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Biomass and grazing potential of the *Stipa* loess steppes in Ningxia (northern China) in relation to grazing intensity

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Summary

The mere amount of biomass is not a suitable measuring unit for the economic value of a plant community, because not all species are equally appreciated by cattle and sheep and some are even unpalatable. That is why we summarised palatability and appreciation to a feeding value. Together with the biomass this feeding value was used to calculate the grazing potential of the plant communities investigated.

In the *Stipa* loess steppes of Ningxia (northern China) the two characteristic feather grasses dominating in ungrazed or slightly grazed areas are estimated as species of very high feeding value. Those species, which show increasing biomass parallel to increasing grazing intensity are of lower feeding value. Except of overgrazed areas, the *Stipa grandis* steppes have a higher grazing potential than the *Stipa bungeana* communities. A comparison of biomass and grazing potential shows that the relative differences between the grazing potential of the communities existing at different grazing levels are much higher than the relative differences in biomass.

Introduction

Steppe represents the main vegetation type of large areas of northern and western China, stretching from the Mongolian highlands across the Loess Plateau to the middle of the Tibetan upland. In the autonomous region of Ningxia and its surrounding 70% of the surface area is classified as steppe and used for pasture-farming (National Research Council, 1992; National Bureau of Statistics of China, 1998).

The dry steppe representing the dominant vegetation type in the autonomous region of Ningxia Hui with about 60 % of the whole surface area (Guo et al., 1988) has suffered extreme degradation over the past 30 years. In previous papers we have shown the effects of different levels of grazing on soil parameters of *Stipa* loess steppes in Ningxia Hui (Xie and Wittig, 2003), and we have identified indicator species of different grazing levels (Xie and Wittig, 2004). In the following we will deal with biomass and grazing potential of the same steppe types in relation to grazing intensity.

Area under Investigation

The area under investigation is a dry steppe landscape located in the southern autonomous region of Ningxia Hui. In Ningxia almost natural steppe vegetation (i.e. ungrazed ore only slightly grazed) exists only in the Yunwushan dry steppe nature reserve, which is situated in the southern part of the autonomous region. Therefore this nature reserve was investigated especially intensively.

The area is approximately 800 km^2 in size and lies between 1.650 m and 2.148 m above sea level (an average elevation of about 1.780 m). Yinchuan, the capital of the autonomous region, is approximately 300 kilometres away by road. As in all other areas of Ningxia (see Ma, 1996) the most significant sources of income are arable farming and animal husbandry. About 54 % of the area are used for grazing. The Yunwushan area was declared a nature reserve in 1982. Arable farming and animal husbandry have been prohibited since then.

The climate of the area of investigation represents a typical continental climate of the northern hemisphere, slightly influenced by the Pacific summer monsoon. Summers are relatively humid and warm; winters are rather cold, dry and windy. Low precipitation and a comparatively strong rate of evaporation lead to high aridity. The potential evaporation occurs at a rate almost 4 times as high as the annual rainfall.

As the area is located in the western part of the north Shanxi-Loess Plateau, the soil is a direct product of the mighty layer of loess. At an altitude of less than 2000 m a rich castanozem can be found, above 2000 m a mountain phaeozem is the characteristic type of soil. Some more information on these two prevailing types of soil as well as some climate data are given by Xie and Wittig (2004).

Methods

Grazing intensity. The intensity of grazing activities was defined according to monitoring data collected (number and breed of livestock grazing per grazing area unit, frequency of grazing activities) and interviews with responsible officials of the nature reserve and with farmers in the area. The grazing intensity (G) was broken down into the following 5 levels, which are explained in detail by Xie and Wittig (2003, 2004):

- G0: not or very slightly grazed;
- G1: slightly grazed;
- G2: moderately grazed;
- G3: intensively grazed;
- G4: over-grazed.

Measuring the aboveground biomass. In the *Stipa bungeana* and the *Stipa grandis* steppe three plots of 5 m x 5 m were chosen from each level of grazing intensity. At the end of the vegetation period (end of September) of the year 1999 five samples (1 m^2 each) of the above ground biomass (separated for species) were collected from equidistant points along the two diagonals in each plot. The harvested material was dried and the twelve most important species were weighted separately each. The remaining species were weighted together. For each plot the total biomass and the percentage of the twelve species was calculated.

Calculation of the grazing potential. Not all species are equally appreciated by cattle and sheep and some are even unpalatable. Therefore the mere amount of biomass alone does not represent an adequate parameter for the economic value of a grazed area or a plant community. That is why we attributed a feeding value, ranging from 0 to 4, to all those species which together represent 80 to 90 % of the biomass of the *Stipa* steppes of the investigated areas. This feeding value is based on literature (GUO et al., 1988; WU, 1997) and on interviews with local farmers. Together with its biomass the feeding value of a species allows to characterise its grazing potential. From the grazing potential of all species the total grazing potential of a plant community can be calculated (see Formula 1 and 2).

Formula 1: grazing potential (p_i) of a species

$$p_i = w_i \; x \; b_i$$

b_i: average biomass of a species; w_i: feeding value of a species

Formula 2: total grazing potential (p_{tot}) of a plant community

$$p_{tot} = \Sigma p_i$$

Results

Biomass. Different grazing intensities clearly lead to differences in the above ground biomass (Fig. 1 and Tab. 1). Only between G0 and G1 the difference is rather low and not significant. Regarding all other grazing levels the biomass differs significantly (T-test: p=0.01). Generally one can observe a steady but not linear decrease of biomass from G0 to G4. Particularly evident is the reduction of the biomass when regarding the two highest grazing levels: at level 3 only 55 %, at level 4 only 25 % of the biomass present in G0 were measured for the *Stipa bungeana* steppe. Regarding the *Stipa grandis* steppe, this reduction is even stronger, particularly at level G4 (only 19 % of G0).

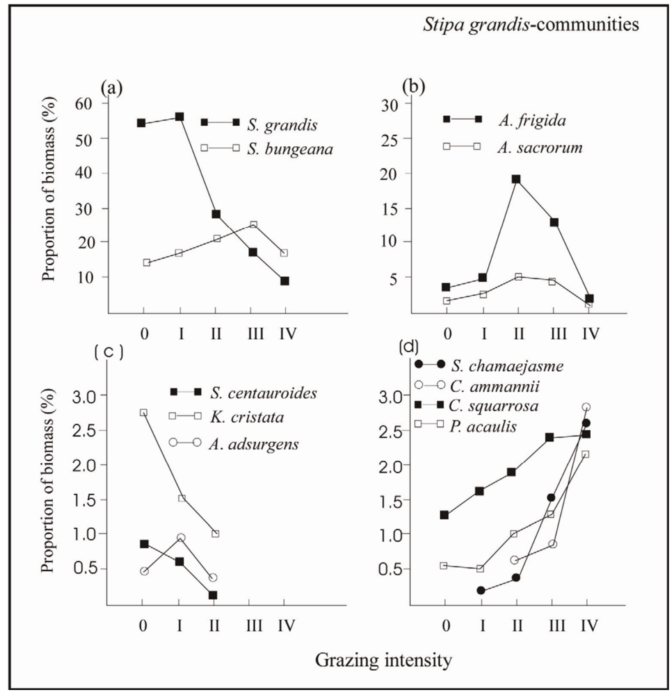

Fig. 2: Relative biomass (percentage of the total biomass) of important species of the *Stipa grandis* steppes on loess soils in the Yunwushan area (Ningxia, PR China), in relation to grazing intensity

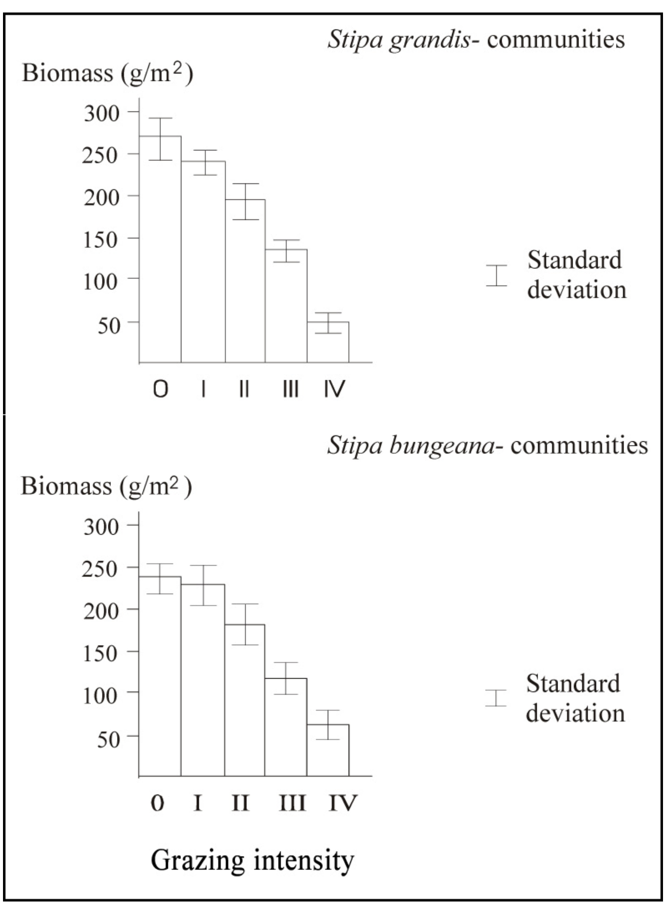

Fig. 1: Aboveground biomass of the *Stipa* steppes on loess soils in the Yunwushan area (Ningxia, PR China), in relation to grazing intensity

Comparing the two types of *Stipa* steppes at levels G0 to G3 the *Stipa grandis* steppe is more productive than the *Stipa bungeana* steppe. At the level of overgrazing (G4), the *Stipa bungeana* steppe has a higher biomass than the *Stipa grandis* steppe. However, this difference is not significant. Relatively the decrease of biomass with increasing grazing intensity is at all grazing levels higher in the *Stipa grandis* steppe than in the *Stipa bungeana* steppe.

In G0 the *Stipa* species represent the highest percentage of the total biomass (see Fig. 2 and 3). With increasing intensity the biomass of the *Stipa* species decreases more rapidly than the total biomass. Comparing the two species, *S. grandis* reacts more sensitive than *S. bungeana* and is often totally absent at grazing intensity G4. Similarly, but on a lower level, reacts *Koeleria cristata*. *Adenophora potaninii* and *Serratula centaureoides* only occur at levels G0 to G2.

A second group of species shows increasing biomass parallel to increasing grazing intensity, however, decreases at level G4. This group consists of *Agropyron cristatum*, *Carex stenophylloides*, *Artemisia sacrorum*, *Artemisia frigida* and *Thymus mongolicum*. Particularly evident is the high biomass of *Artemisia frigida* at level G2 (and a little bit lower at G3) of the *Stipa grandis* community and that of *Artemisa sacrorum* in the analogous grazing levels of the *Stipa bungeana* community.

A third group of species (*Convolvulus ammannii*, *Potentilla acaulis* and *Stellera chamaejasme*) shows a continuing increase of its biomass with increasing grazing intensity.

Feeding value and grazing potential. The two characteristic feather grasses dominating at intensity G0 and G1 are estimated as species

Tab. 1: Aboveground biomass of 16 important plant species of Stipa steppes on loess soils in the Yunwushan area (Ningxia, PR China), in relation to grazing intensity[1)]

***Stipa grandis* steppe**		mean biomass (mb) and standard deviation (sd)									
	life form	G0		G1		G2		G3		G4	
		mb[2)]	sd	mb[2)]	sd	mb[2)]	sd	mb[2)]	sd	mb[2)]	sd
total biomass		262.8		245.3		187.6		127.9		50.1	
% of G0		100		93.3		71.4		48.3		19.1	
Stipa bungeana	graminoid	41.6	2.06	42.5	3.95	38.6	4.66	31.4	5.12	8.6	1.44
Stipa grandis	graminoid	144.6	4.11	136.8	12.33	51.5	6.42	23.3	2.63	5.3	0.21
Koeleria cristata	graminoid	7.6	0.14	4.1	0.86	2.3	0.18				
Cleistogenes squarrosa	graminoid	3.6	0.21	3.9	0.66	5.7	0.26	6.3	0.45	6.2	0.91
Agropyron cristatum	graminoid	5.4	0.85	6.4	1.14	7.6	0.66	1.7	0.21		
Carex stenophylloides	graminoid	1.6	0.31	2.4	0.32	2.7	0.42	2.4	0.31	0.7	0.11
Artemisia sacrorum	subshrub	6.4	1.21	6.5	0.85	12.3	2.11	10.2	2.01	2.6	0.36
Artemisia frigida	subshrub	9.3	1.12	11.5	1.54	48.6	5.77	31.2	2.76	2.9	0.32
Thymus mongolicum	subshrub	2.3	0.81	2.6	0.33	3.8	1.20	4.1	0.39	0.7	0.10
Convolvulus ammannii	forb					1.7	0.25	2.4	0.74	7.2	2.51
Potentilla acaulis	forb	1.6	0.21	1.4	0.34	2.7	0.66	3.3	0.46	6.4	0.88
Stellera chamaejasme	forb			0.6	0.22	1.5	0.32	2.1	0.19	6.7	1.14
Astragalus adsurgens	forb	1.5	0.13	3.2	0.98	1.3	0.18				
Bupleurum chinense	forb	0.2	0.16	0.2	0.09	0.1	0.04				
Adenophora potaninii	forb	0.7	0.17	0.4	0.11						
Serratula centauroides	forb	2.6	0.56	1.7	0.23	0.1	0.06				
sum		229.0	8.54	224.2	5.64	180.5	8.63	118.4	9.74	47.3	7.13
% of the total biomass[3)]		87.00		91.00		96.00		92.00		94.00	

***Stipa bungeana* steppe**		mean biomass (mb) and standard deviation (sd)									
	life form	G0		G1		G2		G3		G4	
		mb[2)]	sd	mb[2)]	sd	mb[2)]	sd	mb[2)]	sd	mb[2)]	sd
total biomass		238.6		232.4		177.8		122.1		58.7	
% of G0		100		97.4		74.5		51.2		24.6	
Stipa bungeana	graminoid	151.4	6.22	148.4	7.69	63.5	3.91	28.1	3.11	13.7	1.52
Stipa grandis	graminoid	5.6	0.74	4.7	0.63	2.8	0.32	2.1	0.31		
Koeleria cristata	graminoid	8.3	1.14	7.4	0.65	1.8	0.23				
Cleistogenes squarrosa	graminoid	2.6	0.31	2.3	0.24	3.7	0.56	3.9	0.45	4.3	0.57
Agropyron cristatum	graminoid	4.8	0.66	7.6	1.14	6.9	0.77	2.1	0.24		
Carex stenophylloides	graminoid	1.8	0.32	2.2	0.32	3.2	0.42	2.5	0.31	0.4	0.08
Artemisia sacrorum	subshrub	9.3	0.54	12.4	1.24	36.1	3.01	41.4	2.89	8.5	0.62
Artemisia frigida	subshrub	5.3	0.63	4.4	0.62	7.4	0.98	6.1	0.83	3.4	0.28
Thymus mongolicum	subshrub	3.4	0.22	3.8	0.31	8.3	0.96	11.2	2.11	4.7	0.37
Convolvulus ammannii	forb			1.9	0.26	2.1	0.31	2.3	0.44	6.7	0.86
Potentilla acaulis	forb	1.3	0.21	1.4	0.34	3.1	0.48	3.6	0.29	4.1	0.67
Stellera chamaejasme	forb			1.6	0.31	2.2	0.61	4.3	0.58	7.4	0.86
Astragalus adsurgens	forb	3.6	0.22	3.9	0.54	1.7	0.31				
Bupleurum chinense	forb	2.3	0.22	2.1	0.38	0.6	0.11				
Adenophora potaninii	forb	0.2	0.07	0.1	0.06						
Serratula centauroides	forb	0.60	0.11	0.20	0.07	0.10	0.04				
sum		200.5	11.31	204.4	7.64	143.5	6.86	107.6	8.61	53.2	6.57
% of the total biomass[3)]		84.00		88.00		80.00		88.00		92.00	

1) 15 repetitions per grazing intensity
2) [g/m^2]
3) see Fig. 1

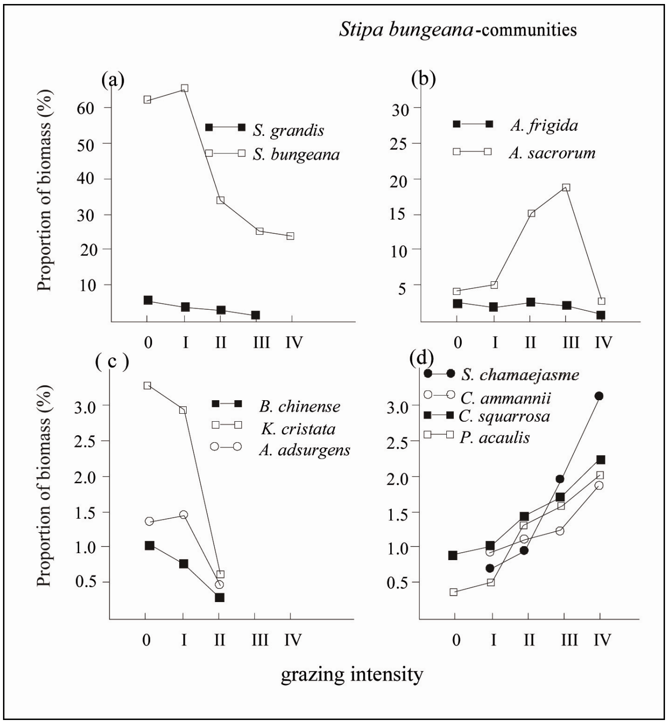

Fig. 3: Relative biomass (percentage of the total biomass) of important species of the *Stipa bungeana* steppes on loess soils in the Yunwushan area (Ningxia, PR China), in relation to grazing intensity

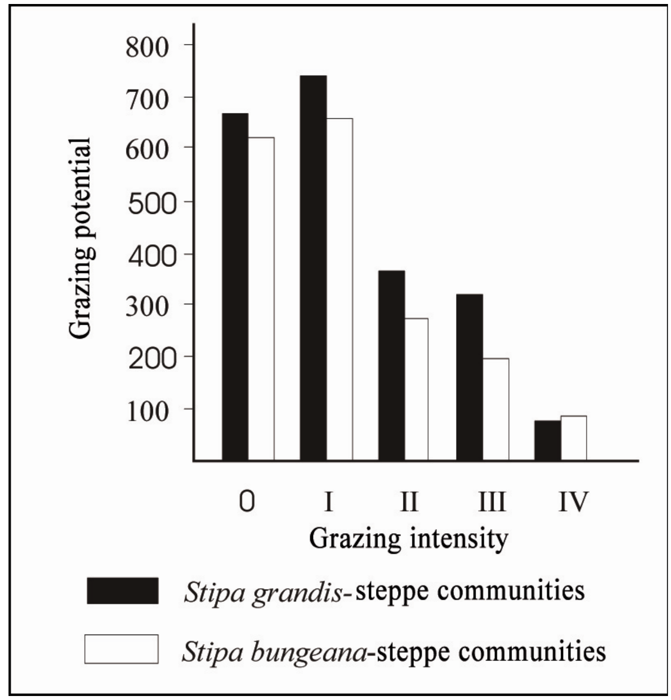

Fig. 4: Grazing potential of the *Stipa* steppes on loess soils in the Yunwushan area (Ningxia, PR China), in relation to grazing intensity

Tab. 2: Grazing value of important members of the *Stipa* steppes growing on loess soils in the Yunwushan area (Ningxia, PR China)

Species	feeding attributes	feeding value
Carex stenophyloides, Cleistogenes squarrosa, Koeleria cristata	very valuable: appreciated and preferently eaten	4
Agropyron cristatum, Astragalus adsurgens, Stipa bungeana, Stipa grandis	valuable: main fodder, regularly eaten	3
Artemisia frigida, Convolvulus ammannii, Potentilla acaulis, Thymus mongolicum	suitable: important fodder substitute when main fodder plants have decreased	2
Artemisia sacrorum, Bupleurum chinense	little suitable: only used during hunger periods	1
Stellera chamaejasme	not suitable: avoided	0

of high feeding value (Tab. 2). Those species, which show increasing biomass parallel to increasing grazing intensity, are of lower feeding value.

Except of overgrazed areas, the *Stipa grandis*-steppes have a higher grazing potential than the *Stipa bungeana* communities (Fig. 4). A comparison of Fig. 4 and Fig. 2 shows that the relative differences between the grazing potential of the communities established at different grazing levels are much higher than the relative differences in biomass (Fig. 2).

Discussion

Composition and cover of species in grazed ecosystems result from two processes running contrarily: Disturbance and regeneration (NUMATA, 1969; WILLMS et al., 1990). Fine- to medium-scale disturbance leads to local succession, whereas on a larger scale a dynamic equilibrium often exists (HERBEN et al, 1993a, b). Disturbance is caused by grazing and trampling, and it leads to a reduced growth and reproduction. Nevertheless those species, which are less appreciated by grazing animals than others (i.e. species possessing a low feeding value), obtain a relative advantage (RISSER, 1988; GOLDSTEIN et al., 1990; PIEPER, 1994; CHEN, 1997; BORK et al., 1998). Less appreciated are in particular hairy and thorny species, species with a high amount of sclerenchym as wells as bad tasting ones. Totally avoided are toxic species. Thus species composition and cover as well as the grazing value of the community mirror the grazing intensity (BELL, 1971; AUSTIN et al., 1981; CHENG and ZHANG, 1992; ARCHER and STOKES, 2000; MANÉ-BIELFELDT, 2000).

Our results confirm these expectations: Increasing grazing intensity leads to a change in species composition and to a reduction of the grazing potential of the community. With increasing grazing level, species of high feeding value more and more disappear, leaving the cattle and sheep no other choice than to feed on the less appreciated species. Not only in the area of investigation but also in other holarctic steppes particularly *Artemisia* species are favoured by high grazing intensity (see e.g. LI, 1989; PEER et al., 2001). These species are hairy, highly sclerenchymatic and taste badly. However, the *Artemisia* species of the area under investigation are not unpalatable and therefore have not been attributed with the lowest grazing value. When the level shifts from "highly grazed" to "overgrazed", unpalatable and toxic species become dominant resulting in a steppe community of a very low grazing potential.

It is common knowledge that grassland communities of humid areas show a higher productivity and consist of less sclerenchymatic and badly tasting species than those of dry areas. As the *Stipa grandis* steppe grows at an altitudinal belt, where the climate is not as dry as that of the belt of the *Stipa bungeana* community, it is no wonder that, at all grazing levels except of G4, the *Stipa grandis* steppe shows a higher grazing potential than the *Stipa bungeana* steppe. In semi-arid regions overgrazing generally causes desertification. That is why one can conclude that at least some desert species are less vulnerable of overgrazing than species of non-desert areas. Thus we have an explanation for the exception observed at level G4: As *Stipa bungeana* and the most characteristic members of its community are central Asiatic species (MA and LIU, 1986, 1988), they are better adapted to desert conditions than the Mongolian *Stipa grandis* and its characteristic companions.

When regarding the results, it should not be forgotten that our investigation represents a freeze frame recording, not a monitoring. The productivity of a grazed ecosystem, however, is not only depending upon the intensity of grazing, but also on the climate (SHIPLEY, 1942; STODDART, 1975; BROWN, 1995; SHEN, 1995; ZHANG, 1998). Thus different absolute results will be obtained in different years. However, one may assume that the interannual climate variation will only slightly influence the relative differences between different grazing levels. Freeze frame recording also means that our results do not refer to the annual biomass but to the biomass of the harvest date. But again this investigation gap does not influence the validity of the relative results.

Conclusions

Our results confirm that the mere amount of biomass is not a suitable measuring unit for the economic value of a plant community. The grazing potential calculated from biomass and feeding value of the different species of the community, decreases much more rapidly with increasing grazing intensity than the biomass. Thus the calculation of sustainable densities of animal husbandry should not be based on biomass but on the grazing potential of the grazed communities.

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