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青藏高原高寒灌丛植被对长期放牧强度试验的响应特征

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摘　要:在青藏高原中国科学院海北高寒草甸生态系统定位研究站对金露梅高寒灌丛草场植被开展了长期不同放牧强度试验,分别在短期(4年)、中期(11年)和长期(18年)放牧阶段研究不同放牧干扰强度对草地植物物种多样性、群落结构、地上生物量和草场质量的影响。研究表明,在不同放牧阶段,随着放牧强度增加植物群落的高度和盖度都降低。在中期放牧干扰阶段,物种多样性指数和均匀度指数随着放牧强度增加呈现典型的单峰曲线模式;在长期放牧干扰阶段,随着放牧强度增加,占优势地位的灌木和禾草被典型杂类草替代,其中的重度放牧干扰简化了高寒灌丛植被群落结构,减少了地上现存生物量,特别是可食优良牧草生物量。植被对放牧的响应除了与放牧强度和放牧时间阶段密切相关外,还与该地区水热条件的变化有一定的相关性。针对长期放牧干扰的反应特性可将金露梅灌丛草场中植物划分为增加型、敏感型、忍耐型和无反应型4种类型。除了丰富度指数、多样性指数和均匀度指数外,其它一些特征参数并不支持著名的中度干扰假说。本研究发现,长期重度放牧促进了青藏高原高寒草地退化,适度放牧有利于高寒灌丛草场的生物多样性保护和牧草利用;"取半留半"的放牧原则在青藏高原草场放牧管理实践中值得推荐,它将有利于防止草场退化,提高牧草利用率和维持较高的生物多样性。

关键词:金露梅灌丛;物种丰富度;物种多样性;植物群落结构;地上生物量;放牧强度

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Vegetation Responses to A Long-term Grazing Intensity Experiment in Alpine Shrub Grassland on Qinghai-Tibet Plateau

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Abstract: The grassland of the Qinghai-Tibet Plateau is one of the world's most remarkable grazing lands. Livestock grazing appears to exert significant effects on the vegetation and ecosystem processes on the plateau, although the effects of livestock grazing on grasslands are in need of further study. In this study, a long-term grazing experiment with different stocking rates in alpine *Potentilla fruticosa* shrubland was carried out at Haibei Alpine Meadow Ecosystem Research Station, Chinese Academy of Sciences. The effects of grazing intensity on plant species diversity, community structure, above-ground standing biomass and grassland quality were analyzed after grazing for 4, 11 and 18 years which represented short-term graz-

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ing ,medium-term grazing and long-term grazing ,respectively. Our results suggest that the height and cover of plant community were decreased with the increase of stocking rate in different grazing period. The change in biodiversity and evenness indices as stocking rate increased was a typical unimodal curve after grazing for 11 years. The dominated shrub and gramnoids were replaced by the typical forbs with the increase of the stocking rate in the long-term heavy grazing period. Long-term heavy grazing simplifies the alpine shrub community and decreases the standing above-ground biomass, especially palatable herbage plants. The heights and cover of plant communities were decreased as the stocking rate increased. Changes in the vegetation of different grazing treatments was also correlated with the variation in local moisture-temperature conditions except key factors such as grazing intensities and grazing time. From grazing release ,light grazing to heavy grazing ,the dominant shrub and graminoid species were replaced by typical forbs after grazing for 18 years. All species of *Potentilla fruticosa* shrubland in this study can be sorted into 4 groups which were fostering ,sensitive ,tolerant and indifferent to long-term grazing disturbance. Our results did not support the intermediate disturbance hypothesis very well except three cases ,i. e. ,richness , biodiversity and evenness indices. It is concluded that long-term heavy grazing plays an important role in alpine grassland degradation on Qinghai-Tibet Plateau. From responses of species diversity and standing biomass of different functional types to grazing ,moderate grazing appears to be suitable for biodiversity conservation and the utilization of alpine shrub grassland. The standard grazing rule of "take half leave half "is recommended as a conservative management tool to prevent grassland degradation ,to improve grass utilization ,and to sustain higher biodiversity on Qinghai-Tibet Plateau.

Key words : *Potentilla fruticosa* shrub ;species richness ;species diversity ;plant community structure ;above-ground standing biomass ;stocking rates

The grassland of the Qinghai-Tibet Plateau , the highest and most majestic such area on earth ,is one of the world's most remarkable grazing land ecosystems[1] ,with over 130 million hm^2 of grassland and 70 million head of livestock[1,2]. Adverse climatic conditions and a short growing period in alpine grazing land of Qinghai-Tibet Plateau abide a rich diversity of herbaceous flora and grasses[3]. In the Qinghai-Tibet Plateau grassland ecosystems ,understanding grassland ecological functions and processes under grazing disturbance is fundamental to conserving biological diversity and grassland conditions because ,as Noss and Cooperrider[4] emphasized , ecological process determines landscape patterns. Livestock grazing is also one of the major conservation and development concerns on the Qinghai-Tibet Plateau[5]. Due to the inaccessibility of this area ,few studies have been made of grazing effects in these alpine grasslands so far. Livestock have a wide range of effects on grassland ecosystems that can be both positive and negative[6] and grazing impacts can be seen at the species ,community and landscape levels[1]. Livestock grazing has impacts on individual plants or species , plant communities ,soils and watersheds ,and wildlife. Stocking rate directly influences the frequency and intensity of defoliation of individual plants which ,in turn ,impacts plant succession and energy flow in grazed ecosystems[7-9]. The responses of vegetation to stocking rates are best evaluated using long-term experiments[10,11] ,and studies evaluating grazing effects on plant composition and structure should be done over a period of a minimum of 10 years[12]. Numerous similar studies pertaining to tropical and temperate grazing lands have been performed by many scientists[13,14]. Many studies about anthropogenic disturbance (such as grazing , fertilizing , and fire) to shrub vegetation were carried out in different habitats[2]. However , few long-term studies have evaluated the effects of livestock grazing in these high-elevation grasslands on Qinghai-Tibet Plateau[8,15] ,and ,there is limited understanding of long-term livestock grazing impacts on plant composition and ecosystem processes to support management and policy in alpine shrubland ecosystem. Alpine shrub is the dominated vegetation on Qinghai-Tibet Plateau[8,15] , and its vegetation degradation is significant like as alpine Kobresia meadow[1,15]. The objectives of this study were to:1) determine the influence of long-term grazing on plant community structure, species diversity and standing above-ground biomass; and 2) appraise the status of grazing disturbance on alpine grassland degradation and biodiversity conservation on Qinghai-Tibet Plateau.

1 Study site and methods

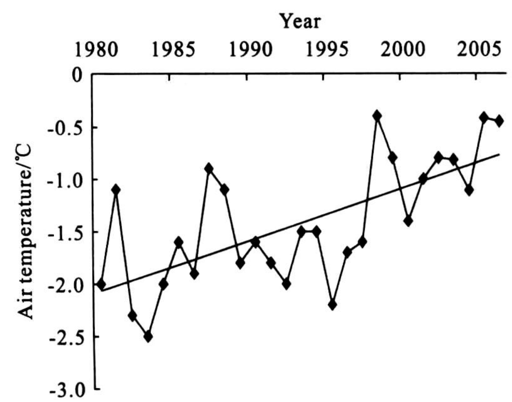
1.1 Studying site description

This study was conducted in an area dominated by the alpine shrub *Potentilla fruticosa* at the Haibei Alpine Meadow Ecosystem Research Station (Haibei Station), Chinese Academy of Sciences. The Haibei Station is located in the Qinghai-Tibet Plateau region[16,17], in a large valley oriented NW-SE surrounded on all sides by the Qilian Mountains at latitude 37°29′～37°45′N and longitude 101°12′～101°23′E. The average altitude of the mountain area is 4 000 m above sea level and 3 200 m for the valley area. The climate of the Haibei Station is dominated by the southeast monsoon and the high pressure system of Siberia. It has a continental monsoon type climate, with severe long winter and short cool summer. The annual mean air temperature is -1.5 ℃ with extremes of maximum 27.6 ℃ and minimum -37.1 ℃[18]. During winter, the mean temperature can drop to -15 ℃～-20 ℃ in highland areas; during summer, the temperature in the warmest month (July) averages 14 ℃～22 ℃ in the valleys and 4 ℃～10 ℃ in the mountains. Mean annual precipitation ranges from 426 to 860 mm (Fig. 1), 80% of which falls in the short summer growing season from May to September. The annual mean sunlight is 2 462.7 h with 60.1% of total available sunshine[17,18].

The soil types of the Haibei Station are dominated by Mollic-gryic Cambisols and Mat cryo-sod soil (Chinese soil taxonomy) rich in three elements: nitrogen, phosphorus and potassium. The soils are characterized by high organic matter content, under development, with a thin soil layer[19]. Nitrogen and phosphorus exist mostly in organic state and mineralization rates are low. The alpine meadow, dominated by *Kobresia humilis* and various grasses and forbs (depending on grazing density) are widely distributed in this region along the valley floor. The shrub, *Potentilla fruticosa* and shrubby *Salix* species are located on the slopes facing north and northwest[19]. *Kobresia humilis* meadow and *Potentilla fruticosa* shrub are main vegetation types on the Qinghai-Tibet Plateau[1]. *Kobresia humilis* meadow belongs to cold season pasture which is always utilized in spring and winter; *Potentilla fruticosa* shrub belongs to warm season pasture which is always utilized in summer and autumn[17,20,21]. With respect to the overall land use pattern in the region, the higher shrublands on the mountains surrounding the valley are common summer grazing lands. The meadow vegetation is grazed in winter and is privately owned; ownership is generally demarcated by barbed wire fences.

1.2 Experimental design

This grazing experiment with 3 stocking rates and one control plot has been in progress at the *Potentilla fruticosa* shrub of shady mountain slope



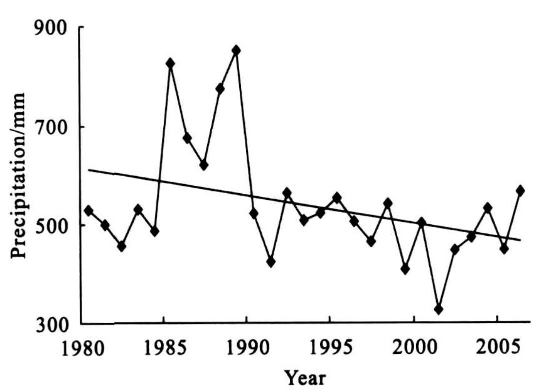


Fig. 1 The fluctuation of annual mean air temperature and precipitation at the Haibei Station

at Haibei Station since 1985[17]. The total study area is 6.06 hm^2 (303.00 m ×200 m) which included 4 plots. These plots were heavily grazed (HG), moderately grazed (MG), lightly grazed (LG) and ungrazed (CK), respectively. The stocking rates are shown in Table 1[22,23]. The livestock used for the grazing experiment were healthy 2 year old male Tibetan sheep. New Tibetan sheep with similar weight were employed for the experiment every May 1 and removed on September 30. Each plot was fenced to protect it from other livestock grazing. Before the construction of experimental plots, vegetation across the whole study area was investigated with the quadrat method as discussed. Vegetation responses to the grazing treatments were assessed after grazing for 4, 11 and 18 years which represented short-term grazing, medium-term grazing and long-term grazing, respectively.

Table 1 Stocking rates in the experimental plots

Item	Plot			
	HG	MG	LG	CK
Designed utilization of herbage/ %	60	45	30	0
Length of grazing season/ month	5	5	5	0
Available grazing area/ hm^2	0.92	1.39	2.75	1.00
Number of grazing Tibetan sheep (No.)	5	6	7	0
Stocking rate (Tibetan sheep/ hm^2)	5.35	4.30	2.55	0

Note: Data in the table is from Zhou *et al*.[22] and Liu *et al*.[23].

1.3 Measurements and analyses

Investigation with the quadrat method[24] was conducted at the three grazing plots (plot HG, MG, LG) and one control plot (plot CK) at four times (before grazing; and after short-term grazing; medium-term grazing and long-term grazing). Sampling occurred during October before the plants begin to wither. Plant parameters were measured with two 50 cm ×50 cm quadrats placed every 5 m on two sides of the transect. Transects were 25 m in length and there were 10 replicates of sampling quadrats at each plot. Measured parameters included cover, height, and density of plant populations in each quadrat; plant community height and cover; and above-ground standing biomass. Edges of fences were avoided by at least 2 m when sampling the plots.

We used the point-intercept method for vegetation sampling according to guideline of the International Tundra Experiment[25]. A 50 cm ×50 cm point-frame with 100 cross hairs set 5 cm apart was used to collect data for coverage by species at each quadrat. At each crosshair on the frame, a line was visually extended down to the vegetation, and we recorded the species hit. Multiple hits at every point were possible by moving aside the first plant structure and extending the point to the next species until every species bellow the point was recorded. At the same time, plant height of every species at all quadrats was measured and averaged. Density of plant populations was acquired by counting at each quadrat. Monogenus plants were counted by their tillers while dicotyledonous plants were counted by their individuals[26].

Using a standard quadrat harvest method[27,28], above-ground standing biomass was estimated by harvesting 10 selected 50 cm ×50 cm quadrats, as close to the ground as possible, after investigating work as above. We clipped the fresh stems and leafs in the quadrats as the standing biomass of the shrub, *P. fruticosa*[29]. The harvested samples were separated into live shoots (sorted according to species and economic functional types) and dead material. After sorting, the samples were oven-dried at 60 ℃ until they attained constant weight and then weighed to the nearest milligram. Dead material was also dried and weighed.

To identify the change in the relative importance of species under different grazing treatments, importance values (*IV*) for each species encountered in different plots were developed following Jiang[30]: IV = (Relative cover + Relative above-ground standing biomass)/2 ×100 %.

To show the influence of different stocking rates on plant biodiversity, the following indices were developed:

(1) $S = n$, n is the number of species per quadrat (Richness index);

(2) Shannon-Wiener index $H = -\sum_{i=1}^{S}(Pi \times \mathrm{Ln}\, Pi)$, Pi is relative IV of species i (Species Diver-

sity index[31]) ;

(3) Pielou index $J = H/\mathrm{Ln}(S)$, (Evenness index[31]) ;

The data were analyzed by *t*-test, one-way ANOVA and Duncan's multiple comparisons tests using the Statistical Package for the Social Sciences[32].

2 Results and analysis

2.1 The change of dominant and main companion species

Based on importance values of the plant populations in each treatment plot, the dominant species, sub-dominating species and main companion species are listed in Table 2. At the heavily grazed plot (HG), dominant species were not replaced and there were only minor changes in the main companion species after grazing for 4 years. With an increase in grazing time, the monodominant community slowly became a polydominant community. Dominant and companion species of the plant community were partly replaced after grazing for 18 years. For example, the dominant status of *P. fruticosa* was slowly replaced by *Leontopodium namum*, *P. anserina* and *Gueldenstaedtia diversifolia*. After grazing 11 years, The companion species, graminoids and sedges, were replaced by some typical forbs, such as *P. nivea*, *Lancea tibetica*, *Saussurea katochaete*, *S. superba*, *Aster flaccidus* and *Thalictrum alpinum*. Judged by the degradation level of alpine grassland[33], alpine shrub grassland degraded severely under long-term heavily grazing. The replacement of plant species was correlated with their grazing tolerance, ecological and biological characteristics.

With an increase in grazing time, the dominant status of *P. fruticosa* and accompanying status of graminoids and sedges were not replaced though the number of dominant species and main accompanying species were increased in the moderately grazed plot (MG). This plot has not exhibited a trend towards degradation since grazing began. In the ungrazed plot (CK) and lightly grazed plot (LG), the dominant species and main accompanying species were not replaced by other plant species following 4 and 11 years of grazing. The dominant status of *P. fruticosa* and accompanying status of graminoids and sedges were not influenced though more dominant species and main accompanying species were found after grazing for 18 years. However, low utilization of herbage and stocking rates (Table 1) at these two plots will influence the growth of understory forbs and their richness, which is not good to biodiversity conservation.

With the increase of stocking rates from plot CK to plot HG, the dominant species following short-term grazing for 4 years was the same as before grazing, while the change in main accompanying species was minor. Under medium-term grazing for 11 years, *L. namum* increased as the dominant species, and the main accompanying species (graminoids and sedges) were replaced by forbs. At long-term grazing for 18 years, the dominant species were replaced by poisonous forbs and *P. fruticosa* while the main accompanying species were replaced by low quality forbs. The replacement of plant species (Table 2) was determined by stocking rates and grazing time. Long-term heavy grazing easily resulted in the severe degradation of alpine shrub grassland.

2.2 Effect of grazing on plant diversity

Total species numbers increased in grazed plots HG, MG and LG flowing grazing for 4 years (Table 3). Under a proposed general model of the relationship between biomass and realized richness[34], the responses of plant species number was correlated not only with grazing factor but also with good moisture and temperature conditions in 1987 and 1988 (Fig. 1) which accelerated the seed germination at seed bank of soil. The change of species number at ungrazed plot CK was minor which was correlated with high dead material accumulation and greater growth redundancy[35] following grazing release. When grazed for 11 years, the species numbers were decreased in all plots compared with short-term grazing for 4 years. The decrease of plant species in this period was correlated with longer grazing time , low air temperature and

Table 2 Changes of dominant species and main companion species in different grazing period with different stocking rates

Grazing period	Plot	Dominant and sub-dominating species	Main companion species
Before grazing	HG MG LG CK	*Potentilla fruticosa*	*Kobresia capillifolia*, *Kobresia humilis*, *Potentilla nivea* and *Stipa aliena*
Short-term grazing (Grazing for 4 years)	HG	*Potentilla fruticosa*	*Kobresia humilis*, *Kobresia capillifolia*, *Lancea tibetica*, *Stipa aliena*
	MG	*Potentilla fruticosa*	*Kobresia humilis* and *Stipa aliena*
	LG	*Potentilla fruticosa*	*Kobresia capillifolia*, *Stipa aliena* and *Festuca ovina*
	CK	*Potentilla fruticosa*	*Stipa aliena*, *Helictotrichon tibeticum* and *Festuca ovina*
Medium-term grazing (Grazing for 11 years)	HG	*Potentilla fruticosa* and *Leontopodium namum*	*Potentilla nivea*, *Lancea tibetica* and *Thalictrum alpinum*
	MG	*Potentilla fruticosa*	*Kobresia humilis*, *Potentilla nivea*, *Lancea tibetica*, *Festuca ovina* and *Thalictrum alpinum*
	LG	*Potentilla fruticosa*	*Thalictrum alpinum*, *Festuca ovina*, *Stipa aliena*, *Potentilla nivea*, *Elymus nutans*
	CK	*Potentilla fruticosa*	*Festuca ovina*, *Stipa aliena*, *Elymus nutans*, *Ligularia virgaurea* and *Saussurea katochaete*
Long-term grazing (Grazing for 18 years)	HG	*Leontopodium namum*, *Potentilla anserina*, *Gueldenstaedtia diversifolia* and *Potentilla fruticosa*	*Potentilla bifurca*, *Saussurea katochaete*, *S. superba*, *Aster flaccidus* and *Thalictrum alpinum*
	MG	*Potentilla fruticosa*, *Leontopodium namum*, *Gueldenstaedtia diversifolia* and *Stipa aliena*	*Festuca ovina*, *Saussurea katochaeta*, *Lancea tibetica*, *Anaphalis lactea*, *Kobresia humilis*, *K. capillifolia*, *Saussurea superba*, *Gentiana farreri* and *Stellera chamaejasme*
	LG	*Potentilla fruticosa*, *Kobresia capillifolia* and *Stipa aliena*	*Festuca ovina*, *Elymus nutans*, *Helictotrichon tibeticum*, *Potentilla nivea*, *Leontopodium namum*, *Polygonum viviparum* and *Saussurea katochaete*
	CK	*Potentilla fruticosa* and *Stipa aliena*	*Helictotrichon tibeticum*, *Elymus nutans*, *Kobresia capillifolia*, *Festuca ovina*, *Saussurea katochaete*, *S. superba*, *Lancea tibetica* and *Ligularia virgaurea*

Note: We use the dominant species and main companion species of total studying area (6.06 hm^2) to represent those of different plots before grazing. The determination of dominant species and main companion species was based on importance values. The importance value of dominant species is larger than 10.0 while that of main companion species ranges from 2.0 to 10.0 in alpine *Potentilla fruticosa* shrub[29].

precipitation in 1995 (Fig. 1). Due to the long-term grazing and unsuitable moisture and temperature conditions in 2002 (Fig. 1), the change of species richness was obvious following grazing for 18 years. The species richness at all plots were decreased compared with the period of grazing for 11 years. Among of them, the species numbers at heavily grazed plot (HG) and ungrazed plot (CK) were below that of before grazing period. The species numbers at lightly grazed plot (LG) and moderately grazed plot (MG) were similar with that of before grazing period.

Species richness was the greatest in the moderately grazed plot (MG) on all sample dates (Table 3). With the increase of stocking rates from plot CK to plot HG, the changing patterns of species richness were typical single peak curves. Long-term fencing influenced the species diversity, too. Two plant species decreased after the exclosure for 11 years. Nine plant species decreased after the exclosure for 18 years (Table 3). The pattern of species richness dynamics was correlated with the variation of diversity (Table 4) and cover (Table 5).

With the increase of grazing time, the species diversity and evenness indices had a pattern of decreasing (Table 4). The change of biodiversity index and evenness index at moderately grazed plot (MG) and lightly grazed plot (LG) was minor compared with that of heavily grazed plot (HG) and ungrazed plot (CK) following grazing for 18 years. But, the indices at plot HG and plot CK were decreased significantly (Table 4. $P < 0.05$). With the increase of grazing time and stocking rates from plot CK to

Table 3 The change of plant species number of plots

Grazing period	Plot HG	Plot MG	Plot LG	Plot CK
Before grazing	45b	45b	45b	45a
Grazing for 4 years	50a	52a	50a	44a
Grazing for 11 years	43b	48b	48ab	43a
Grazing for 18 years	39c	47b	43b	36b

Note: Data with the different letter in one column are significantly different at 0.05 level ($P < 0.05$). We use a mean value to represent the plant species number of different plots before grazing. The same as below.

HG plot, the maximum values of the species diversity and evenness indices were varied from plot HG to plot MG. The decrease of species diversity and evenness at plot HG was caused by long-term heavily grazing. However, the decrease of the indices at plot LG and CK were caused by light grazing and grazing release which resulted in the mulch accumulation and influenced the herbage growth.

2.3 The change of plant community structure

With the increase of grazing time, the height and cover of plant community were decreased in heavily grazed plot (HG) and moderately grazed plot (MG) from the Table 5. In lightly grazed plot (LG) and ungrazed plot (CK), the plant community cover was increased slowly and the height was increased at short-term grazing for 4 years and then decreased. At the different grazing periods, the mean height and cover of plant community had increasing patterns along with the stocking rates from HG to CK (Table 5).

2.4 The change of above-ground standing biomass of different functional types

The standing biomass of dead material was the greatest in ungrzaed plot (CK) and the lowest in heavily grazed plot (HG) during different grazing periods. With the increase of stocking rates, the standing biomass of dead material was decreased (Fig. 2, A). After the grazing experiment began, the standing biomass of dead material for 11 years was the lowest while that at long-term grazing period for 18 years were the greatest in different grazing plots. The dynamics of standing biomass of dead material was correlated not only with grazing time and intensities but with local moisture and temperature conditions.

The standing biomass of *P. fruticosa* at short-term grazing period and medium-grazing period was decreased and that at long-term grazing period was increased compared with that of before grazing period (Fig. 2, B). The standing biomass of *P. fruticosa* in heavily grazed plot (HG) was the lowest at different grazing periods. On the short-term grazing period, the standing biomass of *P. fruticosa* in ungrazed plot (CK) was the greatest. However, on the other grazing periods, the standing biomass of *P. fruticosa* in lightly grazed plot (LG) was the greatest (Fig. 2, B).

The standing biomass of graminoids was the greatest in ungrzaed plot (CK) and the lowest in heavily grazed plot (HG) during different grazing periods (Fig. 2, C). With the increase of stocking rates, the standing biomass of graminoids was decreased. At the short-term grazing for 4 years, the standing biomass of graminoids in ungrazed and lightly grazed plots (LG) were increased while those in the moderately (MG) and heavily grazed plots (HG) were decreased compared with that of before grazing periods. At the medium-term grazing for 11

Table 4 The change of the biodiversity index and evenness index

Grazing period	Biodiversity index				Evenness index			
	HG	MG	LG	CK	HG	MG	LG	CK
Before grazing	3.52a	3.52a	3.52a	3.52a	0.92a	0.92a	0.92a	0.92a
Grazing for 4 years	3.51a	3.50a	3.42a	3.25b	0.90ab	0.89ab	0.87b	0.86ab
Grazing for 11 years	3.28b	3.32b	3.24b	3.19b	0.87b	0.86b	0.84b	0.84b
Grazing for 18 years	2.87c	3.29b	3.08b	2.76c	0.78c	0.85b	0.82b	0.77c

Table 5 The change of height and cover on plant community

Grazing period	Height/ cm				Cover/ %			
	HG	MG	LG	CK	HG	MG	LG	CK
Before grazing	35.0a	35.0a	35.0b	35.0b	93.0a	93.0a	93.0a	93.0a
Grazing for 4 years	27.7b	30.2a	42.8a	43.0a	79.9b	84.7b	92.8a	97.0a
Grazing for 11 years	15.3c	30.4a	35.8b	40.0a	66.0c	85.0b	95.0a	97.5a
Grazing for 18 years	9.9d	27.5b	30.0b	37.0ab	61.2c	84.3b	96.7a	98.7a

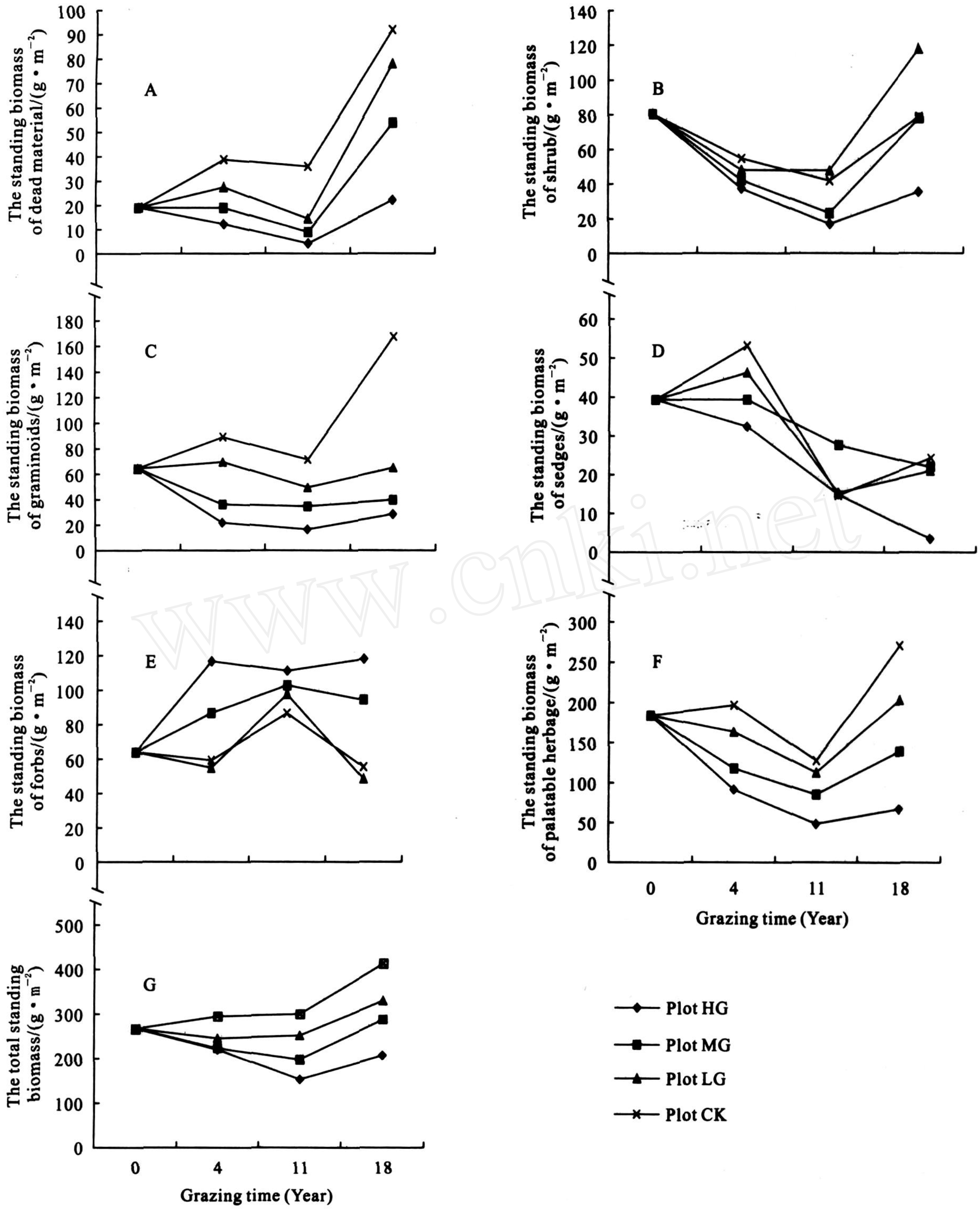


Fig. 2　The change of above-ground standing biomass of different functional types

We use mean values of the whole studying area to represent the above-ground standing biomass of different plots before grazing in this study

years, the standing biomass of graminoids was decreased on all plots compared with that of short-term grazing period. At the long-term grazing for 18 years, the standing biomass of graminoids was increased on all plots, especially that in ungrazed plot.

At the short-term grazing for 4 years, the standing biomass of sedges was increased in ungrazed (CK) and lightly grazed plots (LG), and it was decreased in heavily grazed plot (HG) whereas that did not fluctuate at moderately grazed plot (MG) (Fig. 2, D). With the increase of stocking rates, the standing biomass of sedges was decreased in this period. At the medium-term grazing for 11 years, the standing biomass of sedges was decreased in all plots. In this period, the standing biomass of sedges in moderately grazed plot (MG) was the greatest while that in other plots was same. At the long-term grazing for 18 years, the standing biomass of sedges in heavily grazed plot (HG) and moderately grazed plot (MG) continued to decrease, and the former reached to the lowest value. The standing biomass of sedges in lightly grazed plot (LG) and ungrazed plot (CK) was increased to similar with that of moderately grazed plot (MG).

The standing biomass of forbs was the greatest in heavily grazed plot (HG), the second one was moderately grazed plot (MG), and the third one was lightly grazed plot (LG) or ungrazed plot (CK) at different grazing periods (Fig. 2, E). After long-term grazing, the standing biomass of forbs had a pattern as below: increasing in heavily grazed plot (HG) and moderately grazed plot (MG), decreasing in lightly grazed plot (LG) and ungrazed plot (CK). At the short-term grazing for 4 years, the standing biomass of forbs was increased in heavily grazed plot (HG) and moderately grazed plot (MG) while those were decreased in lightly grazed plot (LG) or ungrazed plot (CK). At the medium-term grazing for 11 years, the standing biomass of forbs was increased in ungrazed, lightly and moderately grazed plots except that in heavily grazed plot. At the long-term grazing for 18 years, the standing biomass of forbs was decreased in ungrazed, lightly and moderately grazed plots while that was decreased in heavily grazed plot (Fig. 2, E). The dynamics of standing biomass of forbs under grazing disturbance can indicate the grassland degrading degree and degrading trend very well[33]. The heavily grazed plot had degraded in this long-term grazing experiment because the standing biomass of forbs and its proportion was the greatest during different grazing periods. The standing biomass of forbs in lightly and ungrazed plots was lower than other plots because of little grazing disturbance and suppression effects of much dead material accumulation. The grassland quality of lightly and ungrazed plots was declined though palatable herbage dominated the plant communities.

Correlation test indicated a negative correlation between the standing biomass of palatable herbage and stocking rates ($r = -0.7722$, $n = 12$, $P < 0.01$). The standing biomass of palatable herbage was the greatest in the ungrazed plot and the lowest in the heavily grazed plot during different grazing periods (Fig. 2, F). Following short-term grazing for 4 years, the standing biomass of palatable herbage in the ungrazed plot increased, while that in the other plots decreased. Following medium-term grazing for 11 years, the standing biomass of palatable herbage in all plots decreased which was correlated with poor moisture and temperature conditions in this period. Following long-term grazing for 18 years, the standing biomass of palatable herbage in all plots was greater than that following the medium-term grazing period.

Correlation test indicated it was negative correlation between the total standing biomass and stocking rates ($r = -0.7832$, $n = 12$, $P < 0.01$), too. The total standing biomass was the greatest in ungrazed plot and the lowest in the heavily grazed plot during different grazing periods (Fig. 2, G). That means the more livestock you have, the greater the consumption, thus the smaller standing biomass left at the end of the growing season. At the short-term grazing for 4 years, the total standing biomass in ungrazed plot was increased while that in other plots was decreased. At the medium-term grazing for 11 years, the total standing biomass was increased in ungrazed and lightly grazed plots while those in other plots were decreased. At the long-term grazing for 18 years, the total standing biomass in all plots were increased compared with those in medium-term grazing period.

3 Discussion and conclusion

3.1 Long-term grazing and replacement of main plant populations

Plant species in the community showed different response to stocking rates, related to their palatability, season, growth rates, colonizing abilities and forms[36]. Tibetan sheep grazing influenced plant composition through selective grazing by increasing the dominance of unpalatable forbs and decreasing palatable, perennial sedges and grasses[17]. The most palatable and nutritious plants are the first to be removed under heavy grazing. At the same time, other plants that are less palatable or more tolerant of grazing, may increase. Excessive grazing pressure stresses the most palatable plants by removing too much photosynthetic tissue.

All species in this study can be sorted as 4 groups which were fostering, sensitive, tolerant and indifferent to long-term grazing disturbance, respectively. After long-term grazing for 18 years, the dominant shrub and graminoids species were replaced by typical forbs from ungrazed plot (CK) to heavily grazed plot (HG). The abundance of *L. nanum*, *G. diversifolia*, and *P. anserina* were significantly greater in heavily grazed plot (HG) than that in lightly grazed plot (LG) and ungrazed plot (CK). These forbs seem to benefit from continuous heavy grazing and promoted by the long-term heavy grazing disturbance. They are serious noxious plants and greatly reduce the fodder value of pasture. They are always fostered as the stocking rate increase. Some palatable herbage species suffered from continuous heavy grazing and decreased significantly. The standing above-ground biomass of graminoid decreased from ungrazed plot (CK) and lightly grazed plot (LG) to heavily grazed plot (HG). With the decrease of stocking rates, the *IV* of these graminoids and sedges (e. g., *S. aliena*, *F. ovina*, *H. tibeticum* and *K. capillifolia*) were increased as well as that of *P. fruticosa*. They are always sensitive to long-term heavy grazing disturbance. *K. humilis* is a typical sedge species on Qinghai-Tibet Plateau, which is tolerant to livestock grazing and trampling[1]. Some forbs, such as *A. lactea*, *G. farreri* and *T. mongolicum* were indifferent to long term grazing disturbance. They occurred on 4 plots during different grazing periods in this study.

3.2 The change of plant community structure and standing biomass

Livestock can influence grassland vegetation by altering its composition, structure, and productivity[6]. Livestock grazing can also affect litter accumulation, thereby influencing plant growth processes, since the plant microclimate is influenced by litter through soil temperature buffering and soil moisture conservation. The change of biomass and vegetation structure of grassland in central Japan had the inherent time-lag response to long-term grazing disturbance[37]. In this study, we had not find the evidence for this phenomenon. The response of vegetation to long term grazing on alpine *P. fruticosa* shrubland on Qinghai-Tibet Plateau was similar to the results obtained in the Colorado Plateau[38]. Long-term grazing kept shrub vegetation short[38] and prevented accumulation of litter[39] as confirmed in this study. Mulch was more abundant in ungrazed plot than that in other grazed plots. The height and cover of plant communities were negative correlated with stocking rates. Also standing dry mass was influenced by different grazing treatments at different grazing periods. The total aboveground biomass in heavily grazed plot was less than that in the lightly grazed plot at the certain grazing period which are similar to the results obtained by Sims *et al*. [40]. All of this suggests that long-term grazing disturbance simplified the alpine shrub community gradually since grazing experiment beginning. Plant height, cover and standing biomass simply reflected the effects of different stocking rates on plant community. This does not mean that overall productivity has been reduced at all grazed plots. More Tibetan sheep consumed more forages so it would be expected that standing biomass would be lower as stocking rate increased at the same grazing period. However, this does not mean that forage production has been reduced because of growth redundancy of herbages[24,35]. To get an actual biomass production, some form of pair cage design and more than one clipping date in one year are necessary at next study.

3.3 Long-term grazing and grassland degradation

Grazing disturbance by livestock frequently causes important changes in the composition of the plant and animal populations[38]. Heavy livestock concentrations can lead to overgrazing, severe trampling, accumulation and concentration of organic matter and chemicals from fecal matter and urine, increased sediment production, loss of infiltration, and other associated consequences[41]. Heavy livestock grazing is defined as that amount or pattern of grazing that results in a reduction of the most palatable plant species, a change in species composition, and serious erosion and site damage. Long-term heavy grazing usually depletes soil nutrients[23]. Long-term heavy grazing always influence the grassland greatly and caused the grassland degradation from the study in Inner Mongolia. After long-term grazing, the heavily grazed plot (HG) showed some typical degraded characteristics, such as the lowest community height and cover, low standing biomass of palatable herbage and serious destruction by rodents[23]. Traditionally, changes in vegetation (productivity, cover, species) have been used as the main indicators of degradation on grasslands. *L. namum*, *G. diversifolia*, *L. tibetica*, *P. anserina* and other forbs, were used as indicator plants of alpine grassland degradation[17]. Their IVs under heavy grazing were greater than those under light grazing. The standing biomass of graminoids decreased and forbs increased significantly ($P < 0.05$, $n = 10$) from ungrazed plot (CK) to heavily grazed plot (HG). From these discussion and our results, heavy grazing disturbance, especially the long-term heavy grazing plays an important role on alpine grassland degradation on Qinghai-Tibet Plateau.

3.4 The climate dynamics and the characteristics change of plant community

It is necessary to keep in mind that livestock constitute only one component of grassland ecosystems, and many extrinsic factors, especially weather variations are instrumental in influencing ecosystem components. However, the practice of livestock grazing has not been the sole factor contributing to changes in plant composition on grasslands. Grazing along with both natural and anthropogenic factors has had a cumulative influence on plant succession and when interpreting vegetation trends on grasslands, it is often difficult or impossible to separate the effects of heavy livestock grazing from the myriad of interacting environmental parameters[12].

The fluctuation of herbage yield and plant community structures are always influenced by the variation of climate conditions in different years. In the study area, the precipitation and air temperature are the most important climatic factors which affected the structure and functions of plant community[1,17]. The change of species richness of each plot in different grazing periods can confirmed this point. At the short-term grazing for 4 years, the species richness was increased compared with that of before grazing, and was decreased ensued. It was determined mainly by grazing intensities and grazing time, and was also influenced by the moisture-temperature conditions of this period.

3.5 The influence of grazing on species diversity

Species diversity is an important characteristic of biological communities. Smith *et al*.[42] suggested that low grazing intensities caused the species diversity of plant communities to decrease in grassland ecosystems. Huston[43] suggested that there were a few species with high competitive ability on protected grassland. Moderate grazing induced coexistence of many species on grassland[35,43]. In this study, the Shannon-Wiener index and Pielou index on moderately grazed plot (MG) were the greatest compared with other plots after grazing for 11 years. The species richness was the greatest on moderately grazed plot (MG) compared with other plots since grazing experiment beginning. Our long-term grazing experiment with different stocking rates in alpine *P. fruticosa* shrub verified these hypotheses. Hobbs and Huenneke[44] suggested that substantial disturbance such as heavy grazing and protection from grazing reduced plant biodiversity. In this study, the Shannon-Wiener index and Pielou index on heavily grazed plot (HG) and ungrazed plot (CK) were less than other plots also verified this conclusion. The biodiversity index and richness at the greatest stocking rate was greater than those on ungrazed plot in this study, which were not similar with the result by Hiernaux[14] in grasslands of the Sahel. Light to moderate levels of livestock grazing can result in a richer diversity of plant species than heavy grazing or no grazing at all. This richer diversity is always caused by opening the vegetation canopy and allowing more species to compete successfully. In a word, long term heavy grazing easily caused the grassland degradation and species diversity loss. And, light grazing or grazing release always caused low herbage utilization, much accumulation of dead material which influenced the grassland quality and biodiversity conservation.

3.6 The intermediate disturbance hypothesis and grazing management

We have long known that herbivores influence community-level diversity through differentially utilizing or trampling plants variously susceptible to defoliation and other physical damage. Moderate intensities and periodicities of grazing and trampling usually increase community level diversity of plants by decreasing the ability of community dominants to competitively exclude other species and by creating physical gaps and freeing resources such as light, moisture, and nutrients[45]. At the moderately grazed plot (MG), the species richness and diversity were the greatest while the standing biomass was not the largest one at three clipping dates. It is worth to remember that the intermediate disturbance hypothesis[43] does not deal exclusively with plant diversity but rather with most of the components of a plant community, including standing biomass, plant cover etc. The result did not support the intermediate disturbance hypothesis very well although the change of the biodiversity and richness indices as the stocking rate increased was the typical unimodal response curve after grazing for 11 years. Other more experimental including productivity measurements in detail are necessary to test this hypothesis.

Grassland management aims to attain sustainable utilization, more palatable herbage and higher species diversity[1]. There is little argument that poor grazing practices were and in some areas still are, a primary cause of redirecting or accelerating plant degrading succession towards less desirable new plant communities. Because of severe situation of grassland degradation on the Qinghai-Tibet Plateau[33], it is urgent necessary to design appropriate management systems for pastoral production and biodiversity conservation in this fragile ecosystems. Moderately grazing on grassland can increase primary productivity, species diversity and the proportion of palatable herbage[46]. The moderately grazed treatments in this study removed 45% of annual above-ground growth[17,23]. Our results indicate moderate level of livestock grazing was desirable in the alpine shrub pasture of Qinghai-Tibet Plateau. Hence, results from the study on the Qinghai-Tibet Plateau seem to indicate that the standard grazing rule of "take half leave half" which has been recommended as a conservative management tool, may also have a significant positive impact on biodiversity conservation and preservation of range condition. Continuous grazing of a pasture at a constant high stocking rate is in effect zero management[47]. Studies on optimum grazing intensity in alpine grasslands[1] suggested optimum grazing intensities in warm season pasture and cold season pasture of 4.11 Tibetan sheep/hm^2 and 3.80 Tibetan sheep/hm^2, respectively. Grazing management of alpine shrub should be performed with this criterion to prevent grassland degradation, to improve grass utilization, and to sustain higher biodiversity on Qinghai-Tibet Plateau.

The response of plants to grazing is highly variable and depends upon the physiological and morphological characteristics of individual plant species, and varies widely with climatic conditions, grazing habits of animals, and the intensity and duration of grazing. The ecological and ensuing economic problems raised by heavy grazing and biodiversity loss in grasslands will be a major driving force for reducing analysis of grassland degradation[29,33]. On the Qinghai-Tibet Plateau, it will be important to progress from studying single factors in the grassland ecosystem to studying the interactions of multiple factors. Long-term grazing with different stocking rates appeared to have a significant effect on plant structure, species diversity, standing biomass and grassland quality as well[15]. However, impacts on system characteristics such as mammals, soils and environment[48], should be monitored by further studies. Herbage utilization by livestock grazing, lot of feces and urine from livestock will affect the nutrient recycling and availability of grassland, which is need more research work in *P. fruticosa* shrub in future. Such research will be important for establishing critical ecological thresholds for grassland succession and the role of biodiversity in grassland ecosystem functioning and resilience, as well as identifying threatened species and ecosystems.

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