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Effects of grazing disturbance on plant diversity, community structure and direction of succession in an alpine meadow on Tibet Plateau, China

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ABSTRACT

To elucidate the effects of grazing intensity and grazing time on plant diversity and community structure, as well as the successional differentiation in an alpine meadow, a controlled grazing trial, with six grazing intensities on an alpine meadow was conducted in the eastern Qilian Mountain region for four years. Using species accumulation curves, RDA ordination and variance decomposition, we analyzed the changes in proportion of dominant species, richness, abundance, as well as the life forms of plant communities under grazing disturbance. Both the grazing intensity and grazing time had a significant effect on these dominant species, richness, abundance, as well as the life forms in the plant community ($P < 0.01$). More detailed results showed that: (1) The richness and abundance of plant species were highest in the light grazing plot, and these increased as time passed. In the heavy grazing plot, the abundance of plant species decreased as time passed, but the richness of these species did not change significantly. (2) The abundance of Gramineae and Umbelliferae were negatively and significantly correlated with the duration of grazing treatments, whereas Plantaginaceae and Geraniaceae were positively and significantly correlated with the grazing intensity. Over time, the abundance of bunch-type plants decreased and other life forms of plants have increased. With the increase in grazing intensity, the plants' abundance with the rosette type did not change, but other life forms of plants decreased. The results of variance decomposition indicated that grazing disturbance has had greater effects on life forms and plant populations, followed by the changes in the dominant species and their abundance, with lesser effects on the richness of the species. Grazing intensity had a greater effect than the duration of the grazing treatment had. The results of PCA showed that the climax community in both the lowest and the highest grazing intensity plots had changed over time. In the sample plots with light grazing intensity, the plant community changed to an *Elymus nutans* + *Poa crymophila* community, but later changed to a *Melilotoides ruthenicus* + *Kobresia humilis* community under heavy grazing.

Alpine meadow is the most important ecosystem of the Qinghai-Tibet Plateau [1–2]. Presently, the grassland ecosystem in the region sees increasingly aggravated degradation, for which the human grazing disturbance is viewed as a key inducing factor [3]. The influence of grazing disturbance on plant communities could either be positive or negative, which does not solely depend on the type of grassland, but depends more on the intensity of grazing treatment [4–5]. Grazing intensity induces the changes in the plant composition of community and their combination dynamics [6–7], and it significantly influences the structural type and diversity of the grassland plant community at both the individual plant level and the community level [8–9]. Moreover, as a comprehensive inter-annual disturbance to the vegetation and soil, the grazing time destabilizes the steady climax community. With time passing by, the structure of the plant community deviates from its original changing pattern [10] and it inclines to differentiation [11–12], which acts more significantly upon annual short stoloniferous plants [12], and this has a cumulative effect over time [13].

Plasticity changes for different plant levels under grazing disturbance are the major forces that drives the changes in plant community and its functions [14], and these changes eventually causes a cascade reaction at the ecosystem scale all the way through the individual plant, population and community scale [15]. Presently, almost all natural grasslands are under different levels of grazing disturbance, to which the plants adapt at both the individual level and the community level under the cumulative effect annually, until a relative steady state of community is reached [10,14]. However, different plant species and their different plant levels all responds differently to a certain grazing intensity, and the competitive relations within a community always changes under the cumulative effect of time [10] and these influences the final arrival of the relatively steady community. Previous studies of the grazing disturbance to changes in plant composition of community were usually conducted by the means of gradient space, rather than gradient time [6–7], laying more emphasis on the effect of grazing

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intensity, but also taking less consideration on the influence of cumulative effect of grazing time on plant communities at a certain grazing intensity, thus they couldn't analyze the respective effects of grazing time and grazing intensity on community changes. However, in this study, we chose the plant community in an alpine meadow on the northeast border of Qinghai-Tibet Plateau as the research subject. We also selected controlled plots to be treated at different grazing intensities, explored the effects of those various grazing intensities on the dominant species, richness, abundance, population and life forms of different plant communities under the cumulative effect of grazing time by year, and we conducted variance decomposition of grazing time and grazing intensity, in order to elucidate their respective effects on dominant species and their richness, so as to provide the scientific basis for the recovery of degraded vegetation and establishment of a proper grazing management system.

1. Materials and methods

1.1. Profile of the research area

The research area is located at the northeast border of Qinghai-Tibet Plateau. In terms of administration, it is affiliated to Zhuaxixiulong Township, Tianzhu County, Gansu Province. Its geographical coordinates are 37°11′ - 37°14′N, 102°40′ - 102°47′E, with an elevation of 2958 m, average annual temperature − 0.1 °C and annual accumulated temperature (>0 °C) 1380 °C. Its annual precipitation is 416 mm, which mainly occurs from July to September, and its period sees 76% of annual total. There is no absolute frost-free period in this area, while the growing periods for plants are 120–140 days. Its soil type is of alpine meadow. The major grassland type is *Kobresia pygmaea* sub-meadow, while the dominant species are *Elymus nutans*, *Poa crymophila*, *Stipa grandis*, *Kobresia humilis*, *Melissitus ruthenica*, etc. The local herdsmen breed the white yak, alpine fine-wool sheep and indigenous Tibetan sheep as the major livestock species to graze on the natural grassland.

1.2. Experimental design

Based on the systematical investigation on the vegetation conditions and the practical grazing capacity in the research area, we found out that the medium-level grazing capacity was 4.5–5.0 sheep unit per hectare, around which the various grazing intensities were set up. The Gansu alpine fine-wool sheep with the same body weight were chosen as the research subjects. A total area of 10 hm^2, with level terrain and uniform grassland and with *Elymus nutans* and *Stipa grandis* as the dominant species was chosen to be divided into six plots, of which each had a different grazing intensity (Grazing intensity = Sheep unit × Grazing time / Grazing area) for trial (Table 1). The grassland with uniform primary conditions could eliminate other disturbance from the terrain and climate to grazing. In August 2012, the plots were fenced and the trial began. For 4 consecutive years, fixed-point investigation was carried out on the plant communities in the plots, in order to check the response of dominant species, richness, abundance, population and life forms of communities to the grazing time (2012–2015) and the grazing intensities (2.75–7.20 sheep unit/hm^2). Taking the quadrat as a unit, we employed the multivariate ordination method, to conduct variance decomposition of grazing time and grazing intensity in order to quantitatively analyze their individual effects on different plant levels of alpine meadow, and to also elucidate the effect of different grazing intensities on the changes of communities, along with the accumulation of grazing time.

1.3. On-site sampling

In August of each year, starting from 2012 to 2015, plant communities in the plots were investigated. A systematic random sampling method was applied to the plots, each of which was regularly divided into 9 smaller parts. In each of these parts, a quadrat was marked out randomly but it had to avoid margins of plant community and conglomerates of single-dominant-species clones. In other words, each plot was sampled 9 times repeatedly and a total of 216 quadrats were investigated in a period of 4 years. To integrate the research on the succession of communities, each sampling point had to be fixed after the first sampling, so that in the following years, those fixed points could be sampled again. The specific investigation methods are described as follows:

a. For the cover of each species in the communities: a 0.25m^2 of quadrat was applied with 100 pin points;
b. For the height of species: each of the species was measured 10 times randomly;
c. For the frequency of species: around the perimeter of each quadrat a sampling circle was tossed 20 times to record the frequency of each species. A maximum-value normalization method was applied, in order to calculate the relative values of each species' height, cover and frequency.

1.4. Data processing method

1.4.1. Species' abundance

Species' abundance = (Relative cover + Relative height + Relative frequency)/3 [16–17]. In each plant community, the top species ranked by abundance ordination are the dominant species. The total abundance of a plant community is the sum of each species' abundance. The LSD method was applied to the community abundance, in order to conduct multiple comparative analyses between various grazing times and various grazing intensities. The plants were categorized by family, which means that the family was designated to represent the population, and the sum of the abundance of each family of plants represented the abundance of the population in the category. According to the method of classification by plant functions, all the species were classified into 6 life forms (bunch type, rhizomatous type, rosette type, stoloniferous type, annual type and erect type) [18].

1.4.2. Species' richness

Richness was represented by the amount of species in each quadrat and it was denoted as *SRs*; the species' richness in the same plot but in a different year was denoted as SR_p; the species' richness in the same year but in a different plot was denoted as SR_Y; the total species' richness was denoted as SR_T. The LSD method was applied to *SRs*, in order to have multiple comparative analyses between various grazing times and various grazing intensities. The first-order Jackknife index [19] (Jack 1)—$SR(J) = SR(ob) + a * n / (n - 1)$—was used to predict the species' richness of plots in different years and at different intensities. In the

Table 1
Information of studying plots.

Plots	Areas/hm^2	Species richness	Cover/%	Biomass/(g/m^2)	Livestock number	Grazing intensity/(sheep unit/hm^2)
1	2.18	8.00 ± 1.63b	88.50 ± 3.42a	310.40 ± 76.97a	6	2.75
2	1.10	8.25 ± 2.22b	91.00 ± 6.22a	321.00 ± 17.40a	4	3.63
3	1.61	13.40 ± 2.07a	89.20 ± 6.30a	293.60 ± 31.70a	7	4.36
4	1.26	10.00 ± 2.23b	89.20 ± 4.44a	260.00 ± 44.18a	6	4.78
5	2.50	10.40 ± 1.67b	91.20 ± 1.48a	310.40 ± 76.97a	13	5.19
6	1.11	11.00 ± 1.00b	90.57 ± 3.67a	298.50 ± 55.71a	8	7.20

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