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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 km² 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 m² 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.

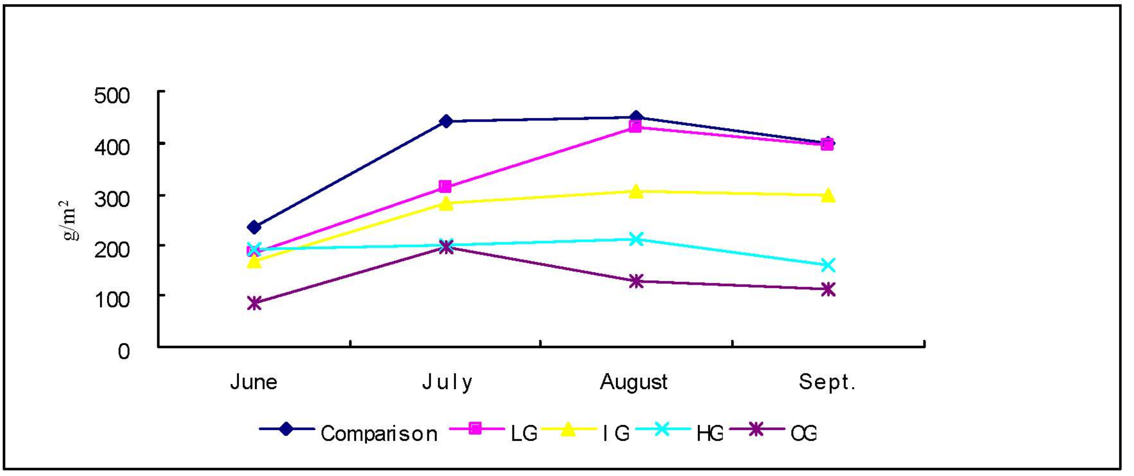

Fig. 1. Change of aboveground biomass under different grazing intensities in north-western Sichuan.

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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