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A scale-depending grazing gradient in an *Artemisia*-desert steppe? - A case study from western Mongolia -

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Abstract

Data about stand density, above-ground 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: distance from the grazing hot spot and 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; our study took place only within a single plant community comparing different populations of one species.

Keywords: desert steppe, herbivory, plant population, piosphere, research scale

Zusammenfassung

In einem Steppenökosystem der westlichen Mongolei wurden an stark beweideten Standorten entlang von Beweidungsgradienten Daten zur Vegetationsdichte, der oberirdischen Biomasse und Individualgewichte sowie zur Anzahl blühender Individuen des Kurzstrauches *Artemisia xerophytica* erfasst. Bodenkundliche Daten wurden verwendet um zwischen dem Beweidungseinfluss und edaphischen Einflussfaktoren unterscheiden zu können. Die für *Artemisia xerophytica* erfassten Daten spiegeln den angenommenen Beweidungsein-

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fluss bis zu einer Entfernung von 800 m vom Beweidungsschwerpunkt wider. Bei abnehmendem Beweidungsdruck nehmen die Vegetationsbedeckung und die absolute Biomasse pro Einheit zu. Die durchschnittliche Wuchshöhe der Sträucher als Indikator für die Vitalität der Pflanzen, zeigt einen Zusammenhang sowohl zur Entfernung vom Beweidungsschwerpunkt als auch zur Bestandesdichte. Letzteres kann durch einen zusätzlichen intraspezifischen Wettbewerb bei höherer Bestandesdichte erklärt werden. Mit zunehmender Distanz vom Beweidungsschwerpunkt werden diese Merkmale jedoch von den den Bodenwasserhaushalt beeinflussenden pedologischen Eigenschaften überprägt, woraus relativ ähnliche Degradationsformen resultieren. Diese Ergebnisse stehen im Widerspruch zu anderen auf dem Skalenniveau von Pflanzengemeinschaften durchgeführten Studien, die keine signifikanten Veränderungen entlang von Beweidungsgradienten nachweisen konnten. Eine mögliche Erklärung dafür sind die unterschiedlichen Skalenebenen der Untersuchungen. Die vorliegende Untersuchung erfolgte innerhalb einer einzelnen Pflanzengemeinschaft mit dem Vergleich verschiedener Populationen einer Art.

Schlüsselbegriffe: Wüstensteppe, Herbevorie, Piosphäre, Skalenebenen

Introduction

The privatisation of former state co-operatives has led to a considerable increase in livestock numbers and increased grazing pressure in most regions of Mongolia (Mearns 1993, Müller 1994, Müller 1999, Janzen & Bazargur 2003). Overgrazing and degradation as consequences are often mentioned in the literature (Babaev & Sarantuyaa 1995, Opp 1996, Stubbe 1997, Janzen & Bazargur 1999, Adiyasuren et al. 2002, Opp & Hilbig 2003, Batkhishig & Lehmkuhl 2003, Hilbig & Opp 2005). 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 (Batkhishig & Lehmkuhl 2003, Janzen 2005). However, as long as incentives for short-term profits from high lifestock numbers exist, Mongolia's pastures land will be continuously threatened by overgrazing and degradation (Batkhishig & Lehmkuhl 2003, Janzen & Bazargur 2003, Janzen 2005).

Grazing degradation series have been described regarding changes in vegetation composition and proportions of single species, increasing share of species with low palatability, changes in above-ground biomass production and life form composition for the steppe zone of Mon-golia by Golubeva & Polyanskya (1990), Tserendash & Erdenebaatar (1993), Babaev & Sarantuyaa (1995), Gunin et al. (2002), and Danzhalova (2005). Gorshkova & Grineva (1977) gave detailed information

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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 Trans-Baikal 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 & 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 & Retzer (2005) and Wesche (2005) who found larger differences in vegetation cover between the years than between grazed plots and ungrazed enclosure control plots in the southern desert steppe of Mongolia. The few studies available for Mongolian desert steppes describe mostly changes in plant communities so far. Detailed investigations of grazing influences on growth and stand structures of single plant populations within a community have not been carried out. However, as reported by Oba et al. (2003), the detection of grazing effects in arid ecosystems depends significantly on the map scale applied. *Artemisia xerophytica* is common within southern and western Mongolia desert steppe communities (Hilbig, 1995, Gubanov 1996). Being a well palatable, important fodder plant especially suite for fattening camels in autumn, winter and spring (Yunatov 1954, Jigjidsuren & Johnson 2003) it can be seen as a key species to detect grazing influence. The presented study investigates the effect of grazing on vitality, stand structure and density of *Artemisia xerophytica*. To distinguish between grazing effects and edaphic influences, selected soil parameters were analysed and correlated with *Artemisia xerophytica* cover values.

Material and Methods

Study area

The sampling area is situated at the north-eastern shore of lake Khar Us Nuur (nuur – Mongolian: lake) in the Great Lake Basin in Dörgön district; a part of western Mongolia's Khovd province (Fig. 1). 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 high interannual fluctuations varying between 11-140 mm.

About 70-90 % 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 minus 20 °C

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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 data 1985-2000: Climate Station Dörgön, approx. 5 km northeast from sampling area; see Fig. 1). Due to common gaps in Mongolia's climate station records, we tried to verify these data by comparison with those from other climate stations and by questioning of local people about extreme years. The climate

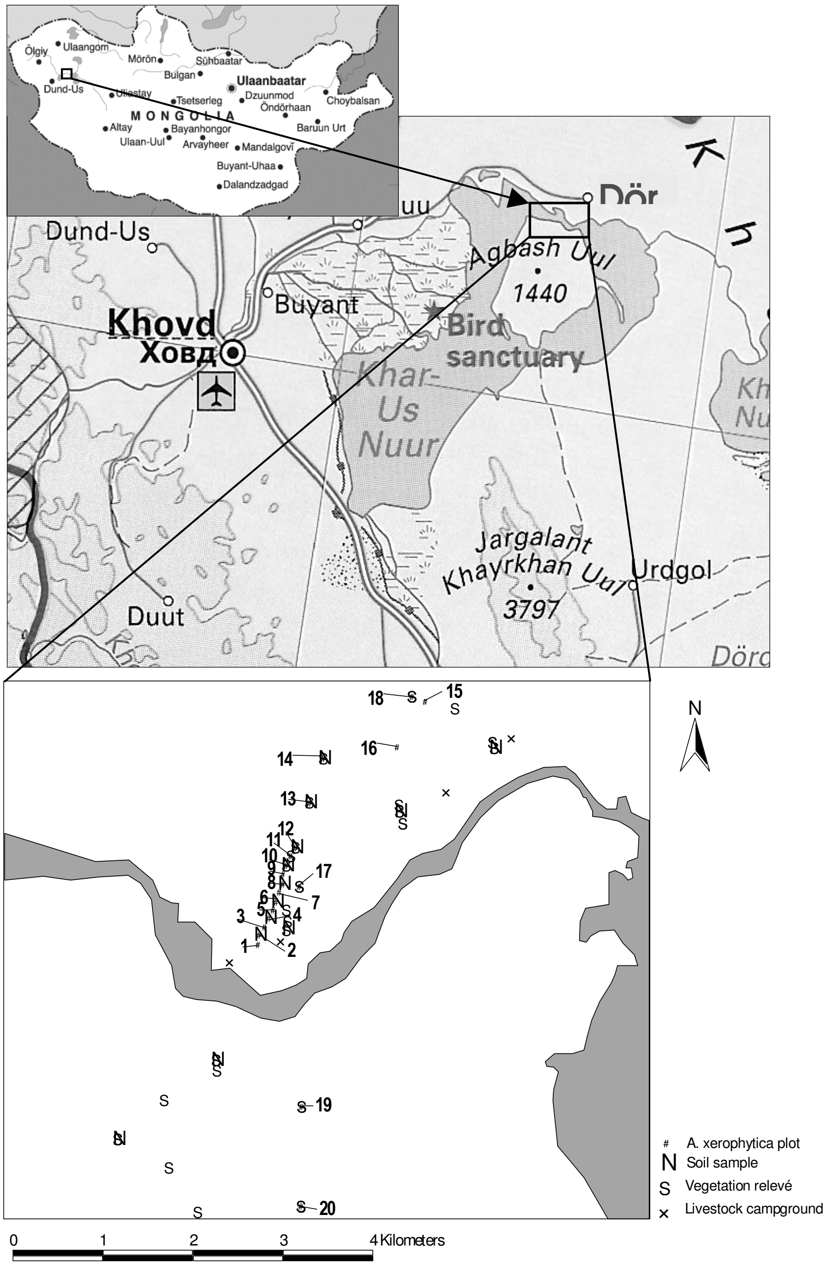

Fig. 1: Position of the study area in the Great Lake Basin in western Mongolia (modified from Tibet Family, Tours and Travel; ITMB Publishing Ltd. 2000)

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model of Böhner (2004) gives a mean annual precipitation of 52 mm, a value slightly lower than the 62 mm recorded. With 182 mm reported by Dörgön station for 2003 (the highest value since 1985), we carried out our investigation in an extremely moist year. In our 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. 1).

***Tab. 1**: Soil parameters recorded for a subset of the sampled Artemisia xerophytica plots.*

Plot no.	**2**	**4**	**6**	**8**	**10**	**12**	**13**	**14**	**r_S with distance from graz. hot spot**
Distance from grazing hot spot [m]	**310**	**250**	**350**	**500**	**700**	**900**	**1450**	**1400**	
P content [ppm dm]	1300	1412	1289	1878	1888	1737	1564	1509	0.476 / 0.05
Corg [%]	0.12	0.08	0.11	0.24	0.09	0.12	0.11	0.04	- 0.108 / 0.05
N [%]	0.02	0.02	0.03	0.04	0.02	0.04	0.02	0.01	- 0.153 / 0.05
Corg/N	5.4	4.4	4.2	6.2	4.8	2.9	5.7	3.1	- 0.095 / 0.05
pH [in $CaCl_2$]	7.7	7.3	7.8	7.5	7.3	7.6	7.5	7.6	- 0.036 / 0.05
CaCO3 [%]	1.4	1.4	1.6	3.8	0.8	3.8	0.6	1.8	- 0.036 / 0.05
Salinity / EC [mS/cm]	2	2	4	3	2	9	1	2	- 0.268 / 0.05
$CEC_{eff.}$ [cmol/kg]	5.2	3.6	0.2	8.9	3.6	14.9	4.6	5.7	0.383 / 0.05
Gravel [%]	15	25	23	16	19	17	19	17	-
Clay [%]	5	3	4	12	4	19	3	5	-
Silt [%]	9	6	7	17	7	15	5	6	-
Sand [%]	87	92	90	73	89	68	92	89	-

The area is covered by an *Artemisia xerophytica* desert steppe community with an average total vegetation cover of 13 %, varying between 5-30 %. 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 our community.

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***Fig. 2**: Flowering plant of Artemisia xerophytica (Photo: M. Schnittler).*

The whole study area is used as a spring pasture. During the grazing season herders set up their gers (ger – Mongolian: traditional living tent of Mongolian herders) along the river.

Data of Dörgön 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. 3).

Sampling methods

The choice of sampling plots follows the piosphere concept according to Andrew & Lange (1986) and Andrew (1988). 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. 1). One of these

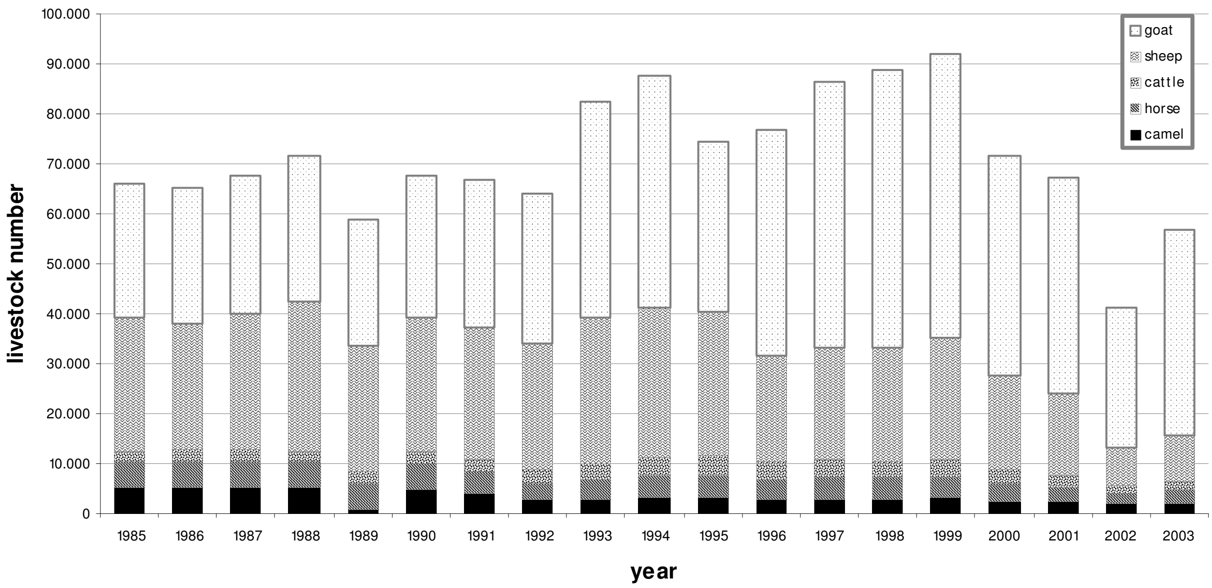

***Fig. 3**: Annual counts for livestock numbers in Dörgön district/Khovd Khovd province (Office for statistical data of Khovd province administration, collected 2004 by Octyabr Vasha).*

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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. 3), are herded every day around 3–5 km away from the camp but spend the night in these campgrounds (Kenter 2005). This utilization pattern should translate into a clear-cut grazing gradient in the sense of the piosphere concept. Counts of faecal pellets, a usual method to validate grazing gradients, had been proved to be inappropriate in our study area since pellets are moved away by wind and accumulate under shrubs.

Twenty plots each comprising 100 m² were sampled (no. 1-20). Together with all livestock campgrounds and ger camps situated nearby their position was recorded with a 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 m² (all plots except 15 and 16). The aboveground 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. 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. 1). Nomenclature of vascular plants follows Gubanov (1996).

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. 1). 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

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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. 1).

Data analyses

All vegetation data and soil nutrient values were correlated with the grazing gradient; soil data were furthermore used to tell apart edaphic from grazing influences.

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

Results

Soil Data

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. 1). 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 significant 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 CEC depends mostly on clay content.

EC values vary from 1-9 ms/cm. Clay content varies from 3-19 % (Tab. 1).

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

Data for *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. 4 (Appendix), 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

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hot spot with rS = 0.871 at p = 0.01 (Fig. 4). Showing a similar pattern, total biomass of all *Artemisia xerophytica* plants rises from 0.23 g/m2 at 400 m to 33 g/m2 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 rS = 0.945 at p = 0.01 (Fig. 5, Appendix). 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. 6 in combination with Fig. 7 (see Appendix) show the dependence of plant weight on distance from grazing hot spot and on stand density. Fig. 7 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 rS = 0.896 at p = 0.01 (Fig. 6). The proportion of flowering plants increases from 3 to 75 % 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 rS = 0.883 (p = 0.01, Fig. 8, Appendix).

Discussion

Taken all sampled parameters of a 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 well with values for salinity tolerance of the closely related *Artemisia frigida* (6 ms/cm, 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.

Our 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

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necessary. The grazing pressure detected by us may be the consequence of continued grazing over decades, or caused by short-term changes in livestock numbers (especially goat) since the nineties (Janzen & Bazargur 2003, Janzen 2005).

In comparison with studies of grazing influences on steppe ecosystems our results confirm findings of decreasing standing-crop biomass and plant numbers with increasing grazing pressure as reported by Gorshkova & 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 & Diaz 1999, 2000; species composition, species richness and above-ground standing biomass production in grazed and ungrazed plots in different years: Wesche & Retzer 2005, Wesche 2005).

We suggest two possible reasons 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) seem to have a much higher influence on vegetation than grazing (Zemmrich, pers. obs.). 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, our 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: distance from the grazing hot spot and 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

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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.

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Appendix

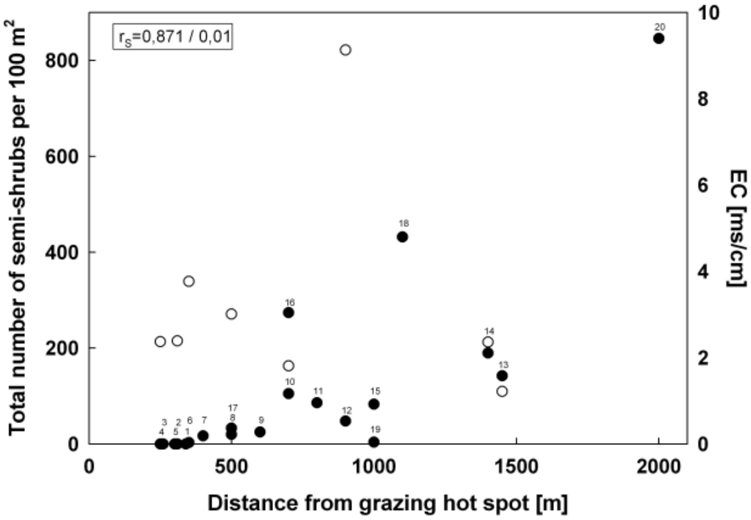

***Fig. 4**: Salinity and density of Artemisia xerophytica semi-shrubs (plants per plot) along the grazing gradient (filled circles: numbers of Artemisia plants, open circles: salinity).*

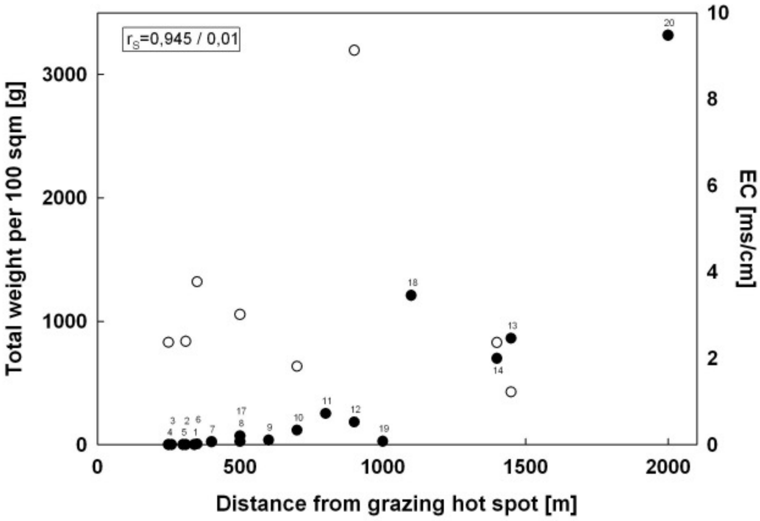

***Fig. 5**: Salinity and total biomass of Artemisia xerophytica along the grazing gradient (filled circles: biomass, open circles: salinity).*

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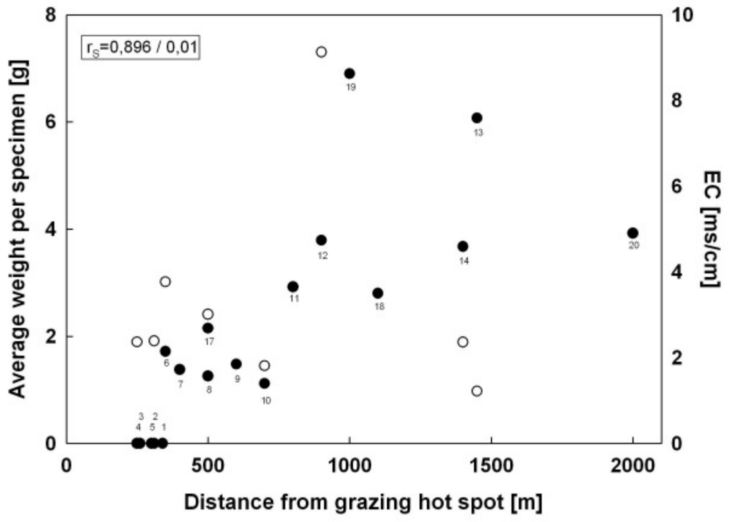

Fig. 6: *Salinity and average plant weight of Artemisia xerophytica specimen (average of fresh weight of 100 plants) along the grazing gradient (filled circles: weight, open circles: salinity).*

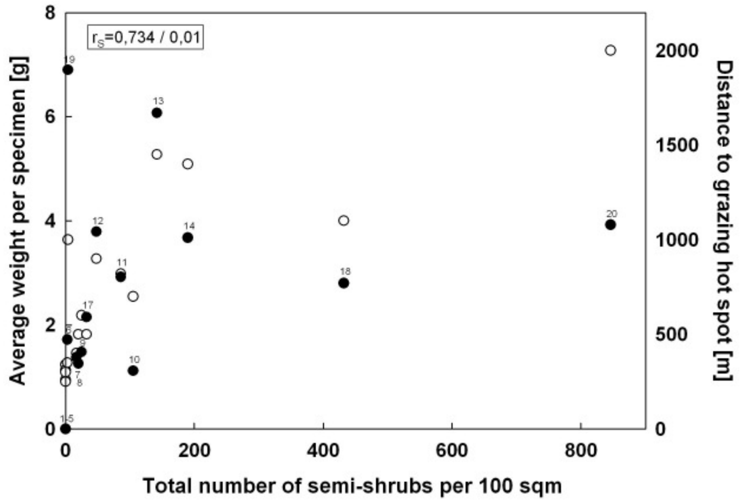

Fig. 7: *Average plant weight versus stand density of Artemisia xerophytica (filled circles: average weight, open circles: distance of the plot from grazing hot spot).*

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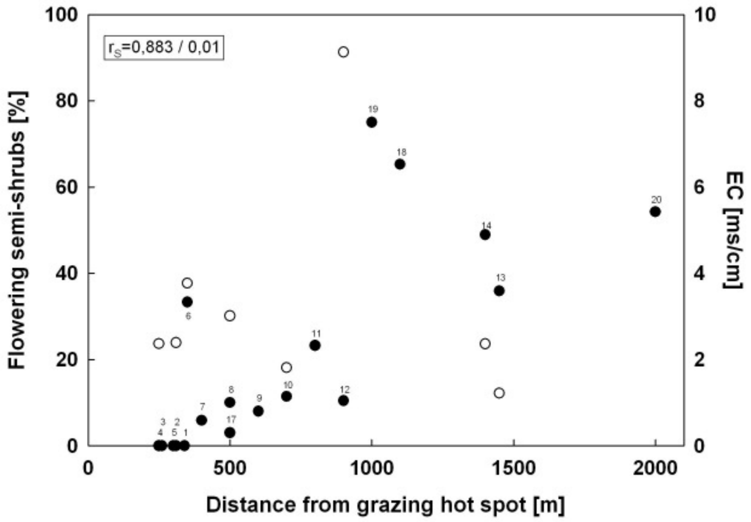

Fig. 8*: Salinity and proportion of flowering Artemisia xerophytica plants along the grazing gradient (filled circles: percent flowering plants, open circles: salinity).*

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