13. Rodent Pest Management in the Qinghai–Tibet Alpine Meadow Ecosystem

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Abstract

The available area of the natural grasslands of the Qinghai–Tibet Plateau is about 1.4 million km^2. As a result of inappropriate reclamation and over-grazing in the past decades, serious degeneration of up to 0.71 million km^2 of the grasslands has occurred. Of this area, 0.37 million km^2 has been damaged by rodents and about 40,000 km^2 of black sandy soil has been formed due to rodent infestation. The plateau pika (*Ochotona curzoniae*) and the plateau zokor (*Myospalax baileyi*) are the two dominant rodent species.

Rodent control is essential for reversing the heavy degeneration of the grassland so that it can be used again for grazing. Beginning in the 1960s, more than ten types of rodenticide have been used for controlling rodents in the Qinghai–Tibet Plateau. In order to reduce the risk of rodenticides to predators and to improve baiting efficiency, a baiting machine was invented which puts baits into the rodents' underground tunnels, based on the invading behaviour of zokors. Both the baiting and killing efficiencies, as well as the safety advantages of using the baiting machine, are greater than the traditional, manual method of ground baiting.

Since the mid-1980s, studies have shifted to developing a sustainable strategy for managing pika and zokor damage by understanding their ecology and interaction with the grazing activities in the region. A demonstration area of 200 ha was set up in a heavily degenerated region with black sandy soil. An integrated management program, which included use of a baiting machine, seeding, fencing, control of weeds and control of grazing intensity, was implemented. The vegetation and the productivity of the grassland were increased shortly after treatment began. An increase of about 648.4 t of dried grasses was observed in the area during the next three years.

Keywords

Alpine meadow, Qinghai–Tibet Plateau, plateau pika (*Ochotona curzoniae*), plateau zokor (*Myospalax baileyi*), integrated pest management

Introduction

The area of natural grassland in the Qinghai–Tibet Plateau is about 1.4 million km^2, with alpine meadow being the most widespread vegetation type. This area is an important base for animal husbandry. As a result of inappropriate reclamation and overgrazing in past decades, the grasslands have been seriously degenerated. These degenerated grasslands comprise about 0.71 million km^2, of which 0.37 million km^2 is infested with rodents. The main pest rodents are plateau pika (*Ochotona curzoniae*), plateau zokor (*Myospalax baileyi*), *Ochotona daurica*, *Pitymys irene* and *Marmota himalayana*. Plateau pikas and plateau zokors are the dominant rodents and their feeding and burrowing activities damage grasslands. About 40,000 km^2 of black sandy soil has been formed as a result of rodent infestation. In the grasslands of the Qinghai–Tibet Plateau, the average densities of the plateau pika and plateau zokor are more than 4.29 individuals/ha and about 1.07 individuals/ha, respectively. These rodents compete with livestock for food resources. They consume about 0.15 billion t of fresh grass every year, which is equal to the total food intake of 0.15 billion sheep. Rodents also dig and destroy vegetation causing many serious problems such as soil erosion, and reductions in livestock carrying capacity and ecosystem biodiversity.

Zinc phosphate, a rodenticide, was first used for rodent control in the Qinghai–Tibet area in 1958. During the early 1960s, the area of grassland treated with zinc phosphate was more than 333 km^2 in southern Qinghai. From 1964 to 1965, more than 26,667 km^2 in 20 counties was treated using both zinc phosphate and '1080' (fluoroacetate). The area of rodent infestation was reduced from 54,000 km^2 in 1960s to 38,130 km^2 in 1990. Cumulatively, more than 208,000 km^2 of the infested area was treated with rodenticides during this period.

However, zinc phosphate and 1080 also caused many serious social and environmental problems. Both are acute poisons that have secondary poisoning effects, and are unsafe for non-target species including humans. With the appearance of anticoagulants such as diphacinone, diphacinone-Na, gophacide, difenacoum, bromadiolone and brodifacoum, use of the acute poisons was no longer permitted. A new type of rodenticide, botulin C, was also found to be very effective in killing plateau pika and plateau zokor in the grasslands. The killing rate with botulin C was up to 98%, with less environmental pollution and no secondary poisoning effects on other animals (Shen 1987).

Although anticoagulants and botulin C are effective in reducing pika and zokor damage initially, the populations of these rodents recover rapidly after treatment (Liang 1982). Since the mid-1980s, studies have shifted towards developing a sustainable strategy for managing pika and zokor damage by understanding their ecology and interaction with the grazing activities in this region. In this chapter, the major achievements of these studies are reported and future research priorities are discussed.

Ecological Aspects of the Plateau Pika and Plateau Zokor

Plateau pika

Habitat

Pikas mainly inhabit the plateau steppe, steppe meadow, plateau meadow, alpine meadow and alpine desert steppe at an elevation of 3,100–5,100 m above sea level. They prefer open habitats and avoid dense shrub or thick vegetation (Shi 1983). Table 1 shows that the number of pika burrows decreases with increased vegetation cover and height.

Burrow systems

The burrow systems of the pika comprise two types. One type is the simple or temporary burrow that is shallow and short. It is mainly used in summer and usually has two or three openings, but may only have one opening to the surface. The other type is the complex burrow system which occupies areas of 21–162.14 m^2. The average length of the tunnels is 13 m, with a maximum length of up to 20 m. The average depth of the burrows is 0.33 m, but they may be up to 0.6 m deep. The burrow system has many branches which are connected to each other to form a complex network, sometimes with two layers. There are usually five or six openings, although some have 13 openings. The diameter of the openings is about 8–12 cm. There is one nest in the burrow system, which is located about 0.45 m below the surface (Xiao et al. 1981).

Feeding behaviour and activity rhythms

The plateau pika is a herbivore and responds variably to different plants and plant parts. Enclosure experiments indicate that of 31 plant species in the natural habitat, pikas feed on 23 grass species (mainly belonging to the Gramineae), as well as species belonging to the Cyperaceae and Leguminosae. An adult pika consumes (on average) 77.3 g of fresh grass per day, which is about 50% of its body weight, whereas a 375 kg cow consumes 18 kg of fresh grass per day, which is only 4.8% of its body weight. The food intake of 56 adult plateau pikas equals the food intake of one Tibetan sheep (Pi 1973).

Table 1.
The relationship between the cover and height of ground vegetation and the number of active burrow holes of plateau pika (Shi 1983).

Habitat type[a]	1	2	3	4
No. of plots	9	41	3	8
Vegetation cover (%)	84.22 ± 4.09	96.93 ± 0.84	66.67 ± 8.28	90.63 ± 2.90
Vegetation height (cm)	9.22 ± 2.57	69.29 ± 4.25	2.00 ± 0.00	85.00 ± 6.61
No. of pika holes	24.67 ± 6.74	3.93 ± 1.54	43.33 ± 8.82	0.00 ± 0.00

Key to habitat types: 1 = natural grassland; 2 = original grassland which was cultivated for several years, then abandoned due to deterioration; 3 = grassland which was ploughed but then considered unsuitable for cultivation; 4 = grass sown in deteriorated grassland.

Feeding comprises 63–78% of the total activity of pikas. When feeding, pikas look around frequently and have a special feeding pattern termed 'pecking'—after feeding for a moment they look around or move a short distance, then feed again. Feeding frequency is 5.7 ± 1.3 pecking bouts per minute (Bian et al. 1994; Fan and Zhang 1996).

The plateau pika is a diurnal animal. Its above-ground activities appear to have two peaks (forenoon and afternoon), and these change according to the different seasons. In October the first activity peak occurs at 09:00 h and the second at 18:00 h, while in July the activity peaks are at 08:00 h and 19:00 h, respectively.

Life span

Based on observations of 401 ear-tagged individuals over three years, the average life span of a plateau pika is 119.9 days, with the longest life span recorded being 957 days (Wang and Dai 1989).

Home range and territory

Plateau pikas live in family groups and show territorial behaviour. Before the reproductive period (March), the average home range is 1,262.5 m^2, while in the breeding season (April) the home range expands to 2,308 m^2. Plateau pikas protect their territories all year. In the breeding season, males and females form pairs to establish new families and new home ranges and protect this territory. During the period of oestrus, the female holds no territory, but the male monopolises the female and drives away other invading males (Wang and Dai 1990).

Reproduction and sex ratio

Each year an adult female can produce 3–5 litters with 1–9 individuals per litter. In the Kuaierma region (37°26' N, 98°42' E), a total of 1,529 plateau pikas were captured from 1964 to 1965. Males made up 46.5% of the total capture and were less abundant than females ($\chi 2 = 7.35$, $p < 0.01$). The average litter size was 4.55 ± 0.95 individuals. In the Duofudun region (35°15' N, 101°43' E), a total of 777 pikas was captured. Males made up 53.16% of the total capture. The average litter size was 4.68 ± 1.29 individuals (Shi et al. 1978).

Plateau zokor

Habitat

The plateau zokor mainly inhabits the alpine meadow, steppe meadow, alpine shrub, farmland, banks and wasteland and is widely distributed in Qinghai, southern Gansu and western Sichuan. Their choice of habitat is characterised by moist soil and degenerated grassland with many weeds.

Burrow system

The plateau zokor constructs a very complicated burrow that consists of one or two main nests, feeding and transportation tunnels, food store holes and blind endings. Feeding tunnels, which are formed during feeding activities, are 60–100 mm deep and 70–120 mm in diameter. The transportation tunnels are about 200 mm deep, and are smooth, large and stable paths from the main nest to the feeding tunnels, with some holes for storing food built nearby. One or two vertical tunnels connect the transportation tunnels to the main nest, which is 0.5–2 m deep, about 150–290 mm in diameter, and often filled with dry and soft grass. The nests of females are commonly deeper than those of males. The holes for food storage and a defecation site are usually near the nest (Fan and Gu 1981).

Feeding habits

Plateau zokors mainly feed on roots, rhizomes and other underground parts of weeds. They also frequently pull parts of plant stems into the burrow as food or nest material. Only the rhizomes and green leaves of Gramineae spp. are consumed. *Potentilla anserina* and *Aiania tenuifolia* are also important food resources for the zokor in *Kobresia humilis* meadows. Zokors store root tubers of *P. anserina* and subterranean stems of *A. tenuifolia* mainly as food over winter (Fan et al. 1988).

Activity rhythms

Although plateau zokors live in the subterranean environment, they exhibit circadian rhythms in the dark burrow systems. Based on a study of 80 marked animals, two peaks of digging and feeding activity occurred in summer and autumn. These were from 15:00 h to 22:00 h (making up 65.3% of the total day's activities) and from 0:00 h to 7:00 h (making up 21.6% of the day's activities). In winter, the activity frequency is low and the daily activities are mainly limited to near the nest at 12:00–22:00 (making up 79.7% of the total day's activities) (Zhou and Dou 1990).

Home range

The home range of zokors changes between seasons. In the reproductive season (spring), the home range of males (499.0 ± 390.9 m^2) is larger than that of the female (21.0 ± 11.8 m^2). In the other seasons, there are no significant differences in the home ranges of males (156.5 ± 45.4 m^2) and females (162.1 ± 153.9 m^2) ($t = 0.332$, $p > 0.05$) (Zhou and Dou 1990).

Reproduction

The plateau zokor has one litter of 1–5 individuals (2.91 ± 1.08) every year. About 38.4% of litters are all males (Zheng 1980). The reproductive period is from March to July with a lactation period of about 50 days (Zhang et al. 1995). A radio-telemetry study indicated that adult males and females never live together, even when females are in oestrus. Mating occurs at the intersection of two tunnels of a male and a female burrow system. An analysis of 20 burrow systems of zokors showed that, in the mating period, the male digs a few long tunnels to intercept the female burrow systems, and usually these tunnels have two branches in order to increase the chance of meeting a female. The situation where two males meet each other has never been observed. A male may mate with several females and a female also may mate with a few males. Therefore the mating system of zokor is probably promiscuous. In the Fengxiakou area of Menyuan County, the sex ratio of the adult male to female is 1:1.67. The mosaic distribution of male and female home ranges increases the chance of meeting with each other (Zhou and Dou 1990).

Invading behaviour

Field studies showed that a burrow system was often occupied rapidly by its neighbours if the host zokor was removed (Fan et al. 1990). This observation indicates that zokors tend to invade any vacant territory. This invading behaviour was further studied in the laboratory, using two large boxes connected by a wooden tunnel. Each box contained one zokor and was filled with damp soil so that the zokor could build its burrow system. After the burrow systems in both boxes were built, one zokor was removed, and the remaining animal's behaviour was monitored. In six experiments, the remaining zokor invaded the other burrow system rapidly, usually within 2–30 hours. In four of the six experiments, the burrow tunnels but not the nests were occupied; in the other two cases, both the tunnels and nests were occupied (Fan et al. 1990).

Based on this observation, a baiting machine, which digs tunnels under the grassland and puts baits in the tunnels, was invented. It was found that zokors used some parts of these artificial tunnels. The longest section used by zokors was 32 m and the shortest section was 0.3 m. Most of the artificial tunnels created by the baiting machine were incorporated into the zokors' natural burrow systems (Fan and Gu 1981; Fan et al. 1990).

Aggressive behaviour

The behaviour patterns of the plateau zokor are classified as follows: sleeping and resting, feeding, carrying food, digging, self–grooming, moving, exploring, approaching, contacting, attacking, escaping and retreating. In the reproductive period, the duration of digging, approaching, contacting, attacking, escaping and retreating increases and mutual tolerance is higher than that in the non–reproductive period. Mutual tolerance between zokors of the same sex is lower than that between males and females (Wei et al. 1996).

Digging behaviour

The zokor is a fossorial animal. Its front claws are very stocky and strong. The digging process is divided into seven steps: excavating, digging up, kicking, pushing, humping up soil, feeding and modifying the tunnel (Wang et al. 1994). By digging, zokors build burrow systems for foraging, hoarding food, reproduction and avoiding predators. One zokor was observed to push 1,023.82 kg of dry soil to the ground surface (30.8% in the grass-greening period, 6.3% in the grass-growing period and 62.9% in the grass-withering period) and form 242.1 mounds per year. The mounds covered about 22.53 m^2 of the grassland (Table 2). In the grass-greening period (April–June) which corresponds to the reproductive period of the zokor, the level of digging is medium. The level of digging is lowest in the grass-growing period (July–August) because the zokor can feed partly on green plants above ground. The level of digging is highest in the grass-withering period (September–November) because dispersal and hoarding activities of the zokor are high (Wang and Fan 1987; Fan and Gu 1981).

Table 2.
The number of and area covered by mounds of the plateau zokor from April to November (Wang et al. 1994).

Month	Stage of grass growth	No. of zokors	Mounds/zokor	Mound volume (m^3)	Area covered by each mound (m^2)	Dried weight of soil for each zokor (kg)
April	Greening	29	36.00	4.42	2.33	87.60
May	Greening	25	28.98	7.42	2.61	113.77
June	Greening	22	23.96	9.16	2.58	113.40
July	Growing	27	10.06	6.48	0.90	2.94
August	Growing	33	4.03	5.34	0.32	8.68
September	Withering	33	29.97	8.75	3.02	157.80
October	Withering	36	95.04	8.05	9.09	403.31
November	Withering	35	14.04	10.14	1.68	116.32
Total			**242.08**		**22.53**	**1023.82**

Interactions Between Rodent Damage and Grassland Degeneration

The Qinghai–Tibet alpine meadow ecosystem is very vulnerable to disturbances that reduce the coverage and height of the grass vegetation, such as over-grazing by livestock and cultivation. Weeds, as well as rodents, will invade degenerated grassland. Jing et al. (1991) reported that the number of zokor mounds increased with increased grazing intensity ($r = 0.795$, $r_{0.05} = 0.707$, $p < 0.05$) (Table 3).

Table 3.
The density of zokors under different grazing intensities (Jing et al. 1991).

Plot[a]	Grazing intensity (sheep/ha/yr)	Zokor density (mounds/0.25 ha)
1	5.30	462
2	4.43	198
3	3.55	164
4	2.68	4
5	1.80	152
6	6.07	362
7	3.12	270
8	2.12	68

[a] Plots 1 to 5 are in grasslands on the slope of a mountain; plots 6 to 8 are in grassland on the plain.

In Tianjun County of Qinghai in 1959, the area of available grassland was 14,664 km^2, but decreased to 12,901 km^2 by 1984 because of over-grazing and rodent infestation. It is estimated that the livestock carrying capacity was decreased by 1.33 million sheep over this period (2.7 million sheep in 1959 to 1.4 million sheep in 1984) (Table 4). Up to 1991, there was at least 547.6 km^2 of black sandy soil created by rodent activity following grassland degradation, with the area of grassland available for winter and spring use being only 5,873.6 km^2—45.5% of the total area. In theory, this area has a carrying capacity of only 1.03 million sheep, but is actually grazed by 1.30 million sheep (Ma 1991). Therefore, in the first year after management strategies have been implemented (e.g. chemical control and re-seeding or fencing), livestock grazing should be prevented, with only low-level grazing permitted in the second year; this will prevent further degeneration of the grassland through rodent infestation.

A study by Shi (1983) showed that the population densities of the plateau pika and the plateau zokor in abandoned, cultivated grassland was much higher than that in original grassland (Table 5). Cultivation and overgrazing by humans created the suitable habitats for pika and zokor.

In summary, over-grazing by livestock and the inappropriate reclamation of the grasslands for other purposes are the major reasons for grassland degeneration. In the presence of invasion by weeds and rodents, the degenerated grassland will continue to be changed as follows: over-grazing by livestock leads to grassland degeneration which results in rodent infestation and further grassland degeneration. Human activities, especially cultivation and livestock grazing, play an important role in this vicious circle.

Table 4.
Comparison of the area of different grassland types, the yield of fresh grasses and the livestock carrying capacity between 1959 and 1984 (Ma 1991).

Grassland type	Year	Grass yield (kg/ha)	Area of grassland (km^2)	Carrying capacity (sheep/ha)
Steppe	1959	2052.0	2284.67	1.45
	1984	1467.3	2156.20	1.01
Meadow	1959	1731.0	12303.07	1.40
	1984	1278.3	7368.60	0.88
Shrub	1959	3154.5	384.60	2.17
	1984	2049.3	382.53	1.42
Swamp	1959	2980.5	3560.00	1.55
	1984	1951.8	2882.53	0.46
Degenerated grassland[a]	1959	1795.5	105.80	1.15
	1984	586.7	2484.20	0.33

[a] ʻNote that the area of degenerated grassland has increased greatly during this period.

Table 5.
The community composition and population density (individuals/0.25 ha) of small mammals in various grassland types (Shi 1983).

Species	Common name	Artificial grassland	Semi-artificial grassland	Secondary grassland	Wasteland
Microtus oeconomus		70.1 (91.3)[a]	54.3 (85.9)	0 (0.0)	0.0 (0.0)
Cricetulus longicaudatus		1.1 (1.4)	0.6 (1.0)	0.7 (1.1)	7.5 (69.5)
Ochotona cansus		0.0 (0.0)	5.6 (8.8)	0.2 (0.3)	0.0 (0.0)
Myospalax baileyi	Plateau zokor	5.6 (7.3)	2.7 (4.3)	11.1 (17.8)	0.9 (8.3)
Ochotona curzoniae	Plateau pika	0.0 (0.0)	0.0 (0.0)	50.6 (80.8)	2.4 (22.2)
Total		**76.8 (100.0)**	**63.2 (100.0)**	**62.6 (100.0)**	**10.8 (100.0)**

[a]Figures in brackets represent the percentage of each species in each habitat.

Population Dynamics and Their Prediction

Plateau pika

The total available grassland area of Menyuan, Qilian, Haiyian, Gangcha and Tianjun counties in Qinghai Province is about 36,800 km^2, of which up to 12,000 km^2 (32.7%) is occupied by plateau pikas (Wang et al. 1996) (Table 6).

Table 6.
The population densities and area occupied by plateau pikas and plateau zokors in the useable grassland in some counties of Qinghai Province (Wang et al. 1996).

Species	Density (ha)	Area occupied (km^2)	Percentage (%)
Pika	<20	3 872	10.52
	20–70	5 633	15.31
	>70	2 527	6.87
	Total	**12 032**	**32.70**
Zokor	<20	660	1.79
	20–70	433	1.18
	>70	3 370	9.16
	Total	**4 463**	**12.13**

According to a study by Liu et al. (1980) at the Haibei Alpine Meadow Ecosystem Research Station of the Chinese Academy of Sciences, plateau pikas prefer habitats such as banks, terraces, foothills and gentle slopes in the *K. humilis* meadow and the steppe meadow. The highest population density of the plateau pika was found in wasteland with an average density of 74.64 individuals/ha. The second highest density of plateau pikas (70.36 individuals/ha) was found on the banks and gentle slopes. The average population density in the *Kobresia capillifolia* meadow, which is not their primary habitat, is only 18.99 individuals /ha.

A long-term study has shown that pika populations change significantly between years (Figure 1). The factors causing these fluctuations are not clear, but populations appeared to be oppressed after heavy snows in 1982 and 1988 (Zhou and Wei 1994). In a study conducted from 1985 to 1988, using ear-tagged animals, 57% of the animals that reproduced in the population were those which were born in the first litter of the previous year and 26% were from the second litter of the previous year. Most pikas from the third and fourth litters died before winter. Therefore, the survival rate of the first litter not only decides the population numbers for the present year, but is also an important determinant of the population density of pika in the following year (Wang and Smith 1988). Field observations also indicated that if the reproductive period was extended, the adult females had more litters but the mortality rate of the young pika was higher. Therefore, the population density was lower in the next year (Wang and Smith 1988).

Plateau zokor

In the total area of available grassland in Mengyuan, Qilian, Haiyian, Gangcha and Tianjun counties of Qinghai province, 12.13% was inhabited by zokors. Highest densities of zokors occurred over an area of 3,370 km^2 (Wang et al. 1996) (Table 6).

One long-term study at Haibei station from 1976 to 1992 showed that the zokor population was relatively stable until 1987 when it declined coincident with large scale rodent control (Figure 2) (Zhou and Wei 1994). One explanation for the stable numbers is that the effects of climate and natural enemies are minimal (Wang and Fan 1987).

The population density of zokors in autumn is closely related to the numbers of the reproductive females in spring. Density increases after reproduction and is about 1.56 times higher in autumn than in spring. From autumn to the next spring, the population decreases. The population of zokors in spring or autumn can be predicted by using the following regression models (Zhang et al.1991):

$$Y_{Autumn} = 4.864 + 0.9672X_{Spring}$$
$$(r = 0.9823 > r_{0.01} = 0.824, p < 0.01) \quad (1)$$

where Y_{Autumn} is the autumn density of the present year, and X_{Spring} is the spring density in the present year; and

$$Y_{Spring} = 1.426 + 0.7664X_{Autumn}$$
$$(r = 0.8930 > r_{0.01} = 0.824, p < 0.01) \quad (2)$$

where Y_{Spring} is the spring density of the present year, and X_{Autumn} is the autumn density of the previous year.

Damage Assessment and Economic Threshold

According to the definition of Headley (1972), 'economic threshold' is the population density of a pest when the cost for its control equals the minimal value of the product that is lost because of the pest. Therefore, the costs of rodent control should be less than the losses occurring in the absence of control, and the benefits should be maximised. Further, when the cost of pest control in a unit area equals the economic loss due to rodent damage, the pest density is at the economic threshold where rodent control should be undertaken.

Plateau pika

Pikas cause a lot of damage to the grass vegetation, mainly by feeding, gnawing grass roots and burrowing. The damage level to the grassland is closely related to the population density of pikas. The infested area of the grassland escalates with increasing rodent density and high grazing intensity by livestock. Some climatic factors may also influence the level of rodent damage to the grassland (Liang and Xiao 1978; Xiao et al. 1981).

Liu et al. (1980) reported that the population density of the plateau pikas was positively correlated to grassland damage. The relationship between pika density and grass damage can be used to calculate the economic threshold for each habitat using the formula:

$$Y = a + b \log X \quad (3)$$

where Y = % of grass damage and X = pika/ha, and solving for $Y = 0$ (Table 7).

Plateau zokor

Plateau zokors destroy grasslands by feeding and digging. Digging mainly takes place 40–160 mm underground, which destroys most plant root systems (90.7% of the total underground biomass). The original vegetation of grasslands disappears and seriously degenerated grasslands or even large areas of black sandy soil are formed. Field studies indicate that, with increases in zokor density, the total output of grasses decreases while the total output of weeds increases (Fan et al. 1988) (Table 8).

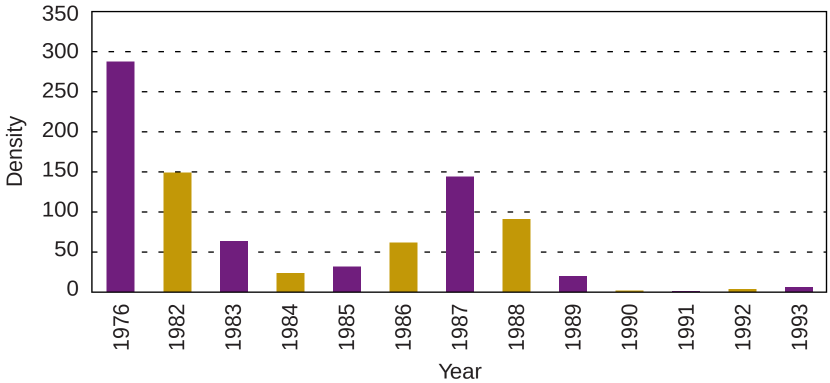

Figure 1.
Population densities of the plateau pika (individuals/hectare) (Zhou and Wei 1994).

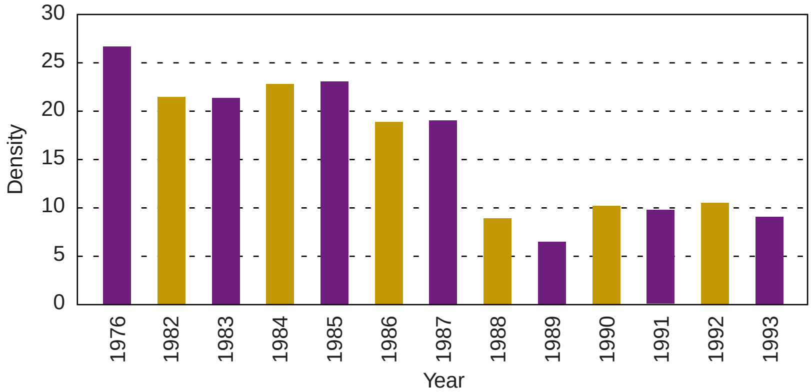

Figure 2.
Population densities of the plateau zokor (individuals/hectare) (Zhou and Wei 1994).

Table 7.
The relationship between the density of pika and the grass damage used to define economic thresholds (Y = percentage of grass damage, X = pika/ha) (Liu et al. 1980).

Habitat	$Y = a + b\log X$	Economic threshold (pika/ha)
All areas	$Y = -115.46 + 120.68\log X$	9.05
First terrace	$Y = -104.42 + 194.73\log X$	5.95
Second terrace	$Y = -70.53 + 101.87\log X$	4.92
Gentle slope	$Y = -63.54 + 88.15\log X$	5.26
Hills	$Y = -40.13 + 63.12\log X$	4.32

Table 8.
The relationship between the density of plateau zokor, the damage to grass and the yield of fresh vegetation types (Fan et al. 1988).

Density rank (zokors/ha)	Average density[1] (zokors/ha)	Damage[2] (%)	Area of mound[3] (m^2)	Grass yield[4] (kg/ha)	Sedge yield[5] (kg/ha)	Weed yield[6] (kg/ha)	Total yield[7] (kg/ha)
0	0	0	0	3020	2360	8212	13592
1–10	6.7	13	116	2797	2158	6229	11184
11–20	14.5	18	212	2277	1206	6750	10233
21–40	30.2	45	481	1046	666	5483	7195
41–70	62.9	64	1076	690	75	7180	7945
>70	91.6	84	1489	229	0	4450	4679
Coefficient of correlation		$r2,1 = 0.982$ $p < 0.01$	$r3,1 = 0.999$ $p < 0.01$	$r4,1 = -0.937$ $p < 0.01$	$r5,1 = -0.905$ $p < 0.05$	$r6,1 = -0.634$ $p > 0.05$	$r7,1 = -0.900$ $p < 0.05$

Notes:
(1) Numbers in superscript in the column headings relate to the correlation coefficients at the bottom of the table. (2) Significant levels of correlation: $r_{0.05} = 0.811$; $r_{0.01} = 0.917$.

Zokors not only gnaw grass roots but also push large amounts of poor quality soil to the ground surface, forming mounds of different sizes (Table 2). These mounds cover the original vegetation and the result is degradation of the grassland. The mound volume of the zokor varies with sex, age and seasons. Generally, the mound volume of males is larger than that of female and the mounds of adults are larger than those of the young. The annual losses of grassland due to damage by feeding, hoarding and covering of vegetation by mounds under different zokor densities (Tao et al. 1990) are listed in Table 9.

In the Haibei region of Qinghai Province, *K. humilis* is the dominant plant species in the alpine meadow. In 1987, the optimal grazing intensity was 3.29 sheep/ha. The maximum productivity of the grass was 3,554.4 kg/ha. The price of each sheep was 110 RMB[1]/sheep. So the price of grass (Y_1, RMB/kg) is:

$$Y_1 = 110 \times 3.29/3554.4 = 0.102 \quad (4)$$

The cost of diphacinone-Na baits used to control plateau zokor was 3.105 RMB/ha and the achieved killing rate was 74.4%. In theory, when the killing rate nears 100%, the rodent damage would be reduced to zero and, at this point, the cost of control (Y_2, RMB/ha) using baits is:

$$Y_2 = 3.105/74.4\% = 4.173 \quad (5)$$

The amount of grass (Y_0, kg/ha) which equals the cost of control should be:

$$Y_0 = Y_2/0.102 = 4.173/0.102 = 40.92 \quad (6)$$

The correlation model between the grass losses (Y, kg/ha) and density of zokors (X, zokors/ha) is:

$$Y = 11.2X - 5.61 \quad (7)$$

If $Y = Y_0 = 40.92$, then the economic threshold $X_0 = 4.16$. That is, when the population density of zokors reaches the level of 4.16 zokor/ha, control by baiting should be undertaken if significant economic losses are to be avoided.

1. RMB = renminbi yuan. As of May 1999, 8.14 RMB = US$1.

Table 9.
Vegetation damage for different densities of zokors over one year (Tao et al. 1990).

Density (zokor/ha)	1	3	4	6	7	11	13	14	19	24
Dry grass losses (kg/ha)	14.75	35.55	39.85	50.80	75.75	132.69	152.81	153.66	235.67	266.69

Integrated Pest Management (IPM)

An experiment that aimed to find a sustainable solution to rodent damage in the Qinghai–Tibet alpine meadow ecosystem was conducted from 1984 to 1989 in the Haibei region. The study area, located at Panpo, Menyuan County, Qinghai Province, was seriously infested by plateau pikas and plateau zokors. From 1984 to 1986, the above-ground mound density of the plateau zokor was 2,683 mounds/ha, and the active burrow density of plateau pika was 752 holes/ha. The seriously infested area made up 53.35% of the total grassland area. The vegetation types are mainly *K. humilis* meadow, and *Dasiphoia fruticosa* shrub and swamp meadow, and the soil types are plateau meadow soil, swamp soil and plateau shrub meadow soil. A series of measures, including chemical control, sowing, fencing, control of grazing intensity and weed control, were carried out in a demonstration area of 200 ha.

The baiting machine

In spring 1987, 0.075% diphacinone-Na and 0.6% gophacide grain baits were delivered into simulated underground tunnels with the aid of the baiting machine. About 19 g of bait was dropped every 5.5 m in each line. The interval between lines was 10 m. The baiting machine delivered the baits at the speed of about 3.3 ha/hr, about 20 times faster than manual baiting. The killing rates with diphacinone-Na and gophacide baits were 85.1% and 77.3%, respectively, for zokors and 96.9% and 99.8%, respectively, for plateau pikas (Jing et al. 1991) (Table 10), calculated 10 days after baiting and based on the numbers of active burrow holes before and after treatment. These zokor killing rate was significantly higher than that obtained by traditional manual baiting on the ground (Table 10) (Fan et al. 1986; Jing et al. 1987). After half a year, the control efficiency of 0.075% diphacinone-Na grain baits was re-assessed. Of 107 zokor burrow systems checked, only 2 were occupied. The control efficiency for zokors remained high (Jing et al. 1991) and indicated that baiting delivered by the machine was effective for long periods in controlling zokors.

Table 10.
Comparison of the efficiency of using the baiting machine and manual baiting methods for the control of plateau zokors and plateau pikas (Jing et al. 1991).

Baiting method	Bait	Killing rate (%)	
		Zokor (active mounds)	Pika (active burrows)
Baiting machine	0.075% diphacinone-Na	85.1	96.9
Baiting machine	0.6% gophacide	77.3	99.8
Manual baiting	0.075% diphacinone-Na	69.3	–

Management by sowing and fencing

Sowing and fencing were implemented after chemical control. Major grass species sown were *Elymus nutas*, *Elymus sibiricus* and *Pucciunelia tenuiflora*. Two years later, the average height of the grass had increased from 99 mm to 860 mm and the average ground coverage increased from 35% to 90%. The grass vegetation formed two layers; an upper layer of sown grasses and a lower layer of weeds. Grasses (Gramineae spp.) became dominant and their yield increased. In 1987, grasses, sedges and weeds made up 18.9%, 19.3% and 61.8% of the total above-ground biomass, respectively. In 1988, grasses, sedges and weeds made up 35.9%, 17.7% and 46.4% of the total above-ground biomass, respectively (Jing et al. 1991) (Table 11). The total biomass of the grass in the demonstration area increased by 1.9 times at the end of the first year and by 9.1 times at the end of the second year. After three consecutive years the population densities of the plateau zokors and the plateau pikas were still at low levels (Jing et al. 1991).

Weed control using herbicide

The degenerated grassland is dominated by weed species and is the optimal habitat for zokors. Therefore, weed control using herbicide will help destroy the habitat of zokors, and also has the added benefit allowing greater growth of foraging grasses by reducing competition from weeds. In June 1987, 2,4-dichlorophenoxyacetic acid was used to kill weeds as they began to germinate. A month later, the yield of grasses and sedges had increased and in correlation with the concentration of herbicide applied. At the optimal concentration of the herbicide (0.75 kg/ha), the yield of weeds decreased by 68.8% while the yield of the forage grasses increased by 47%. In autumn, the zokor density was greatly decreased. At the highest herbicide concentration (2.25 kg/ha), the density of zokor mounds decreased from 323 to 0 mounds/ha (Jing et al. 1991) (Table 12).

Economic impact of IPM

By implementing IPM from 1987 to 1989, rodent damage was reduced and the ground vegetation and productivity of the grassland increased greatly in the experimental area. The weight of dry grasses was only 84.7 g/m^2 in 1987 when the IPM experiment commenced, but it increased to 406.52 g/m^2 by 1989. In the experimental area (200 ha), the total yield of dry grasses increased from 80.6 t (which could feed 122 sheep) in 1987 to 728.9 t (which could feed 1,103 sheep) in 1989 (Jing et al. 1991).

The total investment in this IPM, including machine baiting, fencing and sowing was 40,170 RMB, and the income in the three consecutive years of 1987, 1988 and 1989 was 227,710 RMB. Therefore, the ratio of benefit to cost of the IPM in this region was 5.7 (Table 13) (Jing et al. 1991).

Table 11.
Changes in above-ground biomass after sowing or fencing following chemical rodent control (Jing et al. 1991).

Treatments	Above-ground dry biomass (g/m)							
	Pre-treatment: 1987				Post treatment: 1988			
	Grasses	Sedges	Weeds	Total	Grasses	Sedges	Weeds	Total
Chemical control+ semi-fenced	33.02	33.57	107.54	174.13	97.68	48.17	126.02	271.9
Chemical control+ sowing + semi-fenced	50.81	33.98	107.53	192.32	389.36	48.16	126.03	563.6
Untreated	11.82	32.61	74.54	118.97	29.26	17.68	253.73	300.7

Table 12.
Grass yields after weed control with different concentrations of herbicide and the effect on numbers new mounds created by zokors (Jing et al. 1991).

Herbicideconcentration (kg/ha)	Above-ground dry weight (kg/ha)			Zokor density (mounds/0.25 ha)	
	Grasses	Sedges	Weeds	Pre-treatment (Apr–May)	Post-treatment (Sep–Oct)
0.0	448	793	1206	483	376
0.375	757	995	980	457	164
0.75	1640	972	377	377	46
1.5	1462	503	401	439	9
2.25	1161	310	331	323	0

Table 13.
Comparison of the costs and benefits of integrated pest management in the experimental area located at Panpo, Menyuan County, Qinghai Province, from 1987 to 1989 (Jing et al. 1991).

Cost (RMB[a]) in 1987						Benefit (RMB)		
Machine baiting		Fencing		Sowing		1987	1988	1989
Motor power	Toxic bait	Iron net	Structure	Seed	Ploughing			
1 296	418	20 000	3 516	12 000	2 940	1 209	117 157	109 344

[a] RMB = renminbi yuan. As of May 1999, 8.14 RMB = US$1.

Recommendations and Future Research Priorities

In Qinghai Province, the total area of black sandy soils caused by rodents is more than 13,000 km^2. If the IPM strategy demonstrated in the experimental area could be extended successfully to regions of the Qinghai–Tibet alpine meadow ecosystem with heavy rodent infestation, the degenerated grassland could recover. Indeed the grass production would be over 0.103 billion t and this could feed 0.156 billion sheep. However, there are several important pointers for implementing this IPM strategy:

- For highly degenerated grassland with heavy pika and zokor problems, chemical control using baiting machines should be considered first, with weed control and sowing of grasses following immediately. Grazing by livestock should not be permitted in the first year, and limited grazing should be permitted only after the grassland is fully recovered.
- For lightly degenerated grassland with lesser pika and zokor problems, grazing should be stopped immediately and followed by weed control and sowing. Grazing should not permitted again until the grassland is fully recovered.
- For abandoned, non-cultivated grassland, chemical control using the baiting machine followed by weed control and grass sowing must occur to achieve recovery of the grassland.
- In the alpine meadow ecosystem, one polecat can kill 1,554 plateau pikas or 471 plateau zokors each year (Zheng et al. 1983; Wei and Zhou 1997). Therefore, the natural enemies of the pikas and zokors such as weasels, polecats, foxes and eagles should fully protected.

Because the plateau zokor was found recently to have some medical value in healing rheumatism (like tiger bone) (Zhang and Zhang 1997), it is now believed to be of economic importance in this region. Thus, future studies will focus on finding a solution to the conflict between this newly recognised benefit versus the damage caused by zokors through managing their population at a level suitable for good harvest output but causing little damage to the grassland. For pika management, biological control using parasites and/or contraceptive vaccines that potentially have minimal non-target environmental impacts will be considered as research priorities in the future.

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