EFFECT OF PLATEAU ZOKORS ON VEGETATION CHARACTERISTICS AND PRODUCTIVITY OF ALPINE MEADOW

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Abstract : This research was conducted on alpine meadow site at Menyuan county , Qinghai Province , People 's Republic of China to determine the effects of native , subterranean rodent of Qinghai-Tibet grasslands , the plateau zokors (*Myospalax baileyi*) , on seasonal above-and below-ground plant biomass , plant species diversity and productivity.

Both total peaks of above-and below-ground biomass were the greatest (413. 600 g/m^2 and 2 297. 502 g/m^2) in the patch no any plateau zokors colonized and least (170. 200 g/m^2 , 489. 110 g/m^2) in the patch colonized by plateau zokors over 10 years in August and October , respectively. Both above-and below-ground biomass were significantly increased in the patches where plateau zokors were removed or the burrow systems were abandoned for five years compared to the patches plateau zokors colonized over 10 years. However , both above-and below-ground biomass in abandoned patches were significantly lower than that in uncolonized patches. Monocotyledonous biomass was reduced greatly , but the non-palatable dicots were significantly increased in colonized patches. The palatable biomass of monocots and dicots were increased in abandoned patches. Total plant species diversity was the greatest in uncolonized patchesand least in abandoned patch. The total net primary production in colonized patches was reduced by 68. 98 % compared with uncolonized patches. Although the patches were without any plateau zokors disturbance for fives years , the total net primary production just reached 58. 69 % of the uncolonized patches. The above-ground net primary production in abandoned patches increased 28. 74 % and the below-ground increased 54. 91 % compared with the colonized patches.

We suggest that plateau zokor-induced changes in plant above- and below-ground biomass and species diversity may lead to further alterations of nutrient cycling and trophic dynamics in this alpine meadow ecosystem.

Key words : Plateau zokor (*Myospalax baileyi*) ; Plant biomass ; Plant productivity ; Alpine meadow
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Small mammals via their burrowing activities , can alter varieties of vegetation including species composition , cover , height and above-and below-ground biomass[1 - 6] . As for subterranean herbivore rodents , they forage plants underground or pull it down from below , consuming roots or entire plants. Meanwhile , they continuously excavate underground and remove soil to the surface , and deposit in aboveground[7 ,8] . These activities may have a negative or positive effects upon vegetation , especially when the densities of herbivores in steppe , prairie , and meadow are high[9 - 12] .

The plateau zokor (*Myospalax baileyi*) , is highly specialized subterranean herbivores which is broadly distributed in farm , prairie , alpine prairie and meadow in Qinghai-Tibet plateau[13] . They exhibit several ecological characteristics which could influence the plant communities under which they live. Unlike aboveground herbivores , plateau zokors are constrained in their activities to burrow systems , they spend all their lifetime underground. Few , if any , activities would be involved beyond burrow systems throughout their life. There is only subterranean rodent species in Qinghai-Tibet plateau. The distribution and population density of plateau zokors are strictly limited by natural factors such as elevation , vegetation , precipitation , tundra , and other artificial disturbance[13] . Because plateau zokors have been traditionally viewed as damagers of vegetation and competitors with cattle for range land resources , eradication programs have been carried out by local government and farmers every year to reduce their populations. However , at present they still dwell on about 3.8×10^6 hectares at average densities of 5 - 20 animals/hm^2 in Qinghai province[13] .

After colonizing over many years , plateau zokors have created large , distinct patches within the grassland matrix , and ecosystem processes that occur within the patches may proceed at different rates than those outside the uncolonized area. Despite their obvious influence on the ecological properties of grassland in Qinghai-Tibet , their current status as farm and agriculture pest , and their natural role as agents intensed vegetation disturbance have not been well documented. Their ecological characteristics are poorly known , and the effects on ecosystem structure and dynamics have been ignored or overlooked by those investigating disturbance and patch dynamics[14 ,15] .

An overall goal of this research is to assess the impact of plateau zokors on the seasonal plant biomass , species diversity , plant productivity on Qinghai-Tibet plateau alpine meadow , following colonization for different lengths of time. Specific objectives of the present study were to :

1. Assess the magnitude of burrow activity by plateau zokors in this community ;
2. Determine the effect of plateau zokor digging and grazing activity on plants ;
3. Determine the influence of digging activity on net primary production in alpine meadow.

The hypothesis will be tested in this study is that the long-term colonization of plateau zokors have negative effects on plant biomass , including both above and below ground , and cause species diversity and primary productivity to decrease. Those varieties may lead to further alterations of nutrient cycling and trophic dynamics in this alpine meadow ecosystem.

1 MATERIALS AND METHODS

1.1 Study area

This study was conducted in Haibei Research Station of Alpine Meadow Ecosystem, the Chinese Academy of Sciences, Menyuan County, approximately 155 km north of Xining City, the capital of Qinghai Province, with latitude 37°29′- 37°45′N, longitude 101°12′- 101°33′E, and elevation at 3 200 - 3 300 m, from 1989 to 1998. There is the typical alpine continental climate, the place does not have a real summer, only the cold and warm seasons can be recognized. The annual mean temperature is -2 ℃, ranging from 27.5 ℃ in July to 35.0 ℃ in January. Mean annual precipitation is 530 mm, of which 55 % occurs between June and August[16]. Previous research works about vegetation, animal community, and soil types have been reported in this region[17-19]. There are an extensive grassland of *Kobresia humilis* alpine meadow and shrubs. Dominant graminoids and forbs in the meadow include *Kobresia humilis*, *Stipa aliena*, *Elymus nutans*, *Kobresia pygmaea*, *Poa* sp., *Carex* sp., *Potentilla anserina*, *Ajania tenuifolia*, *Leontopodium nanum*, *Potentilla nivea*, *Potentilla bifurca*, *Elsholtzia calycocarpa*, *Morina chinensis*, *Saussurea Katochaete*, *Aster flaccidus*, *Taraxacum mongolicum*, *Glaux maritima*, *Anaphalis lactea*, *Pedicularis kansuensis*, *Gentiana straminea*, *Gueldenstaedtia diversifolia*, *Trigonella ruthenica*, *Gentiana farreri* and so on. *Dasiphora fruticosa* is the principal shrub in this region.

Plateau zokor is abundant at average densities of 15 animals/hm^2, ranging from 10 - 25 animals/hm^2 in this region. There are also many other small mammals such as the marmota (*Marmota himalayana*), the plateau pika (*Ochotona curzoniae*), the kansu pika (*O. Cansa*), and the root vole (*Microtus oeconomus*).

Study sites were located in *Kobresia humislis* alpine meadow of the broad valley bottoms, 2 km north of the research station. Eighteen circular study sites were selected in May 1989, each 0.25 hm^2 size ($3.14 \times 28.21\ m^2$). While investigating the population densities of plateau zokor, we also marked the patches and mounds created by plateau zokors in study sites on map. Plateau pika and marmots in this region were killed successfully by local government using poison baits in March and April 1989. Only a few kansu pikas and root voles intruded into this region since that time. Some of plateau zokors in 9 sites were removed in 1992 and 1993. The patches left by removed zokors in those sites were investigated and marked on map again. The investigation of population density was conducted in October every year.

According to the patches colonized by plateau zokors for different lengths of time in those sites, three subsets were established for analysis as follows in 1998:

1. The patches created and colonized by plateau zokors over ten years, in which new mounds always appeared during the period of ten years investigation.

2. The abandoned patches. The patches had created by plateau zokors before 1989, but, the zokors were removed or the habitat was abandoned in 1992 and 1993. No any other zokors intruded, and there are not any new mounds and burrows formed after 1993.

3. The uncolonized patches. There is no any mounds or tunnels created by plateau zokors appeared in this area.

1.2 Vegetation sampling

Aboveground plant biomass was measured monthly in three subsets from May to September respectively. In each patch, 5 sampling quadrats (50 × 50 cm^2) were randomly assigned, and other 20 sampling quadrats (25 × 25 cm^2) were selected for investigating plant species, vegetation cover and height in August. Vegetation were clipped, sorted, dried at 60 ℃ for 48 hours and weighted. Root biomass of three subsets were estimated monthly from May to October, 5 sampling cuboids (25 × 25 × 30 cm^3) were taken and separated into three layers at 0 - 10 cm, 10 - 20 cm, and below 20 cm in each subsets. The roots were collected carefully in each layer, washed, dried at 60 ℃ for 48 h and weighted.

1.3 Statistical analyses

Statistical analyses consisted of tests and analysis of variance procedures (ANOVA) and were accomplished with the aid of the Statistical Package for the Social Sciences[20]. Normality of data was tested with g_1 and g_2 statistics and appropriate transformations were utilized[21]. Mean comparisons were performed using Fisher's Protected LSDs. Non-parametric tests were employed in cases where transformations did mot normalize data[22]. Plant species diversity was calculated with the Shannon-Wiener index, $H' = -\Sigma P_i \ln P_i$.

2 RESULTS

2.1 Vegetation characteristics and plant species diversity in three patches

Forty-two plant species were found in uncolonized patches, and twenty-four in both colonized and abandoned patches (Table 1). The vegetation diversity index is the greatest in uncolonized patch as well as monocotyledon and dicotyledon diversity index in August. There were significant differences in vegetation cover ($F = 69.998$, $df = 2, 57$, $P < 0.001$) and height ($F = 33.904$, $df = 2, 57$, $P < 0.001$) between three patches. The vegetation diversity index slightly decreased, although both vegetation cover and height significantly increased in abandoned patches compared to the colonized patches ($t = 5.774$, $n = 20$, $P < 0.001$ for vegetation cover, $t = 4.469$, $n = 20$, $P < 0.001$ for vegetation height).

Table 1 Total number of plant species sampled, plant species diversity (H'), cover and height of vegetation on August 1998 on the patches of plateau zokors colonized over 10 years, abandoned for 5 years and uncolonized in alpine meadow

Vegetation characteristics	Patch		
	Colonized	Abandoned	Uncolonized
Plant species			
Monocotyledon	3	5	10
Dicotyledon	21	19	32
Total vegetation	24	24	42
Plant species diversity (H')			
Monocotyledon	0.816	1.504	2.199
Dicotyledon	2.558	2.067	2.887
Total vegetation	2.719	2.506	3.197
Cover (%)	19.2 ± 2.4 ($n = 20$)	47.1 ± 4.8 ($n = 20$)	81.2 ± 3.5 ($n = 20$)
Height (cm)	9.7 ± 1.4 ($n = 20$)	23.8 ± 3.2 ($n = 20$)	42.2 ± 3.4 ($n = 20$)

2.2 Total plant aboveground biomass in three patches

Maximum total above ground biomass was recorded in August at all three patches in *Kobresia humilis* alpine meadow, although it was slightly decreased in September (Fig. 1a) . The greastest peak biomass, 413. 601g/m^2 , was found on the uncolonized patches. The minimum value for peak above-ground biomass was 170. 192 g/m^2 on the patches colonized over ten years. A 2-way ANOVA was used to detect differences in the total above-ground biomass between patches, and between months. There were significant difference in the total above-ground biomass between patches (F = 62. 440, df = 2, 8, P < 0. 001), and between months (F = 62. 440, df = 4, 8, P < 0. 001) . The uncolonized patches exhibited significantly more biomass than colonized patches (F = 168. 753, df = 1, 4, P < 0. 001) between May and September (F = 38. 398, df = 4, 4, P < 0. 001) . The biomass in abandoned patches were also significantly lower than that in uncolonized patches (F = 108. 600, df = 1, 4, P < 0. 001) during the growing season (F = 53. 023, df = 4, 4, P < 0. 001), although there had not been disturbed by plateau zokors for five years in this area and the vegetation had been in the stage of recovery.

2. 3 Monocotyledon aboveground biomass in three patches

The intraseasonal dynamics pattern of monocotyledon biomass in three patches showed the same pattern as that of total above-ground biomass (Fig. 1b) . The results of 2-way ANOVA revealed that the biomass of monocotyledon in uncolonized patches were significantly higher than that in colonized patches (F = 189. 692, df = 1, 4, P < 0. 001) between May and October (F = 10. 561, df = 4, 4, P < 0. 01) . The monocotyledon biomass in abandoned patches was significantly increased (F = 41. 432, df = 1, 4, P < 0. 001) during the period of growing season (F = 12. 161, df = 4, 4, P < 0. 01) compared to the colonized patches. However, it was obviously lower than that of uncolonized patch (F = 151. 795, df = 1, 4, P < 0. 001) between different months (F = 17. 478, df = 4, 4, P < 0. 01) .

2. 4 Non-palatable dicot aboveground biomass in three patches

In spite of sizeable reductions in total and monocotyledon above-ground biomass, the non-palatable dicot biomass was significantly increased in colonized patches (Fig. 1c) compared to the uncolonized patches (F = 27. 417, df = 1, 4, P < 0. 001) between May and September (F = 53. 305, df = 4, 4, P < 0. 01) . There were not significant difference in non-palatable dicot biomass between abandoned and colonized patches (F = 4. 115, df = 1, 4, P = 0. 486), although plateau zokors in abandoned patches had been removed over five years. Meanwhile, the non-palatable dicot biomass in abandoned patches was greater than that in uncolonized patches (F = 5. 250, df = 1, 4, P < 0. 05) during the growing season (F = 30. 895, df = 4, 4, P < 0. 01) .

2. 5 Palatable dicot aboveground biomass in three patches

In contrast, the palatable dicot biomass was highest in uncolonized patches, higher in abandoned patches and lowest in colonized patches between May and September. Each of the values was significantly different from all others at the 0. 05 level (Fig. 1d) .

2. 6 Below ground biomass in three patches

In terms of below ground biomass (Table 2), there was statistically significant differences be-

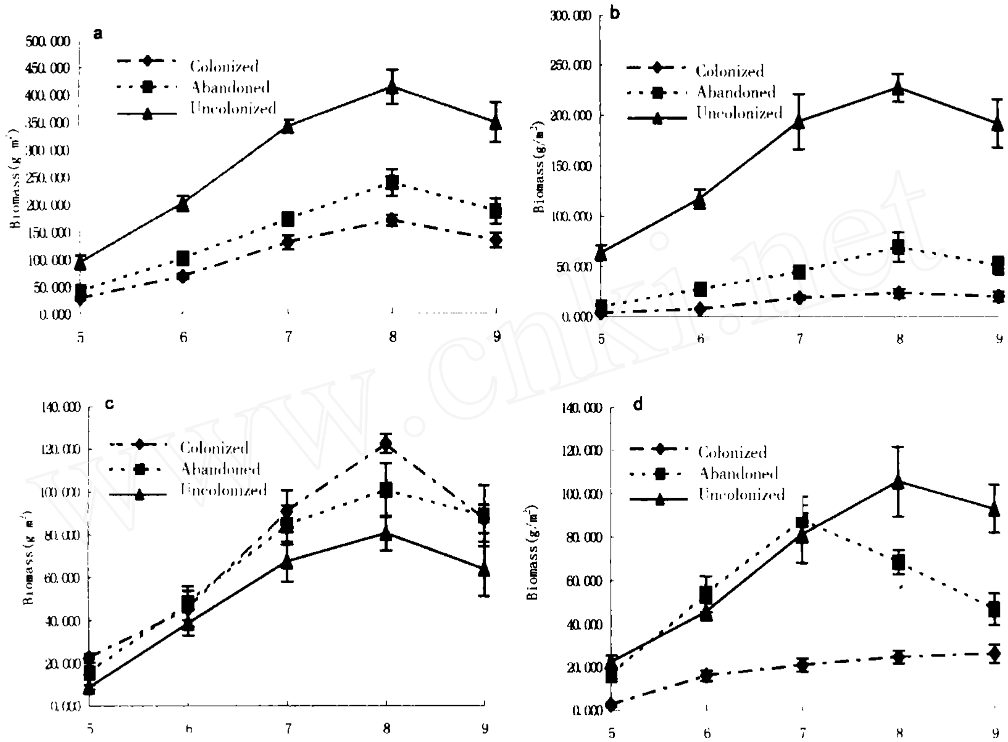

Fig. 1 Intraseasonal variation in total aboveground plant biomass, and three plant functional biomass on the patches of plateau zokors colonized over 10 years, abandoned for 5 years and uncolonized in alpine meadow in 1998

tween three patches ($F = 197.248$, $df = 2, 10$, $P < 0.001$) from May to October ($F = 7.450$, $df = 5, 10$, $P < 0.01$).

Table 2 **The total below-ground biomass of plants** (g/m^2) (**Mean ±SE**) **on the patches of plateau zokors colonized over** 10 **years**, **abandoned for** 5 **years and uncolonized in alpine meadow in** 1998

Month	Patch		
	Colonized (n = 5)	Abandoned (n = 5)	Uncolonized (n = 5)
5	278.898 ±10.378	1021.220 ±16.085	1666.550 ±13.380
6	261.470 ±6.996	1111.884 ±15.776	1586.248 ±12.836
7	228.500 ±6.809	968.636 ±15.294	1472.267 ±16.504
8	363.236 ±13.129	1229.546 ±16.375	1960.074 ±17.302
9	426.152 ±13.189	1369.760 ±16.340	2297.502 ±12.823
10	489.110 ±13.213	1546.640 ±19.360	2450.306 ±16.297

Unlike the intraseasonal dynamic pattern of aboveground biomass, the below ground biomass in three patches gradually decreased form May to July, the lowest occurred in July, and then slowly increased between July and October. The highest of three patches were in October. The below ground biomass in colonized patch reduced by approximately 80 % compared to the uncolonized patch. There was increased nearly 3 - 4 times in below ground biomass in abandoned patch after plateau zokors were removed over five years.

2.7 Net primary production in three patches

Net primary production was calculated with the method introduced by Yang[17]. We assumed the biomass foraged by plateau zokors and cattle was zero, because the sites sampled in those patches was excluded and no any mounds appeared in 1998. The net primary production in three patches was showed in table 3.

Table 3 The net primary production on the patches of plateau zokors colonized over 10 years, abandoned for 5 years and uncolonized in alpine meadow in 1998

Vegetation productivity	Patch		
	Colonized	Abandoned	Uncolonized
Aboveground			
Net primary production (g/m² ·yr.)	170.196	238.842	413.601
Average net production per day in period of growth (g/m² ·d) *	1.261	1.769	3.064
Solar energy storage (kJ/m² ·yr.) **	3292.525	4620.515	8001.313
Belowground			
Net primary production (g/m² ·yr.)	260.610	578.004	978.046
Average net production per day in period of growth (g/m² ·d)	1.930	4.282	7.245
Solar energy storage (kJ/m² ·yr.)	4943.564	10964.270	18552.750
Total			
Net primary production (g/m² ·yr.)	430.806	816.846	1391.647
Average net production per day in period of growth (g/m² ·d)	3.191	6.051	10.309
Solar energy storage (kJ/m² ·yr.)	8236.089	15584.790	26554.060

* The growth period is 135 days in *kobresia humilis* meadow; ** The calorific value of aboveground biomass is 19.345 kJ/g, ash-free, and the belowground is 18.969 kJ/g, ash-free[17]

Dramatic difference occurred between three patches in the net primary production (Table 3). The total net primary production in colonized patches was reduced by 68.98 % compared with uncolonized patches. Although no any plateau zokors disturbed for fives years, the total net primary production just reached 58.69 % of uncolonized patches. The aboveground net primary production in abandoned patches increased 28.74 % and the below-ground increased 54.91 % compared with colonized patches.

3 DISCUSSION

Data from three patches indicated that with long-term colonized by plateau zokors, the plant diversity index, vegetation cover and height were obviously decreased in alpine meadow (Table 1). Both above-and below-ground biomass are reduced approximately by 59 % and 80 % compared to uncolonized patches in August, respectively (Fig. 1a, Table 2). Meanwhile, the long-term colonies of plateau zokors resulted in decreasing net primary production (Table 3). These results supported our hypothesis that the long-term excavating activities underground by plateau zokors had a negative effect on vegetation in alpine meadow.

Unlike other aboveground herbivores, plateau zokors may impact plant community composition in two basic ways: 1) Excavating tunnel systems and foraging underground, and 2) Depositing enough soil during spring and fall on the surface. Excavating and foraging underground is basic ecological characteristics for subterranean rodents, which is the key factor in aspects of impacting vegetation. Spencer et al.[23], Foster and Laycock[24] and Richardson[25] demonstrated that areas with pocket gophers present had reduced overall forage production with selective increase in some plants not preferred by pocket gophers and decrease in plants they preferred. Although numerous studies have demonstrated many subterranean rodents, such as pocket gophers and plateau zokors, are typical generalist herbivores[26,27], some plants are preferred and others are not by plateau zokors, which tested by feeding experiments in laboratory. The difference in biomass between three patches was caused by the significant difference of monocotyledon, dicot palatable and non-palatable on those patches (Fig. 1a, b, c, d). The non-palatable dicot biomass was the greatest in colonized patch, this effect may be due to the preference of plateau zokors for different plants in alpine meadow. The differences between the monocots and dicots in this study illustrate that the dietary preferences of herbivores, whatever aboveground or subterranean, may influence plant community composition and succession process.

Williams and Cameron[28] excluded pocket gophers from a Texas coastal prairie and found a decrease in bare ground and concomitant increase in cover, frequency, and biomass of certain plant species, particularly little blue stem grass. The results of this study suggested that after plateau zokors were removed or the habitats were abandoned over five years, the cover, height and biomass of monocotyledon increased in this patch (Fig. 1b, Table 1). The difference between uncolonized and abandoned patches indicated that the rate of recovery in the patch disturbed by plateau zokors was so slow in alpine meadow that it would take very long time to recover the primary status which was undisturbed before.

Deposition of considerable amounts of soil in the surface could affect species composition, abundance, and biomass of plants. In alpine meadow, plateau zokors deposited large numbers of mounds during spring and fall to cover vegetation[14], Mean survival of plants buried by those mounds are so different that intensively influence plant growth and productivity[10,15,29]. Overall, dicotyledon, especially non-palatable dicotyledon such as *Ajania tenuifolia*, *Leontopodium nanum*, and *Potentilla nivea*, survived burial much better than herbages in alpine meadow[30]. In the long run, this could be the results that the non-palatable dicotylendon became dominant species and the biomass was the greatest in this patch, although the total aboveground biomass was greatly reduced compared to the uncolonized patches. In addition, the plant response to underground grazing is obviously different because of the fibrous roots and taproots among different species plants. The difference in this study could reflect the phenological, morphological, and life historical difference among those plants in alpine meadow.

As pointed out by Grant *et al*[31], the overall effect on the structure of plant community will depend on the relationship between rate of mound and nature of succession process. Differences between three patches causing by plateau zokors in this study and the results about pocket gophers and plateau zokors reported by other authors illustrated this point.

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中 文 摘 要

高原鼢鼠对高寒草甸植被特征及生产力的影响

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本研究结果表明, 高原鼢鼠栖息 10 年的斑块, 植物群落的物种数减少, 植物物种多样性指数下降, 地上、地下总生物量显著降低, 单子叶和可利用双子叶植物生物量极显著减少, 但不可利用双子叶植物生物量显著增加。高原鼢鼠去除 5 年后, 斑块内植物群落的单子叶植物物种数增加, 而双子叶植物下降, 植物群落物种多样性指数下降, 地上、地下总生物量显著增加, 单子叶和可利用双子叶植物生物量增加极显著, 不可利用双子叶植物生物量显著降低。高原鼢鼠栖息 10 年的斑块, 净初级生产量较未栖息地区减少 68.98 %。高原鼢鼠去除 5 年后, 净初级生产量增加, 但仅达到未栖息地区的 58.69 %。

关键词: 高原鼢鼠; 植物生物量; 植物生产力; 高寒草甸