

Changes in plant community diversity and aboveground biomass along with altitude within an alpine meadow on the Three-River source region

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The grassland is an important component of terrestrial ecosystems and plays a significant role in biodiversity and ecosystem functions. In the present study, the changes of plant species diversity and aboveground biomass productivity were examined along with the altitude in natural alpine grassland in the source region of three rivers on the Qinghai-Tibetan Plateau. Eleven experimental locations were selected with altitudes ranging from 3862 to 4450 m above sea level (a.s.l.). The results indicated that *Kobresia pygmaea* meadow, *Kobresia humilis* meadow and *Salix cupularis* shrub meadow had higher indices of diversity and aboveground biomass. The distribution of species diversity, richness and aboveground biomass showed similarly unimodal patterns across the altitude gradient with the highest indices appeared at mid-altitudes locations. The changing trend of species diversity, richness and evenness also showed significant unimodal patterns with total aboveground biomass, and the highest species diversity occurred at intermediate level of productivities. This research would provide a valuable reference for the protection of grassland biodiversity and maintaining of the grazing ecosystem function in the source region of the Three Rivers.

alpine meadow, species diversity, richness, evenness, aboveground biomass, Qinghai-Tibetan Plateau

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Biological diversity plays an important role in the functioning and sustainability of the ecosystems [1]. The changes of plant community structure and decreasing productivity in grasslands in some areas were attributed to the overgrazing, mismanagement of natural grasslands and the destruction of biodiversity [2,3]. The productivity of ecosystem is regarded as a good indicator to evaluate the impact of plant species diversity on function of ecosystem. Many efforts have been made to identify the relationship between species diversity and productivity. However, the observed effects of plant diversity on productivity have been inconsistent possibly due to the complexity in ecological characteristics among investigations [2–4]. In natural biological communities, the relationships between species diversity and productivity have been altering along with time and spatial scales [3,4].

Therefore, further work on relationship between species diversity and productivity at different scales and various ecological contents are still needed.

Qinghai Province is one of the main animal husbandry bases of China. It has natural pastureland of approximately 36.45 million hectares, of which there is alpine meadow of 24.00 million hectares, accounting for 65.06% of total pastureland in Qinghai [2]. The source region of the three major rivers (the Yangtze, Yellow and Lantsang rivers) is one of the most important areas for livestock grazing in Qinghai [5]. However, lack of scientific management of the pasture resources over a long time has led to overgrazing and rodent pest damage [6,7]. In addition, the human activity and global climate change jointly accelerate the potential for degradation of the alpine meadow in this region, and major changes to the species diversity of vegetation communities [5–7]. If a large amount of pastureland keeps degrading, not only the sustain-

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able development and local environmental quality will be threatened, but also the economic development in the lower reaches will be challenged [8]. Maintenance of diversity plays an essential role in the control of water and soil erosion, and keeping ecological balances in both the source area and the lower reaches of the three rivers [2–4,6,7].

The relationship between biological diversity and their productivities in the natural communities could be reflection of species diversity during long-term of evolution [3,4]. However, only few works have been conducted on the relationship between the species diversity and productivity of alpine meadow, especially in the high mountain area [2–8]. This study was carried out in different types of natural vegetation communities in the alpine meadow zone, across a range of altitudes. The trends of the aboveground biomass along with altitude and the relationship between community diversity and aboveground biomass were analyzed. This research would provide a basic reference for the protection and sustainable use of the natural grassland resources, and the rehabilitation of degraded grassland by using natural vegetation [9] in the Three Rivers District.

1 Materials and methods

1.1 Study area and sample collection

The study was carried out at Jianshe township, Dari County, Guoluo Prefecture, in the hinterland of the Three Rivers District, Qinghai Province (33°40′–33°42′N, 99°23′–99°26′E). This area is relatively less affected by grazing activity as animal graze on these grasslands only in winter and spring. The sampling sites were located in a wide valley stretching from southwest to northeast with an average altitude of 4156 m a.s.l. This region has a typical plateau continental climate with an annual mean precipitation of 571.2 mm and annual mean air temperature of 0.3°C. The annual accumulated air temperature above 0°C is 824.6°C and growth duration is 124 d. The main vegetation types are alpine meadow and alpine shrub meadow. The dominant species are *Kobresia pygmaea*, *Kobresia humilis*, *Kobresia tibetica*, *Kobresia capillifolia*, *Poa pratensis*, *Carex tristachya*, *Salix cupulari*. The main soil types are alpine meadow soil and alpine shrub meadow soil.

In August 2010, eleven experimental sites (50 m × 50 m) were chosen at the altitude gradients ranging from 3862 to 4450 m along the valley. Five sampling quadrats (1 m × 1 m and 5 m × 5 m for shrub meadow) were selected from each area of 50 m × 50 m. The detailed geographical information of the samples and the numbers of plant species, the average vegetation height and the vegetation coverage for each sampling sites are listed in Table 1.

1.2 Determination of plant aboveground biomass

The aboveground plant material was cut and dissected to

determine the fresh weight of monocotyledons, dicotyledons and shrubs in each sample. The samples were dried at 80°C in the thermostated container until a constant weight. The aboveground biomass was separated into monocotyledons (Gramineae and Cyperus etc.), dicotyledons (Leguminosae and Compositae etc.) and shrubs.

1.3 Processing of data

Relative vegetation cover was used to calculate indices of the richness, evenness and species diversity using the following methods [10,11]:

Richness index: $R = S$,

Shannon-Wiener index: $H' = -\sum P_i \ln P_i$,

Pielou evenness index: $J = H'/\ln S$,

where P_i is the relative cover of species i ; S is the total number of species i in a certain sample.

Origin Pro 8.0 software package was used for graphing and data analysis.

2 Results and discussion

2.1 Characteristics of the vegetation community

The dominant plant species were used to represent each of the vegetation communities. There were nine vegetation community types recorded across the 11 sampling sites along the elevation gradients (Table 1). The main types were composed of *K. pygmaea* meadow, *K. humilis* meadow, *K. pygmaea*+*Carex tristachya* meadow, *K. pygmaea*+*K. capillifolia* meadow, *K. pygmaea*+*K. tibetica*, *K. pygmaea*+*Poa pratensis* meadow, *K. pygmaea*+*P. anserina* meadow, *S. cupularis*+*Carex tristachya* shrub meadow, *S. cupularis*+*K. capillifolia* shrub meadow.

In such natural environments, the species compositions of different vegetation communities are the result of adaptation to local conditions. In the long-term evolution, the different vegetation communities developed specific structures and species compositions [2]. In this study, the species diversity in the *K. pygmaea*+*C. tristachya* meadow was the highest, and the lowest diversity in the *K. pygmaea* meadow at the highest altitude sites.

The evenness index decreased in the order of *K. pygmaea* meadow, *K. humilis* meadow, *S. cupularis* shrub meadow and *K. pygmaea*+*P. anserina* meadow. The evenness index in the *K. pygmaea* community and *K. humilis* community was relatively higher because their dominant species were more evenly distributed. In contrast, there were only 1 or 2 dominant species in the *K. pygmaea*+*P. anserina* meadow, which might account for the relatively lower evenness index. The highest total aboveground biomass was observed in *S. cupularis* shrub meadow while the lowest aboveground biomass was found in *K. pygmaea* meadow at the highest altitude sites due to the relatively simple community structure compared with the others (Table 1).

Table 1 Geographical information, vegetation coverage, average height, species diversity indices and aboveground biomass at 11 elevation sites

| Altitude (m) | Latitude (N) | Longitude (E) | Vegetation community | Shannon-Wiener index | Total species | Pielous index | Total aboveground biomass(g/m ²) | Coverage (%) | Average height (cm) |
|--------------|--------------|---------------|---|----------------------|---------------|---------------|--|--------------|---------------------|
| 3862 | 33°41.376' | 99°24.883' | <i>Kobresia humilis</i> | 2.86 | 26 | 0.87 | 196.60 | 87 | 4.56 |
| 3905 | 33°41.323' | 99°25.021' | <i>Kobresia pygmaea</i> | 2.89 | 28 | 0.89 | 210.89 | 89 | 4.91 |
| 3960 | 33°41.012' | 99°25.512' | <i>Kobresia pygmaea</i> + <i>Carex tristachya</i> | 2.94 | 32 | 0.89 | 225.61 | 92 | 5.02 |
| 4012 | 33°41.203' | 99°25.315' | <i>Salix cupularis</i> + <i>Carex tristachya</i> | 2.88 | 29 | 0.85 | 279.92 | 87 | 97.25 |
| 4150 | 33°41.667' | 99°25.301' | <i>Salix cupularis</i> + <i>Kobresia capillifolia</i> | 2.86 | 29 | 0.86 | 258.01 | 85 | 92.64 |
| 4190 | 33°41.531' | 99°25.036' | <i>Kobresia pygmaea</i> + <i>Kobresia capillifolia</i> | 2.87 | 27 | 0.88 | 202.49 | 89 | 5.25 |
| 4241 | 33°41.116' | 99°25.136' | <i>Kobresia pygmaea</i> + <i>Kobresia tibetica</i> | 2.83 | 26 | 0.86 | 190.46 | 82 | 5.19 |
| 4299 | 33°41.612' | 99°24.731' | <i>Kobresia pygmaea</i> + <i>Poa pratensis</i> | 2.84 | 25 | 0.85 | 167.86 | 86 | 4.57 |
| 4338 | 33°41.311' | 99°24.136' | <i>Kobresia pygmaea</i> + <i>Potentilla anserina</i> | 2.75 | 21 | 0.82 | 128.27 | 78 | 4.28 |
| 4381 | 33°41.336' | 99°23.552' | <i>Kobresia pygmaea</i> | 2.74 | 20 | 0.83 | 118.23 | 81 | 4.26 |
| 4450 | 33°41.012' | 99°23.116' | <i>Kobresia pygmaea</i> | 2.73 | 19 | 0.82 | 101.32 | 80 | 3.63 |

2.2 Relationship of community diversity with altitude

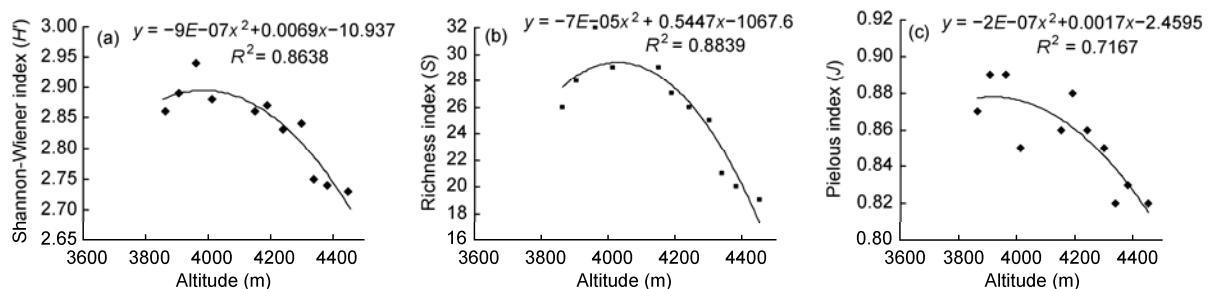
The indices of Shannon-Wiener, richness and evenness of the species diversity varied greatly with altitude (Table 1). The Shannon-Wiener index of the species diversity increased with altitude from 3862 to 3960 m, and reached the maximum at the elevation of 3960 m. Above that point, the Shannon-Wiener index generally decreased with the increasing of elevations, and the lowest index of Shannon-Wiener was found at the highest altitude of 4450 m (Figure 1(a)). The distribution of the species richness and evenness along the altitude were similar to the variations of species diversity index (Figure 1(b) and (c)). The maximum species richness index also occurred at the elevation of 3960 m, and the lowest index of species richness occurred at the elevation of 4450 m. The evenness of the species varied between 0.82 (at altitudes of 4338 and 4450 m) and 0.89 (at altitudes of 3905 and 3960 m).

The trends of species diversity, richness and evenness with altitude were well described by negative quadratic functions with correlation coefficients R of 0.9294, 0.9402 and 0.8466, respectively ($P < 0.05$) (Figure 1(a)–(c)), which suggested that their distribution clearly showed

unimodal patterns across the eleven altitude gradients. In such extreme environmental conditions, especially at highest altitude with lowest temperature stress, some vegetation species disappeared and the species diversity accordingly became lower. The greatest species diversity was found at middle level altitudes whereas multi-dominant species communities led to higher richness and evenness. This observation was similar to the results by Wang et al. [4] and Gentry [12] who also described a “mid-domain” distribution pattern of plant species diversity with the elevations.

2.3 Relationship of aboveground biomass with altitude

The aboveground biomass increased with altitude from 3862 m and reached maximum at elevation of 4012 m and then decreased with increasing elevation (Table 1). The changing trend of aboveground biomass with altitude showed a negative quadratic function with the coefficient R of 0.9251 (Figure 2(a)). In the present study area, the monocotyledonous biomass was found to contribute 49.58%–68.55% (average 60.22%) to the total aboveground biomass, suggesting the monocotyledons biomass had a major

**Figure 1** Relationship of species diversity, richness and evenness index with altitude. (a) Species diversity; (b) richness index; (c) evenness index.

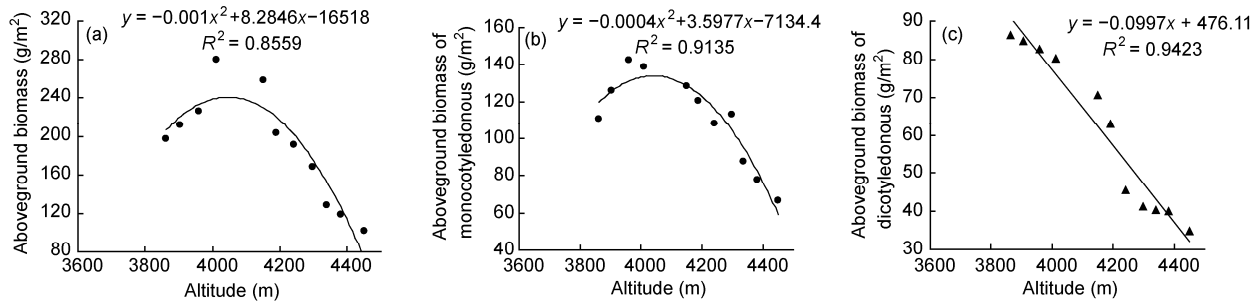


Figure 2 Relationship of aboveground biomass with altitude. (a) Total biomass; (b) monocotyledonous biomass; (c) dicotyledonous biomass.

influence to the overall vegetation community. The distribution of monocotyledons aboveground biomass with altitude was consistent with that of the total aboveground biomass (Figure 2(b)). The dicotyledonous biomass was found to contribute 23.92%–43.90% (average 32.40%) to the total aboveground biomass. The changing trend of dicotyledonous biomass with altitudes exhibited a different distribution pattern. The dicotyledonous biomass decreased with the increasing of the altitude showing a significantly negative linear correlation ($P < 0.05$) (Figure 2(c)).

2.4 Relationship of species diversity with aboveground biomass

The changes in plant diversity at different locations depend on interspecies competition for the limited resources of the plant community [13]. Plant species richness can affect the stability of the grassland ecosystem [14]. The species diversity, richness and evenness were greatest at an intermediate level of aboveground biomass (225.61 g/m²). The lowest Shannon-Wiener index occurred at the highest altitude sites with the lowest biomass production (101.32 g/m²).

The relationships of the species diversity, richness and evenness with the total aboveground biomass showed unimodal distribution patterns, which can be described by quadratic functions with correlation coefficients R of 0.9333, 0.9533 and 0.8953, respectively (Figure 3(a)–(c)). This result was consistent with the findings by Kassen et al. [15], Yang et al. [16] and Wang et al. [3] who observed that the higher species diversity, richness and evenness occurred in

the middle level of productivities. On the one hand, the nutrient availability was usually higher at the lower altitude, which made a few species so robust and thus the less competitive species were excluded [4]. On the other hand, the richness and evenness of the species usually were lower due to the restrictions by the harsh environmental conditions at the highest altitude areas, which accounted for the relatively lower diversity and lower biomass productivity.

2.5 Implications for utilization and protection on the grassland ecosystem

Species diversity can be influenced by many factors including environmental and human factors [17]. It is difficult to change the environmental factors, but we can protect the species diversity by effectively controlling human activities, particularly in relation to livestock management, according to different environmental conditions.

To protect grassland biodiversity and maintain the grazing ecosystem function in the source region of the Three Rivers in Qinghai-Tibetan Plateau, we can carry out different grassland and livestock management measures according to the specific environmental condition [18–21]. For example, we can graze different types of animals in different types of grassland. The *K. pygmaea* meadow is suitable for grazing by yak and Tibetan sheep, whereas the *Kobresia* swamp meadow is suitable for grazing yak only [19]. Because vegetation species diversity and aboveground biomass generally drops with the increasing of altitude, we should adjust grazing intensity according to the altitude of the

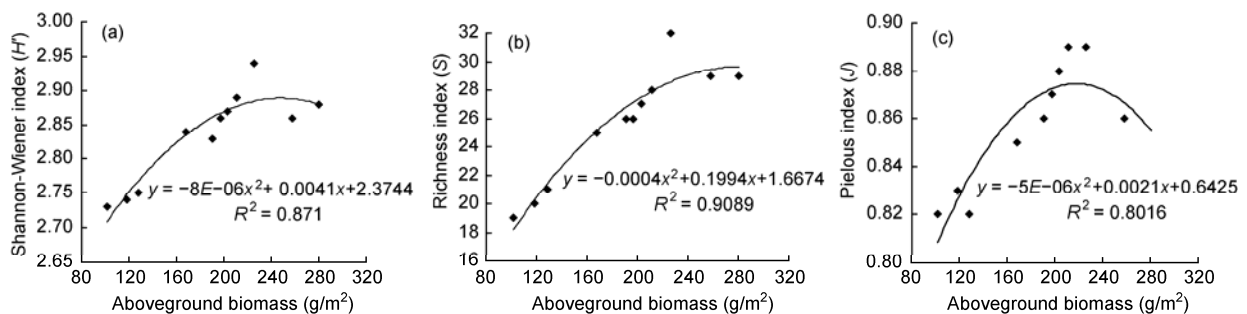


Figure 3 Relationship of Shannon-Wiener index, richness index and evenness index with aboveground biomass. (a) Shannon-wiener index; (b) richness index; (c) evenness index.

specific grassland in order to protect the species diversity and grassland [21].

3 Conclusions

This study examined the species diversity for different vegetation communities across a range of altitudes in natural alpine grassland in the headwater region of the Three Rivers. The *K. pygmaea* meadow is the main type of grassland in the study area and also it has the highest indices of species diversity, richness and evenness. The trends of the species diversity, aboveground total biomass and monocotyledonous biomass showed similar unimodal distribution patterns along with the elevation gradient that the highest species diversity and productivity occurred at the mid-altitude area (3960–4150 m). In contrast, the aboveground dicotyledonous biomass exhibited the trend of continuous decline with the increasing of altitude. The changes in species diversity and productivity of the different vegetation communities could be influenced by the characteristics of individual species and environmental conditions. Further research is still necessary to get a better understanding of the effects of environmental factors such as temperature, soil nutrient and human disturbance (including grazing intensity) on community diversity in this region.

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