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# Soil Erosion and Vegetation Succession in Alpine *Kobresia* Steppe Meadow Caused by Plateau Pika —A Case Study of Nagqu County, Tibet

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**Abstract:** This paper evaluated the impacts of mounds created by the plateau pika (*Ochotona curzoniae*) on the vegetation composition, structure, and species diversity of an alpine *Kobresia* steppe meadow in Nagqu County, Tibet Autonomous Region, China. Based on mound height or the depth of erosion pit, we defined five stages of erosion and compared the floristic features of communities at these stages with those in undisturbed sites. In the study area, the mounds and pits covered up to 7% of the total area. *Lancea tibetica, Lamiophlomis rotata*, and *Potentilla bifurca* were the dominant species in erosion pits, and *Kobresia pygmaea*, the dominant species in undisturbed sites, became a companion species in eroded areas. In the process of erosion, the original vegetation was covered by soil ejected by the pika, then the mounds were gradually eroded by wind and rain, and finally erosion pits formed. The vegetation coverage increased with increasing erosion stages but remained significantly lower than that in undisturbed sites. Improved coverage eventually reduced soil erosion, and pit depth eventually stabilized at around 20cm. Aboveground biomass increased with increasing erosion stage, but the proportion of low-quality forage reached more than 94%. The richness index and Shannon-Wiener index increased significantly with increasing erosion stage, but the richness index in mound and pit areas was significantly lower than that in undisturbed sites.
**Keywords**: plateau pika; alpine *Kobresia* steppe meadow; vegetation succession; diversity; Tibet

## 1 Introduction

Fossorial mammals can produce large area of soil disturbance that have a variety of effects on ecosystem properties and processes (Whitford and Kay, 1999). Their burrowing activities also affect some of soil properties and soil processes (Mielke, 1977; Jones et al., 1994; Litaor et al., 1996; Sherrod and Seastedt, 2001; Kerley et al., 2004) and can decrease erosion and runoff (Hakonson, 1999). Changes in the physical and chemical properties of the soil and changes in soil processes such as decomposition and nutrient cycling (Cortinas and Seastedt, 1996) can affect revegetation rates, improve biomass production (Tilman, 1983; Spencer et al., 1985; Williams et al., 1986; Stromberg and Griffin, 1996), affect plant species composition (Hobbs and Mooney, 1985; Reichman and Smith, 1985; Spencer et al., 1985; Martinsen et al., 1990; Cortinas and Seastedt, 1996; Zhang and Liu, 2002; Graham et al., 2004), and increase species diversity (Grinnell, 1923; Ellison, 1946; Bonham and Lerwick, 1976; Grant et al., 1980; Coppock, 1983; Tilman, 1983; Huntly and Reichman, 1994) on ejecta mounds, but other studies have reported little or no effect on plant species richness and species composition (Rezsutek and Cameron, 2000; Rogers et al., 2001).

Plateau pika (*Ochotona curzoniae*), a rodent and fossorial mammal, is the dominant animal species in the alpine meadows and steppes of the Qinghai-Tibet Plateau (Wang et al., 1980; Jiang and Xia, 1985). In some studies, pikas have been reported to have no effect on soil erosion, and in these studies, soil erosion was instead triggered by overgrazing (Ellison, 1946; Schaller, 1998). However, some researchers have found different results (Miller, 1964; Foster and Stubbendieck, 1980; Tilman, 1983). In particular, some Chinese scientists have suggested that the plateau pika and other fossorial mammals (*Myos-*

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*palax fontanieri, Myospalax baileyi, Ochotona daurica*) have negative effects on the ecology of alpine meadows; these animals not only compete with domestic animals for grass resources, but also decrease vegetation coverage and biomass (Pi, 1976; Liang and Xiao, 1978; Gao et al., 1980; Jiang, 1998; Guo, 1999; Yang and Jiang, 2002; Luosang, 2002; Zhang and Liu, 2002) and can destroy the sod layer due to their burrowing activities; the consequences of these changes may be serious soil erosion. In addition, vegetation succession may occur as a result of differential grazing by the plateau pika and as a result of soil erosion (Xiao et al., 1982). However, researches on the impacts of the ejecta mounds created by the plateau pika on vegetative composition, biomass, and species diversity is still not available; in particular, no such study has been conducted in alpine *Kobresia* steppe meadow. In this paper, we report the results of the investigation on the influences of this pika on the vegetative structure of the community, aboveground biomass, vegetation coverage, and species diversity in Nagqu County, Tibet Autonomous Region, China.

## 2 Study Area

The study was carried out 3km south of Nagqu Town (31°29'N, 91°33'E), which is the capital of Nagqu Prefecture of Tibet Autonomous Region. The region is generally flat, with eastward slopes of 2%–3%, and the mean elevation is 4470m above sea level.

The area has an alpine semi-humid monsoon climate (Su and Xue, 1994). According to the data recorded at Nagqu County Meteorological Station between 1955 and 1980, average annual temperature was –1.9°C and ranged from a minimum of –41.2°C in winter to more than 22.6°C in summer. Snow usually occurs from October to April. The growing season typically extends from May to September, with a growing period of less than 150 days. Mean annual precipitation was 420mm in the period, and 80% of it occurs between June and September. The total amount of sunshine in a typical year averages more than 2852 hours.

The vegetation type is an alpine *Kobresia* steppe meadow (Zhou, 2001). The dominant species in grazed pastures is alpine *Kobresia* (*Kobresia pygmaea*), and the main accompanying species are dwarf *Kobresia* (*Kobresia humilis*), plateau bluegrass (*Poa alpigena*), cinquefoil (*Potentilla anserina, P. bifurca* var. *humilior*), foreign needlegrass (*Stipa aliena*), dwarf edelweiss (*Leontopodium nanum*), and cushion rockjasmine (*Androsace tapete*).

Soils in the study area are alpine meadow soils. Profiles are mostly shallow, with the thickness of the sod layer averaging 9±2.5cm and less than 58cm of sandy loam soil. Soils typically have a small-grained structure, with cataclasite and nutty structures (Land Management Bureau and Animal Husbandry Bureau of Tibet Autonomous Region, 1994).

## 3 Materials and Methods

### 3.1 Characteristics of plateau pika

Plateau pika is mainly found in alpine *Kobresia* steppe meadow. This species prefers habitat with open topography and no obstacles that would conceal predators. The density of pikas is greater on sunny slopes than on shady slopes. The pikas do not undergo winter dormancy. Its favorite foods are most species of grasses and some sedge species (Wang et al., 1980; Jiang and Xia, 1985). The pika reproduces once per year, usually between April and August, though a few individuals may reproduce twice in a single year (Liang, 1981). The average litter size is 4.4±0.43 head. The average life span is only 119.9d (Wang and Dai, 1989).

Pikas create complex burrows (Liang and Xiao, 1978; Luosang, 2002), typically with 6 to 10 entrances, though up to 25 entrances have been reported. Each individual may create up to 6 temporary shelter burrows. The total length of tunnel ranges from 8m to 13m, with each branch of the tunnel extending 1m to 5m and lying 20m to 50cm under the soil surface. The diameter of tunnel averages about 8cm.

### 3.2 Sampling

It is difficult to determine exactly when a burrow was created, but erosion of the mounds of ejecta around entrances by wind and rain provides an indirect measure of burrow age. The piles of mined soil created by the plateau pika are gradually eroded and changes into pits of various sizes, with the pit depth increasing over time until it reaches a relatively stable depth that represents a balance between erosion and increased capture of wind-transported soil and suspended soil in overland flow. As a result, the height of mounds and depth of pits can be used to estimate a burrow's construction time. We divided the process of erosion into five time-based stages: $E_0$, height of mound >10cm; $E_1$, height of mound between

0 and 10cm; $E_2$, depth of erosion pit between 0 and 5cm; $E_3$, depth of erosion pit between 6cm and 10cm; $E_4$, depth of erosion pit >10cm. Five 30m×30m plots in flat alpine *Kobresia* steppe meadow were randomly selected between 28 August and 2 September 2002. Then the plant communities were sampled by using 0.5-$m^2$ quadrats which were further divided into 10cm×10cm blocks. We located these quadrats over randomly chosen mound systems (centered on either a mound or an erosion pit). In each plot, we randomly selected three quadrats for each time gradient. And we also randomly selected three quadrats in undisturbed sites (Ud) without mound or erosion pit. Within each quadrat, we identified all species, counted the number of individuals, and measured the coverage of each species using a point-intercept method (Song, 2001). The stems of each species above ground were sampled to estimate aboveground biomass, and all plant samples were oven-dried at 80°C for 48h before weighing. In addition, we counted the density of mounds and pits per unit area and measured the area occupied by the mounds and pits in each plot. In addition, we interviewed some local herdsmen to find out the time from a mound become a pit.

### 3.3 Data analysis

We calculated the mean coverage, aboveground standing biomass, frequency, and number of individuals for each species in each quadrat. To represent the community diversity, we calculated the importance value for each species, as well as the richness index and the Shannon-Wiener index (Ma et al., 1995), using the following formula:

$$IV=(RD+RF+RB)/3 \quad (1)$$

where *IV* is importance value for each species; *RD*, relative density (percentage of number of each species to total individuals per square meter); *RF*, relative frequency (percentage of samples of each species to total samples); *RB*, relative biomass (percentage of aboveground biomass of each species to total aboveground biomass). The *IV* value for each family was calculated as the sum of all the species′ *IV* values for that family.

$$RI=(s-1)/\ln N \quad (2)$$

where *RI* is richness index; *s*, the total number of species in a quadrat; and *N*, the total number of individuals in a quadrat.

$$H'=-\sum_{i=1}^{s}(p_i)(\ln p_i) \quad (i=1, 2, 3\ldots, s) \quad (3)$$

where $H'$ is Shannon-Wiener index; *i*, number of species; $p_i$, the proportion of all individuals in a sample that belongs to the *i*th species.

We performed *post hoc* analysis of variance and least-significant-difference (LSD) tests using the SPSS 10.0 software to compare the number of species, number of individuals, coverage, biomass, richness index, and Shannon-Wiener index in each plot to detect changes in vegetation composition along the erosion stages from young mound to stable pit.

## 4 Results and Discussion

### 4.1 Changes in community composition

The number of burrow entrances created by the plateau pika equaled 2100/ha, of which mounds accounted for 330/ha. The mounds and pits covered as much as 7% of the total study area. The soil ejected by the pika during burrowing accumulated around the burrow entrance and covered the surface of adjacent vegetation. Local herdsman reported that as soon as the subsoil has been transported to the surface, erosion begins and the ejected soil is carried away in runoff (surface flows) or blown away by wind within 2 to 3 years. The plants buried under the mounds soon die and erosion begins, resulting in the formation of pits with different sizes and depths around the burrow entrances.

During this process of erosion, secondary succession of the vegetation occurs (Table 1). We found no plants in fresh ejecta (stage $E_0$). During stage $E_1$, *Potentilla bifurca*, *Lancea tibetica*, and *Lamiophlomis rotata* were the first species to invade, but a few residual *Kobresia pygmaea* remained. During the change from $E_1$ to $E_2$, the *IV* of *Lancea tibetica* increased while that of *Kobresia pygmaea* decreased, and *Leontopodium nanum* began to invade. More new species arrived during $E_3$, including *Kobresia humilis*, *Lagotis brachystachya*, and *Androsace tapete*, but *Lancea tibetica* remained the dominant species. During $E_4$, the *IV* of *Lamiophlomis rotata*, *Potentilla bifurca,* and *Kobresia pygmaea* increased, but *Lancea tibetica* remained the dominant species. Along the sequence of erosion from $E_0$ to $E_4$, the number of species increased from 0 to 8, but there were 13 species in 7 families in the undisturbed sites. Within the species present in disturbed sites, only *Kobresia pygmaea* is a favorite food of the plateau pika and livestock; *Potentilla bifurca* and *Lagotis brachystachya* are less favored by pika (Pi, 1976). From stage $E_1$ to stage $E_4$, *Lancea*

Table 1 Species and family importance values (*IV*) in undisturbed sites and in eroded sites by plateau pika

| Family | Species | *IV* in eroded site | | | | | *IV* in undisturbed site |
|---|---|---|---|---|---|---|---|
| | | $E_0$ | $E_1$ | $E_2$ | $E_3$ | $E_4$ | |
| Cyperaceae | *Kobresia pygmaea* | 0 | 21 | 8.39 | 6.52 | 12.93 | 45.29 |
| | *Kobresia humilis* | 0 | 0 | 0 | 9.36 | 7.88 | 13.79 |
| | *Carex moorcroftii* | 0 | 0 | 0 | 0 | 0 | 1.29 |
| Subtotal | | 0 | 21 | 8.39 | 15.88 | 20.81 | 60.37 |
| Gramineae | *Poa alpigena* | 0 | 0 | 0 | 0 | 0 | 2.94 |
| | *Stipa aliena* | 0 | 0 | 0 | 0 | 0 | 3.22 |
| Subtotal | | 0 | 0 | 0 | 0 | 0 | 6.16 |
| Rosaceae | *Potentilla bifurca* | 0 | 30.22 | 23.56 | 12.16 | 15.33 | 6.41 |
| | *Potentilla anserina* | 0 | 0 | 0 | 0 | 0 | 4.84 |
| Subtotal | | 0 | 30.22 | 23.56 | 12.16 | 15.33 | 11.25 |
| Compositae | *Ajania fruticulosa* | 0 | 0 | 0 | 0 | 0 | 2.06 |
| | *Taraxacum tibetanum* | 0 | 0 | 0 | 0 | 0 | 1.12 |
| | *Leontopodium nanum* | 0 | 0 | 7.26 | 14.87 | 4.22 | 6.95 |
| Subtotal | | 0 | 0 | 7.26 | 14.87 | 4.22 | 10.13 |
| Scrophulariaceae | *Lagotis brachystachya* | 0 | 0 | 0 | 8.11 | 3.37 | 4.08 |
| | *Lancea tibetica* | 0 | 35.58 | 47.04 | 27.26 | 26.80 | 0 |
| Subtotal | | 0 | 35.58 | 47.04 | 35.37 | 30.17 | 4.08 |
| Caryophyllaceae | *Arenaria polytrichoides* | 0 | 0 | 0 | 0 | 0 | 7.05 |
| Plantaginaceae | *Plantago depressa* | 0 | 0 | 0 | 0 | 0 | 0.96 |
| Primulacaea | *Androsace tapete* | 0 | 0 | 0 | 4.0 | 8.04 | 0 |
| Labiatae | *Lamiophlomis rotata* | 0 | 13.18 | 13.83 | 17.78 | 21.47 | 0 |
| Total | | 0 | 100 | 100 | 100 | 100 | 100 |

Notes: $E_0$ is an erosion stage with height of mound >10cm; $E_1$, height of mound between 0–10cm; $E_2$, depth of erosion pit between 0–5cm; $E_3$, depth of erosion pit between 6–10cm; $E_4$, depth of erosion pit >10 cm

*tibetica* was always a dominant species, even though its *IV* decreased in stages $E_3$ and $E_4$. The *IV* of *Kobresia pygmaea* and *Potentilla bifurca* decreased from $E_1$ to $E_3$, but increased again in $E_4$. The *IV* of *Lamiophlomis rotata* increased throughout these stages. The dominant species *Lancea tibetica* and *Lamiophlomis rotata* were not eaten by the plateau pika and were not found in undisturbed sites. Except for *Kobresia pygmaea*, *K. humilis*, and *Potentilla bifurca*, all the species found growing on mounds or in pits are not favored foods of livestock or inedible. In undisturbed sites, the *IV* of the Cyperaceae was highest, and was much higher than that of the Scrophulariaceae, but in eroded sites, it was less than that of the Scrophulariaceae at all stages of erosion.

### 4.2 Changes in vegetation coverage

The number of individuals increased as erosion progressed from $E_0$ to $E_4$, and this increase was significant ($F$=88.83, $P$<0.05) (Table 2); however, the number remained significantly below that in undisturbed sites even in stage $E_4$. The increasing number of individuals was accompanied by increasing vegetation coverage of the sites (Fig. 1). The vegetation coverage increased significantly from stage $E_0$ to stage $E_4$ ($F$=78.87, $P$<0.05), but remained significantly below that in undisturbed sites. Although the magnitude of the erosion decreased in stage $E_4$ due to the accumulation of soil, litter, and fecal matter and as a result of rainfall harvesting by the pits, the coverage and the number of individuals in stage $E_4$ was still significantly lower than that in undisturbed sites. In the alpine *Kobresia* steppe meadow, the sod layer is essential to protect the soil from erosion by wind and rain. Because the ejected soil leads to the death of the plants that are buried, erosion increases and the sod layer is gradually destroyed. The effects of the plateau pika thus last for at least 2 to 3 years, and the vegetation has still not recovered to the levels observed in undisturbed sites by the end of this progression. Moreover, it is difficult to restore the original vegetation heterogeneity that existed before the creation of the mounds of soil ejecta.

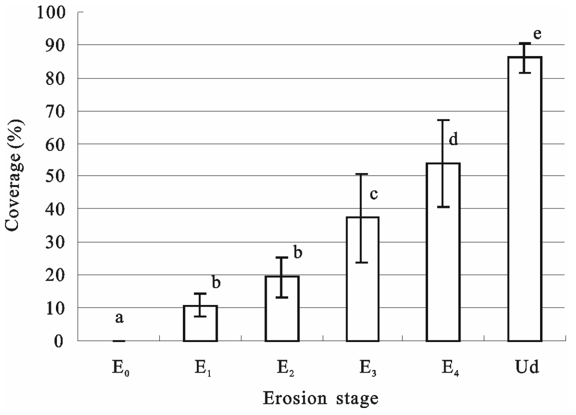
### 4.3 Changes in biomass and forage quality

With the increasing number of invading species and increasing coverage as erosion progressed, the total

Table 2 Average index of diversity in different erosion stages after creation of mounds by plateau pika (mean±standard deviation)

| | $E_0$ | $E_1$ | $E_2$ | $E_3$ | $E_4$ | Undisturbed |
|---|---|---|---|---|---|---|
| Mean number of individuals | 0 a | 48.50±14.90 ab | 129.85±34.50 bc | 209.85±150.77 cd | 295.35±132.30 d | 908.83±59.49 e |
| Number of family | 0 a | 2.35±0.52 b | 2.85±0.75 b | 4±0.90 c | 4.65±0.52 c | 8.00±0.65 d |
| Richness index | 0 a | 0.35±0.11 b | 0.38±0.16 b | 0.58±0.15 c | 0.65±5.46E-02 c | 1.03±0.09 d |
| Shannon-Wiener index | 0 a | 0.70±0.18 b | 0.92±0.19 c | 1.10±0.30 cd | 1.30±0.12 d | 0.94±0.11 ec |

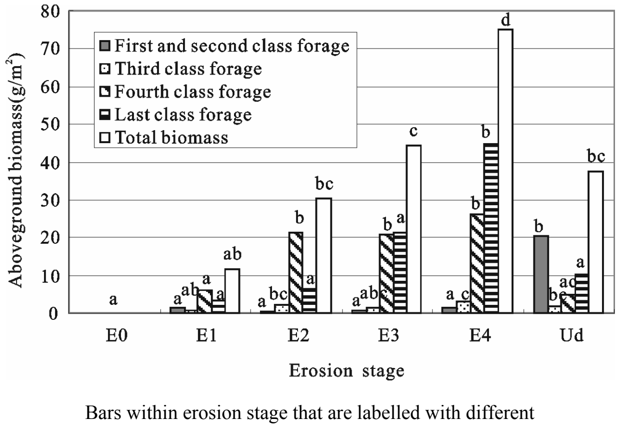
Note: Within a row, numbers followed by different letters differ significantly between erosion stages ($P$<0.05)




Ud represents undistributed site Bars labelled with different letters differ significantly at $P$<0.05

Fig. 1 Changes in vegetation coverage in different erosion stages after creation of mounds by plateau pika

aboveground standing biomass (Fig. 2) increased significantly from stage $E_0$ to stage $E_4$ ($F$=9.3, $P$<0.05), and the total biomass in stages $E_4$ was larger than that in Ud (undisturbed sites) (an average of 37.66g/m$^2$) and other erosion sites. Su and Xue (1994) divided all the forage species in Tibet into five classes according to their nutritional value and palatability to domestic livestock. First-class herbage such as *Kobresia pygmaea* is favored by domestic livestock, and second-class forage (e.g., *Stipa aliena*, *Koeleria argenta*, *Trisetum spicatum*) is also palatable; however, fifth-class forage is inedible. In general, the proportion of first- and second-class forage at a site reflects the overall quality of the grazing land. Based on this classification system, the aboveground biomass of first- and second-class herbage differed significantly between the erosion sites and Ud ($F$=126.8, $P$<0.05). The biomass of first- and second-class forage was larger in $E_1$ than in $E_0$ but no significantly due to the residual *Kobresia pygmaea*, but decreased from $E_1$ to $E_2$; thereafter, from $E_2$ to $E_4$, the biomass of first- and second-class forage increased, but not significantly. The biomass of the third classes of forage increased significantly from $E_0$ to $E_2$, $E_4$, and Ud , with stages $E_4$ having a larger biomass of fourth-class forage than $E_0$ and $E_1$ ($F$= 3.43, $P$<0.05), and Ud having a significantly larger biomass of third-class forage than that of $E_0$. The biomass of the third classes of forage in $E_2$, $E_3$, $E_4$ were larger significant than that of $E_0$, $E_1$ and Ud ($F$= 13.96, $P$<0.05). The stages $E_4$ having a larger biomass of fifth-class forage than others ($F$=5.11, $P$<0.05). The fourth- and fifth-class forage accounted for 79.69%, 91.78%, 94.73%, 94.28%, and 39.8% of total biomass, respectively, in stages $E_1$, $E_2$, $E_3$, $E_4$, and Ud. In contrast, the biomass of first- and second-class forage accounted for 54.86% of total biomass in undisturbed sites. Although the total biomass was larger in pits than in undisturbed sites, most of the plants were inedible or unpalatable to livestock and plateau pika. This means that the grazing quality of alpine *Kobresia* steppe meadow declines in response to burrowing activity and grazing by plateau pika (Fig. 2).




Bars within erosion stage that are labelled with different letters differ significantly at $P$<0.05

Fig. 2 Changes in total biomass and forage quality in different erosion stages after creation of mounds by plateau pika

### 4.4 Changes in species diversity

We found no plants in stage $E_0$, but species diversity increased to 4 species in 4 families in stage $E_1$, 5 species in 5 families in stage $E_2$, and 8 species in 6 families in stages $E_3$ and $E_4$, compared with 13 species in 7 families in undisturbed sites. The *post hoc* LSD analysis showed that stages $E_1$ and $E_2$ had significantly greater numbers of species than stage $E_0$, and that stages $E_3$ and $E_4$ had significantly greater number of species than stages $E_0$, $E_1$, and $E_2$, but that all eroded sites had significantly lower number of species than the undisturbed sites ($F$=112.07, $P$<0.05). The Shannon-Wiener index increased significantly from $E_0$ to $E_4$, and in especial, the Shannon-Wiener index of stage $E_4$ was significantly higher than undisturbed sites ($F$=39.84, $P$<0.05). The stages $E_3$ and $E_4$ had significantly higher indices than the other stages, and the undisturbed sites and stage $E_2$ had significantly higher indices than stages $E_0$ and $E_1$.

The richness index ($F$=60.41, $P$<0.05) also increased significantly as erosion progressed, with stages $E_3$ and $E_4$ having significantly higher values than stages $E_0$, $E_1$, and $E_2$. The stages $E_1$ and $E_2$ had significantly higher values than stages $E_0$. However, the undisturbed sites had significantly higher values than the eroded sites. During the process of erosion of the mounds, the habitat for plants improved gradually as a result of improved soil nutrition and moisture in the pits, and this was responsible for the increased number of species and increased richness index. However, the Shannon-Wiener index depends on more than just the number of species and individuals; it also depends on the evenness of the species distribution. The greater evenness in stages $E_3$ and $E_4$ (0.86 and 0.84, respectively) compared with the value in the undisturbed sites (0.47) means that stages $E_3$ and $E_4$ had significantly higher Shannon-Wiener indices than the undisturbed sites. Even so, the species diversity was clearly lower in the eroded sites than in the undisturbed sites based on the numbers of species and families that we found. In addition to competition among the species, all species were subjected to grazing by plateau pika and livestock, and only species that were inedible or of low forage quality (such as *Lancea tibetica, Lamiophlomis rotata*, *Androsace tapete*, and *Leontopodium nanum*) can grow and reproduce well in the new habitat created by pika.

## 5 Conclusions

In the alpine *Kobresia* steppe meadow, the density of mounds and pits created by plateau pika totaled 330/ha and 1780/ha, respectively, and this disturbance covered as much as 7% of the total area.

*Lancea tibetica, Lamiophlomis rotata*, and *Potentilla bifurca* were the dominant species in erosion pits, and *Lagotis brachystachya* and *Leontopodium nanum* were the main companion species. The dominant species in undisturbed sites (*Kobresia pygmaea*) had become a companion species in eroded areas.

The original vegetation had been buried by soil ejected from the burrows by plateau pika, and initially became denuded patches as the vegetation died. Subsequently, these patches became pits due to erosion by wind and rain. The vegetation coverage increased as erosion progressed, but remained less than that in undisturbed areas. However, this increase in vegetation coverage mitigated the development of erosion, and the depth of erosion pits usually stabilized at less than 20cm.

Aboveground biomass increased as erosion progressed, but the proportion of low-quality forage was greater than 94%. As a result, forage quality decreased in the eroded areas.

The richness index and Shannon-Wiener index increased significantly as erosion progressed, but the richness index in eroded areas was significantly lower than in undisturbed areas.

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