetation of Mongolia, this question is never discussed, and the two sub-belts are summarised and denominated differently as semi-desert or as desert steppe (HILBIG 1995, THIEL 1958). The high proportion of xerophilous grasses in a composition with onion geophytes and shrubs in foliar cover, a peculiarity of Mongolia's desert steppe zone (EVSTIFEEV and RACHKOVSKAYA 1976; LAVRENKO 1978; YUNATOV 1950, 1974), represents one reason for this dispute. This peculiarity is based among others on the low rate of salinity of Mongolia's soils in contrast to Central Asian soils of former Soviet republics with spring precipitation (HAASE 1983, LAVRENKO and KARAMYSHEVA 1993).

The sparse vegetation of desert steppe in the investigation area covers between 5 and 15 percent of soil surface, comprising approx. 83 species of vascular plants and is dominated in foliar cover by perennial dwarf semi-shrubs (*Anabasis brevifolia*, *Artemisia*

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[2] Originally, it is denominated as 'opustynennyy steppe', which means translated word-by-word 'desertified steppe' (EVSTIFEEV and RACHKOVSKAYA 1976, YUNATOV 1974). Since this translation evokes an impression of anthropogenic impact, ZEMMRICH (2005) suggested the term 'northern desert steppe' regarding its geographical position.

*xerophytica*, *Asterothamnus heteropappoides*), small bunchgrasses (*Stipa glareosa*, *Cleistogenes songorica*), and onion geophytes (*Allium mongolicum*). In years rich in precipitation, this dominance is replaced by annual species (*Aristida heymannii*, *Lappula intermedia*, *L. granulata*, *Eragrostis minor*, *Enneapogon borealis*) covering up to 30 – 40 percent of soil surface (LAVRENKO and KARAMYSHEVA 1993, own observations 2002-2003). In transition to northern desert steppe or at specific site conditions of dry valleys and of steep inclined slopes rich in gravel and debris, shrub communities with *Caragana leucophloea* and *Krascheninnikovia ceratoides* appear.

Prevailing soil type of desert steppe represents a weak alkaline Burozem (World reference base for soil resources, henceforth WRB: Calcisol)[3] with shallow soil depth, very low accumulation of humus and an intense calcium carbonate-dynamic (HAASE 1983, ZECH and HINTERMEIER-ERHARD 2002). The not complete relocation of secondary calcium carbonate and its accumulation in deeper horizons represents the main soil-forming process. It leads to the presence of calcium carbonate along total soil profile in contrast to Kastanozem soils of mountain steppe, that are decalcified in the upper soil horizons. The coincidence of rainy season with warm summer season enables a downward percolating water regime through the uppermost topsoil layers and the formation of the diagnostic carbonate horizon in a soil depth between 10 cm and 30 cm. Furthermore, it prevents the salinization and accumulation of gypsum and secondary carbonates at soil surfaces as known for Central Asian Burozem soils of Asian republics of former Soviet Union with spring precipitation. The risk of salinization is further limited by frozen soils during season of lowest precipitation preventing ascendancy of soil solutions (HAASE 1993). The precipitation of secondary carbonates is observed as pseudomycelias and small concretions, diffuse distributed soft powdery lime or as crusts at the bottom sides of stones. The high permeability of coarse and sandy soil substrates, which prevailing comprises Mongolian mountainous sediments, supports the leaching of topsoil layers. The generally dry climatic conditions cause low biomass production, which is subjected to high mineralisation rates due to the coincidence of rainy season with warm summer season (HAASE 1983). Both lead to low humus accumulation with soil organic matter (henceforth SOM) below 1 percent and a thin humus layer less than 30 cm (cf. Appendix IV).

Within the study area of desert steppe, three plant communities are described: *Anabasis brevifolia - Allium mongolicum*-desert steppe, *Artemisia xerophytica*-semi-shrub desert steppe, and *Krascheninnikovia ceratoides*-shrub desert steppe.

In consideration of the peculiarity of Mongolian desert steppe zone, which is described above, desert steppe as the term of vegetation formation was preferred for the designation of plant communities. To emphasize apparent differences in vegetation structure of the communities, the terms semi-shrub and shrub were applied. (For more floristic and ecological details of plant communities of desert steppe, see 2.5.1.)

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[3] Names of soil types refer to regional classification accord. to HAASE (1983). The international equivalence accord. to FAO (1998) is given in brackets.

*Anabasis brevifolia* - *Allium mongolicum*-desert steppe and *Artemisia xerophytica*-semi-shrub desert steppe are distributed on light Burozem (WRB: Haplic Calcisol). Light Burozem differs from typical Burozem in low humus accumulation below 1.5 percent and higher C/N ratio (HAASE 1983) while a Haplic Calcisol represents a Calcisol with the typical expression of Calcisol features (FAO 1998). In dry river valleys and at river terraces with periodically higher groundwater level, the *Krascheninnikovia ceratoides*-shrub desert steppe occurs on Gypsisols (FAO 1998), a soil type not described by HAASE (1983). Similar to Calcisol, Gypsisols are characerised by a cemented gypsic horizon, a higher salinity and lower humus content in the upper soil layers. *Artemisia xerophytica*-semi-shrub desert steppe is distributed adjacent to Lake Khar Us Nuur at peninsula of Agvash Uul while *Anabasis brevifolia* - *Allium mongolicum*-desert steppe and *Krascheninnikovia ceratoides*-shrub desert steppe are found from the pediment area to upper parts of Argalant Mountains up to 1460 m a.s.l. These areas are situated in the colline belt. The colline belt in the forelands of Central Mongolian Altai is characterised by the presence of desert steppes (WEINERT 1966). The present study follows the concept of altitudinal belts of Eurasian vegetation drawn by WEINERT (1966) to be consistent with the main literature of Mongolia's vegetation by HILBIG (1995), where this concept is adopted.

### ***Mountain steppe***

The altitudinal belt of mountain steppe in Mongolian Altai, situated between 1900 and 2200 m a.s.l. in the investigation area is located in much higher altitude than in Khangay Mountains due to the aridity of the region (YUNATOV 1950, cf. Fig. 1: C). The vegetation cover ranges from 20 to 55 percent and comprises approx. 94 species of vascular plants dominated by perennial xerophilous bunch grasses (*Stipa krylovii*, *Koeleria cristata*, *Agropyron cristatum*) and the dwarf semi-shrub (*Artemisia dolosa*) in foliar cover. Summer annuals (*Salsola collina*, *S. tragus*, *Dontostemon integrifolius*) are abundant in moist years. In contrast to mountain steppe of other regions in the Mongolian Altai, the mountain steppe of the study area comprises no shrubs of genus *Caragana* that are common in Mongolian Altai (BUYAN-ORSHIKH 1992, KARAMYSHEVA and KHRAMTSOV 1995). Communities containing this genus could be observed in areas adjacent to the study area.

With its sparse foliar cover and the dominating xerophilous bunch grasses *Stipa krylovii* and *Agropyron cristatum*, mountain steppe belt is similar to the zonal dry steppe of Central Mongolia (KARAMYSHEVA and KHRAMTSOV 1995). The presence of *Festuca lensensis* and further alpine species marks the vegetation as mountain steppe belt (cf. Tab. 5, Appendix II). The tufts of the dominating bunch grasses are densely covered by dead leave sheathes accumulating snow, water and fine soil that improves the ability of water retention. Therewith, this life form demonstrates the advantage under unfavourably conditions of water shortage, low temperatures with insignificant snow cover and grazing by herbivores (LAVRENKO 1941 cited in KARAMYSHEVA and KHRAMTSOV 1995).

While northern slopes of Mongolian Altai in the northerly located province Uvs differ with *Larix sibirica* forest steppe from southern slopes with meadow steppe (HILBIG 1995, KNOTHE et al. 2001), the investigation area shows neither a different vegetation formation nor different plant communities bounded at only northern or southern slopes. It indicates the strong arid conditions caused by the lee position from westerly winds of Central Mongolian Altai (BEKET 2003, VOLKOVA 1994).

Soils of mountain steppe comprise light, middle, and dark Kastanozems (WRB: Kastanozem) and as a result of natural erosion truncated Kastanozems (WRB: Leptosol). Kastanozems have varying humus content of 1-5 percent of SOM in topsoil layer due to high supply of root biomass in consequence of arid conditions with the typical chestnut colour. Beside humus enrichment, further features of soil formation of Kastanozems comprise bioturbation caused by small lagomorph (*Ochotona spec.*, *Citellus spec.*), leaching of calcium carbonate in the upper soil layer within 30 cm from soil surface and a rising enrichment of secondary carbonates and soluble salts in lower soil layer. While HAASE (1983) explains the typically chestnut colour of Kastanozem soils by the fact of envelopes of soil particles rich in iron oxide (cf. profile 5, 12, 13 in Appendix IV), in recent literature this fact is no longer mentioned (ZECH and HINTERMEIER-ERHARD 2002). It is explained by the lower contents of SOM (than in Chernozem soils) and higher contents of secondary carbonates respectively in consequence of the drier climatic conditions accompanied by lower moisture penetration of soils (GENNADIEV 1990). Mongolian Kastanozem soils in contrast to Central Asian Kastanozem soils of former Soviet republics with spring precipitation have lower content of salts and are decalcified in the upper soil horizons (HAASE 1983) as represented by the Kastanozems of the study area (cf. Appendix IV).

Within the study area of mountain steppe, two plant communities including each a grazing community are described: *Stipa krylovii* - *Artemisia dolosa*-mountain steppe and *Rhinactinidia eremophila* - *Stipa krylovii*-mountain steppe. The term mountain steppe is widely accepted in literature (BUYAN-ORSHIKH 1992, HILBIG 1995, VOLKOVA 1994, WALTER 1974, YUNATOV 1950) and is thus applied for the designation of classified plant communities. (For more floristic and ecological details of plant communities of mountain steppe, see 2.5.2.)

*Stipa krylovii* - *Artemisia dolosa*-mountain steppe occurs on middle and dark Kastanozems (WRB: Haplic and Calcic Kastanozems) and *Rhinactinidia eremophila* - *Stipa krylovii*-mountain steppe on light and middle Kastanozems (WRB: Haplic Kastanozems) and on truncated Kastanozems (WRB: Leptosol). Light Kastanozem demonstrates a depth of humus horizons of 20 – 40 cm with content of SOM below 2 percent and upper than middle Kastanozem located secondary carbonates between 10 and 20 cm from soil surface. Middle

Kastanozem has a depth of humus horizon from 30 - 50 cm and a content of SOM between 2 to 4 percent. Depth of humus horizons of dark Kastanozem reaches 50 – 60 cm with a content of SOM more than 4 percent (HAASE 1983). The Calcic Kastanozem that is not additionally distinguished by HAASE (1983) is indicated by an accumulation horizon of secondary calcium carbonate as concretions, as pseudomycelias or as crusts between 50 and 100 cm from the soil surface (FAO 1998). Owing to sparse vegetation cover of mountain steppe at strong inclined slopes, erosion processes occur commonly. As a result, Kastanozem change into truncated shallow Kastanozems (WRB: Leptosol) with less than 10 percent fine soil to a depth of 75 cm or parent rock within 25 cm from the soil surface (FAO 1998).

In the Central Mongolian Altai without forests, the transition of colline belt of desert steppes to the montane belt is characterised by the occurrence of steppes (WEINERT 1966). Hence, the mountain steppe vegetation represents the montane belt.

### *Alpine belt*

Alpine vegetation includes alpine steppe in the lower alpine belt between 2300 m and 2600 m a.s.l. conforming to YUNATOV (1950) who describes the lower border of alpine belt in Mongolian Altai between 2300 – 2400 m a.s.l. (cf. Fig. 1: D & E). It furthermore comprises cryophyte steppe at the slopes of the upper alpine belt between 2650 m and 3050 m a.s.l. and sedge mats on the wet bottom of valleys distributed along total alpine belt (cf. Fig. 1: E).

The alpine steppe covers between 50 to 80 percent of soil surface, comprises approx. 76 species of vascular plants, and is prevailing dominated by perennial grasses (*Koeleria cristata*, *Festuca lenensis, Festuca sibirica*) with sedges (*Carex rupestris*, *C. pediformes*) and dwarf semi-shrubs (*Artemisia dolosa*, *Arenaria meyeri*, *A. capillaris*) in foliar cover. In the alpine steppe belt, mosses occur for the first time along the altitudinal gradient of the investigation area (cf. Appendix III). The species inventory represents a cryo-xerophytic character of the vegetation by small bunch grasses (*Festuca lenensis*, *C. pediformes)* and cushion plants (*Arenaria meyeri*, *A. capillaris*) which has not analogy in the zonal steppe (KARAMYSHEVA and KHRAMTSOV 1995, POLYNOV and KRASHENINNIKOV 1926 cited in YUNATOV 1950, VOLKOVA 1994). The xerophytic character gives the reason for WALTER (1974) and YUNATOV (1950) to reject the term meadow steppe for steppe of the alpine belt in Mongolia (except for *Kobresia* vegetation). In the high mountainous belt of Mongolian Altai, according to VOLKOVA (1994) meadow steppes are only rarely distributed at small areas.

To distinguish alpine steppe from lower montain steppe and to emphasise the high elevation of steppe vegetation into the alpine belt (KARAMYSHEVA and KHRAMTSOV 1995, YUNATOV 1950), the term alpine steppe is used for the designation of the classified plant communities.

Alpine steppe occurs on dark and truncated Kastanozem soils (WRB: Haplic Kastanozem, Calcic Kastanozem, Mollic Leptosol) and on Chernozem (WRB: Haplic Chernozem).

Kastanozem soils are more frequently distributed under alpine steppe while Chernozem soil appears only at inflow sites as channels along mountain slopes or depression areas with advanced moisture supply. A Chernozem represents a humus-rich soil that has a thick topsoil layer with high base saturation (referring to the diagnostic mollic horizon) directly overlaid on the C-horizon which is almost hardly affected by pedogenetic processes. The higher supply of alpine steppe with precipitation enables an enhanced biomass production and intense bioturbation by earthworms and rodents in contrast to Kastanozem soils of mountain steppe. Mineralisation processes are similarly limited due short summer season and dry and cold winter in the alpine belt. As a result, SOM of Chernozem is much higher than in Kastanozem soils of mountain steppe (more than 20 percent in the investigation area, cf. Appendix IV). C/N ratio in Chernozem is somewhat enhanced (ZECH and HINTERMEIER-ERHARD 2002). Instead of specific chestnut colour of topsoil horizons, Chernozem soils have dark brown or black colour. Higher precipitation leads to complete decalcification of humus horizons up to a soil depth between 60 and 80 cm and the accumulation of secondary calcium carbonate in the subsoil (HAASE 1983, cf. profile 06 in Appendix IV). Dark Kastanozem of alpine steppe differ from Kastanozem of mountain steppe in higher content of humus (SOM 5 - 8 percent) and a deeper leaching of calcium carbonates. Within 40 cm from soil surface, a rising enrichment of secondary carbonates is observed (cf. Appendix IV).

The cryophyte steppe covers between 30 to 80 percent of soil surface depending on boulders that are common in this altitude. It comprises approx. 42 species of vascular plants. Dominant species in foliar cover are perennial grasses and sedges (*Festuca lensis*, *Elytrigia geniculata*, *Carex rupestris*, *C. pediformes*) and cushion plants (*Oxytropis oligantha*, *Arenaria meyeri*, *A. capillaries*, *Stellaria pulvinata*) referring to harsh and dry climatic conditions. The high proportion of perennial grasses gives the reason for Russian and Mongolian botanists to designate this vegetation type as cryophyte steppe (BUYAN-ORSHIKH 1992, VOLKOVA 1994). This example was followed and the term cryophyte steppe was applied for the designation of the classified plant communities to emphasise the steppe character of the high alpine vegetation of Mongolian Altai (BUYAN-ORSHIKH 1992, POLYNOV and KRASHENINNIKOV 1926 cited in YUNATOV 1950). Ecological analogies of this vegetation type are only distributed in the Eastern Pamir, Tibet and Central Tyan-Shan but represent a different species inventory (VOLKOVA 1994).

Cryophyte steppe occur on Dernosem soil (WRB: Cryosol, Leptosol) and Derno-Cryosol soil (WRB: Cryosol, Leptosol). Dernosem soils are shallow soils characterised by a high humus accumulation, a dense root horizon of lawn layer, and slightly to moderately acid pH. Underneath the dark coloured topsoil horizon, humus content rapidly decreases. Prevailing low temperatures and short summers of the alpine belt do not permit intense mineralisation and high biological activity in soil. An intense accumulation of humus in topsoil with SOM more than 10-20 percent within a soil depth of 20 cm is a result. Due to the high precipitation and low soil pH in the alpine belt, chemical weathering plays an enhanced role in soil development and causes an increased disintegration of parent rock with high content of fine soil fractions (HAASE 1983). The low Corg/N ratio of investigation area below 11 does not conform to the wide range between 13 to 16 mentioned by HAASE (1983) and indicates a better decomposition rate. It may be a consequence of the dry conditions of the investigation area in the rain shadow of the Central Mongolian Altai. The release of iron, its oxidation and a slight argillization as further processes characterising Dernosem soil (HAASE 1983) could not be detected. Moreover, some recorded soils of the study area represent some particularities that indicate a Derno-Cryosol in a transition position from Dernosem to Derno-Cryosol (cf. profile 8 and 11 in Appendix IV). On the one hand, these soils show a lawn surface with a dense root horizon and a thick A-horizon with an intense humus accumulation as it is typical for Dernosem soils (HAASE 1983). On the other hand, polygonal patterns caused by cryoturbation of soil surface indicate temporary water saturation. The water saturation supports the humus accumulation and prevents mineralisation that leads to high contents of SOM more than 30 percent within the topsoil layer. The water saturation is indicated too by cryoturbate phenomena in the A-horizon and by an oxidation horizon in the lower part of soil profile. Latter is an effect of permafrost melting in its upper layer during the summer season. An oxidation horizon atop the permafrost horizon represents a necessary property of a Cryosol soil. Sufficient water saturation enabling cryoturbate motions is an only local phenomenon of Dernosem soil while oxidation horizons formed by permafrost indicate a Cryosol. According to FAO (1998), Dernosem and Derno-Cryosol soils can appear as Histic Cryosol, Mollic and Humic Leptosol depending on the content of SOM and base saturation of topsoil horizon (distinguishing mollic, histic, and humic type) and total soil depth and content of coarse soil (separating the Leptosol from other soil types).

In a close contact to cryophyte steppe, sedge mats are distributed at moist sites such as on the bottom of valleys or on further sites of water inflow. Vegetation cover is almost closed and the cover values of 65 - 80 percent of soil surface have to attribute to boulders and rocks scatterly distributed. Sedge mats comprise approx. 58 species of vascular plants and are dominated by *Carex* and *Kobresia* species in foliar cover. Sedge mats of the investigation area represent a moist type of *Kobresia* communities that are summarised within the alliance of Kobresion myosuroidis MIRKIN et al. 1983 em. HILBIG 2000. According to HILBIG (1995), a predominant part of alpine *Kobresia* communities represents remains of alpine *Kobresia* larch forests after logging. This fact cannot be confirmed because in the investigation area forests are not distributed. The habitats of sedge mats in the investigation area represent moist sites of water inflow due to their relief position on the bottom of valleys (cf. Fig. 21). These moist conditions are indicated by the occurrence of *Kobresia smirnovii*, which preferably grows at more wet sites than *Kobresia myosuroides* (VOLKOVA 1994, cf. Tab. 8). Because the term 'alpine mat' is widely applied for dense vegetation of high alpine belt in the high mountains of Eurasia

(MIEHE et al. 2004, RATHJENS 1982, SCHUSTER 1995, WINIGER 1992) and to stress the soggiest site conditions with densest vegetation stand of total investigation area, this term was applied for the designation of communities. (For more floristic and ecological details of plant communities of the alpine belt, see 2.5.3.)

Sedge mats of the investigation area occur on Cryo-Gley soils (WRB: Gelic Gleysol). Owing to high water saturation, harsh climatic conditions, and the presence of permafrost, soils are characterised by intense thawing and freezing processes and gleyic processes during summerly melting period. These conditions lead to a high humus accumulation in the topsoil layer, which can result in peat layers due to reduced decomposition of rich biomass in the short and cold summer period. As a result of freezing processes of water saturated active topsoil layers, soil surface forms thufur mounds with a mineral core inside covered with turf and furthermore, polygonal patterns. Topsoil is furthermore characterised by low pH-values in consequence of less decomposed SOM, high CEC values and cryoturbate properties. Already the lower part of topsoil represents oxidation marks followed by a distinct oxidation horizon. The reduction horizon of the summerly wet and winterly frozen subsoil constitutes the final horizon of Gley soils.

According to HILBIG (1995), *Kobresia* communities are also distributed on Derno-Golez soils (WRB: no corresponding soil type), which represent more dry edaphic conditions of the alpine *Kobresia* belt (HAASE 1983) but are not found in the investigation area. In contrast to Dernosem soils, they contain a high proportion of debris or rock material and are characterised by sorting of fine and coarse soil and further cryoturbate effects, accumulation of SOM, release of iron, and gleization of subsoil.

Under the dry climatic conditions where a forest belt and a subalpine belt rich in shrub vegetation are missing, the subalpine belt is marked by the occurrence of high mountainous species in combination with species of montane steppe in the Central and Southern Mongolian Altai (WEINERT 1966). In the investigation area, the alpine belt is characterised by the occurrence of *Kobresia* and *Carex* communities and furthermore by alpine steppe and cryophyte steppe.

The altitudinal gradient of study areas from the lowland to the alpine belt is characterised by climatic conditions with increasing precipitation, decreasing interannual variability of precipitation and a decreasing vegetation period. As a consequence of these changing climatic conditions, gradient characteristics of ecosystems lead from low biomass productivity being almost completely mineralised during prolonged periods of biological activity in the desert steppe to the alpine belt with high biomass productivity with reduced decomposition (due to shortened periods of biological activity) in a shorter vegetation period (cf. CHASE et al. 2000, HAASE 1983). Thus, along this altitudinal gradient, soil organic matter is increasing with decreasing pH-values and decreasing salinity due to reversion of upward soil water flow in soils of desert steppe to downward water flow in soils of the alpine belt with enhanced leaching conditions through lower pH-values.

### 1.2.4 Land use

With 1,6 inhabitants per sqkm, Mongolia has one of the lowest population densities of any country in the world. 57.2 percent of the 2,5 mio. inhabitants belong to urban population which is continuously increasing. The mineral deposits of the country have not been made available yet and the recent economy is traditionally based on mobile livestock keeping. Crop production is limited to less than 1 percent of the area of the country and concentrates to the moister northern parts and in broad lower valleys of rivers with possibilities of supplemental irrigation. Nearly four-fifths of Mongolia's area consists of pasturelands, which support immense herds of grazing livestock. Livestock production comprises goats, sheep, cattle including yaks, horses, and camels and is performed in a semi-nomadic and nomadic style (status of 2002: NSOM 2003). While sheep serve as meat supply, goats for cashmere production represent the main source of cash for herders. Horses, camels and yaks are used as milk suppliers and pack animals for migration between the seasonal pastures.

Since the process of transformation towards market economy and the privatisation of former state-owned farm cooperatives between 1991 and 1993, a considerable increase in livestock numbers and changes in pastoral land use patterns have taken place (JANZEN and BAZARGUR 1999, 2003; JANZEN 2005; MEARNS1993). In Khovd province, the total number of livestock increased from around 1,60 mio. in 1989 to 1,85 mio. in 2004 (VASHA 2005). Between 1999 and 2002, livestock number decreases as a result of two severe winters with heavy snowfall followed by summer drought (cf. Fig. 3).

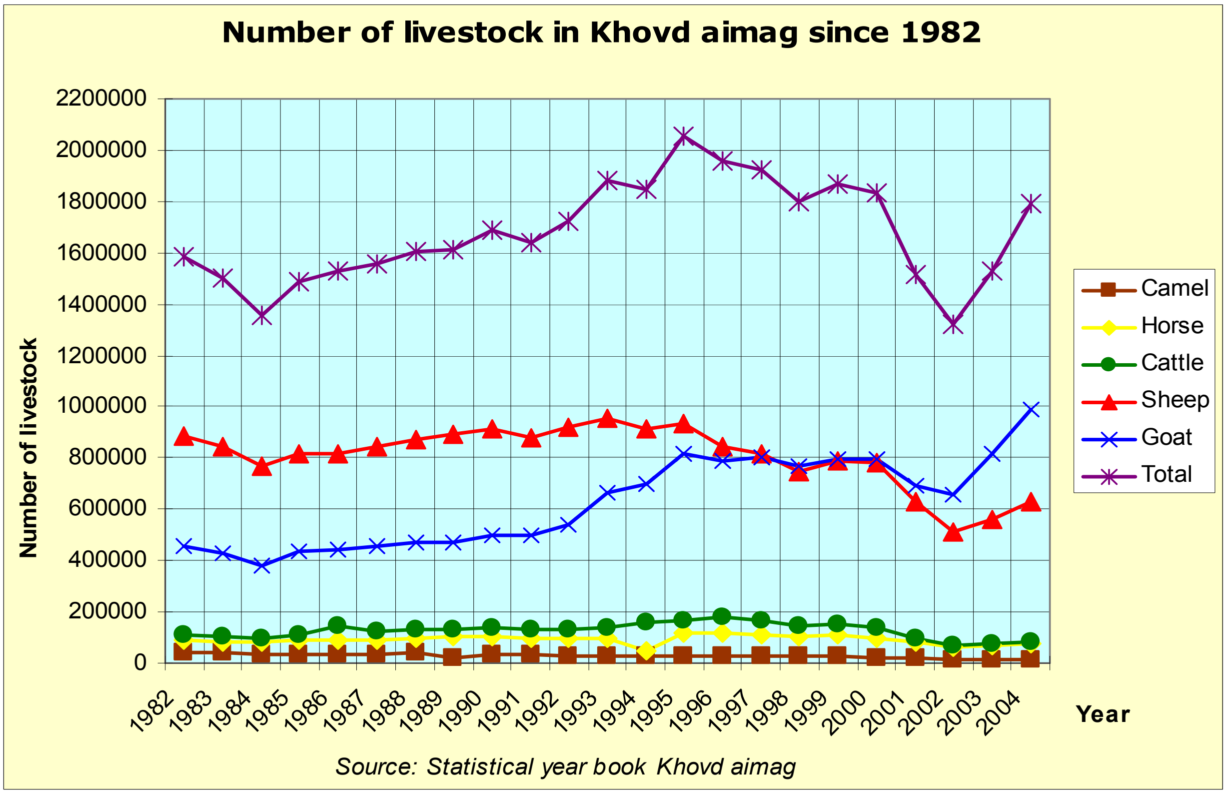

Fig. 3: Development of livestock in Khovd province between 1982 and 2004 (Source: VASHA 2005).

The investigation area is traditionally used on a seasonal basis for mobile livestock keeping. The lower areas of desert steppe around pensinsula of Agvash Uul (cf. Fig. 1) are grazed in spring and winter. Further spring and autumn pastures are situated in the transition belt of northern shrub desert steppe between mountain steppe and desert steppe and in wetland areas of Lake Khar Us Nuur. Both ecosystems are not treated in present study. Owing to favourable climatic conditions resulting of winterly temperature inversions with warmer thermal belts above cold air accumulations in depressions, higher areas of desert steppe in the Argalant Mountains and in the mountain steppe below Tumtiyn Nuruu Mountain Range represent winter pastures. The alpine belt of Tumtiyn Nuruu is used as summer pastures. The distribution of seasonal pastures with their period of utilization is depicted in Fig. 4 for the northern part of Khovd province.

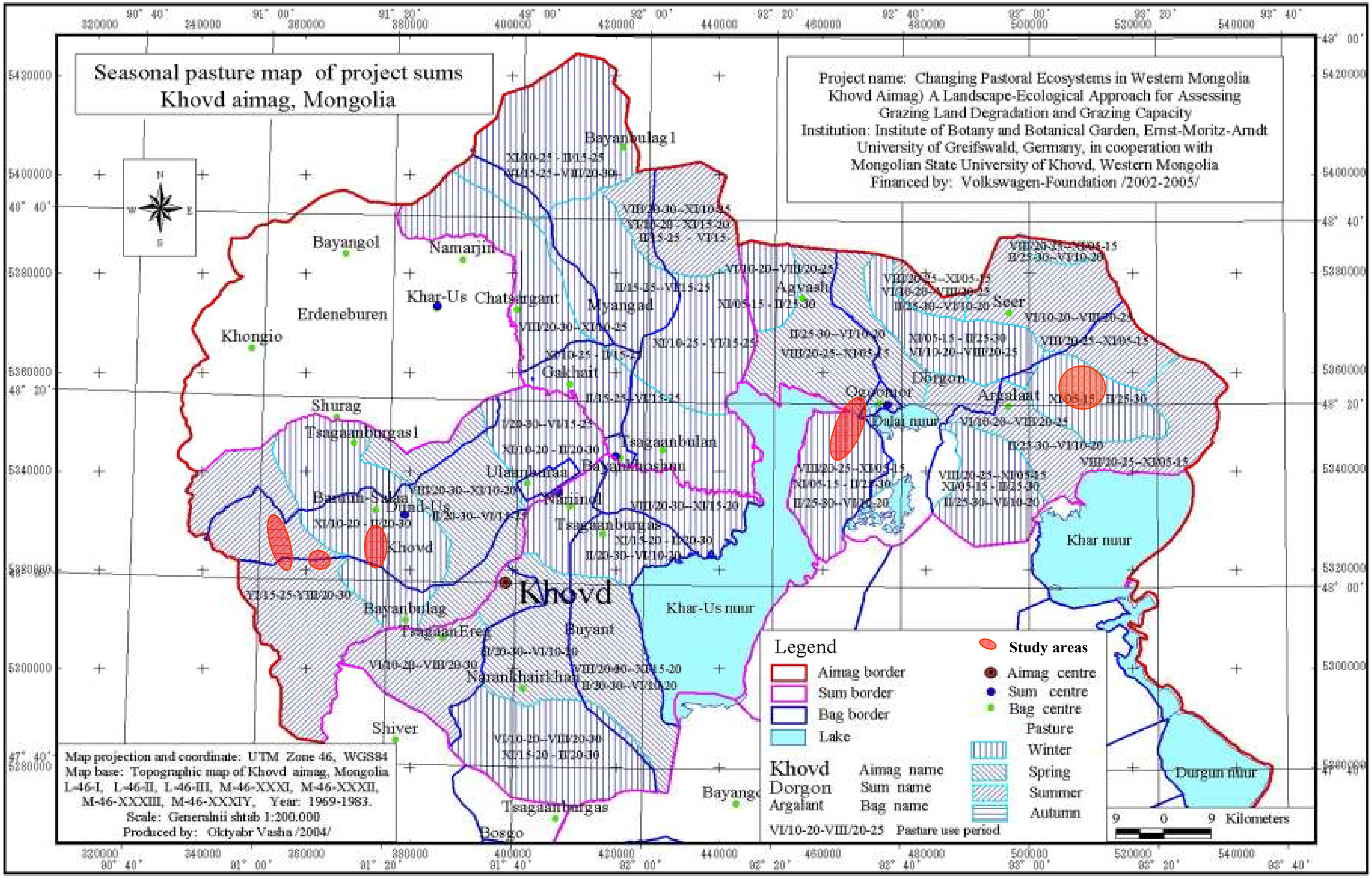

Fig. 4: Seasonal pastures in northern part of Khovd province with the period of grazing seasons. (Red shapes: study areas. Source: VASHA 2005, modified.)

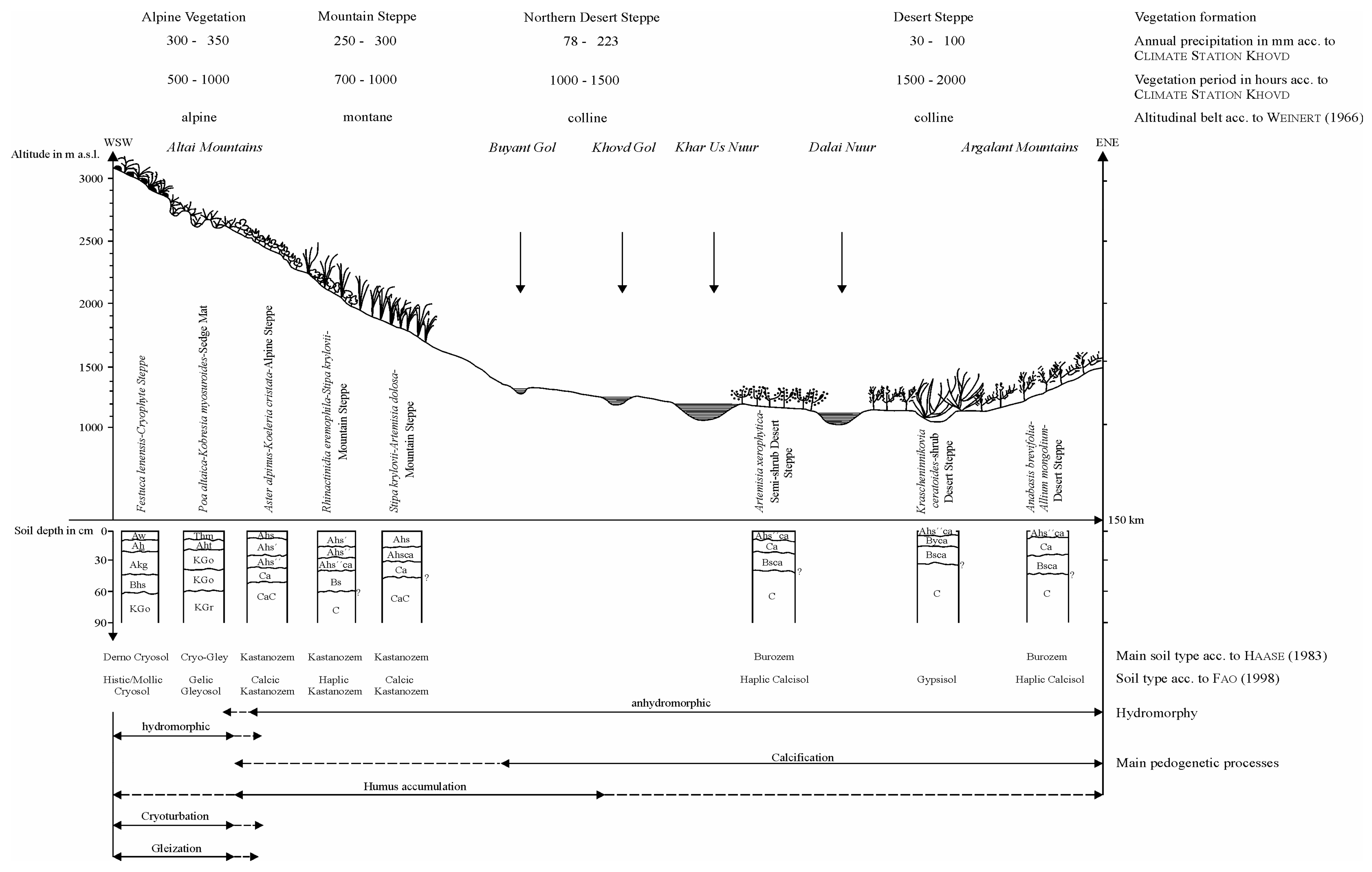

Fig. 5: Transect of the investigation area from the high alpine belt in the Altai Mountains via Lake Khar Us Nuur to desert steppe in the Argalant Mountains[4].

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[4] Denomination of soil horizons follows HAASE (1983) and FAO (1988) with modifications. All horizons are explained in Appendix V.

# 2 Vegetation-determining factors along an altitudinal gradient and their importance for grazing effects – the landscape level

## 2.1 Summary

Up to the recent time, the role of site-ecological conditions has been neglected in the discussion on grazing effects on vegetation. In the present study, the dependence of plant communities on environmental and edaphic conditions is examined to detect vegetation-determining ecological factors in three different vegetation formations of western Mongolia. Data were sampled along an altitudinal gradient between 1150 m to 3050 m a.s.l. from the lowland with desert steppe via mountain steppe to the alpine belt. Within each vegetation formation, data sampling was carried out along grazing gradients, established from grazing hot spots to areas distant from them. By means of environmentally and site-ecologically based vegetation classification, the factors with highest explanation values for largest variation in vegetation were identified. To validate and affirm the result of classifications, three different statistical methods are applied: firstly, environmentally and edaphically adjusted table work supported by cluster analysis of species distribution, secondly, detrended correspondence analysis of vegetation relevés with environmental and soil data, and thirdly, the principle component analysis of environmental and soil data. Besides the detection of vegetation-driving ecological factors, grazing effects in all vegetation formations were examined and compared with each other. Vegetation and soil of all vegetation formations respond to grazing but with different patterns and to a different extent. Results are discussed against the backdrop of an extensive literature review on herbivory and rangeland ecology in an arid environment to assess the role of abiotic and biotic character of vegetation-controlling ecological factors with their influence on grazing sensivity of vegetation formations.

## 2.2 Sampling design

Data were collected along an altitudinal transect of 150 km length passing from lowland with desert steppe vegetation between 1150 – 1460 m a.s.l., via the mountain steppe belt between 1900 – 2200 m a.s.l. to the alpine belt between 2300 – 3050 m a.s.l. (Fig. 1, Fig. 5). Field sampling was conducted in summer 2002, 2003 and 2005. In order to avoid influences of rainfall variations, each vegetation formation was mainly sampled in one year.

The principle of sampling follows the concept of grazing gradient according to ANDREW (1988), and ANDREW and LANGE (1986). It assumes that grazing intensity decreases with increasing distance from grazing hot spots like water sources or livestock corrals. To obtain a clear-cut grazing gradient, in each study area[5] sampling sites were chosen from a grazing hot spot to areas distant from it. Otherwise, the grazing gradients are placed within homogeneous environmental conditions. As grazing hot spots served ger camps (ger – Mongolian, traditional tent of Mongolian herders), wells or so called "zagony" (plural of "zagon" - Russian for animal corrals: places next to gers where goats and sheep are trooped up and spend the night as protection against wolves and coldness).

At each site within homogenous conditions, about 3-5 vegetation relevés and one soil sample were recorded. The size of a relevé varies from 4 to 100 sqm, depending on the homogeneity of vegetation cover. The position of all sample plots, livestock corrals, ger camps and wells situated nearby were recorded with a handheld GPS device. The distance from sample plot to the adjacents grazing hot spots was determined by means of GIS (Geographical Information System).

In the vegetation relevés, all vascular and bryophyte plant species rooting in soil were recorded (soil-dwelling lichens were not found). Their cover was estimated according to the cover-abundance-scale of LONDO (1976), which subdivides especially fine in lower cover values below 5 percent. This scale is considered as most appropriate to detect changes in cover values in the sparse vegetation of desert steppe and mountain steppe. Vascular plants were determined according to GRUBOV (2001). Critical species were validated later in the local herbarium of Khovd State University and by means of the 'Mongolian Collection' of the herbarium of the Martin-Luther-University, Institute of Geobotany and Botanical Garden (HAL). To provide the recent state in taxonomy, nomenclature of vascular plants follows GUBANOV (1996), and of bryophyte plants ABRAMOVA and ABRAMOV (1983).

With each vegetation relevé environmental variables representing key factors for vegetation were recorded: altitude, slope aspect and inclination, relief position, microrelief, water regime, influences of natural and anthropogenic disturbances such as effects of rodent activities or scree streams caused by perdiodically aquiferous rivers, type of seasonal pasture, and distance from grazing hot spot. An index of aspect and inclination was formed as a measure of different insolation and related heat supply at different slope aspects by varying inclination. The index increases with increasing southern aspect and increasing inclination. It ranges from 0 at northern aspect with 90° inclination to 2 at southern aspect with 90° inclination and thus, is only applicable to the investigation area, where inclination does not exceed approximately 45° and with this inclination receives highest insolation at southern aspect. The index was calculated according to the formula of KNOPF and WERHAHN (2004): EI = 1+ [sin(radian (inclination in °)) x cos (radian(aspect in °-180))].

Three volume samples of 100 $cm^3$-cylinders between 5 and 20 cm below soil surface were collected in every sample site and analysed as mixed samples. Thus, all soil data

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[5] A study area conforms to an altitudinal belt, and contains one or more grazing gradients. Along them, sampling sites are placed. A sampling site comprises plots of vegetation relevés and soil samples.

refer to the soil depth of 5-20 cm from soil surface. Vegetation-driving soil variables are supposed to be detected in this soil layer because in different steppe types of northerly adjacent Tuva and southeasterly adjacent Gobi, living root mass is concentrated in a soil depth of around 15 cm from soil surface (BORISOVA and POPOVA 1985, TITLYANOVA et al. 1999).

Soil analyses comprise pH (in a 0,01 M suspension of $CaCl_2$), total soil carbon and total soil nitrogen (N) by means of dry combustion at 1200 °C in a CN analyser (Elementar Analyser "Vario EL"/Germany) with the mathematical calculation of soil organic carbon ($C_{org}$) and the ratio of $C_{org}/N_{total}$ ($C_{org}/N$) by subtraction of mineral carbon containing in carbonate, calcium carbonate ($CaCO_3$) volumetrically according to Scheibler (AG BODEN 1994), electrical conductivity (EC) as a degree of total salinity in a soil-water saturation extract with soil-water ratio of 1:5, effective cation exchange capacity ($CEC_{eff.}$) with $BaCl_2$ as exchange solution and $MgSO_4$ as re-exchange solution and measured with atomic absorption spectrometer, plant available phosphorus with the analysis of phosphate soluble in citric acid and mathematical conversion into pure phosphorus (P) according to HEINRICH (1987), and determining of soil texture with content of gravel and content of sand, clay and silt in fine soil part. Sand fraction was analysed with sieving method, clay and silt fractions with pipette method according to German DIN methods (AG BODEN 1994). The assignment to particle sizes keeps the regulation of the German particle size classification (AG BODEN 1994). The proportion of different fine soil fractions in total soil sample was calculated mathematically as a phytoecological relevant parameter (e.g. sand in total soil). All soil data except texture data of total soil refer to dry fine soil fraction (105°C / < 2 mm). All soil analyses except the determination of phosphorus were carried out in the soil laboratory at the Institute of Botany at University, Greifswald, Germany. Phosphorus was analysed in the laboratory at the Institute of Geography and Geology at University, Greifswald, Germany. Bulk density samples were measured in the laboratory of Khovd University. Fresh field soil samples were oven-dried until weight constancy was reached.

In the presented study, 411 vegetation relevés with 90 soil samples were evaluated.

## 2.3 Data analysis

The derivation of plant community-differentiating environmental variables follows the 'vegetation form concept' of SUCCOW and KOSKA (KOSKA 2001, KOSKA et al. 2001, SUCCOW 1988). This concept integrates a vegetation classification with the classification of the environmental and site-ecological conditions in an iterative mutually-verified way. As a result, a vegetation typology is derived with high indication values for abiotic site conditions. Resulting vegetation forms are defined by the upper and lower values of their determining environmental and site-ecological factors. While the 'vegetation form concept' is based on the well-understood vegetation-determining site factors in Europe, in the present study, these vegetation-determining factors had to be detected firstly within the classification process. Available data were not sufficient to determine upper and lower borders of the detected site factors. Therefore, the unranked term ‘community’ was applied for derived vegetation units.

The practical implementation of classification was carried out by means of a combination of clustering and ordinations as suggested by VAN DER MAAREL (2005) and are described in the following. To ensure a deeper exploration of sparse acquainted vegetation of the investigation area and its ecology, vegetation was classified depending on its environmental parameters in a combination of cluster analysis and tabular treatment according to ELLENBERG (1956) in a first step: therefore, species of all vegetation relevés were clumped to species groups according to their joint statistical presence and their cover values with help of cluster analysis separately for each vegetation formation. Within cluster analysis, Ward method was applied as a hierarchic-agglomerative method of classification that depicts relations among all derived classes, minimises distortions in the underlying space (MCCUNE and MEFFORD 1999), and leads to approximate compact even classes (ZÖLITZ-MÖLLER and KLEIN 1994). Squared Euclidian Distance as dis/similarity index is required by the WARD method. In the cluster matrix, cover-abundance values of species were transformed in an average percent cover according to Tab. 1. A furthermore aggregation and adjustment of species groups was performed on the basis of habitat conditions according to own field experiences, habitat specifications of GRUBOV (2001), and descriptive statistics for each sampled environmental variable. Thus, a first identification of environmental variables separating species groups could be gained.

Subsequently, all vegetation relevés were arranged according to their similarity in joint presence and absence of species groups. On the basis of resulting arrangements of relevés, the change of environmental parameters which coincide best with changes in species group patterns was analysed. Detected parameters can be supposed as being responsible for the vegetation patterns found. A clear-cut change in species group composition accompanied by an obvious change in environmental variables marks the border between two plant communities (cf. Tab. 2, 5, 8).

In a second step of data processing, vegetation data were subjected to DCA (Detrended Correspondence Analysis) to validate the vegetation classification and to examine if hitherto derived or further environmental parameters may control the composition of plant communities. As an indirect ordination method, DCA aims at ordering relevés according to the abundance and dominance of species. In a second independent step, it calculates few ordination axes that represent theoretical environmental gradients, which best explain the variance in the vegetation data set (ØKLAND 1996). The ordination axes are calculated in such a way as to maximise the dispersion of species data (abundance-dominance) to an unimodal (bell-shaped response curves) statistical model of how species data varies along gradients.

Constructed axes are subjected to the constraint of being uncorrelated with previous axes. The first calculated axis explains the highest proportion possible of variance in the vegetation data (JONGMAN et al. 1995). In a third step of DCA analysis, sampled environmental variables were tested for correlation with the hypothetical environmental factors (ordination axes), which allows an ecological interpretation and prove to what extent the recorded parameters may explain these hypothetical environmental factors (ordination axes). In the correlation analysis, linear PEARSON coefficient is applied.

The advantage of the independent processing of vegetation and environmental data within the DCA compared to direct methods of ordination analyses represents a quick insight, if at all relevant ecological parameters have been recorded. Furthermore, it allows an unbiased interpretation of the environmental gradient represented by arrangement of vegetation relevés within the ordination space. Contrary to this, a direct ordination method simultaneously processes environmental and vegetation data. Thus, it is biased towards the factors most frequently measured. Factors which are not represented by quantitative data e.g. competition, parasitism or other biotic interactions, are completely ignored (BEALS 1984, WHITTAKER 1967).

In DCA analysis cover-abundance values of species were transformed into ordinal scale with equal distances, which enables an upgrading of lower cover values compared to higher cover values. Thus, the influence of dominant species is weakended. Moreover, it reproduces the fine graduations of Londo's scale (LONDO 1976) in the lower cover values below 5 percent (cf. Tab. 1). To reduce the influence of rare species, only species with a constancy of more than 2 percent were included in the analysis. Furthermore, within the analysis a downweighting of rare species was performed.

On the assumption that a linear relationship is given among recorded environmental variables (TREMP 2005), environmental variables are subjected to principle component analysis (PCA) in a third step, in order to summarise them to main ecological factors and to prove their separation facilities of classified plant communities. PCA as a method of data reduction within the multivariate statistics pools all variables (here environmental variables) according to their linear correlative relations (PEARSON coefficient), and replaces them by few uncorrelated new synthetic components (ordination axes). Factor loadings of variables represent their relation to ordination axes, varying from –1 to +1, and are considered as important with an absolute value higher than 0.5. The Eigenvalue of an axis explains the proportion of the axis on total variance of all variables and will be highest for the first axis. An axis with an eigenvalue below 1 has a lower variance than a single variable. Consequently, this axis does not serve for data reduction, does not explain the total variance of data, and can thus be ignored.

On the base of its environmental dataset, regression factor scores for every axis are calculated for every vegetation relevé. By arranging the vegetation relevés along these regression factor scores it was proved to what extent plant communities, which were derived in the first and second step, can be demarcated by multivariate combination of recorded environmental variables. In the PCA, only environmental variables were included that i) show a variance obviously higher across different plant communities than within the communities, and ii) do not mathematically correlate to linearly close with each other (problem of multicollinearity). The latter leads to a distortion of results. Among simple mathematically correlated variables (e.g. N, C, C/N) the ones which showed highest factor loadings on the first axis in the PCA were chosen. This was tested with a PCA including all variables.

Plant communities are named according to the 'vegetation form concept' (KOSKA 2001) with a combination of one to two names of characteristic plant species of the vegetation formation and corresponding plant community, a term referring to a typical feature of the community physiognomy and the name of the vegetation formation (e.g. *Artemisia xerophytica* – semi-shrub-desert steppe). The application of terms of vegetation formations follows Russian gebotanical terminology according to BUYAN-ORSHIKH (1992) and VOLKOVA (1994) and is discussed in Chapter 1.2.3.

In present study is distinguished between environmental conditions and site resp. edaphic conditions. Site and edaphic conditions refer to soil samples and can vary even at short distances (e.g. salininty, soil texture). Environmental conditions refer to the spatial resolution of a climatically similar altitudinal belt and do not differ at the spatial scale level of sites (e.g. precipitation, vegetation period).

| Cover-abundance scale (accord. to LONDO 1976) | Percent, number of individuals | Average plant cover in percent (applied to cluster analyses) | Ordinal scale (applied to DCA) |
|---|---|---|---|
| **r1** | **< 1, one indiv.** | **0.1** | **1** |
| **p1** | **< 1, 2-5 indiv.** | **0.2** | **2** |
| **a1** | **< 1, 6-50 indiv.** | **0.3** | **3** |
| **m1** | **< 1, > 50 indiv.** | **0.5** | **4** |
| **r2** | **1-3, one indiv.** | **1** | **5** |
| **p2** | **1-3, 2-5 indiv.** | **1** | **6** |
| **a2** | **1-3, 6-50 indiv.** | **2** | **7** |
| **m2** | **1-3, > 50 indiv.** | **3** | **8** |
| **r4** | **3-5, one indiv.** | **3** | **9** |
| **p4** | **3-5, 2-5 indiv.** | **3** | **10** |
| **a4** | **3-5, 6-50 indiv.** | **4** | **11** |
| **m4** | **3-5, > 50 indiv.** | **5** | **12** |
| **1** | **5-15** | **10** | **13** |
| **2** | **15-25** | **20** | **14** |
| **3** | **25-35** | **30** | **15** |
| **4** | **35-45** | **40** | **16** |
| **5** | **45-55** | **50** | **17** |
| **6** | **55-65** | **60** | **18** |
| **7** | **65-75** | **70** | **19** |
| **8** | **75-85** | **80** | **20** |
| **9** | **85-95** | **90** | **21** |
| **10** | **95-100** | **97. 5** | **22** |

Tab. 1: Transformations of LONDOS' cover-abundance scale for statistical analyses.

## 2.4 Technical informations

For the arrangement of species and vegetation relevés, the table calculation software package Microsoft Excel 2003 was used. Descriptive statistics and PCA were carried out by use of the statistical software package SPSS 11.5 (SPSS Inc. 2002). DCA were applied using the software package PC-Ord 4.0 (MCCUNE and MEFFORD 1999).

# 2.5 Results

## 2.5.1 Desert steppe

### *Vegetation classification*

In the desert steppe between 1150 – 1460 m a.s.l., three communities could be floristically and environmentally distinguished: *Anabasis brevifolia - Allium mongolicum*-desert steppe, *Artemisia xerophytica*-semi-shrub-desert steppe, and *Krascheninnikovia ceratoides*-shrub desert steppe. Altogether, they contain 83 species divided in 58 percent of perennial and 42 percent of annual species. Among perennials, forbs dominate with 56 percent proportion in species number, followed by semi-shrubs with 23 percent, shrubs with 10 percent, and grasses with 10 percent. Main important environmental variables determining community composition are altitude, soil texture, $\mathrm{CEC}_{\mathrm{eff.}}$ depending on clay content in fine soil, and erosion as a factor of disturbance leading to differences in soil texture. Various combinations of different soil texture variables (e.g. gravel and clay, gravel and sand etc.) clearly separate all three communities from each other, supported by altitude and $\mathrm{CEC}_{\mathrm{eff.}}$ (Tab. 2). All remaining environmental variables have higher variations within plant communities than across plant communities (cf. Fig. 9 & 10).

| No. of species group | **Plant community** | ***Anabasis brevifolia - Allium mongolicum*- desert steppe** | | ***Artemisia xerophytica* -semi-shrub desert steppe** | ***Kraschenninnikovia ceratoides* - shrub desert steppe** |
|---|---|---|---|---|---|
| | Running number | 1 | | 2 | 3 |
| | **Environmental parameters differentiating communities** | | | | |
| | Anthropogenic disturbance | Winter pasture | | Spring, autumn, and winter pasture | Winter pasture |
| | Natural disturbance | - | | - | **Infrequent erosion by scree streams** |
| | Altitude [m a.s.l.] | 1350-1440 | | **1150-1260** | **1290-1460** |
| | Gravel [%][1] | 0 - 60 | | **10 - 30** | **30 - 60** |
| | Clay [%] | **10 - 40** | | 0 - 20 | **0 - 10** |
| | Silt [%] | **10 - 50** | | 0 - 20 | **10 - 15** |
| | Clay and silt [%] | **20 - 70** | | 5 - 40 | **15 - 25** |
| | Sand [%] | **30 - 70** | | 70 - 100 | **75 - 100** |
| | Soil texture | Sl, **Slu, Ls, Lts, Lt, Ts** | | Ss, Sl, St | Ss, Sl, **Su**, St |
| | Clay in total soil [%] | **5 - 40** | | 0 - 20 | **0 - 5** |
| | Silt in total soil [%] | **5 - 40** | | 0 - 20 | **5 - 10** |
| | Clay and silt in total soil [%] | **15 - 65** | | 5 - 30 | **5 - 15** |
| | Sand in total soil [%] | 20 - 60 | | **50 - 100** | 30 - 70 |
| | CEC$_{eff.}$ [cmol/kg] | **10 - 20** | | 2 - 15 | **0,5 - 10** |
| | **Parameters changed by grazing** | | | | |
| | Distance from grazing hot spot [m] | 0 - 100 | 200 - 1900 | 0 - 2500 | 0 - 1800 |
| | C$_{org}$ [%] | 0.3 - 1.1 | 0.1 - 0.5 | 0.05 - 0.3 | 0.1 - 0.8 |
| | N [%] | 0.06 - 0.09 | 0.03 - 0.09 | 0.01 - 0.04 | 0.02 - 0.08 |
| | C$_{org}$/N | 4 - 14 | 3 - 6 | 2 -10 | 5 - 10 |
| | Average total cover of vegetation [%] | 29 | 7 | 13 | 30 |
| | Average nu. of species in vegetation relevés | 13 | 9 | 8 | 17 |
| | Nu. of relevés | 19 | 58 | 55 | 37 |
| | Nu. of soil samples | 4 | 11 | 13 | 7 |
| | Species of desert steppe | | | | |
| 1 | **Stipa glareosa** | **58** | **59** | **95** | **95** |
| | **Anabasis brevifolia** | **100** | **95** | **44** | **62** |
| | **Allium mongolicum** | **95** | **93** | **13** | **92** |
| 2 | Aristida heymannii | 47 | 97 | 98 | 65 |
| | Lappula intermedia et granulata | 95 | 98 | 38 | 57 |
| | Eragrostis minor | 100 | 78 | 49 | 54 |
| | Enneapogon borealis | 79 | 84 | 44 | 51 |
| 3 | **Artemisia caespitosa** | **.** | **34** | **13** | **.** |
| | **Astragalus monophyllus** | **26** | **10** | **9** | **11** |
| 4 | Micropeplis arachnoidea | 79 | 9 | 42 | 24 |
| | Erodium tibetanum | . | 19 | 24 | . |
| | Disturbance indicators | | | | |
| 5 | Bassia dasyphylla | 47 | . | 78 | 81 |
| | Salsola collina et tragus | 47 | 3 | 38 | 73 |
| | Tribulus terrestris | 5 | . | 47 | 35 |
| | Chenopodium aristatum | 32 | . | 9 | 16 |
| | Characteristic species groups of communities | | | | |
| 6 | **Gypsophila desertorum** | **11** | **33** | **.** | **38** |
| | **Arnebia guttata** | **11** | **21** | **.** | **5** |
| | **Asterothamnus heteropappoides** | **53** | **16** | **.** | **5** |
| | **Reaumuria songarica** | **16** | **12** | **2** | **3** |
| | **Orostachys thyrsiflora** | **.** | **12** | **.** | **5** |
| | **Allium polyrrhizum** | **.** | **7** | **.** | **.** |
| 7 | Euphorbia humifusa | . | 33 | . | 46 |
| | Neopallasia pectinata | 26 | 45 | . | 24 |
| | Senecio subdentatus | 47 | 12 | . | 3 |
| | Kochia melanoptera | 26 | 7 | . | 5 |
| | Axyris prostrata | 26 | . | . | . |
| 8 | Chenopodium album agg. | 79 | . | . | 51 |
| | Chenopodium foliosum | 53 | . | 2 | 14 |
| | Chenopodium hybridum | . | . | . | 8 |
| 9 | **Artemisia xerophytica** | **.** | **.** | **67** | **3** |
| | **Astragalus cf. grubovii** | **.** | **3** | **7** | **3** |
| 10 | Agriophyllum pungens | . | . | 51 | . |
| | Corispermum mongolicum | . | . | 27 | . |
| | Echinops gmelinii | . | . | 15 | . |
| 11 | **Krascheninnikovia ceratoides** | **.** | **.** | **.** | **86** |
| | **Caragana leucophloea** | **.** | **2** | **.** | **70** |
| | **Dontostemon senilis** | **42** | **7** | **.** | **86** |
| | **Ajania fruticulosa** | **5** | **.** | **.** | **22** |
| | **Elytrigia nevskii** | **.** | **.** | **.** | **16** |
| 12 | Plantago minuta | 16 | 3 | 4 | 46 |
| | Senecio dubitabilis | . | . | . | 43 |
| | Setaria viridis | . | . | . | 24 |
| | Artemisia macrocephala | . | . | . | 8 |
| 13 | **Lagochilus ilicifolius** | **26** | **5** | **.** | **49** |
| | **Youngia tenuicaulis et Ixerdium chinense ssp. versicolor** | **.** | **7** | **.** | **43** |
| | **Cleistogenes songorica** | **.** | **2** | **4** | **30** |
| | **Asterothamnus poliifolius** | **.** | **.** | **.** | **38** |
| | **Scorzonera pseudodivaricata** | **.** | **3** | **.** | **38** |
| | **Euphorbia mongolica** | **11** | **3** | **.** | **35** |
| | **Panzerina lanata** | **.** | **.** | **.** | **8** |
| 14 | **Convolvulus gortschakovii** | **.** | **.** | **.** | **24** |
| | **Prunus pedunculata** | **.** | **.** | **.** | **5** |
| | **Zygophyllum pterocarpum** | **.** | **.** | **.** | **8** |
| 15 | **Craniospermum mongolicum** | **.** | **.** | **.** | **11** |
| | **Vicia costata** | **.** | **.** | **.** | **5** |
| | **Stellaria amblyosephala** | **.** | **.** | **.** | **8** |

▨ Species groups with obvious differences in constancy compared to other plant comunites / facies

Tab. 2: Constancy table of plant communities of desert steppe with characteristic species groups and their main differentiating environmental variables (perennial species are in bold style, annual species are in regular style).

Community 1) *Anabasis brevifolia - Allium mongolicum*-desert steppe (Fig. 6) is distributed on the upper parts of the Great Lake Basin between 1350 and 1440 m a.s.l. at flat plains and on gently sloping forelands of adjacent mountains. It growth on sites containing highest proportions of silt and clay and lowest proportions of sand fractions in fine and total soil of all desert steppe plots (Fig. 9). As a consequence of the highest content of clay, the community indicates highest CECeff. of total desert steppe (SCHEFFER and SCHACHTSCHABEL 2002). The content in gravel between 0 to 60 percent covers the whole value range found in desert steppe. The species-poor community contains 38 species appearing frequently, has no own characteristic species groups and is floristically defined by missing the species groups which are bound only to other communities. It is dominated by the dwarf semi-shrub *Anabasis brevifolia,* a character species of the northern deserts (LAVRENKO 1957), the perennial bunch grass *Stipa glareosa*, and the onion *Allium mongolicum*. In normally dry years, the community covers 5 to 15 percent of soil surface what is enhanced up to 30 to 40 percent in moist years by the dominance of annual species. In close proximity to animal corrals in a distance up to 100 m, floristic differences are expressed by additional annual species especially of Chenopodiaceae, thus a higher number of species, and a higher vegetation cover. However, the occurrence of the dominant perennial desert steppe species remains unmodified. Soil variables show hardly any differences except a weak increase in C-, N-, and $C_{org}$/N-values (cf. Tab. 2).

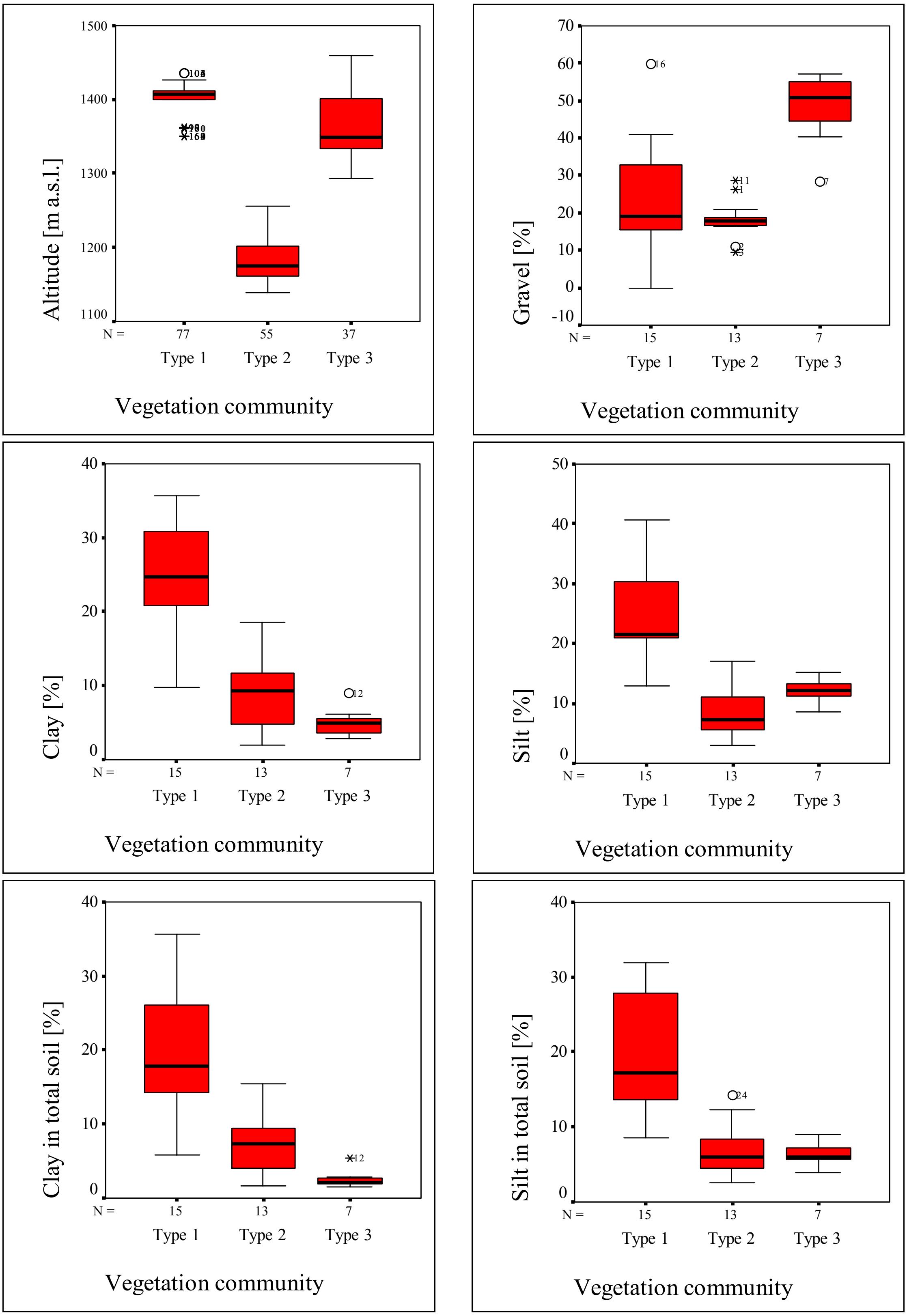
Fig 6: Community 1: *Anabasis brevifolia - Allium mongolicum*-desert steppe (Photo: Kretschmer 2003).

Community 2) *Artemisia xerophytica* - semi-shrub desert steppe is found in the lowest part of the Great Lake Basin between 1150 and 1260 m a.s.l. at flat plains near the lake shore of Khar Us Nuur on sandy soils with lowest content of silt and highest content of sand in total soil of desert steppe (Fig. 7, Fig. 9). $\text{CEC}_{\text{eff.}}$-values have the widest amplitude of all desert steppe plots without reaching the highest values of community 1. With 24 species appearing frequently, the community has the lowest species number of all communities of desert steppe. The community is defined in contrast to *Anabasis brevifolia* - *Allium mongolicum*-desert steppe by the high constancy of the perennial bunch grass *Stipa glareosa*, the presence of the dwarf semi-shrub *Artemisia xerophytica* with hemicryptophytes *Astragalus cf. grubovii* and *A. monophyllus* and the absence of species group number 6 - 8 and 11 - 15. In summers high in precipitation, annual species of group number 2, 4, and 10 will appear dominantly enhancing vegetation cover from around 15 percent to 35 percent. Near grazing hot spots, no conspicuous differences in vegetation and soil variables could be recorded (cf. Tab. 2).

Fig. 7: Community 2: *Artemisia xerophytica* - semi-shrub desert steppe (Photo: Schnittler 2003).

Community 3) *Krascheninnikovia ceratoides* - shrub desert steppe occurs on the middle and upper parts of the Great Lake Basin between 1290 and 1460 m a.s.l. in dry valleys irregularly flooded by water triggering scree streams (Fig. 8). Moreover, it is distributed in areas with abrupt relief incline within mountain forelands. Due to these habitat features, the community is associated to soils with highest proportions of gravel and lowest proportions of clay of total desert steppe. This soil texture results in low $\text{CEC}_{\text{eff.}}$-values. With 49 frequently appearing species and an average plant cover of 30 percent, it is the most diverse and productive community, which contains four species groups occurring only in this plant community. In its physiognomy, it is dominated by the shrubs *Krascheninnikovia ceratoides* and *Caragana leucophloea*. Influenced by infrequent scree stream erosions, the community comprises highest number of annual species groups (2, 4, 5, 7, 8, 12). Similar to community 2, no grazing influences on vegetation and soil could be observed (cf. Tab.2).

Fig. 8: Dry river valley with *Krascheninnikovia ceratoides* - shrub desert steppe (community 3) within *Anabasis brevifolia* - *Allium mongolicum*-desert steppe (community 1). The picture was taken in the lower part of mountain foreland. The depicted river valley with its flat position is not typical. (Photo: Kretschmer 2003).


Altitude [m a.s.l.]
1500
1400
1300
1200
1100
108
N =
77
55
37
Type 1
Type 2
Type 3
Vegetation community
Gravel [%]
70
60
50
40
30
20
10
0
-10
16
11
1
7
N =
15
13
7
Type 1
Type 2
Type 3
Vegetation community
Clay [%]
40
30
20
10
0
12
N =
15
13
7
Type 1
Type 2
Type 3
Vegetation community
Silt [%]
50
40
30
20
10
0
N =
15
13
7
Type 1
Type 2
Type 3
Vegetation community
Clay in total soil [%]
40
30
20
10
0
12
N =
15
13
7
Type 1
Type 2
Type 3
Vegetation community
Silt in total soil [%]
40
30
20
10
0
24
N =
15
13
7
Type 1
Type 2
Type 3
Vegetation community

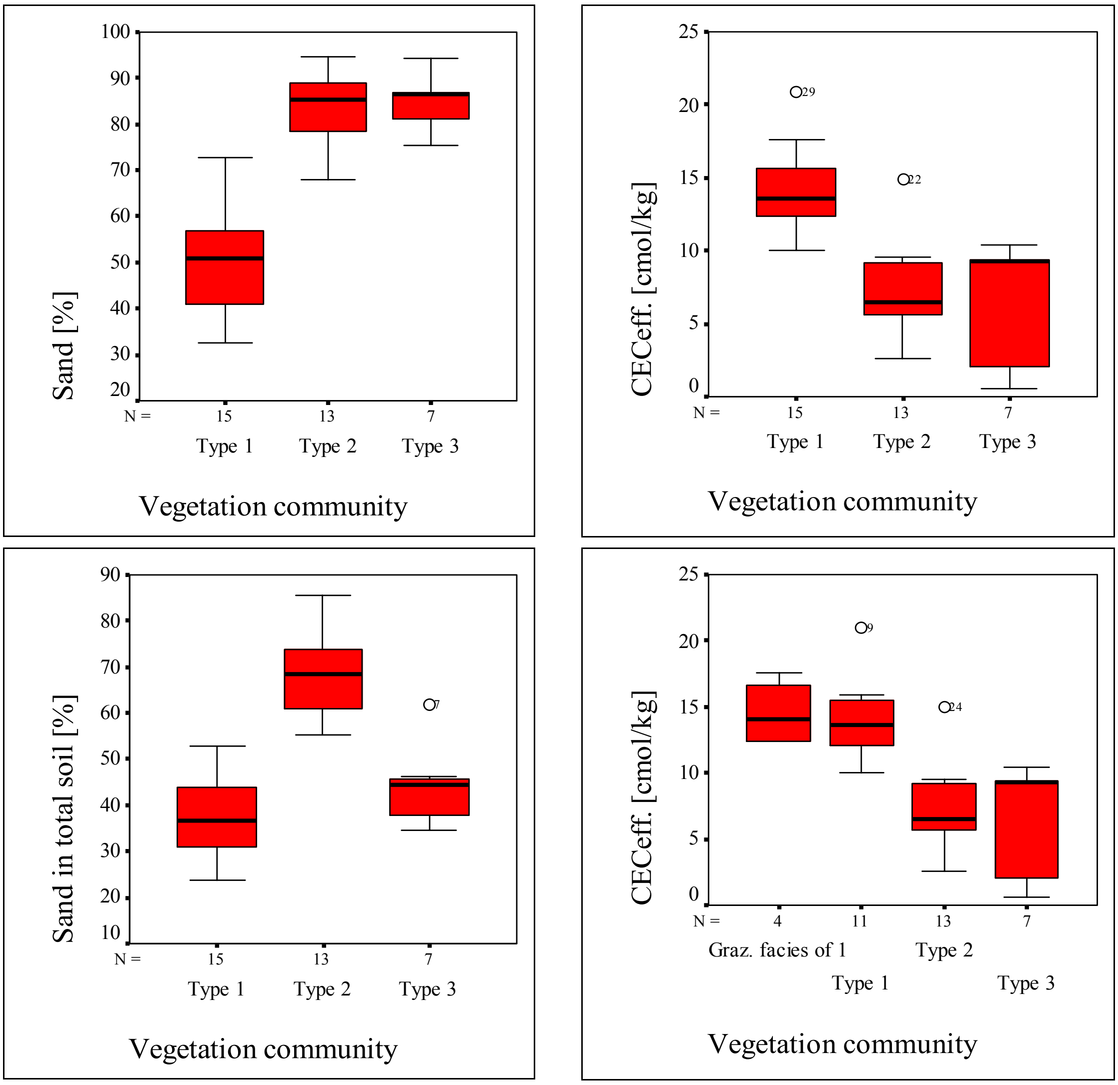
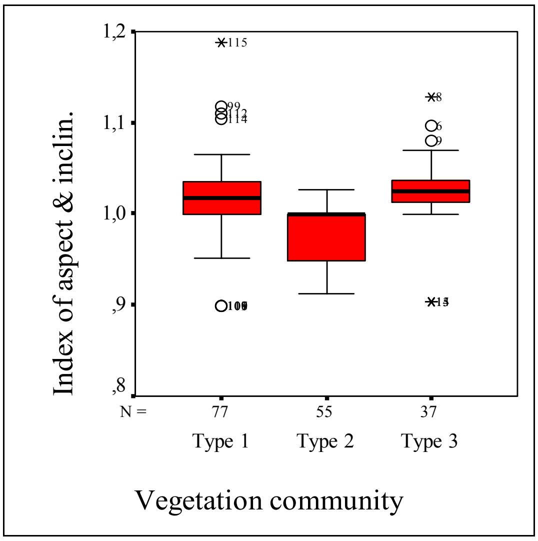
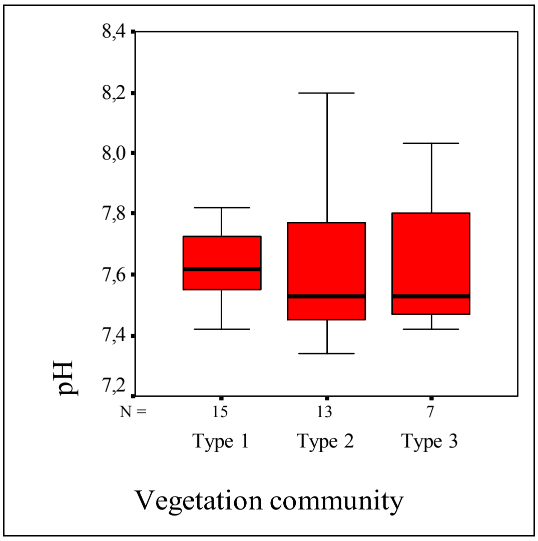
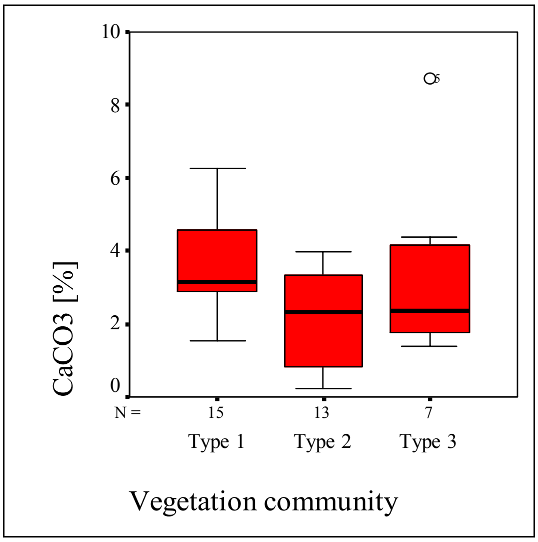
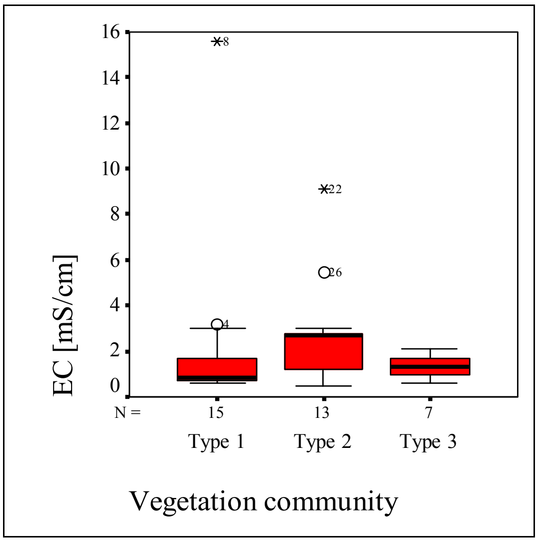


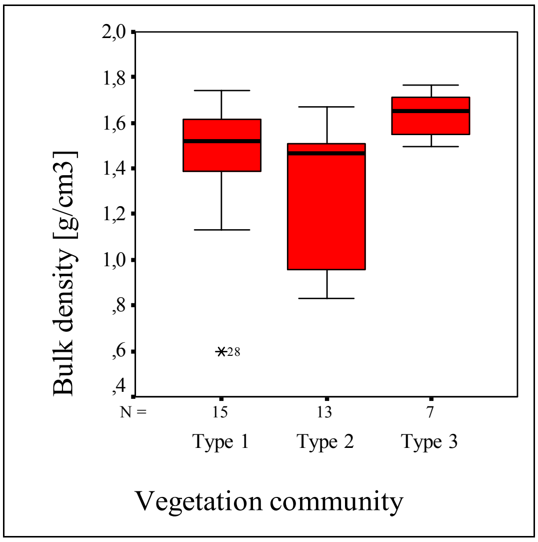
Fig. 9: Box and Whisker Plots for environmental and soil variables obviously differing across plant communities of desert steppe (Graz. facies of 1: grazing facies of type 1 next adjacent to grazing hot spot, Type 1: *Anabasis brevifolia* - *Allium mongolicum*-desert steppe, Type 2: *Artemisia xerophytica* - semi-shrub desert steppe, Type 3: *Krascheninnikovia ceratoides* - shrub desert steppe).

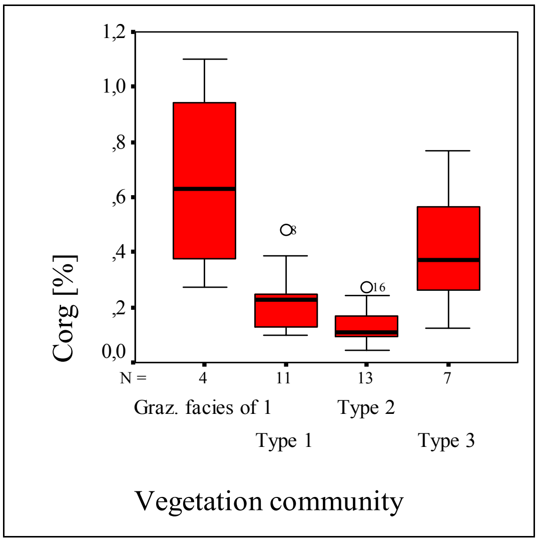

Index of aspect & inclin.
1,2
1,1
1,0
,9
,8
115
99
112
114
108
8
6
9
13
N =
77
55
37
Type 1
Type 2
Type 3
Vegetation community


pH
8,4
8,2
8,0
7,8
7,6
7,4
7,2
N =
15
13
7
Type 1
Type 2
Type 3
Vegetation community


CaCO3 [%]
10
8
6
4
2
0
5
N =
15
13
7
Type 1
Type 2
Type 3
Vegetation community


EC [mS/cm]
16
14
12
10
8
6
4
2
0
8
22
26
4
N =
15
13
7
Type 1
Type 2
Type 3
Vegetation community


Bulk density [g/cm3]
2,0
1,8
1,6
1,4
1,2
1,0
,8
,6
,4
28
N =
15
13
7
Type 1
Type 2
Type 3
Vegetation community


Corg [%]
1,2
1,0
,8
,6
,4
,2
0,0
8
16
N =
4
11
13
7
Graz. facies of 1
Type 2
Type 1
Type 3
Vegetation community

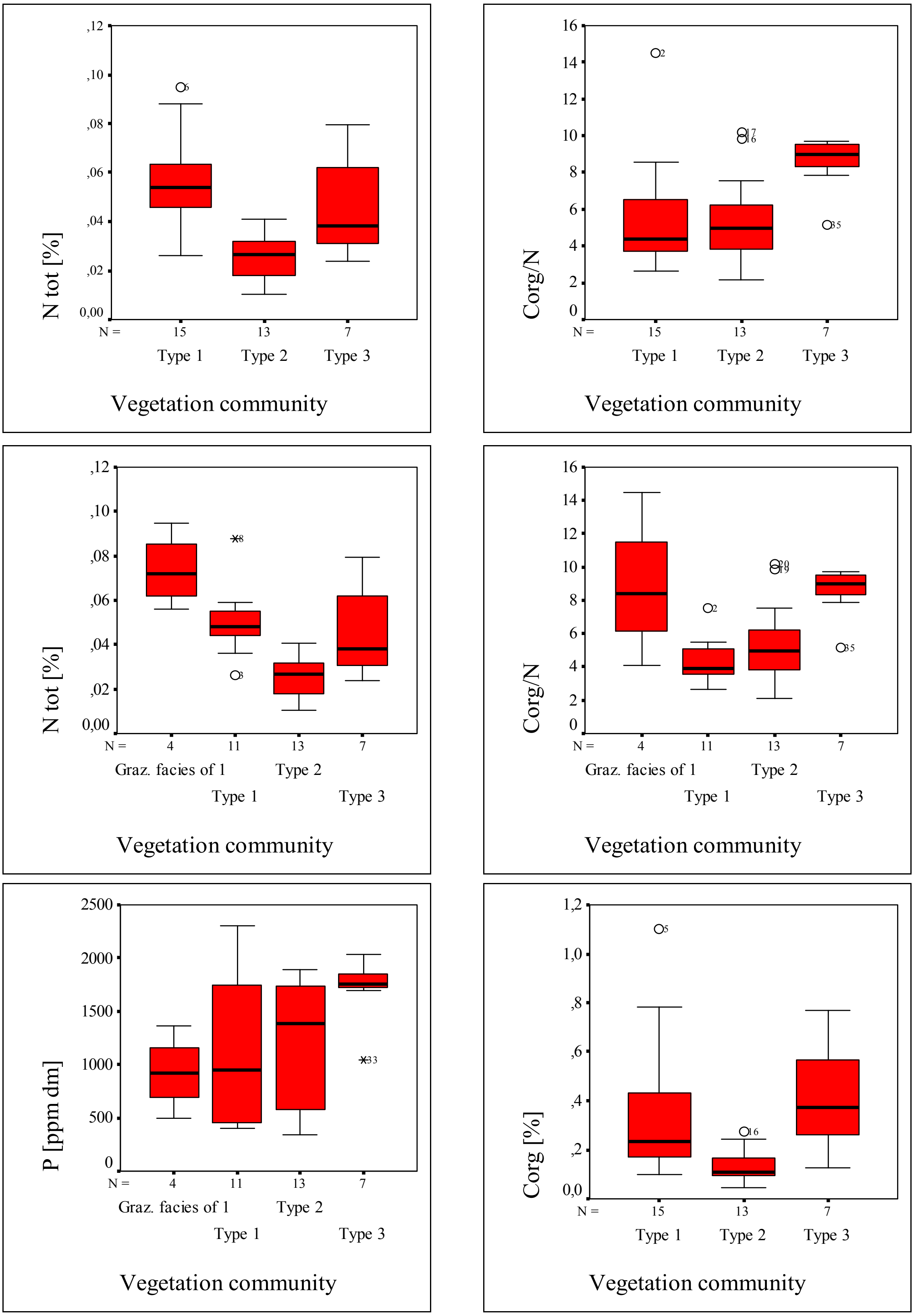


Fig.10: Box and Whisker Plots for environmental and soil variables with high variations within plant communities of desert steppe.

***Detrended Correspondence Analysis (DCA Ordination)***
The DCA results in a total variance of 2.79, which indicates a mean floristic gradient in comparison with mountain steppe and alpine vegetation. The first axis explains 42 percent, together with the second axis 61 percent of total variance in the vegetation data. The strong correlation with altitude and the content of sand in total soil followed by N, $C_{org}$, and gravel vs. fine soil fraction can be interpreted as a gradient of climatic and edaphic moisture and of soil nutrient supply. The second axis is strongly correlated with only soil texture variables and $CEC_{eff.}$ as a function of clay content (cf. Tab. 3). Thus, it can be interpreted as a gradient of edaphic moisture.

In the ordination graph (Fig. 11), vegetation relevés form obvious distinct clusters. Only at the origin of the ordinates, they have close transitions. Especially between community 1 and 2 an slight overlapping exists. Both indicate a high number of joint species (cf. Tab. 2, species groups 1 & 2). The dense arrangement of *Anabasis brevifolia - Allium mongolicum*-community reflects a floristically homogenous composition which is modified by the relevés near grazing hot spots. In contrast, *Artemisia xerophytica*–community and *Krascheninnikovia ceratoides*–community indicate a more heterogeneous species composition, expressed in the wider range of relevé grouping. Both communities are arranged along the first axis and completely separated due to lower altitude, lower content of sand in total soil lower content of gravel, and lowest $C_{org.,}$ and N in the *Artemisia xerophytica*–community. The separation of *Anabasis brevifolia - Allium mongolicum*-community from both of the other communities is performed in a combination of the first with second axis, but mainly along the second axis. In contrast to *Artemisia xerophytica*–community, this community is situated at higher altitude and contains less sand in total soil, more clay, more N, and more C. Compared with *Krascheninnikovia ceratoides*–community it differs in clay and sand in fine soil fraction and clay in total soil, resulting in higher $CEC_{eff.}$-values. The relevés of grazing variant of *Anabasis brevifolia - Allium mongolicum*-community differ in a higher proportion of annual species in the upper part of the ordination graph and show a correlation with N and C content. Yet as a whole, they cannot be clearly separated from the remaining relevés of the community due to the unmodified stand of perennial species and the big number of joint species (cf. Fig. 11, Tab. 2). Since there is no strong correlation of axis 3 with any variable, this axis is not presented here.

High explanation values of the first two axes and strong correlations of recorded environmental variables in combination with a clear aggregation of relevé arrangement imply that relevant vegetation-determining parameters were recorded. The clear separation of plant communities in the DCA confirms the vegetation classification performed in the first step of data analysis. Main environmental variables differentiating community composition are altitude and variables of soil texture. They form a moisture gradient along the first axis compiled by precipitation as an effect of altitude, water availability due to water redistribution in gravely rich sites, and water retention as an effect of soil texture. Increasing moisture supply along the first axis is accompanied by higher N and $C_{org}$. Thus, variables highly loaded on first axis form a gradient of moisture and supply of soil nutrients. The differentiation of desert steppe communities towards N and $C_{org}$ along the first axis emphasises the role of vegetation in altering site conditions especially in shrub desert steppe communities. Along the first and second axes, it is shown that arid ecosystems are not exclusively influenced only by water, and that they already show differences in immobilised soil nutrients such $C_{org}$ and N.

| Total variance (inertia) | 2.791 | | |
|---|---|---|---|
| | **Axis 1** | **Axis 2** | **Axis 3** |
| Eigenvalue | 0.437 | 0.239 | 0.125 |
| Explained variance, cumulative [%] | 42.3 | 60.8 | 65.5 |
| **Variables** | r | r | r |
| Altitude | **0.727** | 0.439 | -0.139 |
| Sand in total soil (sand tot) | **-0.706** | -0.408 | -0.083 |
| N | **0.681** | 0.549 | 0.193 |
| $C_{org}$ | **0.677** | 0.325 | 0.325 |
| Gravel | **0.597** | -0.257 | 0.251 |
| Fine soil | **-0.597** | 0.257 | -0.251 |
| Clay | 0.166 | **0.734** | -0.196 |
| $CEC_{eff.}$ | 0.27 | **0.69** | 0.05 |
| Clay in total soil (clay tot) | 0.099 | **0.672** | -0.247 |
| Sand | -0.231 | **-0.672** | 0.067 |
| Clay & silt (c&s) | 0.256 | **0.661** | -0.103 |
| Clay & silt in total soil (c&s ent) | 0.14 | **0.623** | -0.174 |
| Silt in total soil (silt tot) | 0.169 | ***0.499*** | -0.074 |
| Silt | 0.313 | ***0.484*** | 0.012 |
| $C_{org}$/N | ***0.422*** | -0.09 | 0.177 |
| Distance from grazing hot spot (graz_dis) | -0.387 | -0.181 | 0.031 |
| Index of aspect & inclination (EI) | 0.349 | 0.075 | 0.079 |
| $CaCO_3$ | 0.329 | 0.239 | -0.258 |
| Bulk density | 0.268 | -0.153 | 0.008 |
| Phosphorus (P) | 0.251 | -0.21 | -0.032 |
| Electrical conductivity (EC) | -0.141 | -0.079 | 0.232 |
| pH | 0.08 | 0.144 | 0.042 |

Tab. 3: Results of DCA of desert steppe with correlation coefficients of PEARSON of environmental variables with the ordination axes (strong correlations are in bold, mean in bold and italic style).

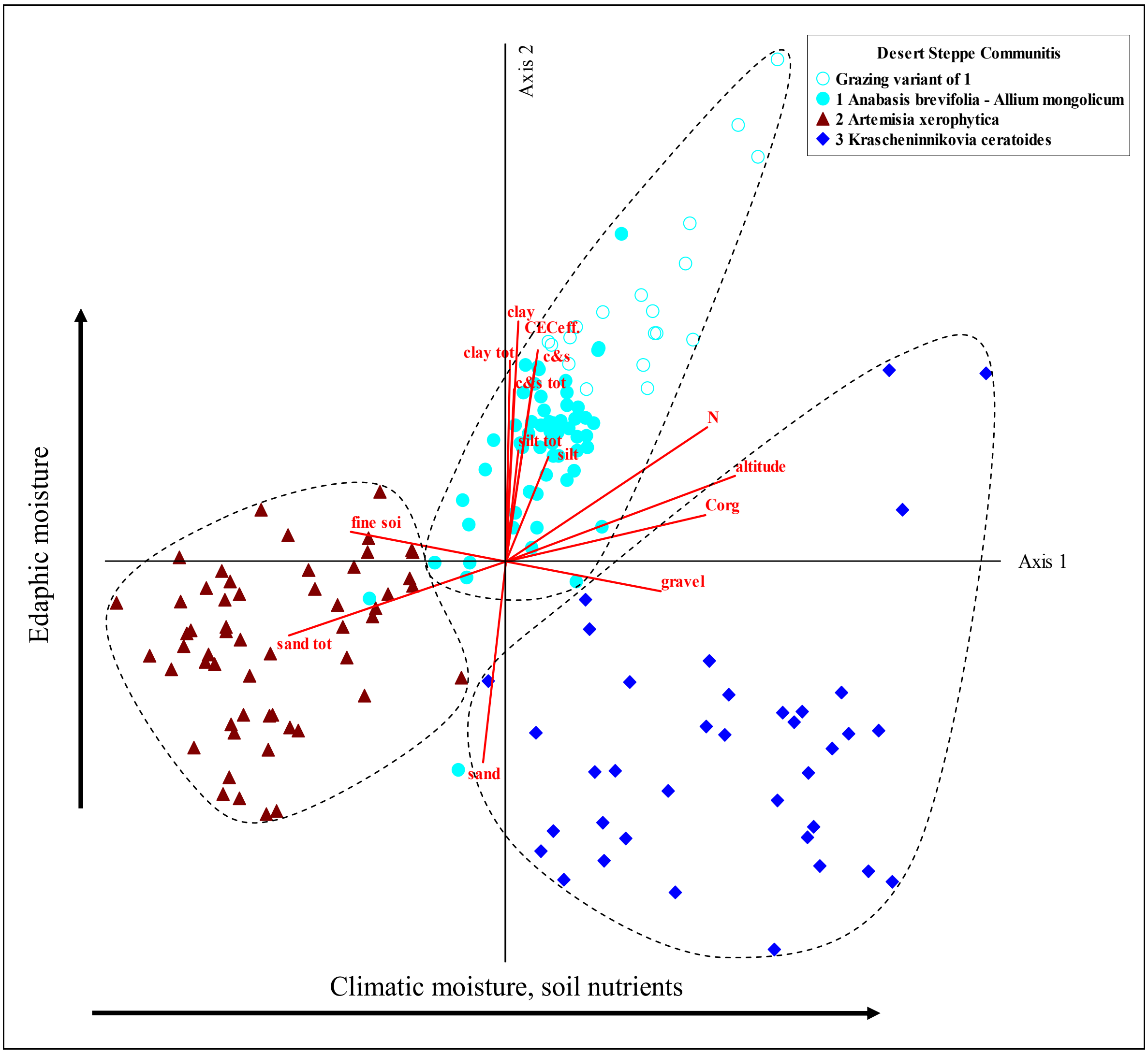


Fig. 11: DCA ordination of desert steppe relevés and correlation of DCA axis with environmental variables, cut off $r^2$-value = 0.3, N = 169 (clay tot – content of clay in total soil, c&s - content of clay and silt, c&s tot - content of clay and silt in total soil, silt tot – content of silt in total soil).

### *Principle component analysis (PCA)*

The PCA includes 11 environmental variables. The following variables were excluded due to their higher variance within rather than across plant communities: electrical conductivity (EC), pH, $CaCO_3$, and bulk density (cf. Fig. 10). Furthermore, silt, clay & silt in fine soil fraction and in total soil, fine soil and $C_{org}$/N were excluded for reasons of multicollinearity (cf. Tab. 4).

| **Variables** | Axis | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Sand | **-.914** | .307 | .173 |
| Clay | **.880** | -.396 | -.121 |
| Sand in total soil | **-.846** | -.372 | .094 |
| $CEC_{eff.}$ | **.840** | -.223 | .180 |
| Clay in total soil | **.807** | -.525 | -.101 |
| Altitude | **.762** | .331 | -.155 |
| Nitrogen | **.741** | .404 | .384 |
| Gravel | -.028 | **.907** | .070 |
| Phosphorus | -.056 | **.666** | -.531 |
| $C_{org}$ | .399 | **.629** | .590 |
| Index of aspect & inclination (EI) | .331 | **.563** | -.468 |

Tab. 4: Component matrix of PCA of desert steppe with factor loadings of 11 environmental variables.

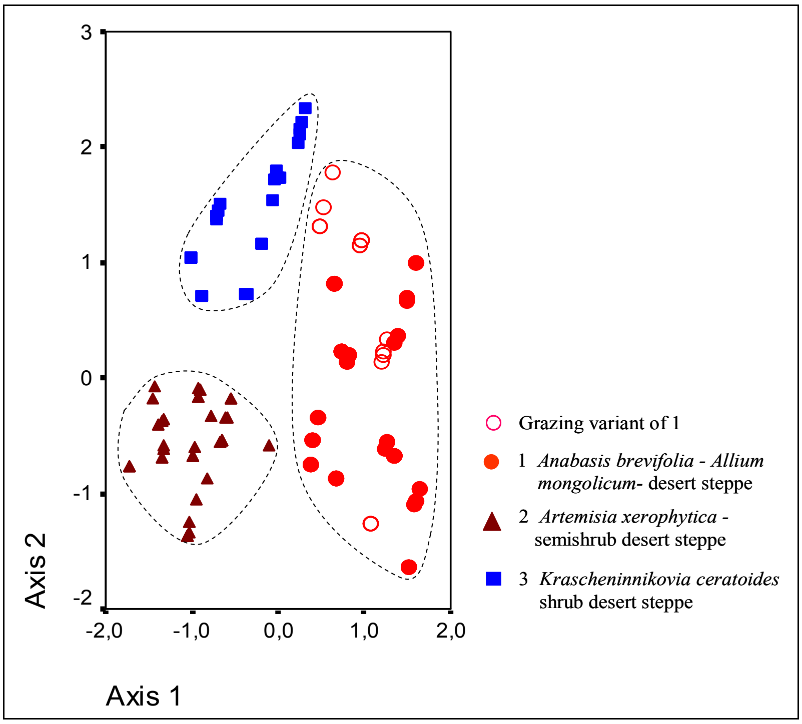


Fig. 12: Ordination graph of vegetation relevés of desert steppe along PCA factor scores (N=35).

The PCA extracted three axes representing 83 percent of total variance of the environmental data set. The first axis explains 46 percent, the biggest portion of data variance. Increasing values along the first axis represent an increase of clay, $CEC_{eff.}$, altitude, and N. The associated decrease in sand causes an increase in water supply due to higher capacity of water retention by higher precipitation (Fig. 12). Improved moisture supply at clayey sites leads to bad soil aeration, i.e. temporary anaerobic soil conditions with reduced decomposition expressed in higher soil N. Thus, the first axis can be interpreted as a combination of moisture and supply of fixed soil nutrients with prevailing proportion of edaphic moisture.

The second axis explains 27 percent of data variance, and is highly loaded with all remaining variables as gravel, P, $C_{org,}$ and the index of aspect and inclination. Noteworthy is the drop of loading values from gravel to P (cf. Tab. 4). Increasing values along the second axis mainly represent an increase of gravel. Increased gravel content in an area located in a hollow (e.g. dry river valley with lower soil surface than adjacent areas) cause higher rates of water inflow, and represent higher microtopographic heterogeneity (HOLZAPFEL et al. 1995). As a result, adjacent habitats with less gravel lose water by run-off, while the *Krascheninnikovia ceratoides*-community as a channel habitat in a deeper located valley position receives water input as surface water or groundwater flowing through parent rock. Temporarily available groundwater allows the establishment of shrubs. Higher habitat heterogeneity explains higher species richness. Both leads to densest vegetation cover of all desert steppe communities. The occurrences of shrubs and the denser vegetation cover as an indication of enhanced productivity might cause higher soil organic matter and phosphorus (NOY-MEIR 1985, WHITFORD 2002). As a consequence, the second axis can be interpreted as a gradient of increasing water input, and increasing variance of site conditions with increased supply of soil nutrients. Since all variables have higher factor loadings of the first and second axes, the third axis can be neglected.

The ordination of relevés along the first axis obviously separates *Anabasis brevifolia - Allium mongolicum*-community as a community of sites with highest edaphic moisture from dry because gravely *Krascheninnikovia ceratoides*-community and sandy *Artemisia xerophytica*-community. *Krascheninnikovia ceratoides*-community and *Artemisia xerophytica*-community are located close to each other along the first axis due to their overlap in sand, clay and $CEC_{eff.}$. Both communities are separated better along the second axis, regarding their preclusive differences in soil content of gravel.

The PCA confirms the vegetation classification carried out by table work on the basis of only environmental variables. The DCA ordination confirms it too based only on data of vegetation relevés. Among environmental parameters, soil texture variables play the most important role, and allow the differentiation of three plant communities.

The wide dispersal of relevés influenced by grazing and their mixing with other relevés of community 1 along the first and more along the second axis confirms that environmental differences are insufficient for an ecologically based separation of a further plant community.

## 2.5.2 Mountain steppe

### *Vegetation classification*

The mountain steppe between 1900 and 2200 m a.s.l. comprises a total of 94 species, subdivided into 84 percent of perennial and 16 percent of annual plants. Among perennials, forbs dominate with 70 percent of proportion in species number, followed by grasses and sedges with 16 percent, semi-shrubs with 9 percent, and shrubs with 5 percent. Contrary to the dominance of forbs in species number, some few perennial grasses (*Stipa krylovii*, *Koeleria cristata*, *Agropyron cristatum*) clearly dominate the proportion of foliar cover (cf. Fig. 13, Appendix II). Four communities were classified floristically and environmentally: *Leymus secalinus*-grazing community, *Stipa krylovii - Artemisia dolosa*-mountain steppe, *Rhinactinidia eremophila - Stipa krylovii*-mountain steppe, and *Leymus chinensis*-grazing community.

Soil texture attributes as the content of silt, silt and clay in total soil and gravel, forming the ecological factor of edaphic moisture, divides mountain steppe in two types of communities (4, 5 and 6, 7). They both are subdivided further into four communities by soil attributes, representing nutrient supply and being susceptible to grazing (P, N, $C_{org}$, $C_{org}/N$, $CEC_{eff}$), salinity, calcium carbonate and pH (Fig. 14). This two-part division is repeated in species composition. Community 4 conforms floristically to community 5 and community 7 conforms to community 6. However, by comparison with one another (community 4 with 5 and 6 with 7), they show obvious changes in species composition and vegetation cover towards a considerable loss of species, and an increase in the abundance and dominance of annuals with low palatability to animals (see Tab. 5).

| No. of species group | **Plant community** | ***Leymus secalinus* - grazing community** | ***Stipa krylovii - Artemisia dolosa*- mountain steppe** | ***Rhinactinidia eremophila - Stipa krylovii*- mountain steppe** | ***Leymus chinensis* - grazing community** |
|---|---|---|---|---|---|
| | Running number | 4 | 5 | 6 | 7 |
| | **Environmental parameters differentiating communities** | | | | |
| | Silt [%]$^1$ | 23 - 41 | | 6 - 32 | |
| | Silt in total soil [%] | **16 - 30** | | **5 - 14** | |
| | Clay and silt in total soil [%] | **26 - 55** | | **7 - 25** | |
| | **Parameters changed by grazing** | | | | |
| | Distance from grazing hot spot [m] | **0 - 30** | **100 - 2300** | **50 - 2700** | **20-40** |
| | P [ppm dm] | **1100-14.500** | **70 - 910** | 90 - 3000 | 800 - 2400 |
| | Electric conductivity [mS/cm] | **2.0 - 9.5** | **0.3 - 1.5** | **0.1 - 0.8** | **1.9 - 2.0** |
| | Corg [%] | **3.4 - 27.0** | **1.0 - 2.6** | **1.2 - 3.0** | **4.6 - 8. 4** |
| | N [%] | **0.4 - 2.0** | **0.1 - 0.5** | **0.1 - 0.4** | **0.6 - 0.7** |
| | Corg/N | **9 - 14** | **2 - 9** | 8 - 10 | 8 - 12 |
| | CECeff. [cmol/kg] | **22 - 40** | **9 - 26** | **6 - 27** | **21 - 29** |
| | pH | **7.1 - 7.4** | **6.0 - 7.0** | 5.4 - 6.9 | 6.4 - 7.0 |
| | CaCO3 [%] | **2 - 5** | **0.0 - 2.8** | **0 - 0.6** | **0.7 - 14.5** |
| | Average total cover of vegetation [%] | **61** | **24** | **23** | **54** |
| | Average nu. of species in vegetation relevés | **3** | **17** | **23** | **12** |
| | Number of relevés | 12 | 58 | 61 | 10 |
| | Number of soil samples | 3 | 11 | 14 | 2 |
| | Species of mountain steppe and alpine belt | | | | |
| 1 | **Festuca lenensis** | . | 97 | 93 | . |
| | **Poa attenuata** | . | 81 | 84 | 10 |
| | Steppe species | | | | |
| 2 | **Artemisia dolosa** | . | 100 | 100 | 40 |
| | **Koeleria cristata** | . | 100 | 92 | 40 |
| | **Stipa krylovii** | 8 | 100 | 95 | 70 |
| | **Bupleurum bicaule** | . | 97 | 97 | 10 |
| | **Agropyron cristatum** | . | 95 | 75 | 50 |
| 3 | **Ptilotrichum canescens** | . | 60 | 64 | 10 |
| | **Astragalus cf. brevifolius** | . | 72 | 46 | 10 |
| | **Artemisia frigida** | . | 33 | 61 | 30 |
| | **Allium anisopodium** | . | 47 | 48 | . |
| | **Scorzonera ikonnikovii** | . | 33 | 51 | 30 |
| | **Oxytropis tragacanthoides** | . | 10 | 48 | . |
| | **Carex duriuscula** | 17 | 53 | 23 | 20 |
| 4 | **Allium tenuissimum** | . | 28 | 43 | 20 |
| | **Sibbaldianthe adpressa** | . | 16 | 10 | . |
| | **Allium eduardii** | . | 7 | 20 | . |
| | **Dracocephalum fruticulosum** | . | 7 | 8 | . |
| | **Potentilla bifurca** | . | 12 | 15 | . |
| | **Potentilla cf. sericea** | . | 9 | . | . |
| | **Clausia aprica** | . | 14 | 10 | . |
| | **Astragalus cf. versicolor** | . | 7 | 3 | . |
| | **Hedysarum ferganense** | . | 5 | 5 | . |
| 5 | **Oxytropis cf. micrantha** | . | 55 | 79 | 10 |
| | **Amblynotus rupestris** | . | 48 | 85 | . |
| | **Pulsatilla bungeana** | . | 43 | 87 | . |
| 6 | **Iris potaninii** | . | 41 | 43 | 10 |
| | **Arenaria meyeri et capillaris** | . | 17 | 84 | . |
| | **Phlomoides tuberosa** | . | 36 | 80 | 50 |
| | **Ferulopsis hystrix** | . | 9 | 33 | . |
| | **Potentilla cf. multifida** | . | 17 | 8 | . |
| | Indicators of disturbance & dry sandy sites | | | | |
| 7 | Salsola collina et tragus | 25 | 97 | 85 | 70 |
| | Dontostemon integrifolius | . | 88 | 84 | 30 |
| | Species of desert steppe | | | | |
| 8 | **Stipa glareosa** | . | . | 11 | . |
| | **Astragalus cf. adsurgens** | . | . | 8 | . |
| | **Cleistogenes squarrosa** | . | 5 | 5 | . |
| | **Vicia costata** | . | 5 | . | . |
| | Characteristic species groups of communities | | | | |
| 9 | **Chamaerhodos altaica** | . | 2 | 38 | . |
| | **Rhinactinidia eremophila** | . | 3 | 70 | . |
| | **Thalictrum foetidum** | . | . | 21 | . |
| | **Youngia tenuicaulis et Ixerdium chinense ssp. versicolor** | . | 2 | 23 | . |
| | **Stellaria dichotoma** | . | . | 16 | 10 |
| | **Oxytropis indet.** | . | . | 18 | . |
| | **Ephedra cf. sinica** | . | . | 16 | . |
| | **Pedicularis flava** | . | . | 16 | . |
| | **Taraxacum cf. collinum** | . | . | 8 | . |
| | **Poa sibirica** | . | . | 8 | . |
| | **Dontostemon senilis** | . | . | 7 | . |
| 10 | Orostachys spinosa | . | . | 30 | . |
| | Chamaerhodos erecta | . | . | 7 | . |
| 11 | **Smelowskia alba** | . | . | 8 | . |
| | **Aconogonon alpinum** | . | . | 7 | . |
| | **Youngia tenuifolia** | . | . | 7 | . |
| | **Oxytropis oligantha** | . | . | 3 | . |
| | **Pachyneurum grandiflorum** | . | . | 3 | . |
| | **Silene altaica** | . | . | 3 | . |
| | **Silene jeniseensis** | . | . | 3 | . |
| | **Linaria hepatica** | . | . | 3 | . |
| 12 | **Leymus chinensis** | . | 2 | 51 | 90 |
| | **Artemisia rutifolia** | . | . | 3 | 60 |
| | Grazing & disturbance indicators | | | | |
| 13 | Chenopodium album agg. | 92 | 52 | 10 | 100 |
| | Axyris prostrata | 25 | 48 | 41 | 90 |
| | Chenopodium aristatum | . | 14 | . | 30 |
| 14 | **Leymus secalinus** | 100 | . | . | . |
| 15 | Chenopodium acuminatum | 8 | . | 33 | 80 |
| | Chenopodium vulvaria | . | . | 3 | 50 |
| | Artemisia macrocephala | 17 | . | 2 | 60 |
| | Senecio dubitabilis | . | 9 | 2 | 50 |
| 16 | **Elytrigia nevskii** | . | . | 2 | 50 |

☐ Species group with obvious differences in constancy compared to other plant comunites

Tab. 5: Constancy table of plant communities of mountain steppe with characteristic species groups and their main differentiating environmental variables (perennial species are in bold style, annual species are in regular style).

### Community 5) *Stipa krylovii - Artemisia dolosa*-mountain steppe and community 6) *Rhinactinidia eremophila - Stipa krylovii*-mountain steppe

Both communities are distributed at plane bottom of mountain valleys and adjacent slightly inclined slopes. Community 5) represents site conditions with higher proportions of silt, and silt and clay in total soil, and lower proportions in gravel and sand as a consequence of its appearance in more plane areas. It contains lower concentrations of $C_{org}$ and N than community 6 (Fig. 14, 15). The community contains 44 frequently appearing species and has no own characteristic species groups. The physiognomy of the community is characterised by the dominance of perennial grasses as *Stipa krylovii*, *Koeleria cristata* and *Agropyron cristatum* and the dwarf semi-shrub *Artemisia dolosa.* Perennial forbs as *Bupleurum bicaule*, *Astragalus brevifolius*, *Ptilotrichum canescens*, and *Oxytropis micrantha* are highly abundant but with low cover values. In contrast to community 6, species groups 5 and 6 are distributed with lower constancies whereas species group 9 - 12 are missing. The sparse cover of total vegetation amounts 20 to 30 percent.

Community 6) occupies more inclined slopes than community 5. Hence, its sites have a higher content of gravel, and lower and lowest content of silt, and silt and clay in total soil (cf. Fig. 14). With 65 species, the community comprises a higher number of frequently appearing species, and is distinguished from community 5 by the presence of species group 9 - 12. The physiognomic appearance of the community is formed by similar species as community 5 whereas the constancy of perennial grasses slightly decreases due to the more stony conditions. In addition, vegetation cover indicates these stony conditions with slightly lower cover values between 15 to 25 percent. The community is furthermore distinguished from community 5 by a high number of characteristic species of group 9 – 12. This high number may probably be a consequence of more stony conditions with higher heterogeneity of microrelief indicated by petrophilous species as *Rhinactinidia eremophila, Chamaerhodos altaica, Thalictrum foetidum,* and *Orostachys spinosa* of group 9 and 10. The high species richness is furthermore supported by the immigration of alpine species of species group 11 indicating the position of the community at elevated slopes (GRUBOV 2001).

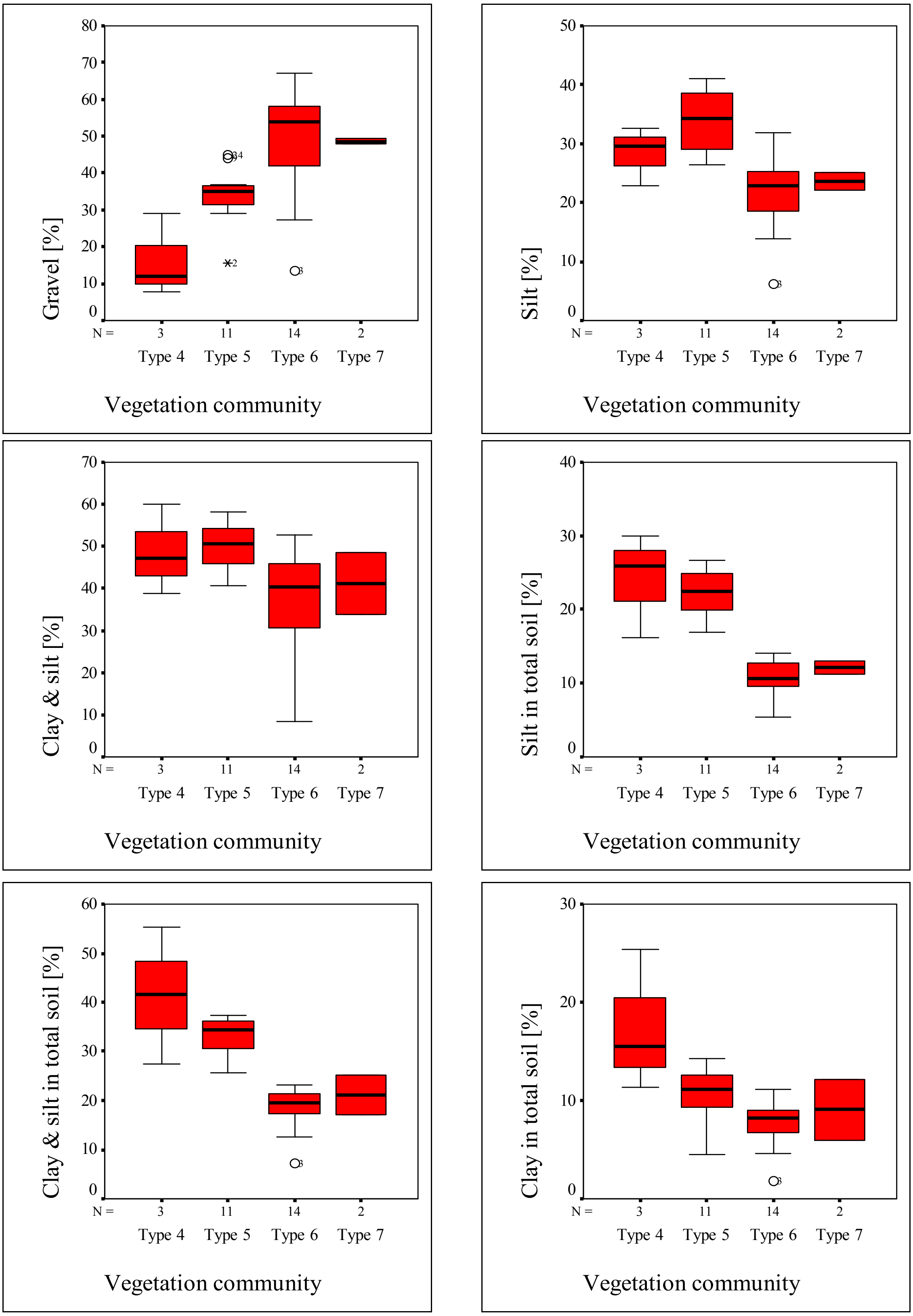
### Community 4) *Leymus secalinus*-grazing community and community 7) *Leymus chinensis*-grazing community

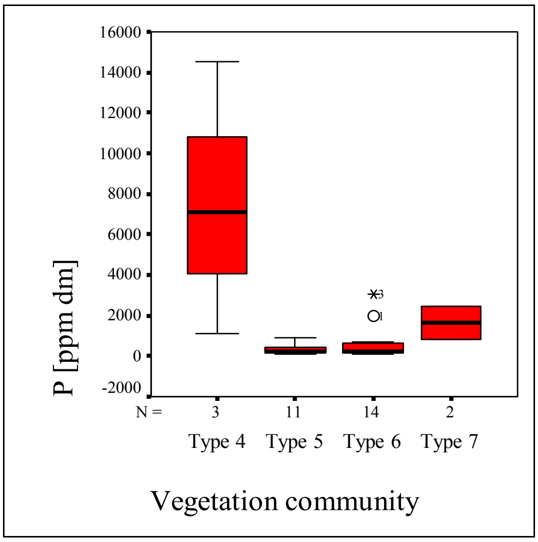
In close proximity to animal corrals, they occur within a distance between 0 to 40 m. With more than 50 percent, both communities have an obvious higher vegetation cover than the non-grazing communities with less than 30 percent but much less species. Community 4 mainly comprises annual species of the Chenopodiaceae as *Chenopodium album agg.* and *Axyris prostrata* and the grazing indicator *Leymus secalinus*. Community 7 contains more characteristic species of community 5 and 6 than community 4. Its physiognomy is formed by grazing and disturbance indicators as *Chenopodium album agg.*, *Axyris prostrata*, *Chenopodium acuminatum* and Leymus chinensis with a high dominance. Due to soil texture characteristics such as content of silt, content of silt and clay in total soil and gravel, community 4 conforms to community 5, and community 7 is similar to community 6 (Fig. 14). With only 8 frequently appearing species, community 4 comprises less than community 7 with 28 frequently appearing species. This is comparable to community 5 with its less frequently appearing species than community 6. Community 4 contains only one characteristic species group (14) and is distinguished from other communities by the absence of the majority of species groups. Community 7 is similar to community 6 in the presence of species groups 12-16, and differs from it in the missing of species groups 9-11. With respect to soil nutrient properties, their sites have obvously higher concentrations of P, N, $C_{org}$ representing immobilised soil nutrients, and $CEC_{eff}$ elevated through the input of organic material by livestock. Even salinity, calcium carbonate and pH show significantly higher values in both communities. With total foliar cover of more than 50 percent, both communities have a much higher productivity but very low species diversity.

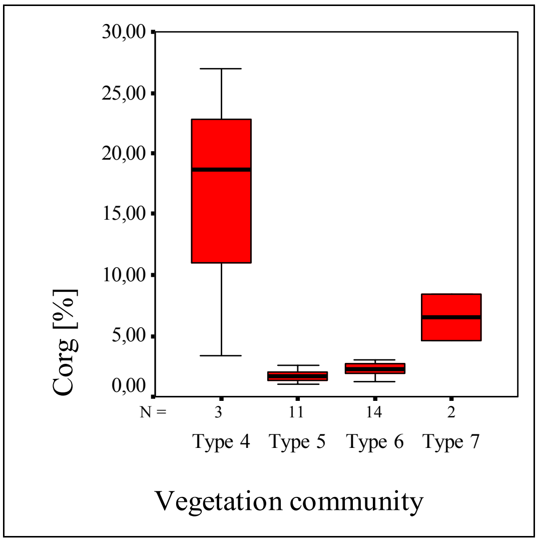
While in community 5 and 6 perennial species prevail with 82 percent and 83 percent, they have a proportion of only 25 percent in community 4, and 64 percent in community 7.

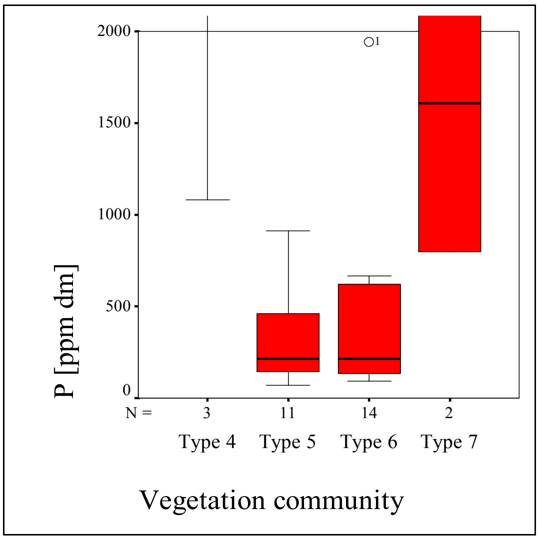
The majority of sites are sampled in an area with low altitudinal differences between 2000 and 2150 m a.s.l. but a higher variation of inclination differences between 2-10°. Differences of slope aspects vary obviously between 0-270°, and represent the majority of possible directions. However, none of these parameters is precisely bound to a single plant community, and thus indicates no vegetation-differentiating environmental property.

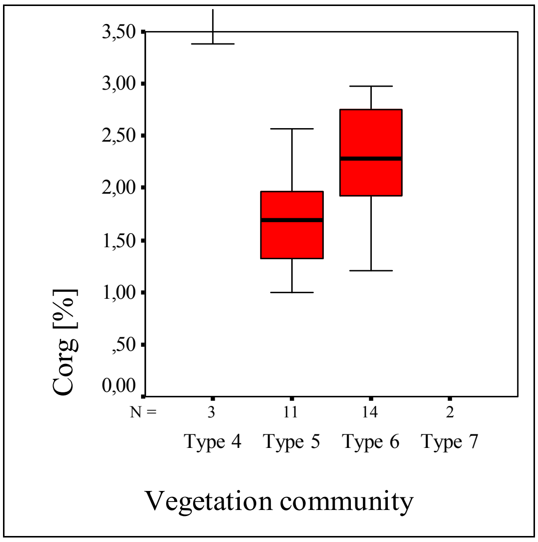
Fig. 13: Vegetation formation of mountain steppe (Photo: Kretschmer 2003).

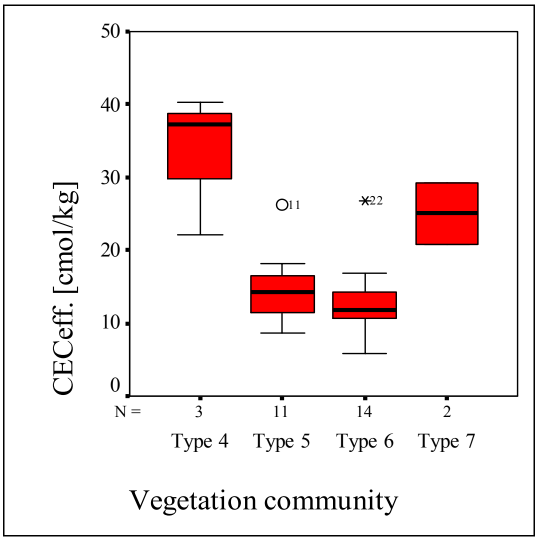

Gravel [%]
80
70
60
50
40
30
20
10
0
34
2
3
Silt [%]
50
40
30
20
10
0
3
Clay & silt [%]
70
60
50
40
30
20
10
0
Silt in total soil [%]
40
30
20
10
0
Clay & silt in total soil [%]
60
50
40
30
20
10
0
3
Clay in total soil [%]
30
20
10
0
3
N =
3
11
14
2
Type 4
Type 5
Type 6
Type 7
Vegetation community

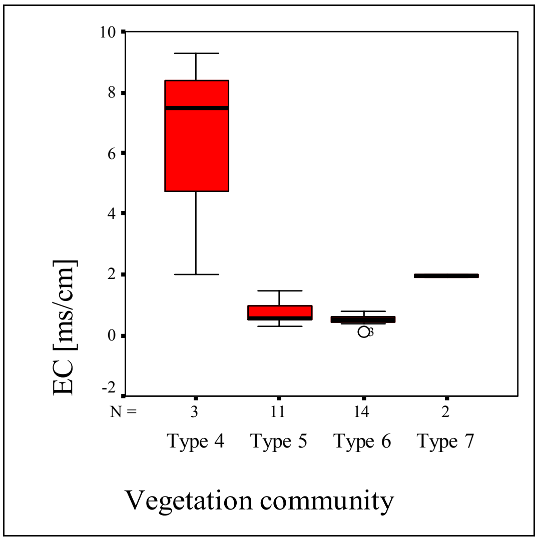

P [ppm dm]
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000
3
1
N =
3
11
14
2
Type 4
Type 5
Type 6
Type 7
Vegetation community


Corg [%]
30,00
25,00
20,00
15,00
10,00
5,00
0,00
N =
3
11
14
2
Type 4
Type 5
Type 6
Type 7
Vegetation community


P [ppm dm]
2000
1500
1000
500
0
1
N =
3
11
14
2
Type 4
Type 5
Type 6
Type 7
Vegetation community


Corg [%]
3,50
3,00
2,50
2,00
1,50
1,00
,50
0,00
N =
3
11
14
2
Type 4
Type 5
Type 6
Type 7
Vegetation community


CECeff. [cmol/kg]
50
40
30
20
10
0
11
22
N =
3
11
14
2
Type 4
Type 5
Type 6
Type 7
Vegetation community


EC [ms/cm]
10
8
6
4
2
0
-2
3
N =
3
11
14
2
Type 4
Type 5
Type 6
Type 7
Vegetation community

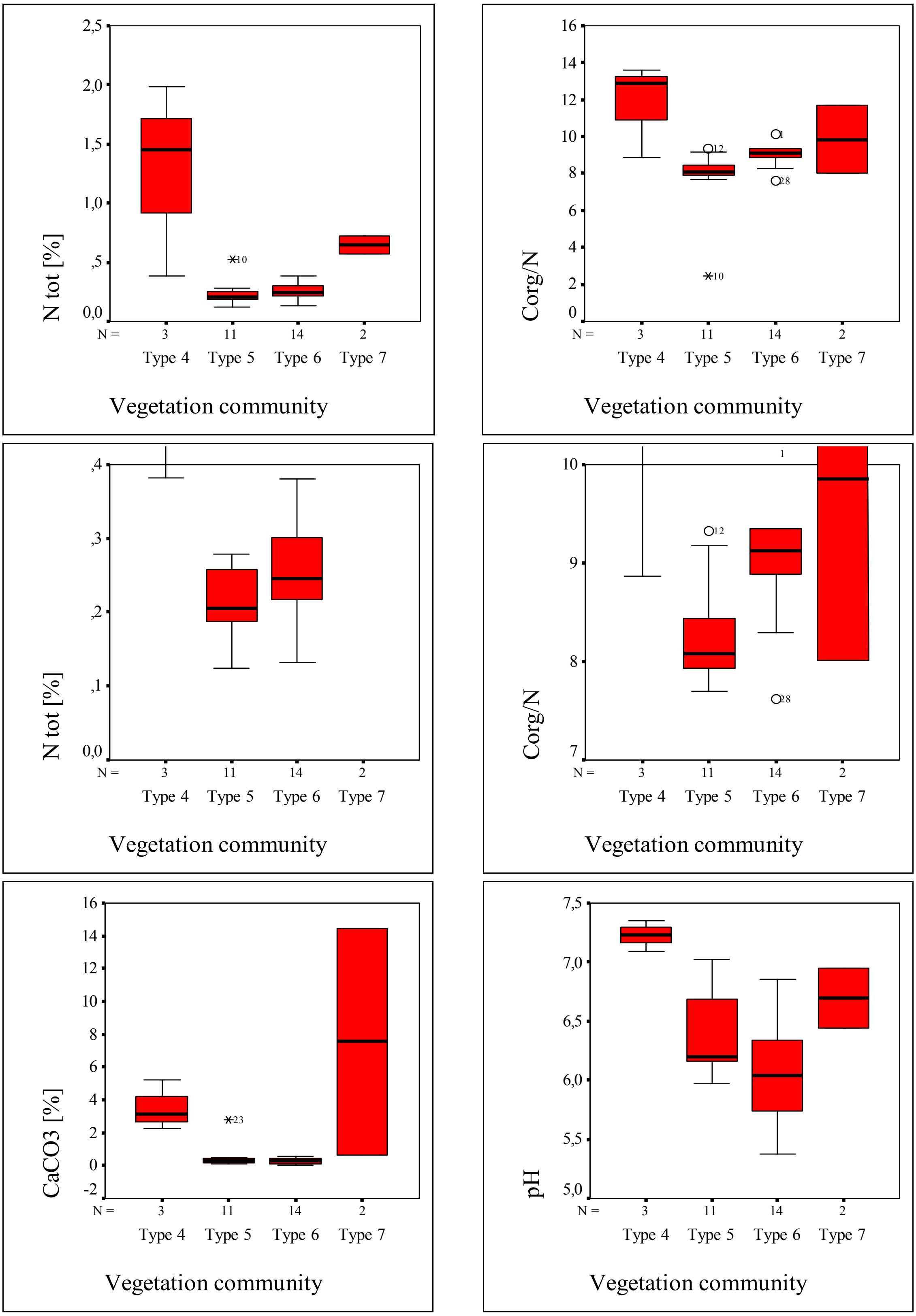
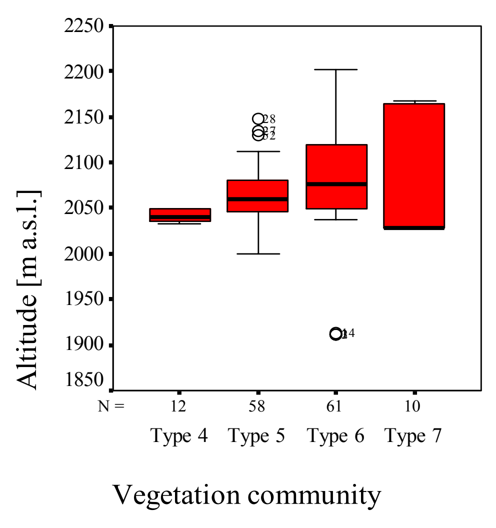
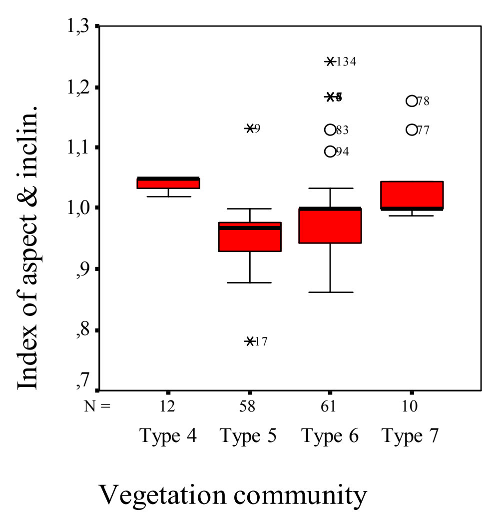
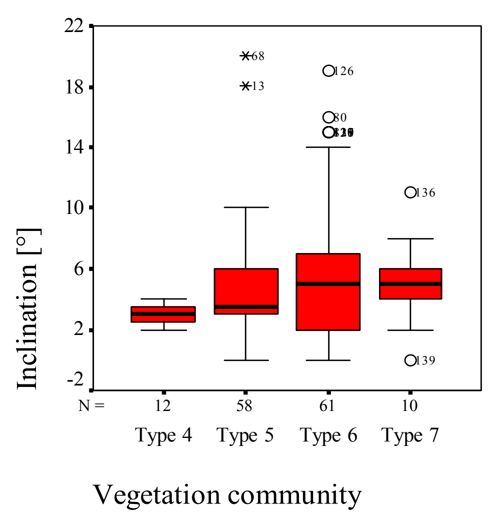
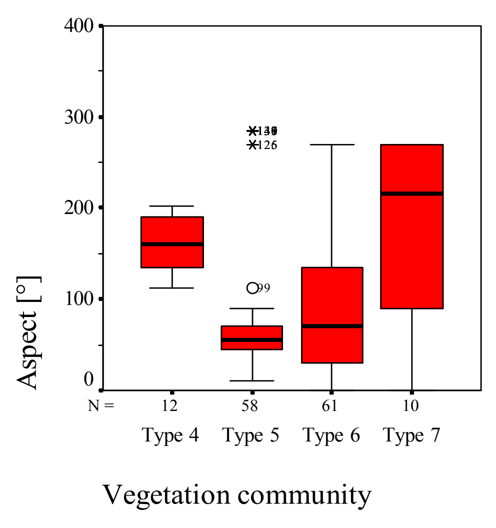


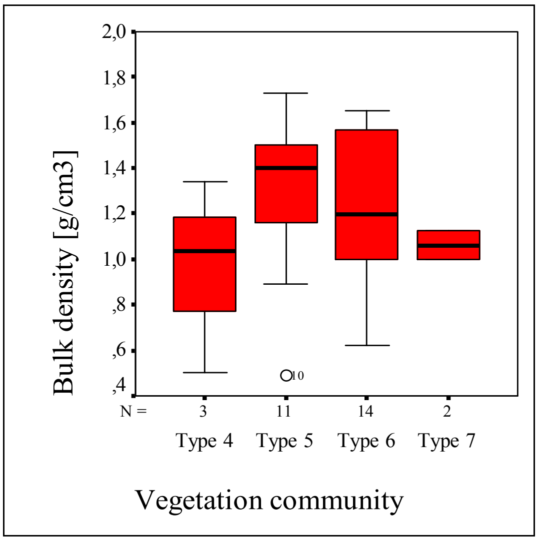
Fig. 14: Box and Whisker Plots for soil variables obviously differing across plant communities of mountain steppe (Type: 4 *Leymus secalinus*-grazing community, Type 5: *Stipa krylovii - Artemisia dolosa*-mountain steppe, Type 6: *Rhinactinidia eremophila - Stipa krylovii*-mountain steppe, Type 7: *Leymus chinensis*-grazing community).

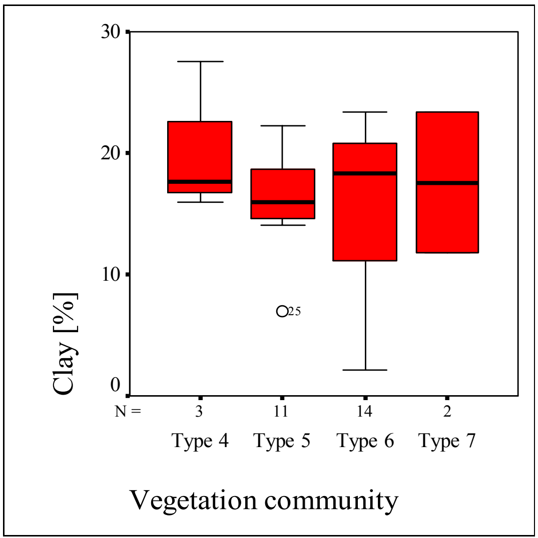

Altitude [m a.s.l.]
2250
2200
2150
2100
2050
2000
1950
1900
1850
N =
12
58
61
10
Type 4
Type 5
Type 6
Type 7
Vegetation community
28
32
14


Index of aspect & inclin.
1,3
1,2
1,1
1,0
,9
,8
,7
N =
12
58
61
10
Type 4
Type 5
Type 6
Type 7
Vegetation community
134
9
83
94
78
77
17


Inclination [°]
22
18
14
10
6
2
-2
N =
12
58
61
10
Type 4
Type 5
Type 6
Type 7
Vegetation community
68
13
126
80
136
139


Aspect [°]
400
300
200
100
0
N =
12
58
61
10
Type 4
Type 5
Type 6
Type 7
Vegetation community
126
99


Bulk density [g/cm3]
2,0
1,8
1,6
1,4
1,2
1,0
,8
,6
,4
N =
3
11
14
2
Type 4
Type 5
Type 6
Type 7
Vegetation community
10


Clay [%]
30
20
10
0
N =
3
11
14
2
Type 4
Type 5
Type 6
Type 7
Vegetation community
25

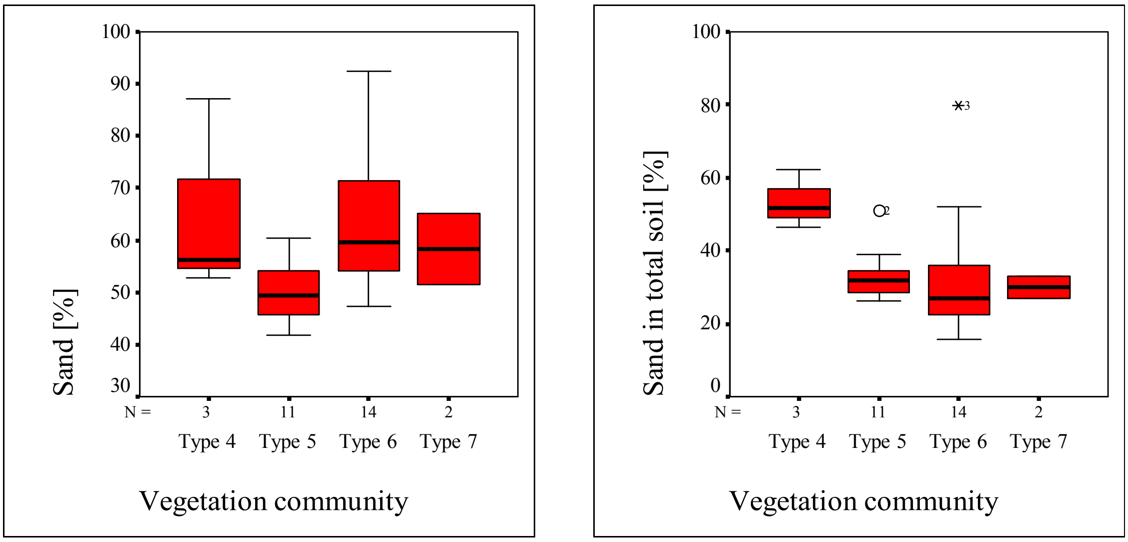


Fig. 15: Box and Whisker Plots for environmental and soil variables with high variations within plant communities of mountain steppe.

### ***Detrended Correspondence Analysis (DCA Ordination)***

DCA results in a total inertia of 2.44 indicating a lower floristic variance than desert steppe. First axis explains 63 percent, together with the second axis 74 percent of total variance in vegetation data.

The first axis is strongly correlated with EC, total N and $C_{org}$, followed by $CEC_{eff.}$, P and pH. The majority of these variables can be treated as being changed by grazing. Thus, the first axis represents grazing as main ecological gradient. The second axis has mean correlations with soil texture variables, and reflects edaphic moisture as ecological gradient (Fig. 16). Since there is no remarkable correlation of axis 3 with any variable this axis is not presented here (Tab. 6)

Fig. 16 clumps four floristic groups, indicating the classified communities. Main floristic differences occur among the communities and their grazing mediated communities. Grazing communities display a higher floristic variance than more narrowly arranged relevés of the other communities. They are arranged to each other in the same order as community 5 and 6 confirming their natural origin: community 7 on the left (upper) side vs. community 4 on the right (lower) side. Grazing communities are separated from community 5 and 6 along first axis strongly correlated with EC and variables susceptible by grazing as N, $C_{org}$, $CEC_{eff.}$, and P. Community 5 and 6 are primarily separated along the second axis, representing community 5 as edaphic moister community due to its higher content of fine soil, clay, and silt in total soil.

Community 6 contains single relevés with a species composition more similar to community 5, just as community 5 contains a relevé more similar to community 6 (relevés marked with a number in Fig. 16). However, they are classified into the named community, due to their presence of species of characteristic species groups and their environmental conditions, which are demonstrated by the PCA ordination graph (cf. Fig. 17).

Since grazing communities are separated along the first axis explaining main proportions of data variance and have strongest correlations with variables susceptible to grazing, DCA gives evidence that grazing has a strong influence on vegetation composition. However, the high explanation values of the first two derived axes, their strong correlations with environmental variables, and a clear relevé aggregation indicate that vegetation-relevant parameters were captured. Salinity, grazing influence and edaphic moisture are exposed as main decisive ecological factors.

| Total variance (inertia) | 2.440 | | |
|---|---|---|---|
| | **Axis 1** | **Axis 2** | **Axis 3** |
| Eigenvalue | 0.681 | 0.167 | 0.076 |
| Explained variance, cumulative [%] | 63.4 | 73.9 | 75.2 |
| **Variables** | r | r | r |
| Electrical conductivity (EC) | **0.861** | 0.163 | -0.383 |
| N | **0.856** | 0.235 | -0.37 |
| $C_{org}$ | **0.846** | 0.239 | -0.375 |
| $CEC_{eff.}$ | **0.783** | 0.246 | -0.337 |
| Phosphorus (P) | **0.749** | 0.089 | -0.3 |
| pH | **0.637** | -0.121 | -0.296 |
| $C_{org}/N$ | ***0.579*** | 0.318 | -0.215 |
| Clay in total soil (clay tot) | ***0.562*** | 0.026 | -0.394 |
| Gravel | ***-0.455*** | ***0.495*** | 0.083 |
| Fine soil | ***0.455*** | ***-0.495*** | -0.083 |
| Clay & silt in total soil (c&s tot) | ***0.484*** | -0.295 | -0.295 |
| $CaCO_3$ | ***0.462*** | 0.154 | -0.142 |
| Distance from grazing hot spot (graz_dis) | ***-0.454*** | -0.376 | 0.449 |
| Silt in total soil (silt tot) | 0.357 | ***-0.446*** | -0.186 |
| Clay | 0.21 | ***0.432*** | -0.352 |
| Sand in total soil (sand tot) | 0.339 | -0.346 | 0.06 |
| Index of aspect & inclination (EI) | *0.307* | -0.085 | 0.11 |
| Silt | 0.051 | -0.266 | -0.154 |
| Clay & silt (c&s) | 0.146 | 0.019 | -0.296 |
| Bulk density | -0.231 | -0.31 | 0.11 |
| Sand | 0.091 | 0.018 | 0.195 |
| Altitude | -0.076 | 0.051 | 0.082 |

Tab. 6: Results of DCA of mountain steppe with correlation coefficients of PEARSON of environmental variables with ordination axes (very strong correlations are in bold underlined, strong correlations in bold, and mean correlations in bold and italic style).

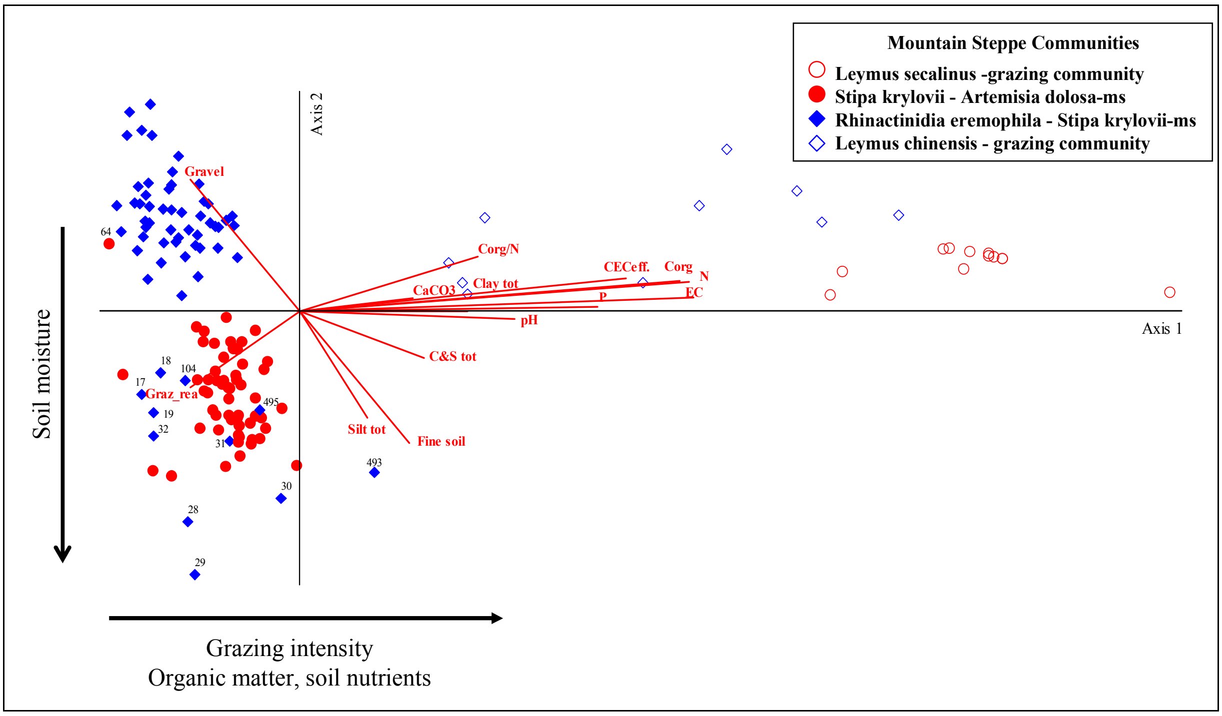


Fig. 16: DCA ordination of mountain steppe relevés and its correlation with environmental variables, cut off $r^2$-value = 0.2, N=141 (Clay tot – content of clay in total soil, C&S tot - content of clay and silt in total soil, Graz_rea – distance from grazing hot spot, Silt tot – content of silt in total soil). Numbered relevés indicate floristic deviations from the corresponding plant community and refer to the same relevés numbered in Fig. 17.

***Principle component analysis (PCA)***

The PCA contains 11variables. The following variables were excluded due to their higher variance within than across plant communities: altitude, slope aspect and inclination, the index of both, bulk density, clay, sand, and sand in total soil (Fig. 15). In addition to this sand, gravel, clay in total soil, and $C_{org}$/N were excluded due to their linear mathematical correlation with clay and silt, fine soil and N and $C_{org}$.

Three axes were extracted representing 84 percent of the total variance of environmental data set. The first axis explains 53 percent, the second axis 21 percent and the third axis 11 percent portion of variance of the environmental data set. The first axis has highest loadings with electrical conductivity, $C_{org}$ and N, and variables of fine soil fractions. Thus, the first axis can be interpreted as a complex gradient of salinity, soil fertility, and edaphic moisture. The second axis is highly loaded with variables of fine soil fractions, and can be treated as gradient of edaphic moisture. The third axis with loadings of carbonate and fine soil represents a complex gradient of soil pH and edaphic moisture (cf. Tab. 7).

Vegetation relevés ordered along regression scores of first and second axis separate grazing communities 4 and 7 with higher soil nutrient level and salinity along the first axis from both of the other communities (Fig. 17). Broad dispersal of relevés of community 4 refers to the high variation in EC and variables representing soil fertility (cf. Fig. 14). Community 5 and 6 are separated in a combination of first with second axis but mainly along second axis. Relevés of community 5 are placed in the direction of the contents of fine soil and silt, representing edaphic moister conditions compared to community 6. The fact that prevailing soil texture variables lead to the separation of both communities is confirmed by Fig. 18, which might separate them along only the second axis loaded with soil texture variables. The relevés marked with numbers in Fig. 16, which are floristically more similar to the other communities, are classified to the edaphically better suitable community as shown in Fig. 17.

However, PCA confirms the vegetation classification indicating salinity, grazing influence, and soil texture as main vegetation-differentiating variables. Furthermore, calculated PCA axes correspond well with hypothetical environmental axes derived from DCA, confirming the strong influence of grazing on vegetation.

| **Variables** | Axis | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Electrical conductivity | **.919** | -.343 | .005 |
| N | **.873** | -.373 | .108 |
| $C_{org}$ | **.854** | -.419 | .029 |
| Clay & silt in total soil | **.847** | .464 | -.166 |
| CECeff. | **.809** | -.194 | .271 |
| Phosphorus | **.805** | -.379 | -.197 |
| pH | **.758** | .021 | .185 |
| Silt in total soil | **.729** | .598 | -.277 |
| Silt | .407 | **.867** | .092 |
| Clay & silt | .491 | **.733** | .374 |
| $CaCO_3$ | .290 | -.186 | **.678** |
| Fine soil | .626 | -.066 | **-.638** |

Tab. 7: Component matrix of PCA of mountain steppe with factor loadings of 12 environmental variables.

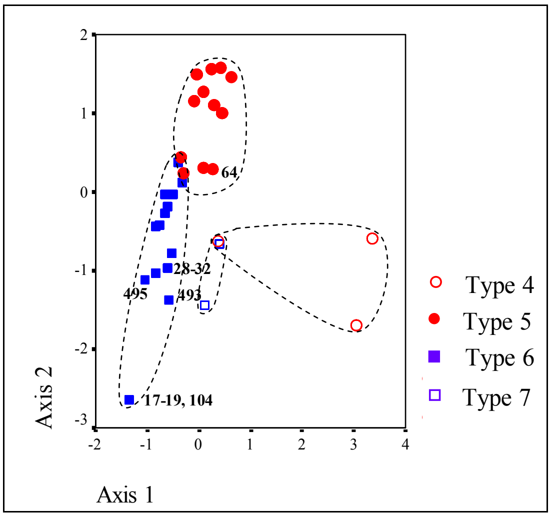


Fig. 17: Ordination graph of vegetation relevés of mountain steppe along PCA factor scores (N=30). Numbered relevés cf. Fig. 16.

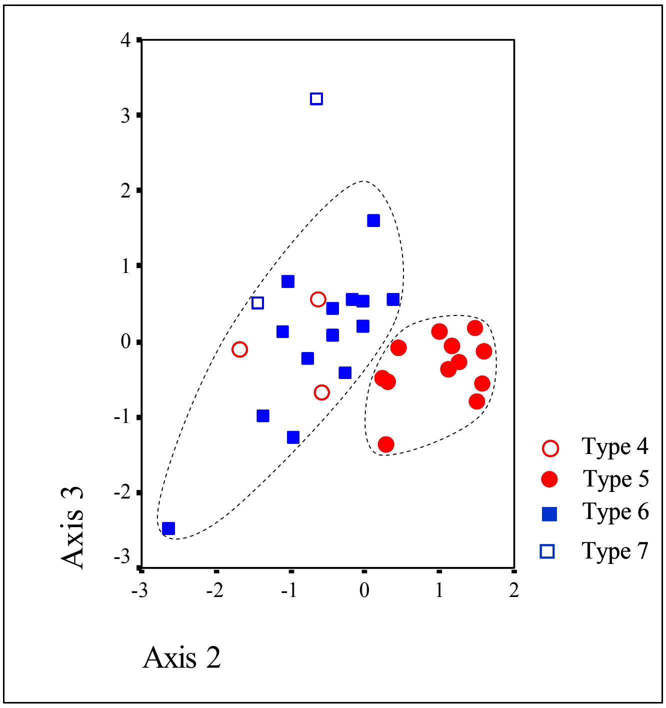


Fig. 18: Ordination graph of vegetation relevés of mountain steppe along PCA factor scores.

### 2.5.3 Alpine vegetation

***Vegetation classification***

In the alpine belt between 2300 and 3050 m a.s.l. six plant communities could be distinguished floristically and environmentally: *Aster alpinus* - *Koeleria cristata*-alpine steppe, *Potentilla bifurca* - *Koeleria cristata*-alpine steppe, grazing community of *Festuca lenensis*-cryophyte steppe, *Festuca lenensis*-cryophyte steppe, *Poa altaica* - *Kobresia myosuroides*-sedge mat, and grazing community of *Poa altaica* - *Kobresia myosuroides*-sedge mat. Altogether, they contain 129 species, the maximum of the whole investigation area what is probably justified by the long altitudinal gradient of alpine belt, representing the longest altitudinal difference among all areas. 88 percent of species are perennials and 12 percent are annuals. Perennials compose of forbs with 66 percent proportion in species number, grasses and sedges with 22 percent, mosses with 8 percent, and semi-shrubs and dwarf-shrubs with 4 percent. The peculiarity of the alpine belt consists in its steppe character with a high proportion of grasses in foliar cover up to the highest parts of the mountains (BUYAN-ORSHIKH 1992, POLYNOV and KRASHENINNIKOV 1926 cited in YUNATOV 1950) represented by the cryophyte steppe.

Altitude and associated bioclimatic conditions as precipitation, thermal regime, and vegetation period control the peculiarity of vegetation formations comprising the alpine steppe in lower alpine belt between 2300-2600 m a.s.l., and the cryophyte steppe and sedge mat in the upper alpine belt between 2700-3050 m a.s.l. (Tab 8). Different climatic conditions in the upper and lower alpine belt cause differences in the weathering processes, which distinguish alpine steppe with highest content of sand caused by probably prevailing physical weathering, and cryophyte steppe and sedge mats with middle and lowest content of sand due to enhanced chemical weathering. Within the upper alpine belt, the topographic position of sedge mat at the bottom of valleys leads to a water inflow with enhanced inflow of smaller fine soil, especially of clay and silt, into sedge mat during thawing summer season. The slope position of cryophyte steppe at mountain slopes or mountain-passes and saddles cause water outflow, and leads to lower content of fine soil fractions compared to sedge mats. Permanent water supply during vegetation period results in higher biomass productivity of sedge mats. Thus, environmental variables reflecting productivity of communities as N and $C_{org}$ distinguish sedge mats from cryophyte steppe. Cryophyte steppe of the upper alpine belt represents prevailing chemical weathering but missing water inflow. Hence, they reveal a mean content of silt and clay among all sites of the alpine belt. Vegetation formations are further subdivided into six communities according to grazing sensitive variables as $C_{org}$, N and $CEC_{eff}$, a variable related to soil organic matter and content of clay. Even the content of $CaCO_3$ shows small differences in comparison to grazed with less grazed communities. However, absolute values between 0.01-0.6 percent are very low among all communities with differences in median values between 0.05-0.14 percent, comparing grazed with its less grazed community. These differences in values are not to distinguish from methodical variances in the analysis method. The subdivision of alpine steppe into *Potentilla bifurca* - *Koeleria cristata*-alpine steppe and *Aster alpinus* - *Koeleria cristata*-alpine steppe is supported additionally by different content of phosphorus and different content of fine soil. The separation of the grazing community of *Festuca lenensis*-cryophyte steppe from the *Festuca lenensis*-cryophyte steppe is supported additionally by different contents of phosphorus as well, and furthermore by $C_{org}/N$. The latter variable also distinguishes the grazing community of *Poa altaica* - *Kobresia myosuroides*-sedge mat from its less grazed community. As opposed to the other study areas, all grazing communities situated near grazing hot spots in the alpine belt have lower $C_{org}$ and N than their corresponding less grazed communities. The higher index of aspect and inclination of grazing communities represents an artefact since grazing hot spots like animal corrals in this study area are situated in plain bottoms of a valley. Grazing gradients were established with increasing distance from them. Hence, all plots closest to grazing hot spots are situated in the upper part of the adjacent slope with strongest inclination. Owing to southern aspect of the majority of plots between 90°-270°, the index of aspect and inclination is increased. Thus, influence of solar radiation cannot be evaluated seriously by means of index of aspect and inclination. However, obvious changes in species composition and site conditions representing soil nutrient supply form self-contained grazing communities (Tab. 8, Fig. 22).

| No. of species group | Altitudinal belt [m a.s.l.] | Lower alpine belt: 2300 - 2600 | | Upper alpine belt: 2650 - 3050 | | | |
|---|---|---|---|---|---|---|---|
| | **Higher level of classification** | **Alpine steppe** | | **Cryophyte steppe** | | **Alpine sedge mat** | |
| | **Plant community** | ***Aster alpinus - Koeleria cristata*- alpine steppe** | ***Potentilla bifurca - Koeleria cristata* -alpine steppe** | **Grazing community of *Festuca lenensis*- cryophyte steppe** | **Festuca lenensis- cryophyte steppe** | ***Poa altaica - Kobresia myosuroides* -sedge mat** | **Grazing community of *Poa altaica - Kobresia myosuroides* - sedge mat** |
| | Running number | 8 | 9 | 10 | 11 | 12 | 13 |
| | **Environmental parameters differentiating communities** | | | | | | |
| | Waterregime during vegetation period | Infiltration | | Infiltration | | **Topogenous / periodically inundated** | |
| | Clay and silt$^1$ [%] | **20 - 30** | | **25 - 55** | | **45 - 80** | |
| | Sand [%] | **70 - 80** | | **45 - 70** | | **25 - 45** | |
| | Clay and silt in total soil [%] | 5 - 30 | | **10 - 40** | | **30 - 80** | |
| | Fine soil [%] | **20 - 45** | **85 - 100** | **40 - 95** | | **60 - 100** | |
| | **Parameters changed by grazing** | | | | | | |
| | Distance from grazing hot spot [m] | 800 - 1300 | 100 - 200 | 0 - 100 | 200 - 2500 | 800 - 1500 | 50 - 800 |
| | CECeff. [cmol/kg] | 12 - 21 | 8 - 21 | **10 - 37** | **7 - 27** | **39 - 45** | **23 - 40** |
| | P [ppm dm] | **300 - 700** | **300 - 3700** | **300 - 600** | **70 - 300** | 200 - 600 | 500 - 600 |
| | Corg/N | 10 - 11 | 10 - 11 | **8 - 9** | **10 - 11** | 10 - 11 | 10 - 13 |
| | Fine soil [%] | **20 - 45** | **85 - 100** | 50 - 75 | 40 - 95 | 70 - 100 | 60 - 100 |
| | Average nu. of species in vegetation relevés | **23** | **12** | **13** | **18** | 17 | 17 |
| | Average total cover of vegetation [%] | **56** | **18** | **46** | **55** | **68** | **75** |
| | Number of relevés | 9 | 12 | 15 | 45 | 10 | 10 |
| | Number of soil samples | 3 | 3 | 3 | 9 | 3 | 3 |
| | Species of mountain steppe & alpine belt | | | | | | |
| 1 | **Festuca lenensis** | 89 | 50 | 100 | 100 | 80 | 40 |
| | **Poa attenuata** | 78 | 17 | 80 | 67 | . | . |
| | **Stellaria brachypetala** | . | 17 | 40 | 78 | 70 | 90 |
| | **Ranunculus pedatifidus** | 22 | . | 60 | 82 | 60 | 80 |
| 2 | **Carex rupestris et pediformes** | 56 | 42 | 80 | 100 | 100 | 90 |
| | **Potentilla cf. multifida** | 33 | 17 | 100 | 78 | 90 | 90 |
| | **Arenaria meyeri et capillaris** | 100 | 50 | 20 | 87 | 50 | 50 |
| | Species of mountain steppe & lower alpine belt | | | | | | |
| 3 | **Koeleria cristata** | 100 | 92 | . | . | . | 70 |
| 4 | **Artemisia dolosa** | 100 | 92 | . | . | . | . |
| | **Potentilla sericea** | 100 | 83 | . | . | . | . |
| | **Bupleurum bicaule** | 78 | 17 | 13 | . | . | . |
| | **Amblynotus rupestris** | 44 | 58 | . | . | . | . |
| | **Allium tenuissimum** | 56 | 8 | . | 2 | . | . |
| | **Festuca sibirica** | 56 | 17 | . | . | . | . |
| | **Astragalus cf. dilutus** | 56 | 8 | . | . | . | . |
| | **Astragalus cf. multicaulis** | 33 | . | . | . | . | . |
| | **Oxytropis tragacanthoides** | 44 | 8 | . | . | . | . |
| | **Phlomoides tuberosa** | 22 | 17 | . | . | . | . |
| | **Pulsatilla bungeana** | 22 | . | . | . | . | . |
| | Characteristic species group of communites | | | | | | |
| 5 | **Aster alpinus** | 89 | . | . | . | . | . |
| | **Aconogonon alpinum** | 89 | . | . | . | . | . |
| | **Dianthus versicolor** | 89 | . | . | . | . | . |
| | **Silene repens** | 56 | . | . | . | . | . |
| | **Oxytropis cf. potaninii** | 56 | . | . | . | . | . |
| | **Thalictrum foetidum** | 56 | . | . | . | . | . |
| | **Gentiana decumbens** | 78 | . | . | . | . | . |
| | **Silene chamarhensis** | 44 | . | . | . | . | . |
| | **Artemisia argyrophylla** | 44 | . | . | . | . | 10 |
| | **Youngia tenuifolia** | 33 | . | . | . | . | . |
| | **Carex stenophylloides** | 33 | . | . | . | . | . |
| | **Lychnis sibirica** | 22 | . | . | . | . | . |
| | **Galium verum** | 22 | . | . | . | . | . |
| | **Bryum argenteum** | 22 | . | . | . | . | . |
| | **Ferulopsis hystrix** | 22 | . | . | . | . | . |
| | Grazing indicator species | | | | | | |
| 6 | **Potentilla bifurca** | 22 | 83 | . | . | . | . |
| | **Agropyron cristatum** | . | 75 | . | . | . | . |
| | **Carex duriuscula** | 22 | 50 | . | . | . | . |
| | **Clausia aprica** | 22 | 33 | . | . | . | . |
| | **Dontostemon senilis** | . | 17 | . | . | . | . |
| 7 | Axyris hybrida | . | 33 | . | . | . | . |
| | Chenopodium glaucum | . | 17 | . | . | . | . |
| | Indicator species of dryness | . | | . | . | . | . |
| 8 | **Oxytropis myriophylla** | . | 33 | . | . | . | . |
| | **Chamaerhodos altaica** | 11 | 25 | . | . | . | . |
| | **Stipa krylovii** | . | 25 | . | . | . | . |
| | **Oxytropis cf. micrantha** | . | 17 | . | . | . | . |
| | **Astragalus cf. brevifolius** | . | 25 | | | | |
| | **Ephedra monosperma** | | 17 | . | . | . | . |
| | Species of upper alpine belt | | | | | | |
| 9 | **Androsace chamaejasme ssp. lehmanniana** | . | . | 40 | 100 | 50 | 50 |
| | **Oxytropis oligantha** | . | . | 33 | 84 | 50 | 60 |
| | **Pachyneurum grandiflorum** | 22 | . | 47 | 80 | 30 | 60 |
| | **Eritrichium pauciflorum** | 22 | . | 40 | 64 | 40 | 30 |
| | **Stellaria pulvinata** | . | . | . | 58 | 40 | 30 |
| | **Saussurea leucophylla** | . | 8 | . | 62 | 40 | . |
| | Species of moist & wet sites | | . | | | | |
| 10 | **Kobresia myosuroides et smirnovii** | . | . | . | 38 | 100 | 70 |
| | **Bistorta vivipara** | . | . | . | 36 | 40 | 40 |
| | **Thalictrum alpinum** | . | . | . | 11 | 60 | 80 |
| | **Carex melanantha** | 33 | . | . | 22 | 30 | 80 |
| | **Taraxacum brevirostre** | . | . | . | 16 | 50 | 50 |
| | **Papaver pseudocanescens** | . | . | . | 18 | 40 | . |
| | **Primula algida** | . | . | . | 7 | 10 | . |
| | **Oxytropis cf. pauciflora** | 33 | 8 | . | . | 10 | 40 |
| | Characteristic species groups of communities | | | | | | |
| 11 | **Alopecurus turczaninovii** | . | . | 33 | 22 | . | . |
| | **Allium amphibolum** | 11 | . | 20 | 18 | . | . |
| | **Artemisia phaeolepis** | 22 | . | 33 | 60 | 20 | 10 |
| | **Plantago komarovii** | . | 42 | 100 | 82 | . | 40 |
| | **Artemisia pycnorhiza** | . | . | 100 | 64 | . | . |
| | **Elytrigia geniculata** | . | 8 | 67 | 87 | 10 | . |
| 12 | **Melandrium apetalum** | . | . | 47 | 58 | 10 | 10 |
| | **Draba eriopoda** | . | . | 13 | 24 | . | . |
| | **Draba pygmaea** | . | . | 47 | 42 | 10 | . |
| | **Potentilla pensylvanica vel soongarica** | . | . | 20 | 73 | 40 | . |
| | **Saxifraga sibirica** | . | . | . | 47 | 10 | . |
| | **Smelowskia mongolica** | . | . | . | 44 | . | 20 |
| | **Saussurea pseudoalpina** | . | . | 7 | 11 | . | . |
| 13 | **Poa altaica** | . | . | . | . | 70 | 50 |
| | **Kobresia smirnovii** | . | . | . | . | 40 | . |
| | **Festuca kryloviana** | . | . | . | . | 40 | . |
| | **Ranunculus pseudohirculus** | . | . | . | . | 40 | 30 |
| | **Saxifraga hirculus** | . | . | . | . | 30 | 30 |
| | Koenigia islandica | . | . | . | . | 10 | 20 |
| | **Pedicularis uliginosa** | . | . | 7 | . | 10 | 40 |
| | **Lagotis integrifolia** | . | . | . | . | 40 | 30 |
| | **Primula farinosa** | . | . | . | . | 40 | 30 |
| | **Poa alpina** | . | . | . | . | 20 | 20 |
| 14 | **Poa sibirica** | . | . | . | . | 40 | . |
| | **Potentilla nivea** | . | . | . | . | 30 | . |
| | **Elymus aegilopoides** | 22 | 8 | . | . | 20 | . |
| | Grazing indicator species | | | | | | |
| 15 | Axyris prostrata | . | . | 33 | 2 | . | . |
| | Dontostemon integrifolius | . | . | 33 | . | . | . |
| | **Sibbaldianthe adpressa** | . | . | 33 | . | . | . |
| | **Stellaria amblyosephala** | . | . | 7 | . | . | . |
| 16 | **Artemisia frigida** | 11 | 17 | 60 | 2 | . | . |
| | **Hedysarum setigerum** | 11 | 25 | 20 | 9 | . | . |
| 17 | **Poa tianschanica** | . | 8 | . | . | . | 20 |
| | **Senecio integrifolius** | 22 | . | . | . | 10 | 50 |
| | Artemisia blepharolepis | . | . | . | . | . | 40 |
| | Mosses | | | | | | |
| 18 | **Schistidium cf. alpicola** | . | . | . | . | . | 40 |
| | **Pohlia longicollis** | . | . | . | . | . | 50 |

☐ Species group with obvious differences in constancy compared to other plant comunities

Tab. 8: Constancy table of plant communities of alpine belt with their characteristic species groups, and their main differentiating environmental variables (perennial species are in bold style, annual species are in regular style).

Community 8) *Aster alpinus - Koeleria cristata*-alpine steppe occurs in the lower alpine belt at mountain slopes with prevailing high inclinations between 10-40°. This steep relief position causes the low proportion of 20-40 percent of fine soil with predominant sand fractions between 70-80 percent, and very low clay and silt proportions in total soil of 5-7 percent, and 14-22 percent in fine soil respectively. The steep slopes of this community are orientated towards northern and eastnortheastern direction and do not receive improved thermal supply. It is indicated by the low index of aspect and inclination. The soils are poor in $C_{org}$ with 2-5 percent, in N with 0.2-0.5 percent, and in $CEC_{eff}$ with 12-19 cmol/kg.

The community comprises 47 frequently appearing species. All are perennials, with 25 percent of grass and sedge species in species number. Grasses and sedges, in particular *Koeleria cristata*, *F. lenensis, Carex rupestris,* and *C. pediformis* attain highest cover values (cf. Fig. 19). Among them, grasses have higher and highest constancies, and thus give the visual impression of steppe vegetation. The community contains one large characteristic species group (no. 5), which is bound exclusively to this community (Tab. 8).

Fig. 19: Community 8: *Aster alpinus - Koeleria cristata*-alpine steppe. The candle-like yellow plant in the foreground shows the biennial *Orostachys spinosa* that abundantly occurs in moist years (Photo: Kretschmer 2003).

Community 9) *Potentilla bifurca - Koeleria cristata*-alpine steppe is closely related to community 8, and occurs in a plain relief position, where herders set up their ger camps in a distance of 100-200 m to grazing hot spots. Sites closest to grazing hot spots were not sampled because they have no vegetation cover at all. The community covers sandy plain sites adjacent to community 8, but with higher content of fine soil fraction, and with similar content of clay, silt, and sand in fine soil. Consequently, among both it represents the edaphic moister community. Species composition with the occurrence of grazing indicators and further species of group 6 and 7 as well as increased phosphorus values indicate an obvious grazing influences. Contrary to expectations, $C_{org}$ and N have lower values than community 8, and $C_{org}$/N does not differ much.

The community comprises 37 species of which 6 percent are annuals. Its average total cover of vegetation with 18 percent and average number of species per relevé with 12 is much lower than in community 8 with 56 percent and 23 species. Characteristic species group 5 of community 8 is missing completely, while species groups 6-8 are bound with obvious higher constancies to community 9 than to community 8. Group 6 and 7 contain ruderal forbs, disturbance-associated and grazing tolerant species that increase in response to grazing (FERNANDEZ-GIMENEZ and ALLEN-DIAZ 2001, GRUBOV 2001, GUNIN et al. 2002, HILBIG and OPP 2005, MIKLYAEVA et al. 2004, YUNATOV 1974).

Community 11) *Festuca lenensis*-cryophyte steppe and its grazing community 10) are distributed along well drained slopes, mountain-passes and saddles of the upper alpine belt, with mean proportions in gravel, clay, silt, and sand in fine soil. Soil organic carbon and total soil nitrogen have slightly higher variance than communities of the lower alpine belt and are considerably lower than in community 12 and 13.

Community 11 represents a typical vegetation of cushion-plant of the alpine belt with a high proportion of perennial grasses (Fig. 20). The community comprises 37 frequently appearing species with 3 percent of annuals. Among perennials, forbs dominate with 76 percent, followed by grasses and sedges with each 11 percent. Most dominant and abundant life forms in cover and constancy are sedges and grasses, such as *Carex rupestris*, *C. pediformes*, *Festuca lenensis*, *Elytrigia geniculata*, and cushion and rosette plants such as *Arenaria meyeri*, *A. capillaries*, *Androsace chamaejasme*, *Oxytropis oligantha*, *Eritrichium pauciflorum*, and the Altai endemic species *Stellaria pulvinata*. Among forbs, there are many cryophilous and high mountain species, such as *Plantago komarovii*, *Melandrium apetalum* and *Draba pygmea* (GRUBOV 2001, KRAMYSHEVA and KHRAMTSOV 1995). The community contains no own characteristic species group, and is floristically distinguished by the dominance and higher constancy of species groups 9 and 12, and missing species groups bound exclusively to other communities such as 3-8, and 13-18.

Community 10) was sampled close to grazing hot spots in a distance from 0 to 100 m. Soil variables sensitive to grazing as $C_{org}$, N, and $C_{org}$/N are slightly decreased compared to community 11, while phosphorus is clearly increased. Higher content in clay may cause higher $CEC_{eff.}$ because soil organic matter, indicated by lower $C_{org}$ values, does not serve as explanation.

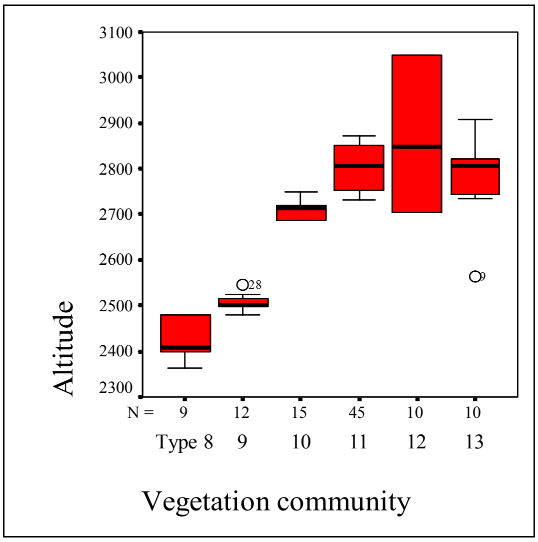
The community contains 30 species with an increased proportion of annuals with 7 percent. Average cover of total vegetation amounts 45, and is slightly lower compared to community 11 with 55 percent. Similarly, there is a decrease in the average number of species, which amounts 13 per relevé compared with 18 in community 11. The community is characterised by the presence of species groups 15 and 16 in combination with species groups 9, 11, and 12. Species of group 15 and 16 with species as *Axyris prostrata*, *Dontostemon integrifolius* and *Artemisia frigida* indicate a heavy grazing pressure in this community (GADZHIEV et al. 2002, GRUBOV 2001, HILBIG and OPP 2005, TSERENDASH and ERDENEBAATAR 1993).

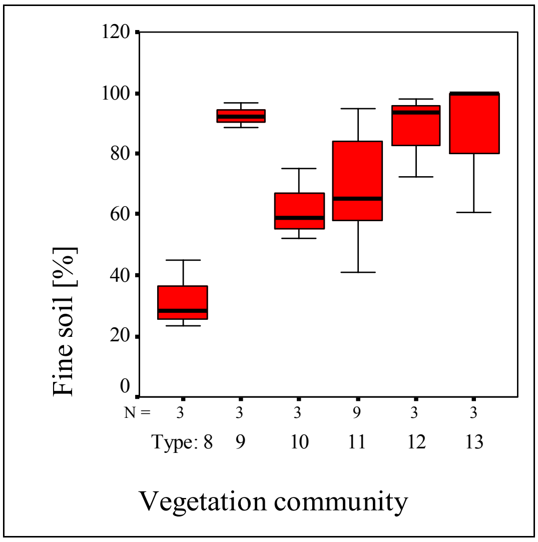
Fig. 20: Community 11: *Festuca lenensis*-cryophyte steppe. The green cushion plant on the right side of the foreground shows the endemic species of Altai Mountains *Stellaria pulvinata* (Photo: Kretschmer 2003).

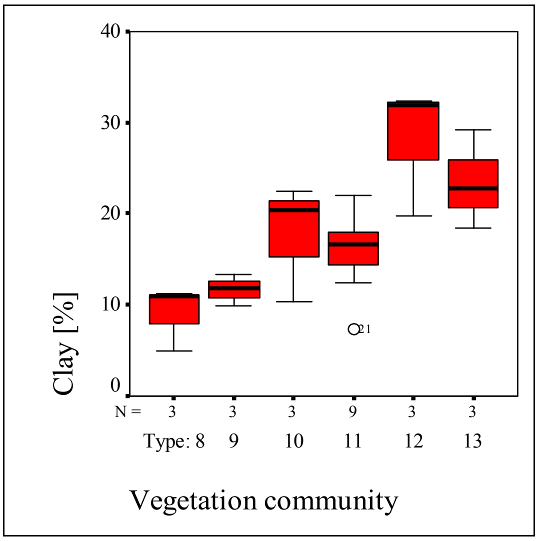
Community 12) *Poa altaica - Kobresia myosuroides*-sedge mat and its grazing community 13) are distributed at the bottom of valleys along the alpine belt (Fig. 21). These sites receive water inflow from adjacent mountain slopes during summer season, and are characterised by the highest proportion of fine soil with highest proportion of small corn size fractions as clay and silt in total alpine belt. The permanent water surplus of the sites causes a high productivity and a reduced mineralisation leading to highest $C_{org}$ and N in total alpine belt. Both variables, high content of clay and soil organic matter cause the highest $CEC_{eff.}$ of total investigation area. Community 12 contains 40 frequently appearing species with 3 percent of annuals. The community is distinguished from the other communities by the presence of species group 13 and 14 with e.g. *Poa altaica*, *Kobresia smirnovii*, *Festuca kryloviana*, *Ranunculus pseudohirculus, Lagotis integrifolia*, and *Poa sibirica*. The mountain steppe species *Poa attenuata* that shares alpine steppe and cryophyte steppe communities, disappears in this community.

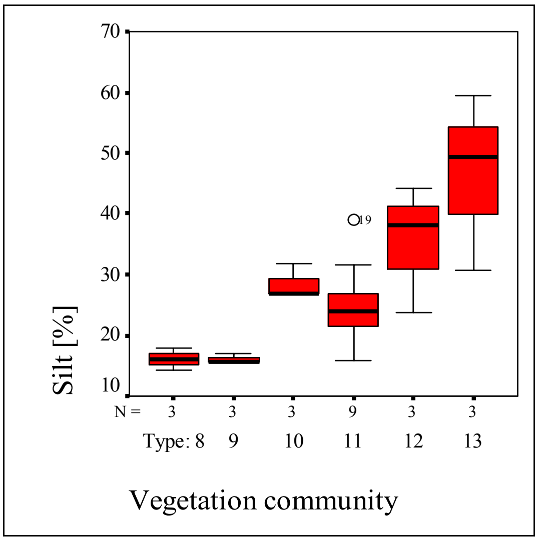
Grazing community 13) appears in a distance from 50-800 m from grazing hot spots. Sites closer to grazing hot spots were not sampled. Contrary to expectations, the sites of this community have lower values of $C_{org}$ and N by comparison with community 12. Lower content of $C_{org}$ together with lower proportions of clay in fine soil cause lower $CEC_{eff}$. The community comprises 36 frequently appearing species with increased proportions of 6 percent of annuals. It is distinguished from community 12 by the presence of species group 3, 17 and 18. The first only consist in *Koeleria cristata*, a characteristic species of mountain steppe that indicates a grazing impact in moist communities of the alpine belt (cf. Tab. 8 with Tab. 5). This phenomenon is described as “xerophytisation” (GORSHKOVA and GRINEVA 1977, GUNIN et al. 2002, OPP and HILBIG 2003, VOSTOKOVA et al. 1995). This grazing community represents with 75 percent a higher cover of total vegetation than its ecologically corresponding community 12 with 68 percent. Both communities present as average number of species per relevé 17.

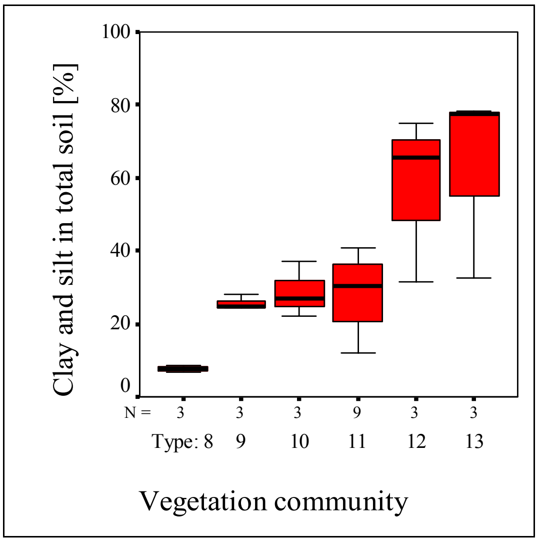
Fig. 21: Community 12: *Poa altaica - Kobresia myosuroides*-sedge mat at the bottom of river valley at 3000 m a.s.l. (Photo: Kretschmer 2003).

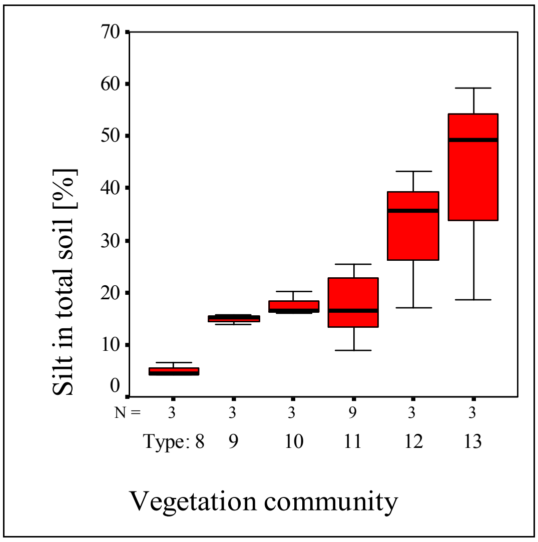

Altitude
3100
3000
2900
2800
2700
2600
2500
2400
2300
O28
O9
N = 9 12 15 45 10 10
Type 8 9 10 11 12 13
Vegetation community

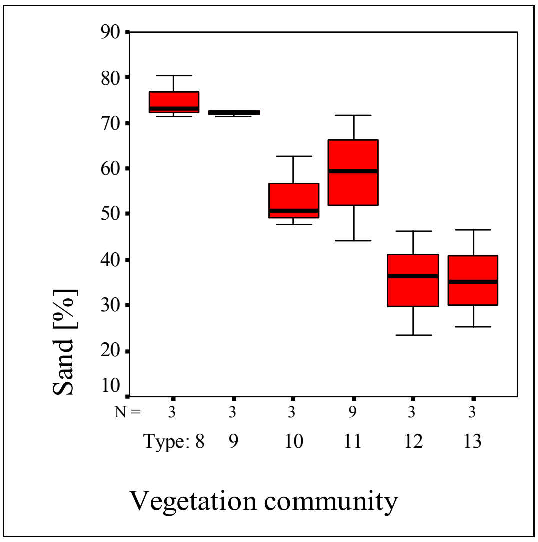

Fine soil [%]
120
100
80
60
40
20
0
N = 3 3 3 9 3 3
Type: 8 9 10 11 12 13
Vegetation community

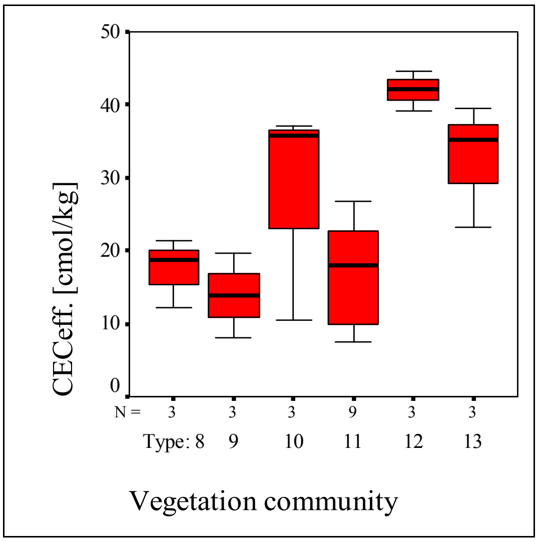

Clay [%]
40
30
20
10
0
O21
N = 3 3 3 9 3 3
Type: 8 9 10 11 12 13
Vegetation community

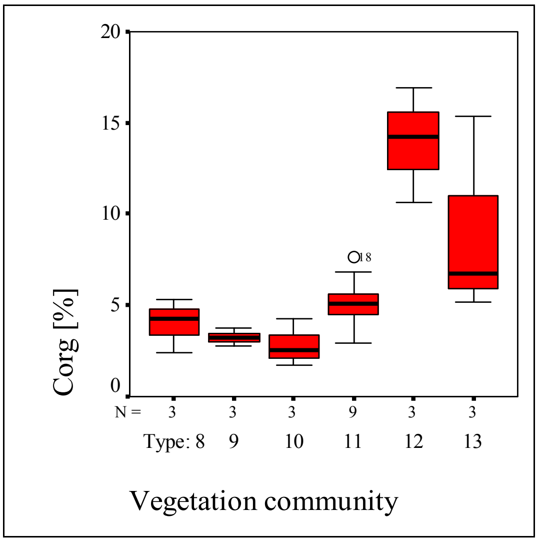

Silt [%]
70
60
50
40
30
20
10
O19
N = 3 3 3 9 3 3
Type: 8 9 10 11 12 13
Vegetation community

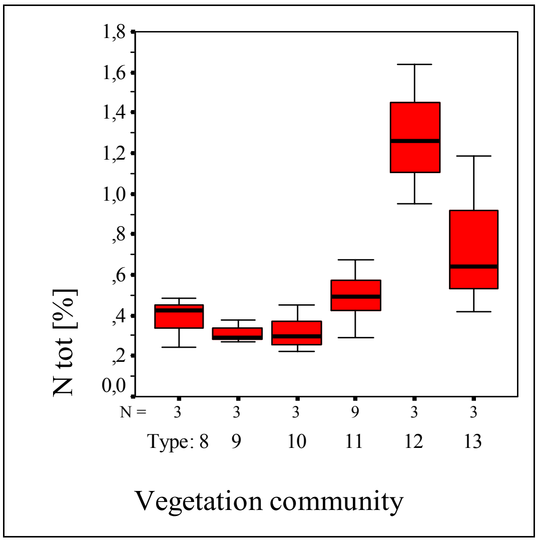

Clay and silt in total soil [%]
100
80
60
40
20
0
N = 3 3 3 9 3 3
Type: 8 9 10 11 12 13
Vegetation community

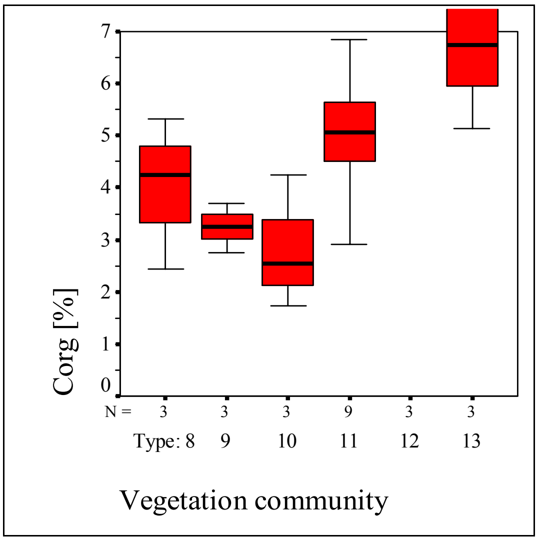

Silt in total soil [%]
70
60
50
40
30
20
10
0
N = 3 3 3 9 3 3
Type: 8 9 10 11 12 13
Vegetation community

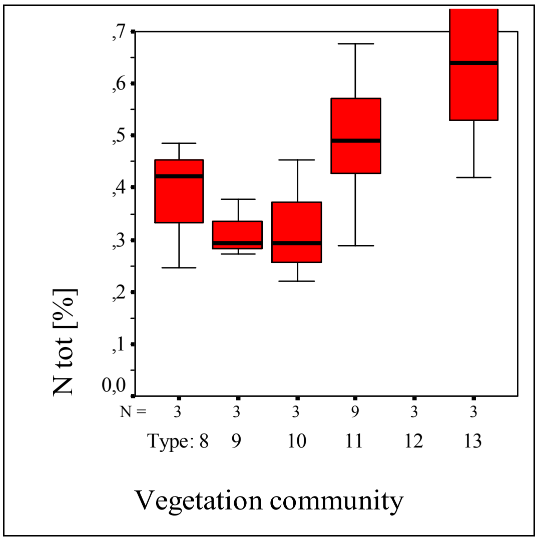

Sand [%]
90
80
70
60
50
40
30
20
10
N = 3 3 3 9 3 3
Type: 8 9 10 11 12 13
Vegetation community


CECeff. [cmol/kg]
50
40
30
20
10
0
N = 3 3 3 9 3 3
Type: 8 9 10 11 12 13
Vegetation community


Corg [%]
20
15
10
5
0
18
N = 3 3 3 9 3 3
Type: 8 9 10 11 12 13
Vegetation community


N tot [%]
1,8
1,6
1,4
1,2
1,0
,8
,6
,4
,2
0,0
N = 3 3 3 9 3 3
Type: 8 9 10 11 12 13
Vegetation community


Corg [%]
7
6
5
4
3
2
1
0
N = 3 3 3 9 3 3
Type: 8 9 10 11 12 13
Vegetation community


N tot [%]
,7
,6
,5
,4
,3
,2
,1
0,0
N = 3 3 3 9 3 3
Type: 8 9 10 11 12 13
Vegetation community

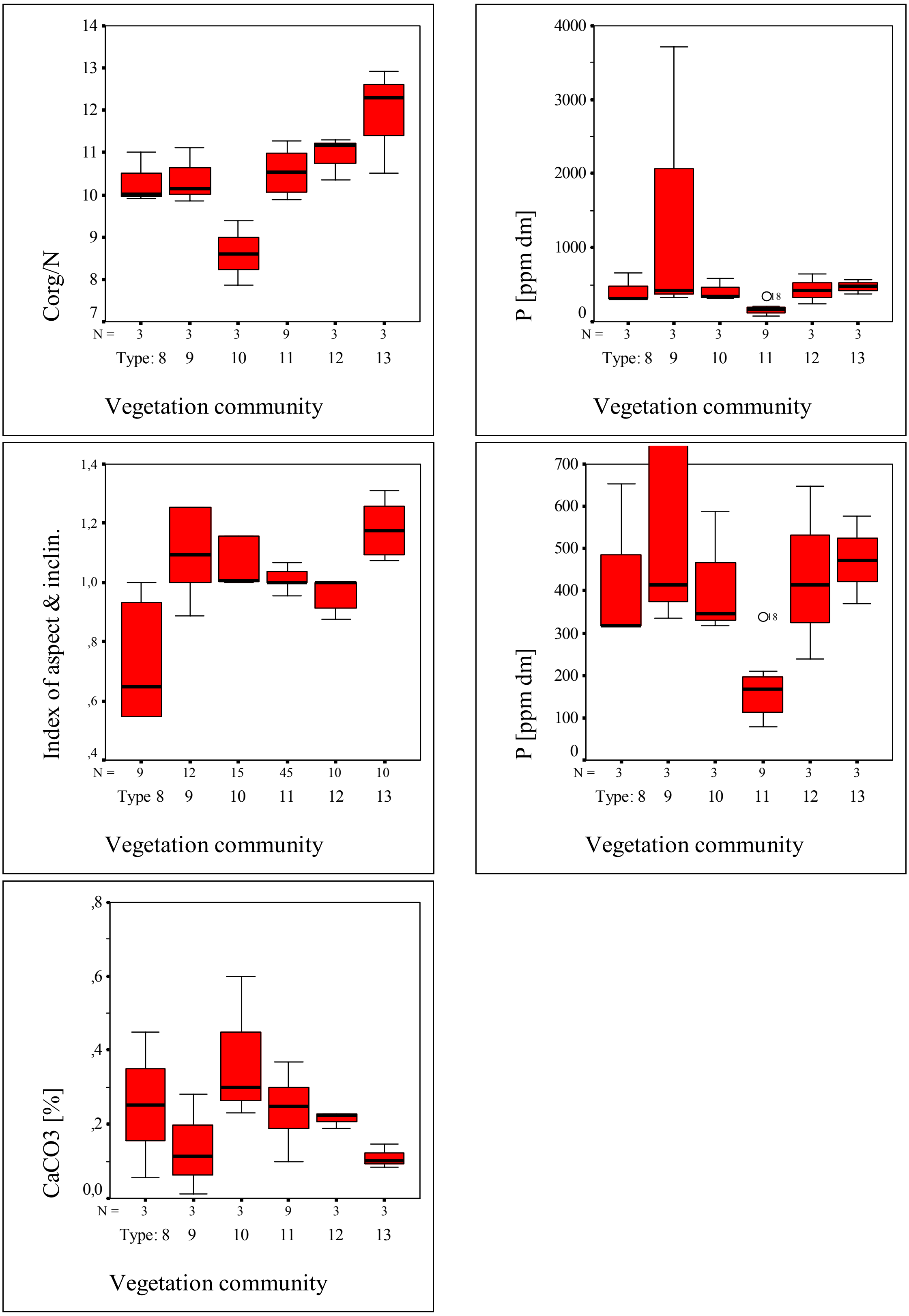


Fig. 22: Box and Whisker Plots for environmental and soil variables obviously differing across plant communities of the alpine belt (Type 8: *Aster alpinus* - *Koeleria cristata*-alpine steppe, Type 9: *Potentilla bifurca* - *Koeleria cristata*-alpine steppe, Type 10: Grazing community of *Festuca lenensis*-cryophyte steppe, Type 11: *Festuca lenensis*-cryophyte steppe, Type 12: *Poa altaica* - *Kobresia myosuroides*-sedge mat, Type 13: Grazing community of *Poa altaica* - *Kobresia myosuroides*-sedge mat).

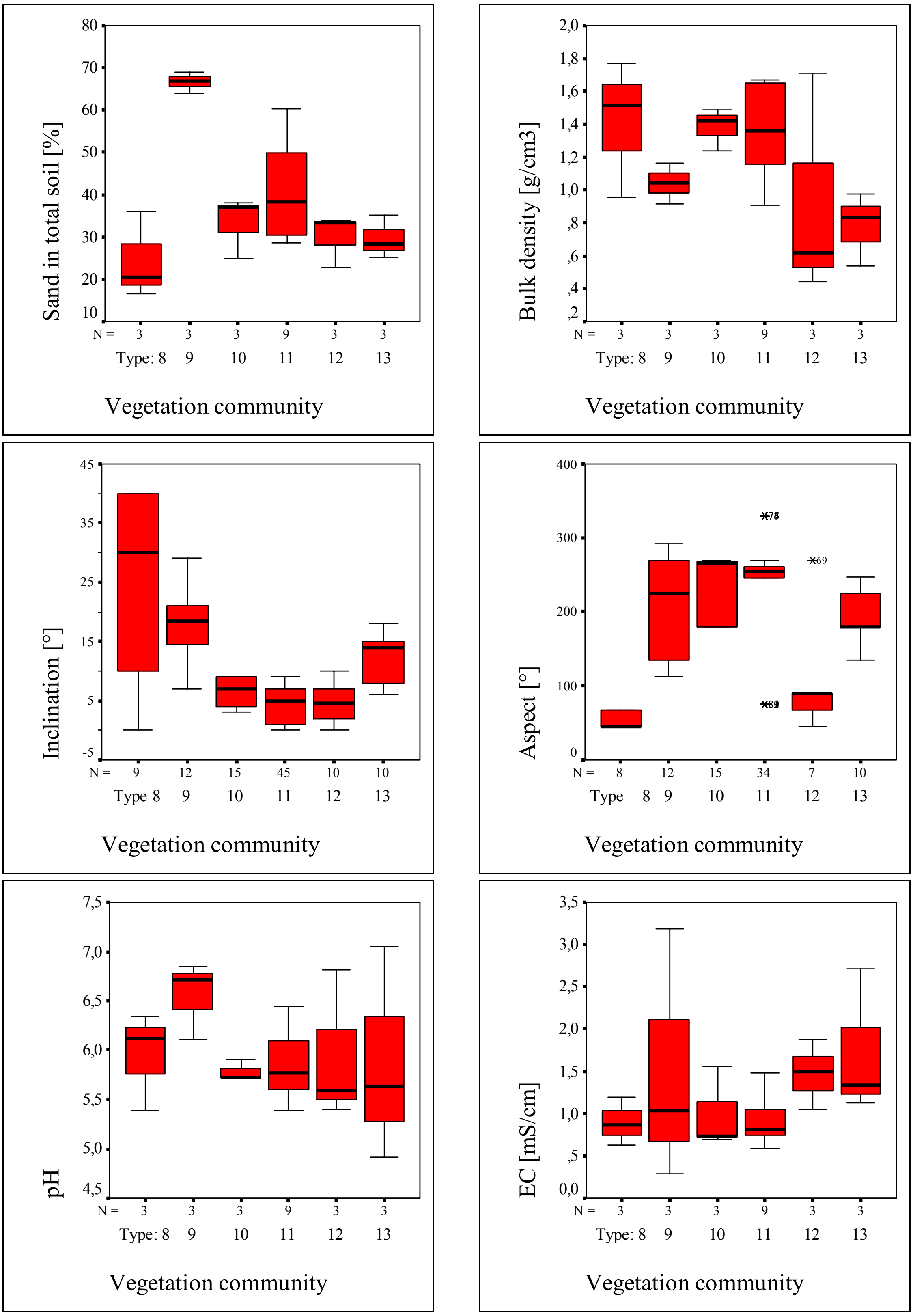


Fig. 23: Box and Whisker Plots for environmental and soil variables with high variations within plant communities of the alpine belt.

***Detrended Correspondence Analysis (DCA Ordination)***

The DCA calculated a total inertia of 3.489, indicating the highest floristic variance in the whole investigation area. The first extracted axis explains 36 percent, the second axis 37 percent, and the third axis 1 percent of variance in the vegetation data. Contrary to DCA results of all other study areas, the second axis has higher explanation values than the first axis (cf. Tab. 9).

According to the strongest correlations with altitude and soil texture variables, the first axis can be interpreted as a gradient of climatic and edaphic moisture. The second axis is strongly and moderately correlated with variables such as $C_{org}/N$, $C_{org}$, N, and $CaCO_3$. All variables except $CaCO_3$ reflect the increasing productivity and reduced mineralisation of soil organic matter of plant communities along the second axis. Increasing productivity is confirmed by increasing cover values of communities arranged along the second axis. Thus, the axis expresses a gradient of productivity which influences soil nutrient supply. According to its exclusively relevant correlation with variables of soil texture, the third axis represents a gradient of edaphic moisture (cf. Tab. 9, Fig. 24, Fig. 25).

The ordination graph of first against second axis (Fig. 24) allows the differentiation of all vegetation formations of alpine belt and furthermore the differentiation of plant communities of cryophyte steppe and sedge mats. The alpine steppe is separated along the first axis due to its lowest altitudinal position. The separation of cryophyte steppe against sedge mat is performed along the second axis mainly due to higher $C_{org}$, N, and $C_{org}/N$ of alpine sedge mat. The overlapping transition of relevés of the latter two communities reflects the high number of joint species opposed to the far distant situated relevés alpine steppe, which share much less joint species with these communities (cf. Tab. 8). A main ecological factor separating the alpine steppe from both other vegetation formation is the low altitude, and additionally the high content of sand. Along the second axis, a further partly separation of alpine steppe communities from sedge mat communities is possible due to higher $C_{org}$ and N contents of the latter communities. This axis divides the communities of cryophyte steppe still better from the communities of sedge mat due to higher contents of $C_{org}$ and N, also reflecting differences in the intensity of decomposition and productivity due to permanent water supply of sedge mat during vegetation period. The grazing community of cryophyte steppe can be separated from its corresponding community 11 due to its lower content in $C_{org}$ and N, and lower ratio of $C_{org}/N$. The grazing community of sedge mat is separated from its corresponding community 12 along the first and second axis according to slightly higher P and higher $C_{org}/N$. Few of their relevés cannot be separated completely, whether along first against second axis, or along second against third axis. Nevertheless, they are classified as grazing communities due to their presence of grazing indicator species of species group 3 and 17, and their environmental conditions (cf. Appendix III). The separation of community 9) *Potentilla bifurca* - *Koeleria cristata*-alpine steppe from community 8) *Aster alpinus* - *Koeleria cristata*-alpine steppe only succeeds along the second and third axis due to higher content of fine soil and related content of sand in total soil (Fig. 25). On the one hand, it emphasises the former community as edaphic moister due to its higher content of fine soil fraction. On the other hand, it indicates that plots next to grazing hot spots are not clearly altered in $C_{org}$ and N (cf. Fig. 22).

The high explanation values of the first two derived axes, their strong correlations with various recorded environmental variables, and the obvious aggregation of relevés indicate that vegetation relevant parameters were recorded. As main environmental variables determining vegetation composition, altitude and water regime could be derived. The latter leads to a different intensities of decomposition, productivity of vegetation and edaphic moisture, influencing soil chracteristics regarding nutrient supply. These factors, together with grazing influence, are consistent with vegetation change, and can be confirmed as decisive ecological factors.

| Total variance (inertia) | 3.489 | | |
|---|---|---|---|
| | **Axis 1** | **Axis 2** | **Axis 3** |
| Eigenvalue | 0.611 | 0.357 | 0.169 |
| Explained variance, cumulative [%] | 35.9 | 73.4 | 74.4 |
| **Variables** | r | r | r |
| Altitude | **-0.845** | 0.038 | 0.013 |
| Sand | ***0.581*** | -0.29 | 0.102 |
| Clay and silt (c&s) | ***-0.533*** | 0.28 | -0.094 |
| Silt | ***-0.498*** | 0.196 | -0.072 |
| Phosphorus (P) | ***0.497*** | 0.128 | 0.189 |
| Clay | ***-0.477*** | 0.351 | -0.107 |
| $C_{org}$/N | 0.031 | **0.736** | -0.036 |
| $C_{org}$ | -0.28 | ***0.568*** | -0.222 |
| N | -0.304 | ***0.513*** | -0.214 |
| $CaCO_3$ | -0.196 | ***-0.462*** | -0.118 |
| Sand in total soil (Sand tot) | 0.362 | -0.016 | ***0.574*** |
| Fine soil | -0.06 | 0.265 | ***0.446*** |
| Gravel | 0.06 | -0.265 | ***-0.446*** |
| Bulk density | -0.162 | -0.393 | 0.063 |
| Clay in total soil (clay tot) | -0.348 | 0.391 | 0.039 |
| Clay & silt in total soil (c&s tot) | -0.366 | 0.348 | 0.061 |
| Silt in total soil (silt tot) | -0.352 | 0.297 | 0.071 |
| $CEC_{eff.}$ | -0.279 | 0.297 | -0.192 |
| pH | 0.294 | -0.132 | 0.32 |
| Electrical conductivity (EC) | 0.096 | 0.267 | -0.003 |
| Index of aspect & inclination (EI) | -0.187 | 0.035 | 0.288 |

Tab. 9: Results of DCA of alpine vegetation with correlation coefficients of PEARSON of environmental variables with ordination axes (very strong correlations are in bold underlined, strong correlations in bold, and mean correlations are in bold and italic style).

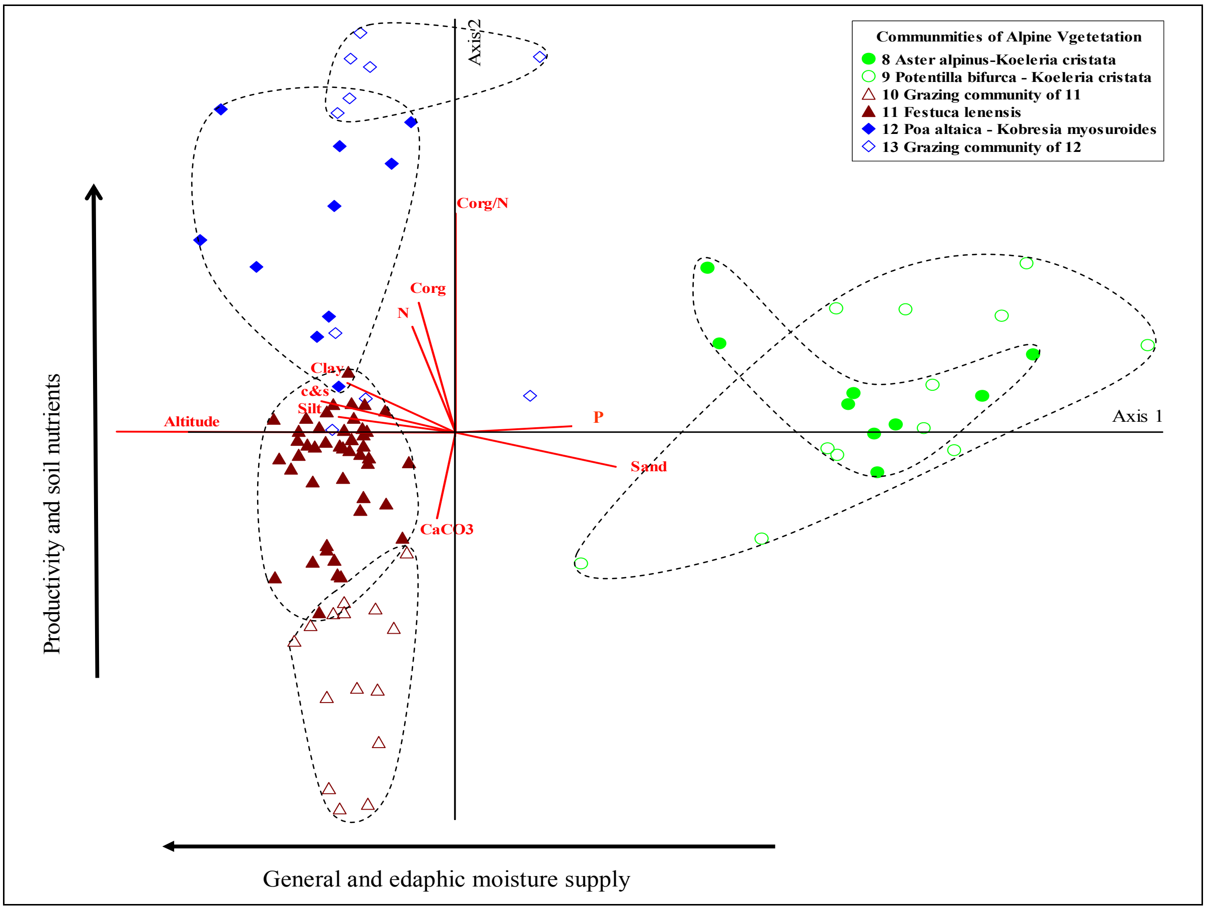


Fig. 24: DCA ordination of alpine vegetation relevés and its correlation with environmental variables, cut off $r^2$-value = 0.2, N=101 (c&s – content of clay and silt).

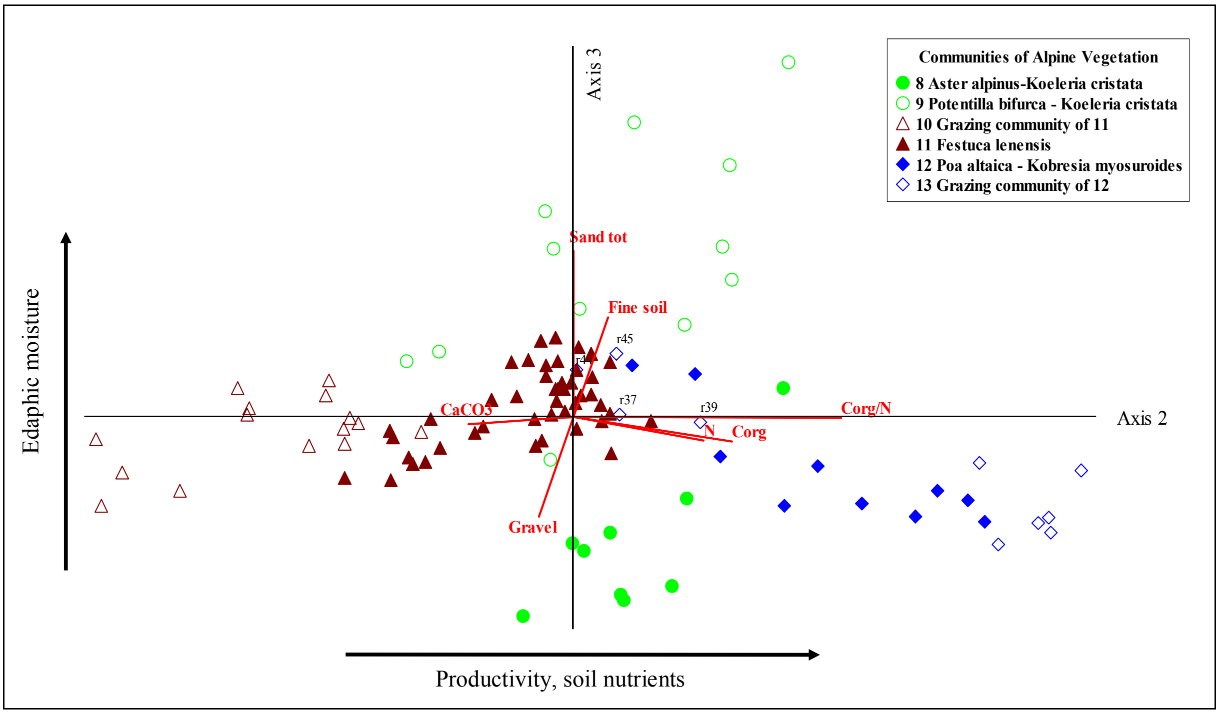


Fig. 25: DCA ordination of alpine vegetation relevés and its correlation with environmental variables, cut off $r^2$-value = 0.2, N=101 (Sand tot – content of sand in total soil).

### *Principle component analysis (PCA)*

The PCA contains 12 variables (Tab. 10). It comprises all variables depicted in Fig. 22 except EI-index, gravel, clay, and $C_{org}$/N. The latter were excluded due to their linear correlation to other variables included in the PCA analysis (multicollinearity). EI-index was excluded due to its artefact feature described above. Variables of Fig. 23 were excluded due to their higher variance within plant communities. Two axes were extracted, explaining in total 70 percent of total variance of environmental data set.

The first axis explains 53 percent, and is highly loaded with soil texture, variables representing soil nutrient supply as N and $C_{org}$, from both depending $CEC_{eff}$, and altitude. Thus, it represents a complex gradient of moisture and soil nutrient supply. The second axis explains 16 percent of the variance of environmental data set. It is highly loaded with P, salinity, and $CaCO_3$, and represents a complex gradient of soil nutrient supply and salinity. Both gradients include variables sensitive to grazing (Tab. 10).

Vegetation relevés ordered along PCA regression scores (Fig. 26) separate alpine steppe communities 8 & 9 from cryophyte steppe communities 10 & 11, and both from sedge mat communities 12 & 13 almost exclusively along the first axis. This arrangement confirms altitude, $C_{org}$, N, and soil texture as main vegetation-determining variables. These variables summarised are representing ecological factors of moisture, soil nutrient supply, and productivity influenced by both variables. The ecological factor that is not included in the PCA, is water regime, which causes water surplus, influencing decomposition, productivity, and soil texture composition.

Since PCA axes are loaded in a combination of variables influenced by grazing with other environmental variables, a clear separation of grazing mediated communities cannot be performed. This is illustrated well on the example of community 9) *Potentilla bifurca* - *Koeleria cristata*-alpine steppe, which is separated from community 8) along the first axis due its difference in soil texture: much higher content of fine soil, clay and silt, and silt in total soil, and altitude pose community 9) to the right of community 8). Along the second axis, the grazing influence leads to straightened upward orientation of some relevés due to their higher contents of P, and furthermore to higher salinity demonstrating the high variance of the community regarding these variables (cf. Fig. 26 and Fig. 22, 23).

| Variables | Axis 1 | Axis 2 |
|---|---|---|
| Clay & silt in total soil | **.955** | .012 |
| Sand | **-.924** | .211 |
| Silt in total soil | **.921** | .000 |
| Silt | **.856** | -.218 |
| $C_{org}$ | **.826** | .000 |
| N | **.819** | -.008 |
| $CEC_{eff.}$ | **.797** | -.021 |
| Altitude | **.633** | -.457 |
| Fine soil | **.590** | .304 |
| Phosphorus | .014 | **.868** |
| Electrical conductivity | .468 | **.742** |
| $CaCO_3$ | -.280 | **-.521** |

Tab. 10: Component matrix of PCA of alpine belt with factor loadings of 12 environmental variables.

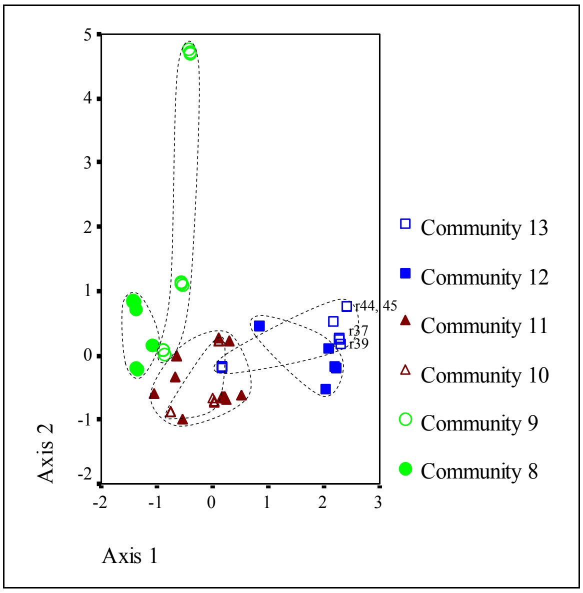


Fig. 26: Ordination graph of vegetation relevés of alpine vegetation along PCA factor scores (N=24).

## 2.6 Discussion

Much research has been carried out on vegetation classification of western Mongolia, especially of Khovd province. Yet, it mainly comprises floristic statistical analyses in descriptive consideration of habitat conditions (Hilbig and Schamsran 1977), or descriptive classifications (Beket 2003; Buyan-Orshikh 1988, 1992, Damdinsurengiyn 1998; Volkova 1994). Numerical classifications on the relationship between vegetation and environmental conditions have not been recorded for western Mongolia so far. The few accessible quantitative studies of Mirkin et al. (1979) and Kazantseva (1978) are confined to only single plant species and their response to environmental parameters for southern provinces of Central Mongolia. However, classified plant communities of the present study comply with corresponding associations in the phytosociological classification of Hilbig (1990, 1995, 2000a), or further classifications of Russian and Mongolian geobotanists (Beket 2003, Buyan-Orshikh 1992, Damdinsurengiyn 1998, Karamysheva and Khramtsov 1995, Volkova 1994).

### 2.6.1 Desert steppe

***Anabasis brevifolia - Allium mongolicum*-desert steppe** is distinguished from other desert steppe communities by its position on the upper part of the Great Lake Basin between 1350 –

1440 m a.s.l., its highest clay and silt proportions, and its highest $CEC_{eff.}$ values. The position at high altitude is confirmed by detailed studies on vegetation of Khovd province, which stress the occurrence of vegetation types corresponding with *Anabasis brevifolia - Allium mongolicum*-desert steppe at the upper parts of pediment areas (HILBIG and SCHAMSRAN 1977) between 1300 – 1600 m a.s.l. (Buyan-Orshikh 1992).

Among site variables without vegetation-differentiating properties (Fig. 10), N and $C_{org}$ of *Anabasis brevifolia - Allium mongolicum*-desert steppe reflect the highest N of total desert steppe, and higher $C_{org}$ compared to *Artemisia xerophytica*-semi-shrub desert steppe, even though absolute values and differences are very low. Under the same climatic conditions, soils of finer soil texture have higher humus contents than sandy soils (PARTON et al. 1987 cited in SCHEFFER and SCHACHTSCHABEL 2002, SCHEFFER and SCHACHTSCHABEL 1992). Thus, the position in higher altitude, high clay and silt content might be the reason of highest N of total desert steppe, and higher $C_{org}$. Position in higher altitude raises higher precipitation supply and changed conditions of vegetation period (thermal supply, duration: henceforth summarised as bioclimate). Clay has the highest water storage capacity, what can cause bad soil aeration and lead more frequently to anaerobic soil conditions. Furthermore, due to adsorptive capacity of clay minerals for organic matter, soils with higher clay contents contain more aggregates, which enclose organic material and prevent its decomposition. Soil organic matter thus has a positive feedback on water storage capacity of soil due to its high water adsorptive capacity (SCHEFFER and SCHACHTSCHABEL 1992). A supporting indication of this relationship offers the significant correlation of N with altitude (Spearman rank correlation coefficient $r_S = 0.639$ at $p = 0.01$), and the significant correlation of N with clay ($r_S = 0.565$ at $p = 0.01$) of all soil samples of desert steppe. Thus, all three variables are combined at one (first) axis of PCA (cf. Tab. 4). In Mongolia, this effect was shown already by CHULUUN et al. (2002) along an east-west steppe transect, where they found highest C and N content at sites with highest clay content. A comparable phenomenon is reported by CEPEDO-PIZARO and WHITFORD (1990) in the Chihuahuan Desert where they found lowest rates of decomposition in a dry lake basin on fine textured clay soils in a comparative study of soils with different aeration. Even if the differences in C and N-values are very low, they are caused by specific abiotic and edaphic conditions, and cannot be considered as a consequence of different vegetation. If they themselves may cause different plant communities has to be proved by means of germination and establishment experiments.

Grazing influence increases vegetation cover, and enhances the proportion of annual species, especially of Chenopodiaceae in that community, while the constancy of typical perennial desert steppe species shows no difference (cf. Tab. 2). Edaphic conditions reflect only a slight increase in C, N- and $C_{org}/N$. Both changes are not sufficient to derive an additional grazing mediated community for more reasons following below. Firstly, field studies were conducted in an extraordinarily moist year with 182 mm total precipitation, while mean annual precipitation amounts to 62 mm (CLIMATE STATION DOERGOEN 1985-2004, situated between 5 – 40 km distant from various sampling areas, cf. Fig. 1). While the appearance of perennial species is less affected by precipitation, the appearance of annual species depends on the amount of summer precipitation (LAVRENKO and KARAMYSHEVA 1993). Thus, the sustainably recurrent appearance of these annuals in years with normal precipitation is not proved. Secondly, a vegetation unit based on the variety of annuals corresponds to a synusia. Consequently, enhanced proportion of annual species represents a synusia and no plant community.

To understand the nature of grazing influence on vegetation and site conditions, an integrative view on new appearing species and changed site conditions shall be applied. The appearance of two annual species groups no. 5 and 8 in community 1) *Anabasis brevifolia - Allium mongolicum*-desert steppe (cf. Tab. 2) can obviously be discussed as a response to grazing. According to GRUBOV (2001), species of species group 5 (cf. Tab. 2) rank among ruderal plants. Own observations (2002-2005) and literature give evidences that they occur especially as disturbance indicators in different altitudinal belts at places where top soil layer is redistributed from time to time, for instance along roads, in dry valleys irregularly flooded by water and scree streams, sandy and rocky slopes, and at sandy places (cf. BORISOVA 1981, GRUBOV 2001). At these sites, annual plants benefit from disturbances, which reduce competition by perennial hemicryptophytes (GRIME 2002, HILBIG 1995 cited in WESCHE et al. submitted). Their constant occurrence in community no. 3) characterised by scree streem erosions and sandy sites of community no. 2 seems to confirm this conclusion. Except *Chenopodium aristatum*, seeds of all species of this species group have hooks, spines, or other anatomic structures representing their dispersal via zoochory by larger herbivores. Adaptation to herbivory also requires an adaptation to nutrient enriched sites where wildlife or domestic animals settle down to rest and ruminate. Both, adaptation to herbivory as an adaptation to nutrient enriched sites, and disturbance constitute their status as ruderal plants (GRIME 2002, GRUBOV 2001, HILBIG 1995). Species of species group 8 belong to genus *Chenopdium* and represent species being favoured by elevated N-concentration in soil. They respond with high competitive power at nutrient-rich sites (BASSETT and CROMPTON 1978, FOULDS 1993, REIMANN 2003).

The appearance of both species groups demonstrates that grazing livestock has both direct and indirect influence on vegetation. Direct effects as defoliation and trampling favour species of species group 5, and indirect effects as the redistribution of $C_{org}$ and N by urinating and defecating of livestock favour species of species group 8. Since nutrient enrichment is quite low, indirect effects play a subordinate role. This conclusion is confirmed by the results at the spatial scale of population in Chapter 3.3 which reveals changes of biomass structure of an *Artemisia xerophytica* population along a grazing gradient as verifiably, while changes in soil cannot be identified (cf. 3.3.1 & 3.3.2).

***Artemisia xerophytica*-semi-shrub desert steppe** is distinguished from other desert steppe communities by its position in the lower altitude of the Great Lake Basin between 1150 – 1260 m a.s.l., its highest sand and low gravel proportions, and its widest $CEC_{eff.}$-amplitude (cf. Tab. 2 and Fig. 9). C and N have the lowest values of the whole desert steppe. Its position at flat plains and its low proportion of gravel cause low habitat heterogeneity. Low habitat heterogeneity with dry site conditions due to sandy soils may induce the low species richness of this community, which is pointed by HILBIG (1995) for an Artemisio xerophyticae-Caraganetum leucophloeae HILBIG (1987) 1990. It concerns a closely related, but not identical community at sandy-stony areas within the Great Lake Basin. A closely related vegetation unit is also documented by BUYAN-ORSHIKH (1992) and RACHKOVSKAYA (1993) as *Artemisia xerophytica* community, and described to be tied to sandy plains on granite bedrock. In contrast to the classified *Artemisia xerophytica*-semi-shrub desert steppe, HILBIG's (1987) 1990 Artemisio xerophyticae-Caraganetum leucophloeae appears on the foothills at sites with abrupt relief incline or at shallow slopes of adjacent hills with more stony soil texture (own observations 2003, 2005). *Caragana leucophloea*, a main species, is absent in *Artemisia xerophytica*-semi-shrub desert as well as shrubs such as *Krascheninnikovia ceratoides*, *Atraphaxis frutescens*, *Atraphaxis pungens*, and *Calligonum mongolicum*. The sandy sites of this community are furthermore confirmed by KARAMYSHEVA and KHRAMTSOV (1995) in their summarising publication on Mongolian steppes, in which they introduce *Artemisia xerophytica* as a psammophilous plant and describe an *Artemisia xerophytica*-desert steppe to be distributed on soils of light soil texture. Due to sandy soil texture, soils are well aerated in contrast to clayey soil of *Anabasis brevifolia - Allium mongolicum*-desert steppe. It may cause an effective mineralisation process of organic matter in summer season, as reported by HAASE (1983) for Mongolian desert steppes and deserts, due to their low biomass production and longer decomposition period compared with colder and moister vegetation types or higher altitudinal belts. Also, the narrow $C_{org}/N$ ratios refer to highly active soils since soil microbes contain a high amount of N (SCHEFFER and SCHACHTSCHABEL 2002). The annual amount of death organic litter and consequently C and N supply of soils (RODIN 1961) is presumably less than in shrub communities e.g. *Krascheninnikovia ceratoides*-shrub desert steppe. Both conditions may explain lowest C and N values of the whole desert steppe.

***Krascheninnikovia ceratoides*-shrub desert steppe** is distinguished from other desert steppe communities by its location in dry valleys formed by scree stream, and thus causing soils of highest gravel content, lowest clay content of the whole desert steppe and low $CEC_{eff.}$. The dry valleys, in Russian literature so called ‘sayr’ similar to the term ‘wadi’ in Arabian deserts, have an infrequent channel flow, carting off fine soil particles and triggering scree stream erosions, and are situated in foothills and forelands of mountains (MURZAEV 1966). Thus, they are characterised by better ground water supply (HILBIG and SCHAMSRAN 1977). Within the study area, they are found in the pediment area of the upper part of the Great Lake Basin close to the mountains.

HILBIG and SCHAMSRAN (1977) describe a closely related community within the shrub semi-desert[6] to be tied at inclined valley slopes and rocky sites within adjacent mountains. The association is designated as Eurotio ceratoidis[7]-Zygophylletum xanthoxyli HILBIG (1987) 1990, and described for the territory between Eastern Gobi and the Great Lake Basin on pebbly-stony soils. LAVRENKO (1957) introduced *Krascheninnikovia ceratoides*, one of the dominant species of this community, as typical for dry valley sites with gravel-rich soil texture, which responds to burying by scree and sand with improved formation of adventitious roots. Species of the genus *Caragana* like *Caragana leucophloea*, the second dominant species of this community, are also known as petrophytes at stony and gravely soils with low capacity of capillary water, but high capacity of water available for plants in deeper soil horizons (KOWALKOWSKI et al. 1983, LAVRENKO and KARAMYSHEVA 1993). Due to its deep unbranched taproot reaching up to 300 cm, *Caragana leucophloea* may utilise deep lying groundwater (BAYTULIN 1993). Both shrub species benefit by burying because it reduces interspecific competition and thus emphasises disturbance as an independent vegetation-driving ecological factor of this community. The high proportion of gravel and stones in soil accompanied by the deeper position of dry valleys (see Fig. 8) causes improved water intake from adjacent elevated sites on the one hand, and on the other hand, an inclined position and pebbly soil texture cause water runoff. This is often observed in desert ecosystems with different microhabitats as for instance in Negev desert in Israel (WHITFORD 2002, YAIR and DANIN 1980 cited in BLUME and BERKOWICZ 1995, YAIR et al. 1980). Thus, improved water availability for plants in deep soil horizons facilitates the establishment of shrubs, and leads to higher vegetation cover. Improved water availability together with higher diversity of microhabitats due to stony and gravely sites induce highest species richness within the whole desert steppe (cf. Tab. 2). Both phenomena are revealed by NOY-MEIR (1985) in his literature review on quantitative data of arid ecosystems. HOLZAPFEL et al. (1995), who compared two desert types in Israel with identical climate, but different edaphic conditions, also record the latter phenomenon. He found higher species richness in the desert type with more heterogeneous sites. High $C_{org}$ and N of soils of this community may be caused by several reasons. Firstly, by the higher supply of organic litter due to the higher vegetation cover of the community, secondly, by the dominant woody shrubs with much root biomass within the community since roots are the main source of carbon inputs into desert soils (WHITFORD 2002), and thirdly, by the effect of shrubs as ‘islands of fertility’, providing a nutrient source for soil microbiota with litter (NOY-MEIR 1985, WHITFORD 2002). Lastly, this may be caused by the ability of N-fixation of roots of *Caragana leucophloea* as species of Fabaceae family

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[6] To the terms desert steppe and semi-desert, see 1.2.3.

[7] From *Eurotia ceratoides* - in GRUBOV (2001), former a synonym for *Krascheninnikovia ceratoides* accord. to GUBANOV (1996).

(KUMINOVA and NAMZALOV 1982 in HILBIG 2000b, SANCHIR 1974). In contrast to soils of *Anabasis brevifolia* - *Allium mongolicum*-desert steppe, high $C_{org}$ and N are a consequence of vegetation, and an indication that already in arid desert steppes vegetation affects and modifies its site condition. In the present case, edaphic conditions and topographic position are necessary perequisites for the establishment of the shrub community. Moreover, the low differences of $C_{org}$ and N among desert steppe communities suggest that it is a less necessary condition for shrub establishment than an effect of vegetation. Likewise, as suggested for *Anabasis brevifolia* - *Allium mongolicum*-desert, germination and establishment experiments could provide clear evidence on this question.

To sum up, as main vegetation-differentiating factors derived from tabular treatment and supported by descriptive statistics can be stated: altitude as a variable of climatic moisture supply and bioclimate, soil texture as a variable of edaphic moisture, water retention and water availability, and disturbance as a variable of (reduced) competition.

Among site variables without vegetation-differentiating properties (Fig. 10), the tendency of higher indices of aspect and inclination of community 1 and 3 has to be considered as an artefact. Both communities were examined only at a southern slope of Argalant Mountains, which resulted in higher indices than the plots of community 2, which were examined at a northern slope or in a plain position at Agvash Uul Peninsula (see Fig. 1). However, all communities were observed at different slope aspects of the study area without any preferences ()own observations 2002, 2005), but sampled at only mentioned positions.

Since water is the main limiting factor of desert vegetation (WHITFORD 2002), and hence all environmental variables influencing site moisture, such as altitude and soil texture have vegetation-differentiating properties, further topographic related moisture variations could be assumed to have vegetation-driving influences. A combination of topographic position (valley bottom, lower or middle slope), slope configuration (concave, convex), slope inclination and aspect are integrated in the Topographic Relative Moisture Index (TRMI) of PARKER (1982) into a one-dimensional scale of topographic related site moisture conditions. Since the variety of plot aspects and inclinations within the study area is so low, TRMI according to PARKER (1982) was not applied (measured values of the index of aspect and inclination vary from 0.9 to 1.1 of potentially possible values from 0 to 2.0; see 2.1: *Sampling design* and Fig. 10). However, because all classified communities were found at different slope aspects and the influence of topographic related site moisture is probably more interfered by soil texture, it has to be assumed that the influence of topographic related site moisture is not detectable on the basis of a community classification.

The independence of vegetation and $CaCO_3$ in desert steppes is confirmed by EVSTIFEEV and RACHKOVSKAYA (1976), who did not find correlations between them. The lowest proportions of gravel in community 2 might explain the tendency of low bulk densities compared to community 1 and 3. Phosphorus shows similar values across all communities. Only the range of values differs, which may be explained with the number of soil samples (Fig. 10). Elevated values of shrub community 3 (*Krascheninnikovia ceratoides*-shrub desert steppe) complies with higher soil fertility under or around shrubs as reported by NOY-MEIR (1985) and WHITFORD (2002), even if differences among communities are quite low. As opposed to statements in literature about the limitation of phosphorus in arid soils (NOY-MEIR 1985), the present content of phosphorus in desert steppe soils is similar to mountain steppe soils, and much higher than in high productive alpine vegetation, but shows no increasing values under grazing influence (cf. 3). The following explanation could be possible: redistribution and extraction of soil nutrients at Mongolian rangelands happens twofold. On the one hand, redistribution happens by grazing and defecating of livestock. On the other hand, faeces of big livestock as cattle, yaks, horses, and camels constitute the main source of fuel in treeless areas of Mongolia as represented by the investigation area. Due to the low productivity of vegetation of the desert steppe, mainly goats and sheep are herded here, the proportion of other animals is quite low and fuel is provided by shrubs or faecal pellets, collected from adjacent cattle pastures near Khar Us Lake (see Fig. 1). These conditions facilitate a higher return flow of phosphorus via faeces of goats and sheep, and a lower deprivation of phosphorus in desert steppe. Since 80 percent of deprived phosphorus is redelivered via animal excrements on rangeland used as full-time pasture (BERGMANN 1969 cited in GLATZLE 1990), it may explain the higher phosphorus of sites of desert steppe compared to the alpine belt prevailing grazed by cattle, yaks, horses and sheep. Yet, this hypothesis needs further investigations.

After the discussion of vegetation-differentiating variables as results of tabular treatment, altitude and soil texture can be confirmed by the multivariate analyses of DCA and PCA as main decisive vegetation-differentiating variables. Disturbance as ecological factor was not included in the analyses due to a lack of measurable parameters. DCA as a method of vegetation ordination confirms the classification of plant communities performed by traditional tabular treatment through the formation of clear separable community groups, and furthermore it emphasises altitude and various variables of soil texture as environmental parameters best differentiating plant communities of desert steppe (Fig. 11). PCA as a method which identifies strong correlated and best differing environmental variables emphasises soil texture as best vegetation-differentiating variable, and confirms the vegetation classification also through formation of clear separable groups of soil sample plots corresponding with groups of derived communities (Fig. 12).

These findings are supported by BUYAN-ORSHIKH (1992), who confirms in his vegetation classification of the Great Lake Basin that vegetation of desert steppes is primarily controlled by soil texture. Apart from general climatic conditions, EVSTIFEEV and RACHKOVSKAYA (1976) and RACHKOVSKAYA and VOLKOVA (1977) state soil texture and intensity of salinity as main environmental parameters which determine vegetation composition of southern parts of arid Mongolia because these parameters strongly influence vegetation-effective water of soils. According to FERNANDEZ-GIMENEZ and ALLEN-DIAZ (2001), species composition of the arid zone of desert steppe in Central Mongolia is driven by edaphic factors as the percent of coarse fragments and bulk density. As floristic factors driving the classification, they identified the presence and absence of salt-shrub species and species with affinities for sandy sites.

The important role of salinity as a vegetation-differentiating parameter could not be detected due to the low variance of measured salinity values. All plots of desert steppe show an EC between 0.5 and 5.5 mS/cm except two outliers of 9 and 16 mS/cm (community 1 and 2: cf. Fig. 10). Salinity tolerance of *Artemisia frigida*, a typical species of vegetation of northern desert steppe and mountain steppe (cf. Tab. 5), is stated with 6 ms/cm (SWIFT 2003). To assess the influence of salinity on vegetation and on classification results, plots with higher variance in salinity are necessary. From own field observation is known that higher salinity suppresses typical desert steppe species like *Stipa glareosa* and *Allium mongolicum,* and only salt tolerant or halophyte species as for instance *Anabasis brevifolia*, *Chenopodium frutescens*, *Reaumuria songarica* or *Micropeplis arachnoidea* survive. These salt-communities were excluded from investigation due to their rare occurrence and their character as azonal vegetation. Nonetheless, salinity as a parameter of vegetation effective edaphic moisture and physiological stress (BRECKLE 1982, STRASBURGER 2002) has to be considered as a vegetation-driving factor of desert steppes, and is included in the summarising factor diagram of vegetation-driving factors of desert steppe (Fig. 27).

However, the role of soil nutrients and soil nutrient supply as N, P, and $C_{org}$ as an environmental factor representing soil fertility shall be further discussed here regarding arid soils. Until recently, it was generally assumed that nutrient limitations are not important in deserts since primary productivity is strongly limited by and correlated with rainfall (NOY-MEIR 1985, WHITFORD 2002). The discovery of shrubs and trees as `islands of fertility′ causing nutrient enrichment with enhanced growth of herbaceous vegetation (CHARLEY and WEST 1975, 1977; GRACIA-MOYA and MCKELL 1970) revealed that plant productivity of arid zones may sometimes be limited by the availability of nitrogen and phosphorus (NOY-MEIR 1985, WHITFORD 2002). Since then, there have been many confirmations of limitations of soil nutrients in arid ecosystems, among them nitrogen and phosphorus are most frequently cited as limiting productivity. Further elements may also be limiting primary production in arid and semi-arid ecosystems, but there are no empirical studies that examine this suggestion (WHITFORD 2002). Nitrogen fertilisation and irrigation experiments demonstrated that nitrogen availability limits productivity if moisture supply is sufficient for a complete plant growth cycle (JAMES and JURINAK 1978, ROMNEY et al. 1978 cited in WHITFORD 2002). MENGEL (1991) explains the role of water in N-cycle with limited N utilisation of plants by water due to reduced diffusion ability. PENNING DE VRIES and DJITEYE (1982 cited in

WHITFORD 2002) reported for southern Sahara-Sahel that productivity was limited by water at average annual precipitation of about 150 mm, and limited by nutrients at higher amounts of average rainfall. Recent studies on Mongolia reported on changed plant community composition and higher standing crop at areas burrowed by small lagomorphs (*Ochotona pallasi*) due to higher soil nutrients. Thus, they confirmed the influences of nutrient limitation on vegetation in dry mountain steppes with slightly higher annual precipitation in southern part of central Mongolia (WESCHE et al. submitted) than in present study. In contrast to this, the comparison of results of experiments on fertilisation and irrigation with only irrigation experiments in a dry desert steppe ecosystem of Mongolia (mean annual precipitation between 80 mm to 170 mm) resulted in inconspicuous differences in vegetation cover and standing crop phytomass (SLEMNEV et al. 2004). However, given precipitation data of that study area comprise only years between 2000 and 2003 and include thus the extraordinary moist year of 2003. Last study within desert steppe vegetation is best comparable with desert steppe ecosystem of present study.

Against the background of the coincidence of a warm with a moist season in Mongolia, the decomposition rate is enhanced since the relative rates of N mineralisation in deserts are determined by rainfall, and furthermore, the growth of microbes again is limited by available N (NOY-MEIR 1985, WHITFORD 2002). From the above, following questions come up: is the primary productivity of desert steppe too low and does decomposition, consisting of fragmentation and mineralisation of dead organic litter (WHIFORD 2002) happen almost completely and quickly (HAASE 1983, RODIN and BAZILEVICH 1965, SCHULTZ 2002) in such an extent that soils with different N and C cannot arise?

Do (abiotic or biotic) conditions exist in Mongolia’s arid ecosystems which facilitate different supply of soil nutrients to such an extent that it supports differences in vegetation composition? How does this process is controlled by the amount of precipitation?

The present study shows that variables representing soil nutrients or supply of soil nutrients in the desert steppe differ slightly due to abiotic edaphic conditions (community 1) and biotic by vegetation-induced conditions (community 3). To take effect as vegetation-driving soil properties, differences are too small for the establishment of different vegetation types on the level of communities. This outcome is supported by the perception that vegetation in arid ecosystems plays only a subordinated role for soil formation processes (EVSTIFEEV et al. 1986, EVSTIFEEV and RACHKOVSKAYA 1976). The only slightly documented fertilisation effects of desert steppes (WESCHE et al. submitted) or rather, because faeces desiccate and remain without effects on soil confirmes this outcome too. Furthermore, burrows of pikas (*Ochotona spec.*) within the study area did not show differences in vegetation to adjacent areas. However, they were not explicitly included in the investigation.

Even if this study is fairly limited with three plant communities, the discussion of results related to literature leads to the conclusion that soil nutrients play a minor role as vegetation-driving factors in Mongolia's arid desert steppe. However, long-term fertilisation experiments including years with different amounts of precipitation and further soil analyses across a big variety of further plant communities may help to enlighten the role of soil nutrients in vegetation patterns of arid desert steppe belt of Mongolia and their role as vegetation-driving site variables.

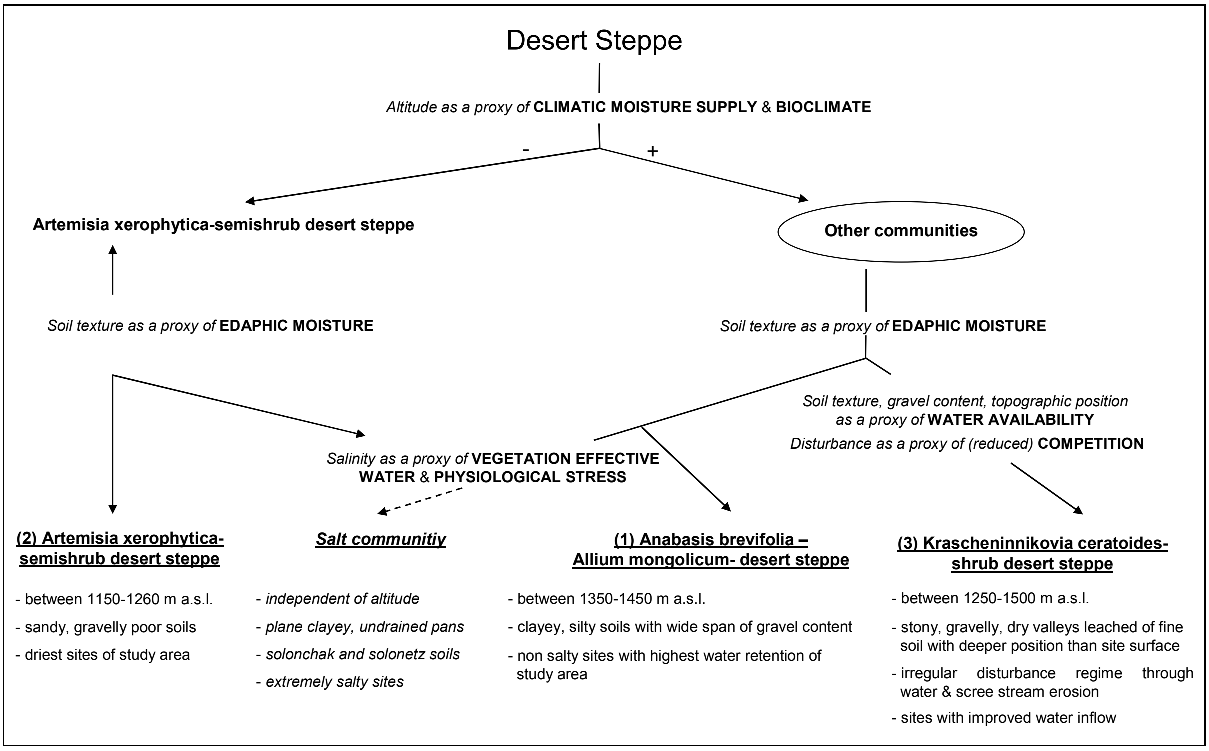

Fig. 27: Factor diagram of desert steppe (italic: measurable environmental parameters, bold capital: derived vegetation-determining ecological factors, bold underlined: classified communities, bold, italic and underlined: potential but not classified communities, dotted arrows: potential vegetation-determining environmental parameters not examined in this study, standard: site description of classified plant communities, italic style of lowermost lines: site description of plant communities not examined in this study).

### *Response of desert steppe to grazing*

In contrast to all other examined vegetation formations, the desert steppe shows no grazing mediated plant community. Even within communities, there are no obviously verifiable changes in vegetation and site conditions except a slight increase in N and $C_{org}$ in community 1 with higher proportion of annual species and increased vegetation cover. It is consistent with the results of BATKHISHIG (2000), who examined the grazing influence of soil cover in different altitudinal belts of Mongolia and did not find different content of soil organic matter in overgrazed Burosem desert soils. He observed a shortened top soil layer due to higher effects of wind erosion. The species group no. 5 with annual species belongs to the species inventory of both of the other desert steppe communities (cf. Tab. 2). Disturbance belongs to the ecological properties of one of these communities, whereas the other community is characterised by sandy soil conditions. Possibly, these soil conditions accompanied by open vegetation with mean cover of 13 percent also facilitate disturbance processes as e.g. wind deflation with relocation of top soil layer in consequence of strong winds, appearing as hurricanes in spring (BARTHEL 1990), or as gust of wind with summer thunderstorms (THIEL 1958). Thus, it may be assumed that grazing directly acts as a disturbance on vegetation more visible in communities, which do not contain disturbance as a natural process.

As pointed out above, it can be shown that all environmental variables affecting moisture supply and conditions of competitions have a strong influence on vegetation composition. In particular, these are **altitude** as a parameter of **climatic moisture** and **bioclimate**, **soil texture** as a water retention reducing parameter of **edaphic moisture**, **salinity** as a parameter of reduced **vegetation effective water,** and furthermore as a variable of **physiological stress,** and disturbance as a parameter of reduced **competition.** These results are compiled in a summarising factor diagram of desert steppe in Fig. 27.

Grazing influence can cause elevated soil nutrients supply (community 1, cf. Fig. 10) but it does not induce autonomous grazing communities. Grazing in arid desert steppe has more direct effects on vegetation by defoliation, disturbance, and by trampling than indirect effects via changed soil conditions as elevated soil nutrients. Thus, vegetation in arid desert steppe is mainly controlled by abiotic conditions what limits its susceptibility to grazing.

### 2.6.2 Mountain steppe

Tabular treatment and statistical analyses divide the communities of mountain steppe into two groups of communities which differ in soil texture attributes and slightly in inclination (cf. Tab. 5, Fig. 14, 16, 17): ***Stipa krylovii - Artemisia dolosa*-mountain steppe** (5) with ***Leymus secalinus*-grazing community** (4) and ***Rhinactinidia eremophila - Stipa krylovii*-mountain steppe** (6) with ***Leymus chinensis*-grazing community** (7). Community 4 with 5 represent edaphically moister conditions than community 6 with 7. Against the expectations, the moister community 5 contains less $C_{org}$ and N than the drier community 6. Since biomass constitutes the basic material of soil organic matter, differences in $C_{org.}$ and N among communities under the same climatic conditions are mainly based on different productivity of vegetation and on soil texture properties (SCHEFFER and SCHACHTSCHABEL 2002). These differences could be explained by the higher edaphic moisture, which may lead to improved microbial activity causing more intensive mineralisation in the summer period of mountain steppe. As microbial biomass is rich in nitrogen (SCHEFFER and SCHACHTSCHABEL 2002), this assumption requires a higher soil nitrogen in the edaphic moister community with a comparable productivity compared to edaphic drier community. However, it cannot be proved with the available data. Only narrower $C_{org}/N$ refers to a higher microbial activity in community 5 (SCHEFFER and SCHACHTSCHABEL 2002). To clarify this phenomenon, further research is needed. However, differences in $C_{org}$ and N among both communities are clearer than among communities of the desert steppe.

The vegetation-driving effect of soil texture differences is confirmed (I) by the site preferences of species, characterising the communities, and (II) by the ecological vegetation classification of HILBIG (1987, 1995, 2000a):

(I) The occurrence of all species of group 9-11 except *Poa sibirica*, characterising community 6, indicates stony and gravely sites. Some of them are even considered to be petrophytes (GRUBOV 2001), or rank among petrophilous species of steppe vegetation (HILBIG 1995).

(II) Regarding their species composition, community 5 and 6 refer to the phytosociological alliance (Verband) Stipion krylovii KONONOV, GOGOLEVA et MIRONOVA 1985. Within this alliance, community 5 mostly corresponds to the Hedysaro pumili[8]-Stipetum krylovii HILBIG (1987) 1990 corr. 1995. Due the occurrence of *Amblynotus rupestris, Chamaerhodos altaica, Orostachys spinosa*, and *Arenaria capillaris* community 6 better corresponds to *Arctogeron gramineum* subassociation of Cymbario-dahuricae-Stipetum krylovii HILBIG (1987) 1990. This *Arctogeron gramineum* subassociation comprises mentioned species as differential species (HILBIG 1995, 2000a, HILBIG personal comm.). Hedysaro pumili-Stipetum krylovii HILBIG (1987) 1990 corr. 1995 represents an association of mountain steppe belt, described for the Gobi Altai, and Cymbario-dahuricae-Stipetum krylovii HILBIG (1987) 1990, an association of dry steppe belt (Hilbig 1995, 2000a). Thus, the latter community refers to drier conditions than the former community, similar as the corresponding community 5 and 6. Furthermore, within dry steppe belt *Arctogeron gramineum* subassociation is bound to stony sites of slopes with low content of fine soil. This additionally confirms the drier site conditions (HILBIG 1995).

Further communities of mountain steppe belt than presented in this study can be expected at soils more different in soil texture composition because soil texture is derived as a vegetation-differentiating variable. In the study area, it only represents two variants. For example, at gravely soils a petrophilous community with the dominant grass *Elytrigia nevskii* is described by VOLKOVA (1994), at stony-rocky sites an *Artemisia rutifolia* community and different shrub communities with species of genus *Spiraea*, *Grossularia*, *Ribes, Lonicera*, and *Amygdalus* within the alliance Spiraeion aquilegifoliae HILBIG 2000 are mentioned by HILBIG (2000a) and by VOLKOVA (1994).

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[8] From *Hedysarum pumilum* – in GRUBOV (2001), former a synonym for *Hedysarum ferganense* accord. to GUBANOV (1996).

Due to their composition of soil texture, community 4 can be assigned as a variation of community 5 (*Stipa krylovii* - *Artemisia dolosa*-mountain steppe), and community 7 as variation of community 6 (*Rhinactinidia eremophila* - *Stipa krylovii*-mountain steppe). Community 4 and 7 both are modified by grazing. This outcome is additionally confirmed by the vegetation classification of Mongolian mountain steppes of HILBIG (1995: 128 Table 18). In this classification, *Leymus secalinus* which only occurs in grazing community 4, represents an abundant species of Hedysaro pumili-Stipetum krylovii and its degradation facies, corresponding to community 5 and its grazing community 4. HILBIG's (1987) 1990 Cymbario-dahuricae-Stipetum krylovii contains in its degradation facies *Leymus chinensis, Axyris prostrata, Carex duriuscula, Artemisia macrocephala, Artemisia frigida*, and annuals of genus *Chenopodium* similar as its corresponding grazing community 7.

Modification through grazing is also reflected in increased vales of variables representing soil nutrient supply and nutrient availability (P, N, $C_{org}$, $C_{org}$/N, $CEC_{eff}$), soil salinity (EC), and soil alkalinity ($CaCO_3$, pH), which all separate the grazing communities within the first derived two community groups (Fig. 14). Both grazing communities 4 and 7 indicate an increase in all of these mentioned soil variables. All sites of grazing communities are situated in close proximity to livestock corrals in a distance of 0-40 m to fenced borders. Thus, they are provided with a high deposition of urine and faeces by livestock, which can reduce soil microbial respiration, and shifts the ratio of humification : mineralisation in support of humification as shown by YAKUTIN and ANDRIEVSKIY (2005) for heavily degraded dry steppe of adjacent Uvs Nuur Basin. Due to their close proximity to livestock corrals, all sites of grazing communities 4 and 7 have to be considered as heavily degraded.

$CEC_{eff}$, commonly depending on the type and content of clay minerals, humus and soil acidity (SCHEFFER and SCHACHTSCHABEL 2002), in the present case is increased as an effect of higher soil organic matter and pH due to grazing, while clay content is fairly similar across all sites within mountain steppe (Fig. 15).

The increase in $CaCO_3$ with associated increase in pH and salinity can also be attributed to the heavy impact of livestock for the following reason: soils of mountain steppe generally contain calcium carbonate from a soil depth of 10 cm below soil surface on with rapidly increasing concentration in higher soil depth below 30 cm below soil surface (cf. 1.2.3: Mountain steppe and Appendix IV). The high concentration of livestock next to animal corrals provides these soils with urine liquid, in which minerals and calcium carbonate are dissolved. Due to the high negative water balance of the mountain steppe in summer (KRÜGER et al. 2001), high evaporation rates cause an uprising soil water stream, and soluble salts, and carbonate precipitate in the upper horizons (BARSCH 2003), a process similar to salinization in irrigated drylands. Due to summer rain, uprising soil water flux occurs temporarily in periods of strong desiccation (BARSCH 2003, KNOTHE et al. 2001, KRÜGER et al. 2001). Higher concentration of calcium carbonate in the top soil layer compared to lower horizons supports this assumption (cf. Fig. 14). Furthermore, increased urine and dung loading rates are known to increase total mineral solutes in soil solution, which is directly related to electrical conductivity (MAPFUMO et al. 2000). That arid summer period controls this process, is reflected in a comparison of grazing effects in arid with humid landscapes. In a climatically comparable landscape of Inner Mongolian grassland with mean annual precipitation of 362 mm, higher pH values were proved in plots of heavy grazing than in plots of less grazing pressure (SU et al. 2002). In contrast to this, in the humid aspen parkland of Alberta/Canada, a significantly greater negative change in soil pH under heavy grazing treatment was determined than for medium and light grazing (MAPFUMO et al. 2000). Thus, the increase in P, N, $C_{org}$, $C_{org}/N$, $CEC_{eff}$, salinity and soil alkalinity (via increased $CaCO_3$) in community 4 and 7 has to be considered as a consequence of high livestock concentration, occurring next to animal corrals.

Hence, in grazing communities annual species especially of the family of Chenopodiaceae, being favoured at N-enriched sites (BASSETT and CROMPTON 1978, FOULDS 1993, REIMANN 2003) or short-lived and rhizomatous species, being favoured by frequent disturbance, become dominantly and/or replace perennial caespitose grasses and herbs. Community 4 responds to grazing with almost a total loss of species. Only disturbance-associated species with short reproduction cycles such as *Salsola collina et tragus* and *Artemisia macrocephala* and species with underground stolons such as *Carex duriuscula,* ruderal species of Chenopodiaceae, and the grazing-tolerant grass *Leymus secalinus* survive (FERNANDEZ-GIMENEZ and ALLEN-DIAZ 2001, GRUBOV 2001, GUNIN et al. 2002, HILBIG 2000b**,** HILBIG and OPP 2005). As the community of drier sites, community 7 survives with more species than does community 4. In this community *Leymus chinensis*, a grazing-tolerant species, becomes an increaser species as described by HILBIG (1995), HILBIG and OPP (2005), MIKLYAEVA et al. (2005) due to its strong compensatory growth after cutting or biting (STAALDUINEN et al. 2005). In both grazing communities 4 and 7, ruderal species such as *Chenopodium album*, *Chenopodium acuminatum,* and *Axyris prostrata* have high competitive ability at N-enriched sites and are known as invaders of overfertiled sites (HILBIG 1995, HILBIG 2000b, HILBIG and OPP 2005). They appear with high cover values in both communities, and with high constancy in community 7 (cf. Tab. 5, Appendix II).

The different numbers of species in both of the grazing communities might be explained by higher livestock concentration at sites of community 4, owing to more plane relief conditions, where animals have better access. Furthermore, it is widely known in rangeland literature that grazing-induced vegetation types indicate drier conditions than climate would indicate (CHRISTENSEN et al. 2004, SKARPE 1991). In the Russian literature on Mongolia, this phenomenon is called “xerophytisation” (kserofitistsiya), and describes that plant species, common in drier ecozones, indicate grazing disturbances in moister ecozones (GORSHKOVA and GRINEVA 1977, GUNIN et al. 2002, OPP and HILBIG 2003, VOSTOKOVA et al. 1995). The reversion of this conclusion, the higher resistance to grazing of arid ecosystems in comparison to more humid ecosystems, represents a main part of the non-equilibrium model of arid rangelands (BEHNKE and SCOONES 1993, ELLIS and SWIFT 1988, SULLIVAN and ROHDE 2002, VETTER 2005, WESTOBY et al. 1989), and is already described for Mongolia by BABAEV and SARANTUYAA (1995), FERNANDEZ-GIMENEZ and ALLEN-DIAZ (1999), STUMPP et al. (2005), and WESCHE and RETZER (2005). Thus, it can be assumed that moister edaphic conditions of community 5 further support a more grazing sensitive vegetation dynamics of community 5. Heavy grazing impact leads to bigger change in species composition of community 4 compared to community 6 with its grazing community 7. This is comparable to the desert steppe, where only the edaphic moister community 1 responds to grazing with changed species composition. It can be derived as a hypothesis, and should be tested in an extended examination of further plant communities with their corresponding grazing modifications in mountain steppe, differing in edaphic moisture or with exclosures. Regarding classified communities, the following can be summarised: soil texture and relief position divide all communities into two groups, which are further subdivided into four communities due to floristic alterations and increased soil nutrients, salinity and soil alkalinity as effects of heavy grazing pressure. Thus, community 5 and 6 represent edaphic different communities without obviously discernable grazing influence. Community 4, due to soil texture composition, belongs to community 5, and represents its heavily degraded grazing modification, similar to community 7, belonging to community 6 as its grazing modification. Due to their obvious alterations in edaphic conditions, which are clearly reflected by their floristic composition, they are derived as discrete communities.

Among site variables without clearly vegetation-differentiating properties (Fig. 15), inclination represents a parameter, which influences soil texture via erosion (KOWALKOWSKI 1978), slope aspect and the index of aspect & inclination which influence thermal supply. Although sampled aspect provide a wide range of theoretically possible directions (varying from 0° to 285°), aspect and index of aspect & inclination could not be detected to have a vegetation-differentiating influence, likewise the outcome of desert steppe and alpine belt. This phenomenon could be observed nowhere during extended excursions through central parts of the Mongolian Altai in western Mongolia during the field work period. Comparable observation is reported by BEKET (2003), who writes that conspicuous asymmetry of northern and southern slopes is not repeated in central parts of Mongolian Altai, where only upper and lower borders of altitudinal belts differ in their position at northern and southern slopes. It demonstrates that slope aspect acts on a higher level of classification. Thus, it will be included in the factor diagram as vegetation-differentiating parameter on the level of altitudinal belt (Fig. 28). In contrast to this, inclination indicates no vegetation-differentiating property in the present study, but should be considered as a vegetation-determining variable, as it can influence gravel content and soil texture via erosion, as reported for the mountain steppe belt of Khangay by KOWALKOWSKI (1978).

Data sampling in the mountain steppe belt was conducted in an area of low altitudinal difference with a view to stay within one altitudinal belt of vegetation formed on the same climatic conditions. This prerequisite could be guaranteed, and is reflected by higher variations of altitude within rather than across demarcated plant communities (Fig. 15). That altitude controls vegetation is widely known and confirmed by the formation of altitudinal belts in vegetation (e.g. as dry steppe, steppe, mountain steppe, alpine steppe and alpine *Kobresia* mat). Thus, altitude has to be stated as a vegetation-determining environmental variable. Therewith, further communities of higher or lower altitudinal belts in specific edaphic expressions have to be expected. It is already indicated by the alpine species *Aconogonon alpinum*, *Oxytropis oligantha* and *Pachyneurum grandiflorum* of species group 11 (GRUBOV 2001), which migrate from the upper alpine belt. Due to the limited number of relevés containing these species, which do not differ clearly in their altitudinal occurrence or in further site-ecological conditions, an additional community was not derived. However, altitude as a vegetation-driving parameter is pointed out in the factor diagram of mountain steppe (Fig. 28).

A further vegetation-differentiating environmental parameter, which can be assumed theoretically, is salinity. Saline site conditions were not found except as a result of grazing but can be expected near lakeshores or mountain creeks with higher groundwater level, at clayey loamy site, where soil texture prevents leaching of salts in soil horizons below the root zone, and facilitates the uprising capillary water stream. Since weathering conditions of the arid Mongolian Altai provide prevailing sandy soils (cf. Fig. 15), these sites have to be considered as special sites, which rarely can be found. This holds true similarly for disturbance as abiotically caused vegetation-driving factor (e.g. by erosion, not biotically caused by grazing) existing in prevailing dry beds of creeks or rivers. These sites have not been located and sampled in the study area, and have a spatially subordinated importance.

Results of the mountain steppe belt are depicted in the factor diagram of mountain steppe (Fig. 28) and suggest the following environmental parameters, which differentiate plant communities with different species composition and represent the following ecological factors:

**Altitude** on a first level divides mountain steppe into communities of higher altitudinal belt with moister, colder, and shorter vegetation period and lower altitudinal belt with reverse conditions in different intensities. Thus, it can be considered as a parameter of **bioclimate** with **different climatic moisture supply**.

Communities within the same altitudinal belt, representing the same bioclimatic conditions, are subdivided according to their **soil texture** composition into communities of different **edaphic moisture**. Due to related different **productivity,** they can differ in variables representing **soil nutrients** and **nutrient supply** as $C_{org}$ and N. But it can be overlaid by

**microbial activity** which can be enhanced by higher edaphic moisture causing higher mineralisation rates. If sites with soil texture composition preventing leaching of salts and enabling uprising capillary stream have higher groundwater level, **salinity** as a parameter of **vegetation effective moisture** and **physiological stress** may demarcate additional salt communities. All communities differentiated so far respond to **grazing** with altered species composition and increased Corg, N, Corg/N, and P, representing **soil nutrients and nutrient supply**. Furthermore, both communities respond with increased concentrations of **calcium carbonate**, related decreased **soil acidity,** and higher **soil salinity**.

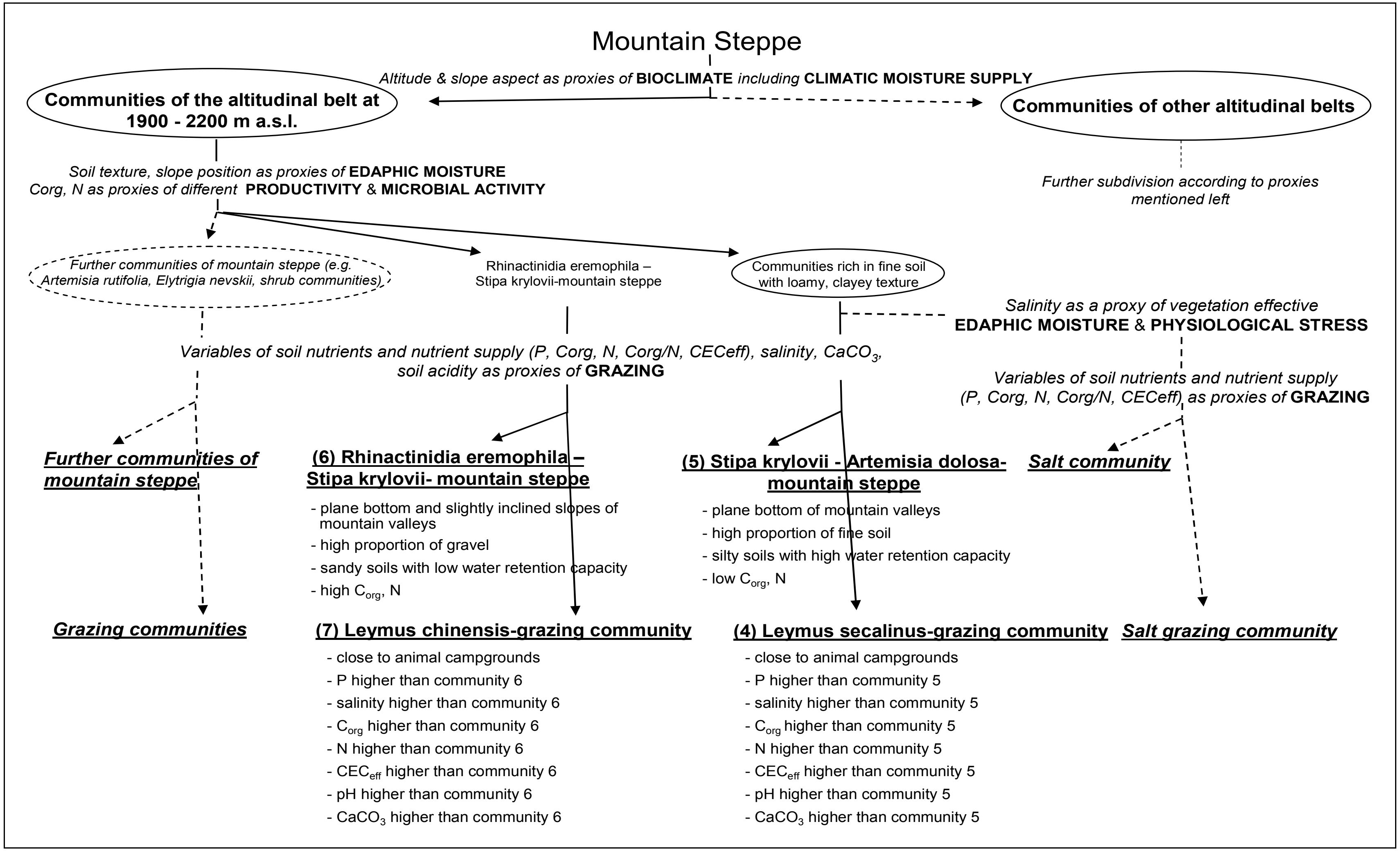

Fig. 28: Factor diagram of mountain steppe (italic style: measurable environmental parameters, bold capital: derived ecological factors, in circles: groups of communities, in dotted circles: groups of communities not examined in this study, dotted arrows: potential vegetation-driving environmental parameters not examined in this study, bold underlined: classified communities, bold, italic and underlined: potential but not classified communities, standard: site description of classified plant communities).

### *Response of mountain steppe to grazing*

In contrast to the desert steppe, grazing obviously alters edaphic site conditions, reflected in floristic composition and thus in separate grazing communities. Floristic differences of communities are weakened under heavy grazing impact because species groups 9-11, distinguishing communities among each other, almost disappear completely. In grazing communities, only species remain which characterise both communities, are specialists of nutrient-rich sites or grazing-tolerant species. However, it has to be pointed out that grazing influence on vegetation and on soil is only detected under heavy grazing impact next to animal corrals up to a distance of 40 m. This might explain different outcomes of STUMPP et al. (2005), who examined soil and vegetation variables along grazing gradients established as transects in distances to grazing hot spots of 50-1500 m in a climatically and floristically similar mountain steppe of southern Mongolia. They did not detect significant correlations of various vegetation variables with grazing gradient. Contrariwise, parameters representing soil nutrients and nutrient supply ($C_{tot}$, total soil nitrogen, phosphorus) significantly decreased with distance to animal hot spots, which corresponds with the present results.

As shown above, heavy grazing pressure in mountain steppe has influenced plant communities both directly, through enhanced disturbance regime of defoliation and trampling indicated by short-lived annual and grazing-tolerant species, and by the depletion of a variety of perennial species in both grazing communities. The indirect impacts lead to the redistribution of certain soil nutrients with resulting fertilisation, increasing soil salinity and soil alkalinity, indicated by ruderal species favoured at nutrient-enriched soil conditions. Direct and indirect grazing influences are already assumed for mountain steppe vegetation of central Mongolia by FERNANDEZ-GIMENEZ and ALLEN-DIAZ (1999), and can be confirmed herewith.

The increased vegetation cover of both grazing communities could indicate increased productivity as an effect of nutrient enrichment, and thus may improve fodder reserves. However, it should be mentioned that the examined mountain steppe areas represent typical winter pastures in the region. For a further assessment of grazing effects, it is necessary to test which proportion of biomass is still usable in the period of winter grazing between the middle of November and the end of January (VASHA 2005). Furthermore, analyses of fodder values of grazing communities compared to non-grazing communities in winter should be provided.

The comparison of grazing effects on both communities shows the same pattern as in desert steppe: the moister community indicates stronger grazing effects in vegetation and soil conditions.

### 2.6.3 Alpine vegetation

Results of ecological subjected classification divide the alpine belt on a first level according to altitude into alpine steppe of lower alpine belt, and cryophyte steppe, and alpine sedge mat of the upper alpine belt. The big altitudinal gradient of the study area with 750 m and associated bioclimatic differences leads to the formation of grass dominated steppe vegetation with high proportion of sedges in the lower alpine belt, and by sedges and cushion plant dominated vegetation with high proportion of grasses in the upper alpine belt. Already POLYNOV and KRASHENINNIKOV (1926 cited in YUNATOV 1950) pointed out the particularities of the steppe character within the alpine belt of Mongolian Altai due to their enclosed conditions and resulting droughty climate. In his vegetation description of western Mongolia, BUYAN-ORSHIKH (1992) underlined that this “high mountainous steppified sedge mats” (vysokogornye ostepnennye osochniki) of Mongolian Altai have no analogy of any mountains of Mongolia.

Along the altitudinal gradient in upward direction, the total productivity and associated ratio of belowground : aboveground biomass change, the mineralisation rate of soil organic matter decreases and leads to humus accumulation due to reduced thermal supply decreasing microbial activity (SCHEFFER and SCHACHTSCHABEL 2002). These conditions mainly cause the increased content of $C_{org}$, N, and $CEC_{eff.}$, depending on soil organic matter, in the alpine belt.

The climatic differences may further cause the importance of physical weathering in the lower alpine belt, leading to high proportions of coarse soil fraction as gravel and sand while in the upper alpine belt chemical weathering appears to be more enhanced. Proportion of fractions of coarse soil fraction such as gravel and sand are thus much lower.

To summarise, on a first level of classification, **altitude** as vegetation-differentiating environmental parameter has to be considered as a **factor** of **bioclimate** including **climatic moisture supply,** and leading to different composition of life forms in vegetation, to different ratios of **aboveground** and **belowground productivity** and different rates of **decomposition.** The latter leads to changed soil nutrients and soil organic matter. Besides, altitude as a factor of **weathering conditions** causes different soil texture composition. Mentioned ecological factors are generally similar within an altitudinal gradient while topographic position can vary much. Consequently, topographic position is considered as vegetation-differentiating parameter on a lower level of classification. This division in upper and lower alpine belt is already drawn by KARAMYSHEVA and KHRAMTSOV (1995), who describe a special sub-belt in Mongolian Altai between 2500-2700 m a.s.l. with communities of *Festuca lenesis* formations and *Poa attenuata* closely related to community 8) and 9).

Within an altitudinal belt with similarly acting ecological factors mentioned above, vegetation formation of the alpine steppe on a second level of classification is subdivided according to slope position and associated soil texture composition into communities with higher and lower content of fine soil. As community 8) ***Aster alpinus* - *Koeleria cristata*-alpine steppe** is situated at mountain slopes with generally higher inclinations, the discharge of fine soil is higher. On the other hand, community 9) ***Potentilla bifurca* - *Koeleria cristata*-alpine steppe** is located in a basin-like position with sites of less discharge of fine soil. Hence, community 8) has to be regarded as edaphically drier and community 9) as edaphically moister. This is indicated by species such as *Bupleurum bicaule, Oxytropis tragacanthoides, Astragalus multicaulis*, and *Pulsatilla bungeana*, in species group 4, which is bound to stony and gravelly mountain slopes or rocks (GRUBOV 2001, KARAMYSHEVA and KHRAMTSOV 1995), and demonstrate higher constancies in community 8). *Thalictrum foetidum* within the community 8)-indicating species group 5, is specified as a character species of the alliance Thalictrion foetidi all. nov. HILBIG 2000 of stony debris-communities in the mountain belt by HILBIG (2000a). *Artemisia argyrophylla* and *Youngia tenuifolia* in the same species group are considered as petrophytes (VOLKOVA 1994). If these species benefit from the edaphic drier conditions or from sandy-stony soil substratum as a basis of roots, is not proved. Both facts are further considered as ecological factors. The moister character of community 9) is not indicated by species due to high direct grazing impact, altering species composition towards drier conditions as described below. Beside the described communities, further communities can be expected at sites more different in soil texture. The communities listed by HILBIG (2000a) within the vegetation class of Scrophylarieta incisae cl. nov. HILBIG 2000 give particular information about their species composition with short descriptions of their edaphic conditions.

Due to the almost daily precipitation and the melting of the upper horizons of permafrost soils during vegetation period in summer, in the upper alpine belt percolating water at the slopes collects in the bottom of valleys and flows off as surface water downwards into mountain brooks and rivers (own observations 2002-2005). Under these circumstances, relief position engenders water regime as a further vegetation-differentiating parameter. As a consequence of the conditions of water surplus in the bottom of the valley, high productive sedge mats are formed. In the present example, a ***Poa altaica* - *Kobresia myosuroides*-sedge** 12) mat dominated by sedges represents site conditions with high content of fine soil, clay, and silt fractions. Due to humus accumulation in consequence of high water saturation of soils and high productivity, soil contains high $C_{org}$ and N. Values of $CEC_{eff.}$ are enhanced due to these high contents of clay and soil organic matter (SCHEFFER and SCHACHTSCHABEL 2002).

At slopes or flat mountain passes and saddles, a ***Festuca lenensis*-cryophyte steppe** 11) with cushion plants, cryophilous forbs, and grasses is formed at sites of drier conditions with lower content of fine soil, clay and silt fractions, lower $C_{org}$ and N due to less productivity and presumably higher mineralisation rate, and lower $CEC_{eff}$ than community 12.

Communities 12), 13) mentioned in Tab. 8 and further alpine *Kobresia* mat communities (cf. HILBIG 1995, 2000a) are not only distributed along the sampled altitudinal range between 2700-3050 m a.s.l. and extend additionally along the total alpine belt. They are reviewed here in the upper alpine belt, because they are only sampled in the mentioned altitudinal range within the study area of the alpine belt. However, they were also observed but not sampled in lower parts of the alpine belt. Demarcated *Poa altaica* - *Kobresia myosuroides*-sedge 12) is closely related to Polygono vivpari-Kobresietum bellardii[9] HILBIG (1987) 1990 within the alliance of Kobresion myosuroidis MIRKIN et al. 1983 em. HILBIG 2000, and is described for lower and upper alpine belt of different mountains of Mongolia at moist, deep soils in troughs, gullies and clefts (HILBIG 1990, 1995). This refers to similar site conditions as described for community 12). The occurrence of *Kobresia smirnovii* indicates moister site conditions than other species of *Kobresia* in Mongolian Altai and Gobi Altai (VOLKOVA 1994). It has to be assumed that at sites with similar water surplus but different water regime (spring water, backwater, periodically inundating water or others) or different soil texture composition, further communities of sedge mats can be expected as designated by HILBIG (2000a) and VOLKOVA (1994).

Demarcated *Festuca lenensis*-cryophyte steppe 11) corresponds closely to *Stellaria pulvinata* community HILBIG 2000, within the high-alpine cushion vegetation of the alliance Rhodioletalia quadrifidae HILBIG 2000. KARAMYSHEVA and KHRAMTSOV (1995) designate a closely related vegetation type of cushion forb – bunch-grass steppe with *Stellaria pulvinata* for the highest parts of the central massifs of Mongolian Altai. VOLKOVA (1994) describes a corresponding vegetation type within high mountain cryophyte cushion vegetation as “podushechnikovoraznotravnye” units (Russ. - cushion vegetation with various herbs) for stormy highest mountain ranges of central parts of the Mongolian Altai at dry, flat areas which are protected from humid western and northwestern winds. This general description complies with the places in which the community was found: highest parts of interior mountain ranges of central parts of the Mongolian Altai at sites with water discharge. At sites differing in site conditions of the described community e.g. in soil texture, or in the surface covered by more or less boulders and causing different microclimate, further communities of cryophyte steppes can be expected.

To summarise, **topographic position** and associated **soil texture composition** has to be considered on a second level of classification as a vegetation-differentiating environmental parameter referring to the ecological **factor** of **edaphic moisture** and of **soil substratum** as a basis for roots. **Topographic position** moreover causes **water regime** as an additional ecological factor, which furthermore determines **soil texture composition**, **productivity** of vegetation and the rate of **mineralisation**. Different intensity of **mineralisation** and

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[9] From *Polygonum viviparum* – in GRUBOV (2001), former a synonym for *Bistorta vivipara* accord. to GUBANOV (1996), and *Kobresia bellardii* - in GRUBOV (2001), former a synonym for *Kobresia myosuroides* accord. to GUBANOV (1996).

**productivity** of plant communities causes different **soil nutrient supply** such as **$C_{org}$, N,** and **$CEC_{eff}$.** Consequently, the latter have to be considered as parameters of both former ecological factors.

On a third level of classification, all mentioned communities show grazing modifications. Only community 9) is not only modified by grazing and additionally represents an edaphic different community, but a community corresponding to community 8). Communities labeled as grazing communities only indicate communities altered by grazing.

If species, indicating stony and gravely sites and being petrophytes as mentioned above in community 8, are missing or less constant in ***Potentilla bifurca* - *Koeleria cristata*-alpine steppe** 9) due to the higher content of fine soil or as an effect of grazing, could not be verified. Only species such as *Oxytropis tragacanthoides* and *Thalictrum foetidum* are known to be ignored by all livestock (JIGJIDSUREN and JOHNSON, 2003, YUNATOV 1954). Thus, it is assumed that their missing rather indicates differences in soil texture composition (GRUBOV 2001). Grazing influence is indicated by species of species group 6 and 7. Some of them are typical grazing indicators, getting benefit from enhanced disturbance regime such as *Agropyron cristatum*, *Carex duriuscula*, *Potentilla bifurca*, *Chenopodium glaucum,* and *Artemisia frigida* (HILBIG 1995, HILBIG and OPP 2005, RETZER 2004, YUNATOV 1974). *Potentilla bifurca, Agropyron cristatum* and *Clausia aprica* have their main area of distribution in the drier mountain steppe (cf. Tab. 5 species group 2, 4) or like *Dontostemon senilis* in the desert steppe (cf. Tab. 2 species group 11). As an example of grazing-induced "xerophytisation", they appear as grazing or disturbance indicators in moister habitats of higher altitudinal belts (GORSHKOVA and GRINEVA 1977, GUNIN et al. 2002, SKARPE 1991, VOSTOKOVA et al. 1995). This is similar to species of group 8 indicating sandy and stony steppe sites of lower altitudinal belts (GRUBOV 2001). Although community 9 represents an edaphic moister condition than community 8), it demonstrates that vegetation of community 9 is stronger influenced by grazing than by edaphic moisture conditions. Grazing probably may affect vegetation of the lower alpine belt more directly by **defoliation** and **trampling,** changing the micrcolimate of vegetation stand and enabling higher **solar radiation** (GEORGIADIS et al. 1989, INSAM et al. 1996, ZIMOV et al. 1995 all cited in STARK 2002). The decreased vegetation cover compared to community 8) indicates this direct grazing impact on vegetation additionally. Indirect grazing impact through redistribution of soil nutrients is not observed because $C_{org}$ and N do not reflect increased values as e.g. in the mountain steppe and the desert steppe although it represents a typical phenomenon of sites with high grazing pressure (GLATZLE 1990, MILCHUNAS and LAUENROTH 1993). A redistribution of soil nutrients is only indicated by P with an obvious wider range of values, which documents the situation of grazed areas as shown by BENNET et al. (2004). However, each of the grazing communities is represented with only three soil samples. Thus, results should not be overrated.

**Grazing community of *Festuca lenensis*-cryophyte steppe** 10) is distributed at a slightly lower altititude than *Festuca lenensis*-cryophyte steppe because it is situated near ger camps of nomadic herders, which are usually situated at the base of mountain slopes. Regarding environmental parameters insensitive to grazing as soil texture composition, inclination, and aspect, community 10) closely corresponds to community 11). Also pH, EC and $CaCO_3$ show no conspicuous differences. $C_{org,}$ and N do not reflect increased values. Only lower $C_{org}$/N may indicate a higher microbiological activity in soil. P is slightly enhanced, which both might be caused by grazing. Community 10) has higher values of $CEC_{eff}$, which can be caused among others by a higher content of clay, or it represents a natural variance, because the total range of $CEC_{eff}$ also includes the low values of community 11). While soil properties do not clearly reflect a grazing influence, species composition of community 10) shows decreased constancies of species with high constancies in community 11) and a loss of species in group 9, 10 and 12, with mean constancies in community 11). Furthermore, grazing indicator species of species group 15 and 16 appear. Comparable with the effect of grazing-induced “xerophytisation” in community 9), floristic composition alters towards drier conditions: species like *Dontostemon integrifolius*, *Sibbaldianthe adpressa*, *Artemisia frigida*, and *Bupleurum bicaule* have their main area of distribution in the drier mountain steppe (cf. Tab. 5 species group 2 – 4, 7), and *Stellaria amblyosephala* in desert steppe (cf. Tab. 2 species group 15). Similar to grazing indicators of species group 6, they indicate a grazing influence under moister conditions (GORSHKOVA and GRINEVA 1977, GUNIN et al. 2002, SKARPE 1991, VOSTOKOVA et al. 1995). *Axyris prostrata* is a disturbance-associated and ruderal species (GRUBOBV 2001, HILBIG and OPP 2005).

**Grazing community of *Poa altaica* - *Kobresia myosuroides*-sedge mat** 13) is distributed in lower altitudes at more inclined slopes towards southern aspect, and thus receives higher solar radiation than its corresponding community 12) without grazing influence, which is less inclined towards eastern directions. Also in this community, soil texture composition, bulk density, pH, EC, and even P distinguish not much from community 12). $C_{org}$ and N show clearly decreased values that may cause lower $CEC_{eff.}$. The total cover of vegetation remains similar and does not indicate lower productivity due to higher solar radiation. However, floristic composition is changed by grazing with the loss of single species of species group 9, 10 and 13, and the loss of all species of group 14. Missing species have prevailing medium constancies in the corresponding community 12). Grazing-induced species alter sedge mats towards drier conditions as species of species group 3 and 17, usually distributed at the lower montaine steppe belt (GRUBOV 2001), indicate. The changes in species composition comply with HILBIG (2000a) and ZHAO and ZHOU (1999), who point out that enhanced grazing pressure in sedge mats support meadow species.

Even if the number of soil samples is limited, a repeated pattern of changing soil and vegetation properties can be recognised in all communities, influenced by grazing: except in the alpine steppe, the communities have similar or only slightly decreased cover of total vegetation as their corresponding communities without grazing influence. Only in the alpine steppe, the average total cover of vegetation is considerably decreased. But floristic composition of every community changed under grazing influence towards drier conditions as an effect of grazing-induced “xerophytisation”. The fact that it can be ascribed to the grazing influence is shown by (I) the edaphic moister condition of grazed alpine steppe 9) compared to less grazed alpine steppe 8), (II) the similar conditions of soil texture and aspect in both communities of cryophyte steppe, and (III) the similar vegetation cover in grazed sedge mat community 13), demonstrating a limited influence of enhanced solar radiation on vegetation.

However, all sites of communities influenced by grazing indicate decreased values of $C_{org}$ and N in contrast to other examined study areas, while values of P are increased to only a low extent. The missing increase in $C_{org}$ and N, as detected in all other study areas, might be caused among others by the higher distance to animal corrals, where sample plots of the alpine steppe and the alpine sedge mat are situated. However, sample plots in cryophyte steppe, similar as in other study areas, are situated directly next to animal corrals, and do also not show increased $C_{org}$ and N.

The decrease in $C_{org}$ and N can be explained with biomass extraction caused by grazing, evidently only in case of the lower alpine steppe, where due to grazing impact the cover of the total vegetation is considerably decreased. However, a grazing mediated biomass extraction can be assumed also in the higher alpine belt. Due to the higher productivity of the community, it is not detectable via reduced vegetation cover. The annual supply of dead organic litter is thus reduced and less soil organic matter, the main storage of $C_{org}$ and N (SCHEFFER and SCHACHTSCHABEL 2002), can be stored in soil and may cause reduced contents. The alpine steppe represents a summer pasture, where herders and livestock provide a higher concentration than in lower altitudinal belts, which are used as winter pastures (JANZEN and BAZARGUR 1999, VASHA unpublished data). In addition, nutritional requirement of livestock is much higher in active periods of reproduction, and lactation at alpine summer pastures. Moreover, the nutritive values and digestibility of plants in regions with high precipitation are lower than in arid regions (GLATZLE 1990). Thus, it has to be assumed that biomass extraction per livestock unit and per area unit in the alpine belt is higher than in lower altitudinal belts. Presumably, the fertilisation effect of livestock near grazing hot spots is overlaid by extensive biomass extraction leading to decreased $C_{org}$ and N.

Furthermore, main losses of N in ecosystems happen via soil erosion, leaching, and denitrification via nitrous oxide or molecular nitrogen. Soil erosion in a large scale could not be detected in the alpine belt. Leaching is positively coupled with precipitation, and denitrification is enhanced in water-saturated soils (GLATZLE 1990, SCHEFFER and SCHACHTSCHABEL 2002). These conditions appear only in the alpine belt and are indicated by hydromorphic soils (cf. Fig. 5). On the other hand, in all ecosystems grazing can have a fertilising effect by urine and faeces, which enhances soil nutrients and soil organic matter (GLATZLE 1990, MILCHUNAS and LAUENROTH 1993). It can be blurred by other indirect mechanisms involved with herbivory (AUGUSTINE and MCNAUGHTON 1998). In arctic-alpine ecosystems, where biological activity is limited by low temperatures similar as in the alpine altitudinal belts, this fertilisation effect is accompanied by enhanced or retarded grazing impacts on decomposition rates and nutrient mineralisation, depending on the underlying mechanisms that may work at opposite directions (STARK 2002). These mechanisms, such as the shift in plant composition towards more or less decomposable species (GRIME et al. 1996, PASTOR and NEIMAN 1992), the change of quality of decomposing material by increasing the nutrient content of plants through induced compensatory growth, promoting the effect on soil nutrient cycling (MCNAUGHTON 1985), the increase in defensive chemicals in plants effecting decomposition rates (BRYANT et al. 1991), the amount of root exudates, which have a major impact on microbial C dynamics (BARGDETT et al. 1998), and the change of soil microclimate through changed vegetation structure influencing soil moisture- and temperature-depending microbial processes (INSAM et al. 1996), determine the net effect of soil nutrient cycling. Soil nutrient cycling then again can outweigh, strengthen or reduce the fertilisation process (STARK 2002). Studies in arctic-alpine ecosystems in northernmost Fennoscandia demonstrated a retarded soil N-cycling with reduced soil C quality (STARK and GRELLMANN 2002), an enhanced N-cycling with improved soil C quality (OLOFSSON et al. 2002, STARK et al. 2002), and a retarded soil N-cycling with no effect on soil C quality (STARK et al. 2002).

Furthermore, grazing experiments in Tibetian alpine meadows have proved that grazing impact leads to enhanced denitrification, and is linked with a loss of nitrogen via nitrous oxide emissions (ZHAO and ZHOU 1999). Generally, denitrification is favoured in soils with high water saturation, sufficient supply of labile C (necessary as electrondonator for soil microbes in the denitrification process), pH range between 6-8, high temperatures, and reduced nitrification compared to ammonification (SCHEFFER and SCHACHTSCHABEL 2002). Except high temperatures, these conditions are given especially for sedge mats as soil data demonstrates (Fig. 22, 23) and with respect to the ratio of nitrification and ammonification process as shown by ZHAO and ZHOU (1999) for alpine *Kobresia* mats.

C and N-cycles in alpine ecosystems represent a multifactorial process, which is very complex. The complete explanation of the decrease of N and $C_{org}$ in the alpine communities influenced by grazing requires a self-contained and independent research project. Hence, it can only be proved that grazing impact decreases $C_{org}$ and N, and thus overweighs the fertilisation effect by urine and faeces in the alpine belt. It seems that the N-cycle and the associated C-cycle operate differently to other altitudinal belts, and lead to decreased $C_{org}$ and N, while they are usually increased under grazing in lower altitudinal belts.

To summarise, on a third level of classification, **grazing** has to be considered as a vegetation-driving ecological factor which has a direct influence on **species composition** and **vegetation**

**cover** via selective grazing and total **biomass extraction.** The changed vegetation structure causes an indirect influence via changed **microclimate** on vegetation and soil nutrient cycling. Moreover, indirect effects include the decrease in $C_{org}$ and N, which indicates a loss of biomass and presumably changes in **soil nutrient cycling**.

Floristical differences as an effect of grazing are obvious, while site-ecological differences are low but have almost the same patterns in all communities. Both give the basis to derive independent communities influenced by grazing.

Among site variables without vegetation-differentiating properties, $CaCO_3$ has to be listed, even if it shows differences along all plant communities in the alpine belt. However, absolute values are very low and differences of mean values among communities are below the reproducibility of the analysis method.

As discussed above, slope aspect and inclination do not have a vegetation-differentiating impact on the level of communities. It is surprising because some hundred kilometres in northern direction in the Uvs Nuur Basin, the slope aspect decides on the formation of forest steppe at northern slopes or meadow steppe at southern slopes (BARSCH 2003, HILBIG 1995, KNOTHE et al. 2001). Nevertheless, as already mentioned above, this observation is confirmed by BEKET (2003), and is caused by the interior position of the study area within the Mongolian Altai, situated in such a way that it is closed for humid western and northwestern winds, as reported by VOLKOVA (1994). However, slope aspect affects the position of the lower and the upper border of the altitudinal belt (BEKET 2003). Comparable to mountain steppe, it is thus included as a vegetation-differentiating parameter in the factor diagram on the higher level of classification of altitudinal belt (Fig. 29).

Electric conductivity in only two of 24 soil samples is more than 2 mS/cm, which has to be considered as outliers. Values over 2 mS/cm can cause harm to cultivated plants (SCHEFFER and SCHACHTSCHABEL 2002). Due to high precipitations in the alpine belt, salinity will not reach vegetation affecting values, and thus does not have to be considered as vegetation-differentiating parameter.

Even if disturbance as an abiotic environmental factor is not integrated in the factor diagram of the alpine belt (Fig. 29), it has to be mentioned as a vegetation-driving factor in the alpine belt, existing similar to mountain steppe in beds of creeks or rivers but with a spatially only subordinated role.

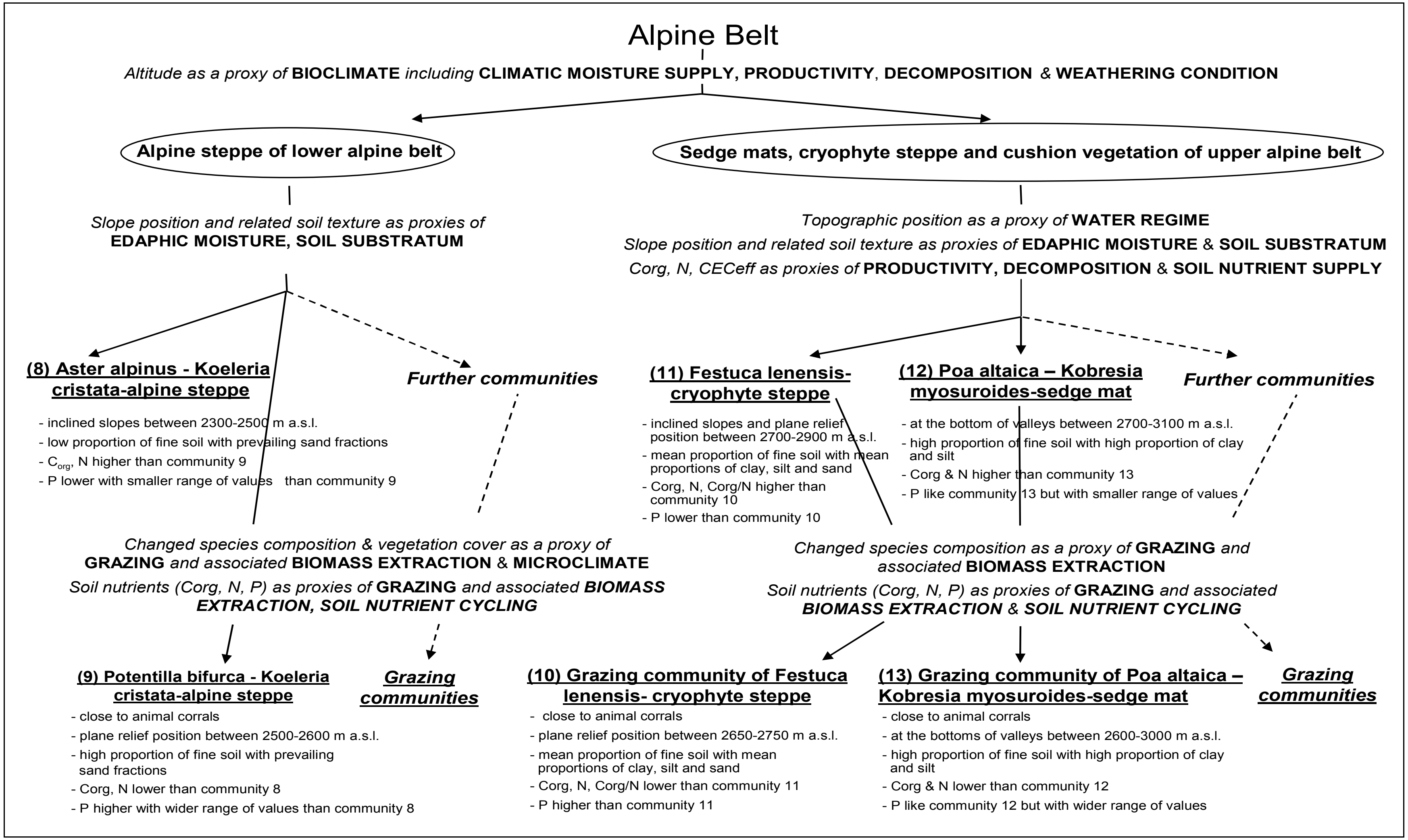


Fig. 29: Factor diagram of alpine belt (italic: measurable environmental parameters, bold capital: derived ecological factors, in circles: groups of communities, dotted arrows: potential vegetation-driving environmental parameters not examined in this study, bold underlined: classified communities, bold, italic and underlined: potential but not classified communities, standard: site description of classified plant communities).

***Response of alpine belt to grazing***

Similar as in mountain steppe, grazing influences lead to grazing mediated additional communities. Regarding soil conditions, grazing causes an extraction of biomass associated with a loss of $C_{org}$ and N in the broader environs of animal corrals. Fertilisation effects with increased $C_{org}$ and N in close proximity to animal corrals could not be proved. Only P increases under grazing influence but only to a small extent. While heavy grazing impact on mountain steppe enhances vegetation cover directly next to animal corrals, in the alpine belt it leads to missing vegetation cover directly next to grazing hot spots, to decreased vegetation cover in the lower alpine belt or to an unchanged or slightly decreased vegetation cover in the higher alpine belt in the broader environs of animal corrals. Spatial dimension of grazing influence is detected from grazing hot spots up to a distance of 100-800 m, and thus clearly exceeds the distances in mountains steppe with only 40 m and desert steppe with 100 m.

Beside the mentioned indirect influence on soil properties, vegetation indicates a direct grazing influence by (I) the loss of characteristic species, (II) the occurrence of disturbance-associated species, and (III) the occurrence of species indicating drier environmental conditions as an effect of grazing-induced “xerophytisation”.

## 2.7 Synopsis of results in the framework of concepts from vegetation ecology

### 2.7.1 Orientation

At the preceding pages, 13 plant communities, based on their environmental and site-ecological conditions along an altitudinal gradient from the desert steppe to the alpine belt were classified. Similar findings in the application of three methods of statistical analyses confirm the record of vegetation-relevant environmental and edaphic conditions on the one hand and on the other hand, the results of classification. The classification gave the basis to derive vegetation-differentiating site-ecological variables, and to discern ecological factors behind them for each vegetation formation. As already mentioned in the discussion, it has to be pointed out that only a choice of existing plant communities are recorded, described, and classified, and in all vegetation formations further communities can be expected. In this respect, also additional vegetation-differentiating site-ecological variables and associated ecological factors can be anticipated and further described. Thus, a precise comparison of the vegetation formations regarding their vegetation-driving ecological factors will remain imperfectly. However, in a comparison of all recorded data an attempt is made to derive the main properties of vegetation-driving ecological factors of all vegetation formations with their commonalities and differences. Beside the so far detected factors driving vegetation composition, further possible factors additionally emphasised by vegetation ecologists shall be considered. They will be introduced from literature in following subchapters against the background of the question, how these factors change along a gradient of altitude, precipitation, and depending productivity. Based on that, a linkage to main ecosystem properties is given to understand the different response to grazing of presented vegetation formations.

### 2.7.2 The vegetation-determining factors and their alteration along the altitudinal belt

The sampled altitudinal gradient is associated with a moisture gradient represented by a change of mean annual precipitation from 62 mm in the lowland with desert steppe to 350 mm in the alpine belt with decreasing rates of evaporations (CLIMATE STATION DOERGOEN 1985-2004, CLIMATE STATION KHOVD b, see Fig. 1). Along this gradient, ecosystems change from water-limited ecosystems to systems limited by temperature and vegetation period. Latter limitation allows a higher productivity than first limitation what is indicated by the change of average vegetation cover from 8-15 percent in the desert steppe to 56-75 percent in the communities of the alpine belt. This productivity gradient is associated with rising precipitation caused by rising altitude. Undoubtedly, along the altitudinal gradient further changes of environmental parameters appear such as of bioclimate, nutrient cycling, weathering conditions, etc., influencing edaphic conditions and vegetation in structure and dynamics. Edaphic changes as shown so far, consist in the increase in soil acidity, soil organic matter, total soil nitrogen, ratio of $C_{org}/N$, and a decrease in salinity, in calcium carbonate, and in phosphorus. Vegetation structure responds to increasing altitude with the increase of species richness, an increase in the proportion of grasses and forbs relative to shrubs, semi-shrubs and annuals. Consequently, different vegetation formations are formed.

It could be shown that altitude in all vegetation formations acts as a vegetation-differentiating parameter if the altitudinal extension of the study area is sufficiently large. This is not surprising because altitude as a criterion of a higher level of classification includes several environmental properties forming gradients such as bioclimate, water regime, weathering conditions, edaphic conditions, and others. Surprisingly, slope aspect is not detected as a vegetation-differentiating parameter on the level of plant communities in any vegetation formation (cf. 2.6). Although it has to be considered as a criterion of a higher level of classification such as vegetation formation, this result is explained by the sheltered position of the investigation area from humid western wind, and the extreme continental climate leading to high solar radiation (VOLKOVA 1994). Both high thermal supply and the aridity of the region cause a strong effect of microrelief and soil texture, which seems to overlay and differentiate the effect of slope aspect on the level of site conditions. At the border between altitudinal belts, this overlapping effect is cancelled, and vegetation-controlling influences of slope aspect are recordable (BEKET 2003). In a classification approach on a higher level of spatial resolution than the community level (e.g. at the level of life forms), slope aspect will be detected as vegetation-controlling factor.

In the desert steppe, the site-ecological gradient explaining most variations in vegetation data represents a combination of edaphic moisture, salinity, and soil erosion as a case of disturbance. All factors constitute abiotic environmental conditions. The low productivity of vegetation associated with high rates of mineralisation due to the coincidence of warm with rainy season (HAASE 1983) prevents the accumulation of soil organic matter, and total soil nitrogen indicating that the influence of vegetation on its own habitat is quite low (cf. 2.6.1).

The increased precipitation of mountain steppe allows a higher variation of soil moisture conditions depending on soil texture. Because mountain steppe is still water-limited, also productivity varies depending on soil moisture. Soil moisture can vary to such an extent that humus accumulation and associated soil nutrient supply differ among plant communities. Compared to the desert steppe, the site-ecological gradient explaining most variations in vegetation data, thus has to expand to a notable contribution of soil nutrient supply. Hence, in contrast to the desert steppe, both abiotic and biotic environmental conditions control the vegetation of mountain steppe (cf. 2.6.2).

The increased water supply in the alpine belt, leads to the exchange of edaphic moisture for water regime as a main ecological gradient. Differences in water regime such as infiltrating, percolating or flooding cause habitats of water deficiency in the lower alpine belt and habitats of water-balanced and of water surplus in the upper alpine belt with correspondingly adapted plant communities. Differences in plant communities are not only expressed in species composition but also in the proportion of life forms causing steppe vegetation, vegetation of cushion plants, and sedge mat. The different plant communities generate big differences in productivity, in the supply of soil organic matter, and depending soil nutrient supply. The importance of edaphic moisture represented by soil texture plays only a subordinated role in the alpine belt. Soil texture as a parameter of edaphic moisture cannot be distinguished in its effect on vegetation from soil texture as a parameter of soil substratum as a basis of roots on the basis of the recorded data. As opposed to the other vegetation formations of lower altitudinal belts, salinity as an ecological factor becomes unimportant in the alpine belt due to downwardly directed soil water flow in consequence of the higher precipitation supply. The site-ecological gradient explaining most variations in vegetation data in the alpine belt compared to the mountain steppe, has to be diversified to a combination of water regime, soil nutrient supply, edaphic moisture, soil substratum, and disturbance. Similar as in the mountain steppe, abiotic and biotic environmental conditions control the vegetation of the alpine belt (cf. 2.6.3).

### 2.7.3 The role of competition as vegetation-determing factor

With increasing altitude, the importance of vegetation as site-forming factor is rising to the same extent as the main limited resource water becomes available. Consequently, vegetation-linked ecological factors such as energy cycling, nutrient supply, and competition among plants have an increasing impact on ecosystem functioning. This result conforms to GRIME (2002), who sums up in the final chapter of his new edition on the CSR hypothesis "…it is an inescapable fact that the capture, processing, and release of energy, carbon, and mineral resources in a terrestrial ecosystem is strongly dependent upon the mass of vegetation and its functional characteristics. On this basis alone we can predict that there will be more differences between ecosystems in their food web structures, productivities, and stabilities that are strongly correlated with differences in the strategies of the dominant plants." CSR hypothesis (from C – competitors, S – stress-tolerators, R – ruderals) of GRIME (1979, 2002) gives a fundamental description of the construction of plants, their interactions with the environment and plant strategies forming communities composition, i.e. processes controlling the structure, composition of vegetation, and the coexistence and dynamics of different plant species in vegetation cover at the spatial level of species. Findings of the present study emphasise vegetation in its ability to influence and create site conditions, and thus becoming itself a vegetation-driving factor. One of the bases of the CSR model consists of the strategies of competition for resources as a determinant of the admission or exclusion of species within communities and thus follows a different approach than presented study. However, presented findings are comparable to and translatable into CSR theory (GRIME 2002) in its emphasis upon productivity to explain properties of ecosystems.

Competition was not included in the investigations but has to be considered as an important vegetation-determining factor by modifying the abundance of species (VAN ANDEL 2005). The role of competition across environmental gradients is contradictorily discussed. According to GRIME (1979, 2002), competition varies in relation to resource availability and reaches its maximum importance under conditions of high productivity. It declines at sites experiencing severe mineral nutritional constraints on vegetation production or in unproductive environments, where mineral resource depletion of biomass is low. Against this, TILMAN (1988) has argued that competition occurs across all productivity gradients, but for which resources may differ. In unproductive environments, competition is primarily for belowground resources and switch to competition for light in more productive environments. MENGE and SUTHERLAND (1987) plead for highest competition at intermediate productivity due to stress limitation under unproductive and grazing limitation under high productive conditions. In case of the desert steppe, it appears as a key question whether water deficiency is a source of competition or a physical stress. As shown so far, availability of water depends more on abiotic conditions as precipitation and soil texture and less on biotic conditions as the density of vegetation cover and associated amount of water uptake by plants. Water deficiency reduces or prevents the utilisation of mineral nutrients especially of N due to reduced diffusion ability (Mengel 1991). Hence, water deficiency has to be assumed less a source of competition than physical stress (FARGIONE and TILMAN 2002). Up to a certain degree of water deficiency, which is probably given but not proved in case of desert steppe, grazing effects on competition processes among plants are overlaid by stress because grazing cannot improve water availability through the reduction of vegetation. In this case, plants do not compete against others for water, and only resist drought stress. This finding represents the spatial scale of plant communities, at which species composition, species abundance, and dominance depending on edaphic conditions are examined (cf. Chapter 4.3.2). Findings on the spatial scale of population, at which numbers and biomass of plant specimens are examined, indicate competition in an *Artemisia xerophytica*-semi-shrub desert steppe (see relationship of average shrub weight and shrub density in Chapter 3.3.2), referring to the role of scaling in ecology (O'NEILL 2001, TURNER 1989, WIENS 1989) especially in rangeland ecology (BRISKE 2003, FUHLENDORF and SMEINS 1999, LANDSBERG et al. 2002). Thus, the suggestion of the preponderance of drought stress compared to competition for water in desert steppe has to derive as a main hypothesis of the study and has to be tested in further investigations.

In case of mountain steppe, competition takes place primarily for water due to the strong arid conditions during the vegetation period in summer, and the higher density of plants with dense root mass (GADZHIEV et al. 2002).

In the alpine belt, where the most dense vegetation cover of the total altitudinal belt is met, dominant plants have short growth form. Small cushion and sedge plants are best adapted to harsh climatic conditions of high mountains. They primarily compete for aboveground and belowground place. To which extent the harsh climatic conditions of the alpine belt affect physical stress with higher influence on species composition than interspecific competitive effects, is a question of further research. The occurrence of fine and tall species as e.g. *Anemone sibirica* only in climatically sheltered conditions of rocks and crevices might be an indication of the limitation of harsh climatic conditions (own observations 2003). Thus, similar as for the desert steppe, it can be hypothesised that the role of competition is limited due to extreme climatic conditions. As an additional hypothesis of the study, it has to be tested in further investigations.

### 2.7.4 Grazing effects along the altitudinal belt

Grazing impact causes different patterns in all vegetation formation. In the desert steppe, grazing effect is proved up to a distance of 100 m from grazing hot spots within one plant community, which represents the edaphically wettest community. Grazing mainly represents a direct impact on vegetation as disturbance impact. The indirect impact on vegetation through redistribution of soil nutrients via fertilization or the removal of upper soil layers caused by trampling is only marginal (cf. BATKHISHIG 2000). Grazing influence causes an only slight eutrophication with an obvious increase in vegetation cover with slightly higher species richness through the occurrence of additional annual species representing ruderal plants. However, to which extent the sustainable occurrence of annual species additionally depends on the amount of summer precipitation or on grazing, can only be enlightened in a temporal comparison of vegetation data, which is not recorded in this study. In the desert steppe, the influence of grazing on soil and vegetation is not sufficient to describe grazing-induced plant communities based on altered site conditions. Thus, grazing as community-driving ecological factor cannot be proved in the desert steppe.

In the mountain steppe, impacts of grazing could be detected in both plant communities up to a distance of 40 m from grazing hot spots. Grazing consists of a direct impact on vegetation and an indirect impact through fertilisation, enhanced salinity, and soil basicity. The direct and indirect impact on vegetation in contrast to the desert steppe leads to a loss of species with enhanced vegetation cover, and an attenuation of floristic differences among communities. Remaining species of grazing communities mainly represent disturbance-associated and grazing tolerant species, specialists of nutrient-rich sites and survivors of the communities of origin. In grazed communities, the proportion of annual species is obviously increased. Similar to the desert steppe, the grazing influence on edaphic moister community results in a higher impact on soil and vegetation, than on a drier community through a stronger modification of species composition, and a higher degree of fertilisation. However, to which extent the higher grazing impact is caused by edaphic moisture, representing a community more sensitive to grazing or more favourable relief conditions for animal access could not be clarified. The considerable impact of grazing on soil and vegetation allows the classification of separate grazing-induced communities, and confirms grazing as an additional vegetation-driving ecological factor.

In the alpine belt, the influence of grazing could be proved in all communities up to a distance of 100-800 m from the grazing hot spot. Similar as in the mountain steppe, the grazing impact consists of a direct impact on vegetation, and an indirect impact through the depletion of soil nutrient supply. The direct impact on vegetation consists of a biomass extraction, higher than in the desert steppe and the mountain steppe, which may additionally explain the depletion of soil nutrient supply. Compared to the mountain steppe, the direct grazing impact on vegetation leads to a marginal loss of species. An obvious decrease in vegetation cover could be recorded only in the lower alpine belt. Grazing-induced new occurring species in the alpine belt represent disturbance-associated species, ruderal species, and species which have their main area of distribution in lower and drier altitudinal belts. The proportion of annual species in grazing communities is only slightly increased. A comparison of the degree of grazing impact among plant communities needs an elaborated concept because communities differ in edaphic moisture and moreover in altitudinal distribution, in water regime and hence, in composition of live forms. Thus, they represent different vegetation formations with a different ecology. External impacts as grazing will induce different processes with different patterns that have to be considered in a elaborated concept of assessment. However, the spatial extension shall nevertheless be consulted: the community of habitats with water surplus indicates the most extended spatial influence of grazing. The grazing impact on soil reflected by vegetation allows the classification of separate grazing-induced communities, and confirms grazing as an additional vegetation-driving ecological factor similar as in mountain steppe.

Along the altitudinal gradient, the grazing influence shows different intensities with different patterns: in the desert steppe, only one of the three communities indicates a slight grazing impact, which is not sufficient to derive a separate grazing-induced plant community. In the mountain steppe and the alpine belt, all communities indicate obvious grazing impacts, which form separate grazing communities, and confirm grazing as a plant community-driving ecological factor. Detectable spatial extension of grazing influence extends from 100 m from grazing hot spot in the desert steppe, via 40 m from grazing hot spot in the mountain steppe to 100-800 m from grazing hot spot in the alpine belt. In the desert steppe, direct grazing impact on vegetation is prevailing. In the mountain steppe and the alpine belt, grazing represents a direct impact on vegetation and an indirect impact on vegetation via changed soil conditions. Direct impact leads to an increase in species richness in favour of annual species accompanied by the increase of vegetation cover in the desert steppe. In the mountain steppe, it causes an obvious loss in species richness also in favour of annual species accompanied by an increase of vegetation cover too. In the alpine belt, only a slight decrease in species richness but also in favour of annual species is recorded. While vegetation cover in the lower alpine belt obviously decreases, it remains almost unchanged in the communities of the upper alpine belt. Compared to the slight modification in species composition, the depletion of soil nutrient supply indicates an enhanced rather indirect than direct effect of grazing in the alpine belt. In all vegetation formations, changed species composition under grazing influence consists of the increase of annual ruderal and disturbance-associated species. In the mountain steppe, specialists of nutrient-rich sites and in the alpine belt, indicators of dryness with the main area of distribution in lower and drier altitudinal belts additionally appear. Indirect grazing impacts on soil consist in a slight fertilisation in the desert steppe, an obvious fertilisation and an increased content of phosphorus with wider variations in the mountain steppe, and a depletion of soil nutrient supply but increased phosphorus in the alpine belt.

In a comparison of ecologically closely related communities differing only in soil texture, the grazing influence seems to be stronger in the communities representing edaphic moister conditions within one altitudinal belt. This pattern seems to repeat the pattern of grazing influence along the altitudinal gradient with less recordable grazing impact in the dry desert steppe and increasing recordable grazing impacts in moister and higher elevated vegetation formations. It leads to the assertion: the wetter an ecosystem is, the more a grazing influence can be assumed in it.

### 2.7.5 The role of herbivory as vegetation-determining factor

Since herbivory as an important factor of vegetation dynamics in ecosystems worldwide is a central issue of plant ecology, as well as community ecology, many concepts and models on its role in plant strategies, vegetation dynamics and ecosystem properties have been developed. Thus, presented results of different grazing effects along the altitudinal belt have to be discussed from widened perspectives with the objective to assess the role of further herbivory-associated vegetation-determining factors regarding their interaction with site-ecological factors. The basic question, why the consequences of herbivory differ across environmental gradients, is multiplicatively discussed in literature (CHASE et al. 2000; GRIME 1979, 2002; HUSTON 1979; MILCHUNAS et al. 1988; OKSANEN et al. 1981; OLFF et al. 1999; PROULX and MAZUMDER 1998; SANKARAN and MCNAUGHTON 2005; TILMAN 1988). This discussion is presented here against the background of study results.

OLFF et al. (1999) give a profound survey on **herbivory depending on interactions within the food web,** and how it affects the structure of plant communities in space and time. Therein HUISMAN et al. (1999) and RITCHIE and OLFF (1999) suggest that the resources the plants are competing for, determines the patterns of herbivory effects and emphasises the role of mechanisms of plant competition. The patterns are summarised by RITCHIE and OLFF (1999), which focus on four different types of habitats in a combination of dry or moist with poor or rich soils. When dominant plants on poor soils (moist or dry) compete for soil nutrients in the absence of herbivory, species assemblage of these habitats consists in a mosaic of abundant plants with low-quality of nutrients in leaf tissue, and rarely appearing plants with high quality of nutrients in leaf tissue. The former may support large herbivores with high metabolic requirements at moist sites where productivity is sufficiently high, while the latter support small herbivores. Both yield compensatory effects of multiple herbivores with weak or negative effects on plant species diversity. In case of dry and poor sites, only small herbivores are supported by low productive vegetation consisting on prevailing low-quality plants. These cases represent a bottom-up control, where plant producers determine herbivore consumers. If dry and poor sites are grazed by large herbivores or diverse herbivore assemblage, dramatic negative effects on plant diversity and on species composition have to be expected - a case of top-down control, where herbivore consumers determine plant producers. When dominant plant species, competing for water on dry and rich soils, are subjected to intense herbivory, they can tolerate it through unlimited regrowth on the base of sufficient soil nutrient supply. Thus, diverse herbivores may consume palatable plants with high tissue nutrient concentrations (supported by rich soils) with relatively little effect on vegetation. On moist and rich soils, where plants primarily compete for light, herbivory mainly concerns dominant light competitor plants, and leads to an increase in species diversity because plants with less competitive ability may immigrate - a case of bottom-up control.

Described patterns may multiplicatively vary depending on plant properties such as palatability of plants (not all plants on rich and moist soils are highly palatable e.g. Cyperaceae of alpine sedge mats, cf. JIGJIDSUREN and JOHNSON 2003, YUNATOV 1954), effectiveness of defence against herbivory, and ability to compensatory growth. Furthermore, the patterns depend on the herbivore assemblage and their fodder preferences (selective consuming depends on the density of vegetation cover, and the necessary energy to browse it; own observations 2002-2005), and the consequences of changed microenvironment caused by herbivores. Moreover, in ecosystems as the investigation area of western Mongolia with a long evolutionary history adapted to herbivory, already reduced plant species pool with primarily grazing tolerant species exist. This may further strongly affect herbivory patterns (MILCHUNAS et al. 1988). As hypotheses derived above, presumably only in the mountain steppe important competition for water appears while in the desert steppe the high water deficiency and in the alpine belt the harsh climatic conditions may cause prevailing environmental stress. Thus, the patterns summarised by RITCHIE and OLFF (1999) do not ideally conform to the study but may offer important perspectives for a comprehensive explanation approach.

PROULX and MAZUMDER (1998) reviewed the literature in a worldwide comparison of effects of **grazing** enclosure, and grazing enclosure **along nutrient gradients**. They detected that under grazing influence species diversity increases in nutrient-rich habitats and decreases in nutrient-poor habitats. Similar to the formerly cited study, as explanation they suggest that nutrient limitation may prevent species regrowth, thereby decreasing diversity. Additionally, in nutrient-poor habitats only few specialists found their niche. Species intolerant to grazing are removed by herbivores, only few remain in the pool, and no further species are able to occupy the released niche, so that consequently species diversity cannot increase. In nutrient-rich habitats, the converse effect is expected (cf. SANKARAN and MCNAUGHTON 2005). Even if the outcome does not conform to the presented results (due to the increase in species richness in desert steppe), the influence of herbivory on environmentally narrow niches refers to conditions of the desert steppe and the alpine belt. PROULX and MAZUMDER (1998) present 30 studies providing 44 comparisons from lake, stream, marine, grassland and forest ecosystems between arctic and tropical regions. On a closer examination, only five studies comprise terrestrial habitats without an obvious nutrient gradient, while a precipitation gradient from Sonoran Desert in Arizona to deciduous forest in Uttar Pradesh, northeast India with annual precipitation of 900-1000 mm becomes discernable. With this view of increased resolution, results present a prevailing increase in species diversity in arid ecosystems, and a decrease in more humid ecosystem. In this perspective, it conforms much better to results of the present study.

A main question, joining the approach of **herbivory with food web interactions along nutrient gradients** is, whether the detected changes in species composition in the transition from rich to poor sites are caused by changed mechanism for what plants compete for, which reflects the above mentioned model of TILMAN (1988). Or do they indicate a declining importance of competition and enhancing importance of other selective mechanisms such as resource limited stress like water deficiency which reflects the above mentioned model of GRIME (1979, 2002)? As already pointed out, the presented study partially agrees with GRIME (1979, 2002) based on FARGIONE and TILMAN (2002), due to the stress of water deficiency in desert steppe, and climatic stress in the alpine belt, which are to be assumed to overlap strongly the conditions of competition.

At this point, the medium disturbance hypothesis suggested by HUSTON (1979) should be mentioned, even if it does not meet the study situation. It assumes that herbivory along **grazing intensity gradients** causes the highest diversity at medium disturbance because disturbance postpones competition exclusion and removal of dominant species prolongs coexistence of species. Additionally, grazing as a disturbance provides safe sites for new seedling recruitment. From habitats of poor environment and low regrowth to habitats of rich environment and regrowth, the medium disturbance as the reason for the highest species diversity increases.

The evaluation of empirical data by CHASE et al. (2000) on **plant-herbivore interactions along a precipitation gradient** has the closest relation to the present study design. They evaluated the relationship between precipitation as a predictor of primary production and vegetation. They identified that the relative effect of herbivores on plant biomass decreases with increasing precipitation, but the ability of herbivores to influence plant species composition increases with precipitation. Both is explained by resources-controlled (bottom-up control) and by consumers-controlled (top-down control) food chain interactions. This pattern was already reflected in the ‘Fretwell-Oksanen hypothesis’ of ecosystem exploitation (OKSANEN et al. 1981 cited in GRIME 2002) developed with specific reference to mammalian herbivores and carnivores. The basic message of Fretwell-Oksanen hypothesis is that the influence of animals on vegetation depends upon productivity: at the lowest productivity, the plant cover is too small or unpalatable to support large populations of herbivores. At intermediate productivity, herbivore number rises and has important controlling effects on vegetation quantity and quality. As productivity still rises, herbivores become a consistent food source for their carnivore predators, which become sufficiently numerous to guarantee by a ‘top-down control’ large and relatively stable and palatable plant biomass. The described patterns largely conform to grazing patterns of this study. Nevertheless, food web structure of ecosystems is primarily human-controlled by grazing utilisation and the pristine but not existing state does not serve as an explanation of grazing effects of domestic livestock. However, the conditions of a traditional and sustainable operating grazing management may conform to the patterns of the food web of a natural ecosystem as shown for the investigation area below.

Ultimately, neither consumer-controlled nor resource-controlled models may satisfactorily explain patterns of herbivory across gradients of productivity, soil nutrients, and interactions within the food web. For a better understanding, the underlying mechanisms of herbivory as the intrinsic properties of plant species such as palatability, effectiveness of grazing defence, phenology of palatable and unpalatable species, ability to compensatory growth, decomposing quality, and extrinsic properties of ecosystems such as the fodder preferences of herbivore assemblage, by herbivory changed micro-environment in soil and vegetation and many others has to be considered (CHASE et al. 2000, PROULX and MAZUMDER 1998, RITCHIE and OLFF 1999, SANKARAN and MCNAUGHTON 2005). Moreover, the perception of grazing effects behind these models depends on the spatial scale of inquiry (SANKARAN and MCNAUGHTON 2005, cf. issue of spatial scale in Chapter 4.4).

Cited literature summarised indicates that herbivory affects vegetation in species composition and production of biomass along a wide range of productivity. Intensity and patterns of vegetation-herbivore interactions vary depending on (I) site conditions, resource availability and thereof depending mechanism of competition (for what plants are competing), (II) precipitation and productivity, (III) intensity of herbivory as a degree of disturbance, (IV) the evolutionary history and evolved adaptation of vegetation to herbivory and (V) so far called underlying mechanisms of herbivory.

However, the majority of cited concepts originates from humid ecosystems of temperate zone and bases on succession theory of vegetation dynamics according to CLEMENTS (1916) and the underlying equilibrium model of ecosystem behaviour (HOLLING 1973, MAY 1977). Integrated in the equilibrium model, they can be summarised as internal ecosystem regulation and stability, but are over-emphasised for an understanding of vegetation dynamics in arid ecosystems (BRISKE et al. 2003, WIENS 1984). The present study was carried out in an arid ecosystem in the transition area from the Eurasian steppe to the desert zone (KARAMYSHEVA and KHRAMTSOV 1995) but includes humid study sites in the high mountain belt. Vegetation dynamics of arid ecosystems with precipitations below 300 mm per year conform better to models of vegetation dynamics as the state-and-transition model (WESTOBY 1980, WESTOBY et al. 1989) or threshold model (FRIEDEL 1991, LAYCOCK 1991), and relate to non-equilibrium model of ecosystem behaviour (ELLIS and SWIFT 1988, FERNANDEZ-GIMENEZ and ALLEN-DIAZ 1999, Wiens 1984). The non-equilibrium model over-emphasised external drivers of ecosystem dynamic as rainfall variability and episodic events and neglected above mentioned discussed internal ecosystem regulations and stability (BRISKE et al. 2003, VETTER 2005, WIENS 1984). The results of the desert steppe in a perspective of recent discussion of rangeland ecology of arid ecosystems are discussed in the final Chapter 4.4.

### 2.7.6 The role of competition and herbivory as vegetation-determining factors in the examined ecosystems

In the present study, competition and interactions within the food web on the scale of plant community have only subordinated explanation value because firstly, as hypothesised above, competition can be assumed to be overlaid by environmental stress. Secondly, interactions within the food web are disturbed since herbivory is anthropogenically controlled and does not reflect natural conditions of a virgin food web structure. Thus, both conditions should be considered rather as underlying mechanisms modifying the effects of herbivory, which are primarily controlled by environmental constraints including conditions of stress, precipitation and associated productivity of vegetation cover. However, it remains to include patterns of land-use in the explanations on observed phenomena.

The lack of detectable influence of grazing on desert vegetation in arid Asia was already mentioned in the early literature. NECHAEVA (1976) reports a decrease in forage yields by 20 percent in the vegetation of Karakum desert as a result of the absence of 4-5 years of grazing. ANTONOVA et al. (1986) explain that degradation of Karakum vegetation with the evolutionary adaption to ungulates and their footsteps, which is necessary to a certain degree to conserve vegetation cover. The lesser influence of grazing primarily on vegetation (and soil which is more rarely examined) in Mongolia’s desert steppe compared to the mountain steppe and the alpine belt is reported in the beginning of the 1980s. According to BABAEV and SARANTUYAA (1995), BORISOVA et al. (1981), DANZHALOVA (2005), and SLEMNEV and GUNIN (2000), communities of vegetation of desert and dry steppe reflect lesser indications of grazing degradation than steppe communities. In the first methodical observations of this phenomenon, FERNANDEZ-GIMENEZ and ALLEN-DIAZ (2001), WESCHE (2005), WESCHE and RETZER (2005) demonstrate a lesser sensivity to grazing of desert steppe than steppe, mountain steppe or vegetation of the alpine belt. STUMPP et al. (2004), KNOPF and WERHAHN (2004) show that soil nutrients decrease with increasing distance to grazing hot spots while vegetation reflects no grazing influence or a slight increase in annuals respectively in the desert steppe and dry mountain steppe. Furthermore, variations of plant communities in species composition and species richness between the years are higher than among exclosures and unfenced controls (WESCHE and RETZER 2005). These results partly conform to the present study outcomes and to patterns detected by CHASE et al. (2000) and PROULX and MAZUMDER (1998). They correspond with grazing patterns described with the ‘Fretwell-Oksanen hypothesis’ of ecosystem exploitation (OKSANEN et al. 1881 cited in GRIME 2002) even if they are therewith not sufficiently explained since underlying mechanisms of herbivory are not considered for these special arid ecosystems.

## 2.8 Conclusions in consideration of climatic, ecological, and grazing peculiarities of the investigation area

In the following, an explanation of the different grazing effects of examined vegetation formations is given with additional consideration of the climatic, ecological, and grazing peculiarities of the investigation area.

The role of vegetation as a site-determining factor increases with increasing productivity. It is still limited in the dry desert steppe but enhances in upward direction from the mountain steppe on. Herbivores directly influence vegetation what means, the more vegetation determines its site, the more vegetation and its site conditions are changed by grazing. Moreover, limited influence of vegetation and consequently limited influence of energy cycling and nutrient supply on ecosystem functioning in desert steppe may explain the prevailing direct grazing impact on vegetation. Only in the mountain steppe and alpine belt, where influences of vegetation on soil becomes obviously, grazing impacts are linked with energy cycling leading to redistribution of nutrients as fertilisation in mountain steppe or nutrient depletion in the alpine belt. All environmental attributes controlling vegetation of desert steppe represents abiotic attributes, which are not susceptible to grazing.

With increasing aridity, which complies with decreasing altitude, the belowground/aboveground ratio of biomass as well as the root/shoot ratio of dominant plants is increasing (GADZHIEV et al. 2004, VAN DER MAAREL and TITLYANOVA 1989). In the steppe vegetation of Central Asia, between 70-90 percent of living phytomass is hidden belowground (TITLYANOVA et al. 1999). A strategy of translocation of organic substances to rhizomes and roots causes sustainability in an arid, climatically variable environment and ensures furthermore a resistance to grazing. It reflects an evolutionary grazing history of an arid steppe ecosystem (TITLYANOVA and ROMANOVA 1997). Thus, in the desert steppe much more regeneration potential in terms of living biomass is stored belowground and may sprout stronger after grazing than in higher altitudinal belts. Moreover, various plants of desert steppe and steppe are capable to enhanced compensatory growth after cutting loss of apical plant parts (FERNANDEZ-GIMENEZ 2000, HILBIG and OPP 2005, STAALDUINEN et al. 2005, own observations 2003). In addition, total vegetation of the investigation area comprises prevailing perennial species, retiring belowground with living biomass in cold wintertime. The proportion of shrub species with living by livestock accessible twigs all the year is lower with 10 percent even in the desert steppe than of semi-shrub species with 23 percent (own data).

The influence of herbivory on competition has to be assumed as limited in the desert steppe and the alpine belt due to high pressure of environmental stress. Hence, competition models do not serve as explanations for grazing effects in a stress-controlled ecosystems as desert steppe (and probably as alpine belt). This scale-depending assumption appears on the scale of plant community and can only be tested on scales of individual plants keeping the consequences for management strategies in mind.

The grazing patterns of pastures, which in the investigation area of Khovd province still follow a traditional way (GENDENZHAVYN 1995), has to be considered as an effective adaption to the limited ecological constraints. Study areas of higher elevated desert steppe and mountain steppe, both due to temperature inversions serve as winter pastures, which are grazed from the beginning-middle of November until the end of February. Areas in lower desert steppe serve as spring pastures, grazed from the end of February until the beginning of June (VASHA 2005). Thus, biomass uptake by livestock starts not until vegetation has finished and not before it has started its cycle of reproduction, disappeared with living organs belowground, left behind dry dead matter keeping high nutrient value during wintertime. Thin or missing snow cover of Mongolian winter facilitates the access of livestock to vegetation biomass all the year round. The dryness and low average temperatures of Mongolian autumn, winter and spring enable the conservation of high nutrient values of dry biomass (in Russian - vetoshi). From winter until the first half of summer, it keeps up to four times more biomass than green parts of plants and first from the mid June, the majority of dry biomass diminishes. In July and August, its complete decomposition is fostered by precipitation and summer temperature (GORSHKOVA 1966). The investigation area of the alpine belt serves as summer pasture from the middle-end of June until the end of August (KENTER 2005, VASHA 2005). Hence, the alpine belt as a vegetation formation with highest productivity is grazed during the vegetation period, which coincides with lactation and reproduction period, when livestock require highest nutritive energy (GLATZLE 1990). The vegetation of alpine belt has to be considered as a vegetation formation most of all capable to compensate grazing pressure during the vegetation period due to its high productivity. Beside the seasonal patterns of grazing, the density of livestock follows the pattern of productivity too. Data from 1982-2003 document an increasing density of livestock in the study areas from the desert steppe to the alpine belt (VASHA 2005). Even if total livestock numbers changed considerably after privatisation between 1991-1993 in total Mongolia (JANZEN and BAZARGUR 2003) as well as in Khovd province (VASHA 2005), these patterns remained constantly. The increasing livestock density is also accompanied by increasing density of herders at summer pastures (cf. JANZEN and BAZARGUR 1999, VASHA unpublished data) due to higher productivity and moreover, due to higher workloads at the end of the summer during the harvest period, when the fattening of livestock finishes and food supply for wintertime has to be prepared. It demonstrates how nomadic grazing patterns follow the ecological patterns of productivity and of vegetation phenology, which provide the basis of the theory of ‘nomadism as a socio-ecological mode of culture’ (SCHOLZ 1995), and is confirmed by MÜLLER (1999) for recent Mongolian nomadism.

These special Mongolian backgrounds represent some further main reasons of increasing grazing sensivity of ecosystems along a precipitation gradient, which are not sufficiently considered in models of herbivory.

# 3 Grazing effects on the population of *Artemisia xerophytica*

## 3.1 Summary

Data about stand density, aboveground biomass, individual plant weight and the proportion of flowering plants of the dwarf semi-shrub *Artemisia xerophytica* were collected along a grazing gradient defined by increasing distance (0 to 2000 m) from grazing hot spots in a desert steppe ecosystem in western Mongolia. Soil data were used to distinguish between grazing and edaphic influences.

All parameters recorded for *Artemisia xerophytica* reflect the assumed gradient of grazing intensity up to 800 m distance from the grazing hot spot. As grazing pressure decreases, plant density and total biomass per plot increase. The average shrub weight, an indicator of plant vitality, is related to both: positively to distance from the grazing hot spot and negatively to stand density, which may be explained by additional intraspecific competition at higher densities. At a longer distance these effects are masked by variations in soil parameters determining water availability, leading to quite similar degradation forms.

These results are in contrast to other studies carried out at the scale of plant communities which did not detect significant changes along a grazing gradient. One explanation is the different map scale; the study took place only within a single plant community comparing different populations of one species.

## 3.2 Material and methods

### 3.2.1 Study material and study area

*Artemisia xerophytica* is common dwarf semi-shrub in the desert steppe communities of southern and western Mongolia (GUBANOV 1996, HILBIG 1995). Being a well palatable, important fodder plant especially suited for fattening camels in autumn, winter and spring (JIGJIDSUREN and JOHNSON 2003, YUNATOV 1954) it can be seen as a key species to detect grazing influence.

The sampling area is situated at the north-eastern shore of Lake Khar Us Nuur in the Great Lake Basin in Doergoen district; a part of western Mongolia's Khovd province (Fig. 30). It touches the northern part of the Agvash Uul Peninsula at 1150 m a.s.l. and extends for 6 km in northern direction. Dominated by *Artemisia xerophytica*, the study area represents a typical ecosystem of western Mongolia's dry rangeland.

Situated on the lee side of the Altai Mountains, the investigation area receives only 62 mm mean annual precipitation with a high interannual fluctuations varying between 11-140 mm. About 70-90 percent of all precipitation occurs in summer. The extreme continental climate of the region is characterised by long, cold and dry winters with mean monthly temperatures below –20 °C in January as the coldest month. The summers are short and hot with mean monthly temperatures of 23 °C in July as the warmest month. Transition seasons in spring and autumn are very short. Extreme daily and annual temperature fluctuations are typical for the region (BUYAN-ORSHIKH 1988; CLIMATE STATION DOERGOEN 1985-2000, located approx. 5 km northeast from sampling area). Due to common gaps in Mongolia's climate station records, it was tried to verify these data by comparison with those from other climate stations and by questioning of local people about extreme years. The climate model of BÖHNER (2004) gives a mean annual precipitation of 52 mm, a value slightly lower than the 62 mm recorded by the Climate Station Doergoen. With annual precipitation of 182 mm reported by the Climate Station Doergoen for 2003 (the highest value since 1985), the investigation was carried out in an extremely moist year.

In the study area, the prevailing type of soil is a sandy weak alkaline Burozem with pH values between 7.3–8.2, an intense calcium carbonate-dynamics and low content of organic matter (see Tab. 11).

The area is covered by an *Artemisia xerophytica* desert steppe community with an average total vegetation cover of 13 percent, varying between 5-30 percent. Dominant and regularly occurring perennial species are *Stipa glareosa*, followed by *A. xerophytica* and *Anabasis brevifolia.* Annual grasses and herbs like *Aristida heymannii*, *Bassia dasyphylla, Agriophyllum pungens* and *Eragrostis minor* were found to be common in 2003, but may give only a notable contribution to vegetation cover in moist years. The shrub *Caragana leucophloea* as described by HILBIG (1990, 1995, and 2000) for the closely related community Artemisio xerophyticae-Caraganetum leucophloeae does not appear in the investigated sandy plain but can be found at the shallow slopes of adjacent hills where the proportion of gravel in soil is higher. Shrubs like *Krascheninnikovia ceratoides*, *Atraphaxis frutescens*, *A. pungens*, and *Calligonum mongolicum* described by HILBIG (1990, 1995, and 2000) as a typical component of Artemisio xerophyticae-Caraganetum leucophloeae are absent in the community.

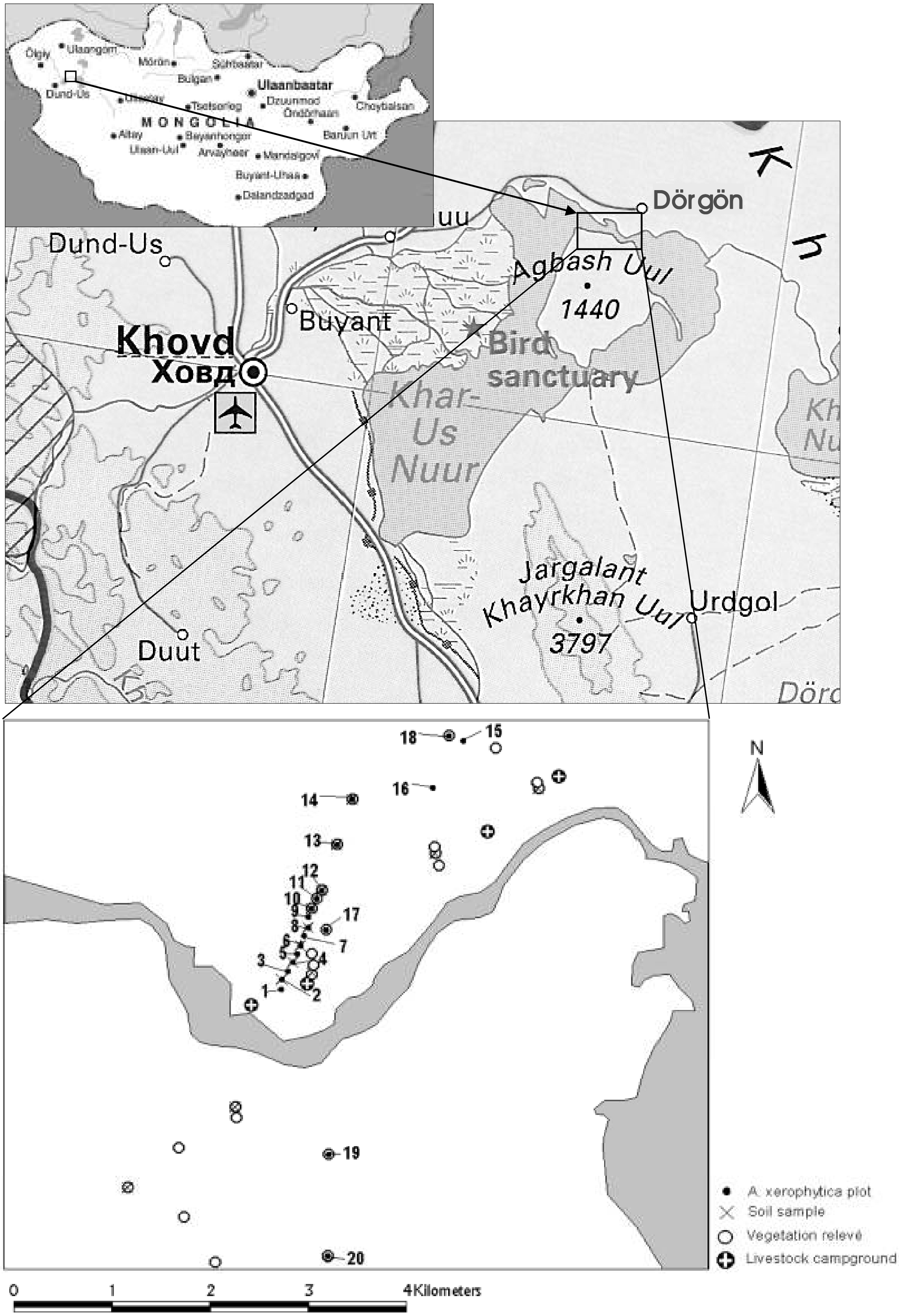


Fig. 30: Position of the study area in the Great Lake Basin in western Mongolia (modified from Tibet Family, Tours and Travel; ITMB Publishing Ltd 2000).

Fig. 31: Flowering plant of *Artemisia xerophytica* (Photo: M. Schnittler 2003).

The whole study area is used as spring pasture. During the grazing season herders set up their gers (ger – Mongolian, traditional tent of Mongolian herders) along the river. Data of Doergoen district indicate an increase of livestock numbers as a result of privatisation between 1991 and 1993 which can be attributed mainly to an increase in numbers of goat and sheep. The decrease from 1999 – 2002 was caused by several consecutive years of severe winters followed by summer drought (Fig. 32).

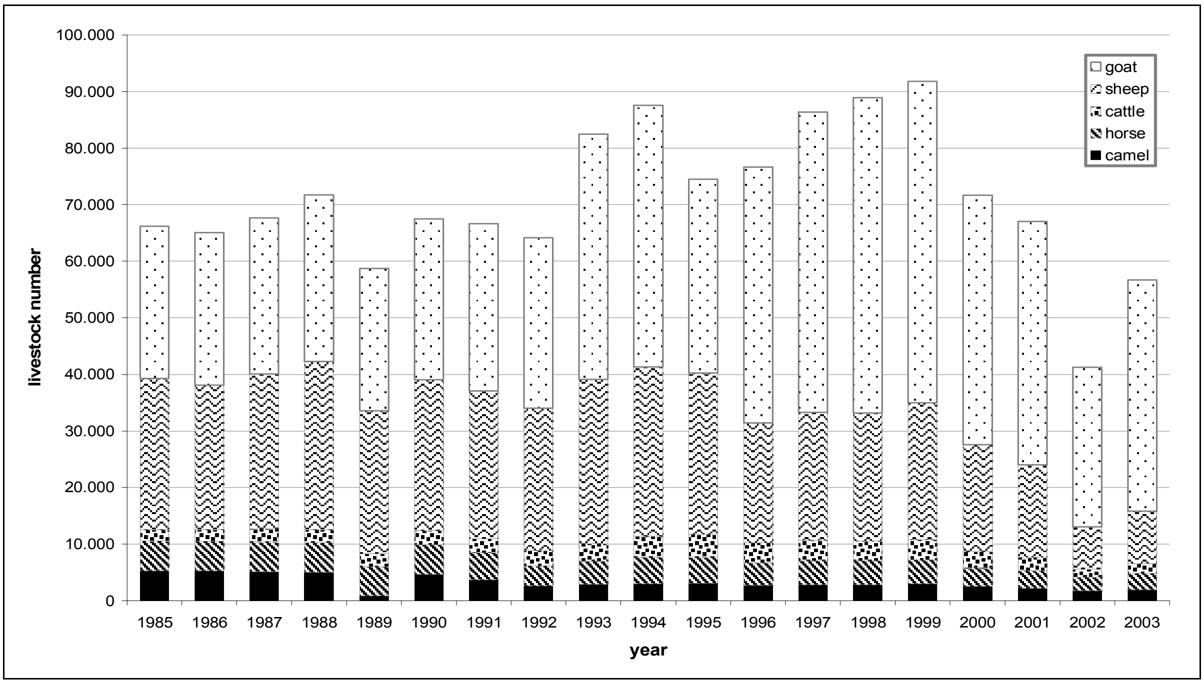


Fig. 32: Annual counts for livestock numbers of Doergoen district in Khovd province (Office for statistical data of Khovd province administration, collected by Octyabr Vasha 2004).

### *3.2.2 Sampling methods*

The choice of sampling plots follows the concept of grazing gradient according to ANDREW (1988) and ANDREW and LANGE (1986). It assumes that grazing intensity decreases with increasing distance from grazing hot spots like water sources or livestock campgrounds. All data were collected during summer 2003 and thus avoid the influence of interannual precipitation variation on vegetation as a typical feature of arid and semi-arid grassland ecosystems. Sampling plots were established as transects starting from obvious livestock campgrounds. A first (northern) transect was intensively sampled with 18 plots; a second (southern) transect was established to provide data for the opposite direction (Fig. 30). One of these campgrounds is used by a ferryman living and herding livestock around the year. Consequently, grazing pressure affects the environment over the whole year and can be assumed as highest in the area. Observations on daily pastoral movement patterns show that sheep and goats, providing the majority of livestock in the study area (Fig. 32), are herded every day around 3–5 km away from the camp but spent the night in these campgrounds (KENTER 2005). This utilization pattern should translate into a clear-cut grazing gradient in the sense of the concept. Counts of faecal pellets, a usual method to validate grazing gradients, had been proved to be inappropriate in the study area since pellets are moved away by wind and accumulate under shrubs.

Twenty plots each comprising 10 x 10 m were sampled (no. 1-20). Together with all livestock campgrounds and ger camps situated nearby their position was recorded with a handheld GPS device.

Shrubs of *A. xerophytica* were counted in all plots. Additionally, in a subset of the 20 plots the number of living, sterile and flowering plants was recorded also at 100 sqm (all plots except 15 and 16). The above-ground biomass of all *A. xerophytica* was cut and weighed fresh. From 100 individual shrubs weight was measured as fresh weight to obtain an average for individual plant weight per each plot. Biomass measurements were carried out in the field immediately after harvesting using PESOLA spring scales. Tests with digital lab scales resulted in different values only for weights below 1 g. Vegetation relevés including all vascular plants together with soil samples were collected for selected plots (Fig. 30). Nomenclature of vascular plants follows GUBANOV (1996).

### *3.2.3 Soil analyses*

For each of eight plots three volume samples from the first 10 cm of topsoil were collected and analysed as a mixed sample (Tab. 11). The analyses comprise pH in $CaCl_2$; total soil carbon and total soil nitrogen (N) by means of dry combustion at 1200 °C in a CN analyser (Elementar Analyser "Vario EL"/Germany) with mathematical calculation of soil organic carbon ($C_{org}$) and $C_{org}$/N by subtraction of mineral carbon containing in carbonate; $CaCO_3$ according to Scheibler (AG BODEN 1994); electrical conductivity (EC) as a degree of total salinity in a soil-water saturation extract; effective cation exchange capacity ($CEC_{eff.}$) with $BaCl_2$ as exchange solution and $MgSO_4$ as re-exchange solution and measured with an atomic absorption spectrometer; plant available P by extraction of $PO_4$ with citric acid and mathematical conversion into pure P equivalents; and soil texture with content of gravel and content of sand, clay and silt in fine soil part. The sand fraction was analysed with the sieving method, but clay and silt fractions were analysed with the pipette method. All analyses were conducted in the soil laboratory at the Institute of Botany, University Greifswald.

To assess edaphic influences on growth features of *A. xerophytica*, soil data and cover values from additional vegetation relevés of the area are included (Fig. 30).

### *3.2.4. Data analyses*

All vegetation data and soil nutrient values were tested for correlation with the grazing gradient; soil data were furthermore used to differentiate edaphic from grazing influences.

Because data are not normally distributed and because of the assumption that there is no linear correlation between *A. xerophytica* attributes and distance from grazing hot spot, the bivariate Spearman rank correlation was applied to test the relationship of vegetation parameters with distance from the grazing hot spot (TREMP 2005). Statistical analyses were conducted using the SPSS 11.5 software-package. Graphs with vegetation parameters of *Artemisia xerophytica* were created in Sigmaplot 8.0.

## 3.3 Results

### *3.3.1 Soil*

All investigated plots are situated between 250 and 2000 m distance from the next grazing hot spot. No significant correlation exists between soil nutrient level and distance to the grazing hot spot (Tab. 11). Values of P fluctuate within a range of 1300 to 1890 ppm dry matter. No significant correlation exists between P content and cover of *Artemisia xerophytica* ($r_S = 0.180$ / p = 0.05). The same holds true for EC (- 0.183 / 0.05) and clay content (-0.261 / 0.05). Only CEC$_{eff.}$ indicates a significant correlation with cover of *Artemisia xerophytica* (-0.410 / 0.01). EC and CEC$_{eff.}$ show similar distribution patterns to clay. Both variables are significantly correlated with clay (EC: 0.821 / 0.01, CEC$_{eff.}$: 0.281 / 0.05). Due to EC in sandy soils clay may hamper mineral leaching and support a precipitation of salts with uprising soil water stream in summer. In soils poor in organic matter, only clay serves as medium of exchange and thus CEC mostly depends on clay content. EC values vary from 1-9 ms/cm. Clay content varies from 3-19 percent (Tab. 11).

All other soil variables have a much lower variance and show no correlation with cover values of *Artemisia xerophytica*.

| **Plot no.** | **4** | **2** | **6** | **8** | **10** | **12** | **14** | **13** | **$r_S$ with distance from graz. hot spot** |
|---|---|---|---|---|---|---|---|---|---|
| **Distance from grazing hot spot [m]** | **250** | **310** | **350** | **500** | **700** | **900** | **1400** | **1450** | |
| **P content [ppm dm]** | 1412 | 1300 | 1289 | 1878 | 1888 | 1737 | 1509 | 1564 | 0.476 / 0.05 |
| **Corg [%]** | 0.08 | 0.12 | 0.11 | 0.24 | 0.09 | 0.12 | 0.04 | 0.11 | - 0.108 / 0.05 |
| **N [%]** | 0.02 | 0.02 | 0.03 | 0.04 | 0.02 | 0.04 | 0.01 | 0.02 | - 0.153 / 0.05 |
| **Corg/N** | 4.4 | 5.4 | 4.2 | 6.2 | 4.8 | 2.9 | 3.1 | 5.7 | - 0.095 / 0.05 |
| **pH [in CaCl$_2$]** | 7.3 | 7.7 | 7.8 | 7.5 | 7.3 | 7.6 | 7.6 | 7.5 | - 0.036 / 0.05 |
| **CaCO3 [%]** | 1.4 | 1.4 | 1.6 | 3.8 | 0.8 | 3.8 | 1.8 | 0.6 | - 0.036 / 0.05 |
| **Salinity / EC [mS/cm]** | 2 | 2 | 4 | 3 | 2 | 9 | 2 | 1 | - 0.268 / 0.05 |
| **CEC$_{eff.}$ [cmol/kg]** | 3.6 | 5.2 | 0.2 | 8.9 | 3.6 | 14.9 | 5.7 | 4.6 | 0.383 / 0.05 |
| **Gravel [%]** | 25 | 15 | 23 | 16 | 19 | 17 | 17 | 19 | - |
| **Clay [%]** | 3 | 5 | 4 | 12 | 4 | 19 | 5 | 3 | - |
| **Silt [%]** | 6 | 9 | 7 | 17 | 7 | 15 | 6 | 5 | - |
| **Sand [%]** | 92 | 87 | 90 | 73 | 89 | 68 | 89 | 92 | - |

Tab. 11: Soil parameters recorded for a subset of the sampled *Artemisia xerophytica* plots.

### 3.3.2 *Artemisia xerophytica*

No semi-shrubs of *A. xerophytica* were found between a distance of 0 and 350 m from the grazing hot spot. From 400 to 2000 m numbers increase from 17 to 846 plants per plot with a decrease between 800 and 1000 m (plots 12 and 19) and at approx. 1400 m (plots 13 and 14). As shown in Fig. 33, the decrease at plots 12 and 19 can be attributed to a high content of salt which shows with 9 ms/cm at 900 m the highest value along the whole transect.

Density of *Artemisia* plants (number of plants per 10x10 m plot) is significantly correlated to the distance from grazing hot spot with $r_S = 0.871$ at $p = 0.01$ (Fig. 33). Showing a similar pattern, total biomass of all *Artemisia xerophytica* plants rises from 0.23 g/m$^2$ at 400 m to 33 g/m$^2$ at 2000 m. Contrary to stand density, plot 13 shows a higher weight at a lower EC value. Distance from grazing hot spot and total biomass show the highest coefficient of correlation among all parameters with $r_S = 0.945$ at $p = 0.01$ (Fig. 34).

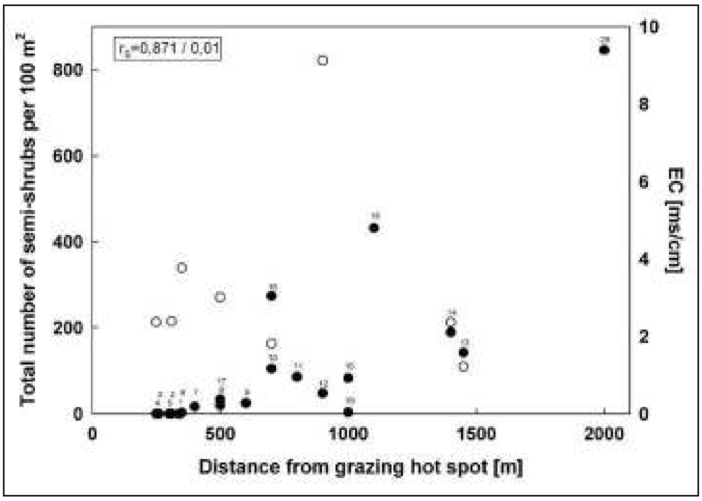


Fig. 33: Salinity and density of *Artemisia xerophytica* semi-shrubs (plants per plot) along the grazing gradient (filled circles: numbers of *Artemisia* plants, open circles: salinity).

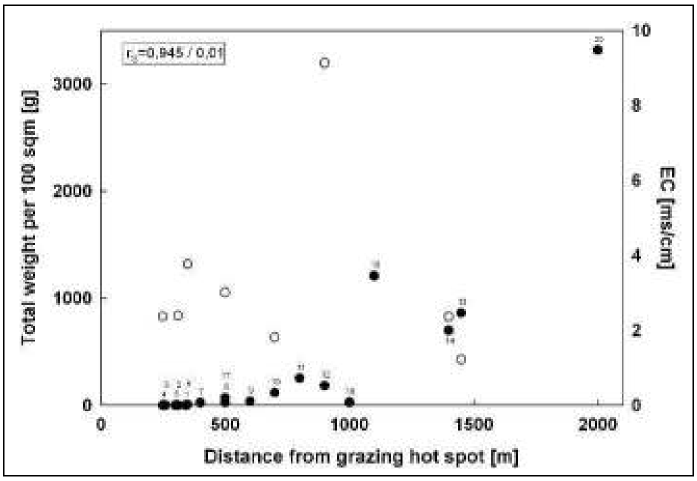


Fig. 34: Salinity and total biomass of *Artemisia xerophytica* along the grazing gradient (filled circles: biomass, open circles: salinity).

Average fresh weight per specimen is with 1-2 g/plant between 400–700 m quite low with little variations. From 800 m it increases to 3-6 g/plant but displays a much higher variation. Fig. 35 in combination with Fig. 36 show the dependence of plant weight on distance from grazing hot spot and on stand density. Fig. 36 shows an increasing average fresh weight per specimen up to almost 200 individuals per 100 square meters. Higher densities do not translate into a further increase of plant biomass, perhaps due to a self-thinning effect caused by intraspecific competition. Despite of variations in average weight per specimen a distinct tendency towards a decreasing grazing pressure is visible. Correlation with distance from grazing hot spot is significant with $r_S = 0.896$ at $p = 0.01$ (Fig. 35).

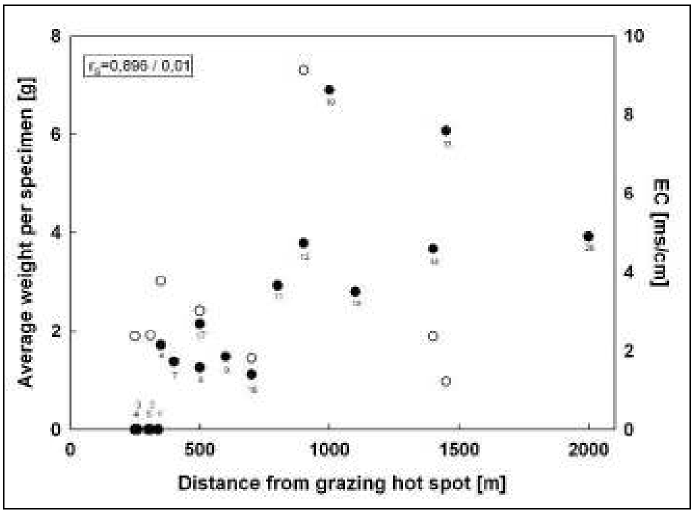


Fig. 35: Salinity and average plant weight of *Artemisia xerophytica* specimen (average of fresh weight of 100 plants) along the grazing gradient (filled circles: weight, open circles: salinity).

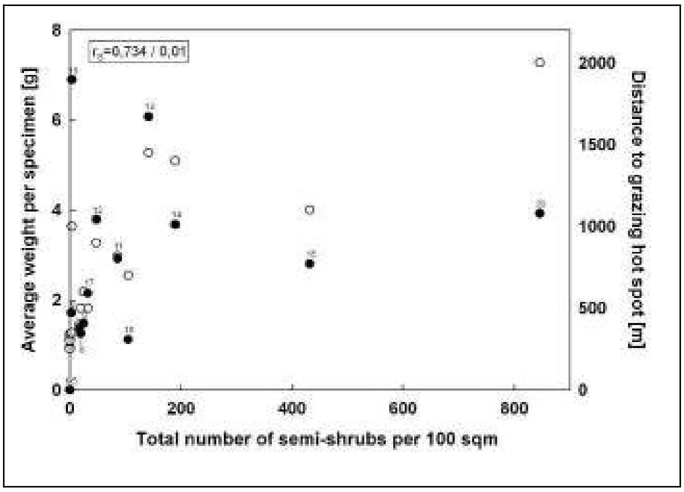


Fig. 36: Average plant weight versus stand density of *Artemisia xerophytica* (filled circles: average weight, open circles: distance of the plot from grazing hot spot).

The proportion of flowering plants increases from 3 to 75 percent along the gradient. Up to 800 m, a constant increase with little variance except for plot 6 can be recorded. From 900 m onwards, the tendency is not uniform and may represent natural variation caused by intraspecific competition or other unknown environmental factors. Correlation with distance from grazing hot spot is strong at $r_S = 0.883$ at $p = 0.01$ (Fig. 37).

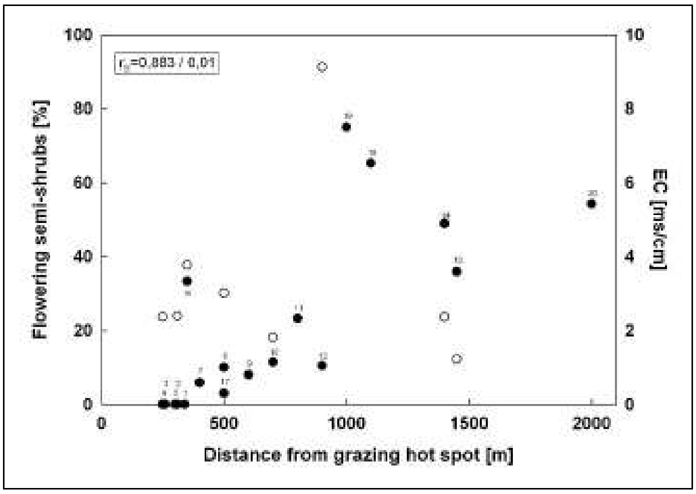


Fig. 37: Salinity and proportion of flowering *Artemisia xerophytica* plants along the grazing gradient (filled circles: percent flowering plants, open circles: salinity).

## 3.4 Discussion

Taken all sampled parameters of the population of *Artemisia xerophytica* (density, biomass, individual plant weight, proportion of flowering plants) together, salinity seems not to have any influence on growth of *Artemisia xerophytica* up to a conductivity of 4 ms/cm. This agrees with values for salinity tolerance of the closely related *Artemisia frigida* stated with 6 ms/cm by SWIFT (2003). If salinity values above 6 ms/cm may cause harm to *Artemisia xerophytica* could not be detected in this study. However, in plots with higher salt content impacts of grazing and salinity overlap and are hard to separate. Nevertheless, increasing values of all sampled vegetation parameters up to 800 m distance from a grazing hot spot clearly indicate a decreasing grazing pressure along the gradient.

The results indicate that grazing influence seems to exceed 900 m from the grazing hot spot, even if natural variation in soil parameters, or perhaps intraspecific competition, may blur this pattern considerably. This is confirmed by the variance of P within in the plots, which indicates the situation of grazed areas as shown by BENNET et al. (2004). To detect the final length of the grazing gradient, a transect in a (perhaps hard or impossible to find) more homogenous environment would be necessary. The detected grazing pressure may be the consequence of continued grazing over decades, or caused by short-term changes in livestock numbers (especially goat) since the nineties (JANZEN 2005, JANZEN and BAZARGUR 2003).

In comparison with studies of grazing influences on steppe ecosystems, the results confirm findings of decreasing standing-crop biomass and plant numbers with increasing grazing pressure as reported by GORSHKOVA and GRINEVA (1977) for Transbaikal region and MIRKIN et al. (1988) for the forest steppe in Khangay. However, several studies in Mongolia’s arid desert steppe carried out on the map scale of plant communities did not detect a change in various vegetation parameters (biomass, functional group cover, species richness and diversity along a grazing gradient: FERNANDEZ-GIMENEZ and ALLEN-DIAZ 1999, 2001; species composition, species richness and above-ground standing biomass production in grazed and ungrazed plots in different years: WESCHE 2005, WESCHE and RETZER 2005).

Two possible reasons are suggested for this contradiction. First, the smaller map scale of studies based on plant communities increases heterogeneity in soil parameters; and especially those parameters connected with water retention (particle size, clay content, salinity) have a much higher influence on vegetation than grazing (cf. 2.6.1). Second, large interannual variations in rainfall make studies comparing subsequent years almost impossible. Contradictory results of grazing effects on different map scale approaches are reported by OBA et al. (2003) for northern Kenya, obtaining a more consistent grazing impact on plant species richness, herbaceous cover, and biomass at larger map scales compared with smaller ones.

Although quite limited, the study seems to allow the following conclusions: all parameters recorded for *Artemisia xerophytica* reflect the assumed gradient of grazing intensity. As grazing pressure decreases, both stand density and total biomass per plot increase. The average shrub weight, an indicator of plant vitality, is related to both: positively to distance from the grazing hot spot and negatively to stand density; which may be explained by additional intraspecific competition at higher densities.

The most severe problem for studies on grazing sensivity of desert steppe ecosystems seems to be the overlap of variation in soil parameters influencing water uptake with grazing pressure, leading to quite similar degradation forms. To overcome this, further studies may focus on traits of individual species important for forage, their reproductive strategies and cycles, compensatory growth and intraspecific competition. Additionally, a better understanding of fluctuations in annual precipitation versus grazing effects on density of perennial plants is important. Since density of perennial plants may be less affected by interannual fluctuations in rainfall than their annual biomass, such studies could be carried out at a much larger map scale. This would eliminate the confounding effect of (even minor) changes in elevation, soil texture and/or salinity. Possible target plants should be perennial species with a high palatability for livestock and rather high salt tolerance; since in bad years survival chances of the animals greatly depend on these species.

# 4 Synopsis of grazing effects at different spatial scale levels in the desert steppe

## 4.1 Summary

For many years, rangeland ecologists have debated about whether the state of semi-arid and arid pastures is the expression of an ecological equilibrium dynamics reached in response to grazing livestock. Since the problem has been considered at different spatial scales, it is recognised that the competing concepts of equilibrium and non-equilibrium dynamics need to be integrated. The present study assesses grazing influence in Mongolia's arid desert steppe at three spatial scale levels. At the landscape level, the investigation focused on the impact of grazing on vegetation-determining ecological factors and on the occurrence of grazing-mediated plant communities. At the community level, the total number of species, the total vegetation cover, the percentage of annual species, the cover of annual species, and the soil nutrient properties within three different communities were assessed along gradients of grazing intensity. At the population level, the total number and weight of plants per plot, individual plant weight and the proportion of flowering plants of the dwarf semi-shrub *Artemisia xerophytica* were recorded along gradients of grazing intensity. The results show that grazing influence increases with decreasing spatial scale. At the landscape level, no grazing influence could be identified. At the community level, different vegetation parameters respond to grazing in different ways, and the responses of the same parameters vary between plant communities. At the population level, the results clearly reflect the grazing gradient in the way predicted by the equilibrium model. The study demonstrates that even arid desert steppes display equilibrial and non-equilibrial properties, depending on the observational scale. As a consequence, the assessment of vegetation dynamics and grazing impact in rangelands requires a multiple-scale approach that duly considers climatic differences. It is further suggested, that future research should draw comparisons between landscapes that co-evolved with herbivory, and those that did without.

## 4.2 Material and sampling methods

### 4.2.1 Study area

The study area extends 55 km eastward from the shores of Lake Khar Us Nuur in the Great Lake Basin, near the northeastern border of Khovd Province (Fig. 1: area A & B). Located on the leeward side of the Altai Mountains, the area receives 62 mm mean annual precipitation with high interannual variations. The extreme continental climate is characterised by long, cold, dry winters and short, hot summers. 70–90 percent of the annual precipitation falls in summer (CLIMATE STATION DOERGOEN 1985-2004, see Fig. 1).

The prevailing soil type is a gravel-rich, shallow Haplic Calcisol.

The sparse vegetation of the desert steppe (cf. ZEMMRICH 2005) is dominated by semi-shrubs, perennial bunchgrasses, and alliaceous geophytes of the genus *Allium*. In rainy summers, annual grasses and herbs prevail temporarily. The vegetation of the study area is a species-poor desert steppe with 9–12 species per 100 $m^2$ representing the typical plant communities of western Mongolia (HILBIG 1995, KHMELEV 2002).

Herders traditionally use the lower parts of the study area as spring pastures and the higher-lying parts as winter pastures. After privatisation between 1990 and 1999, livestock numbers in the district increased by 36 percent. In three consecutive years between 1999 and 2002, heavy snowfalls followed by droughts and a significant migration of herders to urban centres, especially Ulaanbaatar reduced numbers to a level below that of 1985 (VASHA 2005).

### 4.2.2 Sampling methods

Data on vegetation and soil were collected along gradients of grazing intensity in an otherwise homogenous area. Each transect started at a livestock campground and lead up to 2.5 km away. A livestock campground is that part of a ger camp (ger - traditional nomad tent) in which sheep and goats, the most common livestock in the study area, are rounded up every night to protect them against wolves and the cold. Grazing intensity is highest near the campgrounds and decreases with the distance (KENTER 2005).

Vegetation relevés were conducted following ELLENBERG (1956) and included potentially vegetation-determining environmental variables such as altitude, slope aspect, meso- and microrelief, disturbance, and type of land use. One soil sample was collected from a homogenous site comprising about three to five relevés each, and tested for pH, N, $C_{org}$, $CaCO_3$, electric conductivity (EC), $CEC_{eff}$, P and soil texture (for applied methods of soil analyses, see 2.2). The distance between sampling plots and livestock campgrounds was measured using GIS.

In 20 additional 100 $m^2$ plots, located within the area covered by the *Artemisia xerophytica* plant community, the total number of *A. xerophytica* specimens was recorded. Additionally, the total above-ground biomass of all *A. xerophytica*, the proportion of their flowering plants and the average weigth of the individual plants were determined (in 18 of the 20 plots). To distinguish between grazing effects and edaphic influences, soil samples from eight of the 20 *A. xerophytica* plots were analysed as described above.

In the present study, a total of 169 vegetation relevés and 35 soil samples were evaluated. The methods used in the statistical analysis are described in the corresponding subchapters of following chapter.

## 4.3 Results

### 4.3.1 Landscape level

The main ecological factors determining the vegetation in the study area are identified in Chapter 2.6.1. They comprise the climatic moisture supply and bioclimate (represented by altitude a.s.l.), the availability of soil moisture and water (represented by soil texture, gravel concentration, soil salinity, topographic position), and conditions of competition represented by the adaptation of species to water and scree stream erosion (cf. Fig. 27: Factor diagram of desert steppe). No grazing-mediated plant communities could be identified, because the vegetation-determining factors represented by abiotic environmental variables are insensitive to grazing.

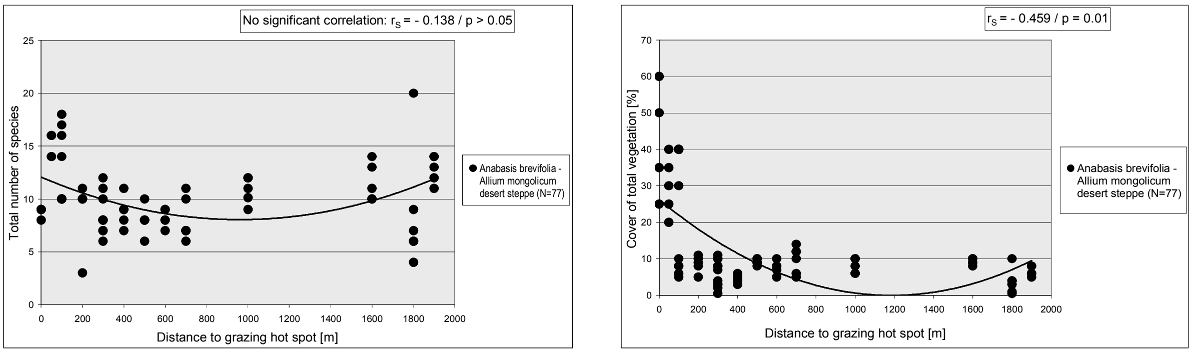
### 4.3.2 Community level

Three plant communities were identified (cf. 2.5.1, Fig. 27) and are examined in this study. They represent environmentally and edaphically homogenous sites. Therefore, changes in vegetation properties can be interpreted as the results of different grazing intensities.

Because most data are not normally distributed, their correlation with the grazing intensity (represented by distance from the livestock campground) was calculated by means of the Spearman rank correlation test (TREMP 2005).

In all plant communities, only the cover of total vegetation and the percentage of annual species are weakly but significantly correlated with grazing intensity. While in the *Anabasis brevifolia–Allium mongolicum* desert steppe, the correlations of all vegetation parameters with grazing intensity are negative, they change from positive to negative in the *Artemisia xerophytica* semi-shrub desert steppe and from negative to positive in the *Krascheninnikovia ceratoides* shrub desert steppe (Fig. 38).

In all communities, the values of the vegetation parameters show considerable variation at similar distances from the livestock campgrounds.



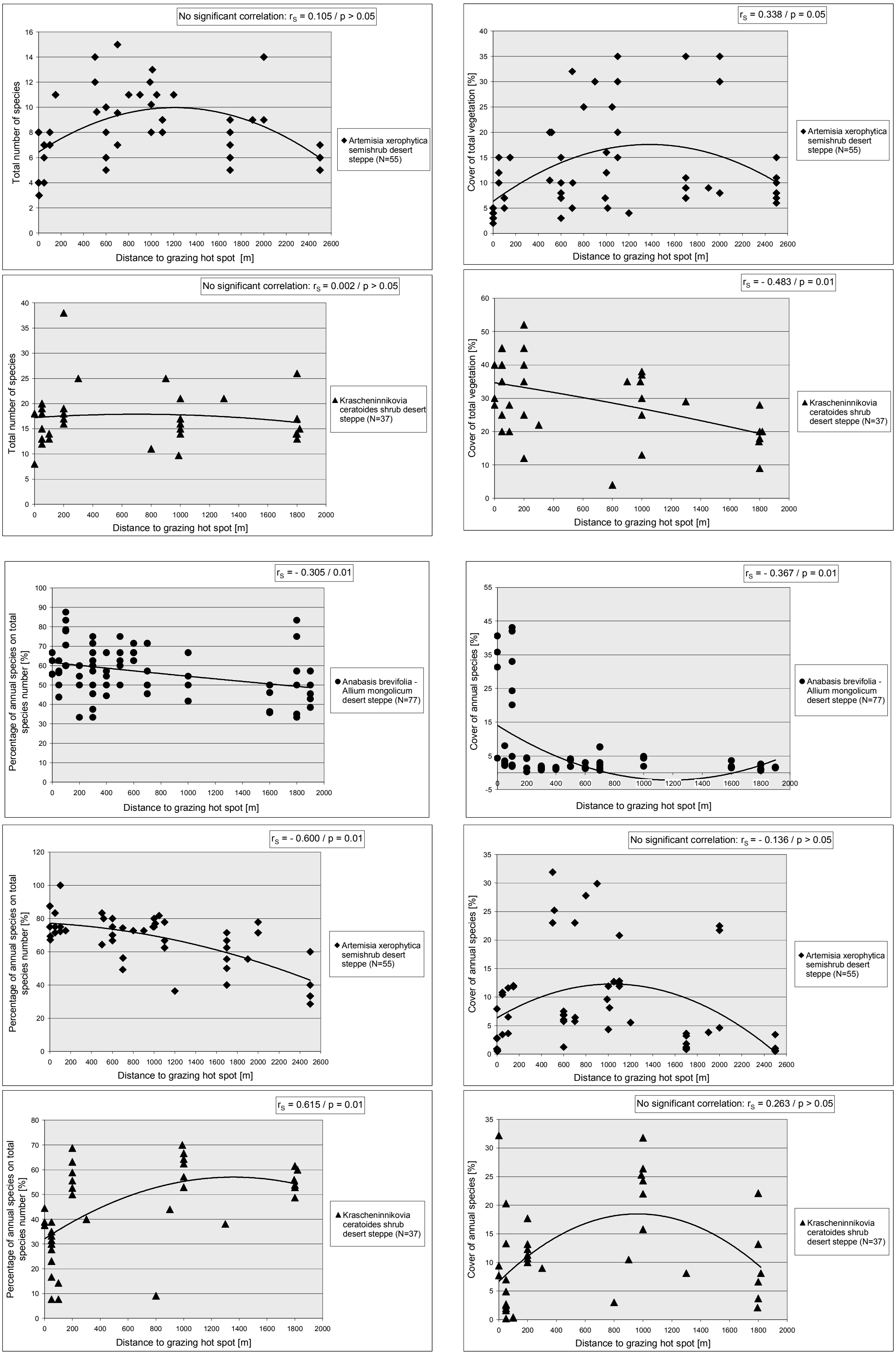


Fig. 38: Selected parameters of vegetation structure along the grazing gradient in plant communities of desert steppe.

Among the soil parameters, only the $C_{org}$ and N concentrations in the *Anabasis brevifolia–Allium mongolicum* desert steppe and in the *Kraschenninnikovia ceratoides* shrub desert steppe show a significant, strong negative correlation with grazing intensity, whereas P concentrations are not significantly correlated in any community. Both $C_{org}$ and N concentrations show a clear trend over the first 400 m of the transect in the *Anabasis brevifolia–Allium mongolicum* desert steppe. In the *Kraschenninnikovia ceratoides* shrub desert steppe, a continuous downward trend extends over the entire transect. The absolute concentrations of $C_{org}$ and N are very low.

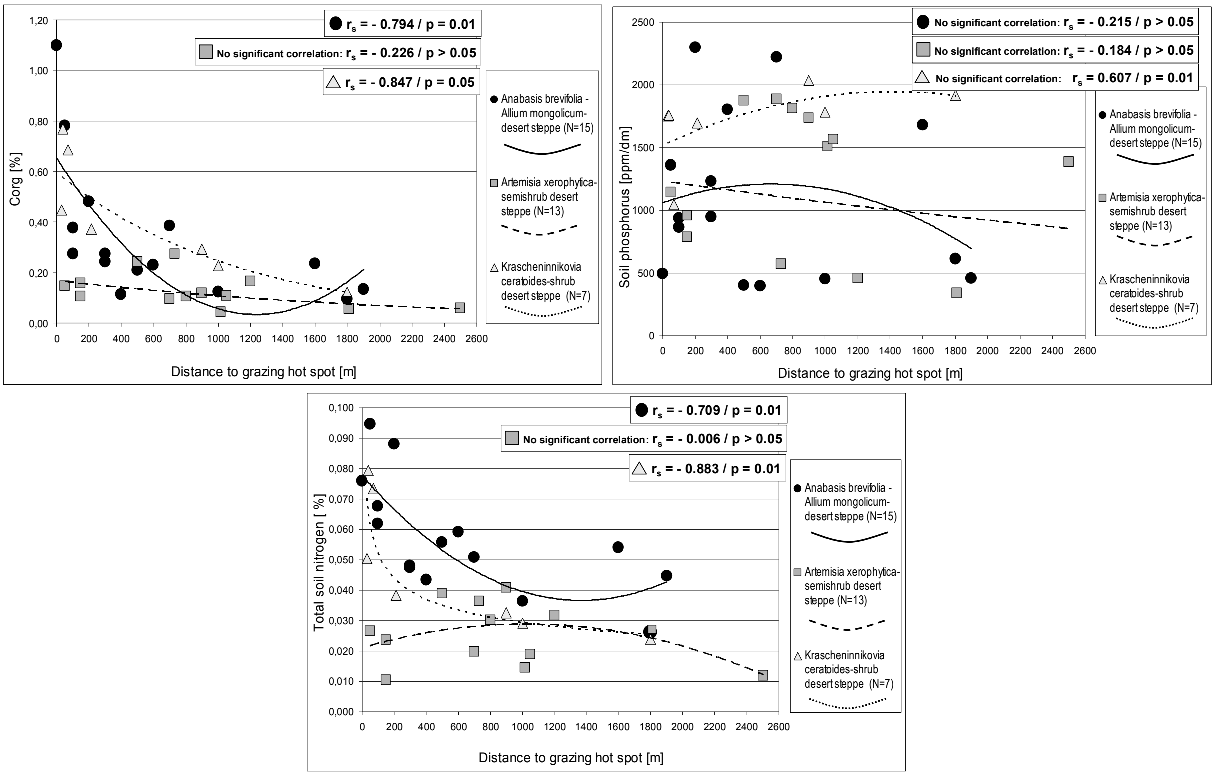


Fig. 39: Selected soil parameters along the grazing gradient in plant communities of desert steppe.

### 4.3.3 Population level

The investigation at population level was carried out in the *Artemisia xerophytica* semi-shrub desert steppe, the community least affected by grazing at community level (cf. Fig. 38, Fig. 39).

While the soil nutrient concentrations remain constant (Fig. 39), the values of all recorded vegetation parameters increase over the first 800 m of the transect and display a clearly significant correlation with grazing intensity (Fig. 40). The total number of specimens, the total weight of the above-ground biomass, and the percentage of flowering specimens in *A. xerophytica* clearly decrease near plot 12 at a distance of 900–1000 m from the livestock campground. This effect can be attributed to the high local soil salinity (EC 9 mS/cm). From 1000 m onwards, the general upward trend in the vegetation parameters is not uniform and may represent natural variation caused by intraspecific competition due to increased stand density (cf. 3.3).

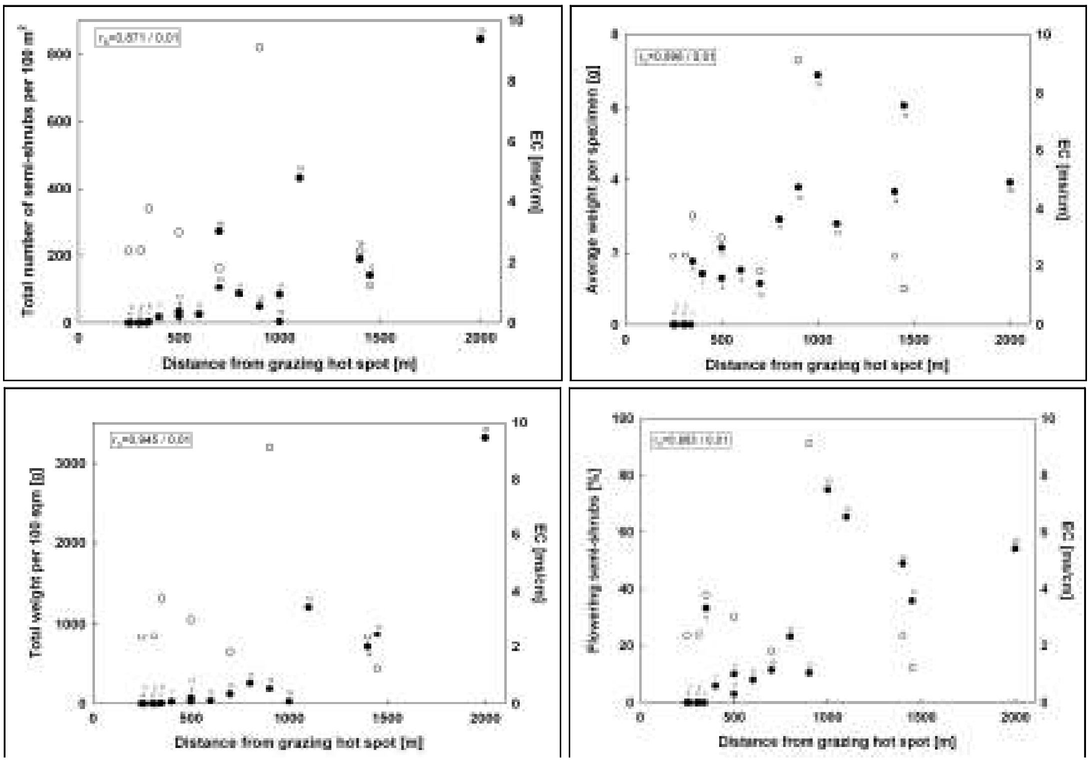


Fig. 40: Salinity and selected structural parameters of *Artemisia xerophtytica* semi-shrubs along the grazing gradient (filled circles: structural parameters, open circle: salinity, number atop circle: plot number).

## 4.4 Discussion and conclusions

The identification of vegetation-determining factors and the assessment of their effects individually for each environmentally and edaphically homogenous plant community individually allow to separate grazing from edaphic influences at all spatial scale levels, as postulated by FERNANDEZ-GIMENEZ and ALLEN-DIAZ (2001).

The grazing impact becomes more apparent as the spatial scale decreases[1)], which matches the findings of OBA et al. (2003). While no grazing effect could be identified at the **landscape level**, the results at the **community level** contain partly statistically significant correlations of grazing intensity with vegetation parameters and clearly significant correlations with soil parameters. Different vegetation parameters respond to grazing in different ways (FERNANDEZ-GIMENEZ and ALLEN-DIAZ 1999). Furthermore, a vegetation parameter may

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[1)] In this paper, in contrast to the usage of the terms in cartography, 'large scale' means a large area (= small map scale), and 'small scale' means a small area (= large map scale).

have different patterns in different communities (e.g. positive correlation of total vegetation cover in the *Artemisia xerophytica* semi-shrub desert steppe versus negative correlation in the *Anabasis brevifolia-Allium mongolicum* desert steppe and in the *Krascheninnikovia ceratoides*-shrub desert steppe, cf. Fig. 38). Significant correlations of grazing intensity with soil nutrient concentrations indicate an eutrophication in two communities. A comparison of vegetation and soil properties points at a greater indirect influence of grazing on vegetation via increased soil nutrient concentration than the direct effect on vegetation. The study reaffirms the findings of STUMPP et al. (2005) in Mongolia's dry steppe, who detected no changes in vegetation parameters near a grazing hot spot, but a significant increase in the concentration of soil nutrients like $C_{tot}$, N and P. This is contradicted by our findings at the **population level**. The edaphic conditions in the *Artemisia xerophytica* community were homogenous, except for the salinity peak at plot 12. However, at least to a distance of 800 m all recorded population parameters of *Artemisia xerophytica* indicate the grazing gradient (Fig. 40) consisting of a direct impact through defoliation and trampling.

The results at landscape level match most community-level findings from other studies on in Mongolia's desert steppe and dry steppe that failed to detect a change in prevailing vegetation parameters (biomass, functional group cover, species richness, diversity along a grazing gradient: FERNANDEZ-GIMENEZ and DIAZ 1999; species composition, species richness, aboveground standing biomass production in grazed and ungrazed plots in different years: WESCHE and RETZER 2005). At the landscape level, the desert steppe vegetation conforms to the non-equilibrium model: it does not respond to grazing but varied significantly from year to year pointing at climatic variability as the primary driver of vegetation dynamics, as predicted by the non-equilibrium model (WESCHE and RETZER 2005, FERNANDEZ-GIMENEZ and DIAZ 1999). The present study does not provide a time-series of vegetation development, but it can safely be assumed that climate-dependent interannual variations occur at the study sites. Through the detection of additional equilibrial properties, WESCHE and RETZER (2005) and FERNANDEZ-GIMENEZ and DIAZ (1999) demonstrated that Mongolia's desert steppes are in an intermediate position between equilibrium and non-equilibrium systems. This is confirmed for the community-level by the present study.

Our results show that non-equilibrial properties of Mongolia's desert steppes emerge most clearly at the landscape level, while at the community level they display an intermediate position between equilibrium and non-equilibrium ecosystems (cf. BRISKE et al. 2003, DEANGELIS and WATERHOUSE 1987, WIENS 1984). At the population level, they conform to the equilibrium model.

This divergence of grazing response between scale levels is due to the fact that different ecological factors – like climate, competitive interactions, disturbance regimes, and soil properties – operate at different scales (O'NEILL 2001, WIENS 1989), thus confounding grazing impact across various spatio-temporal scales (FUHLENDORF and SMEINS 1997).

Furthermore, also vegetation properties function perceptible at different scale levels and consequently will show different responses to grazing and climatic variability (BRISKE et al. 2003).

The present study shows that vegetation dynamics even in the extremely arid desert steppes of western Mongolia respond to grazing in both equilibrial and non-equilibrial ways, depending on the observational scale. These results corroborate the necessity of a multiple-scale approach for assessing vegetation dynamics and grazing impact in rangelands (FUHLENDORF and SMEINS 1999, OBA et al. 2003). In a revised concept of rangeland ecosystems, which integrates the equilibrium model and non-equilibrium model by applying them to different scales of observation, the crucial questions are: at which scale levels do specific system properties change from non-equilibrial to equilibrial? Are these scales levels and properties relevant to management strategies? The latter question, negated by SULLIVAN and ROHDE (2002), requires thorough research separately for each ecological zone. Applied to the present study, it leads to further questions: at which grazing intensity do *A. xerophytica* populations become extinct? Which is the minimum population size *A. xerophytica* needs to reproduce sustainably under a variable rainfall regime? These questions could be answered by comparing arid landscapes that co-evolved with wild herbivores (e.g. Mongolia) with landscapes that evolved without (e.g. arid Australia, cf. HARRINGTON et al. 1984). The answer may help to understand a further crucial issue of rangeland ecology: to what extent is current vegetation secondary, a deviation from the original state? Did humans only replace wildlife with domestic animals, or was their ecological impact much greater?

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# Appendix IV:

Soil profiles of the investigation area with field description and data of laboratory analyses *(arranged according to plant communities of Fig. 5 in chapter 1.2 on page 20 from right to left)*

| | |
|---|---|
| Soil type (acc. to HAASE 1983 / FAO 1998): | **Light Burosem / Haplic Calcisol** |
| Altitudinal belt / Type of vegetation: | Colline / *Anabasis brevifolia - Allium mongolicum*-Desert Steppe |
| Altitude in m a.s.l.: | 1400 |
| Profile: | 24 |
| Date: | 04.08.2003 |
| GPS: | 102 |
| No. of vegetation relevés: | 134-139 |

| Parent rock / sediment | Geomorphological type | Mesorelief | Microrelief | Expos. | Inclin. in ° | Utilization |
|---|---|---|---|---|---|---|
| Vulcanite / plutonite: granite, basalt, porphyry, diorite | Mountain in forelands, above pediment area | Small ridge at upper part of slope | Vertically and horizontally rectilinear | SSE | 2 | Winter pasture |

Field description

| Depth of horizon (cm) | Horizon (HAASE 1983) | Colour (KA4: 106) | Soil moisture (KA4: 114) | SOM (KA4: 108) | Fine soil (KA4:132/135) | Coarse soil (KA4:133/141) | Structure (KA4: 117) | CaCO3 (KA 4: 110) | Compaction (KA4: 122) | Consistence dry/moist (FAO 1990: 52) | Roots (KA4:130) | Further pedogenetic properties | Soil sample |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-15 | Ahs"ca[10] | - | feu1 | ? | Lts | gGr4 | sub | c3 | Vf3 | SHA/FR | W3 | - | 3VP, 2x |
| 15 | Bsca | - | feu1 | - | Lts | fX5-6 | sub | c4 | Vf3 | SHA/FR | - | - | - |

Data of analysis

| Depth of soil sample in cm | Colour dry (Munsell) | Bulk density [g/cm3] | pH (CaCl2) | CaCO3 (%) | Corg (%) | Humus (%) | Corg/N | N (%) | EC (mS/cm) | CECeff. (cmol/kg) | P (ppm TS) | Fine soil (%) | Coarse soil (%) | Soil texture (KA4: 135) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2-10 | - | 1.26 | 7.45 | 4.98 | 0.26 | 0.52 | 5.51 | 0.05 | 4.38 | 15.70 | 1374.79 | 88.76 | 11.24 | Lt2 |
| 5-15 | 10 YR 6/4 | - | 7.67 | 1.53 | 0.33 | 0.66 | 5.96 | 0.06 | 2.46 | - | 737.80 | 75.86 | 24.14 | Ls3 |
| 10-15 | - | - | 7.40 | 0.80 | 0.28 | 0.56 | 5.85 | 0.05 | 2.19 | - | 361.19 | 60.49 | 39.51 | Lts |

---

[10] Denomination of soil horizons follows HAASE (1983) and FAO (1988) with modifications. All horizons are characterised in Appendix V.

Soil type (acc. to HAASE 1983 / FAO 1998): **Light Burosem / Haplic Calcisol**
Altitudinal belt / Type of vegetation: Colline / *Anabasis brevifolia* - *Allium mongolicum*-Desert Steppe
Altitude in m a.s.l.: 1404
Profile: 26
Date: 30.08.2003
GPS: 103
No. of vegetation relevés: 146-151

No photo availabale

| Parent rock / sediment | Geomorphological type | Mesorelief | Microrelief | Expos. | Inclin. in ° | Utilization |
|---|---|---|---|---|---|---|
| | | No description of profile | | | | |

Field description

| Depth of horizon (cm) | Horizon (HAASE 1983) | Colour (KA4: 106) | Soil moisture (KA4: 114) | SOM (KA4: 108) | Fine soil (KA4:132/ 135) | Coarse soil (KA4:133/141) | Structure (KA4: 117) | CaCO3 (KA 4: 110) | Compaction (KA4: 122) | Consistence dry/moist (FAO 1990: 52) | Roots (KA4:130) | Further pedogenetic properties | Soil sample |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | No description of profile, three volume and one common samples taken | | | | | | | | | 3VP, 1x |

Data of analysis

| Depth of soil sample in cm | Colour dry (Munsell) | Bulk density [g/cm3] | pH (CaCl2) | CaCO3 (%) | Corg (%) | Humus (%) | Corg/N | N (%) | EC (mS/cm) | CECeff. (cmol/kg) | P (ppm TS) | Fine soil (%) | Coarse soil (%) | Soil texture (KA4: 135) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1-7 | - | 1.50 | 7.74 | 5.48 | 0.17 | 0.33 | 4.36 | 0.04 | 2.87 | - | 1476.79 | 62.98 | 37.02 | - |
| 1-7 | - | - | 7.17 | 4.61 | 0.38 | 0.77 | 7.55 | 0.05 | 2.30 | 12.51 | 2220.14 | 62.80 | 37.20 | Ls4 |

| | |
|---|---|
| Soil type (acc. to HAASE 1983 / FAO 1998): | **Light Burosem / Haplic Calcisol** |
| Altitudinal belt / Type of vegetation: | Colline / *Krascheninnikovia ceratoides*-Shrub Desert Steppe |
| Altitude in m a.s.l.: | 1401 |
| Profile: | 25 |
| Date: | 29.08.2003 |
| GPS: | 118 |
| No. of vegetation relevés: | 140-145 |

| **Parent rock / sediment** | **Geomorphological type** | **Mesorelief** | **Microrelief** | **Expos.** | **Inclin. in °** | **Utilization** |
|---|---|---|---|---|---|---|
| Basalt | Mountain in forelands, above pediment area | Bottom of upper reaches of dry creek valley | strongly undulated | SW | 2 | Winter pasture |

Field description

| **Depth of horizon (cm)** | **Horizon** (HAASE 1983) | **Colour** (KA4: 106) | **Soil moisture** (KA4: 114) | **SOM** (KA4: 108) | **Fine soil** (KA4:132/135) | **Coarse soil** (KA4:133/141) | **Structure** (KA4: 117) | **CaCO3** (KA 4: 110) | **Compaction** (KA4: 122) | **Consistence dry/moist** (FAO 1990: 52) | **Roots** (KA4:130 ) | **Further pedogenetic properties** | **Soil sample** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-39 | Ahs"ca | - | feu1 | No record | mS | fGr2, fX5 | - | c3 | Vf1 | LO/LO | W3-W4 | - | 3VP, x |

Data of analysis

| **Depth of soil sample in cm** | **Colour dry** (Munsell) | **Bulk density [g/cm3]** | **pH (CaCl2)** | **CaCO3 (%)** | **Corg (%)** | **Humus (%)** | **Corg/N** | **N (%)** | **EC (mS/cm)** | **CECeff. (cmol/kg)** | **P (ppm TS)** | **Fine soil (%)** | **Coarse soil (%)** | **Soil texture** (KA4: 135) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1-8 | 7.5 YR 5/6 | 1.58 | 7.62 | 8.74 | 0.37 | 0.75 | 9.72 | 0.04 | 1.43 | 2.43 | 1695.25 | 49.12 | 50.88 | Ss |
| 10-25 | - | - | 7.41 | 8.00 | 0.26 | 0.52 | 7.51 | 0.03 | 2.34 | - | 1392.44 | 55.41 | 44.59 | - |

| | |
|---|---|
| Soil type (acc. to HAASE 1983 / FAO 1998): | **Light Burosem / Haplic Calcisol** |
| Altitudinal belt / Type of vegetation: | Colline / *Krascheninnikovia ceratoides*-Shrub Desert Steppe |
| Altitude in m a.s.l.: | 1390 |
| Profile: | 27 |
| Date: | 30.08.2003 |
| GPS: | 112 |
| No. of vegetation relevés: | 152-157 |

No photo availabale

| **Parent rock / sediment** | **Geomorphological type** | **Mesorelief** | **Microrelief** | **Expos.** | **Inclin. in °** | **Utilization** |
|---|---|---|---|---|---|---|
| No description of profile | | | | | | |

Field description

| **Depth of horizon (cm)** | **Horizon** (HAASE 1983) | **Colour** (KA4: 106) | **Soil moisture** (KA4: 114) | **SOM** (KA4: 108) | **Fine soil** (KA4:132/135) | **Coarse soil** (KA4:133/141) | **Structure** (KA4: 117) | **CaCO3** (KA 4: 110) | **Compaction** (KA4: 122) | **Consistence dry/moist** (FAO 1990: 52) | **Roots** (KA4:130) | **Further pedogenetic properties** | **Soil sample** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No description of profile, three volume and one common samples taken | | | | | | | | | | | | | 3VP, 1x |

Data of analysis

| **Depth of soil sample in cm** | **Colour dry** (Munsell) | **Bulk density [g/cm3]** | **pH (CaCl2)** | **CaCO3 (%)** | **Corg (%)** | **Humus (%)** | **Corg/N** | **N (%)** | **EC (mS/cm)** | **CECeff. (cmol/kg)** | **P (ppm TS)** | **Fine soil (%)** | **Coarse soil (%)** | **Soil texture** (KA4: 135) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1-8 | - | 1.52 | 7.47 | 1.96 | 0.60 | 1.19 | 16.74 | 0.04 | 2.24 | - | 1611.43 | 72.12 | 27.88 | - |
| 1-7 | - | - | 7.42 | 2.08 | 0.23 | 0.46 | 7.84 | 0.03 | 1.96 | 1.75 | 1781.64 | 71.55 | 28.45 | Su2 |

Soil type (acc. to FAO 1998): **Petric Gypsisol**
Altitudinal belt / Type of vegetation: Colline / *Krascheninnikovia ceratoides*-Shrub Desert Steppe
Altitude in m a.s.l.: 1350
Profile: 28
Date: 02.09.2003
GPS: 105
No. of vegetation relevés: 158-163

| Parent rock / sediment | Geomorphological type | Mesorelief | Micro-relief | Expos. | Inclin. in ° | Utilization |
|---|---|---|---|---|---|---|
| | | No description of profile | | | | |

Field description

| Depth of horizon (cm) | Horizon (HAASE 1983) | Colour (KA4: 106) | Soil moisture (KA4: 114) | SOM (KA4: 108) | Fine soil (KA4:132/135) | Coarse soil (KA4:133/141) | Structure (KA4: 117) | CaCO3 (KA 4: 110) | Compaction (KA4: 122) | Consistence dry/moist (FAO 1990: 52) | Roots (KA4:130) | Further pedogenetic properties | Soil sample |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-6 | Ahs’’ca | | | | | No description of horizon | | | | | | Crusts of secondary carbonates at bottom sides of stones | 3VP, x |
| 6-13 | Byca | | | | | No description of horizon | | | | | | Cemented petrogypsic horizon | - |
| 13 | Bsca | | | | | No description of horizon | | | | | | - | x |

Data of analysis

| Depth of soil sample in cm | Colour dry (Munsell) | Bulk density [g/cm3] | pH (CaCl2) | CaCO3 (%) | Corg (%) | Humus (%) | Corg/N | N (%) | EC (mS/cm) | CECeff. (cmol/kg) | P (ppm TS) | Fine soil (%) | Coarse soil (%) | Soil texture (KA4: 135) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1-7 | - | 1.40 | 7.73 | 3.10 | 0.10 | 0.19 | 3.69 | 0.03 | 16.00 | 13.62 | 612.75 | 71.76 | 28.24 | Slu |
| 1-7 | - | - | 7.48 | 4.42 | 0.06 | 0.12 | 2.41 | 0.03 | 16.00 | - | 999.58 | 69.95 | 30.06 | - |
| 10-16 | - | - | 7.59 | 1.95 | 0.06 | 0.11 | 3.48 | 0.02 | 15.36 | - | 373.09 | 48.23 | 51.77 | - |

| | |
|---|---|
| Soil type (acc. to Haase 1983 / FAO 1998): | **Light Burosem / Haplic Calcisol** |
| Altitudinal belt / Type of vegetation: | Colline / *Artemisia xerophytica*-Semishrub Desert Steppe |
| Altitude in m a.s.l.: | 1140 |
| Profile: | 21 |
| Date: | 31.07.2003 |
| GPS: | 121 |
| No. of vegetation relevés: | 112-119 |

| Parent rock / sediment | Geomorphological type | Mesorelief | Micro-relief | Expos. | Inclin. in ° | Utilization |
|---|---|---|---|---|---|---|
| Basalt, slate | Plain in Great Lake Basin | Lower part of slightly inclined slope | Even | N | 3 | Spring pasture |

Field description

| Depth of horizon (cm) | Horizon (HAASE 1983) | Colour (KA4: 106) | Soil moisture (KA4: 114) | SOM (KA4: 108) | Fine soil (KA4:132/ 135) | Coarse soil (KA4:133/ 141) | Structure (KA4: 117) | CaCO3 (KA 4: 110) | Compaction (KA4: 122) | Consistence dry/moist (FAO 1990: 52) | Roots (KA4:130) | Further pedogenetic properties | Soil sample |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-15 | Ahs"ca | - | feu1 | - | mSs | mGr2-gGr4 | ein - sub | c4 | Vf2 | LO/VFR | W3 | Crusts of secondary carbonates at bottom sides of stones, lower part of horizon loamy | 3VP, 2x |
| 15-40 | Bsca | - | feu1 | ? | fSl | gGr6 | ein | c5 | Vf1 | SO/VFR | W3 | Crust of carbonates at bottom sides of stones, sandy substrate rich in gravel | - |

Data of analysis

| Depth of soil sample in cm | Colour dry (Munsell) | Bulk density [g/cm3] | pH (CaCl2) | CaCO3 (%) | Corg (%) | Humus (%) | Corg/N | N (%) | EC (mS/cm) | CECeff. (cmol/kg) | P (ppm TS) | Fine soil (%) | Coarse soil (%) | Soil texture (KA4: 135) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1-7 | 10 YR 5/3-2 | 1.51 | 7.54 | 2.02 | 0.30 | 0.60 | 7.74 | 0.04 | 2.95 | 6.12 | 1734.94 | 80.91 | 19.09 | Su2 |
| 5-10 | 7.5 YR 4/6 | - | 7.59 | 2.70 | 0.28 | 0.55 | 7.56 | 0.04 | 2.75 | 2.96 | 572.72 | 73.76 | 26.24 | Sl4 |
| 10-15 | 7.5 YR 4/6 | - | 7.57 | 2.14 | 0.09 | 0.17 | 4.05 | 0.02 | 2.73 | - | 443.57 | 82.65 | 17.35 | - |

Soil type (acc. to HAASE 1983 / FAO 1998): **Light Burosem / Haplic Calcisol**
Altitudinal belt / Type of vegetation: Colline / *Artemisia xerophytica*-Semishrub Desert Steppe
Altitude in m a.s.l.: 1140
Profile: 22
Date: 01.08.2003
GPS: 122
No. of vegetation relevés: 122-127

| Parent rock / sediment | Geomorphological type | Mesorelief | Micro-relief | Expos. | Inclin. in ° | Utilization |
|---|---|---|---|---|---|---|
| | | No description of profile | | | | |

Field description

| Depth of horizon (cm) | Horizon (HAASE 1983) | Colour (KA4: 106) | Soil moisture (KA4: 114) | SOM (KA4: 108) | Fine soil (KA4:132/135) | Coarse soil (KA4:133/141) | Structure (KA4: 117) | CaCO3 (KA 4: 110) | Compaction (KA4: 122) | Consistence dry/moist (FAO 1990: 52) | Roots (KA4:130) | Further pedogenetic properties | Soil sample |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | No description of profile, three volume and two common samples taken | | | | | | | | 3 VP, 2x |

Data of analysis

| Depth of soil sample in cm | Colour dry (Munsell) | Bulk density [g/cm3] | pH (CaCl2) | CaCO3 (%) | Corg (%) | Humus (%) | Corg/N | N (%) | EC (mS/cm) | CECeff. (cmol/kg) | P (ppm TS) | Fine soil (%) | Coarse soil (%) | Soil texture (KA4: 135) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1-7 | - | 1.51 | 7.48 | 2.79 | 0.09 | 0.19 | 4.54 | 0.02 | 2.53 | - | 1183.35 | 88.27 | 11.73 | - |
| 5-10 | - | - | 7.32 | 3.97 | 0.06 | 0.12 | 2.14 | 0.03 | 2.68 | 6.50 | 340.84 | 88.94 | 11.06 | St2 |
| 10-15 | - | - | 7.51 | 6.69 | 0.22 | 0.43 | 7.12 | 0.03 | 2.92 | - | 359.38 | 83.75 | 16.26 | - |

| | |
|---|---|
| Soil type (acc. to HAASE 1983 / FAO 1998): | **Light Burosem / Haplic Calcisol** |
| Altitudinal belt / Type of vegetation: | Colline / *Artemisia xerophytica*-Semishrub Desert Steppe |
| Altitude in m a.s.l.: | 1247 |
| Profile: | 23 |
| Date: | 02.08.2003 |
| GPS: | 123 |
| No. of vegetation relevés: | 128-133 |

| **Parent rock / sediment** | **Geomorphological type** | **Mesorelief** | **Micro-relief** | **Expos.** | **Inclin. in °** | **Utilization** |
|---|---|---|---|---|---|---|
| | | | No description of profile | | | |

Field description

| **Depth of horizon (cm)** | **Horizon** (HAASE 1983) | **Colour** (KA4: 106) | **Soil moisture** (KA4: 114) | **SOM** (KA4: 108) | **Fine soil** (KA4:132/135) | **Coarse soil** (KA4:133/141) | **Structure** (KA4: 117) | **CaCO3** (KA 4: 110) | **Compaction** (KA4: 122) | **Consistence dry/moist** (FAO 1990: 52) | **Roots** (KA4:130) | **Further pedogenetic properties** | **Soil sample** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | No description of profile, three volume and two common samples taken | | | | | | | | 3 VP, 2x |

Data of analysis

| **Depth of soil sample in cm** | **Colour dry** (Munsell) | **Bulk density [g/cm3]** | **pH (CaCl2)** | **CaCO3 (%)** | **Corg (%)** | **Humus (%)** | **Corg/N** | **N (%)** | **EC (mS/cm)** | **CECeff. (cmol/kg)** | **P (ppm TS)** | **Fine soil (%)** | **Coarse soil (%)** | **Soil texture** (KA4: 135) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2-8 | - | 1.67 | 7.47 | 0.24 | 0.06 | 0.12 | 4.99 | 0.01 | 0.50 | 2.58 | 1385.88 | 90.46 | 9.54 | Ss |
| 5-10 | - | - | 7.33 | 0.26 | 0.11 | 0.22 | 5.64 | 0.02 | 2.00 | - | 1206.49 | 93.60 | 6.40 | Ss |
| 10-15 | - | - | 7.68 | 2.26 | 0.01 | 0.02 | 0.64 | 0.01 | 2.51 | - | 426.76 | 87.78 | 12.22 | - |

| | |
|---|---|
| Soil type (acc. to HAASE 1983 / FAO 1998): | **Light Burosem / Haplic Calcisol** |
| Altitudinal belt / Type of vegetation: | Colline / *Artemisia xerophytica*-Semishrub Desert Steppe |
| Altitude in m a.s.l.: | 1160 |
| Profile: | - |
| Date: | 06.09.2003 |
| GPS: | 225A1, 226A3, 226A5, 226A7, 226A9, 226A11, 226A12, 226A13 |
| No. of vegetation relevés: | 179, 181-183 |

No photo availabale

| **Parent rock / sediment** | **Geomorphological type** | **Mesorelief** | **Micro-relief** | **Expos.** | **Inclin. in °** | **Utilization** |
|---|---|---|---|---|---|---|
| | | No description of profile | | | | |

Field description

| **Depth of horizon (cm)** | **Horizon** (HAASE 1983) | **Colour** (KA4: 106) | **Soil moisture** (KA4: 114) | **SOM** (KA4: 108) | **Fine soil** (KA4:132/135) | **Coarse soil** (KA4:133/141) | **Structure** (KA4: 117) | **CaCO3** (KA 4: 110) | **Compaction** (KA4: 122) | **Consistence dry/moist** (FAO 1990: 52) | **Roots** (KA4:130) | **Further pedogenetic properties** | **Soil sample** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No description of profile, eight top soil samples from eight sights in a distance of 200 m between each sample taken | | | | | | | | | | | | | 8x |

Data of analysis of top soil samples

| **GPS** | **Soil sample** | **Depth of soil sample in cm** | **pH (CaCl2)** | **CaCO3 (%)** | **Corg (%)** | **Humus (%)** | **Corg/N** | **N (%)** | **EC (mS/cm)** | **CECeff. (cmol/kg)** | **P (ppm TS)** | **Fine soil (%)** | **Coarse soil (%)** | **Soil texture** (KA4: 135) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 225A1 | AZ 56 | 1-5 | 7.65 | 1.40 | 0.12 | 0.24 | 5.41 | 0.02 | 2.39 | 5.16 | 1300.37 | 84.68 | 15.32 | Ss |
| 226A3 | AZ 46 | 1-5 | 7.31 | 1.37 | 0.08 | 0.17 | 4.37 | 0.02 | 2.37 | 3.59 | 1412.46 | 75.08 | 24.92 | Ss |
| 226A5 | AZ 37 | 1-3 | 7.81 | 1.58 | 0.11 | 0.21 | 4.15 | 0.03 | 3.77 | 0.19 | 1288.54 | 77.46 | 22.54 | Ss |
| 226A7 | AZ 58 | 1-5 | 7.46 | 3.78 | 0.24 | 0.48 | 6.21 | 0.04 | 3.01 | 8.94 | 1878.29 | 83.74 | 16.26 | Sl4 |
| 226A9 | AZ 50 | 1-5 | 7.27 | 0.82 | 0.09 | 0.19 | 4.81 | 0.02 | 1.81 | 3.55 | 1888.12 | 81.42 | 18.58 | Ss |
| 226A11 | AZ 53 | 1-5 | 7.61 | 3.83 | 0.12 | 0.24 | 2.91 | 0.04 | 9.13 | 14.93 | 1737.34 | 82.78 | 17.22 | St3 |
| 226A12 | AZ 55 | 1-5 | 7.53 | 0.62 | 0.11 | 0.22 | 5.68 | 0.02 | 1.22 | 4.57 | 1564.47 | 81.20 | 18.81 | Ss |
| 226A13 | AZ 38 | 1-5 | 7.63 | 1.75 | 0.04 | 0.09 | 3.10 | 0.01 | 2.36 | 5.65 | 1509.25 | 82.85 | 17.15 | St2 |

| | |
|---|---|
| Soil type (acc. to HAASE 1983 / FAO 1998): | **Dark Kastanozem / Calcic Kastanozem** |
| Altitudinal belt / Type of vegetation: | Montane / *Stipa krylovii* - *Artemisia dolosa*-Mountain Steppe |
| Altitude in m a.s.l.: | 2068 |
| Profile: | 13 |
| Date: | 05.08.2002 |
| GPS: | 72 |
| No. of vegetation relevés: | 62-65 |

| **Parent rock / sediment** | **Geomorphological type** | **Mesorelief** | **Microrelief** | **Expos.** | **Inclin. in °** | **Utilization** |
|---|---|---|---|---|---|---|
| Slate | Lower mountain range in Altai foreland | Mountain saddle with slightly inclined NE exposition | Vertically and horizontally rectilinear | NE | 5 | Winter pasture, as main road additional pasture of passage |

Field description

| **Depth of horizon (cm)** | **Horizon** (HAASE 1983) | **Colour** (KA4: 106) | **Soil moisture** (KA4: 114) | **SOM** (KA4: 108) | **Fine soil** (KA4:132/135) | **Coarse soil** (KA4:133/141) | **Structure** (KA4: 117) | **CaCO3** (KA 4: 110) | **Compaction** (KA4: 122) | **Consistence dry/moist** (FAO 1990: 52) | **Roots** (KA4:130) | **Further pedogenetic properties** | **Soil sample** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-15 | Ahs | braun | feu1 | h2/3 | Sl | mGr3 | einz | - | Vf1 | LO / LO | W4 | - | 3VP, x |
| 15-36 | Ahsca | braun | feu1 | h2/3 | Sl | mGr3 | einz | C3 | Vf1 | LO / LO | W4 | Crusts of secondary carbonates at bottom sides of stones, colour differences of cut and fissure areas of soil aggregates | x |
| 36 | Ca | - | - | - | - | - | koh | C4 | Vf1 | LO / LO | W3 | Carbonate concretions scattered distributed in total horizon | x |

Data of analysis

| **Depth of soil sample in cm** | **Colour dry** (Munsell) | **Bulk density [g/cm3]** | **pH (CaCl2)** | **CaCO3 (%)** | **Corg (%)** | **Humus (%)** | **Corg/N** | **N (%)** | **EC (mS/cm)** | **CECeff. (cmol/kg)** | **P (ppm TS)** | **Fine soil (%)** | **Coarse soil (%)** | **Soil texture** (KA4: 135) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1-14 | 10 YR 4/6 | - | 7.25 | 0.50 | 1.90 | 3.81 | 8.89 | 0.21 | 0.83 | - | 910.40 | 75 | 25 | - |
| 4-8 | - | 1.21 | 6.90 | 0.69 | 2.09 | 4.19 | 8.96 | 0.23 | 0.94 | - | - | 83 | 17 | - |
| 5-9 | - | 1.37 | 7.05 | 0.65 | 1.96 | 3.91 | 9.25 | 0.21 | 0.90 | - | - | 73 | 27 | - |
| 6-10 | - | 1.20 | 7.02 | 0.39 | 2.19 | 4.38 | 9.18 | 0.24 | 1.45 | 9.77 | - | 85 | 15 | Sl4 |
| 15-21 | 10 YR 4/6 | - | 6.99 | 1.58 | 1.89 | 3.78 | 8.24 | 0.23 | 0.88 | - | - | 59 | 41 | - |
| 39-51 | 10 YR 6/4 | - | 7.45 | 9.32 | 1.30 | 2.60 | 8.10 | 0.16 | 4.65 | - | - | 78 | 22 | - |

| | |
|---|---|
| Soil type (acc. to HAASE 1983 / FAO 1998): | **Middle Kastanozem / Haplic Kastanozem** |
| Altitudinal belt / Type of vegetation: | Montane / *Rhinactinidia eremophila* - *Stipa krylovii*-Mountain Steppe |
| Altitude in m a.s.l.: | 2200 |
| Profile: | 12 |
| Date: | 03.08.2002 |
| GPS: | 68 |
| No. of vegetation relevés: | 28-32 |

| **Parent rock / sediment** | **Geomorphological type** | **Mesorelief** | **Micro-relief** | **Expos.** | **Inclin. in °** | **Utilization** |
|---|---|---|---|---|---|---|
| Granite / slate | Lower mountain range in Altai foreland | Bottom of valley in mid-slope | Even | - | - | Hay harvest, irrigation along small margin stripes |

Field description

| **Depth of horizon (cm)** | **Horizon** (HAASE 1983) | **Colour** (KA4: 106) | **Soil moisture** (KA4: 114) | **SOM** (KA4: 108) | **Fine soil** (KA4:132/ 135) | **Coarse soil** (KA4:133/141) | **Structure** (KA4: 117) | **CaCO3** (KA 4: 110) | **Compaction** (KA4: 122) | **Consistence dry/moist** (FAO 1990: 52) | **Roots** (KA4:130) | **Further pedogenetic properties** | **Soil sample** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-31 | Ahs' | hellbraun | feu1 | h3 | Sl | mGr5 | einz | - | Vf1 | LO / LO | W5 | - | 3VP, x |
| 31 | Ahs"ca | hellbraun | feu1 | h3 | Sl | mGr5 | einz | C4 | Vf1 | LO / LO | W5 | Secondary carbonates as concretions scattered distributed | x |

Data of analysis

| **Depth of soil sample in cm** | **Colour dry** (Munsell) | **Bulk density [g/cm3]** | **pH (CaCl2)** | **CaCO3 (%)** | **Corg (%)** | **Humus (%)** | **Corg/N** | **N (%)** | **EC (mS/cm)** | **CECeff. (cmol/kg)** | **P (ppm TS)** | **Fine soil (%)** | **Coarse soil (%)** | **Soil texture** (KA4: 135) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2-6 | - | 1.28 | 6.34 | 0.00 | 1.84 | 3.67 | 10.11 | 0.18 | 0.40 | 7.35 | - | 70 | 30 | Sl3 |
| 2-6 | - | 1.32 | 6.56 | 0.00 | 0.60 | 1.19 | 10.58 | 0.06 | - | 7.35 | - | 54 | 46 | Sl3 |
| 3-7 | - | 1.63 | 6.53 | 0.00 | 1.21 | 2.43 | 9.23 | 0.13 | 0.65 | - | - | 43 | 57 | - |
| 4-17 | 10 YR 5/4 | - | 6.67 | 0.00 | 1.07 | 2.15 | 9.23 | 0.12 | 0.45 | 3.35 | 1944.00 | 47 | 53 | Sl3 |
| 37-45 | 10 YR 5/4 | - | 7.27 | 1.57 | 0.65 | 1.31 | 7.80 | 0.08 | 0.80 | - | - | 62 | 38 | - |

| | |
|---|---|
| Soil type (acc. to HAASE 1983 / FAO 1998): | **Light Kastanozem / Haplic Kastanozem** |
| Altitudinal belt / Type of vegetation: | Montane / *Rhinactinidia eremophila* - *Stipa krylovii*-Mountain Steppe |
| Altitude in m a.s.l.: | 1911 |
| Profile: | 5 |
| Date: | 16.07.2002 |
| GPS: | 48 |
| No. of vegetation relevés: | 17-19 |

| Parent rock / sediment | Geomorphological type | Mesorelief | Micro-relief | Expos. | Inclin. in ° | Utilization |
|---|---|---|---|---|---|---|
| Granite | Lower mountain range in Altai foreland | Bottom of valley in mid-slope | Even | - | - | Winter pasture |

Field description

| Depth of horizon (cm) | Horizon (HAASE 1983) | Colour (KA4: 106) | Soil moisture (KA4: 114) | SOM (KA4: 108) | Fine soil (KA4:132/135) | Coarse soil (KA4:133/141) | Structure (KA4: 117) | CaCO3 (KA 4: 110) | Compaction (KA4: 122) | Consistence dry/moist (FAO 1990: 52) | Roots (KA4:130) | Further pedogenetic properties | Soil sample |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-5 | Ahs'' | rotgrau. graurot | feu2 | h2-h3 | Su | fGr (mGr)3 | ein | - | Vf1 | - | W4 | Transition to following horizon gradually, horizon differing from following in slightly grey | x |
| 5-30 | Ahs' | graubraun (rotbraun) | feu2 | h1 | Su | fGr (mGr)3 | ein | - | Vf1 | - | W4 | Flashy color | x |
| 30-45 | Ahs' | hellbraun | feu1 | h1 | Su | mGr5 | ein | - | Vf1 | - | W2 | - | x |

Data of analysis

| Depth of soil sample in cm | Colour dry (Munsell) | Bulk density [g/cm3] | pH (CaCl2) | CaCO3 (%) | Corg (%) | Humus (%) | Corg/N | N (%) | EC (mS/cm) | CECeff. (cmol/kg) | P (ppm TS) | Fine soil (%) | Coarse soil (%) | Soil texture (KA4: 135) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-5 | 10 YR 5/4 | - | 6.14 | 0.06 | 0.49 | 0.99 | 8.67 | 0.06 | 0.30 | 5.27 | 3269.50 | 69 | 31 | Sl2 |
| 5-30 | 10 YR 5/4 | - | 6.56 | 0.09 | 0.87 | 1.73 | 8.35 | 0.10 | 0.20 | 7.30 | - | 69 | 31 | Sl2 |
| 30-45 | 7.5 YR – 10 YR 5/4 | - | 6.67 | 0.14 | 0.84 | 1.68 | 8.32 | 0.10 | 0.34 | - | - | 39 | 61 | - |

| | |
|---|---|
| Soil type (acc. to HAASE 1983 / FAO 1998): | **Middle Kastanozem / Haplic Kastanozem** |
| Altitudinal belt / Type of vegetation: | Montane / *Rhinactinidia eremophila* - *Stipa krylovii*-Mountain Steppe |
| Altitude in m a.s.l.: | 1913 |
| Profile: | 5.1 |
| Date: | 29.08.2002 |
| GPS: | 81 |
| No. of vegetation relevés: | 17-19 |

No photo availabale

| **Parent rock / sediment** | **Geomorphological type** | **Mesorelief** | **Micro-relief** | **Expos.** | **Inclin. in °** | **Utilization** |
|---|---|---|---|---|---|---|
| Granite | Lower mountain range in Altai foreland | Bottom of valley in mid-slope | Even | - | - | Winter pasture |

Field description

| **Depth of horizon (cm)** | **Horizon** (HAASE 1983) | **Colour** (KA4: 106) | **Soil moisture** (KA4: 114) | **SOM** (KA4: 108) | **Fine soil** (KA4:132/135) | **Coarse soil** (KA4:133/141) | **Structure** (KA4: 117) | **CaCO3** (KA 4: 110) | **Compaction** (KA4: 122) | **Consistence dry/moist** (FAO 1990: 52) | **Roots** (KA4:130) | **Further pedogenetic properties** | **Soil sample** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-8 | Ahs' | hellbraun | feu1 | - | S | fGr-mGr2 | ein | - | Vf1 | - | W4 | Slightly darker than lower horizon | 3VP, 2x |
| 8-30 | Ahs'' | No record | No record | No record | No record | No record | No record | - | No record | - | W3 | - | VP, 1x |

Data of analysis

| **Depth of soil sample in cm** | **Colour dry** (Munsell) | **Bulk density [g/cm3]** | **pH (CaCl2)** | **CaCO3 (%)** | **Corg (%)** | **Humus (%)** | **Corg/N** | **N (%)** | **EC (mS/cm)** | **CECeff. (cmol/kg)** | **P (ppm TS)** | **Fine soil (%)** | **Coarse soil (%)** | **Soil texture** (KA4: 135) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2-6 | - | 1.32 | 6.81 | 0.06 | 1.17 | 2.34 | 11.93 | 0.10 | 0.70 | - | - | 86 | 14 | - |
| 3-7 | - | 1.53 | 6.25 | 0.13 | 0.56 | 1.13 | 10.37 | 0.05 | 0.22 | - | 3253.50 | 88 | 12 | - |
| 3-9 | 10 YR 5/3-4 | - | 6.74 | 0.14 | 0.83 | 1.67 | 11.13 | 0.07 | 0.43 | - | 3037.50 | 89 | 11 | - |
| 4-10 | 10 YR 6/4 | - | 6.51 | 0.18 | 0.86 | 1.73 | 9.94 | 0.09 | 0.23 | - | - | 87 | 13 | - |
| 5-10 | - | 1.57 | 5.37 | 0.00 | 1.21 | 2.42 | 9.24 | 0.13 | 0.11 | 5.89 | - | 86 | 14 | Su2 |
| 6-9 | 10 YR 6/4 | - | 5.45 | 0.18 | 0.85 | 1.69 | 8.65 | 0.10 | 0.13 | - | - | 78 | 22 | - |

| | |
|---|---|
| Soil type (acc. to HAASE 1983 / FAO 1998): | **Chernozem / Haplic Chernozem** |
| Altitudinal belt / Type of vegetation: | Alpine belt / Alpine Steppe |
| Altitude in m a.s.l.: | 2365 |
| Profile: | 06 |
| Date: | 17.07.2002 |
| GPS: | 50 |
| No. of vegetation relevés: | 22-25 |

| **Parent rock / sediment** | **Geomorphological type** | **Mesorelief** | **Microrelief** | **Expos.** | **Inclin. in °** | **Utilization** |
|---|---|---|---|---|---|---|
| Granite, slate | Mountain range of Altai | Mid-slope, run-off channel | Steps as terraces, vertically concave, horizontally rectilinear | NE | 20 | Winter pasture |

Field description

| **Depth of horizon (cm)** | **Horizon** (HAASE 1983) | **Colour** (KA4: 106) | **Soil moisture** (KA4: 114) | **SOM** (KA4: 108) | **Fine soil** (KA4:132/135) | **Coarse soil** (KA4:133/141) | **Structure** (KA4: 117) | **CaCO3** (KA 4: 110) | **Compaction** (KA4: 122) | **Consistence dry/moist** (FAO 1990: 52) | **Roots** (KA4:130) | **Further pedogenetic properties** | **Soil sample** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-16 | Aw | d bn,sm sw, h gr | feu2 | h6 | Su2 | fX1 | einz | - | Vf 1 | Lo / Lo | W6 | - | x |
| 16-28 | Ah | d gr-bn | feu2 | h5 | Su2 | mX3, gGr4 | einz | c1 | Vf 1 | Lo / Lo | W5 | Weak crusts of secondary carbonates at bottom sides of stones | x |
| 28-40 | Ahca | gr-bn | feu2 | h4 | Slu | gGr3, mX4 | einz | c3 | Vf 1 | Lo / Lo | W4 | Crusts of secondary carbonates at bottom sides of stones | - |
| 40 | Ah'ca | bn | feu2 | h2 | Slu | gGr3, mX4 | einz | c4 | Vf 2 | Lo / Lo | W3 | Distinct crusts of secondary carbonates at bottom sides of stones | x |

Data of analysis

| **Depth of soil sample in cm** | **Colour dry** (Munsell) | **Bulk density [g/cm3]** | **pH (CaCl2)** | **CaCO3 (%)** | **Corg (%)** | **Humus (%)** | **Corg/N** | **N (%)** | **EC (mS/cm)** | **CECeff. (cmol/kg)** | **P (ppm TS)** | **Fine soil (%)** | **Coarse soil (%)** | **Soil texture** (KA4: 135) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2-10 | 2.5 YR 3/2 | - | 6.41 | 0.13 | 13.76 | 27.53 | 11.90 | 1.16 | 1.26 | 35.84 | 842 | 69.35 | 30.65 | Sl4 |
| 19-30 | 2.5 YR 4/2 | - | 7.01 | 0.00 | 5.13 | 10.25 | 10.49 | 0.49 | 0.89 | - | - | 64.65 | 35.35 | - |
| 40-50 | 2.5 YR 6/2 | - | 7.20 | 1.87 | 1.45 | 2.90 | 9.51 | 0.15 | 1.08 | - | - | 44.41 | 55.59 | - |

| | |
|---|---|
| Soil type (acc. to HAASE 1983 / FAO 1998): | **Dark Kastanozem / Calcic Kastanozem** |
| Altitudinal belt / Type of vegetation: | Alpine belt / Alpine Steppe |
| Altitude in m a.s.l.: | 2425 |
| Profile: | 07 |
| Date: | 18.07.2002 |
| GPS: | 51 |
| No. of vegetation relevés: | 20-22 |

| **Parent rock / sediment** | **Geomorphological type** | **Mesorelief** | **Microrelief** | **Expos.** | **Inclin. in °** | **Utilization** |
|---|---|---|---|---|---|---|
| Slate | Mountain range of Altai | Upper part of slope | Steps as terraces, vertically and horizontally rectilinear | NNE | 40 | Summer pasture |

Field description

| **Depth of horizon (cm)** | **Horizon** (HAASE 1983) | **Colour** (KA4: 106) | **Soil moisture** (KA4: 114) | **SOM** (KA4: 108) | **Fine soil** (KA4:132/135) | **Coarse soil** (KA4:133/141) | **Structure** (KA4: 117) | **CaCO3** (KA 4: 110) | **Compaction** (KA4: 122) | **Consistence dry/moist** (FAO 1990: 52) | **Roots** (KA4:130) | **Further pedogenetic properties** | **Soil sample** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | Ahs | h bn | feu2 | h4 | Us-Ss (FS) | gG5, fX2 | ein | - | vf1 | Lo / Lo | W6 | - | 10 |
| 10-36 | Ahs' | gr-bn, fa ge | feu1 | h1-2 | Su4-Ss (FS) | gG5, fX2 | ein | - | vf1 | Lo / Lo | W5 | - | 10-36 |
| 36 | Ca | bl-gr | feu1 | h0 | Su4 | gG5, fX3 | ein | c6 | vf1 | Lo / Lo | W4 | Crusts of secondary carbonates at bottom sides of stones & soft powdery lime | 36 |

Data of analysis

| **Depth of soil sample in cm** | **Colour dry** (Munsell) | **Bulk density [g/cm3]** | **pH (CaCl2)** | **CaCO3 (%)** | **Corg (%)** | **Humus (%)** | **Corg/N** | **N (%)** | **EC (mS/cm)** | **CECeff. (cmol/kg)** | **P (ppm TS)** | **Fine soil (%)** | **Coarse soil (%)** | **Soil texture** (KA4: 135) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2-8 | 5 Y 3/2 | - | 6.12 | 0.06 | 2.43 | 4.87 | 9.91 | 0.25 | 0.63 | 12.15 | 652.7 | 44.83 | 55.17 | Su2 |
| 18-26 | 2.5 Y 6/3 | - | 6.59 | 0.13 | 1.42 | 2.84 | 9.89 | 0.14 | 0.49 | - | - | 40.75 | 59.25 | - |
| 42-56 | - | - | 7.22 | 7.32 | 0.60 | 1.19 | 11.23 | 0.05 | 0.59 | - | - | 54.39 | 45.61 | - |

Soil type (acc. to HAASE 1983 / FAO 1998): **Dark Kastanozem / Haplic Kastanozem**
Altitudinal belt / Type of vegetation: Alpine belt / Alpine Steppe
Altitude in m a.s.l.: 2480
Profile: 14
Date: 21.08.2002
GPS: 79
No. of vegetation relevés: 26-27, 51, 52, 60

| Parent rock / sediment | Geomorphological type | Mesorelief | Microrelief | Expos. | Inclin. in ° | Utilization |
|---|---|---|---|---|---|---|
| Slate | Mountain range of Altai | Upper part of slightly inclined slope | Vertically and horizontally rectilinear, gravelly surface | N | 7 | Summer pasture |

Field description

| **Depth of horizon (cm)** | **Horizon** (HAASE 1983) | **Colour** (KA4: 106) | **Soil moisture** (KA4: 114) | **SOM** (KA4: 108) | **Fine soil** (KA4:132/135) | **Coarse soil** (KA4:133/141) | **Structure** (KA4: 117) | **CaCO3** (KA 4: 110) | **Compaction** (KA4: 122) | **Consistence dry/moist** (FAO 1990: 52) | **Roots** (KA4:130) | **Further pedogenetic properties** | **Soil sample** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-7 | Ahs$_1$ | bn | feu1 | h3 | Su2 | fGr1 | ein | - | vf1 | Lo / Lo | W6 | Darker than lower horizon | x |
| 7-24 | Ahs$_2$ | h bn | feu1 | h2 | Su2 | - | ein | - | vf1 | Lo / Lo | W5 | - | x |
| 24-46 | Ahs$_3$ | ge-bn | No record | h2 | Ss | - | ein | - | vf1 | Lo / Lo | W4 | Roots up to 56 cm | x |
| 46-70 | Bs | No record | No record | h1 | No record | No record | No record | - | No record | No record | W2 | Soil temperature 0°C | - |

Data of analysis

| **Depth of soil sample in cm** | **Colour dry** (Munsell) | **Bulk density [g/cm3]** | **pH (CaCl2)** | **CaCO3 (%)** | **Corg (%)** | **Humus (%)** | **Corg/N** | **N (%)** | **EC (mS/cm)** | **CECeff. (cmol/kg)** | **P (ppm TS)** | **Fine soil (%)** | **Coarse soil (%)** | **Soil texture** (KA4: 135) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-4 | 10 YR 3/3 | - | 6,71 | 0,11 | 3,71 | 7,42 | 9,85 | 0,38 | 3,18 | 7,98 | 540,75 | 92,13 | 7,87 | Sl3 |
| 9-24 | 10 YR 3/3 | - | 6,14 | 0,13 | 1,70 | 3,40 | 2,29 | 0,74 | 0,70 | 11,33 | - | 86,92 | 13,08 | Sl2 |
| 37-46 | 10 YR 3/3 | - | 6,19 | 0,12 | 2,06 | 4,13 | 9,24 | 0,22 | 2,11 | - | - | 91,48 | 8,52 | - |

Soil type (acc. to HAASE 1983 / FAO 1998): **Derno-Cryosol[11] / Histic Cryosol**
Altitudinal belt / Type of vegetation: Alpine belt / Cryophyte Steppe
Altitude in m a.s.l.: 3050
Profile: 08
Date: 20.07.2002
GPS: 67
No. of vegetation relevés: 46-49

| Parent rock / sediment | Geomorphological type | Mesorelief | Microrelief | Expos. | Inclin. in ° | Utilization |
|---|---|---|---|---|---|---|
| Granite | Mountain range of Altai | Side moraine in mountain range, mid-slope | Undulate, hummocky | ESE | 12 | Summer pasture |

Field description

| Depth of horizon (cm) | Horizon (HAASE 1983) | Colour (KA4: 106) | Soil moisture (KA4: 114) | SOM (KA4: 108) | Fine soil (KA4:132/135) | Coarse soil (KA4:133/141) | Structure (KA4: 117) | CaCO3 (KA 4: 110) | Compaction (KA4: 122) | Consistence dry/moist (FAO 1990: 52) | Roots (KA4:130) | Further pedogenetic properties | Soil sample |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | Aw | h sw | feu2 | h6-5 | Us | gGr1 | einz -koh | - | vf2 | - | W6 | Polygonal patterns in lawn surface due to cryoturbation | x |
| 10-19 | Akgca | sw-d bn | feu2 | h4 | Us | gGr, mX4 | koh | - | vf2 | - | W5 | Cryoturbate displacement of SOM | x |
| 19-45 | Bhs | bn-h bn | feu2 | h2 | Us | gGr, mX4 | kon | - | vf2 | - | W3 | - | x |
| 45 | KGo | bn-h bn | feu2 | h2 | Us | gGr, fX4 | kon | - | vf2 | - | W1 | Single marks of oxidation, ice lenses | x |

Data of analysis

| Depth of soil sample in cm | Colour dry (Munsell) | Bulk density [g/cm3] | pH (CaCl2) | CaCO3 (%) | Corg (%) | Humus (%) | Corg/N | N (%) | EC (mS/cm) | CECeff. (cmol/kg) | P (ppm TS) | Fine soil (%) | Coarse soil (%) | Soil texture (KA4: 135) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1-7 | 10 YR 3/2 | - | 6.82 | 0.23 | 16.96 | 33.93 | 10.35 | 1.64 | 1.50 | 42.11 | 648 | 93.40 | 6.60 | Lt2 |
| 10-15 | 10 YR 5/4 | - | 6.83 | 2.56 | 4.87 | 9.73 | 9.61 | 0.51 | 1.53 | - | - | 68.77 | 31.23 | - |
| 21-39 | 10 YR 6/4 | - | 6.78 | 0.85 | 1.34 | 2.67 | 10.01 | 0.13 | 0.88 | - | - | 64.25 | 35.75 | - |
| 47-52 | 7.5 YR 6/4 | - | 6.79 | 0.01 | 0.90 | 1.79 | 10.02 | 0.09 | 0.60 | - | - | 58.85 | 41.15 | - |

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[11] According to HAASE (1983), Derno-Cryosol is exactly denominated in German language as Derno-Kryotaigaboden.

| | |
|---|---|
| Soil type (acc. to HAASE 1983 / FAO 1998): | **Derno-Cryosol / Mollic Cryosol** |
| Altitudinal belt / Type of vegetation: | Alpine belt / Cryophyte Steppe |
| Altitude in m a.s.l.: | 2760 |
| Profile: | 11 |
| Date: | 03.08.2002 |
| GPS: | 66 |
| No. of vegetation relevés: | 40-43 |

| Parent rock / sediment | Geomorphological type | Mesorelief | Microrelief | Expos. | Inclin. in ° | Utilization |
|---|---|---|---|---|---|---|
| Fluvial sandy sediments | Mountain range of Altai | Upper part of slope, margin of river valley, third terrace of creek | Vertically and horizontally rectilinear | S | 7 | Ger camp of summer pasture |

Field description

| Depth of horizon (cm) | Horizon (HAASE 1983) | Colour (KA4: 106) | Soil moisture (KA4: 114) | SOM (KA4: 108) | Fine soil (KA4:132/135) | Coarse soil (KA4:133/141) | Structure (KA4: 117) | CaCO3 (KA 4: 110) | Compaction (KA4: 122) | Consistence dry/moist (FAO 1990: 52) | Roots (KA4:130) | Further pedogenetic properties | Soil sample |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-13 | Aw | sw | feu 3 | h6 | Uls | - | ein-koh | c1 | vf1 | Lo / Lo | W6 (root felt) | Polygonal patterns in lawn surface due to cryoturbation | x |
| 13-18 | Ah | d bn | feu 3 | h5 | Ut | fX, single | ein-koh | c1 | vf1 | Lo / Lo | W5 | - | x |
| 18-34 | Akg$_1$ | h bn | feu 3 | h4 | Us | fX, single | ein-koh | c1 | vf1 | Lo / Lo | W5 | Chestnut colour, cryoturbate displacement of SOM | x |
| 34-54 | Akg$_2$ | h bn | feu 3 | h3 | Su2 | fX, single | ein-koh | c1 | vf1 | Lo / Lo | No record | Cryoturbate displacement of SOM | x |
| 54 | Bhs | ge-bn | feu 3 | h2 | Su2 | fX, single | ein-koh | c1 | vf1 | Lo / Lo | No record | - | - |

Data of analysis

| Depth of soil sample in cm | Colour dry (Munsell) | Bulk density [g/cm3] | pH (CaCl2) | CaCO3 (%) | Corg (%) | Humus (%) | Corg/N | N (%) | EC (mS/cm) | CECeff. (cmol/kg) | P (ppm TS) | Fine soil (%) | Coarse soil (%) | Soil texture (KA4: 135) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2-8 | - | - | 6.52 | 0.20 | 11.97 | 23.95 | 10.72 | 1.12 | 0.97 | 41.38 | - | 100.00 | 0.00 | Lu |
| 14-17 | - | - | 7.05 | 0.10 | 6.74 | 13.48 | 10.52 | 0.64 | 2.71 | 35.15 | 576.2 | 99.67 | 0.33 | Ut4 |
| 22-30 | - | - | 6.40 | 0.06 | 4.49 | 8.97 | 10.43 | 0.43 | 0.36 | - | - | 99.59 | 0.41 | - |
| 36-39 | - | - | 7.02 | 0.00 | 3.72 | 7.44 | 10.27 | 0.36 | 0.42 | - | - | 100.00 | 0.00 | - |

Soil type (acc. to HAASE 1983 / FAO 1998): **Cryo-Gley[12] / Gelic Gleysol**
Altitudinal belt / Type of vegetation: Alpine belt / Sedge Mat
Altitude in m a.s.l.: 2730
Profile : 10
Date: 02.08.2002
GPS: 63
No. of vegetation relevés: -

| Parent rock / sediment | Geomorphological type | Mesorelief | Microrelief | Expos. | Inclin. in ° | Utilization |
|---|---|---|---|---|---|---|
| Slate. granite | Mountain range of Altai | Bottom of river valley in upper part of slope, first terrace of creek | Hummocky, rich in boulders, vertically concave, horizontally rectilinear | S | 7 | Summer pasture |

Field description

| Depth of horizon (cm) | Horizon (HAASE 1983) | Colour (KA4: 106) | Soil moisture (KA4: 114) | SOM (KA4: 108) | Fine soil (KA4:132/135) | Coarse soil (KA4:133/141) | Structure (KA4: 117) | CaCO3 (KA 4: 110) | Compaction (KA4: 122) | Consistence dry/moist (FAO 1990: 52) | Roots (KA4:130) | Further pedogenetic properties | Soil sample |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0-10 | Thm | dubn | feu4 | h5 | Lt | fGr1 | koh | - | vf5 (roots) | No record | W6 (root felt) | - | 3 VP, x |
| 10-19 | Aht | bn | feu4 | h4 | Lt | mGr2, fX | koh | - | vf5 (roots) | No record | W6 (root felt) | Weak oxidation patches along roots | x |
| 19-36 | KGo | ro bn, patchy | feu5 | h3 | Ls | mGr4, gGr3, fX4 | ein | - | vf1 | No record | W4 | Clear oxidation marks | x |
| 36-59 | KGro | ro gr, patchy | feu5-6 | h2 | Ls | mGr4, gGr3, fX4 | ein | - | vf1 | No record | W4 | Water of melting permafrost | x |
| 59-90 | KGr | gr | feu6 | h0 | Ls | mGr4, gGr3, fX4 | einz | - | vf1 | No record | W2 | Permafrost | - |

Data of analysis

| Depth of soil sample in cm | Colour wet (Munsell) | Bulk density [g/cm3] | pH (CaCl2) | CaCO3 (%) | Corg (%) | Humus (%) | Corg/N | N (%) | EC (mS/cm) | CECeff. (cmol/kg) | P (ppm TS) | Fine soil (%) | Coarse soil (%) | Soil texture (KA4: 135) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2-9 | 2.5 Y 3/2 | 0.52 | 5.63 | 0.08 | 15.35 | 30.69 | 12.92 | 1.19 | 1.33 | 39.51 | 472.9 | 100.00 | 0.00 | Lt2 |
| 11-18 | 10 YR 3/3 | - | 5.38 | 0.10 | 9.10 | 18.20 | 12.24 | 0.74 | 0.40 | - | - | 100.00 | 0.00 | - |
| 20-34 | 10 YR 6/6 | - | 6.08 | 0.00 | 1.67 | 3.35 | 14.71 | 0.11 | 0.27 | - | - | 36.02 | 63.98 | - |
| 43-58 | 2.5 Y 5/2 | - | 6.44 | 0.00 | 0.63 | 1.27 | 14.17 | 0.04 | 0.24 | - | - | 25.44 | 74.56 | - |

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[12] According to HAASE (1983), Cryo-Gleysol is exactly denominated in German language as Kryo-Grundgley.

# Appendix V:

Labelling and characterisation of soil horizons of the investigation area

Corresponding soil units of the investigation area in which the horizons appear, are given according to Haase (1983) and according to FAO (1998) in brackets. Labelling of soil horizons follows Haase (1983) and FAO (1988) with modifications.

| Master horizon | Diagnostic horizon | Description of properties |
|---|---|---|
| **Humic mineral horizons of soil solum (topsoil and subsoil)** | | |
| A | | Mineral surface horizon characterised by accumulation of soil organic matter (SOM) |
| | Aw | Root felt horizon of topsoil with very dense structure consisting of living roots, SOM > 20 percent, in Chernozem, Derno-Cryosol (Cryosol) and Cryo-Gley (Gelic Gleyosol). |
| | Ah̲ | Topsoil humus horizon with greyish brown to black color, SOM > 10 percent, in Chernozem and Derno-Cryosol (Cryosol). |
| | Ah | Topsoil humus horizon with greyish brown to black colour, SOM 3-10 percent, in Chernosem and Derno-Cryosol (Cryosol). |
| | Ah’ | Topsoil humus horizon with greyish brown colour, SOM < 3 percent, in Chernozem. |
| | Ahca | Topsoil humus horizon with greyish brown to black colour, SOM 3-10 percent, contains secondary calcium carbonate as pseudomycelias, concretions, soft powdery lime, or crusts at bottom of stones up to 10 percent or < 5 percent more than upper or lower horizon, in Chernozem. |
| | Ah’ca | Topsoil humus horizon with greyish brown colour, SOM < 3 percent, contains secondary calcium carbonate as pseudomycelias, concretions, soft powdery lime, or crusts at bottom of stones up to 10 percent or < 5 percent more than upper or lower horizon, in Chernozem. |
| | Ahs | Topsoil humus horizon with chestnut colour of Burozem (Calcisol) and Kastanozem, Colour according to Munsell Color Co. (1994) Hue of 7.5 and10 YR with Value 3-4 and Chroma of 3-4 (rare 2), contains traces of secondary calcium carbonate < 1 percent, SOM 3-8 percent. |
| | Ahs’ | Topsoil humus horizon with chestnut colour of Burozem (Calcisol) and Kastanozem, contains traces of secondary calcium carbonate < 1 percent, with SOM 1.5 – 3 percent. |
| | Ahs’’ | Topsoil humus horizon with chestnut colour of Burozem (Calcisol) and Kastanozem, contains traces of secondary calcium carbonate < 1 percent, with SOM <1.5 percent. |
| | Ahsca | Topsoil humus horizon with chestnut colour, SOM 3-8 percent, contains secondary calcium carbonate as pseudomycelias, concretions, soft powdery lime, or crusts at bottom of stones up to 10 percent or < 5 percent more than upper or lower horizon, in Kastanozem and Burozem (Calcisol). |
| | Ahs’’ca | Topsoil humus horizon with chestnut colour, SOM < 1.5 percent, contains secondary calcium carbonate as pseudomycelias, concretions, soft powdery lime, or crusts at bottom of stones up to 10 percent or < 5 percent more than upper or lower horizon, in Kastanozem, Burozem (Calcisol and Gypsisol). |
| **Brown horizons of soil solum (subsoil)** | | |
| B | | **Mineral horizons formed below A.** |
| | Bhs | Horizon below A with brown or yellowish brown colour and SOM 1-3 percent, it may contain traces of secondary calcium carbonate < 1 percent, in Derno-Cryosol (Cryosol). |
| | Bs | Horizon below A with brown colour and SOM < 1 percent, it may contain traces of secondary calcium carbonate < 1 percent, in Burozem (Calcisol) and Kastanozem. |
| **Accumulation horizons of secondary calcium carbonate and gypsum** | | |
| | Bsca | **It combines characteristics of accumulation of calcium carbonate with brunification weathering (Bs, Bhs) in Burosem (Calcisol and Gypsisol).**<br>**With secondary calcium carbonate as pseudomycelias, concretions, soft powdery lime, or crusts at bottom of stones up to 10 percent or < 5 percent more than lower or upper horizon, pH > 7, SOM < 1 percent.** |
| | Byca | It contains cemented gypsum and secondary calcium carbonate as pseudomycelias, concretions, soft powdery lime, or crusts at bottom of stones up to 10 percent or < 5 percent more than lower or upper horizon, pH > 7, SOM < 1 percent, in Gypsisol.<br>(Because Haase 1983 did not include Gypsisol and its corresponding horizons, this designation represents a combination of Bca (Haase 1983) and the suffix y indicating the accumulation of gypsum in the international concept of soil classification (FAO 1988). |

| | | |
|---|---|---|
| Ca | Ca | Accumulation horizon of secondary calcium carbonate as pseudomycelias, concretions, soft powdery lime or crusts at bottom of stones, calcium carbonate > 10 percent or > 5 percent more than upper or lower horizon, Value of Hue higher (lighter) than in upper or lower horizon, observed in Kastanozem but further possible in Chernozem, Burosem (Calcisol and Gypsisol). |
| | CaC | Transition horizon with no further pedogenetic properties than accumulation of secondary calcium carbonate predominantly as crusts at bottom of stones and less than as pseudomycelias, concretions or soft powdery lime < 10 percent and < 5 percent more than upper horizon, Value of Hue with slight to no difference to upper or lower horizon, observed in Kastanozem but further possible in Chernozem, Burosem (Calcisol and Gypsisol). |
| **Cryic hydromorphic horizons** | | |
| | Akg | Topsoil humus horizon with marks of cryoturbate displacement of SOM, SOM 5-30 percent, in Derno-Cryosol (Cryosol). |
| | Akgca | Topsoil humus horizon with marks of cryoturbate displacement of SOM, SOM 5-30 percent, contains secondary calcium carbonate < 10 percent or less than 5 percent more than upper or lower horizon, in Derno-Cryosol (Cryosol). |
| K | | Permafrost horizon containing frozen water or with properties indicating water surplus as a result of stagnation effect of lower horizon. |
| | KGo | Oxidation horizon with patches of rust, it contains marks of permafrost (cryoturbate motions, ice crystals, ice lenses), it may contain SOM 1-4 percent and represents corresponding brown colour, in Derno-Cryosol (Cryosol) and Cryo-Gley (Gleysol). |
| | KGro | Oxidation horizon with reduction patches, it contains marks of permafrost (cryoturbate motions, ice crystals, ice lenses), it may contain SOM 1-4 percent and represents corresponding brown colour, in Derno-Cryosol (Cryosol) and Cryo-Gley (Gleysol). |
| | KGr | Reduction horizon with reduction patches, it contains marks of permafrost (cryoturbate motions, ice crystals, ice lenses), it may contain SOM < 3 percent and represents corresponding brown colour, in Derno-Cryosol (Cryosol) and Cryo-Gley (Gleysol). |
| **Semi-hydromorphic and hydromorphic horizons** | | |
| | Aht | Transition horizon between T and Ah horizon with hydromorphic marks as oxidation and/or reduction patches, contains considerable SOM > 15 percent, dark brown to black colour, from thawing water and slope percolation water permanently moist or frozen during majority of the year, completely wet only short periods, in Cryo-Gley (Gleysol). |
| T | | Organic surface horizon characterised by accumulation of rawly decomposed soil organic matter and peat. |
| | Thm | Contains considerable amount of SOM > 30 percent under continuous water saturation, pH < 6.0, in Cryo-Gley (Gleysol). |
| C | | Mineral horizon or layer which is hardly affected by pedogenetic processes. |