Workshop:
Natural Pastures and Mobile Animal Husbandry Under Pressure:
The Cases of Lapland and the Tibetan Plateau
University of Oulu, Finland, June 2002.

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Special Issue No. 15, 2004
Workshop 'Natural Pastures and Mobile Animal Husbandry Under Pressure:
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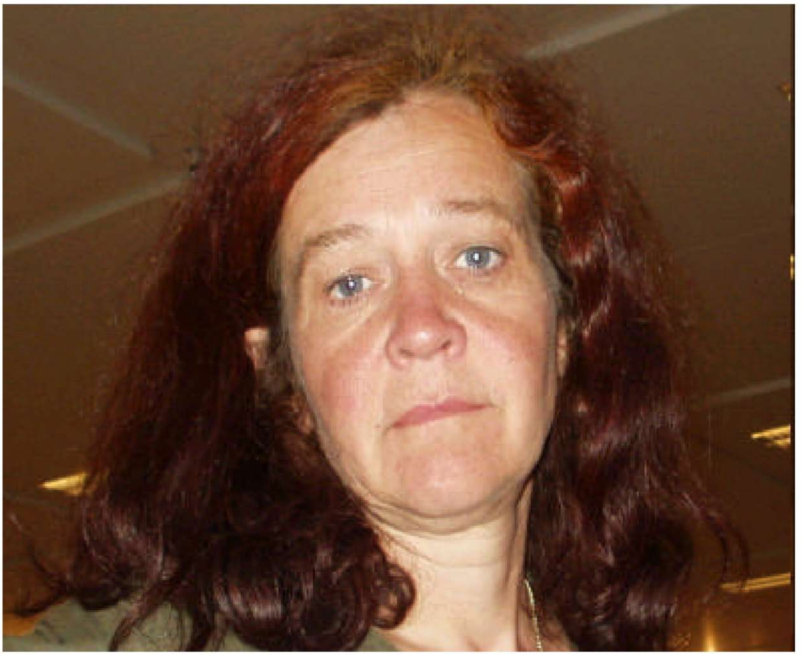
Issue editors: Angela Manderscheid, Alfred Colpaert
Editor of Rangifer: Rolf Egil Haugerud

Special Issue	2004	No. 15

Contents **Page**

Obituary - Angela Manderscheid



Dr. Angela Manderscheid passed away on December 11th, 2003. Angela was a true scientist, who was very deeply devoted to her research on Tibetan nomads. She received her Staatsexamen (M.Sc.) from the Teachers' College in Bonn in 1980 and her Ph.D. from the Free University of Berlin in 1998. The title of Angela's doctoral dissertion was "Lebens- und Wirtschaftsformen von Nomaden im Osten des Tibetischen Hochlandes". Since 1995 she was doing research in the Department of Geography of the University of Oulu, Finland. Angela made many research trips to the nomadic regions on the eastern Tibetan plateau. The last trip took place in November 2002, just a few days before her terminal illness was diagnosed. In 2000-2002, she was the coordinator and senior researcher in the project "Ecological Carrying Capacity of Natural Pastures: A Case Study on the Tibetan Plateau" funded by the Academy of Finland. With this project she also wanted to promote collaboration between researchers specialized in Tibet and Lapland, respectively. This interest led to the successful joint workshop organized in Oulu in June 2002. May this special issue serve as a tribute to her significant scientific work and her interests in bringing together knowledge from both Tibet and Fennoscandia.

Matti Pietikäinen	Alfred Colpaert
Angela's husband	Co-chair of the workshop

Example of referring to this issue:
Manderscheid, A., Naukkarinen, A., Wu, N. & Colpaert, A. 2004. From subsistence to market economy: Responses of Tibetan pastoralists to new economic realities. – Rangifer Special Issue No. 15: 29-37.

Workshop "Natural Pastures and Mobile Animal Husbandry Under Pressure: The Cases of Lapland and the Tibetan Plateau", University of Oulu, Finland, June 2002

Workshop committee: Angela Manderscheid (co -chair: mobile animal husbandry), Alfred Colpaert (co - chair: pasture evaluation), Arvo Naukkarinen, Wu Ning, Ole Bruun, Jouko Kumpula.

Preface

Mobile animal husbandry is conducted in regions which are usually unsuited to other forms of land use, e.g. due to low or erratic precipitation, and high altitude or latitude. Natural pastures or rangelands are sources of forage for the livestock, and grazing management is based on the change of pasture grounds. The lifestyle of the owners is adapted to the migration of the herd (*e.g.* by a nomadic lifestyle). According to these changing socio-economic and ecological contexts, their way of life and production is subject to ongoing and rapid adaptation. Natural pastures, and mobile animal husbandry included, are under pressure globally due to various factors which include new borders, increased animal numbers, pasture degradation, the application of new technologies, exploration of natural resources, tourism, nature reserves and reforestation projects. The herders as well as those responsible for planning, developing and administering the regions in question have to cope with these dynamics.

A Workshop on Natural Pastures and Mobile Animal Husbandry Under Pressure: The Cases of Lapland and the Tibetan Plateau was arranged at the University of Oulu, Finland, on June 12-14, 2002. The aim was to compare mobile animal husbandry in different regional contexts. The core regions were Lapland and the Tibetan plateau. The issues of mobile animal husbandry in both of the regions were raised in the presentations of the invited speakers and other workshop participants. Contributions from other regional backgrounds, application-oriented reports on rangeland management and an interdisciplinary dialogue were also included. The overall objective was to update knowledge of region-specific dynamics and translate them into other regional contexts in order to create ideas as a base for new directions in mobile animal husbandry management. The workshop also served as a platform to present the results of the research project entitled "Ecological Carrying Capacity of Natural Pastures: A Case Study on the Tibetan Plateau", which was financed by the Academy of Finland.

This special issue contains extended and refereed versions of eight papers presented in the workshop. We would like to thank all those whose contributions made this special issue possible, including the authors of the papers, the reviewers and workshop participants. Many thanks to Matti Pietikäinen and Kerttu Kaikkonen for their help in the editing work. The financial support provided by the Nordic Council for Reindeer Research, the Trace Foundation, Turveruukki and the University of Oulu is gratefully acknowledged.

Angela Manderscheid
Alfred Colpaert

Program of the Workshop 'Natural Pastures and Mobile Animal Husbandry Under Pressure: The Cases of Lapland and the Tibetan Plateau'

Wednesday 12.6. 2002

Opening session — Chair: Prof. A. Naukkarinen

09:30	Welcome address by **Prof. O. Heikkinen**, *Vice-Dean of the Faculty of Sciences, University of Oulu*
9:45-11:15	**Invited speaker** **Prof. Wu Ning** *Chengdu Institute of Biology, Academy of Science, China* Rangelands in eastern Tibetan Plateau: Ecology and sustainable management issue

Session 1 — Chair: Prof. P. Mathiesen

11:30-12:00	**Prof. R. Helle** *Helsinki School of Economics and Business Administration, Finland* An important industry in the North American arctic. Reindeer industry shrank to the present relatively small-scale economy
12:00-12:30	**Dr. J. L. Fox, P. Mathiesen, D. Yangzom, M. W. Næss, Xu Binrong** *Dept. of Biology, Univ. of Tromsø, Norway* Modern wildlife conservation initiatives and the pastoralist/hunter nomads of northwestern Tibet

Session 2 — Chair: Dr. J. Fox

13:30-14:00	**M. W. Næss, Dondrup Lhagyal, Drolma Yangzom, P., Mathiesen, J. L. Fox** *Dept. of Social Anthropology, Univ. of Tromsø, Norway* Nomadic pastoralist livelihood constraints in a nature reserve in northwestern Tibet
14:00-14:30	**Dr. A. Manderscheid, Yan Zhaoli, Wu Ning, A. Colpaert** *Dept. of Geography, Univ. of Oulu, Finland* From subsistence to a market economy: the current top three commodities of nomads on the Eastern Tibetan plateau
14:30-15:00	**sKal-bzang** *Southwest Institute of Nationalities, Chengdu, China* Case study of pasture use on the Tibetan plateau

Session 3 — Chair: Dr. M. Nieminen

15:30-16:00	**S. Lefrère** *René Descartes University - Paris V / Ethnology Department.* *Reindeer Research Station (FGFRI)* Diurnal activities, social dominance and cardiac rhythm of female reindeer *Rangifer tarandus tarandus* L. in wintertime according to non-biotic parameters changes

16:00-16:30 **H. Norberg, M. Nieminen**
Finnish Game and Fisheries Research Institute, Reindeer Research Station, Kaamanen, Finland
Predation on semi-domesticated reindeer in Finland: predators, compensations and current research

16:30-17:00 **Dr. J. Kumpula, A. Colpaert, U. Fielitz**
Finnish Game and Fisheries Research Institute, Reindeer Research Station, Kaamanen, Finland
Studying effects of forestry and tourism on the pasture use of reindeer with GPS-tracking

Poster session 17:00-18:00 **Chair: Dr. P. Åman**

1. **V. Väisänen, J. Mikkola, A. Colpaert, J. Kumpula, M. Nieminen, O. Heikkinen**
Dept. of Geography, Univ. of Oulu, Finland
Spatial and socioeconomic impacts of reindeer husbandry in northern Finland

2. **E. Goldings**
The Trace Foundation, New York, USA
Nomads and markets: challenges of decentralized production—the case of yak cheese

3. **Prof. M. Sillanpää, R.M. Hulkkonen, A. Manderscheid, K. Pirkanniemi**
Dept. of Environmental Engineering, Univ. of Oulu, Finland
Drinking water quality in the rangelands of the Eastern Tibetan plateau

4. **H. Kitti, T. Kumpula**
Arctic Centre, Univ. of Lapland Rovaniemi, Finland
Classification of reindeer pastures: Mapping based on Traditional Ecological Knowledge (TEK) and remote sensing

5. **S. Zgleyshevska, R. Zadoyan**
The Faculty of Geology, Yerevan State University, Armenia
Harmful and useful influence of small and big moving of animal husbandry, connected with erosion activity

Thursday 13.6. 2002

9:00-10:30 **Invited speaker**
Dr. M. Nieminen,
Finnish Game and Fisheries Research Institute, Kaamanen, Finland
Finnish reindeer herding in change

Session 4 Chair: Dr. A. Colpaert

10:45-11:15 **Pekka Aikio**
Sami Parliament in Finland
Holistic overview of reindeer herding and its interactions

11:15-11:45 **Dr. J. Å. Riseth , B. E. Johansen**
NORUT Social Science Ltd., Tromsø , Norway
Development of a dynamic two-pasture – herbivore model

11:45-12:15 **Dr. P. Åman**
Dept. of Geography, Univ. of Oulu, Finland
Peat production areas as reindeer feed cultivation use – the case in the Paarnitsa-aapa mire, Northern Finland

Session 5 — Chair: Dr. J. Å Riseth

13:15-13:45 **T. Kumpula, A. Colpaert, A. Manderscheid**
Dept. of Geography, Univ. of Oulu, Finland,
Inventory of high altitude pastures of the eastern Tibetan plateau using remote sensing

13:45-14:15 **Dr. C. Uhlig, T. E. Sveistrup, I. Schjelderup**
Holt Research Centre, The Norwegian Crop Research Institute, Tromsø, Norway
Impacts of reindeer grazing on soil properties on Finnmarksvidda, Northern Norway

14:15-14:45 **Prof. Du Guozheng**
State Key Laboratory of Arid Agroecology, Lanzhou University, China
Effect of fertilization on plant species diversity in an alpine meadow

Session 6 — Chair: Dr. C. Uhlig

15:15-15:45 **R.M. Omer, M.D. Swaine, A.J. Hester, I.J. Gordon, S.M.Raffique**
Macaulay Land Use Research Institute, Aberdeen, UK
Influence of environmental factors on plant communities of semi arid areas of Hindukush, Karakoram and Himalayan mountain ranges of Northern Pakistan

15:45-16:15 **B. Burkhart, F. Müller**
Ecology Center, Univ. of Kiel, Germany
System analysis and modelling of Northern Scandinavian reindeer management

16:30-17:30 **Round table discussion** **Chair: Prof. Wu Ning**
New directions for mobile animal husbandry

19:00 **Banquet**

Friday, 14.6. 2002 — Excursion by bus to reindeer husbandry sites

9:00 Departure from Oulu

- Kuikkasuo (Peat area): *Peat production and reindeer husbandry. Some aspects* (P. Åman), Coffee/tea
- Sarakylä: Visit of a *reindeer "farm" and the reindeer roundup place* of the Pudasjärvi herder cooperative. Ari Rytinki is reindeer owner and secretary of the reindeer herder cooperative, Pudasjärvi.
- Lunch at the holiday resort Iso-Syöte
- *Reindeer pasture evaluation.* A demonstration in the field (T. Kumpula)
- Pudasjärvi: *Slaughter house and reindeer meat processing enterprise* (P. Juotasniemi) ca. 19:00 Arrival in Oulu

Natural Pastures and Mobile Animal Husbandry Under Pressure:
The Cases of Lapland and the Tibetan Plateau, 12-14 June 2002,
University of Oulu, Oulu, Finland.

Grazing intensity on the plant diversity of alpine meadow in the eastern Tibetan plateau

Wu Ning*, Liu Jian & Yan Zhaoli

Chengdu Institute of Biology, Chinese Academy of Sciences, 610041 Chengdu, Sichuan, P. R. China.
* corresponding author (wuning@cib.ac.cn).

Abstract: Because of the remoteness and harsh conditions of the high-altitude rangelands on the eastern Tibetan Plateau, the relationship between yak grazing and plant diversity has not been so clear although livestock increase was thought as the main issue leading to the degradation of rangeland. In the debate of rangeland degradation, biodiversity loss has been assumed as one of the indicators in the last two decades. In this paper authors measured the effects of different grazing intensities on the plant diversity and the structure of *Kobresia pygmaea* community in the case-study area, northwestern Sichuan. The results indicated that plant diversity of alpine meadow has different changing trends respectively with the change of grazing intensity and seasons. In June the highest plant diversity occurred in the intensively grazed (HG) plots, but in July and September species biodiversity index of slightly grazed (LG) plots is higher than other experimental treatments. In August the intermediate grazed (IG) plots has the highest biodiversity index. Moreover, it was found that intensively grazing always leads to the increase of plant density, but meanwhile the decrease of community height, coverage and biomass. Over-grazing can change the community structure and lead to the succession from *Kobresia pygmaea* dominated community to *Poa pratensis* dominated. Analyzing results comprehensively, it can be suggested that the relationship between grazing intensity and plant diversity is not linear, *i.e.* diversity index is not as good as other characteristics of community structure to evaluate rangeland degradation on the high altitude situation. The change of biodiversity is so complicated that it can not be explained with the simple corresponding causality.

Key words: biodiversity human's impact, *Kobresia* meadow, Shannon-Wiener index, western Sichuan.

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Introduction

It is well known that the factors affecting meadow biodiversity can be generalized to human impacts and natural disturbances. The aftermath made by the former is so serious that it was thought as the key issue leading to the degradation of rangelands in the last few decades (Yang *et al.*, 1999). What is the rangeland degradation? Or which indicators can be used to evaluate the health of rangeland ecosystem? As to these questions, many researchers have carried out different projects, which covering the field of soil, plant community, nutrients, and livestock (Wu, 1997a; Wang & Li, 1999). In the last two decades the change of biodiversity under the grazing impacts has been paid a lot of attentions, because it was identified as an important characteristic in a disturbed ecosystem (Kuramot & Bliss, 1970; Austin *et al.*, 1981; McNaughton, 1985; Bakker, 1989; Yang *et al.*, 1999; Wang, 1993; Wang *et al.* 1995; Fisher & Wipf, 2002). However, a contrary conclusion about relationship between grazing intensity and biodiversity has been drawn out from these studies (Sousa, 1984; Collins, 1987; Bakker, 1989), which indicated the complexity to evaluate the human disturbance and biodiversity decline in rangelands. Although there are still many debates, an identical view about the biodiversity change in rangelands which has been accepted based upon the former studies is that heavy disturbance (grazing) can lead to the decline of plant diversity in grass community, but an intermediate disturbance may increase species diversity (Connell, 1961; Quinn &

Robinson, 1987; Wu, 1997a). The reason is that intermediate disturbance weakens the competition between dominant species in community and creates potential niche, which lead to the diversity increasing in community level consequently. However, these studies were done in prairie where the most important and ubiquitous source of disturbance to grassland is burrowing by mammals (Molles, 2000) and the key environmental factor dominating the process of ecosystem dynamics is precipitation. Whether this conclusion is fitful for thehigh-altitude meadows on the eastern Tibetan Plateau where yak grazing is the most important disturbance and cold climate controls the dynamic process is still vague for academic fields (Manderscheid, 2001a; Wu & Yan, 2002). Moreover, most of former studies on the relationship between grazing intensity and biodiversity change were static, *i.e.* there is not a temporal scale. Based on the assumption that plant diversity may change not only under the different grazing intensities but also with the alternation of seasons, the data of *Kobresia pygmaea* dominated meadow were observed and recorded in 2000 with the case study in northwestern Sichuan.

Material and methods

Studying site

Northwestern Sichuan is an extensive part of the Tibetan Plateau and one of the most important pastoral regions in China. The landscape is characterized by low massif and widespread high-altitude meadows with an average altitude above 3500 m a.s.l.. Because of the high elevation and the related harsh environment, mobile animal husbandry is the representative economy throughout this region and has supported Tibetan nomadic societies for centuries (Manderscheid, 1999; Wu, 1997a; 1997b; Wu & Richard, 1999). Traditionally, the local Tibetan herders partitioned their common-used rangelands into two parts: summer pastures and winter pastures, then these rangelands were grazed alternately according to different seasons. In the last decade, owing to conversion of land tenure in pastoral region, the lifestyle of Tibetan nomads has been transformed from migratory to more sedentary, and the utilizing pattern of seasonal pastures has been also changed (Wu, 1999; Wu & Richard, 1999). Hay meadows are introduced which are located nearby winter houses or newly built permanent settlements. The allocated pastures are fenced for the purpose of "scientific management", *i.e.* used in a rotation way. The better infrastructure reduces the livestock loss during the cold winter and spring. With the increase of livestock population (especially yak), the pressure of rangelands has not been alleviated as decision-makers hoped, because the traditional subsistence economy has not been transformed successfully into market-oriented economy at the same time (Manderscheid, 2001b). The conflict between unlimited increasing quantity of livestock and the limited source of forage available still exists although supplementary feeding (hay meadow) has been developed recently (Foggin & Smith, 1996; Wu & Yan, 2002).

The study-site, Hongyuan County, is located 500 km to the northwest from the provincial capital city, Chengdu. The county covers an area of about 8439.9 km^2 and is spread between longitudes 101° 51'-103°23' E and latitudes 31°50'-33°22' N. Of the total area, 91.47% is natural rangeland. The overall relief of Hongyuan consists of high-altitude plateau, with the average elevation exceeding 3400 m. Baihe River, a branch of Yellow River and its drainage area making up approximately 79% of county's land surface, flows northwards through the county. According to the meteorological observation, the annual mean temperature is 1.1 °C and there is not an absolute frost-free period. The highest monthly mean temperature is 10.9 °C in July and the lowest is -10.3 °C in January. The annual precipitation is 753 mm, among which over 86.4% concentrates in the period from May to October. Tibetan people are the main part of ethnic group which accounting to 76.62% of the total population. In this county animal husbandry is the major industry which formed over 78.83% of the GDP as a whole (County Report in 2000).

The soften deposit on top of massif in the area is mainly composed of autochthonous soil, and the dry pitch is mainly composed of plateau meadow soil. Affected by soil type and distribution of water, rangelands in this region are mostly dominated by sedge species, such as *Kobresia pygmaea*, *K. setchwanensis*, *K. capillifolia*, and occasionally dotted by shrublands, such as *Spiraea alpina*, *Sibiraea angustata* and leaflet rhododendron (Jiang, 1960; Wu, 1997c).

Methods

Based on the number of livestock and the coverage of vegetation in every enclosure, four sampling plots located at the same elevation (3580 m a.s.l.) with the area of 10×10 m^2 were chosen. The sampling plots are dominated by the same species *Kobresia pygmaea*, and defined as slightly grazed (LG), intermediate grazed (IG), intensively grazed (HG) and over-grazed (OG). The grazing intensity in each enclosure is 7.21, 12.01, 25.00 and 140.77 animal equivalent (One animal equivalent means one ewe weights 40 kilogram and consumes 0.47 ha grassland per day. Sheep unit is the common term to be used in China.) per hectare respectively. Another enclosure with no disturbance was selected as control plot for the final comparison. The coverage, frequency, density of vegetation and the aboveground biomass were measured in every month during the growing season (from June to September), then the important value (IV = (C'+F'+A'+D')/4 × 100, where C' = relative coverage, F' = relative frequency, A' = relative abundance, D' = relative density), Shannon-Wiener index (H = -? $p_i \ln p_i$, where p_i = IV of species i divided in total vascular plant cover), richness index (d_{ma}= (S-1)/lnN, where S = number of species; N = total number of plants in quadrate) and evenness index (J_{sw} = (-S ($P_i \ln P_i$)/lnS, where P_i and S mean same as above mentioned) were calculated separately. Finally, the relationship between grazing intensity and plant biodiversity was analyzed with the software SPSS10.0.

Results

Growing season of plants in northwestern Sichuan

Within a single growing season, herbaceous plants show a fairly consistent growth pattern. On the plateau initiation of growth is largely determined by temperature in spring and in most cases growth does not commence until air temperatures reach about 6 °C (Wu, 1997a). As to perennial plants, such as *Kobresia* in case-study area, normally they start to grow in May or even at the beginning of June, which is synchronized surprisingly with the migrating time of nomads from cold-season pastures to warm-season pastures (Wu, 1997b). For the gramineal grasses reproduced by seeds, the amount and distribution of rain at the beginning of the growing season always can determine the features of herbaceous stratum in summer and seed supply for the coming year.

As the season progresses, senescence increases at the end of August. For stresses upon the plants becoming greater due to lower radiation inputs and reduced ambient temperature, the plants cease to be able to compete so successfully. Generally speaking, in the northwestern Sichuan herbaceous plants begin to wither and then dormant in October, during which yak herders also move back to their traditional winter pastures. Therefore, the change of plant diversity mainly occurred during the period of growing season, *i.e.* from June to September.

Diversity index change under different grazing intensities

Generally speaking, in the northwestern Sichuan the maximum diversity index occurs in August, just as the change in the control plot (Table 1). Under the different grazing impacts, however, the diversity index appears different developing trends. Except for the over-grazed plots, diversity index in every plot escalated at first and then decreased slowly. For example, with the higher grazing intensity, such as IG, HG and OG, the diversity index in July is lower than that in June. The main reason is that more intensively grazing may lead to the disappearance of species or suspension of growth. Generally, after the commencement of growth in May or early June, plants grow rapidly and the daily accumulation of dry matter can get to the peak within six to eight weeks. Thus, this phase of vegetative growth, as it is known, mainly leads to an increase in both the mean height of herbaceous communities and their densities. After the grazing disturbance is introduced, the vegetative bodies of plants are consumed or trampled by livestock, which resulting in the decrease of tillering and establishing ability. Owing to the loss of competition for light, nutrient elements and water, the species, specially palatable species, could be disappear or loss its dominate role in communities in the following period.

Table 1. Biodiversity change of *Kobresia pygmaea* meadow under different grazing intensities.

Grazing intensity	June	July	Aug.	Sept.	Average
Control	1.519	1.561	1.562	1.507	1.537
LG	1.433	1.445	1.493	1.479	1.463
IG	1.441	1.437	1.5	1.474	1.463
HG	1.454	1.424	1.449	1.368	1.423
OG	1.17	1.002	0.676	0.646	0.873

Because the diversity index is calculated based on IV, it may fluctuate not only with the change of species number but also the biomass and the coverage of each species. In August vegetative growth of most species give way to reproductive growth, and the flowering stems then extend. Especially for grasses and sedge, such as *Elymus nutans, Festuca ovina, Poa* spp., *Carex* spp., *Potentilla anserina* and *Oxytropis kansuensis, etc.*, the prosperous growth in August lead to the increase of important value again in communities and then increase of diversity index. Except for the OG plots, diversity index get to the maximum in all of sampling plots during this period.

Considering the change of diversity index in one month, the different grazing intensities can lead to a unique changing trend in June when livestockstart to be grazed in summer pastures. The ordination of diversity index is: control > HG > IG > LG > OG, which is different with that in the following months. What should be paid attention is that diversity index in the HG plots is higher than that in IG and LG plots. The reason is that the volume ofstanding dead and litter in the HG plots is fewer in comparison with other plots in winter. More solar radiation may lead to the rapid increase of temperature on ground surface, and then the sprouting time of herbaceous plants in the HG plots is earlier. However, in over-grazed plots (OG) the diversity index is still the lowest because there is not enough deposited seeds or dormant plants in this field. During the period of germination and vegetative growth, the diversity index is related to aboveground biomass in a great extent. Analyzed by software, it appears that the ordination of diversity index is similar to that of aboveground biomass in June, which are in linear correlation significantly ($r = 0.969$, $P < 0.01$).

After the dversity index get the maximum in August, the highest value occurs in the IG plots. This phenomenon is resulted from the highest evenness of communities occurred in intermediate grazing plots. Data indicates that there is a significant linear correlation b etween diversity and evenness in August ($r = 1.000$, $P < 0.01$).

In view of the average values during the growing season, a general trend of diversity indexes can be found, *i.e.* control > IG > LG > HG > OG. The evenness of communities is still in significant correlation with diversity index ($r = 0.998$, $P < 0.01$). Because the grazing intensity is directly related to the number of livestock (animal equivalent), a linear regression equation about average biodiversity and number of livestock can be set up:

$$DI_a = 1.522 - 6.906^{-2} N$$

(where DI_a = average diversity index; N = number of animal equivalent)

Change of aboveground biomass under different grazing intensities

On alpine meadows aboveground biomass increase from June onwards, normally gets its maximum in July or August and then falls down slowly after August (Fig. 1). As to the increasing rate in June and July, it is found that aboveground biomass in the OG plots increases quicker than others. The reason for this phenomenon is that the dominator of OG community was conversed from perennial plants - *Kobresia pygmaea* into annual species - bluegrass (*Poa pratensis*), and aboveground biomass of bluegrass always booms in June. On the contrary, the dominant plants in the HG plots are mainly composed of *Kobresia pygmaea* and *K. setchwannensis*, which are small and grow slowly. The perennial dominators decide the smooth change of aboveground biomass during the growing season.

With the increase of grazing intensities, the aboveground biomass decline apparently, specially after July. It can be explained that grazing disturbance affects the growth of herbaceous plants after the booming period and result in the similar developing trends of biomass.

Importance change of main plants under different grazing intensities

Important value (IV) may indicate the role of different plants in communities. However, except for *Kobrisia setchwannensis* and *Potentilla anserine*, it has not been found that there is a significant correlation between important value and grazing intensity. It is valuable to mention that the IV of *Aster tongoliama* and *Aster diplosterphioides* always get the maximum in the IG plots, and the highest IV of *Thalictrum alpinum* occurs in the LG plots because of its shade tolerance. Although the important value of gramineous plants does not change obviously with the increase of grazing intensity, *Poa pratensis* can still become dominant species in the OG plots, and its important value escalates monthly during the growing season.

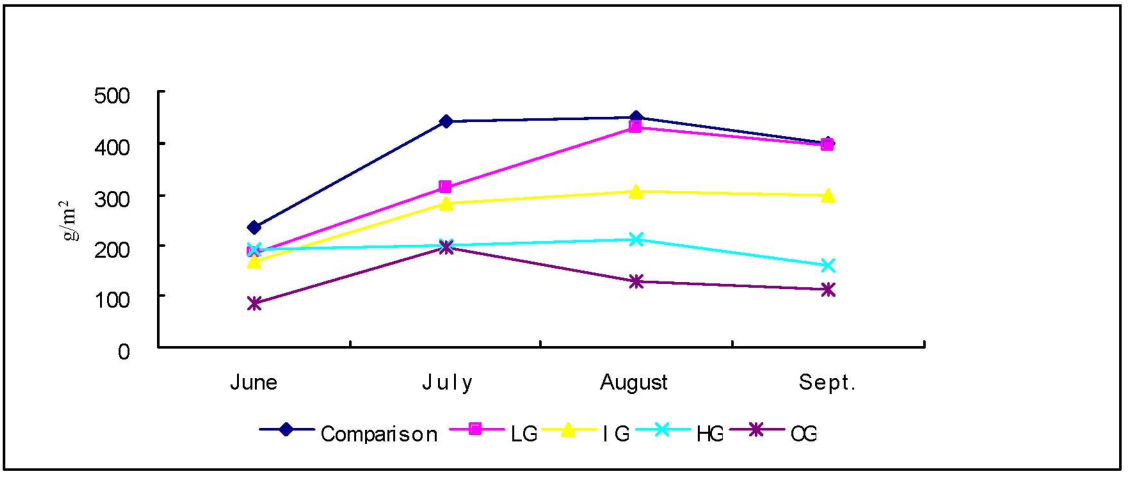

Fig. 1. Change of aboveground biomass under different grazing intensities in north-western Sichuan.

Discussion

The change of diversity index can reflect the dynamic process of biodiversity on high-altitude rangelands. Under the different grazing intensities and/or even in different months of growing season the diversity index is discrepant. Grazing may change the community structure and floral composition in the last year, and then lead to the different appearance of biodiversity in the following year. Generally speaking, the diversity index in germination period mostly dependent on the grazing situation of the last year, but the dynamics during the period of vegetative and reproductive growth is result from the *in-situ* grazing effects. At the beginning of growing season there are more competitions among different species for niche. Meanwhile, multiple factors, such as precipitation, temperature, stand dead residues, aboveground litter can determine what time and which species germinate firstly. All of these may affect the result of diversity measurement. When herbaceous plants step into the booming stage in summer, yak grazing may lead to the loss of some occasional species and a more stable community after the intensive species competition. The changing trends of diversity index are much regular accordingly. Even so, with the conditions of high altitude, cold climate, long winter, short growing period and great day-night difference of temperature, there are apparent similarities in floral composition of these high-altitude rangelands. The change of species is not so great as other ecosystems under the human's disturbance.

If the over-grazed plots were excluded, the correlation between grazing intensity and aboveground biomass is significant. In the case-study area, over-grazed plots were mostly resulted from yak trampling other than directly grazed, because these pastures are mainly located nearby newly constructed settlements or camping sites where yak herders stay longer for milk sale during the growing season. It was found that market-oriented milk production in Hongyuan had led to the degradation of rangelands, specially along the highway and main roads, where there are fewer movements in between pastures (Wu, 1999; Wu & Richard, 1999).

On the eastern Tibetan Plateau a number of factors determine biodiversity change in a year round. The most significant of these can be grouped as geomorphology, precipitation, temperature and grazing. It is important to realize that rarely only one of these factors is operative solely in the ecosystems under discussion. Most often several works at the same time in a particular ecosystem and their joint impacts may have a cumulative effect upon the dynamics of species occurrence. Specially, the managing system was changed in the last decade because of the alternation of land tenure system. More sedentary life style may lead to the new effects on rangeland ecosystem, but this issue has not fully understood so far.

The high-altitude rangelands on the eastern Tibetan Plateau are mainly composted of perennial and medium (eumesophytic) herbaceous plants, which is good tolerant to be grazed, specially for yaks. The trend of diversity changing under different grazing intensities also indicates that the rational utilization can be beneficial to the maintenance of plant diversity, although the productivity of *Kobresia pygmaea* meadow is not as high as the artificial pastures. Because of the good capability of regeneration, this kind of pastures is perfect for summer grazing (Jiang, 1964; Wu, 1997c). There is an apparent sod-layer in this kind of rangeland, which is very important for the conservation of soil. Furthermore, the colder it is, the tighter and thicker the sod-layer is, because there are more biomasses accumulated in the underground parts o f plants than in the aerial parts and the decomposition of organic matter is slower.

The complex relationship between grazing animals and plant communities has long been recognized by rangeland workers. It should be pointed out that in most experimental w ork making use of herbivores, it is virtually impossible to control more than a few variables at any one time. Grazing has three main effects on vegetation: a) the sward is defoliated; b) nutrients in the form of dung and urine are returned or removed from the rangeland ecosystem; and c) the plant life suffers physical damage by trampling. In order to maintain the productivity of high-altitude rangeland, movement of livestock in a year round is necessary (Wu & Richard, 1999). Generally, with the seasonal alternation, livestock repeatedly have to cover a long distance in search of food and water, which lead to the migration in seasonal pastures (Wu, 1997a; 1997c). This strategy does usually promote sustained-yield resource exploitation whenever land becomes scarce, and in particular when seasonal grazing sites are as far as inaccessible by any other ways. Traditionally, the aim of the pastoral herdsmen is to control all three components - by migration, by changing grazing routes, by regulating the staying duration in one place, by determining grazing season in different seasonal pastures and by controlling the livestock. They thereby regulate the inputs to and the outputs from the system, as well as its internal structure. It should also be remembered that they are affected by the operation of the system, not always directly, but often indirectly through the economic implications of rangeland productivity. Therefore, the conservation of biodiversity in the pastoral region must be based on the profound understanding of the process of socio-economic development, and exclusion of livestock is not beneficial to the conservation of rangeland ecosystem.

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Natural Pastures and Mobile Animal Husbandry Under Pressure:
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Modern wildlife conservation initiatives and the pastoralist/hunter nomads of northwestern Tibet

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Abstract: In 1993 the Tibet Autonomous Region (TAR) of China established the 300 000 km^2 Chang Tang Nature Preserve on the northwestern Tibetan plateau, an action precipitated by rapidly diminishing populations of chiru (Tibetan antelope) and wild yak. Some 30 000 nomadic pastoralists use areas within this reserve for livestock grazing, with many having traditionally depended in part on hunting for supplementary subsistence and trade. Following a 1997 request from TAR leaders for international assistance in addressing the conservation issues associated with the creation of this reserve, the TAR Forestry Bureau and the Network for University Co-operation Tibet – Norway began a 3year research collaboration program in 2000 to outline human-wildlife interactions and conservation priorities in the western part of the reserve. To date, four excursions (2-6 weeks each) have been made to the western Chang Tang region, and investigations of interactions between pastoralists and wildlife conservation objectives have been initiated in an area of about 5000 km^2, including the 2300 km^2 Aru basin located at 5000 m elevation at the northern edge of pastoralist inhabitation. The Aru site is unique in that nomads have only recently returned to this previously off-limits basin. But, as in surrounding areas, the people's lives are undergoing changes recently influenced by the introduction of permanent winter houses, changing international trade in shahtoosh and cashmere wool, and a move towards stricter hunting regulations. The northwestern Chang Tang, with the Aru basin as a prime site, represents one of the last strongholds of the endangered chiru and wild yak, as well as home to Tibetan gazelle, kiang, Tibetan argali, blue sheep, wolf, snow leopard and brown bear. In autumn 2000, for example, with approximately 12 000 of the wild ungulates (mostly the migratory chiru) within the Aru basin along with some 8000 domestic livestock, issues of land use overlap and possible grazing competition are clear to both local nomads and reserve managers. Whereas livestock development actions elsewhere on the Tibetan plateau are promoting increased livestock production, they are doing so at the expense of wildlife, and such an approach will not be appropriate in areas where wildlife conservation is a major priority. Although some of the ongoing livestock development programs may be adapted to the western TAR, new approaches to pastoral development will have to be developed in the reserve. The ultimate goal of enhancing the nomads' standard of living, while conserving this truly unique array of biodiversity, presents a daunting challenge.

Key words: Chang Tang Nature Preserve, chiru, conservation and development, wild yak.

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Introduction

In conjunction with a late 1997 visit to Europe by leaders of the Tibet Autonomous Region (TAR), China, interest was expressed in receiving international assistance in addressing conservation issues associated with the creation of a large nature reserve in nomadic pastoral areas of the northwestern Tibetan plateau. The TAR had recently established the second largest protected area in the world, the 300 000 km^2 Chang Tang Nature Preserve, and was interested in assistance in the development of suitable management initiatives. In response to this request, in 1998 the two senior authors visited Tibet to make initial contacts with appropriate authorities, and in the spring of 1999 both accompanied TAR Forestry Bureau and other government officials on a reconnaissance survey traversing over 800 km across the central portion of the reserve. In the spring of 2000 the TAR Forestry Bureau (TARFB) and the University of Tromsø, under the auspices of the Network for University Co-operation Tibet – Norway, signed a 3-year research collaboration program designed to study human-wildlife interactions and their conservation consequences in the western part of the nature reserve. Field research was initiated in summer of 2000 with a month-long excursion to the site selected for intensive study, the remote Aru basin (Fig. 1), and has continued with 6-week excursions to the area in autumn of 2000 and 2002, and early summer of 2001. In addition to TARFB participation, the fieldwork has been conducted in co-operation with the Tibet Academy of Social Sciences, the Biology Department of Tibet University, and the Tibet Agriculture and Animal Husbandry College.

Chang Tang Nature Preserve

The Chang Tang Nature Preserve was established in 1993. This action, brought about by recent reductions in populations of chiru or Tibetan antelope (*Pantholops hodgsoni*) and wild yak (*Bos grunniens*) (Fig. 2) throughout their ranges on the plateau, reflects a growing commitment by the TAR to conservation of its natural resources. The TAR's initial request for assistance noted that "... wildlife have high economical values, in order to prohibit catching and killing, preserve ecological balance, it is imperatively important to set up a wildlife nature reserve". At the time, chiru populations were being decimated over much of the Tibetan plateau, precipitated by a spectacular jump in pelt prices to supply an increasing international market for "shahtoosh" garments woven from the chiru's fine wool (Kumar & Wright, 1998; Schaller, 1998). Although much of the chiru's slaughter has been carried out by organised poachers, smaller-scale but increased hunting and trapping by nomads has exacerbated the species' decline. In fact, many nomad families in what is now the reserve probably substantially increased their cash flows in the early 1990's as chiru pelt prices rose (Næss *et al.,* 2004), and many were able to purchase trucks or other vehicles for the first time (Fig. 3).

Fig. 1. The Chang Tang Nature Preserve, showing the location of the primary study area within the catchments of Aru and Memar lakes, the major travel routes to the basin, and the routes of our cross-reserve traverses.

Fig. 2. Chiru (Tibetan antelope) and wild yak in the Aru basin.

Some 30 000 nomadic pastoralists depend on rangelands within the reserve for livestock grazing, and those in areas with significant wildlife density have traditionally depended in part on hunting for supplementary subsistence and trade (in part for shahtoosh). With rapid changes in wildlife markets, government subsidised modernisation of pastoralism, and concerns over preserving Tibet's wildlife populations, the establishment of the nature preserve has brought into sharp focus conflicting aspects of these various factors. The TAR's 1997 request for assistance focussed on development aid associated with the creation of the reserve; our project aims to provide baseline information upon which management of wildlife and livestock can be developed to ensure the continued presence of threatened wildlife as well as a better standard of living for nomads in the reserve.

The northwestern TAR is one of the least productive and poorest parts of the region. At an average elevation of over 4500 m it is too high to support any cropping, and nomadic pastoralism remains the primary livelihood for most residents. Whereas other parts of the Tibetan plateau in the TAR and Qinghai Province have seen significant livestock and community development activity, the northwest has yet to see much, and officials are admittedly looking to financial advantages associated with nature preserve designation as one means to improve nomads' livelihoods.

In Qinghai Province, for example, programs in pastureland privatisation and a concomitant livestock "ranching" approach to management are changing the scope of pastoralism by decreasing mobility while trying to stabilise livestock numbers. Although livestock productivity and overall density may be increasing in some areas, the distribution among families is skewed (and becoming more so) (van Wageningen & Sa, 2001), and the long-term development advantages of some changes are debatable (Goldstein, 1996; Miller, 1998). But unlike the traditional pastoralism that co-existed with abundant populations of large wild herbivores, these development actions have the potential to fully utilise the productivity of the rangeland, and exclude wildlife. In its retention of the traditional, common ownership of pasture land, the Tibet Autonomous Region (TAR) has taken a somewhat different approach to livestock development, although similar investments to increase livestock productivity are also being introduced and are likely to greatly alter the scope of pastoralism in the TAR. The Chang Tang Nature Preserve represents the first instance of a large-scale effort to combine wildlife protection with pastoral development in western China, and the application of development initiatives currently promoted elsewhere on the plateau will require objective re-evaluation in relation to wildlife conservation goals.

In any case, the effects of development actions on the plateau should be evaluated within the context of this unique high elevation rangeland ecosystem. One of the most dramatic aspects of traditional pastoralism on the Tibetan plateau is the potentially devastating effect of snowstorms on the survival of livestock. Large-scale losses are rare, but they do happen, for example during the winter of 1997-1998 over 3 million head of livestock were lost due to heavy snowfalls in the TAR alone (Miller, 1998). Less widespread losses are a normal fact of life for the nomads, and their strategy under such conditions is to constantly attempt to increase livestock numbers; the more livestock the herder has, the easier it will be to recover from the density-independent snow-caused losses. Some observers of pastoralism in Tibet (Miller, 1998, in press; Goldstein, 1996) have noted that the ecosystem, at least in the relatively dry western portion, resembles

Fig. 3. Nomad camp in the Aru basin, with a recently purchased truck used for moving camp and transportating wool to market.

the non-equilibrium system of the dry Sahel region of Africa where nomadic pastoralists face periodic drought-induced livestock die-offs (Ellis & Swift, 1988). In such a system, annual vegetation productivity is highly variable and grazing density-dependent effects are not apparent. In Tibet, "the recurrent episodes of livestock decimation appear to have been frequent enough to create a stable, non-equilibrium system in which grasslands were not systematically destroyed despite continuous utilisation for at least one, perhaps two or more, millennia" (Goldstein, 1996). Others suggest that the Tibetan plateau rangelands do resemble an equilibrium ecosystem in that a fairly predictable annual monsoon-driven vegetation production occurs (Schaller, 1998), and vegetation productivity and composition can be more influenced by grazing. It is, then, rather the unpredictable snow events (possible at any season) that cause significant localised livestock mortality and bring a dis-equilibrium to the pastoral system. In either case, however, the rational herder strategy remains one of continuous increases in livestock numbers. But, if snow-determined forage availability is the major environmental factor, then unlike the similarly unpredictable drought-affected pastoral systems where fundamental forage production is greatly affected, in Tibet the forage is there (and often enhanced by the moisture brought in the form of snow) and in-situ recovery potential for livestock is high once the snow disappears. Such a significant factor in pasture management needs to be better incorporated into pasture productivity and carrying capacity modeling for the Tibetan plateau, for example as is being attempted with other snow-affected ungulate ecosystems (Hobbs *et al.*, 2002; Wang *et al.*, 2002). Reassessments of pastoral ecosystem function are being attempted from sociological and organisational perspectives (Roe *et al.,* 1998), but an ecological evaluation of the snow-affected ecosystems is overdue.

The environmental conditions on the Tibetan plateau have several consequences for livestock development that are different from the drought-dominated non-equilibrium situation. The primary difference is that with interventions to successfully reduce livestock mortality associated with extreme cold and snowfall events, the herder should be able to maintain a higher and more stable or predictable livestock population. Such a situation could then permit pastoralists to more closely approach the forage carrying capacity of the rangeland, and can conceivably bring about relatively easily gained "productivity" advances in livestock development. The downside is that overuse of forage resources, a virtually inconceivable situation under traditional pastoralism in western Tibet, may be reached without careful evaluation of carrying capacity. Assuming such a scenerio, it is not difficult to envision that over the past millennia or two in the traditional pastoral system the frequent episodes of snowfall-induced livestock mortality kept pastoralist livestock density well below forage carrying capacity and allowed a coexistence with abundant wild herbivores. Although the wild herbivores were also undoubtedly affected by severe snow storms, if they are able to better deal with or recover from such environmental conditions, then the available forage could support their substantial populations in addition to livestock. Therefore, the recent elimination of large wild herbivores with efficient modern weapons over much of the Tibetan plateau

(Schaller, 1998), and the widespread poisoning of small herbivores (Fan *et. al.*, 1999) arguably leaves more of the forage productivity available to any increases in livestock density. This may be fairly straightforward with regard to the large ungulate herbivores, but as the small fossorial herbivores (*e.g.*, pikas) may also influence soil quality and consequently forage characteristics, the effects of their removal on long-term productivity of the rangeland is still unknown (Smith & Foggin, 1999; Holzner & Kriechbaum, 2001). From the development point of view, easily obtained increases in livestock density (over traditional levels) may be seen over the short term, but continued increases in livestock density are likely to quickly overstep the limits of the pastures. In any case, livestock development actions made under the above assumptions leave essentially no room for conservation of wild herbivores, and their direct application to conservation areas where natural biodiversity is highly valued is not appropriate.

Biodiversity values

Unlike in much of the rest of the Tibetan plateau, where wildlife populations are much reduced from levels of a century ago, in parts of the northwestern Chang Tang wildlife numbers have probably not greatly changed or are only beginning to decrease. Due in part to its low overall productivity and its remoteness (*i.e.*, little human exploitation), the northwestern Tibetan plateau today constitutes one of the best remaining examples of extant flora and fauna, especially that of large mammals, in central Asia. In fact, the relatively undisturbed large wild herbivore populations and their predators represent one of only a few such remaining assemblages on earth, prompting the renowned field biologist George Schaller to refer to it as a "high-altitude Serengeti" (Grosvenor, 1986). Although in the past wildlife densities were probably higher elsewhere in the more productive areas of Tibet, the best wildlife areas remaining today are also the least productive simply because they are also the most remote. Large populations of migratory chiru, and other large herbivores such as wild yak, Tibetan gazelle (*Procapra picticaudata*), Tibetan argali sheep (*Ovis ammon*), blue sheep (*Pseudois nayaur*), and Tibetan wild ass (*Equus kiang*) still roam much of the high plains and mountains of northwest Tibet, along with their predators that include wolf (*Canis lupus*), snow leopard (*Uncia uncia*), brown bear (*Ursus arctos*) and lynx (*Lynx lynx*). Besides the larger herbivores and their predators, other species include the Tibetan woolly hare (*Lepus oiostolus*), Himalayan marmot (*Marmota himalayana*), black-lipped pika (*Ochotona curzoniae*) and small rodents. Smaller predators include Tibetan sand fox (*Vulpes ferrilata*), red fox (*Vulpes vulpes*), steppe polecat (*Mustela eversmanni*), and possibly the manul or Pallas's cat (*Felis manul*). The resident bird fauna is not numerous (Zheng *et. al.*, 1983; Schaller, 1998), but several of the larger species include the Lammergeyer (*Gypaetus barbatus*), Himalayan griffon (*Gyps himalayanus*), upland hawk (*Buteo hemilasius*), saker falcon (*Falco tinnunculus*), Tibetan snowcock (*Tetraogallus tibetanus*) and Tibetan sandgrouse (*Syrrhaptes tibetanus*). The bar-headed goose (*Anser indicus*) and ruddy sheldrake (*Tadorna ferruginea*) as well as other migratory species are summer breeders on the high lakes or steppe, and a number of other long-distance migrants (*e.g.*, little gull, gadwall) apparently use the lakes and marshes as rest stops during spring or autumn. There are no amphibians and only one reptile present, a lizard (*Phrynocephalus theobaldi*). Whereas many of the large mammal species have been greatly reduced in number on other parts of the Tibetan plateau, the Chang Tang reserve presents a unique opportunity to protect the last remaining widespread populations of several of these species.

As one can imagine, however, this wealth of wildlife abundance represents something of an implied paradox for development of the nomadic pastoralist populations that make a livelihood there. On the one hand, where wildlife is still abundant, the nomads, as they have traditionally done, depend on some hunting for sustenance and sources of trading commodities. This is especially true near the northern limits of human habitation in the Chang Tang; the core areas and their vicinity in the reserve. On the other hand, where increases in livestock productivity are demanded by human population increases and modernisation, the presence of significant numbers of potentially competing herbivores and predators that kill livestock is anathema to the herders. Once abundant large wild herbivores have been eliminated or greatly reduced from most of the Tibetan plateau (Goldstein, 1996; Schaller, 1998); current pasture improvement and livestock development programs will probably preclude their return. How then does one promote improvements in pastoralist livelihoods while at the same time ensure wildlife conservation. Or, as has been argued in parts of Africa, are these mutually exclusive alternatives (see Prins, 1992).

Aru basin study site

The Aru basin is an approximately 2300 km² fully enclosed catchment (no outlet), situated at about 5000 m elevation near the northern limit of pastoralism (Fig. 1), and is included within part of the original core area designation of the Chang Tang Nature Preserve (TARFB, 1998). It has been described as one of the best areas for wildlife in the entire reserve (Schaller & Gu, 1994), and efforts to minimise human impacts on wildlife are considered to be a high priority (TARFB, 1998). It encompasses unparalleled biodiversity values that characterise the rationale for the reserve's creation, and thus represents one of the key areas for wildlife conservation within the entire 300 000 km² area. Abundant forage on the *Stipa*-forb vegetated alluvial fans and alpine hills on the eastern slopes of the Aru mountains make for relatively rich grazing lands compared with elsewhere in the northwest Chang Tang, and the abundance of both wildlife and sought-after grazing areas for livestock is not surprising (Fig. 4). Farther from the mountains, the drier and less productive *Stipa* and *Ceratoides-Carex* steppe typical of most of the northern Chang Tang predominates. The Aru basin's only significant drawback as livestock grazing areas is that at this elevation the relatively frequent mountain-induced snowfalls near the Aru range (even in summer) often reduce the availability of forage.

The Aru basin site is also unique in that nomads have only recently returned; it having been off-limits for some 15 years in efforts to keep pastoralists closer to administrative centers. The abundance of wildlife may also be a consequence of that rest from potential competitors for forage and from hunters. The basin is situated within a larger region of more moderate wildlife abundance, with ongoing administrative and livestock development activities that recognise a higher priority for pastoral development, while within the context of the nature reserve still trying to minimize negative impacts on wildlife.

Pastoralists

The nomads throughout the area are currently undergoing a modernising of livelihoods affected by the introduction of permanent winter houses (altering seasonal migration patterns), development of local community administrative centers, vehicular transportation, changing international trade in shahtoosh and cashmere and a move towards stricter wildlife conservation laws (Næss *et al.*, 2004). As Schaller & Gu (1994) have noted, "in 1991, 5 families (~40 people) moved their 600 sheep and goats and 45 yaks into the [Aru] basin permanently, primarily to hunt wildlife". This was in addition to about 21 families with about 8600 livestock that used the basin on a seasonal basis at that time (Schaller & Gu, 1994). In 2000, there were about 19 permanently resident families within the Aru basin, and another 30 families that used it part

Fig. 4. Nomad women milking goats at 5000 m elevation in the Aru basin. Chiru and gazelle are common and kiang occasional on the plains in the foreground, whereas wild yak, blue sheep, snow leopard and brown bear are found in the lower parts of the mountains.

of the year for livestock grazing. In the summer of 2000 there were about 230 people and 15 000 livestock using the Aru basin for grazing, whereas during autumn of the same year there were about 105 people and 8000 livestock (Næss *et al.*, 2004). Nomads moved their camps often, and during all seasons were affected by occasional snowfalls that influenced their movement decisions and timing, especially for those nomads with much of their grazing areas abutting the eastern slopes of the Aru mountains. With 20 permanent winter houses currently in the basin, the amount of settlement and grazing use we observed contrasts sharply with the only 5 year-round families and no permanent houses reported from 1991 (Schaller, 1998); indicating a substantial increase in human use within the basin over the past decade.

The nomads today are aware of competitive pressures on good grazing land, and in view of the current ban on hunting, a good livelihood is even harder to maintain than it was just 5 years ago, when hunting was still a legal option. The herders complain of an increase in abundance of an unpalatable, and apparently sometimes poisonous, legume (*Oxytropis* sp.); a situation that could be due to increasing levels of grazing in the basin. In June of 2001, 3 of the 19 families permanently resident in the Aru basin decided to move their permanent base to the west of the Aru basin, due to the difficult environment and perceived decreasing quality of grazing conditions in the basin. It is clear that the nomads are experiencing uncertainties regarding their future that relate to both grazing and hunting, and thus affecting their strategic thinking in determining the best alternatives for improving livelihoods for themselves on the high pastures.

Wild ungulate populations

Based on surveys conducted during 2000-2002, the chiru population in the Aru basin varied from about 1500 males (and a few barren females) in summer to over 11 000 individuals of both sexes (including newborns) in autumn of 2000 (Fox *et al.*, in review). The summer numbers are similar but the autumn count is much higher than reports from the early 1990's (Schaller & Gu, 1994), and probably reflects the variable migratory behaviour of this species, with large numbers wintering within the basin in 2000-2001 and 2002-2003, whereas they had wintered farther south in 1990-1992. There are currently about 250 Tibetan gazelle, 150 Tibetan wild ass and 350 blue sheep resident in the basin (Fox *et al.*, in review), and these numbers do not appear to have changed substantially from those documented in the early 1990's (Schaller & Gu, 1994). The situation for wild yak, however, is quite different, with summer numbers declining from over 680 in 1990, to about 350 in 1992 when pastoralists had fully occupied the basin (Schaller & Gu, 1994), to less than 200 observed during 2000-2002 (Fox *et al.*, in review). Whereas hunting has probably contributed to the decrease in wild yaks, current levels of livestock grazing may also be detrimental to wild yak survival, an interaction that needs to be better assessed.

For ungulates other than wild yak, livestock use does not appear to have had a significant effect on populations to date. Regarding chiru, hunting has not as yet decimated numbers this far west; the Aru basin appears to represent an important part of the migratory range of the still largely intact Western Chang Tang herd. In any case, with some 8000 livestock and close to 12 000 chiru and other wild ungulates using the Aru basin in some winters, forage resources may be approaching a limiting level at least in some parts of the basin (perhaps illustrated by increases in unpalatable forage species). An assessment of forage productivity and estimation of sustainable livestock and wild herbivore stocking rates is greatly needed, and is a future objective of the project.

Nomads and wildlife

The resident nomads indicate that life in the Aru basin is hard; far from modern amenities and subject to unpredictable environmentally-related factors that pose many challenges to successful livestock husbandry. They do live at the northern edge of human presence in the Chang Tang, thus contending with a region of low productivity which is clearly marginal for human subsistence. They believe that the large numbers of wild ungulates present in the basin consume substantial amounts of forage, especially in the areas the nomads are saving for the winter grazing of their livestock. Furthermore, the nomads consider the wolf to be a major problem, with their livestock suffering from frequent night-time attacks, and the only protection afforded is the presence of dogs to scare off predators. Brown bears and snow leopards are lesser threats to livestock, but the bears can wreck a tent camp or the new houses where supplies are stored, and be quite dangerous to humans if surprised. Male wild yaks can greatly disrupt the domestic yak herds, especially during mating season, and are thus greatly disliked by the nomads. South of the Aru basin, kiang are numerous in some areas and constitute a competitive grazing menace according to some of the nomads. Pikas, abundant on some of the pastures, are subject to eradication programs elsewhere on the plateau.

Hunting of chiru, wild yak and other large herbivore species has been an important traditional nomad activity in the Chang Tang, an activity carried down from the first nomadic hunter inhabitants of the region over 20 000 years ago (Brantingham *et al.*, 2001). Today, hunting is no longer an option in the many areas of the Tibetan plateau where large wild herbivores have been eliminated, but in those areas where some wildlife remains, *e.g.*, for the Phala nomads on the south-central plateau, hunting is still considered a secondary option (Goldstein & Beall, 1990; Goldstein *et al.*, 1990). In the northwestern Chang Tang, hunting has been an important livelihood component for some nomads until recently and, as indicated earlier, was a major reason for the return of nomads to the Aru basin in the late 1980's. Although the nomads in the Aru basin report formally that they ceased hunting in the mid-1990's, once the government's 1993 prohibition began to be enforced, it is clear that some local hunting continues here as well as elsewhere in the reserve. Before the hunting ban, chiru were especially sought after because the nomads could get both meat from the animals and good prices for the pelts (later traded to India for "shahtoosh" weaving). Many of the Aru nomads have in recent years been caught and fined for illegal possession or sale of chiru pelts, and there is thus currently a clear conflict of interest between wildlife conservation and local community interests in the basin (Fig. 5). As a consequence, following the prohibition of hunting, the nomads feel their life situation has become worse, forced to rely totally on the uncertainties of livestock husbandry under marginal pasture conditions. Now, if they lose too many animals due to snowstorms and wolves, they are concerned that they no longer have the hunting option, with its provision of both meat and income.

Wildlife conservation and nomadic pastoralism in the northwestern Chang Tang

Although organised poaching of chiru is currently a major problem elsewhere, it has not yet become so in and around the Aru basin. Nevertheless, the decreasing chiru population throughout its distribution has made the few remaining chiru strongholds, such as the Aru basin and vicinity, critical to chiru conservation. The nomads around the Aru basin do not appreciate this conservation imperative and feel discriminated against because the chiru are still abundant in their midst. Very limited subsistence hunting could be a management option here, although the problems with controlling corollary hunting could be overwhelming. On the other hand, although wild yak are still present in the Aru basin, their current number of about 100 represents a 75% reduction in the decade since people returned, and the wild yak's apparent susceptibility to human disturbance needs to be seriously addressed in conservation zones designed for their protection.

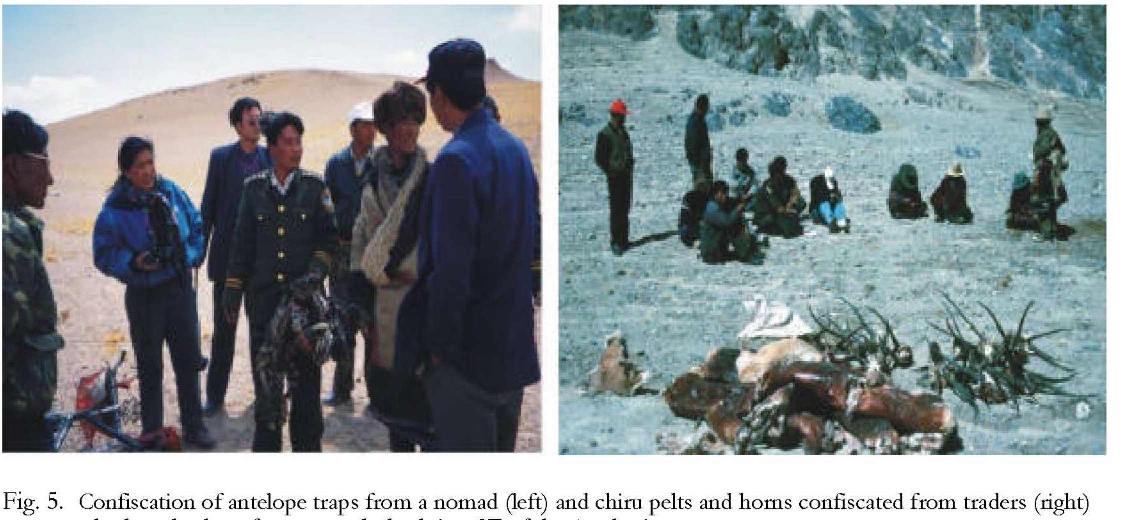

Fig. 5. Confiscation of antelope traps from a nomad (left) and chiru pelts and horns confiscated from traders (right) who bought them from nomads, both just SE of the Aru basin.

In terms of the larger development picture, where wildlife conservation is a major goal, the widespread and popular pastoral development programs to increase livestock productivity are not compatible with maintaining populations of wild ungulates and other herbivores (Fox, 1997). Simply put, in areas set aside for large ungulate conservation, livestock densities cannot be as high, relative to carrying capacity, as in areas where domestic animal production is the primary goal. Increases in the human population that depend on pastoralism will not be possible either, and certainly not to the extent seen recently in the Aru basin.

What development actions then, are appropriate where wildlife conservation is a major goal? Clearly, as a start, better basic education and health facilities are needed in the areas designated for pastoral development priority, and a commitment to reserve management, including education and hire of locals as staff, can contribute to an enhancement of living standards. Regarding livestock development, with careful application of some of the initiatives being undertaken elsewhere in Tibet and Qinghai, nomads in the Chang Tang Nature Preserve can probably achieve substantial benefit from the increased and more stable livestock survival brought about by improved overnight holding pens and better veterinary care, but numbers will have to be limited. Some fencing of winter pasture in non-core areas of the reserve may be appropriate, but any large-scale fencing programs will probably be detrimental to the migratory chiru, and wild yak. In this sense, maintaining the mobility of pastoralism, in contrast to moves towards sedentarisation elsewhere on the plateau, may be an important means to insure compatibility between wildlife and nomads in the reserve. The rodent and pika poisoning prevalent on other parts of the plateau will also not be appropriate in the Chang Tang Nature Preserve, especially given the apparent ecological importance of the pika in maintaining biodiversity (Smith & Foggin, 1999).

Eco-tourism in the Chang Tang could probably offset some of the livelihood loss due to restrictions on livestock numbers, but a substantial infrastructure in the form of roads and lodging is required before that potential can be exploited. In the meantime, such tourism will not develop significantly unless the large populations of ungulates, a primary attraction, are maintained. Regardless, it should be clear to planners that the Chang Tang will never achieve visitation rates approaching those in spectacularly scenic areas such as Qomolongma.

The currently designated Chang Tang Nature Preserve, at 300 000 km^2, is an immense area to be devoted to nature conservation. Clearly, a careful designation of core areas is required wherein natural biodiversity protection is the highest management priority, with substantial portions of the reserve designated to accommodate human livelihood enhancement as a major priority. And as indicated above, uncritical application of development actions underway elsewhere on the plateau will not be sufficient to the attainment of this goal, and alternatives need to be researched. The choice of appropriate livestock development initiatives will be critical to maintaining a workable balance between pastoralism and wildlife conservation.

In any event, if the reserve is to be successful, wildlife conservation measures designed to include recognition of the livelihood and development requirements of the local nomads are required urgently. In essence, the nomads have had to constantly re-evaluate their overall strategies in recent decades, in response to new outside-initiated livestock development and nature conservation initiatives with which they are conceptually not familiar. Hunting bans, and other restrictions without proper explanation and compensatory action will only antagonise the reserve's residents. We suggest that conservation initiatives should plan high priority in efforts to: a) prevent organized outside poaching; b) address the decreased nomad standard of living brought on by the current hunting ban; c) control livestock depredation by wolf; d) improve livestock survival in severe conditions and improve monetary return per cashmere goat; e) maintain sufficient grazing access for the wild ungulates that use the Aru basin on a seasonal or year-round basis, including limiting disturbance to the remaining wild yaks; and f) evaluate where limits to livestock use within the basin might be placed. The first two items demand immediate law enforcement and development aid programs, respectively. The second two items can be addressed with some of the programs used elsewhere, such as improved livestock shelters and veterinary care. The last two will require additional research to address issues of pasture productivity and allocation, and a close co-ordination between such research and the design of management actions. Lastly, improved education for residents of the reserve, from basic education to training appropriate for hire as reserve staff, will probably serve to enhance all aspects of a conservation program. Protection of the Chang Tang's environment lies in the balance, and we hope to see initiation of some of the above actions in the near future.

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Natural Pastures and Mobile Animal Husbandry Under Pressure:
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From subsistence to market economy: Responses of Tibetan pastoralists to new economic realities

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Abstract: In many regions around the world the pastoral economy shifted from subsistence-oriented to a market-oriented production. Pastoral goods acquired monetary value and became a market commodity that entailed changes in the production system and in the attitude towards livestock. On the Tibetan plateau this shift did not follow a linear way. Until the 1950s, most consumption requirements could be satisfied with animal products. Economic exchange relations were essential to provide grain requirements, at least for those households who relied exclusively on animal husbandry. During the Mao era, animal husbandry was carried out in line with state targets and the produce was delivered according to central planning. In the late 1970s the transition towards a market-oriented production began. This paper discusses the recent reactions of pastoralists to the new realities in one specific area on the eastern Tibetan plateau. This shift from pastoral products to market commodities, the commercial network established as well as the market places for pastoral produce, are examined in this paper. These facts show that the pastoralists in question successfully market their produce. The research area, Dzoge county, is located on the eastern border area of the Tibetan plateau, where different ethnic groups live in proximity to each other. Grassland predominates the landscape, used by nomads as pastures for livestock breeding (yak, sheep and horses). Mobile animal husbandry and the marketing of the livestock products are decisive to guarantee the livelihood of the majority of the population.

Key words: China, commercial networks, market places, nomads, Pastoral economy, Tibetan plateau.

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Introduction: From subsistence oriented to market oriented

In various regions of the world the pastoral economy shifted from subsistence oriented to market oriented production. "This shift occurs when monetary exchange becomes regular and so generalised that pastoral products are no longer solely produced for *direct use* by the production unit, but acquire a *monetary value*, realisable through market exchange. When this happens, the character of pastoral products as marketable commodities is taken into account a priori, during the process of production itself. " (Sikana *et al.*, 1993). Sikana *et al.* discuss this process for Africa's pastoral production sector, and they conclude that the commercialisation often leads to specialisation by narrowing the range of products extracted from the herd. Frequently this specialisation goes with a shift from milk production to meat production which is encouraged by a general price decline for milk due to competing products, *e.g.* milk-powder.

Other strategies, allowing the pastoralists to respond to the demand from the new markets, include a change in the herd composition and a transition from intensive herding management to more extensive forms. In Lapland the former nomadic reindeer owners gave up milking reindeers completely and focused on meat production, which is a precondition for extensive animal husbandry (Paine, 1994). Nowadays, the 'semi-domesticated' reindeer roam around freely during the whole year in Finland. They are rounded up two times a year, in summer to mark the calves and in early winter to select slaughter animals. According to Ingold (1980) this is a 'ranching economy'. In Norway and Sweden the reindeer are herded in parts of the year and the animals migrate or are moved usually long distances between discrete winter and summer pastures.

With respect to herding management it seems that an obstacle arises at the point where pastoral strategy of decision making shifts from the necessity to assure the households' food requirements towards maximising cash income from the sales. This entails, among others, a change in the valuation of the livestock. "In respect to livestock rearing, the fundamental question is whether the herd is an intrinsic value for a pastoralist or a market commodity. Certainly and unsurprisingly, the market factor has increasing importance." (Paine, 1994).

The nomadic economy of the Tibetan plateau had to provide subsistence and self-sufficiency. Most food consumption requirements could be satisfied with the animal off-take, the need for exchange was little[1]. In the case where the nomadic household relied exclusively on animal husbandry, exchange relations were only essential for grain requirements. In the case under discussion here, the pastoralists acquired grain from agro-pastoralists in the county itself. In addition, grain caravans were sent to the neighbouring farming areas of the lower altitude levels. The goods were bartered (grain for animal products) or paid for in cash (Informant in Dzoge, 2001).

During the Mao era (from 1960s to the early 1980s), the agricultural sector was centrally planned and administered on a national level all over China. The production process was organised and directed by the plans and instructions of the Collective's leadership and the government. All pastoral produce was delivered according to state planning and product targets. The aim was not to provide subsistence for the local inhabitants but to produce commodities for consumers all over China. This suggests that the transition from subsistence to market-oriented production did not progress in a linear way as was the case in other regions of the world.

The communes were dissolved in the early 1980s, the livestock was divided among the families, and the households became responsible again for everyday livestock management. The reform policies launched by Deng Xiaoping included a shift to a market-oriented economy. Central planning no longer regulated the production, which was instead regulated by the demand from markets. State subsidies ceased. The need to have cash in-hand increased during the following years, in case the pastoralists had to pay for grain and food requirements, for taxes and modernisation developments (like fencing-in pastureland and building winter houses), education, health care and transportation. The shift away from self-sufficiency diffused the everyday consumption patterns of the pastoralists and they began to substitute home-made products by ready-made goods bought from the markets.

The changing conditions primarily meant that the nomads have to manage now the marketing of their produce themselves. Secondly the pastoralists must cope with rising monetary needs. Based on data collected during two field excursions in the years 2000 and 2001, this paper examines the responses of pastoral producers to the new realities. The change from the pastoral products towards market commodities, the establishment of a network of commercial exchange relations and the market places for pastoral products were all examined. Based on this investigation, we may conclude that Dzoge's pastoralists successfully market their produce. The sustainability effects of this development, as well as the impact on the natural resources and cultural identity are not dealt with in this paper.

The study area: Dzoge county on the eastern Tibetan plateau

Dzoge county (Chin. *Xian*) is located on the eastern fringe of the Tibetan plateau in the north-west of Sichuan province, with neighbouring provinces Gansu and Qinghai (Fig. 1). This border location makes it a transition area. A widely used road which links the Sichuan "Red Plain" with the "remote" north-western China (Tibetan plateau and Xinjiang) cuts through the county.

[1]The relevance of additional activities like salt tracks and transportation services should be discussed in the future.

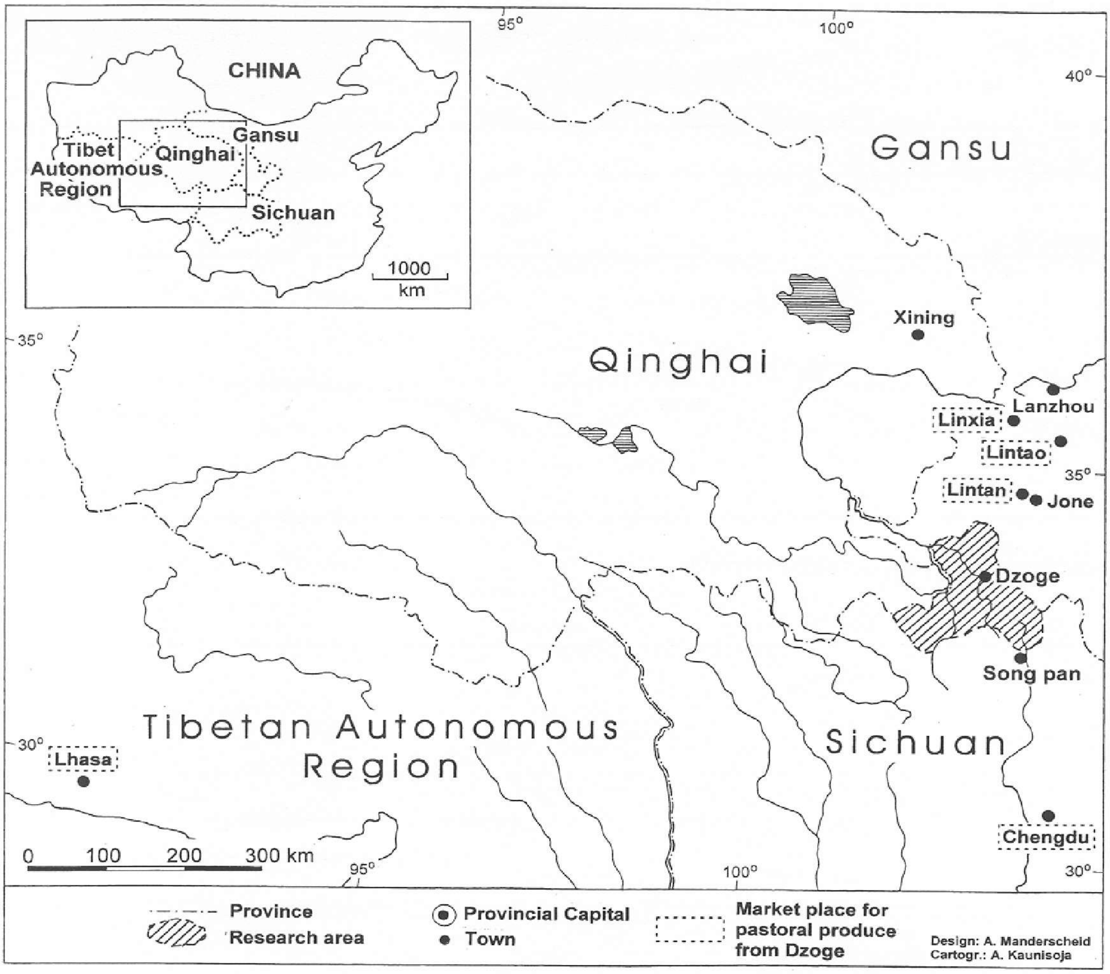

Fig. 1. The research area Dzoge county. The hatched cities are market places for pastoral produce.

This road climbs up through the narrow Minshan river valley frequently threatened by landslides. In order to enable the rapidly increasing traffic, especially heavily-laden trucks, to pass unhindered, the road has been considerably reconstructed and improved during the last 10 years.

The western border between Qinghai province is marked by the Yellow River, which has a bend here of nearly 180 degrees. This landmark can be recognised easily from aerial images and is dominated by a Buddhist monastery (*Thang skor*), which played a significant religious-cultural role both in the region and outside.

The Hongyuan-Dzoge plateau (3400-3800 m) dominates the terrain of the county, which is covered by alpine meadows and swamps. All these natural resources are used as pastures to carry out mobile animal husbandry. About 60% of the total area of 6060 km^2 can be used for this purpose. The pastoralists keep yak, sheep and horses, of varying compositions. The swampy areas, for instance, are not suitable for sheep breeding. The pastures are state property, but since the 1990s they have been leased gradually to the pastoral households on a leasing basis founded on the Rangeland Law which came into force in 1985 (Ho, 1996)[2]. Therefore, most of Dzoge's rangeland is currently leased to individual families and fenced in[3].

The northern and eastern part of the county is mountainous, as high as 4200 m, the lowest part of the valley is at 2800 m. The slopes are covered by

[2]For English translation of the wording see (Manderscheid, 1999).
[3]See Wu Ning and Richard, C. (1999) for the impact of the privatisation process.

forests, but since the logging ban launched in 1998, wood extraction has stopped. Arable fields (< 1% of the counties total area) spread along the river valleys. Here the pastures, located above the tree-line on the ridges of the mountains and hills, are used for mobile animal husbandry.

In more than 50% of the administrative districts (*Xiang*), two different land-use systems complement each other. In the regions where grassland prevails, the inhabitants rely exclusively on animal husbandry, in the more dissected parts they combine field-cultivation with animal husbandry (agro-pastoralists). Pure farming is negligible. In the remaining seven districts, all the inhabitants are pastoralists only. This study focuses on the latter districts which are located in the west and south of the county. About 80% of Dzoge's inhabitants are Tibetans (data for 1990. Tabulation on China's Nationality: 1990 Census Data, Marshall & Cooke, 1997), more specific *Amdo* Tibetans[4]. They follow Tibetan Buddhism, in this county the *Gelugpa* school prevails, and the influential Labrang monastery in the Gansu province dominates their religious orientation. Most Dzoge Tibetans are pastoralists or agro-pastoralists. Han-Chinese immigrated significantly after 1956, when the county was incorporated into the Peoples Republic of China (PRC). They are mainly employed in the areas of administration, education, health-care or carry out wholesale commerce.

With regard to trade and commercial business on the Tibetan plateau, and especially in its border regions, the Islamic Hui merchants play a decisive role. In 1990 they constituted up to 3% of Dzoge's total population (including a small proportion of the Qiang nationality; Marshall & Cooke, 1997). Generally, they live between the plateau inhabited by Tibetans and lowlands populated by the Han-Chinese so that the Hui play the role of middlemen. The Hui population has a long trading tradition in China. In order to do business, they travel extensively and according to existing records they had already been visiting the nomads in the early Manchu Qing dynasty (1644-1911). Under these harsh conditions they specialised in small-scale retail trade. Often they adapted to Tibetan culture by adopting their language, clothing and food habits by intermarrying (Moevus, 1995). In Dzoge, most of the restaurants and shops are owned and run by Huis.

All counties which are governed by the Aba Tibetan Autonomous Prefecture (TAP) have similar environmental features and land-use systems as Dzoge county. It is remarkable that the primary sector in Dzoge contributes 71% of the Gross Domestic Product (GDP), which is much higher than any other county (data for 1994; Marshall & Cooke, 1997). This proves that animal husbandry and marketing of the pastoral commodities are developing adequately. In Dzoge the extraction of products from land resources (mushrooms and medicinal herbs) plays only a little role as an additional economic activity, at least for the pastoralists investigated here. They stressed that they do not dig medicinal herbs intentionally because it diminishes the quality of the pasture and is also forbidden by law. However, some pasture was rented to extractors from outside the county.

Pastoral produces shift to a market commodity

The shift from producing for their own consumption to a market commodity is exemplified by a number of the cu rrent top commodities of Dzoges nomads, which contain *churra* (dried cheese), butter and livestock. Traditionally, milk was not included in the pastoral produce for trade. The commercial sale of milk began only some decades ago, and will be briefly discussed in this chapter.

It was a big surprise for us that dried cheese belongs to the current top commodities of Dzoges pastoral producers. *Churra* is a by-product of butter processing. When dried in the sun it serves as a staple food, when mixed with *tsampa* (roasted barley-flower), or as provisions for migration and other trips. Nomadic families often save a surplus, and until about 10 years ago it was used almost exclusively for their own consumption and was not for sale.

The new demand is caused by at least two factories in Gansu province. In one of these plants *churra* is used as an ingredient in paint production, the other plant needs it to produce the sachets of medical pills. However, these factories in Gansu province are not the only users. It is traded to a greater extent via Linxia to Guangzhou, Shanghai, Shenzheng and Hongkong (pers. comm. Du, 2002)[5]. The pastoralists sell *churra* seldom for cash, but barter it with traders who visit their tents or winter houses. Its high market value is reflected in the exchange rate: for 1 *jin* (about half a kilogram) of *churra* the nomadic women could get in the autumn 2001 ten *jin* of apples. The

[4]Due to the traditional Tibetan division is Amdo the northeastern province. For location Huber, 2002, Fig. 1.

nomads declared that, from all their products, *churra* is the easiest to sell. However, it can be assumed that the factories will soon substitute *churra* by some other products. Butter is the main dairy product of Tibetan nomads and serves as one of their basic food items. In this subsistence-oriented economy, part of the annual butter production was stored as a "hidden reserve", and larger amounts were bartered or sold in local markets when the need for cash arose. Ultimately the main consumers were, and still are, the Tibetan Buddhist temples and monasteries, where butter is used as fuel to be burnt in the butter lamps. Tibetan families who own only a few yaks, buy butter for their own consumption as well. A great demand comes for instance from Central Tibet (TAR), even though mobile animal husbandry is widespread there too. But, in contrast to the eastern Tibetan plateau, sheep and goats dominate the herd composition in Central Tibet and therefore the butter production is low. Since transportation facilities and long distance trade improved, butter from the eastern Tibetan plateau is transported to TAR. According to some nomads, butter as fuel for the butter lamps is increasingly substituted by factory products imported from India. Livestock constitutes the third pastoral product here, namely yak and sheep. For cultural-religious reasons, meat is seldom marketed. In a subsistence economy yak and sheep produce food, fiber, transportation and fuel for pastoralists. A pastoral family owning about 60 yaks and 140 sheep, slaughters only one yak and five sheep per year for their own consumption, and sell three to four yak and 20 sheep alive.

With the increasing commercial involvement the pastoralists began to substitute home manufactured products like the narrow stripes woven from yak hair for the black tents or woollen blankets with ready-made goods bought from the markets (Manderscheid, 2001a). A new demand for beef and mutton from urban areas in China occurred during recent years. The livestock raised on the Tibetan plateau, and from the pastoral areas of Xinjiang and Inner Mongolia, are able to meet this growing demand. In order to satisfy these requirements private traders now buy livestock directly from the nomads.

In the past the consumption rate and sale of milk has little meaning for Tibetan pastoralists. In their subsistence oriented economy Tibetans processed all their milk into butter and smaller quantities into curd. In Hongyuan county a state milk processing factory was founded in 1956, and in other counties of Aba TAP, *e.g.* in Dzoge, this happened in the 1970s. Their most important output is milk powder which is sold all over China. Generally speaking, in Hongyuan county the pastoralists are now eager to sell milk. Meanwhile the factory has been privatised. But the state milk powder factory in Dzoge closed two or three years ago, because the pastoralists did not supply enough milk. The nomads reported that the price was too low and the factory did not pay on time. Now they have reverted to making butter from all their milk. Only some families with pastures located close to the Dzoges *Xian*-center sell milk locally to the town dwellers.

Dzoges pastoralists and the new economic realities

The market places for the pastoral products and the economic exchange relations of Dzoges pastoralists will be discussed now, focusing on their selling activities. Fig. 2 presents an overview of different market places and Table 1 an example of the sales of a pastoral family.

Local places

During the Mao era, the administrative centres, such as in Dzoge (Dzoge Xian) and the district provided all kinds of infrastructures for the herders' centres (*Xiang*). In terms of commerce, the earlier one or two state-run shops are now joined by a wide range of private shops, street sellers, market compounds, direct sales from trucks etc. During recent years, the variety of supplies and number of merchants increased significantly. Even in the small village-centres (*Cun*) and in the state farms (*Mushan*), one or two small shops offer basic supplies. On the other hand, the nomads sell some of their animal products to wholesale buyers at the local markets. In summertime, large tent-shops in the summer pasture areas increase their shopping opportunities. These shops also serve as buying-stations, for butter for instance.

[5]Probably serving the same purpose.

Table 1. Sales of a pastoral family in Xiamen *Xiang* in the year 2000. (7 family members, 105 yak, 210 sheep; the animal numbers are above district average).

Product	Amount (1 jin = 500 g)	Sale to	Month	How important
Living yak	15	Traders from Gansu, state meat factory, local traders	9-11	1 (very important)
Sheep	55	State meat factory	9-10	2
Butter	300 jin	Traders from Gansu, Tibet, local traders	7-10	3
Churra	100-200 jin	Local market, traders from Gansu	7-10	4
Sheep wool	350 jin	Local market, traders from Gansu	8	7
Yak down	100 jin	Local market, traders from Gansu	8	6
Yak hide	11	Local market, traders from Gansu	1-12	5
Sheep skin	15	Local market, traders from Gansu	1-12	5

Regional market places

These are located at lower altitudes adjoining the pastoral living areas market places for pastoral products multiplied in the 1990s. Relevant for Dzoge are those in neighbouring Gansu province (see Fig. 1). Number one is Linxia near Lanzhou, about 400 km away from Dzoge, called "Little Mecca". It has the largest Hui community in north-west China and for decades it has been an important commercial centre. A special market for stock exchange (sheep, yak, horses, animal products) is located in the outskirts of the city (Dillon, 1999). Traders and wholesale buyers from the provinces of Henan, TAR, Qinghai, Sichuan and Gansu frequent this trading centre. During Muslim festival times, the demand for mutton from this market increases above the already considerable average demand.

Inside the city boundaries, in the centre of the Muslim quarter, there is another market area. Besides jewellery, rosaries, skins, Tibetan cloth (Moevus, 1995) there are all kinds of goods on display which Tibetans need, and rarely find on a local market. The nomads have a good choice of solar panels, and there are cement rings to support the walls of water wells dug into the pastureland. Exceptionally - Honda motorbikes are also on display in local market places, demonstrating the growing importance of modern traffic. Other relevant market places in Gansu province are: Linxian, Lintan, Wai mo near Jone (Pers. inform. Du, 2002) and Lintao (Moevus, 1995).

Dzoge county is located approximately half way between Linxia and Chengdu. Chengdu, the capital of Sichuan province 500 km away, acquires mainly live animals from Dzoge. Two slaughter houses for yak and sheep are located in the outskirts of the city. The traders bring back ready-made products from Chengdu. No other specific market areas for pastoral products exist which would be attractive for a visit. The nomads interviewed, preferred to go to the markets in Gansu province, often combining it with a visit to Labrang Monastery. Older nomads mentioned that they visited the monastery one or two times a year before the Mao era[6], and that it is now again an attractive destination for them. The market area, adjoining the monastery compound, is spacious and offers a rich collection of religious goods, cloth, kitchen utensils etc., but there is only a small choice of "modern" goods for nomads. It is popular now to combine a visit to the monastery with a trip to Gansu's markets, without a special need for shopping, just for leisure and fun.

With regard to the national markets, great quantities of frozen beef and mutton from the Dzoges state slaughterhouse reach Beijing. Lhasa and the TAR is an important destination for butter from Dzoge, the "export" of *churra* having been mentioned above.

Marketing of pastoral produce

The importance of private wholesale traders for economic exchange increased significantly. They often belong to the Hui nationality, but Han Chinese also act as intermediate traders. The interest of most traders is to buy the main pastoral commodities (livestock, butter and *churra*) on the

[6]van Spengen (2000) describes the formes role of monasteries as centres for trade in terms of seasonal fairs, markets for pilgrims and stop-over places on trading routes.

spot. They arrive in the nomadic area by truck and take back directly what they bought. The pastoral producers who were interviewed reported that the traders visited them frequently, and that they can sell as much as they like during the right season. Nomads who live in very remote regions of the county, however, stated, that they are only seldom visited by the traders.

Commodities which the pastoral producers offer themselves to a station or shop at the local market places are hides and wool for instance. At present their demand is low, and traders seldom ask for them. Another motivation to sell is a sudden need for cash, as well as a very good price. Direct marketing can be carried out by an individual family, but likewise it can be organised by a household-group or a village. If the pastoral producers plan to sell livestock to a slaughterhouse in Chengdu, they rent a truck, hire a driver, collect livestock and transport it there. Markets located further away than the regional markets in Gansu province and Chengdu, are rarely supplied by the pastoral producers themselves, but by commercial traders.

With the exception of remote pastoralists, the Dzoge nomads sell most of their produce to external traders who visit their tent or winterhouse. They emphasised that they usually pay best. Self-organised transportation can bring a good profit, but it is more risky, because the price might already have dropped when the truck arrives atits destination. In addition, the external traders are eager to sell products to the nomads directly. In summer they drive across the plateau, the back of their three-wheel cars loaded with seasonal products like pears, apples, cabbage, onions. They stop in front of the tent, and offer the goods, which are often bartered for *churra* (Fig. 3). They take also orders for special ware from Gansu's markets which they deliver on their return journey.

Dzoge's butter trade is dominated by a group of local traders, the so-called "Bobtso" trader group[7]. They own a hotel in the capital, which serves as a buttershop location. Moreover, the group carries out regular buying trips to the nomadic areas, and for the nomads these traders represent a reliable possibility to sell their butter. However, the price paid by them is slightly lower than the offers by traders from beyond the county. This group of traders transports the entire butter to Lhasa. Local Tibetan traders, however, seem to be an exception. Reports from Hongyuan county state that the butter trade there is handled by Hui from Gansu.

The state quota purchases has almost ended, yet there is still a state quota on products which are nationally or internationally in demand. Some districts in Dzoge have a state quota on livestock, for example in Hongyuan county a state quota exists on milk. These quotas supply the regional state enterprises. In Dzoge for example supplies the slaughterhouse, and the price paid is below the market price. Even the better paid sales to the state enterprises, which exceed the quota sales, are not very popular[8]. The nomads sometimes sell livestock to the slaughterhouse if no other buyers turn up.

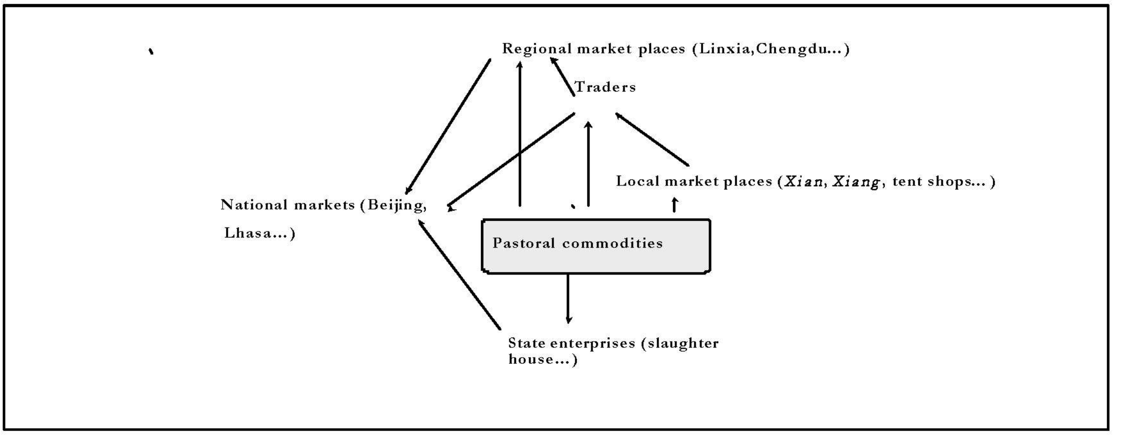

Fig. 2. Market places for pastoral commodities. The pastoral producers offer fome commodities at markets, while others reach the markets via wholesale traders or state enterprises.

[7]The name derives from their place of origin, the *Xiang* Bobtso in southeastern Dzoge.
[8]The state meat processing factory of Dzam-thang county (Aba TAP) which opened in 1995 closed down 3 years later due to insufficient supply from the producers (Manderscheid, 2001b).

Fig. 3. A Hui trader from Gansu province sells produce straight from his car in front of the tent.

Discussion and conclusions

In the past, wool was the main pastoral product demanded from the Tibetan plateau. The consumption patterns of the majority of the Chinese population did not include beef or dairy products. Only in pastoral regions, adjoining Muslim inhabited areas, some mutton could be sold.

Yet a market for beef and dairy products has emerged gradually in China, and motorised transportation has facilitated long-distance trade. New market places for pastoral products have developed fast at the fringe of the Tibetan plateau, like in the province of Gansu. Wholesale traders, often Hui from Gansu, purchase pastoral commodities, especially live animals, butter and dried cheese directly from the producers in order to supply these markets. Furthermore, the markets offer those goods which the pastoralists need. This development leads in the long run to a steady integration of the formerly economically isolated Tibetan plateau into the national market system.

In spite of these increased marketing opportunities, many features of pastoral production and livestock management have remained the same as in the period of subsistence-oriented production. But the marketing process of pastoral produce eventually adapted to the new economic realities, exemplified through the established commercial networks. The shift from subsistence to commercial production thus may be seen as a gradual participation of the nomads in the national Chinese market.

This paper proves that a widespread lack of marketing opportunities for pastoral products is not true for the area under discussion. Dzoge pastoralists have favourable trade conditions due to new demands for pastoral products and due to their location at the fringe of the plateau, mid-way between the cities of Lanzhou and Chengdu and adjoining Muslim inhabited regions. The general feedback of the nomads concerning this matter was: "We can sell as much as we want and need". They can cope well with their increasing demands to have cash ready at their disposal. However, this does not always reflect the situation of other pastoral areas, even in Dzoge itself the inhabitants of remote regions often have less good opportunities. Location plays a major role in the market opportunities, and can explain the significantly higher contribution of the primary sector to Dzoge's GDP in comparison with the other counties of Aba TAP.

It can be assumed that some of the present top commodities will lose their market value soon, therefore there is a need for innovative production strategies and new products. Attention should also be focused on the sustainability potential of the ongoing process and its impact on the natural resources (*e.g.* crossing the pastures with heavy trucks making deep off-road tracks).

The newly established commercial networks are controlled by private wholesale traders, most of them coming from outside the county. More local pastoral organisations, like the Bobtso trader group, could monopolise the direct marketing of the products, which would minimise the nomads dependency on external middlemen. However, Dzoge's nomads cannot be considered as wealthy in spite of their favourable sales opportunities. In practice, modernisation methods are costly and taxes are high. In order to establish and develop alternative livelihoods, savings should or must be re-invested in different kinds of business ventures and especially in education.

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Nomadic pastoralism in the Aru basin of Tibet's Chang Tang

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Abstract: Nomadic pastoralists live at the northern extent of human habitation within the *ca.* 5000 m elevation Aru basin, in the nortwestern part of the Chang Tang Nature Preserve, Tibet. These nomads herd primarily sheep and goats, a lesser number of yaks, and a few horses. Goats are increasing in importance because of the value of cashmere wool in national and international markets. Although sheep wool production is greater per animal than for the cashmere goats, the price obtained for its wool is much lower. Still, households keep more sheep than goats, primarily because sheep meat is preferred for consumption and sheep wool is important for the nomads' own use. The Aru nomads have traditionally depended on hunting to compensate for livestock lost to predators and unpredictable climatic phenomena such as blizzards. The prohibition of hunting in the reserve from 1993 has apparently resulted in a lowering of their standard of living, even with an overall rise in cashmere prices. According to the nomads, without hunting they have thus lost a safety measure important during years with heavy livestock losses. Conservation related development initiatives in the reserve should address this issue.

Key words: cashmere wool, Chang Tang Nature Preserve, China, hunting, livestock herding.

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Introduction

According to Spooner (1973:3) the term "nomadism" has been applied to any society that is not settled in permanent dwellings, although etymologically it implies a pastoral subsistence base. According to Seymour-Smith (1986) the word '*nomad*' is derived from the Greek word *nemo*, which roughly means, "to pasture". Although the word 'nomad' refers both to mobility and to a pastoral base of subsistence, we distinguish between nomadism[1] as referring to *mobility*, and pastoralism as a *mode of subsistence.* Dyson-Hudson (1980) similarly defines nomadic pastoralism as a social form characterised by the combination of dependence on livestock and spatial mobility. Although many terms have been suggested for different forms of nomadic pastoralism, we concur with Dyson-Hudson & Dyson-Hudson (1980:18) that discussing movement patterns of nomadic pastoralists and their livestock with reference to categories like *transhumance* and *semi-sedentary* is "[…] an intellectually sterile enterprise."

[1]Humprey & Sneath (1999:16), however, argue that the category nomadism is useless analytically, and prefer the term 'mobile pastoralism', since "Mobility here is seen as a technique that is applicable in a range of institutions, rather than as a holistic lifestyle suggested by the word 'nomad'." Our use of the term 'nomad' here refers specifically to this aspect of mobility (moving spatially), *i.e.* as a strategy used in *making a living,* and not to a *value orientation* (see Salzman & Galaty, 1990 for further discussion).

Pastoralists fall into the category of *food-producing economies*, since they rely on domesticated animals that are controlled by the pastoralist and "[…] the sex and age composition of a herd is, ideally, an artifice of the pastoralist, who, at the same time, allocates different 'tasks' to his animals" (Paine, 1994:15). Pastoralists exert control over their animals based on their preference for livestock products, either *directly*, or *indirectly* (Spooner, 1973). Directly, in the form of meat, blood, milk, hair, wool and hides, usually referred to as primary pastoral products. Secondary, but still direct, pastoral products include butter, cheese, cloth and carpets. Indirect use of pastoral products refers to the pastoralist's trading or selling to obtain products not produced themselves.

Although pastoralism refers to a subsistence based on livestock, the type of livestock reared and the type of pastoral products used, varies across cultures. Nevertheless, nomadic pastoralists should be differentiated from nomadic hunters-gatherers, whose economy can be classified as a *food-extracting economy*, *i.e.* hunter-gatherers do not alter the animals they live off of, as a nomadic pastoralist does through selective breeding (*e.g.*, domesticated animals tend to give more milk and more wool than their wild counterparts) (Khazanov, 1994).

What constitutes a nomadic pastoral adaptation in one society, however, cannot be described and compared with a basic "ideal type", but has to be investigated empirically in order to be properly understood. Spooner (1973:3) argues "[…] there are no features of culture or social organization that are common to all nomads or even that are found exclusively among nomads." Consequently, our aim herein is to give a preliminary empirical description of what constitutes nomadic pastoralism in remote northwestern Tibet, using the Aru basin as a specific, and probably somewhat unique, example.

The *ca.* 300 000 km² Chang Tang Nature Preserve (Fig. 1), the second largest protected area in the world after Greenland, was established in 1993 to protect endangered chiru or Tibetan antelope *Pantholops hodgsoni*, wild yak *Bos grunniens* and other wildlife inhabiting the Tibetan plateau (Schaller, 1998). The *ca.* 2300 km² Aru basin lies at 5000 m elevation and is known to be one of the best areas for wildlife within the entire reserve (Schaller & Gu, 1994). It is also home to nomadic pastoralists at the northern limit of inhabitation on the Tibetan plateau. Within the Aru basin some nomads use the grazing areas on a seasonal basis, others year-round (Fig. 1), presenting an ideal situation for investigating the interaction between wildlife and nomadic populations. The basin still supports abundant wildlife populations and the opportunity is being taken to gather data about this interaction to help build a sound base for management initiatives in the new reserve that take into consideration both human and wildlife needs.

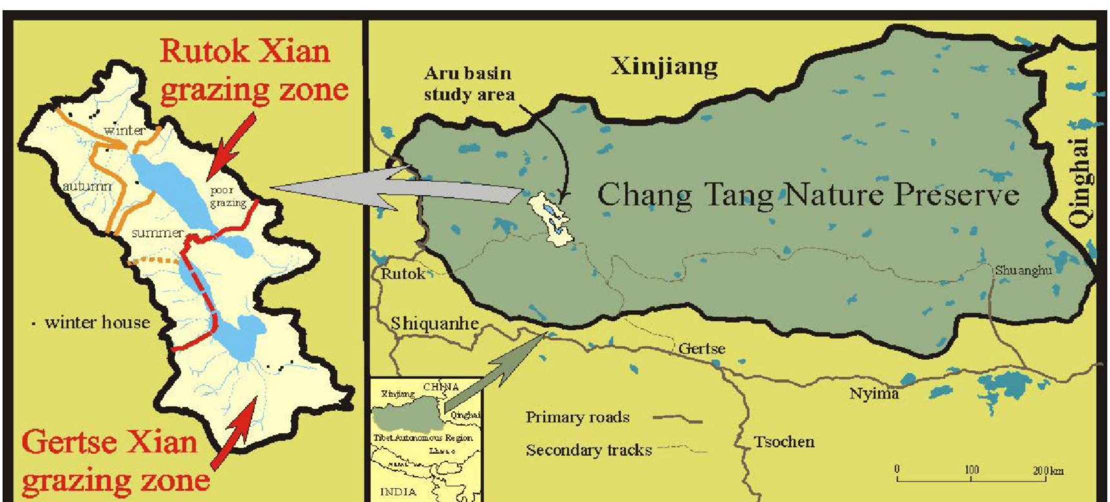

Fig. 1. The ca 2300 km² Aru basin study area within the ca. 300 000 km² Chang Tang Nature Preserve. The basin's grazing areas are divided between two administrative districts: a) the Gertse Xian portion has no distinct seasonal grazing pattern, several permanently resident families, and additional seasonal use by herders based outside of the basin, whereas b) the Rutok Xian grazing zone has distinct seasonal areas. Only Rutok herders from outside the basin use the summer grazing area below the dotted line.

Table 1. Numbers of people and livestock in the Aru basin during 2000-2001. Information is based on both counts and interviews[2].

Season/Location	People	Yaks	Sheep & goats	Horses
June 2000				
Gertse	?	165	3650	13
Rutok[3]	163	372	12009	5
Total	163	537	15659	18
Sept.-Oct. 2000				
Gertse	67	178	838	10
Rutok	60	157	3079	0
Total	127	335	6917	10
June 2001				
Gertse	59	163	3131	29
Rutok	[4]50	330	7035	0
Total	109	493	10166	29

Material and methods

Three 2-6 week periods of fieldwork were conducted within the Aru basin, in June and September-October 2000 and May-June 2001. Information on pastoralist activities was gathered primarily through in-depth interviews with ten out of 36 households in June, fifteen households out of 28 in September/October 2000, and fifteen households out of 24 present in May-June 2001. Informal interviews with all households present in the basin were conducted during at least one of our three trips, and interviews with local leaders and Tibet Autonomous Region (TAR) Forestry Bureau officials was also carried out. Separate counts of livestock numbers were conducted in some areas in conjunction with wildlife populations estimates during the same field trips.

Results and discussion

Pastoralism

The Aru basin has, according to the nomads, been used by pastoralists and hunters for several thousand years. However, with the onset of the Cultural Revolution in western Tibet in 1972, the basin was left uninhabited for around 15-20 years. During this period private ownership of animals was banned and nomads were settled into communes close to already existing government centres. The Cultural Revolution ended in 1976, and was marked by the implementation of a new economic system called the "responsibility" system. Production responsibility shifted from communes to households and private ownership of animals was reinstated (Goldstein *et al.*, 1990). However, these changes did not affect the nomads from the Aru basin until 1983, and only in the early 1990s did nomadic pastoralists again start to use the basin, both because some wanted to move back to what they referred to as their "homeland", and also because they were told to move there by the government. Although nomads have utilized the basin for a very long time, the use of the area has changed in modern times. Prior to the recent changes, the basin was used only seasonally, and then mainly during winter when hunting was most productive; the rest of the year they lived outside of the basin.

Today, administrative responsibility for the basin is divided between two counties, or *xians*, Rutok and Gertse (Fig. 1). During 2000-2001 fifteen households from Rutok Xian and about six or seven households from Gertse Xian used the basin permanently. Approximately 27 other households (21 within Rutok Xian and around six in Gertse Xian) used the basin seasonally for grazing, and move their livestock outside the basin during

[2]During June 2000 Gertse nomads were not interviewed, and livestock numbers there are based on survey counts only. All numbers for Rutok during this period are based on interviews only. All numbers for September-October 2000 are based on interviews only, whereas numbers for June 2001 are based on both interviews and survey counts.

[3]Numbers in this area are somewhat questionable due to sampling difficulties (see Næss, 2003 for details).

[4]This number only refers to one group of nomads from Rutok, and the number of people from the two other groups is unknown.

winter. Consequently, the use of the basin changes seasonally, with summer as the season with the highest number of livestock and people (Table 1).

The Aru nomads rely mainly on sheep and goats, with a smaller number of yaks (Table 1). Horses are few, according to the nomads because they graze untended and thus subject to predation by wolves (*Canis lupus*). Livestock products directly provide food, clothing and shelter and, indirectly through trade, other products such as grain, tea, ironware and manufactured clothes. Domestic yaks were traditionally used for transportation, but today trucks are more commonly used for this purpose in the Aru basin. Yaks also provide the nomads with food, shelter and clothing. The yak's coarse belly hair is spun and woven into tent material. The much finer wool, or *kullu* as the Aru nomads call it, is used to make ropes and blankets. Traditionally, the yaks' hide was used to make soles of shoes or boots, but nowadays most nomads prefer to buy shoes, which, although of lower quality, are labour saving. Yaks also provide the nomads with meat, and the female yak can provide large quantities of milk throughout the year. Nevertheless, yaks comprise only about 4% of livestock numbers, probably linked to the low forage productivity in this region.

Both sheep and goats produce milk, meat and wool and skins for the nomads. Goats produce more milk, and for longer periods of time than sheep, but the Aru nomads prefer milk and meat from sheep. Sheep were traditionally more important in the Tibetan nomads' overall economy. However, it is probable that goats have long played an important role in the economic life of nomads inhabiting the Aru basin and surrounding areas, because of close proximity to the Indian cashmere market. There has been a long tradition of bartering cashmere wool to traders from Ladakh, and cashmere wool was to some extent used to pay taxes. Nevertheless, sheep were traditionally more important for overall subsistence, because of the nomads' preference for sheep milk and meat. Recently, however, with government interest in the production of cashmere wool for cash, nomads have started to value goats more than sheep.

As with pastoralists in other marginal environments, the Aru nomads experience significant fluctuations in their livestock numbers as a result of unpredictable and uncontrollable natural disasters. For example, snowfalls in the spring of 2001 had significant effects on livestock survival in the Aru basin. In May-June 2001 twelve households from one group in Rutok Xian reported an average of 35% mortality to their livestock, against an average recruitment of newborns of 20%. The high losses were attributed primarily to severe snowfall conditions, especially during April and May. Within these 12 households, 9 experienced an overall decrease in livestock from the previous year, whereas 3 saw their herds increase. Families in the Aru basin that had campsites near the mountains (where forage is better) were probably most detrimentally affected by the deeper snow that is associated with sites near the high mountains. The livestock losses and births varied considerably from one family to another, ranging from 15-63% mortality and 9-56% recruitment, based on herd size from June 2000. Predators such as wolves and bears (*Ursus arctos*) are also a constant threat to livestock and contribute to unpredictable livestock mortality. For example, Schaller (1998:209) reported that five households in the Aru basin lost about 4.5% of their animals to wolves during 1991. Such uncontrollable ecological factors change from year to year, causing growth and decrease in herds in a typically non-stable manner (Goldstein *et al.*, 1990; Miller, 1998; Miller 2000). The nomads themselves stress the fact that life in the basin, at the northern edge of human presence in the Chang Tang, is very hard. Consequently, the Aru nomads have traditionally relied on other means of subsistence to compensate for the unpredictable losses, for example, hunting.

Hunting

Nomads in Aru have traditionally relied on hunting as a supplementary means to make their living. Locations such as the Aru basin have supported a high diversity and density of herbivores (Schaller & Gu, 1994), and recent surveys indicate that this is still the case (Fox *et al.*, 2004 & unpubl. data). The Aru nomads hunted chiru primarily to obtain meat but also to trade the skins. Pelts from the chiru were traditionally traded to Ladakh, India, from where they were transported to Kashmir and the fine "shahtoosh" wool was woven into high quality shawls (Schaller, 1998). Wild yaks were also hunted, primarily for meat, but the skins made good material for shoes. Blue sheep, Tibetan wild ass and Tibetan gazelle were hunted mainly for meat. Some people also used the skins from blue sheep to decorate their dresses, and monks occasionally bought the skins because they are good material for making drums. According to the nomads, the various wildlife species were hunted in different seasons, with wild sheep and gazelle only hunted during February, chiru of both sexes hunted in winter and male chiru primarily during summer after the females migrated north for calving.

From the late 1980s and early 1990s the motivation for hunting chiru changed. By the early 1990s the demand for shahtoosh had increased dramatically. Shahtoosh shawls had become fashionable for the elite in Europe and America, and prices for the skins increased accordingly. Prior to 1990 one skin could bring in ¥60-70 (10 ¥ = ca. US $1.26), but in the early 1990s one skin could give up to ¥400. With the traditional flintlock rifle and leg-hold traps (Fig. 2), one hunter could typically kill around 20-30 animals per year. The chiru began to give nomads a potential for cash income that far exceeded their income from sale of livestock products. By investing in modern rifles the take could easily increase to over 100 chiru per year. As a consequence, an average household in the Aru basin, with a modern rifle, could easily make ¥40 000 annually by selling skins from the chiru, about 10 times as much as an average household would make by selling livestock products, and enough to purchase a good used truck.

In 1993 a ban was declared on all hunting in the nature preserve, and in 1995 it began to be effectively enforced in the Aru basin. In other parts of their range the chiru were being killed by the thousands, often by organized poaching rings, and the overall population was decreasing dramatically. The Aru nomads, who until then had relied on their ability to hunt, albeit exaggerated in recent years, now experienced a substantial decrease in living standard. Several nomads have emphatically noted that their livestock do not produce enough milk, wool and meat to sustain them throughout the year. Thus, with no hunting the nomads have to consume a larger part of the yield of their capital (livestock) than they would otherwise have done. This can have dire consequences, since they constantly are under threat of losing part of their herds due to environmental factors, and smaller herd size makes it more difficult to survive a disaster by recouping herd size during good years (Goldstein *et al.*, 1990). Hunting gave the nomads a sense of getting something substantial back from the presence of wildlife. Today they feel strongly that wildlife, and especially the chiru, compete with their domestic animals for forage, and some nomads showed strong resentment about this still abundant animal. Such resentment, however, is grounded in their belief that traditional hunting, using homemade traps and flintlock rifles, poses no extinction threat to the wildlife species inhabiting the basin. Today, because of these circumstances, the hunting ban is not rigorously enforced for a limited hunting take (although the ban on sale of chiru skins is enforced), but it is clearly an issue that will have to be dealt with in determining appropriate management for the nature reserve.

Cashmere wool

During the last 15-20 years cashmere wool products have become more and more popular internationally. Before that, cashmere was considered a luxury and only the elite could afford to buy it. With the increasing popularity of cashmere products, the government of The People's Republic of China (PRC), including the TAR, has increased its control over cashmere wool markets within its borders. This is mainly done by imposing quotas on production of both sheep and goat wool for nomad families, determined by the local government based on the individual household's herd size. The nomads complain that government quotas are based on yields per animal that are higher than Aru animals produce (1 kg quota per sheep *vs.* 0.75/male and 0.5/female produced by Aru animals; 0.25 kg quota per goat *vs.* 0.15/male and 0.10/female produced by Aru animals), thus causing further strains on livelihood. Failure to provide the quota is punished by a fine of ¥15 for each animal producing less than the quota, but fines are usually determined after estimating the households' economic situation, *i.e.* its capacity to pay. Failure to meet the sheep wool requirement is usually not punished since sheep wool is not as important as cashmere wool.

The sale of cashmere wool (Fig. 3) provides a substantial part of the nomads' cash income, but because prices fluctuate according to world market demand, such income can also fluctuate significantly on an annual basis. The price for cashmere wool has seen an overall increase during the last ten years, although seasonal and annual fluctuations on the international market can be dramatic. On the southern plateau, in 1988 the county trade office in the Phala area, Shigatse Prefecture, paid nomads ¥13 for one jin (*ca.* 0.5 kg) of cashmere wool (Goldstein & Beall, 1991), whereas in 2000 nomads from the Aru basin were paid ¥150/jin. Over the same period, sheep wool prices have not increased, with the Phala nomads receiving ¥3/jin in 1987 (Goldstein *et al.*, 1990), and the Aru nomads receiving ¥2.1/jin in 2000.

Fig. 2. Aru basin nomads demonstrating how to use a traditional leg-hold chiru trap, and an old Tibetan flintlock rifle.

Fig. 3. Nomads comb the shedding cashmere wool from their goats in June every year.

Over the past decade the average price for cashmere wool has increased, but prices still fluctuate dramatically on a year-to-year basis. During the years 1990-1999 prices received by Aru nomads ranged from ¥65 to ¥170/jin, with such large differences often occurring from one year to the next (Table 3). The nomads have to sell all their cashmere production to the government, even though they would get better prices from private traders. In 1999, for example, the government paid ¥65/jin, while the price from the private traders was almost ¥20 higher. This had also been the case between 1993-1999, but in 2000 the government price was high enough that it didn't make much difference whether they sold to private traders or to the government. Cashmere production makes up a substantial portion of the Aru nomads' cash income. In September-October 2000, for example, an average household in the Aru basin (4.5 people, 165 sheep, 82 goats and 12 yaks) had made about ¥4000 from their June production of cashmere and sheep wool; 70% from the former. Although white cashmere can get a better price than coloured, there are no organised efforts in western Tibet to market separately and herds are apparently not managed to increase the white proportion.

Table 3. Cashmere wool prices received from government buyers during 1993 to 2000, as reported by Aru nomads. 1 jin = *ca.* 0.5 kg.

Year	Yuan (¥) per jin
1993	75
1994	75
1995	65
1996	110
1997	75
1998	170
1999	65
2000	150

Noting an increasing percentage of goats in the herds of Phala nomads on the southern part of the high plateau, Goldstein & Beall (1990) suggested that with the increasing value of cashmere wool, goats could be a new economic basis for nomadic pastoralists in Tibet. However, even though the cashmere prices have increased dramatically since the Phala study (Goldstein & Beall, 1990), our data from Aru indicates a continued relatively low proportion (30%) of goats. One of the reasons for this, according to some of the nomads, is that the mortality rate for newborn goats is much higher than for sheep. Some claimed that this was so because the grass in the basin is much better for sheep than for goats, resulting in goats not producing enough milk for their kids. On the other hand, there are more male goats in the nomads' herds than are necessary for reproductive purposes; an average 1:1 male/female ratio. In a herd of 100 goats, only 2-3 male goats are kept fertile, the rest are castrated. The emphasis on cashmere production has apparently led to an increase in the male component of the goat population, thus potentially negatively affecting the herd's ability to recover following environmental catastrophes. The rationale for keeping herds with such a large number of males is apparently related to their greater production of cashmere wool, as also suggested by Miller (2000). The nomads explained that adult male goats tend to yield more and better quality cashmere than females, since pregnant animals canalise energy to the baby, which reduces the growth and quality of the wool. Pregnant goats also tend to demand more care, and greater physical contact with these animals leads to the shedding of some wool. The nomads also report that wool quality is dependent on the amount of fodder the animals get, and during years with heavy snow and limited access to fodder, the cashmere will be of relatively poor quality. All these factors influence the nomads' cash income, and they strongly feel that they seldom make enough money to cover their basic needs.

With the increased importance of cashmere wool, the general pastoral production system has changed, thus introducing an additional source of livelihood uncertainty for the nomads. Such volatility in income from cashmere, coupled with dramatic income swings associated with the shahtoosh trade, restrictions on subsistence hunting , and changing societal demands for education of their children that affect manpower on the rangelands, the nomads are increasingly dealing with decision trade-offs that are difficult to calculate and anticipate. If the protection of wildlife is to become a primary management goal in the Aru basin, then re-establishing some stability to the nomad livelihood decisions will be an important component to achieving that end.

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Natural Pastures and Mobile Animal Husbandry Under Pressure:
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Drinking water quality in the alpine pastures of the eastern Tibetan plateau

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Abstract: The need for water quality research on the Tibetan plateau has arisen after the rangeland was allocated and leased as pasture grounds to individual nomadic families in the 1990s. These policies changed the access to water sources. The imposed fencing of the pasture tenures makes the situation even more delicate. Nomadic families are now obliged to use only water sources existing on their own site. The restrictions have caused the urge to use all available water, which resulted in increasing water quality and quantity problems. In the past, natural water sources were in common use. During the Collective era, machine-dug wells near the collective settlements facilitated the procurement of drinking water. Based on recent investigations in Dzoge county (Sichuan province), the nomadic families of some regions considered the availability of adequate drinking water for humans and animals as their biggest problem. For this study, eight water samples were collected from the Dzoge county area. All samples were from different kinds of sources, but all in continuous use by humans and animals. The samples were analyzed for typical potable water quality factors (hygienic and technique-aesthetic). The results show that the Chinese national guideline values were exceeded for NO_4-N and PO_4-P in most open sampling locations. Those parameters do not spoil the water by themselves, but together with suspended solids and organic materials produce a great environment for bacteria like *E. coli* and fecal streptococci to grow. The result analysis and pictures seen from the location reveal that bacterial growth may be the biggest problem in water quality. Even primitive protection around the water source (i.e. concrete rings, wooden barriers around edges, covers) seem to have a great impact on water quality.

Key words: access to water resources, animal husbandry, China, nomads, rangelands.

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Introduction

Atmospheric conditions, as well as rock and soil sources derive the chemical composition of surface waters. In addition, human acticity is an important factor. Human activities have changed the quality of surface waters directly and indirectly by atmospheric pollution, effluent discharges and land use. Therefore it is necessary to monitor the quality of surface water, as well as ground water, used for human consumption.

The purpose of this study was to examine how potable waters from different sources in the rangelands of the Tibetan plateau meet the existing national water quality standards. The samples were collected in 2001 in Dzoge (Chinese: Zoige) county, Sichuan province, from water sources used for human consumption. The main interest was on trace element concentrations and general water quality.

Up-to-date investigations on drinking water quality on the Tibetan plateau were rare. Yaxin *et al.* (1995) made studies in the southern part of the Tibetan Autonomous Region (TAR). In the year 1991, they collected 10 water samples from natural water sources like lakes and streams. The obtained results revealed that chromium and cadmium levels were elevated in two samples. The authors suggested that the increasing anthropogenic influences affect the water quality which urges long-term monitoring, and that further research is warranted from a health point of view.

The research area is located on the eastern Tibetan plateau, in the northwest of the Sichuan province, at the border of the provinces Qinghai and Gansu. The landscape of the county is dominated by the Hongyuan-Dzoge basin which has an average altitude between 3400 and 3800 meters, with the highest elevations reaching 4300 meters. The average annual temperature is 0.8 °C. The annual precipitation of 654 mm results mainly from monsoon precipitation. More than 50% of the annual rainfall comes during the summer months (June-August), and almost 90% between April and September. In winter the average snowfall is 15 mm. The main water systems in Dzoge county are the Yellow River (Tibetan: rMa chu), and its two tributaries, the Bai He (Tib.: dGa' chu) and the Hei He (Tib.: sMe chu). The water level of the rivers fluctuate significantly during the year. In terms of geomorphology, ancient sand dunes, sand fields, sand losses and swamps cover most of the ground in the Dzoge basin. The groundwater quantity in the swampy areas varies a lot within the year, but also between years (Lehmkuhl, 1993; Lehmkuhl, 1997).

The main vegetation type is alpine meadows, which are used as pastures by Tibetan nomads for mobile animal husbandry. Their livestock consists of sheep, yaks and horses (Manderscheid, 1999). Arable field cultivation makes up less then 1% of the total area.

During investigations in Dzoge county in the years 2000 and 2001, the nomadic families of some regions considered the availability of adequate drinking water for humans and animals as their biggest problem. Since the pastures were allocated to the individual families in the 1990s, using rights and access to water sources changed. The imposed fencing of the pasture tenures makes the situation even more delicate. Nomadic families are now obliged to use only water sources existing at their own site. In the past, natural water sources like rivers and depressions, in which water accumulated, and was in common use, even though the pasture tenures were allocated to the individual households due to the conventions of their tribal affiliation. The nomads reported that water problems occurred already in connection with the drainage of the swamp areas during the Collective era (1960s-1980s). Machine-dug wells near the collective settlements facilitated the procurement of drinking water.

The latest situation has caused the urge to use all available water. Nomadic families reported to have access to inadequate quantities of water for human consumption and for livestock, since not all households possess a site with available groundwater sources, or the possibility to build decent wells. Due to a lack of finances, the governments on the district and county levels are not able to help build wells in the seasonal pastures of the individual families. It is questionable whether a well in each pasture tenure denotes the appropriate measure for a sustainable development of rangelands used by mobile animal husbandry.

Materials and methods

In September 2001, 8 water samples were collected in two periods (4 samples per period). Fig. 1 shows the research area. The samples were collected in 250-ml acid-rinsed plastic bottles, and were then transported to Oulu, Finland, where they were analyzed by the Trace Element Laboratory and Water Resources and Environmental Engineering Laboratory of Oulu University approximately after 1 week of sampling. The analyses were done using ICP-AES (Inductively Coupled Plasma – Atomic Emission Spectroscopy) and a graphite oven. All major constituents and trace metals were analyzed.

Biological oxygen demand (BOD), suspended solids and bacterial growth were not analyzed since they require a large sample size. At this point, only small sample volumes were able to be obtained.

Sample 1 from Xiamen district was collected from a 5-m deep well (diameter 1-m), in an alpine meadow at an elevation of about 3500 m, used as a summer pasture. The well is used by four nomadic families to get drinking water for animals and people. The walls of the well and the one adjacent to it (see Fig. 2), were supported by concrete rings near the water surface. When the wells were not in use, they were covered. The edges of the well were fixed with wooden bars. A well-user stated that the pasture tenure is not very favorable for digging a well because it is a dry place and the ground water level is very low. In the past, they guided the livestock to the Yellow River or used a depression in the meadow where water gathered after rainfall.

Sample 2 was from the shores of the Yellow River. Water fetched from the river is used for human and animal consumption during the winter stay at the river banks. The water was reported to be clean by the locals. Any problems that could occur take place in the winter when the river freezes, and a hole must be made into the ice.

Fig. 1. Research area (Manderscheid, 1999).

The third sample was collected from a small river, Den Chu, in a swamp meadow at the altitude of 3475 m. The water was in animal and human consumption, and no water problems were reported.

Sample 4 at 3597 m was from a small current used for human consumption by a nomadic family. The stream has its source in a spring at a slope, and was considered by the family as clean. The stream runs near bedrock.

Sample 5 was from a spring in the steep Bobtso valley, where a water pipe delivered the water out of the slope near the street. The water was used for human consumption.

Sample 6 was collected from Torma valley near Dzoge Xian. The water source was a small stream running through alpine meadow, and it was used as drinking water by people and animals. No water problems were reported.

The seventh sample was from a well located near the road connecting Dzoge and Tankhor. The well (diameter 0.3 m) was dug by nomads in a swamp meadow (Fig. 3). The well was 2 m deep with a sand base, and had no covers, which caused problems with the water quality (the surface water runs into the well during rainy days). Surface water from swamps was reported to cause stomach problems for livestock.

Sample 8 was tap water from a hotel in the town of Dzoge.

Fig. 2. The water source of sample 1. The well is protected by wooden barrens around the edges and a cover. The nomads use this well for drinking water for humans and animals. (Photo: A.Manderscheid, 9/2001).

Fig. 3. The water source of sample 7. The well was dug in swamp meadow. When it rains the surface water runs into the well. (Photo: A.Manderscheid, 9/2001).

Results and discussion

Table 1.Results of water chemistry characterization. The electric conductivity (EC) is in units mS m^{-1} and chemical oxygen demand (COD_{Mn}) is in units mg l^{-1} O_2. All other parameters are in units µg l^{-1}.

Sa	pH	EC	NH_4-N	total N	PO_4-P	total P	Cl	SO_4	COD Mn	Na	K	Mg	Ca
1	7,4	66	<10	<500	<10	36	4502	9530	2,3	6357	1879	11040	100400
2	7,8	25	130	1192	183	270	3151	7785	10,8	4652	2331	6913	29670
3	7,5	30	100	1105	163	310	4237	<1000	15,6	5793	3394	6008	41500
4	7,5	21	10	1194	<10	33	1760	1083	3,7	5253	3504	3717	24600
5	7,9	42,0	21	854	<10	<10	2851	14074	0,5	8007	2174	19660	33400
6	7,6	14,0	38	622	63	144	1495	988	12,0	2647	1301	2219	16250
7	6,1	12,4	98	1345	51	93	1364	8147	27,4	8564	354	1831	9802
8	7,4	17,4	11	<500	<10	<10	13695	2233	1,7	3035	1586	2522	19770

Table 2. Heavy metal concentrations (mg l^{-1}).

Sam.	Mn	Fe	Cu	Cd	Pb	Zn	Ni	Cr	Co	As	Hg
1	<0.1	0.31	<0.1	<0.1 µg l^{-1}	0.001	<0.1	<0.1	<1 µg l^{-1}	<0.1	<0.5	<0.002
2	0.13	1.8	<0.1	<0.1 µg l^{-1}	0.0025	<0.1	<0.1	<1 µg l^{-1}	<0.1	<0.5	<0.002
3	<0.1	0.27	<0.1	<0.1 µg l^{-1}	0.0024	<0.1	<0.1	<1 µg l^{-1}	<0.1	<0.5	<0.002
4	0.18	4.0	<0.1	<0.1 µg l^{-1}	0.0008	<0.1	<0.1	<1 µg l^{-1}	<0.1	<0.5	<0.002
5	<0.1	0.14	<0.1	<0.1 µg l^{-1}	0.001	<0.1	<0.1	<1 µg l^{-1}	<0.1	<0.5	<0.002
6	<0.1	0.60	<0.1	<0.1 µg l^{-1}	0.0012	<0.1	<0.1	<1 µg l^{-1}	<0.1	<0.5	<0.002
7	<0.1	0.98	<0.1	<0.1 µg l^{-1}	0.0007	<0.1	<0.1	<1 µg l^{-1}	<0.1	<0.5	<0.002
8	<0.1	0.15	<0.1	<0.1 µg l^{-1}	0.0005	<0.1	<0.1	<1 µg l^{-1}	<0.1	<0.5	<0.002

In China, water quality standards exist on a national level as well as on provincial and county levels. In this article, the cited standards are sourced from the national level and are presented in Table 3. The values for surface waters are the lowest maximum and the highest maximum level. The differences in maximum levels are due to different water use. The strictest values are for water used from springs and nature protection areas. The higher values are for water used to agricultural purposes.

The guideline values for drinking water are met for all parameters except for NH_4-N and PO_4-P. Those parameters are exceeded in samples 2,3,5,6, and 7 for NH_4-N, and 2 and 3 for PO_4-P. The nitrate and nitrite levels in all samples were below the detection limit of 500 µg l^{-1}, except for NO_3-N in sample 5 (690 µg l^{-1}). The results reveal that the samples are from Ca-dominant waters, since the electric conductivity is quite low in all samples. The average conductivity is 28,5 mS m^{-1}.

Samples 2 and 4 exceed the criteria for Mn, and samples 1, 2, 4, 6 and 7 for Fe when compared to Chinese guideline values. All other trace element concentrations meet the existing standards.

When compared to Finnish guideline values (7) for potable water quality in small house units (953/1994) and potable water quality (74/1994), the analyzed water samples meet the guideline values. The analyzed concentrations exceed the guideline values slightly for total N in samples 2,3,4 and 7, for PO_4-P in samples 2 and 3, for COD_{Mn} in samples 2,3,4,6 and 7, and for Mg in sample 5. However, all the parameters exceeded are technique-aesthetic, and have no significant relevance in health related water quality. Mg causes a peculiar taste to the water, but is not dangerous for human health at existing concentrations.

Reasons for the over-limit concentrations might be that samples 2, 3, 4 and 6 are from open waters (stream or a river), and sample 7 is from an open well. The surface waters have straight access to the water. For those samples, the guideline values are too strict for water without treatment. By purification one can remove the possible bacteria growth, but not the actual cause. The best way to achieve the existing guidelines is to prevent the surface water access to the water source, and to reduce use of fertilizers near the water sources. However, the latter is of no relevance for the area in discussion because only less than 1% of the total area is in agricultural use. This means that the most likely sources of nitrogen and phosphate contaminants come from the soil itself (fertile soil type), or as fall-out with rain. The high natural nutrient content in the soil is most likely the reason for high concentrations in the water samples. During heavy rain seasons the momentary flows can be quite significant. When the rain season is over, the water volumes get smaller. During dry season when water volumes are small, the nitrogen and phosphate concentrations are relatively large. Heavy rain brings fall-outs to wells, but also dissolves nitrogen and phosphate from soil. These kind of problems are easily solved by covering the well when it is not used.

The best way to prevent the soil from collapsing into the well (bringing more nitrogen and phosphate into water) is to block the walls and edges by barriers.

Table 3. National Chinese water quality standards (Dimianshui Huanjing Xhiliang Biaozhun GH2B1, 1999 and Sternfeld, E., 1997).

Parameter	Drinking water	surface water*)
pH	6.5-8.5	6.5-9
NO_2-N	-	<10-25 mg l^{-1}
NO_3-N	-	0.06-1.0 mg l^{-1}
NH_4-N	-	0.02-0.2 mg l^{-1}
total N	-	0.5-2 mg l^{-1}
PO_4-P	-	0.02-0.2 mg l^{-1}
total P	-	
Cl	-	<250-250 mg l^{-1}
SO_4	-	<250-250 mg l^{-1}
COD_{Mn}	-	<15-25 mg l^{-1}
Na	-	-
K	-	-
Mg	-	-
Ca	-	-
Mn	0.1 mg l^{-1}	<0.1-1.0 mg l^{-1}
Fe	0.3 mg	<0.3-1.0 mg l^{-1}
Cu	1.0 mg l^{-1}	0.01-1.0 mg l^{-1}
Cd	0.01 mg	0.001-0.01 mg l^{-1}
Pb	0.05 mg l^{-1}	0.01-0.1 mg l^{-1}
Zn	1.0 mg l^{-1}	0.05-2.0 mg l^{-1}
Ni	-	-
Cr	0.05 mg l^{-1}	0.01-0.1 mg l^{-1}
o	-	-
As	0.05 mg l^{-1}	0.05-0.1 mg l^{-1}
Hg	0.001 mg l^{-1}	<0.00005-0.001 mg l^{-1}

*) Five different categories depending on the water usage

Conclusion

Total N and PO_4-P together with suspended solids and organic matter produce a good environment for bacteria. Since nitrogen and phosphate come partly from agricultural activities and use of fertilizers, they may cause some increase in bacterial growth if the suitable media is available. In this case, the impact is not expected to be significant. In this kind of environment, the most common bacteria is *E. coli*, but also fecal streptococci can occur (due to animal and human manure). The bacteria can be destroyed by boiling the water, using disinfection chemicals or partly by filtration.

In further studies, bacterial cell counts should also be analyzed. The cell counts should be analyzed immediately on-site, or the samples should be preserved. If the samples are preserved for example by thiosulphate, *E. coli* and fecal streptococci can also be analyzed after a few days of sampling. The preserved samples must be stored in a steady temperature before analysis. In the latter case, the results will not be accurate, but they will give a rough estimate of the type and quantity of bacteria existing within the samples.

When results from sample 1 are compared to results from any of the open water sampling places, one can conclude that even primitive technical solutions can prove the water quality. The well where the first sample was taken had only one concrete ring, and some wooden barriers around the edges, but it was enough to achieve better water quality. The main benefit of this well compared to open sources was the cover. It not only preventsthe nitrogen and phosphate from running into the well, but it also prevents small animals (rodents, birds) from getting into the well. If a rodent drowns in the well, it can cause a significant increase in bacterial growth hence polluting the water.

Water problems occurring in Dzoge county were mainly caused by a lack of water. The insufficient access to drinking water occurred in some areas only, but there the impact was significant and alarming. The collected water samples showed that significant differences in water quality exist as well. The differences were affected by the state and protection of the water sources.

The nomadic families as well as the local authorities are beginning to cope with such water problems. The local administrative bodies stated that they have no financial resources to support the individual families.

Firstly, most of the existing wells were dug by themselves or they paid workers to do this (total costs for one well are about 1500 Yuan or 200

Euro). Furthermore, they had collected information about measures for improvement of the wells, and visited far away market places to buy, for instance, concrete rings to support the walls. Others supported the walls of the wells by stones, which they transported from mountainous regions within the county. Even wooden barrens, which were used around the fringes of the wells, are not easily available in those woodless areas. However, not every family in need is able or can afford this. An individual well in each seasonal pasture for all families is not necessarily the only and best solution. As well, the practised fencing and the changed water using rights must be scrutinized.

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Natural Pastures and Mobile Animal Husbandry Under Pressure:
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Remote sensing in inventory of high altitude pastures of the eastern Tibetan Plateau

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Abstract: The animal husbandry practised on high altitude pastures of the eastern Tibetan Plateau is based on the use of natural pastures. The livestock consists of yaks, sheep and horses. During the recent decades the number of animals has increased in the Dzoge study area, which is located in the north western part of the Sichuan province at an altitude of 2800-4000 meters. Most of Dzoge is treeless grassland with large peat land areas. The remote sensing and Geographical Information System (GIS) methods combined with the conventional pasture mapping provide a methodology to make a cost effective and reliable inventory of large areas. Providing accurate data about the quality and quantity of pastures and also of the amount of natural forage resources promotes sustainable use of the pastures. Two field trips were made to Dzoge. Random test plots (186) covering the main vegetation types in the research area were selected. The Landsat TM image is the remote sensing data in used this study. The image classification was done in the ERMapper program. The final map producing and the accuracy assessment were performed in the ArcGIS program. The Landsat TM image proved to be a useful data source in the mapping of pastures in the Dzoge area. The main vegetation classes were classified accurately. The estimations of the biomass of different vegetation types were made. Elevation differences were relatively small and the shadows on the slopes did not affect the classification significantly.

Key words: high altitude pastures.

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Introduction

The animal husbandry practised on the eastern Tibetan Plateau is based on the use of the natural pastures. The livestock consist of yaks, sheep and horses. Traditional nomadic animal husbandry has adapted to harsh environmental conditions. In traditional herd management the quality of pastures has always been a matter of concern. Basic pasture rotation from summer to winter pastures is essential for the recovery of the pastures (Manderscheid, 2001). During the last few decades the amount of animals has increased in our study area in Dzoge county (Ao & Shiyi, 1988; Local administration, 2000). In Dzoge the local grassland bureau is concerned about the condition of the pastures. There are signs of overgrazing and pasture degradation. The situation in Dzoge is quite similar to the rest of the western Sichuan province where there have been reports of increasing pressure onpastures by a growing livestock number during recent decades. The fencing of pastures has increased during the last five to ten years (Wu, 1997; 1999). Fencing has been used to separate winter and summer pastures as well as to separate pasture land for individual herders. In the Dzoge some erosion areas have been fenced off from grazing by the local administration.

Remote Sensing and Geographical Information System (GIS) methods combined with conventional pasture mapping provide a methodology to make a cost effective and reliable inventory of large areas. Providing accurate data about the quality and quantity of pastures and also about the amount of natural forage resources promotes a sustainable use of pastures (Price *et al.*, 2001). Reliable remote sensing of pastures requires high quality field material (Colpaert, 1998).

Remote sensing has been used in the study of ungulate pastures since the 1970's. In Alaska and northern Canada it was used in studies of caribou, musk ox and bison pastures (George *et al.*, 1977; Adams, 1978; Thompson, 1980; Ferguson 1991; Matthews, 1991; Pearce, 1991). The remote sensing aided pasture inventory method for the study of the reindeer herding area of Finland (115 000 km^2) was developed by the Geography Department of the University of Oulu and the Finnish Game and Fisheries Research Institute (FGFRI) (Colpaert *et al.,* 1995). In the studies of the reindeer pastures in northern Scandinavia satellite data (usually Landsat TM) has proven to be a suitable tool for the pasture mapping of large areas. The studies have contributed valuable knowledge to the decision making and managing of the pasture lands. These studies have been based on extensive amount of field material (Tømmervik & Lauknes, 1987; Colpaert *et al.,* 1995; Kumpula *et al.*, 1997).

Only a few remote sensing and GIS studies on pastures have been conducted on the Tibetan plateau, in Northern China and Mongolia (Ryavec & Veregin, 1997; Rasmussen *et al.,* 1999). Rasmussen *et al.* (1999) discovered that a SPOT satellite image combined with a Digital Elevation Model (DEM) is useful in pasture research in Mongolia. In China there is significant concern about soil and vegetation degradation, erosion and desertification. These phenomena are usually related to the conditions of the pastures. Remote sensing and GIS have been used in many studies in those areas where degradation and erosion are a problem. For example Zhang *et al.*'s. (1996) research conducted in central Tibet where they used remote sensing and GIS successfully in mountain soil erosion mapping. In some cases the cause of degradation has been supplemented by increased grazing and human impact (Sujatha *et al.*, 2000; Gao & Zha, 2001; Collado *et al.*, 2002).

A major objective of our efforts was to estimate the usability of the Landsat TM 5 images for natural pasture classification on the eastern Tibetan Plateau. Our aim was to distinguish the main pasture types, summer and winter pastures and the intensity of grazing. A further objective was to estimate the biomass on the basis of image classification and field measurements. The research methods used in the Finnish reindeer pasture inventory were adjusted to the local environmental conditions (Kumpula *et al.,* 1997:4-12).

The research area

The study area is located in the county of Dzoge, in the north western part of the Sichuan province (Fig. 1). The area is located on the eastern edge of the Tibetan Plateau at an altitude of 2800 - 4000 meters a.s.l. In the eastern part of Dzoge there are deep valleys with large vertical differences and the treeline is at about 2900 a.s.l. Smooth slopes, wide valleys, treeless grassland with vast peat land areas on the flat plateau are characteristic of most of Dzoge. Altitudinal differences are less than 400 meters. The annual mean temperature is 0.6 °C and in July the average is 10.4 °C. The annual rainfall in the area is about 645 mm per year and most of it occurs between April and October. The winter is long and the grazing animals have to survive with low temperatures, snowstorms and the frost of the pasture grounds. The time for recovery and to fatten the livestock for the winter is about 6 months (Lehmkuhl, 1993; Wu, 1997).

The Dzoge grasslands are divided into high frigid meadows, swamp meadows and alpine shrub meadows. The soil is fertile and produces high-yield herbage with strong renewability and high nutritive value (Wu, 1997). Dzoge is an important part of the north western Sichuan grazing ground and it is one of the five wide pastoral areas in China. Nomadic animal husbandry is the main source of livelihood. The livestock on the grasslands consists of 430 000 yaks, 540 000 sheep and 30 000 horses (Local administration, 2000).

The case study area of the research is located in the western part of Dzoge where the Yellow River makes a 180 degree turn back to the northwest (Fig. 1). It was chosen because there the image was almost cloud free and the main vegetation types of Dzoge county were represented. The area is relatively flat with diverse meadows (Wang *et al.*, 2001). There are large areas of fluvial deposits in the Yellow River valley. Sandy deposits like dunes are vulnerable to erosion. Active erosion areas are found in the region (Lehmkuhl, 1993). In this area animal husbandry is the main form of land use, besides which there are some small scale oat (*Avena*) and turnip rape (*Brassica rapa*) fields. There is a sparse road network and a few small villages. Pastures are fenced mainly between the families and partly between villages and some family groups. In many cases the summer and winter pastures are separated by iron fence (Fig. 2).

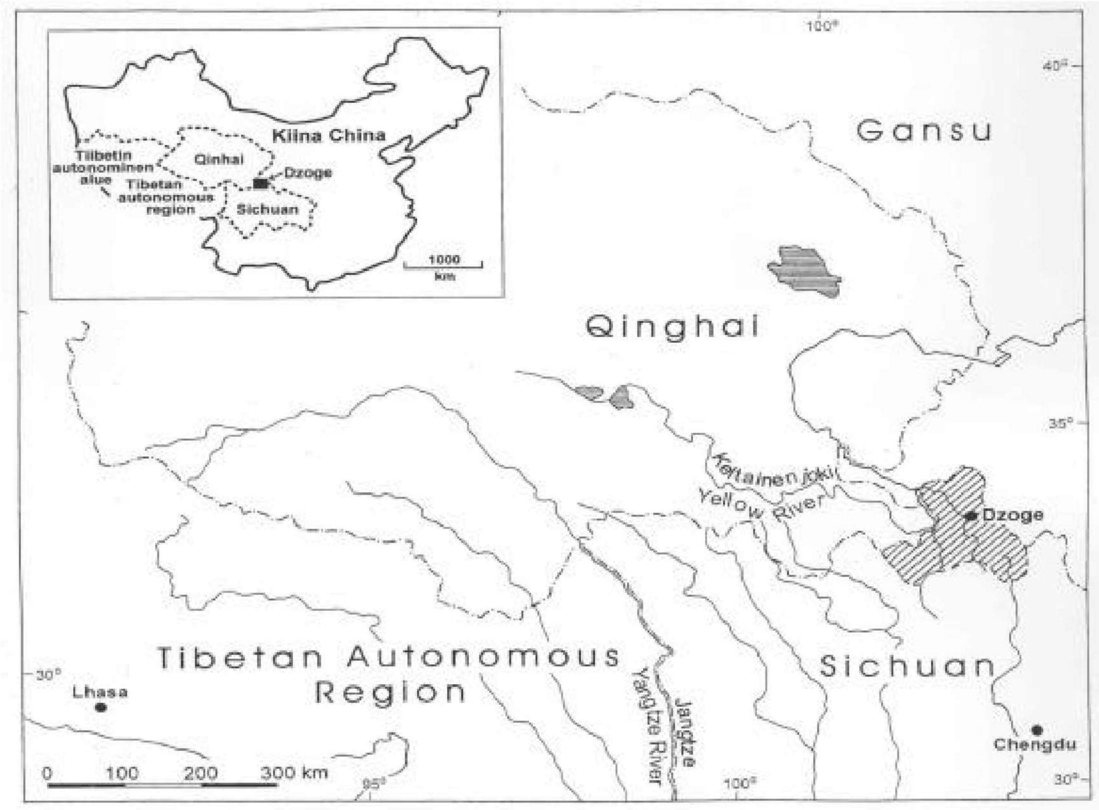

Fig. 1. The location of the Dzoge county.

Fig. 2. A fence dividing winter and summer pastures near the Yellow River. A tall grass meadow is on the left and short grass meadow on the right. These borders are also visible in the Landsat TM 5 image (see Fig. 3).

Methods and material

Field work and data

Two one month field excursions were made in the Dzoge area (in August 2000 and September 2001). The field sampling method used was basically the same as the one used in Finland (Colpaert *et al.,* 1995), although vegetation classes and the pasture type classes were different. Preliminary vegetation classes based on the literature (Wu, 1997) and on the first field trip in the year 2000 were developed further to be used in the second field trip and in the image classification.

Each test site selected and inventoried for the classification represented a homogenous vegetation or land use type. A test site size of at least two hectares (200 m x 200 m) proven to be satisfactory (Kumpula *et al.*, 1997). Smaller areas were not accepted as a class in classification because they are not usually visible in the Landsat TM 5 image. The test sites were selected randomly. The aim was to collect test sites from the main vegetation types and land use patterns in the research area. A total of 185 field sites were inventoried. The vegetation and landuse type and intensity of grazing were estimated from each test site. Intensity was evaluated on the scale little-moderate-heavy according to signs of grazing. Then from each site 5-10 vegetation quadrates (50 cm x 50 cm) were inventoried. Plant species percentage to the lowest possible taxon and bare soil coverage, and the average height of the plants were measured. The locations of test sites were measured with GPS. The average height of plants was also measured in order to differenciate between moderately grazed, heavily grazed and low grazed sites. Digital camera images were taken from each test site and quadrate.

The biomass of the vegetation was measured from 122 test sites. All the plants from one quadrate in each test site were cut and weighed. The biomass values represent the total fresh, above ground grass yield. The area of the quadrate is 0.25 m^2 (0.000 025 ha). For each class, a fresh biomass average was calculated. The biomass estimations were used to indicate the productivity of each pasture type. Altogether, 22 ground control points (GCP) for the image rectification were collected using GPS.

Satellite remote sensing data and image processing

The remote sensing data used in this study was the Landsat TM 5 image acquired on 31st August 1999. The spatial resolution of image is 30 meters. The cloud percentage is 10-15, and totally cloudless images were not available for the growing season (May - August). Cloud conditions on the Tibetan plateau are naturally such that a cloud free Landsat TM 5 image (185 km x 185 km) is almost impossible to obtain. Haas (1992) pointed out that the degree of pasture utilization differences shows best when the acquisition date of the Landsat TM 5 image follows the active growing season.

The ERMapper 6.3 image processing software was used for the image processing. For visual interpretation, different RGB (Red, Green and Blue) combination algorithms were created from different Landsat TM bands. The band combination 2, 3 and 4 which is a green, red and near infrared combination was the most suitable for visualization of the vegetation (Fig. 3). Then the image was rectified into the UTM- coordinate system by using the rectification test sites collected from the field. Rectification was successful with an RMS error of less than 1 (the unit is pixel size, in the case of Landsat TM 5 it is 30 meters).

According to the field data and the visual interpretation of the image, the suitable number of vegetation and landuse classes to be used in the classification was between 12-15. The unsupervised classification with 12 and 15 classes confirmed our suggestion. A higher number of classes leads to the mixing of classes and a lower number of classes was too generalized for our research purposes. The supervised classification of the image used both maximum likelihood and minimum distance methods. The accuracy assessment, the GIS–processing and the final map producing were done in the ArcGIS program (Fig. 4).

Fig. 3. The RGB combination of the Landsat TM 5 image bands 2, 3 and 4 presenting part of the study area. The Yellow River with white sand banks is on the left side of the picture. At the point of arrow is a fence between the winter and summer pasture (see Fig. 2 which is taken from this point). The road from the south to the north is on the right.

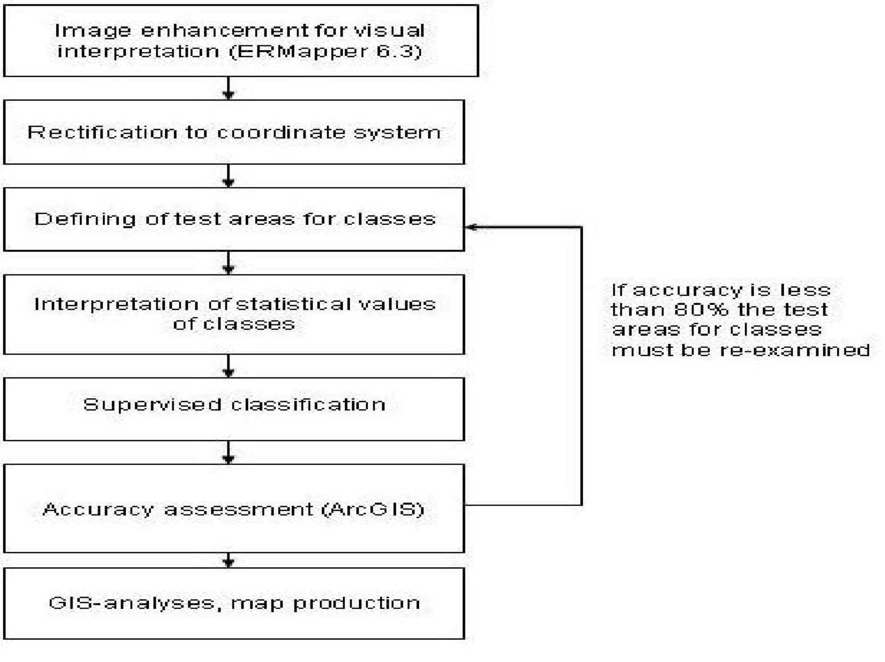

Fig. 4. The image processing procedure.

Results

Pasture type classification

The grasslands of Dzoge were divided into 12 classes in the satellite image classification. Eight classes represented different vegetation types, one class represents sand (erosion areas), two classes water and one clouds (Table 1).

Tall grass meadows are mainly used as winter pastures. Along the Yellow River, the distribution of tall grass meadows is very high. This is the most productive pasture type according to the biomass estimation (Table 1). The most common plant genera are *Polygonum, Potentilla, Kobresia, Carex, Festuca, Gentiana, Ranunculus, Aconitum, Anemone* and *Thalictrum.*

Short grass meadows are summer pasture. The short grass meadows by the Yellow river have been used as summer pastures. This type, in most cases, is the result of grazing; originally this type of meadow has been either tall grass meadow or grass meadow (moist). Bare soil coverage is usually about 20%, but in some cases it can be as high as 30%. This indicates the heavy grazing pressure. There are also other visible signs of grazing and trampling *e.g.* a high amount of yak and sheep trails, and droppings. The biomass on this type is relatively low, but that is the result of grazing that has continued throughout the whole summer (Table 1).

Grass meadow (moist) is usually used during the summer period. The fresh biomass productivity of this type is 3200 kg per hectare. The main plant genera are *Poa, Deschampsia, Stipa, Polygonum, Potentilla, Kobresia, Carex, Festuca, Gentiana, Ranunculus, Anemone* and *Thalictrum.*

Alpine short grass meadow is a typical pasture type on the hills. The biomass productivity is noticeably lower than in the tall grassland (Table 1). The slopes are dry habitats, and the productivity is naturally lower. This type is sensitive to degradation because of the topography and grazing all the year. The main plant genera are *Potentilla, Berberis, Taraxacum* and *Elymus.*

Shrub and grass meadows are usually distributed on slopes and especially on those slopes facing north. This type is used both as summer and winter pasture. The main plant genera are *Potentilla fruticosa, Spirea alpina* and *Spenceria.*

Sedge peatland is a spring and early summer pasture. The main plant genera are *Carex, Kobresia, Potentilla* and *Pedicularis***.** Wet peatland is important spring and early summer pasture. The constant depth of water is 5 cm to 30 cm. The main plant genera are *Carex, Kobresia, Pedicularis* and *Juncus.* The biomass of fresh grass is quite high in both peatland type (Table 1).

Dry peatland areas have been dried or there have been some attempts to do so to increase the productivity. Drainage has not given the desired result, rather it has led to the degradation of these areas. This type as pasture land is not valuable. If the biomass of this type is compared to sedge peatland or wet peatland which might have been the earlier type before the drying, the productivity is drastically lower.

The sand class consists of active sand dune areas, erosion areas and sand bars in the Yellow River. In some places, re-activated sand dunes have been fenced off to prevent the grazing, and in some locations there are some willows (*Salix* sp.) planted to help the re-vegetation process. The biomass productivity of this type is extremely low (Table 1).

The biomass of the fresh above ground vegetation varied between 200 and 6000 kg per hectare in the different pasture types (Table 1). The tall grass meadow is the most productive pasture type. In the five pasture types productivity was over 2000 kg per hectare. The short grass meadow low values are due to the grazing which had been practised throughout the whole summer when the August and October field measurements were made.

The accuracy of the classification

The first stage in accuracy interpretation was to calculate in ERMapper 6.3 the statistics for each class. By examining the distance between the means of the classe values it is possible to make preliminary estimations of the accuracy of the following classification. From earlier studies we have found that when the distance between classes values is lower than three, in classification it will cause considerable mixing between these two classes (Table 2).

In the final accuracy assessment, we used 134 test sites collected from the field as reference data. Also 5 sites from the RGB- combination image were chosen to present clouds, and 5 sites water (total number 144). The classification of the Landsat TM image was compared to the classification done at each test site in the field. Each site was checked with a 3 * 3 pixel grid which means 90 m x 90 m in the nature. In this way we avoided the possible position errors that are due to the GPS- accuracy and the rectification of the satellite image. Classification was estimated as accurate when a minimum of 5 out of 9 pixel matched the classification done in the field. Only by checking each site individually could a reliable estimation of accuracy be conducted. This procedure allows the use of other supporting checking methods, like the comparison of the achieved classification to the RGB- composition, field data, the digital photographs taken in the field etc.

The final accuracy of the classification was 84% (Table 3). The lowest accuracy value of 73% is in the alpine short grass meadow class. According to distance between mean values (Table 2), this was to be expected.

Table 1. Characteristics of the pasture classification classes.

Class	Herb. %	Grass %	Sedge %	Shrubs %	Plant height cm	Bare ground %	Biomass kg/hec.	Biomass plots (nr)	Grazing time
Tall grass meadow	40	30 - 40	> 10	> 10	> 30	< 5	6000	30	Winter
Shortgrass meadow	35	40	10	> 10	10 - 20	20 - 40	800	19	Summer
Grassmeadow (moist)	20 - 30	> 40	20	< 15	25	< 20	3200	19	Summer
Alpine short grass mead.	< 30	30 - 40	30 - 40	< 20	10 - 20	20 - 30	1400	8	Winter
Shrub- and grass mead.	30	30	< 5	> 30	20 - 35	20 - 35	2400	11	Winter/ summer
Sedge peatland	< 20	< 5	35 - 85	0	15 - 30	< 10	2800	17	Spring
Wet peatland	5 - 15	< 5	40 - 85	0	30 - 40	0	2800	4	Spring
Dried peatland	10	1	30	0	2 - 10	40 - 50	400	5	Spring
Sand	5	5	0	1	2 - 15	> 75	200	9	-
Cloud	-	-	-	-	-	-	-	-	-
Water	-	-	-	-	-	-	-	-	-

Table 2. The distance between the means of the classes. When the value is higher than 3, the mixture of classes diminishes.

Class	Cloud	Dried peatl.	River	Sedge peatl.	Grassmead (moist)	Lake	Sand	Alp. short grass m.	Shortgrass m.	Shrub and grass m.	Tall grass mead.	Wet peatl.
Cloud	0,0	14,0	33,1	28,6	28,1	31,7	6,7	21,4	11,5	28,2	28,9	24,0
Dried peatland	14,0	0,0	15,5	5,9	5,3	11,0	10,2	5,6	6,4	4,4	7,6	13,2
River	33,1	15,5	0,0	12,1	20,1	6,3	30,4	27,7	26,8	20,9	26,5	9,8
Sedge peat.	28,6	5,9	12,1	0,0	5,1	12,1	21,2	9,9	11,3	5,5	8,3	14,2
Grassmeadow (moist)	28,1	5,3	20,1	5,1	0,0	16,5	19,4	5,6	8,2	3,3	3,2	18,6
Lake	31,7	11,0	6,3	12,1	16,5	0,0	24,9	20,3	19,6	16,5	21,7	15,6
Sand	6,7	10,2	30,4	21,2	19,4	24,9	0,0	13,9	6,3	18,9	20,2	23,8
Alp. short grass	21,4	5,6	27,7	9,9	5,6	20,3	13,9	0,0	4,1	5,0	6,3	22,2
Shortgrass meadow	11,5	6,4	26,8	11,3	8,2	19,6	6,3	4,1	0,0	7,8	8,6	19,7
Shrub and grass m.	28,2	4,4	20,9	5,5	3,3	16,5	18,9	5,0	7,8	0,0	7,3	19,7
Tall grass meadow	28,9	7,6	26,5	8,3	3,2	21,7	20,2	6,3	8,6	7,3	0,0	21,7
Wet peatl.	24,0	13,2	9,8	14,2	18,6	15,6	23,8	22,2	19,7	19,7	21,7	0,0

Discussion

The Landsat TM 5 images proved to be a useful data source in the mapping of pastures of the Dzoge area. The spatial coverage of the Landsat TM images (185 km x 185 km) is suitable for eastern Tibet conditions The resolution of the Landsat TM 5 (30 m) allows the use of a certain number of classes so that the main vegetation types can be classified accurately. If more detailed pasture classification is desired the use of higher resolution satellite images is required. These would be for example, the IKONOS-2 (4 m resolution) and the Quickbird-2 (2.6 meter resolution) satellites, the spatial coverage of which is about 10 km x 10 km. In the study of large areas the use of these small scale images would be very expensive and the size of data would increase considerably. The limiting factor in the use of the Landsat TM is the availability of cloud free images from the region and from the growing season period.

Misclassifications were caused for several reasons. Cumuli clouds were classified correctly, but on the edge of the clouds there were some pixels classified as sand, which was not correct. This was because the pixels on the edge of a cloud had a quite similar spectral reflection as the actual sand areas. On the other hand, in sand areas there were no pixels classified as clouds. The second problem connected to the clouds was their shadows. The shadows affect the reflection of the vegetation in the image. The vegetation *e.g.* the pasture type that was in the shadow was always misclassified. In the darkest shadows, dry grasslands were classified as water. In some cases the shadows caused by the topography resulted in misclassification. There were for example, some steep North West oriented slopes that were in the shade. The misclassifications caused by the topography were, however, a minor problem in this area because of the low relief.

Altogether the pasture classes used differentiated from each other relatively clearly. The spectral similarity between the alpine short grass meadow type and the short grass meadow type caused misclassification between these two classes. If the data had been divided into even more exact vegetation types there would have been more misclassifications between the classes. A more detailed vegetation type division is not possible with the Landsat TM 5 image.

The fresh biomass values of the pasture types can be used as an indicator of grazing pressure. On the other hand, all vegetation types are different and some produce less than others, even without grazing. In those test sites where the biomass was very low, there were also signs of heavy grazing pressure. For example, a lot of yak and sheep trails, a high amount of bare soil coverage and visibly grazed vegetation. On the other hand when the biomass was very high there were few signs of grazing, and usually those test sites were fenced off to be used in winter. On some of the test sites where the biomass values were very low, the amount of unpalatable plant species (*e.g. Ligularia virgaurea*) was higher than on the low grazed test sites.

The fresh biomass values were connected to the yearly use of pasture. The field work was carried out at the end of the summer when the animals had been grazing on the pastures for three to four months. This, of course, affected the biomass values of certain pasture types. On the other hand, the winter pastures had been recovering for the whole summer, and at the time of the field work they were in their best shape.

Winter and summer pastures were well distinguishable on the satellite image in some cases. Especially in those cases where these two pasture types were separated by a fence into summer and winter pastures *e.g.* grazing intensity were detectable. In these cases the differences were clearly visible also in the field. The differentiation of summer and winter pastures *e.g.* intensity of grazing from the Landsat TM 5 image would be much more difficult without fences. The boundary between these pasture units is less drastic in nature than it is with clear boundaries like fences. To detect winter and summer pastures from the Landsat TM 5 image requires basic information about the pasture using system from the study area. Also this emphasizes the importance of field work.

In China, land degradation is a serious problem. The amount of degraded areas has been increasing. At the same time, the degradation degree has been increasing (Li *et al.*, 2001). In this study, we noticed that the condition of the pastures in the Dzoge county was not alarming although there were some sites which were noticeably overgrazed or degraded. The proportion of sand or seriously eroded areas was not significant.

The local nomadic herders who are managing the pastures are concerned about the condition of their pastures. The most important management method is pasture rotation, which gives time for the pastures to recover from grazing. The increasing use of the fencing is changing the traditional system. The local administrators in the grassland bureau also have their concerns for the pastures. The erosion areas are fenced off from grazing, the suitable number of animals is estimated in each region etc., although there is pressure to increase the number of animals due to free trade and the opening of the markets.

Table 3. Classification accuracy. User's accuracy describes the percentage of the pixels that are classified into a certain class representing the same class also in the field data. Producer's accuracy describes the amount of the field points that were also classified also into a certain class (Longley *et al.*, 2001: 326-327).

Class	Tallgrass meadow	Shortgrass meadow	Grass meadow (moist)	Alpine shortgrass meadoe	Shrub and grass meadow	Sedge peatland	Wet peatland	Dried peatland	Sand	Cloud	Water	Total	User's accuracy %
Tall grass meadow	**23**	1	2									26	88
Shortgrass meadow	1	**16**		3								20	80
Grassmeadow (moist)	1	1	**15**		1							18	83
Alpine short grass mead.		3	1	**11**								15	73
Shrub- and grass mead.		1		1	**10**							12	83
Sedge peatland					1	**16**	3					20	80
Wet peatl.							**6**					6	100
Dried peatl.							1	**4**				5	80
Sand									**13**			13	100
Cloud										**5**		5	100
Water											**5**	5	100
Total	25	22	17	15	12	16	10	4	13	5	5	**144**	
Producer's accuracy %	92	72	88	73	83	100	60	100	100	100	100		**84**

Conclusions

Remote sensing is a suitable tool for pasture inventory in the eastern Tibetan Plateau. It can be used when collecting background information about the pastures and can be further processed by the GIS. The information and results produced are usable for planning and management purposes of the grasslands on the eastern Tibetan plateau.

The Landsat TM 5 images proved to be a useful data source in the mapping of pastures of the Dzoge area. The Landsat TM image used in this study was taken in late August, at a time when the summer pastures were already heavily grazed. This was visible both in the field and in the satellite image. Winter and summer pastures were distinguishable from the image. Further information on different pasture type characteristics was established by estimating the biomass of fresh green grass.

The accuracy of the classification was 84%. Clouds and their shadows affected negatively the classification results. Because the topography of the area is quite smooth the shadows on the hill slopes did not affect the classification significantly.

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Aspects of a two-pasture – herbivore model

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Abstract: Pastures for reindeer can be divided into green pastures (mainly herbs and grasses) of summer time and more or less snow-covered lichen pastures of winter. Fall and spring pastures have a composition in-between these extremes, but for model purposes bisection is sufficient. For the animals the green-pasture season is an anabolic phase with a physiological building-up of protein reserves, while winter is a catabolic phase where food-intake is reduced and the animals to a considerable extent survive on the accumulated reserves from summer. While protein reserves are stored from summer to winter, lichen pastures are stored from year to year. Grasses and herbs not being grazed are wilting by the end of the growing season, while lichens not grazed can live for many years. This corresponds with fundamental differences in both growth pattern and resilience. The implications of the different features, and their interconnections, are not easy to survey without formal modeling. The point of departure is a simple pasture-herbivore model, well known from the literature building on a set of differential equations. A new two-pasture-herbivore model is developed. The model includes as basic elements the Klein (1968) hypothesis and that a residual lichen biomass is kept ungrazed due to snow-cover protection. Further the annual cycle is divided into four stylized seasons with herd rates of winter survival, spring calving, summer physiological growth and fall slaughtering. Isoclines are derived for summer pasture, winter pasture and herbivores. Stability properties are discussed in relation to various situations of seasonal pasture balance. Empirical examples, particularly that of changes in pasture balance and vegetation cover in Western Finnmark, Norway, are discussed. The article finds that the two-pasture model provides important features of reality, such as the stability aspects of pasture balance, which cannot be displayed by a one-pasture model. It is suggested that this type of modeling can be used as a basis for further research, *e.g.* implications of climate change.

Key words: Enrichment paradox, Finnmark, lichen pastures, overgrazing, pasture balance, vegetation changes.

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Introduction

Pastures for reindeer can broadly be divided into green pastures (mainly herbs and grasses) of summer time and more or less snow-covered lichen pastures of winter. Fall and spring pastures have a composition in-between these extremes, but for model purposes bisection is sufficient. For the animals the green-pasture season is an anabolic phase with a physiological building-up of protein reserves, while winter is a catabolic phase where food-intake is reduced and the animals to a considerable extent survive on the accumulated reserves from summer. While protein reserves are stored from summer to winter, lichen pastures are stored from year to year. Grasses and herbs not being grazed are wilting by the end of the growing season, while lichens not grazed can live for many years. This corresponds with fundamental differences in both growth pattern and resilience.

The implications of the different features, and their interconnections, are not easy to survey without formal modeling. However, it is difficult to keep formal models simple enough to handle them analytically without losing too much realism still having explanatory interest. We try to meet this challenge by a step-wise approach. First, we investigate a standard pasture herbivore model (Rosenzweig & Mac Arthur, 1963). Next we present a new two-pasture – herbivore model (Riseth, 2000). This model is built around the Klein (1968) hypothesis of winter survival and summer growth of northern ungulates. Further we bring in some empirical examples from contemporary reindeer management, focusing Western Finnmark, Northern Norway, and finally we evaluate the achievement of the two- pasture herbivore model.

One-pasture herbivore model

Models describing pasture-herbivore relations can be expressed as either differential or difference equations. The use of differential equations assumes effectively continuous processes, whereas use of difference equations means implicit that we include growth and breeding seasons etc. As no such system is truly continuous, the use of the differential option is a simplification for convenience. Factors and parameters for a simple basic model are provided in Table 1.

Table 1. Factors and parameter in a one-pasture herbivore model.

Vegetation		Herbivores	
V	Vegetation biomass	H	Herbivore biomass
G	Vegetation growth rate	r	Herbivore growth rate
		m	Herbivore mortality rate
D	Vegetation self saturation coefficient	c	Herbivore consumption rate

The two basic assumptions of the model are: Change in vegetation biomass is vegetation growth[1] minus herbivore consumption (eq. 1), and change in herbivore biomass is herbivore growth minus herbivore mortality[2] (eq. 2).

(1) $dV/dt = Vg(1-V) - c\,[(V/(V+D)]H$

(2) $dH/dt = H[rV/(V+D) - m]$

Isoclines are demarcation curves indicating constant biomass for the trophic level in question. Inserting $dV/dt = 0$ in to (1) and $dH/dt=0$ into (2) produce the vegetation isocline (3), and the herbivore isocline (4), respectively:

(3) $H=g/c\,(1-V)(V+D)$

(4) $V=mD/(r-m)$

The system of the isoclines, the equations (3,4), is depicted in Fig. 1.

The *vegetation isocline*, $dV/dt= 0$ in the figure (eq. 3), represents the herbivore biomass (in practice: herd size), which exactly keeps the vegetation biomass constant. The intersection of the V-axis, 1, is the vegetation maximum carrying capacity. At this point the vegetation produce no new growth and the herbivores thus would be extinct. At the intersection of the H-axis $H=gD/c$ for $V=0$, *i.e.* there is a positive plant biomass growth consumed by a number of herbivores. A possible interpretation is that the growth gD is sprouting from plant roots, that means V must be interpreted as the accessible over-ground level vegetation, which would be compatible for the growth pattern of perennials. Herd sizes over the isocline represent overgrazing, while herd sizes under the isocline represent undergrazing.

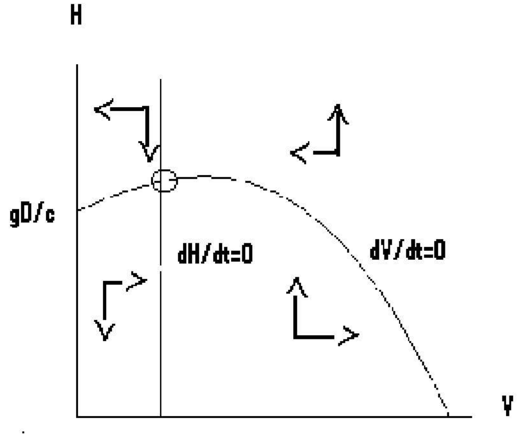

Fig. 1. The Isoclines of Vegetation and Herbivores. The arrows are vectors and indicate movement directions.

The *herbivore isocline*, $dH/dt=0$ in the figure (eq. 4), represents the vegetation biomass exactly sufficient to sustain a stable herd size. All parameters being positive numbers; V is positive when growth is greater than mortality ($r>m$). The graph of this isocline, made up of parameters all being constants, can be depicted as a vertical straight line from one value at the V-axis. Vegetation levels to the right of the herbivore isocline imply an increase in herd size, while vegetation levels to the left of the herbivore isocline lead to reduction in herd size. Depending on the magnitude of V in equation 4, the intersection between the two isoclines can be placed for any nonnegative value of V. The two isoclines create four sectors with particular movements each. The arrows represent the direction of movement for both trophic levels. The intersection of the two isoclines represents the adaptation where both plant and herbivore biomass is sustained and is marked with a circle.

The stability of our system depends of where the intersection of the isoclines is placed in relation to V_{MSY} (the maximum point of the vegetation isocline). According to Maynard Smith (1973): (1) If the $dH/dt=0$ crosses the $dV/dt=0$ curve to the left of V_{MSY}, both vegetation and herbivore will perform temporary oscillations with constant amplitude. (2) If the equilibrium is to the right of the maximum point, the system will perform dampened oscillations, and the number of both trophic levels will stabilize over time[3]. Considering the growth rates, we note that increasing g will lift the vegetation isocline, but not influence V_{MSY}. Increasing the herbivore intrinsic growth rate, r, will move the herbivore isocline over to the left and be synonymous with increased instability. Increasing the mortality, m, will on the contrary have a stabilizing effect by moving the herbivore isocline to the right. That is, increasing the herbivore net growth rate, r-m, will have a destabilizing effect on the system.

Studying the effect of varying the magnitudes of D in the herbivore isocline, low D-values[4] are consistent with animals being efficient grazers. These will have a less stabile adaptation than *inefficient grazers* (high D-values). Increasing the value of the self-saturation coefficient D in an existing system, will both shift the H-isocline to the right and also the level of V_{MSY} to the left, thereby stabilizing the system performance (*cf.* Øye, 1996). Opposite, reducing D will shift the level of V_{MSY} to the right and thereby contribute to system destabilization. This is what Rosenzweig (1971) named *the enrichment paradox*. Obviously the paradox is that increasing accessible pasture capacity means lowered stability. Adding our knowledge about herbivore growth rates, we can sum up that for an existing system in initial balance: *(1) High accessibility of pasture through a low self-saturation coeffisient D and (2) a high herbivore net growth rate (r-m),* by themselves and in combination*, have the potential of implying system destabilization*.

Discussing the real world implications of instability in models for ungulates, Caughley (1971:211-215) asserts that no cycling ungulate population has ever been recorded, neither has oscillations of increasing amplitudes been reported for herbivores of any area. Including an investigation of the well-known example of reindeer population eruption and crash at St. Matthew Island (Klein, 1968) he concludes that though limit cycles and unstable equilibria are theoretically possible, they are not a feature of ungulate population dynamics (see also Gunn *et al.,* 2003). Metzgar and Boyd (1988) do not consider stability a general feature of ungulate-forage relations and expect catastrophic vegetation instability in relative simple environments where vegetation is particularly vulnerable to herbivores. They therefore find that persistence of such systems will depend on *herbivore migration.*

Two-pasture model - basic attributes

We note that the theoretical sources of instability seem to be connected to the enrichment paradox, and that in practice herbivore migration might be a stabilizing feature. We now proceed to a two-pasture-herbivore model (Riseth, 2000) in search for somewhat more realistic assumptions. Recalling our initial remarks that continuous time and differential equations can serve as a simplification, we try to combine continuous and discrete time.

The new model is thus based on two differential equations on summer and winter pastures respectively (eq. 5 and 6), as we imagine continuous time in a long-tern perspective (between years). In addition, we connect them with a *herd equation* (eq. 9) modeling stylized seasons within the year. For the summer pasture, the basic equation of the one-pasture model (eq.1) is used[5] (eq. 5). For winter pasture, the growth term is for simplicity a logistic model[6], like the summer model. For the consumption term a residual lichen biomass, denoted R, is kept ungrazed (*cf.* Gaare & Skogland, 1980) due to snow-cover protection (eq. 6). The pasture equations of motion thus become:

(5) $dV/dt=f_{su}(V,H_{su})=g_{su}V(1-V)- c_{su}[V/(V+D)]H_{su}$

(6) $dL/dt= f_w(L, H_w) = g_L L(1-L) - c_L (L-R)H_W$

Inserting $dV/dt = 0$ and $dL/dt = 0$ produces the pasture isoclines:

(7) $H_{su} = g_{su}/c_{su} (1-V)(V+D)$

(8) $H_W = (g_L/c_L) L(1-L)/(L-R$

The winter isocline[7] (eq. 8) is depicted in Fig. 2.

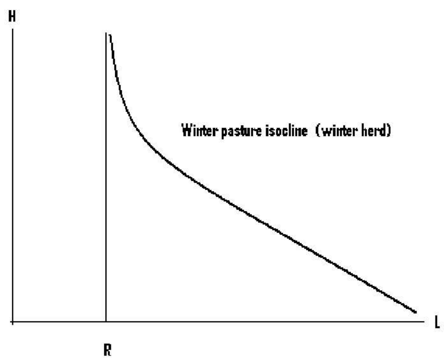

Fig. 2. Winter pasture (lichen) isocline. R= residual (not grazed) lichen biomass.

With lowered lichen biomass L the herd size just grazing the new vegetation is increasing towards a vertical asymptote[8] in R. Between 0 and R herd size is negative (not shown), *i.e.* no grazing on lichen.

We now proceed to the discrete time modeling of herd changes within each year. The annual cycle is divided into four stylized seasons with herd rates of winter survival, spring calving, summer physiological growth and fall slaughtering, *cf.* Fig. 3.

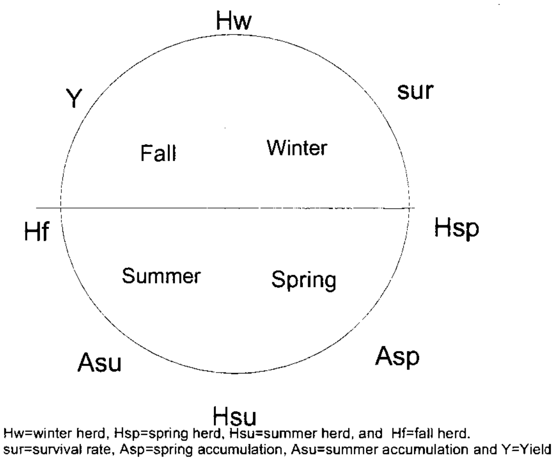

Fig. 3. An annual cycle of herd dynamics. Inspired by Virtala (1992:236).

Two of these seasons, spring and summer, are characterized by herd *increments*, while the two remaining, fall and winter, are characterized by herd *decrease*. For simplicity we thus assume but one event per season; for winter it is *survival*[9] (sur), for spring *calving* (spring accumulation-A_{Sp}), for summer *growth*[10] (summer accumulation- A_{Su}), and for fall we have *harvest* (Y). The three first of these are given by functional relationships being dependent on the relevant pasture biomass (L or V), while the last one, harvest is a *control variable*, *i.e.* an outcome of human decision. Here we introduce the policy of *long-term steady state winter herd* ($dH_w/dt=0$) and make the overall decision *every year to harvest the natural herd increment,* defining the output $Y= H_F - H_w$. We now inquire the implications of this policy. Following the circle in Fig. 3 we further define the connections between the seasons:

Spring herd: $H_{Sp}=H_W \cdot sur$
Summer herd: $H_{Su} = H_{Sp} A_{Sp} = H_W sur A_{Sp}$
Fall herd: $H_F = H_{Su} A_{Su} = H_W sur A_{Sp} A_{Su}$

Combining these definitions by the definition of output $Y= H_F - H_{wa}$, and inserting, we receive the expression:

(9a) $Y = H_W \cdot (sur A_{Sp} A_{Su} - 1)$

As this is the condition for $dH_w/dt=0$, it is also the herd-isocline, and thus the third basic equation of our two-pasture-herbivore model. The events, parameters, connections and functional relations for each of the seasons are specified in Table 2.

Winter survival is considered dependent of a mortality rate and increasing with increase in lichen biomass, fastest with small amounts towards an asymptotic level. The biologic rationale is that the effects of increased pasture access are limited when the pasture abundance is relatively high. Calving success (spring accumulation) is governed by a polynomial of degree 3, increasing slowly with low lichen biomass magnitudes, faster for medium ones, and again slower for high ones. The rationale is based on that physiological and nutritional status of the female animals is the most important factor for calving success (Lenvik, 1989). We sum up the functional relationships to winter pasture and the connections between seasonal herd, as functions of lichen biomass, in Fig. 4. The winter herd-isocline (eq. 8) is used as a basis. Winter herd is thus the herd in balance with growth on lichen pasture, spring herd the outcome of winter survival, while summer herd is the outcome of calving and the herd moving into summer pasture. The summer-winter herd connection is given in equation 9b.

Table 2. The events of the herd year connected and specified. All parameters are nonnegative <1.

SEASON	*HERD*	Event	*PARAMETER*	CONNECTIONS AND FUNCTIONAL RELATIONS
Winter	Winter herd (H_W)	Survival rate (sur)	Mortality rate (m)	$H_{Sp}= H_w(1- m/L)$
Spring	Spring herd (H_{Sp})	Spring accumulation (A_{Sp})	Natality rate (n)	$H_{Su}=H_{Sp}(1+n)(\alpha L^3+\beta L^2+\chi L+\delta)$
Summer	Summer herd (H_{Su})	Summer accumulation (A_{Su})	Growth rate (r)	$H_F= H_{Su}(1+(rV/V+D))$
Fall	Fall herd (H_F)	Harvest (Y)	Harvest rate (x)	$Y= H_w x= H_F - H_w$

(9b) $H_{Su} = f(H_W, L) = H_W \; sur \; A_{Sp} =$
$(1 - m/L)(1+n)(\alpha L^3 + \beta L^2 + \chi L + \delta)$

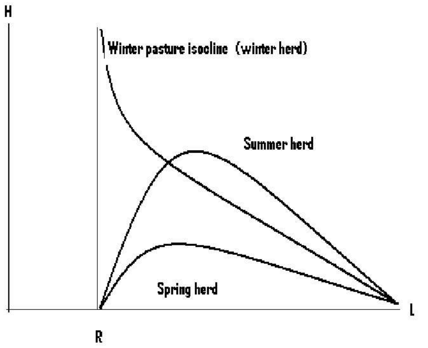

Fig. 4. Winter, spring and summer herds as functions of lichen biomass.

By inserting all the specifications of Table 2 into the herd isocline (eq. 9a), we receive the *specified herd isocline* in eq. 9 c:

$$(9c)\; Y = f(L, H_W, V) = H_W(surA_{Sp}A_{Su}-1) = [(g_L/c_L)L(1-L)/(L-R)][(1-m/L)(1+n)(\alpha L^3+\beta L^2+\chi L+\delta)(1+(rV/V+D))-1]$$

Herd output is basically herd size times total productivity, which is a composite factor of three rates depicted in Fig. 5.

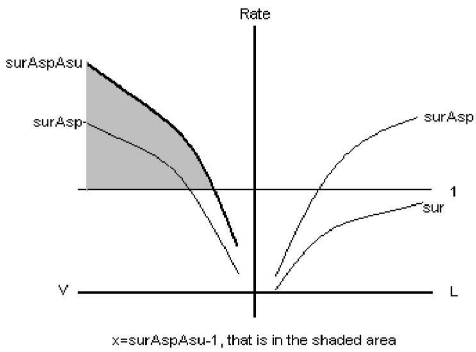

Fig. 5. Herd isocline specified as rates. RHS rates have their mirror image on LHS.

In the figure, the composite factor from survival and calving is transferred by a mirror image from winter pasture to summer pasture where summer growth is added. The shaded area represents the *equilibrium harvest rate* x. To evaluate *how changes in winter herd size affect output* we take the total derivative of the function Y= f [(L(Hw), Hw, V (Hw)], *cf.* eq. 9, and receive:

$$(10)\quad \partial Y/\partial Hw = \partial Y/\partial L \;*\; \partial L/\partial Hw + \partial Y/\partial Hw + \partial Y/\partial V \;*\; \partial V/\partial Hw$$

Total effect= (1) Indirect effect winter pasture +(2) Direct effect+ (3) Indirect effect summer pasture.

The full expression of eq. (10), as well as a more extensive discussion of the terms, is given in appendix A. The outcome of the discussion of signs, sizes and equilibria for the terms (1), (2), and (3) is given in Table 3.

Analyzing the results we note that both expressions for indirect effects (1) and (3) have maxima of their own, while the direct effect are higher, the higher are the L and V-values. Splitting up the direct effect, we note that *the two elements dependent of L have maxima for intermediate L, while the indirect effect of winter pasture have maxima for intermediate or lower L*. That is, *the effects connected to winter pastures imply a definite maximum for intermediate or lower lichen biomass.*

For summer pastures we have two detrimental effects; on the one hand summer accumulation (A_{su}) and effect of increased summer biomass ($\partial Y/\partial V$) indicate *higher output with higher summer vegetation biomass*, while on the other hand reducing herd size below the vegetation MSY-point V=(1-D)/2 will reduce output.

Even though we have not reached a definite overall equilibrium by modeling, the model provides arguments for that an equilibrium L-value is a good candidate as a second best choice of an overall equilibrium. Taking into account real world facts, as the low lichen growth rate, strengthens these. We can make the following inferences about management implications:

(1) adapt Hw to $\partial L/\partial Hw$, *sur* and A_{sp}, that is an *intermediate or lower value of L*.
(2) adapt Hs to V= (1-D)/2.
(3) If there is excess V biomass, this will influence output positively.

Table 3. Effects on output, Y, of changes in winter herd, Hw (*cf.* Appendix A).

Terms	Elements	Sign and size	Term equilibria
Indirect effect winter pasture $\partial Y/\partial L * \partial L/\partial Hw$ *(How output is influenced by changes in lichen biomass)*	$\partial Y/\partial L$ (1a)	Negative for high L. **Around zero for intermediate L-values**. Positive for small L-values.	Negative for high L Positive for low L Possible zero-values for intermediate and lower values of L=> **Possible maxima for intermediate and lower values of L**
	$\partial L/\partial Hw$ (1b)	Negative for high H and high L, 2L +H>1, including all H>1 and all L>½. **Zero for combinations of L and H, 2L+H=1.** Positive for combinations of L and H, 2L+H=1 <1, both L and H>0. *I.e.* **conditioned possible maxima for L<½**	
Direct effect $\partial Y/\partial Hw =$ $(sur*A_{sp}*A_{su}-1)$ *(How output is influenced by changes in herd size)*	Sur (2a)	Polynomial in L. Positive and decreasing when L increases from low to intermediate. **Zero for an intermediate L-value.** Negative for high L-values	Positive when product of sub-elements >1 (*cf.* Fig. 5) => **Positive for relative high values of L and H**
	A_{sp} (2b)		
	A_{su} (2c)	Positive and increasing with increasing V towards an asymptote	
Indirect effect summer pasture $\partial Y/\partial V * \partial V/\partial Hw$ *(How output is influenced by changes in green pasture biomass)*	$\partial Y/\partial V$ (3a)	Positive and increasing with increasing V towards an asymptote	**Definite maximum for V=(1-D)/2**
	$\partial V/\partial Hw$ (3b)	Positive for V<(1-D)/2 Negative for V>(1-D)/2 => Maximum for V=(1-D)/2 (*cf.* V-isocline in Fig. 1)	

Two-pasture model; deviating pasture balance situations

We have now discussed the two-pasture model in a long-term steady state situation where the natural increment is harvested from year to year. In practice we know that deviations from this are common. Following the enrichment paradox logic we can ask *how the balance between the capacities of the two seasonal pastures affects stability*. In principle we can have three different balance situations. (1) We denote the situation where both season pastures and the herd size are stable as a *situation of perfect summer and winter pasture balance* and use this situation as our standard reference situation. In deviating situations either of the seasonal pastures is in minimum; we denote them situations of (2) *summer pasture limitation* and (3) *winter pasture limitation*, respectively, defined in Table 4.

The situation of perfect pasture balance is depicted in Fig. 6. Of the right-hand-side three curves the summer herd one is the crucial, representing herd size entering summer pasture. When this herd size equals the summer vegetation isocline on the left-hand-side, the pasture capacity of each season pasture fits the herd dynamic requirements exactly. That is; the summer herd on the right-hand-side $H_{Su(Y(L)Max)}$ equals the summer herd $H_{Su(Max)}$ on the left-hand-side. This is marked by the summer herd-line in the figure. *The adaptation is stable.*

Next we consider the situations where one of the seasonal pastures is in minimum and thus is a constraint upon possible herd size. That is, adaptations *outside* one of the three isoclines.

Let us first consider the situation of summer-pasture limitation, *cf.* Fig. 7. On the left-hand side, we note that the summer-pasture isocline is lower than the entering summer herd, *i.e.* standing crop of summer vegetation will be reduced if herd size is not lowered down to a level on the summer pasture isodine.

If overgrazing of summer pastures is chosen as a policy, this implies *instability and temporary oscillations in V and herd size* (*cf.* p. 66-67). This instability is not dampened by winter pasture capacity since it is higher than summer pasture capacity. Moreover, the situation of inadequate summer pasturage may, in settings where this is possible, lead to *grazing out of season* in winter pastures, which may lead to winter pasture overgrazing much faster than normal winter grazing.

Next we consider the option of winter-pasture-limitation, depicted in Fig. 8. On the left-hand-side, winter-pasture-limitation is equivalent with excess summer-pasture capacity. Observing the summer herd-line we note that it crosses the summer-pasture isocline at two points corresponding to the vegetation biomass values, $V_{High}>V_{MSY}$ and $V_{Low}<V_{MSY}$, *i.e.* two possible adaptations[11]. Here the combined effect of winter mortality and natality through spring accumulation will dampen the oscillations also for the $V_{Low}<V_{MSY}$ option meaning that *winter pasture limitation is a balanced situation*[12].

Turning our attention to output for the deviating situations Fig. 9 compares the harvest rates of winter-pasture-limitation and summer-pasture limitation with the standard situation of perfect summer and winter pasture balance.

Using subscripts PPB for perfect (summer and winter) pasture balance, SPL for summer pasture limitation and WPL for winter pasture limitation, the figure building on Fig. 5 demonstrating that the balance harvest rates; $x_{WPL}>x_{PPB}>x_{SPL}$ for the same value of V. For the same winter herd, H_W, all three situations, this implies that $Y_{WPL}>Y_{PPB}>Y_{SPL}$, when compared for the same value of V, i.e., the relatively higher $H_{Su(Max)}$ is, compared to $H_{Su(Y(L)Max)}$, the higher becomes V, when staying on the summer pasture isocline, *and thus harvest rate and output.* Recalling our discussion on management implications (*cf.* p. 69), this is in line with WPL being the more productive adaptation. Considering output as a function of winter herd size, we have depicted various functional forms for all three pasture-balance situations in Fig. 10.

Table 4. Situations of seasonal pasture capacity relations.

	Entering summer herd	Summer pasture capacity
Perfect summer and winter pasture balance	$H_{Su(Y(L)Max)} = H_{S(Max)}$	
Summer pasture limitation	$H_{Su(Y(L)Max)} > H_{S(Max)}$	
Winter pasture limitation	$H_{Su(Y(L)Max)} < H_{S(Max)}$	

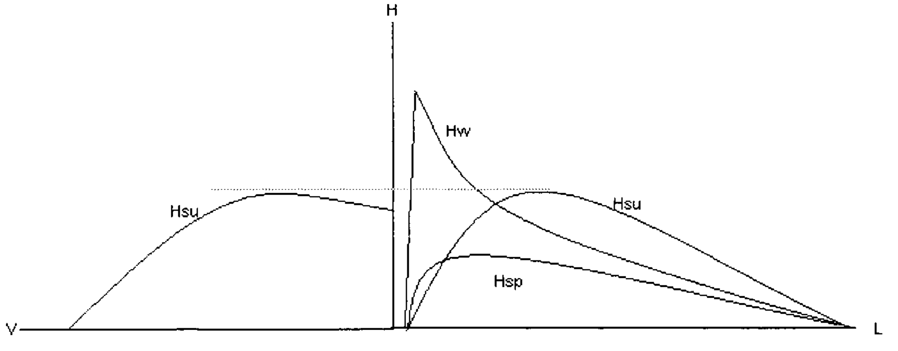

Fig. 6. The situation of perfect summer and winter pasture balance.

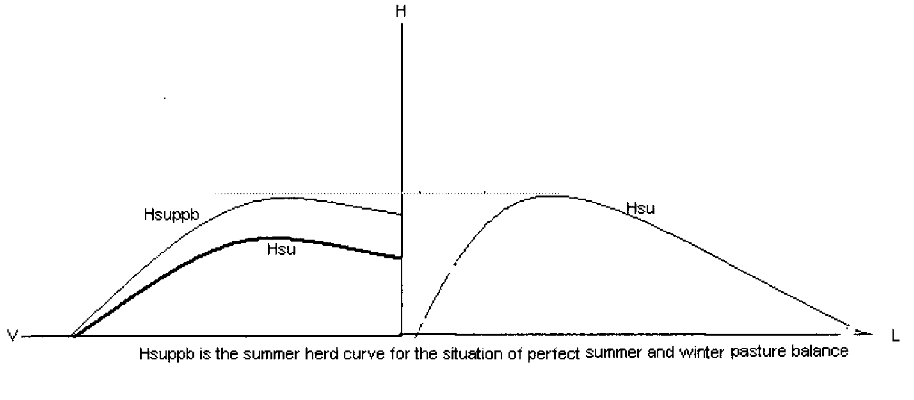

Fig. 7. The situation of summer-pasture limitation.

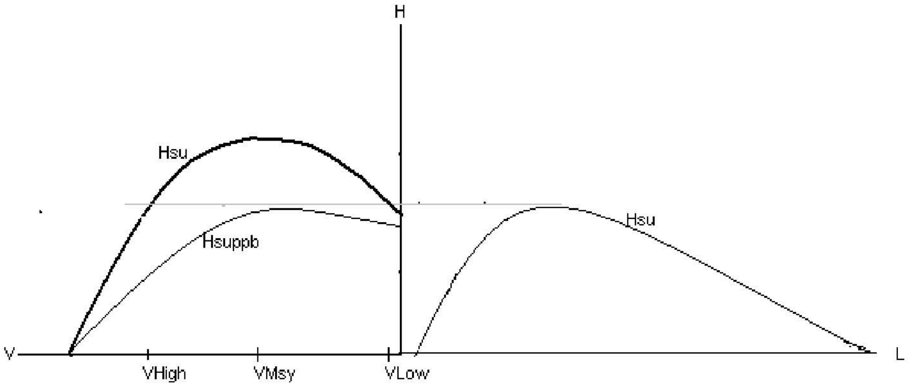

Fig. 8. The situation of winter-pasture limitation.

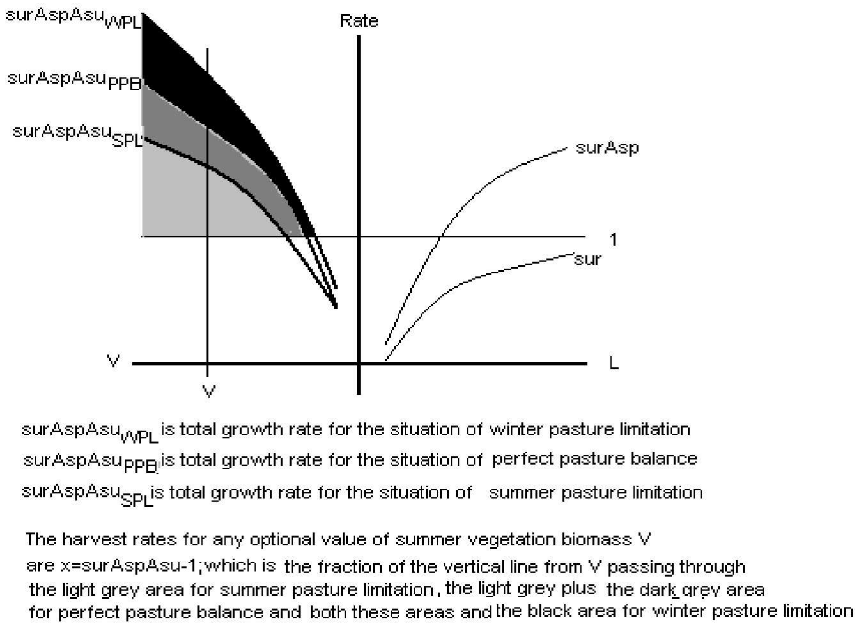

Fig. 9. Harvest rates, x, as functions of summer pasture capacity, V, for the situations of perfect (summer and winter) pasture balance (PPB), summer pasture limitation (SPL), and winter pasture limitation (WPL), when winter herd is given.

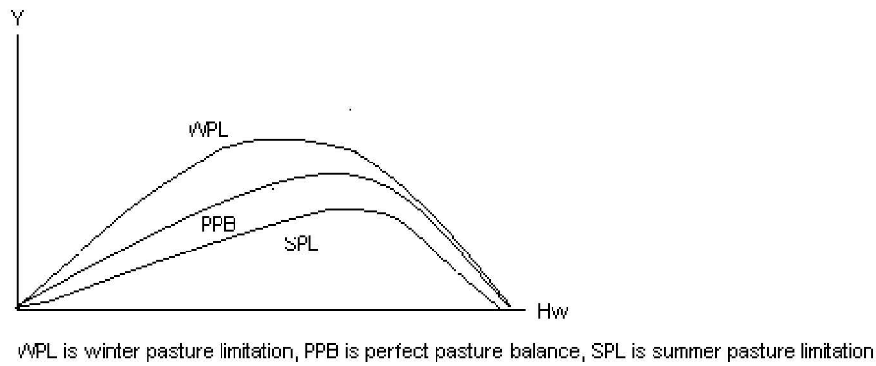

Fig. 10. Output as a function of winter herd for various pasture-balance situations.

For the situation of winter pasture limitation *the output is consistently higher than the output for the standard situation* (perfect summer and winter pasture balance). A WPL pasture area also has its output maximum at a lower herd size than the standard situation. The stronger is the winter pasture limitation, the clearer are these features. Thus a winter pasture limited area can support a *smaller* herd than the standard situation, but *each animal will be more productive*. The situation of summer-pasture limitation will, on the contrary, tend to have a lower output than the standard situation for all herd sizes. The maximum output is also found for a relatively higher herd size than the standard situation. Thus a SPL area can support a *large herd, but with low productivity per animal*.

Above we found that the situation of summer pasture limitation could promote grazing out of season and lichen pasture overgrazing to depletion. Whether this is feasible, depends on factors including landscape structure. As *landscapes without natural borders* require the most intensive herding, the tendency for grazing out of season will also be higher in such landscapes than *landscapes with natural borders*. Imagine the case of a summer pasture limited area hosting a relatively large herd with low productivity. In a landscape without natural borders between summer and winter pastures adjacent pastures could be used out of season, thus removing the limitation set by the capacity of each of the seasonal pastures. The potential adaptation of *keeping a large herd on insufficient summer pasture while compensating by using winter pastures out of season* provides a possibility of increased output in the short run, but grazing lichen pastures not protected by snow-cover drops R, and may thus leads to*resource depletion and herd reduction* in the long run.

Empirical examples

Our model suggests clear connections between possible output (productivity) and pasture balance. Let us see if we can find any such connections in contemporary reindeer management.

In Norway the highest productivity of Sami reindeer management, during a couple of decades, are found in South Sami areas, particularly in the areas of South Trøndelag/Hedmark and North Trøndelag (Riseth, 2000:171), see Fig. 11. Most of these areas are clearly winter-pasture limited (*op.cit.*:185-186). In Northern Norway the highest productivity is found in Eastern Finnmark, particularly in Varanger (see Fig. 11), which also is in lack of sufficient winter pastures. Thus we have good indications that winter-pasture limitation is stabilizing. However, the situation in the Norwegian regions Troms and Nordland show that too severe winter conditions are detrimental to productivity. These areas have most of their natural winter pastures in the Swedish inland. Due to limitations in the border crossing migration rights in the bilateral Norwegian Swedish border convention as well as encroachments and obstructions from forestry, hydro-electrical power regulations, the herders of Nordland and Troms mainly have to rely on limited coastal winter pastures and uncertain sub-oceanic areas on the Norwegian side. Thus, it seems as *if winter pasture limitation are to promote productivity, it must be moderate, in the meaning that the winter pastures, though they are limited, must be rather certain.*

Going to the deviating balance situation of summer–pasture limitation (SPL), an important point in our modeling is that lichen pastures are protected by snow-cover in winter. When reindeer stay in lichen areas in (dry) summer period trampling destroys much more lichen than grazing.

For example, two potential problem areas are Härjedalen and northern Torne Lappmark in Sweden, both poor in precipitation[13], with a high proportion of dry lichen-rich heather vegetation in the sub-alpine and alpine belt Oksanen (1992). One of these areas, Härjedalen, has recently encountered overgrazing problems, while the other has not. The reason is clear, since the erection of a reindeer convention[14] bar fence (in the 1970s), the Härjedalen Sami lost access to mountain summer pastures on the Norwegian side[15]. The northern Swedish Sami still has convention summer pastures areas in Troms, and the lichen pastures on Swedish side of the border are neither trampled nor grazed in summer.

An even more striking example is the inland mountains of Finnish Lapland, which has been exposed to summer grazing over decades with the outcome that lichens are eroded on the tops of the landscape, and also has marked vegetation changes on lower landscape levels. As much as this includes areas adjacent to the Norwegian border, the contrast to intact lichen carpets on the Norwegian Finnmarksvidda side of the border bar fence has been very sharp, and served as an illustrative example. However the situation at Finnmarksvidda is changing rather fast, and that will be our main example.

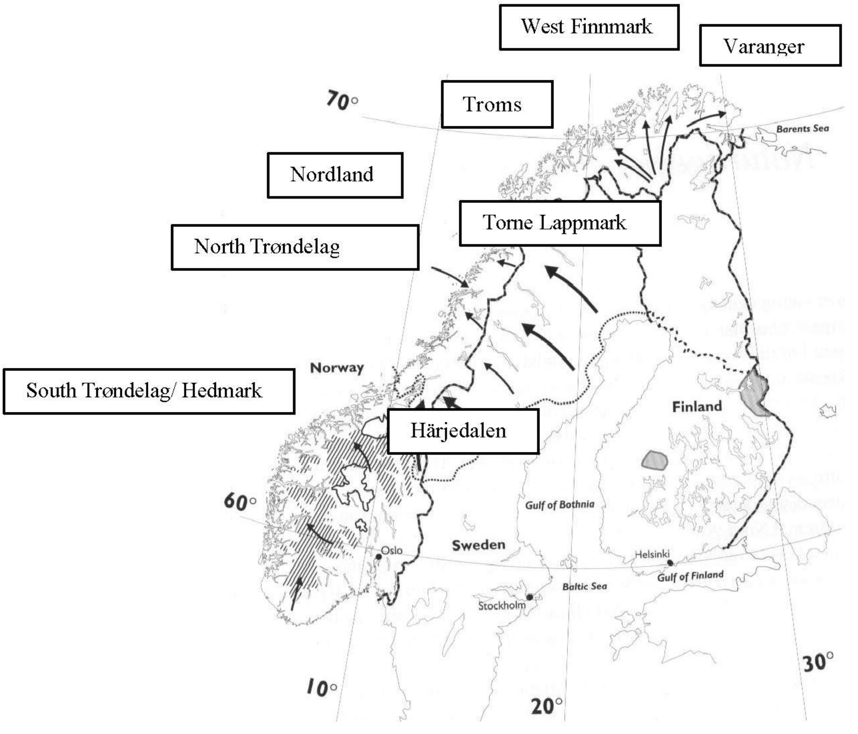

Fig. 11. Reindeer management areas of Fennoscandia. From Gaare (1997:8).

The changes of Finnmarksvidda lichen pastures are particularly interesting and well suited for study by this type of models. From the early 1970s and into the new millennium the lichen biomass at the fall and winter pastures declined dramatically. The dramatic increase in the reindeer population size during the 1980s is regarded as one of the main explanation of the problems faced today. In 1976 the reindeer population in Finnmark was estimated to 90 000 animals. In 1988 the population size had increased to 210 000. On Finnmarksvidda the vegetation types rich in lichen were reduced to half the extent compared to the situation in the beginning of the 1980s (Johansen *et al.*, 1995; Johansen & Karlsen 1998; 2000; Riseth & Vatn, 1998). Damages to the vegetation surface, visible as erosion flats or erosion ridges, are reported at several localities within the spring and fall areas (Evans 1993; Johansen *et al.*, 1996). Concerning current data on reindeer body-weights, reproduction rates, and mortality describes an even more discouraging picture of the today's herding. By comparing reindeer body-weights from early 1960s (Movinkel & Prestbakmo, 1968) with corresponding weights from the period 1998-2000 (RA-1998, 1999, 2000), a significant decrease is observed. In addition to the low body-weights, a high rate of mortality and low calving success are reported for several districts (RA-1998, 1999, 2000). The overall situation in Finnmark reindeer pastoralism presents as an archetypal example of the «tragedy of the commons» (Sara 1993; Riseth 2000; Riseth 2001). Much of a similar situation is reported both in Finland (Helle & Kojola 1993; Käyhkö & Pellikka 1994; Kumpula *et al.,* 2000) and Sweden (Bergstedt *et al.*, 1999).

We will here focus the region West Finnmark where the overgrazing is connected to an extraordinarily increase in herd size; reindeer numbers more than doubled from about 1975 to 1990. This was followed by a gradual decrease through the 1990s, reaching the level of the 1970s by 2000. Simultaneously seasonal pasture use was gradually changed. For a further study we need to know the physical organization of seasonal pastures, depicted in Fig. 12. Panel A shows that summer pastures[16] are towards NW; on islands, peninsulas and sub-coastal inlands. The winter pastures with lichen heaths are in the SE towards the Finnish boarder, while the fall and spring pastures are in-between. Panel B details the same map zoning summer pasture districts into inner and outer based on relative position.

The spatial development pattern of overgrazing is especially interesting. The herd increase is connected to changes in seasonal pasture use. Fig. 13 depicts a time series of satellite images of lichen biomass impact at Finnmarksvidda fall and winter pastures[17]. Some of the lines on the map are main roads; the road between Karasjok (East) and Kautokeino (West) indicates the border between fall and winter pastures.

We can note that an increasing grazing pressure starts in the NW, at fall pastures, and gradually spreads towards SE and into the winter pastures. Before 1980 winter pastures are not affected, in 1987 West Finnmark fall pastures are all overgrazed, and by 2000 only a minor part of the winter pastures are fully intact.

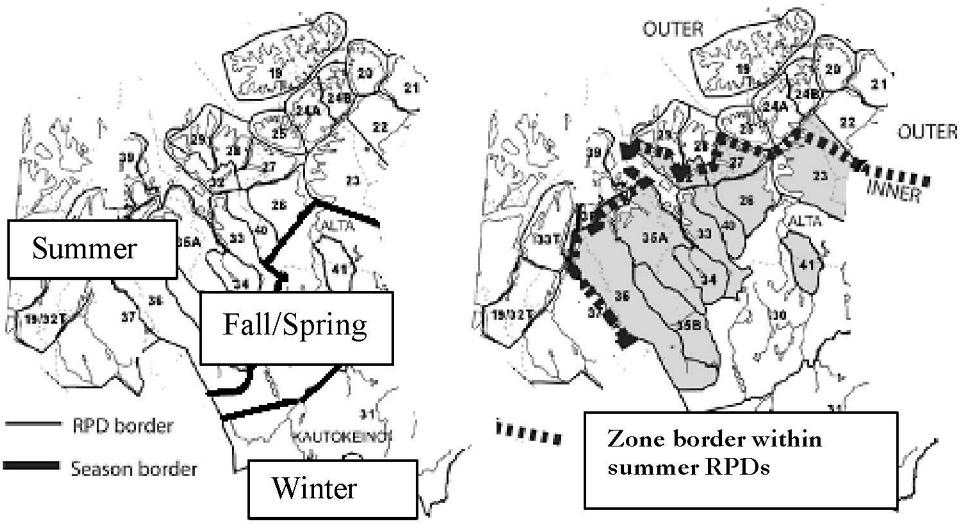

Fig. 12. Panel A. Seasonal pastures (RPDs). Panel B. Zonation of summer RPDs (Inner *vs.* outer).

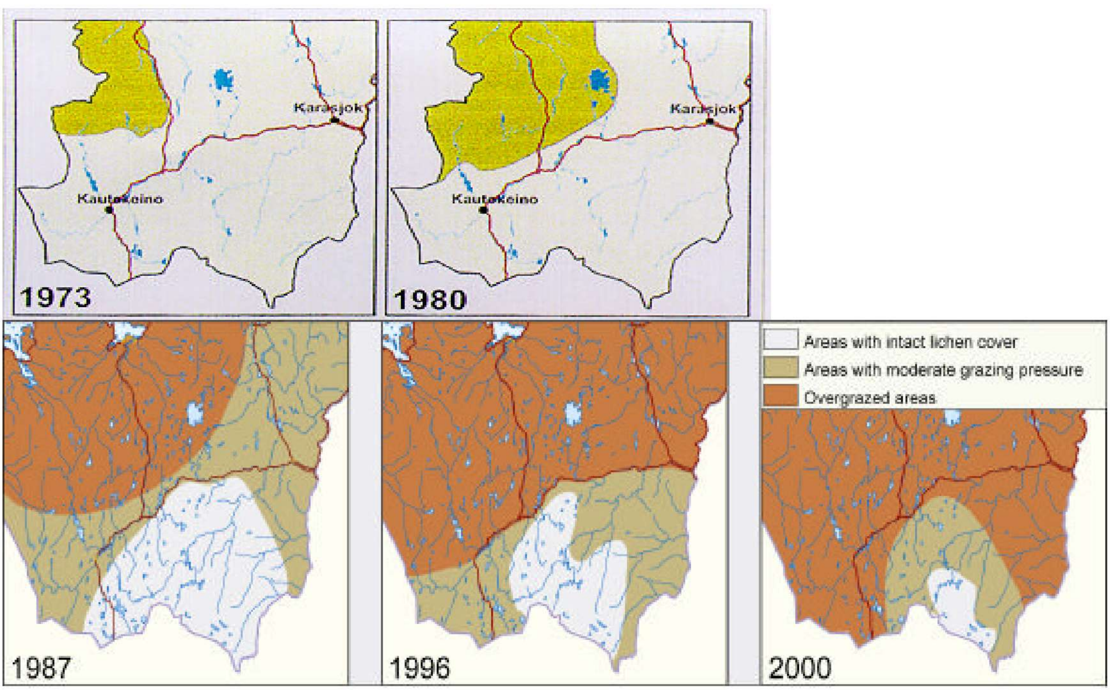

Fig. 13.Time series panel of grazing impact on lichen pastures of Finnmarksvidda 1973-2000. From Johansen, B. & S.R Karlsen (1998, 2002).

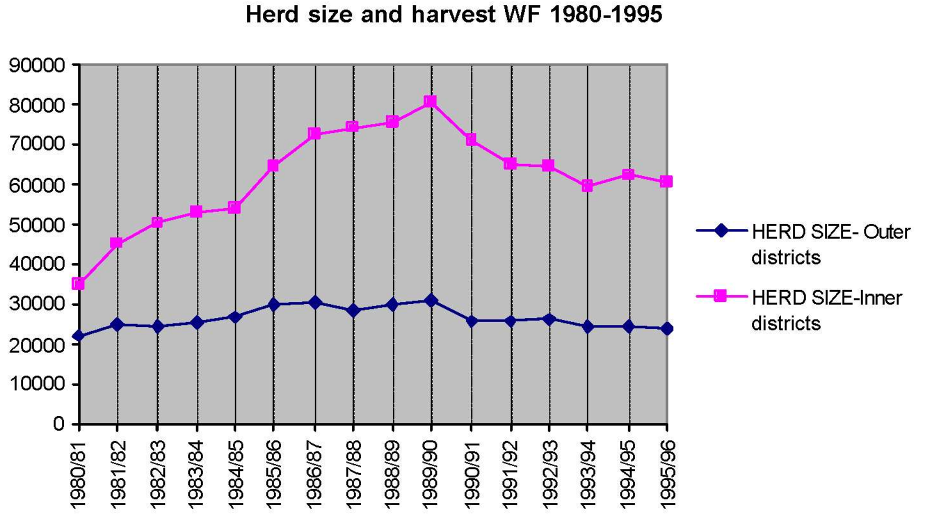

Fig. 14. Herd size development pattern for West Finnmark inner and outer districts 1980 to 1995. Own computation of statistics (Reindriftsadminstrasjonen/Reindriftsforvaltningen 1980-1998).

For the understanding of the development pattern, it is interesting to know that in the late 1960s West Finnmark as a region was evaluated as clearly summer-pasture-limited, *i.e.* with winter pastures in excess. Both registrations and accounts document that there were ample space between winter siidas up to the mid 1970s. The further development can be traced by annual administration reports. In the early 1970s some of the inner districts, *cf.* Fig. 12B, had started to graze at fall and spring during the summer. This practice expanded during the 1980s. Technological change, the introduction and spread of all-terrain vehicles (ATVs) promoted[18] this by increased potential of herd control. Reports during the 1980s assert that (1) the capacity of the summer pastures are too limited, that (2) several siidas use the spring and fall pastures far more than the given pasture time, and that (3) competition is very great at spring/fall and winter. The irregular grazing in the spring/autumn pastures particularly harms siidas belonging to outer RPDs, being behind in the queue. From the early 1980s reports express that the northern part of the winter pastures is heavily exploited causing the siidas having their pasture in these parts to move out early. From 1985 the reports express that the winter pastures now are used several times during the winter (probably still so) and that the total herd size were all to great in relation to the winter pasture capacity. From 1988 one of the western and inner districts changed their pasture use pattern by a rapid fall migration through a wide area of the winter pasture of several other siidas. The reports clearly indicate that inner districts are the more expansive, due to their strategic advantage of being nearest to the fall pastures (Riseth, 2000). This is also reflected in the herd size development patterns, *cf.* Fig. 14.

It is remarkable that the sum increase for the outer districts is less than 50% while the inner districts more than double their total number from 1980 to 1990. On average inner districts had both higher gross and net growth rates than the inner ones, *cf.* Table 5.

Table 5. Average growth rates for total populations 1980-1990.

	Gross growth rate	Harvest rate	Net growth rate
Inner RPDs	35.9	29.6	6.3
Outer RPDs	28.0	26.4	1.6
West Finnmark	33.2	28.5	4.7

Net growth rate (annual herd increment) = Gross growth rate – Harvest rate (Riseth, 2000).

These numbers and the administrative reports clearly indicate that inner district actors govern the development pattern, and that these actors pursue expanding strategies. Recalling Fig. 9 we note that the relative high growth rates for inner districts deviates from what we would expect for a SPL situation. The explanation seems to be that these districts undermine the limitation by expanding into fall and winter pasture areas belonging to others.

Paine (1994:115-130) found that these siidas (in 1962) before the technological revolution did not have the possibility to realize their full expansion potential. Our analysis is that in the 1990s they utilized the new possibilities (*cf.* Riseth 2000:124).

Data on district/siida[19] level can clarify to what extent these siidas expanded at the cost of others. Comparisons of different siidas relative share of the winter pasture area reveal that some of the inner districts have expanded their relative share of the winter pasture very clearly, *cf.* Table 6.

Table 6. West Finnmark Summer RPDs. Relative share of winter pasture areas (RPD31) 1957 -1997. For location see Fig. 12, Panel B.

RPDs	Relative share of winter pasture (in percent)			Relative change
	1957	1997	Change	Percent
23	6.4	8.2	+1.8	+28
34	7.5	11.0	+3.5	+46.7
35A/35B	11.8	12.2	+0.4	+3.4
36	2.9	8.2	+5.3	+182.8
40/41	5.8	7.2	1.4	+24.1

From Riseth (2000).

The RPDs/siidas in Table 6 are the major inner districts, which to a large extent dominate the development of West Finnmark in the period. In Fig. 15 we can see that the relative change of lichen biomass is not uniform for this group. Particularly D40 and one of the siidas in D 41 have good pastures up to the year 2000, as they are located rather far SE (*cf.* Fig. 13).

Another feature of SPL adaptation in our model is low growth per animal. Slaughter weights are good indicators of that, *cf.* Table 7.

Table 7. Average slaughter weights 1997-2000. Chosen inner RPDs and WF average.

RPD#	Calves	Males >2yrs	Males 1-2yrs	Females >2yrs	Females 1-2yrs
23	14,3	36,0	23,4	27,2	19,9
33	13,4	34,8	20,8	24,6	18,5
34	15,6	35,0	22,1	25,2	19,8
35A	14,1	44,0	22,1	27,1	18,2
36	18,3		21,6	24,0	19,0
40	13,1	35,2	21,1	23,9	17,7
41	13,2	34,8	20,8	24,6	18,5
WF average	**15,6**	**42,1**	**23,0**	**26,1**	**19,1**

From Reindriftsforvaltningen (2002).

We note that almost all numbers in Table 7 is well below the West Finnmark average. Further the major inner districts also differ to some extent in herd size development, *cf.* Fig. 16. We note that 35A/B, 23 and 40/41 have the clearest raise and fall development in the middle of the period. We still have data only for a preliminary analysis, but both their absolute size and the fact that all three groups were included in early out-of-season grazing seem to have some explanatory power. Thus, we have clear indications that the expanding strategy has been successful only so far there were more areas to expand into. During the late 1990s the expansive inner siidas, which earlier expanded in herd size and area, now face low slaughter weights and low lichen biomass at winter pastures.

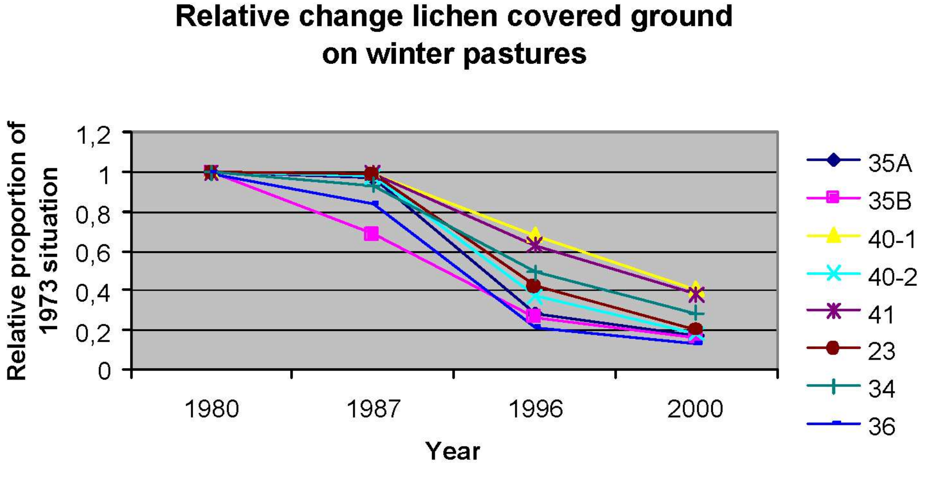

Fig. 15. Relative change in lichen covered ground on winter pastures for chosen inner RPDs/siidas. Own computations based on satellite data.

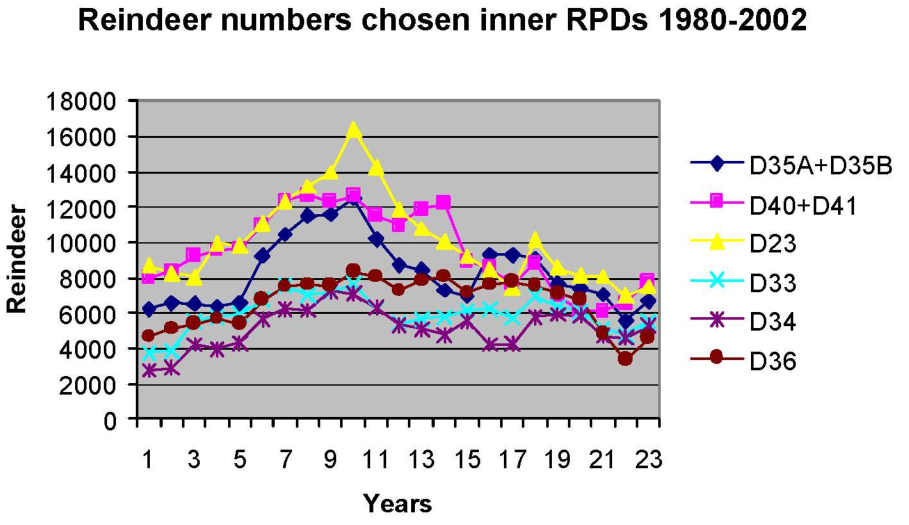

Fig. 16. Herd size development in major inner RPDs. Own computations based on Ims (2002).

Discussion

We started this contribution with discussing a standard one-pasture model, finding the enrichment paradox to be a challenge to stability in pasture-ungulate relations. Through the two-pasture model we deepened the discussion of stability finding that *pasture balance* is a major concern. In our empirical examples we have found examples suggesting both connections between winter-pasture limitation and high productivity as well as summer-pasture limitation and low productivity.

We have focused our investigation on one problem area, West Finnmark, and particularly the siidas having taking advantage of their strategic position to graze out-of-season in fall and winter pastures. We have tracked the development of expansive inner siidas using their strategic position to change their land-use. In herd size both inner siidas as a group, and three leading ones, display a typical rise and fall pattern. Our interpretation is that these siidas have expanded out of the pasture limitation both by season and original areas, but during the late 1990s they also met the limitations by eroding lichen pastures. We find that the two-pasture model has provided us with good analytic tools to understand this particular development.

The main purpose of this model is analytic, and we consider this work as start of a search for bio-economic models for reindeer management. We think that the strength of this model work is its firm basis in the *enrichment paradox* and the *Klein hypothesis*. However, the model should be refined and worked out as full and coherent mathematical model. Continued model work should *e.g.* try to find better functional forms than the logistic model for the lichen pasture growth model.

A step into dynamic modelling is taken by, *e.g.* the work of Virtala (1992). However, we think static models could achieve much still. New challenges as climate change could also be an area for bio-economic modelling. Moxnes *et al.* (2003) also have provided important simulation work of reindeer pasture adaptation. Even though simulation is interesting, we think analytic models still have a role to play, by providing increased understanding of how different factors co-work. The empirical implementation on West Finnmark problems shows that the model can be used to catch main features of the development during the latest decades.

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Footnotes

[1]In standard models K=vegetation carrying capacity is a factor. To simplify K is omitted in equation 1, assuming that K=1.

[2]Here m is considered to be constant; a more realistic model would consider mortality dependent on pasture biomass.

[3]The stability pattern is connected to the marginal growth rates of both vegetation and herbivores. Generally low marginal growth rates are stabilizing, and the change to dampened oscillations when the isocline intersection is to the right of V_{MSY} may be an outcome of that the marginal pasture growth rate is negative (Øye, 1996).

[4]We should note that in model where we defined D=0 as a possible value this would be compatible with a situation where all plant parts, roots included, were removed. Thus there would be no renewal of vegetation and the herbivores would extinct. This is possible to imagine for efficient grazers as *e.g.* goats.

[5]Except for the use of subscripts su for summer.

[6]With K=1/2 though a more realistic model would have been K=1/3 *cf.* Andreyev (1977), Kärenlampi (1973), Helle *et al.* (1990).

[7]Inspecting equation (8), we find that H_W is undefined for L=R and zero for L=0 and L=1. H_W is negative for $0<L<R$ and positive for $R<L<1$. We interpret negative herd size as no grazing on lichen.

[8]Negative part of a hyperbolic function with a vertical asymptote in R.

[9]We thus assume that all natural morality takes place in winter.

[10]The physiological growth of each animal.

[11]Recalling the stability properties of the one-pasture model; the option $V_{High}>V_{MSY}$ in that model imply dampened oscillations and stability, while $V_{Low}<V_{MSY}$ imply temporary oscillations and instability.

[12]Independent of whether the actual adaptation is to the right or to the left of V_{MSY}.

[13]The southern area poor in precipitation is situated in an extensive rain shadow created by the South Norwegian high mountains. The northern area poor in precipitation represents both a rain shadow and a transition area from the West European climate rich in precipitation to the Arctic climate poor in precipitation (Oksanen, 1992:7), my translation JÅR.

[14]The Norwegian-Swedish reindeer pasture convention of 1972.

[15]Storvigelen, Vigelfjella, Skardølsfjella, Sylene (Oksanen, 1992:10).

[16]RPD=reindeer pasture district.

[17]Also including Karasjok areas East of Kautokeino areas.

[18]Inner districts had so far been stuck with very intensive herding through summer (Paine, 1994).

[19]District and siida is partly used interchangeably as data is partly on either level.

Appendix A

$$(10)\quad \partial Y/\partial Hw = \partial Y/\partial L \;*\; \partial L/\partial Hw \;+\; \partial Y/\partial Hw \;+\; \partial Y/\partial V \;*\; \partial V/\partial Hw$$

(1a) (1b) (2) (3a) (3b)

where;

$$(10\text{-}1a)\quad \partial Y/\partial L = H_w * d(sur*A_{sp}*A_{su}-1)/dL + dH_w/dL*(sur*A_{sp}*A_{su}-1)$$

$$=(g_L/c_L)\,[L(1-L)/(L-R)][(1+n)(1+rV)/(V+D)]\,\{d[(L-m))(\alpha L^3+\beta L^2+\chi L+\delta)/L)/dL\}$$

$$+\,(g_L/c_L)\{[-L^2+2RL-R]/(L-R)^2\}\,\{[(L-m)/L](1+n)(\alpha L^3+\beta L^2+\chi L+\delta)[1+rV/(V+D)]-1\}$$

$$=[g_L/c_L(L-R)]\,\{[(1+n)(1+rV)/(V+D)][3\alpha L^4-2m\alpha L^3+(\chi-m\beta)L^2+m\beta][L(1-L)]$$

$$+\{[-L^2+2RL-R]/(L-R)]\{[(L-m)/L](1+n)(\alpha L^3+\beta L^2+\chi L+\delta)[1+rV/(V+D)]-1\}\}$$

$$(10\text{-}1b)\quad \partial L/\partial Hw = (c_L/g_L)(L-R)/(1-2L-H_W)$$

$$(10\text{-}2)\quad \partial Y/\partial Hw = (1-m/L)(1+n)(\alpha L^3+\beta L^2+\chi L+\delta)(1+(rV/V+D))-1$$

$$(10\text{-}3a)\quad \partial Y/\partial V = [g_L L(1-L)/c_L(L-R)]\{[(L-m)/L](1+n)\,(\alpha L^3+\beta L^2+\chi L+\delta)r\; d[V/(V+D)]/dV$$

$$= \{[g_L L(1-L)/c_L(L-R)]\{[(L-m)/L](1+n)\,(\alpha L^3+\beta L^2+\chi L+\delta)\}\; rD/(V+D)^2$$

$$(10\text{-}3b)\quad \partial V/\partial Hw = 1/(1-2V-D)$$

Equation	**V**	*0*		*(1-D)/2*	*1*
	L	*0*	R		*1*
10-1a	$g_L/c_L(L-R)$		+++++++++++++	++++++++++++	++++++ 0
	(1+n)(1+rV)/(V+D)	++++	+++++++++++++	++++++++++++	++++++++
	Polynomial in L		+++++++++++++	???? 0 ????	------------------
	L(1-L)		+++++++++++++	++++++++++++	++++++++
	Term 1		+++++++++++++	??? 0 ???----	------------------
	$-L^2$+2RL-R]/(L-R)		-------------------------	------------------	-------------------
	$sur*A_{sp}*A_{su}-1$		------------0 +++++	+++++++++++++	+++++++++
	Term 2		**+++++++0--------**	**--------------------**	**--------------------**
	1a(Term1+ Term 2)		**++++++++ ?? ? ? ?**	**?? ? ? ??? ? ?----**	**--------------------**
10-1b	$(c_L/g_L)(L-R)$		++++++++++++++	+++++++++++++	+++++++++
	$1-2L-H_W$ [1)]		+/-+/-+/-+/-+?????	-------------------	-------------------
	1b		+/-+/-+/-+/-+?????	**------------------**	**-------------------**
	Indireff. WP		**+/-+/-+/-+/-+?????**	**?????? ? +++**	**+++++++++**
10-2	$(sur*A_{sp}*A_{su}-1)$ by **L**		-------------0+++++++	+++++++++++++	+++++++++
	$(sur*A_{sp}*A_{su}-1)$ by **V**	+++++	++++++++++++++	++++++++++++	+++++++++
	Direct effect		---------------0++++++	+++++++++++++	+++++++++
10-3a	Const* $rD/(V+D)^2$	+++++	++++++++++++++	+++++++++++++	+++++++++
10-3b	1/(1-2V-D)	+++++	++++++++++++++	0 ----------------.	-------------------
	Indir effect SP	**+++++**	**++++++++++++++**	**0 ----------------.**	**-------------------**

Table note

1) Sign for low values of L will depend on the relative size between L and H. Positive for combinations of low L and H –values, *i.e.* 2L+H<1. Positive for L<½ given that H is not to large in relation to L. For L<½, H<1, L-->0 when H -->1. Negative if H>1 , L>½ or combinations of L and H =>2L+H>1.

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Impacts of reindeer grazing on soil properties on Finnmarksvidda, northern Norway

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Abstract: Numerous investigations have documented changes in vegetation due to reindeer grazing in Finnmark County, Northern Norway. However, rather few studies have focused on impacts of reindeer grazing on soil properties. The aim of this investigation was to identify possible changes in physical and chemical soil properties due to reindeer grazing. Furthermore, root distribution was detected. At four different locations on Finnmarksvidda three sample sites each were selected subjectively according to lichen and plant cover: A) ample, B) reduced, and C) poor lichen and plant cover. It was supposed that differences in lichen and plant cover were due to differences in reindeer grazing intensity. Results showed that the organic layer beneath ample lichen cover had an about 20% higher CEC and a 30–50% higher concentration of plant available Ca and Mg, and total Mg compared to those beneath reduced ones. At sites with poor lichen and plant cover, an organic layer was mostly missing. The exposed mineral Eh-horizons at these sites had a significant ($P \leq 0.05$) higher organic C content, higher CEC, concentrations of total P, Ca and K, and plant available K, when compared to E-horizons beneath better lichen covers. Rooting depth and amounts of plant available water in the rooting zone were lower at sites with reduced and poor lichen cover. A relation was found between soil organic C and CEC for all soil samples, indicating that soil organic matter is an essential key factor for soil fertility at the investigate sites on Finnmarksvidda. Assuming that differences in lichen and plant cover are related to differences in grazing intensity, results indicate that overgrazing by reindeers can cause a significant degradation of the organic layer, followed by significant losses of essential plant nutrients, a reduction in plant available water and consequently soil fertility.

Key words: CEC, nutrients, organic matter, podzol, reindeer pasture, soil degradation.

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Introduction

Overgrazing is the world's furthermost reason for soil degradation (Oldeman *et al.*, 1991). Also on Finnmarksvidda there is evidence that soil degradation takes place. Evans (1996) found that the organic horizons on less grazed sites were significantly thicker compared to more grazed ones at some sites, and that at some locations the organic horizon was "stripped off" the beneath mineral material. Trampling and grazing of lichens and plants by reindeer are today major factors controlling vegetation cover and composition all over the northern Fennoscandia (Väre *et al.*, 1995; Stark *et al.*, 2000; Kumpula, 2001). During the last three decades the investigation on the effects of reindeers on lichen dominated winter pastures has received special attention (*e.g.* Johansen & Karlsen, 2000). This is due to the importance of lichens as fodder for the survival of reindeers during winter. The condition of lichen ranges still form one of the most important economic bottlenecks for semi-domesticated reindeer management in northern Europe (*e.g.* Kumpula, 2001).

The county of Finnmark, North Norway, manages by tradition, the greatest number of reindeer in Norway. From 1976 to 1988 the reindeer population size in Finnmark County increased from approximately 86 000 to 191 000 animals. Since then the number of animals decreased to about 144 000 animals in 1997

(Johansen *et al.*, 1995; Ims, 1998) and less than 110 000 in 2001 (Hætta, 2002). Causes for these considerably decreases in reindeer population during the last decade are multifaceted, and combinations of historical, social, cultural, political, economical and natural reasons are discussed (*e.g.* Haugerud, 1999).

One commonly discussed cause is the unbalance between numbers of reindeer in relation to steady decreasing pasture resources. Evidence for reindeer grazing is widespread throughout Finnmark: from the almost ubiquitous presence of dung to the disappearance of lichens by trampling in summer grazings and by overgrazing in winter grazings (*e.g.* Johansen *et al.*, 1995; Johansen & Karlsen, 1998); to the present of bare soil in many localities (Evans, 1996). Thus, there is widespread evidence for overgrazing by reindeers throughout Finnmark County.

Serious changes in soil structure and nutritional composition have been reported at locations with heavy trampling, as for example along reindeer fences (Evans, 1996; Olofsson *et al.*, 2001). It has been general questioned, whether plants of the original vegetation still possess the ability to grow at these locations (Johansen & Karlsen, 1996). However, little is known about the impacts of reindeer grazing on soil properties of lichen dominated winter pastures.

The aim of this investigation was to document changes in physical and chemical soil properties due to reindeer winter grazing.

Material and methods

Selection of sample sites

The investigation was performed between the two sami villages of Kautokeino and Karasjok on the continental part of Finnmarksvida. The climate is characterized by a mean annual air temperature of -3.1 °C and an annual precipitation of 366 mm (Siččajavri; DNMI, 1999). Johansen & Karlsen (1996) characterized this area according to lichen cover as moderately grazed to overgrazed. However, remaining islands with apparently ample lichen cover are found solitarily. The following locations were chosen: 1) Suosijavrre I (69° 22.235'N, 24° 4.921'Ø); 2) Suosijavrre II (69° 21.849'N, 24° 23.080'E); 3) Lappoluobbal (69° 12.579' N, 23° 45.021' E); and 4) Bieddjučårro (69° 13.099'N, 23° 46.713'E). At each location 3 sample sites (only two found at Lappoluobbal) were selected due to a subjective evaluation of the lichen and plant cover in accordance with the classification of Johansen & Karlsen (1996): A) ample, B) reduced, and C) poor lichen and vegetation cover. The sampling areas chosen were to be topographically and edaphically uniform, allowing us to assume that the vegetational differences between the sample sites are caused by grazing and not by environmental variation. Thus, to increase comparability between soil profiles all sample sites were established at locations with no or little inclination (0-2°) and a continuously morainic till as basic substrate. The morainic till were deposited by the glaciers of the Pleistocene glaciations and covers most of Finnmarksvidda (Olsen *et al.*, 1996). Vegetation types chosen were lichen rich mountain birch forest (Suosijavrre I, Lappoluobbal and Bieddjučårro) and lichen rich dwarf shrub tundra (Suosijavrre II), which by area and usage represents important habitats for reindeer husbandry.

Soil description, sampling and analysis

At each sample site soil profiles with an approximately dimension of 100 cm x 100 cm x 80 cm were carefully excavated and thoroughly described by horizons according to FAO (1990) during the first weeks of September 1999 and 2000. Size, amount, orientation and distribution of roots were described in accordance to Hodgson (1976). The rooting zone was measured as the thickness of the O-horizon plus the depth of the mineral soil with root development. Due to the very stony composition of the morainic substrate, soil samples were taken from one open pit per sample site only. For chemical analysis soil samples were collected into polyethylene bags according to horizons and stored at approximately +5 °C until further treatments at the Chemical Analysis Laboratory of the Holt Research Centre. Prior to chemical and textural analysis, all samples were dried at 105 °C and passed through a 2 mm sieve to remove stones and large roots. Soil samples were analyzed for the following parameters: Particle-size distribution (Elonen, 1971), pore-size distribution (Richards, 1947; Richards, 1948), particle density (De Boodt *et al.*, 1967), pH_{H2O} (1:2,5 soil water suspension), organic carbon (Leco IG 212 carbon system), Kjeldahl-N (Bremner, 1960), base saturation (BS) and potential cation exchange capacity (CEC_{pot}) (Ogner *et al.*, 1975; Ogner *et al.*, 1977), plant available Ca, Mg, K and P (Egnér *et al.*, 1960). Analysis of filtered solutions were performed using a Perkin-Elmer Optima 3300 DV. Plant available water was calculated on basis of as the difference between field capacity (100kPa) and permanent wilting point (1500kPa).

Statistical analysis

The number of soil samples in this investigation was not sufficient to check for normality in the data. However, in a similar study with fully comparable soil data, normality tests showed, that the investigated soil chemical parameters are normally distributed in general. Thus, analysis of variance was performed on all data using the GLM procedure of SAS (version 6.12). Chemical properties of the different soil horizons with different lichen cover were compared using the different locations as replicates. The individual means were compared using the Student-Newman-Keuls test. Significance was assigned to a test if $P \leq 0.05$.

Results

Soils were shallow podzols, stony with coarse-textured gritty matrix and a generally low clay fraction (Table 1). The soil texture was rather uniform, and all samples were loamy sands or sandy loams boardering to the loamy sand texture class. Soil densities were between 1.4 and 1.7 g/cm^3, the soil porosity between 40 and 50%, and air-filled porosity between 16 and 32% (data not shown) and there were rather little differences between sites. The pH in the soil profiles increased with increasing soil depth from about 4.0 in the organic layer to approximately 6.0 in the mineral C-horizon (Table 1).

The organic layer was generally thickest where lichen cover had the greatest thickness. Humus beneath ample lichen cover had a significant higher content of organic C and a higher CEC compared to humus beneath moderate lichen cover. There was a high correlation ($r_c = 0.99$) between organic C and CEC (Fig. 1). Furthermore, humus beneath ample lichen cover had higher concentrations of plant available Ca and Mg and total Mg (Fig. 2a). Contents of Kjeldahl-N in the O-horizons varied between 0.86-1.48%, and were thus about 10-fold of those detected in the Eh-horizons (on weight basis). N concentrations in the B-horizons were in general below the detection limit of 0.05%.

No or only rather thin partial fragments of an earlier humus layer were found at sites with strongly reduced lichen cover. The accumulations of coarse mineral soil particles as coarse sand and gravel on the surface at these sites indicate that wind erosion has taken place to some extent. However, growth of pioneer lichens (*e.g. Lecidea* spp.) and mosses (*e.g. Polytrichum* spp.) had partly consolidated some of the exposed mineral soil. Characteristic for these sites were the occurrence of an Eh-horizon with a significant higher organic C content (3%) than E-horizons (0.4%) beneath better lichen covers. Furthermore, Eh horizons contained higher concentrations of total P, Ca and K, plant available K (Figs. 2a, 2b), and a significant higher CEC. However, base saturations were generally below 5% (Table 1).

In B- and C-horizons no differences in physical and chemical soil properties between sites with different lichen cover were detected

Growth of plant roots was concentrated in or directly below the O-layer with a mainly horizontal distribution. A more shallow root development and lower amounts of plant available water were found at sites beneath reduced and poor lichen cover (Fig. 3). Vascular plants like *e.g. Empetrum nigrum* or *Vaccinium vitis-idaéa* growing at sites with poor lichen cover had a somehow stunted growth, and some chlorosis were observed.

Discussion

Due to no significant differences in chemical soil properties of C- and B- horizons, it was concluded that all investigated soils had developed from rather similar morainic till. The degree of podzolization, concerning the thickness of the E and B-horizons and the chemical properties, indicates further that soil genesis has taken place under rather similar conditions at all locations. If present differences in lichen and vegetation cover had existed for a longer period, more profound differences *e.g.* in pH or in the thickness of the characteristic podzolic-horizons would be expected. The general similarity of all soil profiles indicate that differences in vegetation, and thus also the variability in soil characteristics of the uppermost soil horizons, are of rather recent character. Thus, based on the results about changes in lichens cover on Finnmarksvidda (Johansen & Karlsen, 1998) we assume that the most profound differences in soil properties between the investigated sites have occurred during the last 30 years.

Table 1. Selected soil properties for representative pedons of the four study sites. O = organic, E = eluvial, B = illuvial horizon.

Locations and horizons	Depth of horizon (cm)	Color (moist)	pH (H_2O)	Coarse % >2 mm	Particle size % sand 2-0.063 mm	silt 0.063-0.002 mm	clay < 0.002 mm	base saturation %
Suosijavrre I "ample"								
O	9-0	5YR 2/2	4.1					22.0
E	0-12	7.5YR 3/2	4.7	15	77.0	21.4	1.7	3.3
Bs	12-35	7.5YR 2/2	5.1	34	78.4	20.3	1.3	2.7
Bs-C	35-41	7.5YR 3/3	5.3	25	68.4	29.6	2.0	2.7
C	>41	7.5Y 5/2	5.5	30	70.3	26.9	2.8	2.9
Suosijavrre I "reduced"								
O	5-0	7.5YR 1/1	4.1					14.1
E	0-4	5Y 7/4	4.7	8	85.2	13.3	1.5	4.1
Bs	4-33	7.5YR 2/2	5.9	23	78.1	20.2	1.7	2.0
Bs-C	33-41	10YR 5/2	5.6	15	72.8	25.9	1.3	2.6
C	>41	7.5Y 5/2	5.7	19	45.3	47.7	7.0	5.1
Suosijavrre I "poor"								
Eh-Bs	0-8	2.5Y 2/1	5.0	25	79.8	18.3	1.8	7.1
Bs	8-40	7.5Y 4/2	5.5	14	69.1	29.1	1.7	4.0
C	>40	5Y 5/1	6.0	26	64.5	31.1	4.5	6.9
Suosijavrre II "ample"								
O	1-0	10YR 2/2	3.8					12.6
E	0-4	10YR 6/2	4.4	7.0	73.6	24.9	1.4	3.9
Bs	4-21	10YR 4/6	5.4	24.0	72.3	26.1	1.6	2.4
Bs-C	21-40	2,5 Y5/3	5.2	29.0	70.4	28.1	1.5	2.8
Suosijavrre II "reduced"								
O	2-0	10YR 2/1	4.1					9.4
E	0-10	10YR 6/2	4.6	7.0	76.5	21.8	1.6	2.5
Bs	10-21	7,5YR 3/4	5.2	19.0	74.5	24.5	1.1	1.0
Bs-C	21-40	2,5Y 5/3	5.2	27.0	71.1	27.9	1.1	2.0
Suosijavrre II "poor"								
Eh-Bs	0-3	7,5YR 4/3	5.1	23.0	69.6	28.3	2.1	1.3
Bs	3-21	7,5YR 3/4	5.0	26.0	67.8	29.2	3.1	1.1
B-C	21-40	2,5Y 5/4	5.1	21.0	69.1	28.5	2.5	2.7
Lappoluobbal. "ample"								
O	1-0	10YR 2/1	4.0					12.0
E	0-3	10YR 5/1	4.5	10	76.6	21.6	1.9	4.4
Bs	3-21	10YR 4/4	5.1	14	72.3	24.4	3.3	2.5
Bs-C	21-30	2.5Y 4/3	5.3	19	54.6	42.9	2.6	3.6
C*	>30	7.5YR 2/1	5.8	28	68.6	29.1	2.4	7.6

Table 1
(Continued)

Lappoluobbal. "reduced"								
O	1-0	10YR 2/1	4.0					8.6
E	1-5	2,5 Y5/2	4.7	24	75.7	23.1	1.3	3.6
Bs	10-15	10YR 4/4	5.2	30	72.3	25.5	2.2	2.5
BsC	28-32	2,5Y 4/4	5.3	39	67.9	29.1	3.0	7.2
C*	>32	7.5YR 2/1	5.8	28	68.6	29.1	2.4	7.6
Biėddjučårro "ample"								
O	5-0	7.5YR 2/1	3.9					15.0
E	0-5	2.5Y 6/2	4.8	2	64.5	34.0	1.5	3.4
Bs	5-30	10YR 4/6	5.5	23	68.4	29.3	2.3	2.4
C	>30	7.5Y 5/2	6.0	12	67.9	29.7	2.3	6.3
Biėddjučårro "reduced"								
O	2-0	10YR 2/2	4.2					11.2
E	0-3	10YR 6/1	4.9	16	73.6	24.6	1.7	6.5
Bs	3-29	10YR 4/4	5.4	17	72.9	24.7	2.5	1.8
C	>29	7.5Y 6/2	5.8	36	74.8	22.9	2.3	6.0
Biėddjučårro "poor"								
Eh	0-2	10YR 3/3	5.2	10	58.7	38.3	3.0	4.5
Bs	2-30	10YR 3/4	5.5	8	63.5	34.2	2.3	1.7
C	>30	10Y 5/1	6.0	18	71.4	26.7	2.0	6.5

*Results from analysis of one combined sample of the C-horizons at *Lappoluobbal.*

Levels of plant available Ca, Mg, K and P in the O-layer beneath ample lichen cover corresponded well with results reported from mountain birch forests in Kevo and Kilpisjärvi (Wielgolaski, 2001). Differences in soil chemistry between sites with different lichen covers were limited to the O- and E-horizons, thus generally the uppermost 10 cm of soil profiles. The approximately 20% lower organic C content, the about 27% reduction in CEC, and the between 30 to 50% reduction in total and plant available Ca and Mg at sites with moderate lichen cover indicate, that considerable qualitative changes of the humus has taken place. A reduction in plant available Ca and Mg in the organic layer of about 50% at sites with reduced lichen cover, is of a similar magnitude as reported for a North Finnish pine forest at heavily grazed sites (Väre *et al.*, 1996). In contrast, no significant decrease of either total P or K could be detected in this investigation.

Despite the distinct differences between chemical soil properties of the organic layer beneath ample and reduced lichen cover, there were no differences in the mineral E-horizon. However, significant differences in chemical soil properties were found between the E- and Eh-horizons. The organic C contents in mineral E-horizons at sites with poor lichen cover were about 8-fold increased compared to sites with better lichen cover. Indications for the existence of a previous superficial O-layer at sites with poor lichen cover suggest, that the significant increase in soil carbon contents is a result of the incorporation of previous O-layer fractions with the underlying E-horizon due to grazing and trampling by reindeers. Differences in soil organic matter content are hold responsible for the detected differences in CEC and nutritious status between the Eh-and E-horizons. However, CEC of the mineral Eh-horizon was, on weight basis, less than 10% compared to that of the O-layers. Furthermore, base saturation of Eh-horizons was in average 4% (Table 1), about 3 to 4 times less than in the O-layer. Poor root development and stunted vascular plant growth at heavy degraded sites indicate that losses of lichen cover and O-layer effect growing conditions negatively.

The decreasing thickness of the organic horizon with supposed increasing grazing pressure until its final loss, as also reported by Evans (1996), indicate considerable quantitative losses of soil organic matter. A high correlation (r = 0.99) between the organic C content and CEC (Fig. 1) emphasize that the organic matter, in particular due to the rather low clay content (Table 1) of the morainic till, possesses a key function for soil fertility.

Consequently, any loss of organic matter would decrease soil fertility. There are no indications that the degradation of the superficial O-horizon has enhanced the nutritious status of mineral soils below, except for the E-horizons. Detected changes in C and nutritious status of Eh-horizons are significant, but too small to compensate losses from O-horizons. Therefore, it is assumed that a considerable amount of organic matter and nutrients were lost from sites with reduced and poor lichen cover.

Losses of organic matter and nutrients from sites with disturbed lichen cover could be partly due to erosion. Results from Fahnestock *et al.* (2000) indicate that the redistribution of litter by wind and snow during winter is an important mechanism of nutrient transfer across the arctic landscape. At sites with continuous vegetation cover redistribution of litter may be limited to above ground plant debris. However, once vegetation cover is disrupted, either by grazing, trampling or digging, also soil organic matter may get exposed to erosional forces, like *e.g.* deflation processes (Thannheiser, 1977). Evans (1996) reports that many of the descriptions of erosion in northern Scandinavia refers to the importance of wind erosion. Incidences of erosion due to reindeer grazing has been noted previously in Finnmark (Lyftingsmo, 1965; Väre *et al.*, 1995; Johansen & Karlsen, 1998).

The declining amounts of actual plant available water in the rooting zone with reduced vegetation and humus cover indicates (Fig. 3), that reindeer grazing also has a significant impact on soil water budget. In general, a well developed lichen surface acts as an effective mulch and elevates the soil moisture status throughout the summer period by preventing evaporation (Larson & Kershaw, 1976; Kershaw, 1977; Kershaw, 1985). In subarctic well-drained terrain acute summer droughts are quite common which are assumed to be lethal to fine roots of trees and dwarf shrubs, that develop close to the soil surface (Crittenden, 2000). The observed reduction in root development (Fig. 3) may therefore to some extent be due to decreasing amounts of plant available water during the growing season. Thus, in addition to decreasing soil mineral nutrients, periodic drought may also be a significant factor suppressing vascular plant vigour.

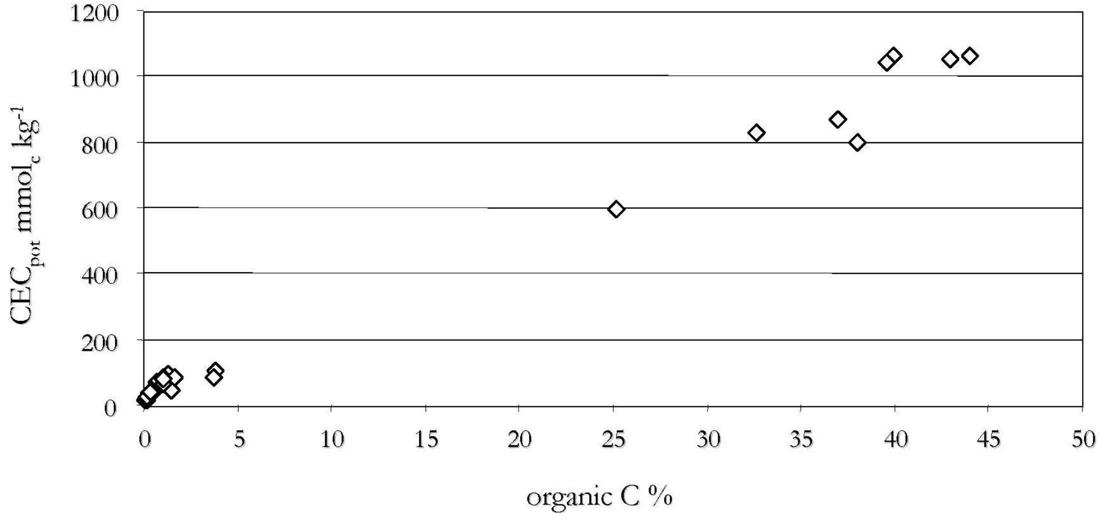

Fig. 1. Correlation between organic carbon (%) and CEC_{pot} ($mmol_c$ kg^{-1}) in soil material from all soil horizons and sample sites studied on Finnmarksvidda.

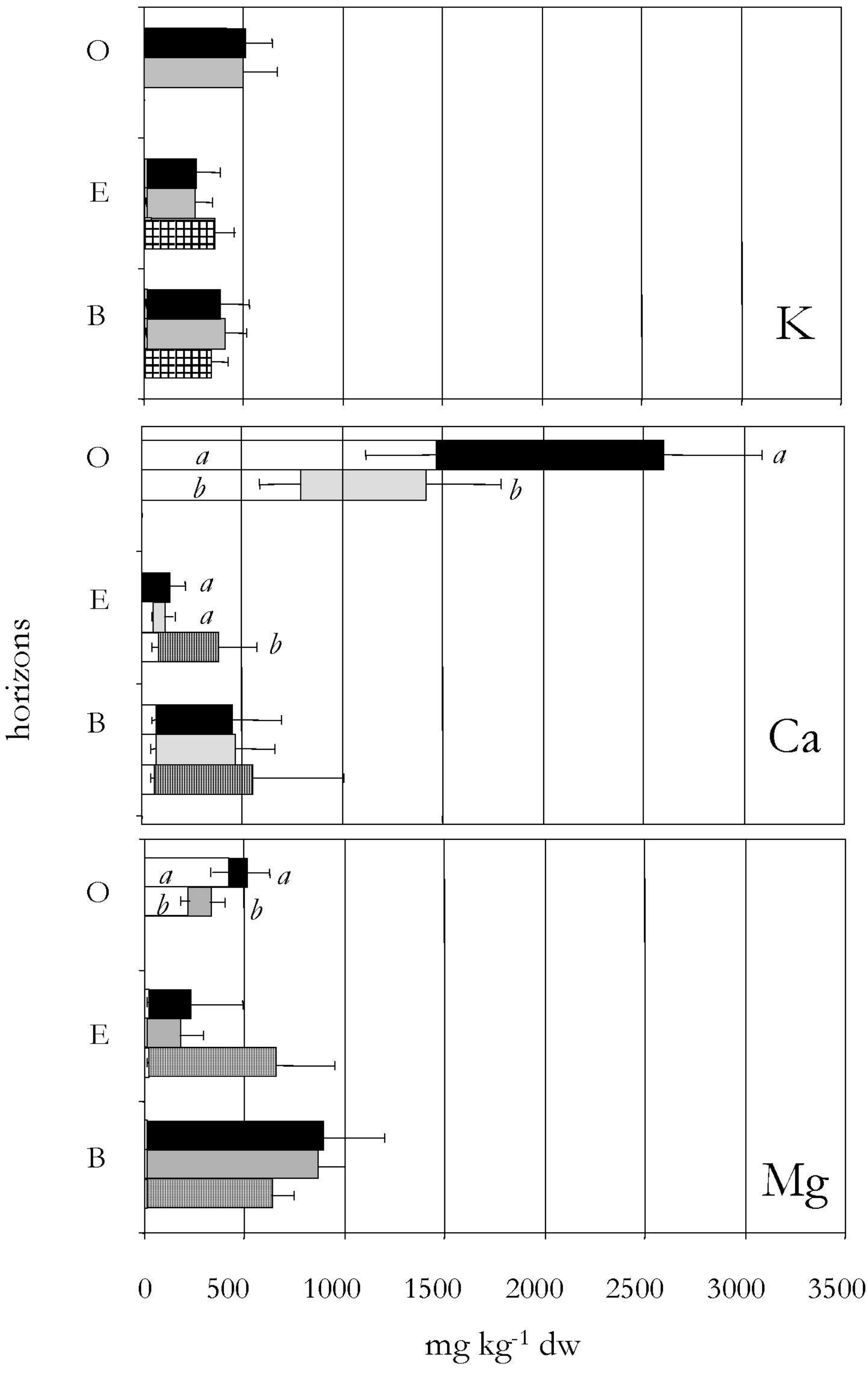

Fig. 2a. Total concentration of K, Ca and Mg in different soil horizons beneath different fruticose lichen cover: ■ ample, ▩ reduced, ⊞ poor. □ indicates plant available concentrations of the cations. Significant differences ($P \leq 0.05$) between plots with different lichen cover are indicated by letters.

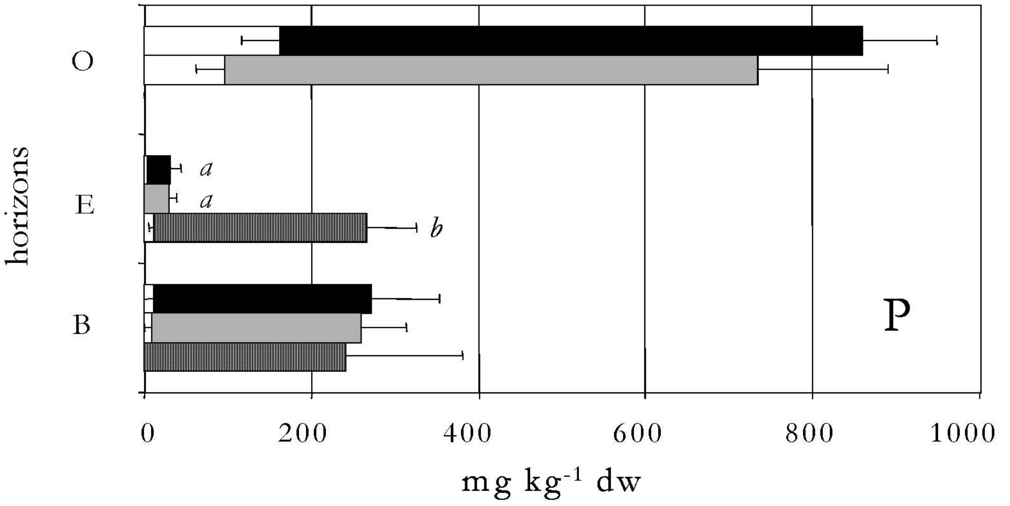

Fig. 2b. Total concentration of P in different soil horizons beneath different fruticose lichen cover: ■ ample, ▩ reduced, ◫ poor. □ indicates plant available concentrations of P. Significant differences ($P \leq 0.05$) between plots with different lichen cover are indicated by letters.

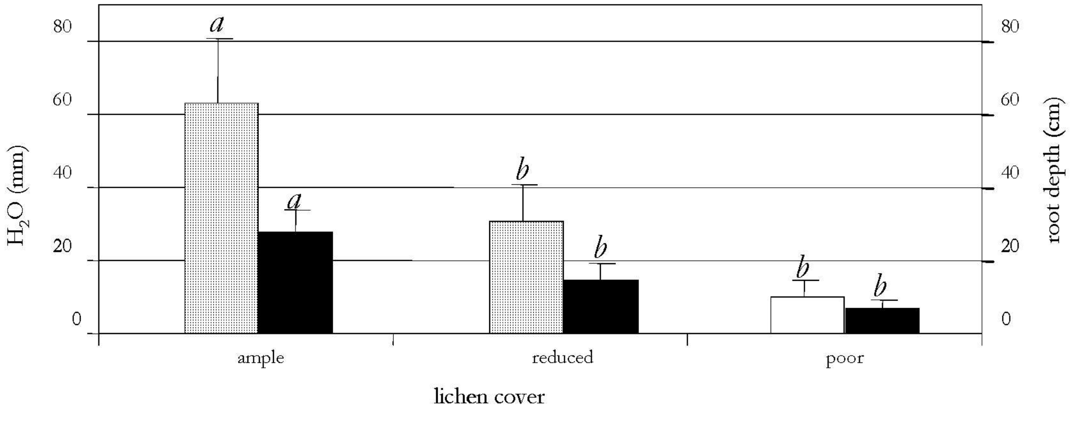

Fig. 3. Comparison of plant available water (▥) and rooting depth (■) at plots with different lichen cover. Significant differences ($P \leq 0.05$) between plots with different lichen cover are indicated by letters.

Conclusions

The O-horizon posses a key role for soil fertility in the lichen dominated tundra-mountain birch forest on Finnmarksvidda. Over-grazing by reindeers can cause a significant degradation of the organic layer, followed by significant losses of essential plant nutrients, a reduction in plant available water and consequently soil fertility. Thus, over-grazing of winter lichen pastures may reduce vascular plant productivity and thus pasture quality and quantity. Further studies should focus on processes and extension of soils degradation due to reindeer grazing on Finnmarksvidda.

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