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Burrowing rodents as ecosystem engineers: the ecology and management of plateau zokors *Myospalax fontanierii* in alpine meadow ecosystems on the Tibetan Plateau

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ABSTRACT

1. Plateau zokors, *Myospalax fontanierii*, are the only subterranean herbivores on the Tibetan plateau of China. Although the population biology of plateau zokors has been studied for many years, the interactions between zokors and plants, especially for the maintenance and structure of ecological communities, have been poorly recognized. In the past, plateau zokors have been traditionally viewed as pests, competitors with cattle, and agents of soil erosion, thus eradication programmes have been carried out by local governments and farmers. Zokors are also widely and heavily exploited for their use in traditional Chinese medicine.

2. Like other fossorial animals, such as pocket gophers *Geomys* spp. and prairie dogs *Cynomys* spp. in similar ecosystems, zokors may act to increase local environmental heterogeneity at the landscape level, aid in the formation, aeration and mixing of soil, and enhance infiltration of water into the soil thus curtailing erosion. The changes that zokors cause in the physical environment, vegetation and soil clearly affect the herbivore food web. Equally, plateau zokors also provide a significant food source for many avian and mammalian predators on the plateau. Zokor control leading to depletion of prey and secondary poisoning may therefore present problems for populations of numerous other animals.

3. We highlight the important role plateau zokors play in the Tibetan plateau ecosystem. Plateau zokors should be managed in concert with other comprehensive rangeland treatments to ensure the ecological equilibrium and preservation of native biodiversity, as well as the long-term sustainable use of pastureland by domestic livestock.

Keywords: biodiversity, biogeochemistry cycling, fossorial rodents, secondary poisoning, subterranean mammals, wildlife exploitation

INTRODUCTION

Mammalian herbivores affect the dynamics of biological communities, the direction of succession, microgeomorphic changes, and biogeochemistry cycling in a number of different terrestrial ecosystems (Bryant, 1987; Inouye *et al.*, 1987, 1994; Huntly & Inouye, 1988; Brown & Heske, 1990; Gibson & Brown, 1992; Kielland & Bryant, 1998). Subterranean rodents, despite their relatively small size, are an important organism controlling ecosystem structure

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and development. Thorn (1978, 1982) has discussed the role of pocket gophers *Geomys* spp. in the alpine zone of Colorado Front Range and shown that they may be the dominant geomorphic agents there. Reichman & Seabloom (2002) have also shown pocket gophers to be subterranean ecosystem engineers in worldwide. These rodents excavate vast burrow systems and deposit soil in abandoned tunnels and on the ground surface, and alter strongly the soil characteristics in texture and water-holding capacity. Recent studies on pocket gophers reveal that their extensive excavations and the associated impacts generate a dynamic mosaic of nutrients and soil conditions that promotes diversity and maintains disturbance-dependent components of plant communities (Reichman & Seabloom, 2002). Meanwhile, these disturbances significantly accelerate erosion and downslope soil movement on shallow slopes while inhibiting them on steep slopes (Reichman & Seabloom, 2002). Grinnell (1923) asserts that 'our native plant life, on hills and mountains, would soon begin to depreciate, were the gopher population completely destroyed.'

Plateau zokors *Myospalax fontanierii*, are small (approximately 220 g for females and 270 g for males), subterranean rodents that inhabit the Tibetan plateau, China (Smith & Foggin, 1999; Zhang, Fan & Wang, 1999). Because of their fossorial life-style, their behaviour, and their population structure, plateau zokors may influence this ecosystem in diverse ways. Their burrowing activity, below-ground foraging, and production of excrement all have direct and indirect, long-term and short-term, effects on other ecosystem components (Zhang, 2000). Like other subterranean rodents, plateau zokors have profound impacts on alpine ecosystem from consuming vegetation to altering the soil physically. After many years of occupation, plateau zokors have created large, distinct areas within the grassland matrix by burrowing and mound-building; here, ecosystem processes may proceed at different rates than those outside unoccupied areas (Zhang, 1999, 2000). Individuals are aggressively territorial (Fan, Jing & Zhou, 1990), populations tend to be spatially clumped (Zong *et al.*, 1991), and individuals use vegetation patches at different spatial and temporal scales (Zhou & Dou, 1990; Zhang, 1999). These treats create heterogeneity in their influence that may be important to the community dynamics, biogeochemistry, and biodiversity in the plateau ecosystem. We review the effects of plateau zokors on ecosystems and discuss their critical ecological role in this ecosystem. We argue that the prevailing idea of the plateau zokor as a rodent pest is not based on a holistic assessment of their role in the ecosystem. Pocket gophers and prairie dogs have also been viewed as competitors with cattle for rangeland resources in North America and have previously been the subject of large-scale eradication campaigns. However, we highlight the recent recognition by the public of their important roles in natural ecosystem and the resulting mass of work undertaken for protecting and restoring populations of gophers and prairie dogs since the 1950s (Huntly & Inouye, 1988; Whicker & Detling, 1988). Similarly, zokors and plant species living on the Tibetan plateau have formed co-evolutionary relationships. These interactions occurring between two trophic layers have promoted the development of ecosystem structure and function.

The Tibetan plateau is located in south-west China (27–40°N, 75–105°E; average elevation > 4000 m). It occupies 2.5 million km^2, approximately 25% of the area of China. An estimated 70% is high altitude grassland, and Tibetan pastoralism is the primary sustainable use of this rangeland habitat (Smith & Foggin, 1999). The range of daily temperature is great, and the annual mean temperature is < 0°C (Xia, 1989). There is no frostless season, and the thickness of permafrost can be found in extensive areas including mountains and grasslands in August (Smith *et al.*, 1986). Principal soil types are alpine meadow soil, alpine scrubby meadow soil and bog soil (Xia, 1989). The major types of plants are classified as alpine meadow, alpine shrub, alpine prairie and alpine steppe meadow and the dominant forms are

Carex spp., *Kobresia* spp., *Stipa* spp., *Achantherum splendens*, and *Potentilla fruticlsa* (Xia, 1989).

PLATEAU ZOKOR BIOLOGY

Plateau zokors are members of the rodent family Cricetidae. They are active year-round and excavate caches in their burrow system to store food to provide sustenance when fresh vegetation is not readily available. Plateau zokors are highly specialized subterranean herbivores broadly distributed in farm, prairie, alpine prairie and meadow habitats across the Tibetan plateau (Zhang *et al*., 1999). They are morphologically and behaviourally similar to pocket gophers (Andersen, 1987; Zhou & Dou, 1990). Unlike above-ground herbivores, plateau zokors spend 2–3 hours a day feeding and using systems of tunnels that they actively excavate and maintain. In constructing tunnels, plateau zokors move soil to the ground surface and deposit it in mounds. An average of 1.04 mounds are formed by an individual zokor every day (Wang & Fan, 1987). Tunnelling is often extensive. The average length of tunnels is about 100 m and mounds and their associated earth cores may cover as much as 15–20% of the ground surface (Wang & Fan, 1987; Fan *et al*., 1989; Zhang, 1999). Plateau zokors spend 85–90% of their lifetime in underground nests, which are usually over 2 m deep for females and approximate 1.5 m for males (Zhou & Dou, 1990). Feeding activities do not occur beyond burrow systems. Foraging and burrowing activity of plateau zokors mainly took place at a depth of 3–20 cm in alpine meadows (Zhang, 1999). The home range of a male zokor exceeds 1500 m^2 and is larger than a female range of less than 500 m^2 (Zhou & Dou, 1990).

Vleck (1979), studying pocket gophers, estimated that the energy cost of burrowing was 360–3400 times that of above-ground travel. Like pocket gophers, Su & Wang (1992) measured that the burrowing metabolic rate of a plateau zokor is 4.6282 mL O_2/g hour. The daily energy consumption per gram of body weight by a plateau zokor is 4.1 times the consumption of a Tibetan sheep (Wang *et al*., 1980; Pi, 1982). Because of these high energetic demands (667.5 KJ/individual/day) and year-round activity, plateau zokors have major effects as consumers, despite their relatively small size.

Plateau zokors have broad diets, consuming both roots and shoots of annual and perennial grasses, forbs, and a few shrubs (Wang *et al*., 2000; Zhang, 2000). Even though their diets are broad, plateau zokors forage selectively. They prefer areas with a soft soil layer and high primary productivity (Wang *et al*., 2000; Zhang, 2000). Some study results indicate that forbs are preferred over grasses and that succulent below-ground storage organs are consumed preferentially (such as *Notopterygium forbesiide*, *Potentilla anserina*, and *Morina chinensis*; Fan *et al*., 1989; Wang *et al*., 2000; Zhang, 2000).

The distribution and population density of plateau zokors are limited by elevation, vegetation, precipitation, and anthropogenic disturbance (Zhang *et al*., 1999). It was estimated that they occupied a range of approximately 3.8×10^6 ha (Fig. 1) at an average density of 15 animals/ha, but ranging from five to more than 70 per hectare in Qinghai province in the 1980s (Wang & Fan, 1987; Zhang *et al*., 1999). Knowledge of the plateau zokor's role in the Tibetan plateau ecosystem is lacking because they have traditionally been viewed as pests, competitors with cattle for rangeland resources, and as agents of undesirable soil erosion (Hall, Boelhouwers & Driscoll, 1999). Annual eradication programmes have been carried out by local governments and farmers with the result of reducing zokor populations in 2000 to less than 31.6% of those in 1990 (Zhang *et al*., 1999; Zhang, 2000). Their tunnelling activity, consumption and composting of plants, and production of excrement all have direct and indirect, long-term and short-term effects on other components of plateau ecosystem (Wang & Fan, 1987; Zhang, 2000).

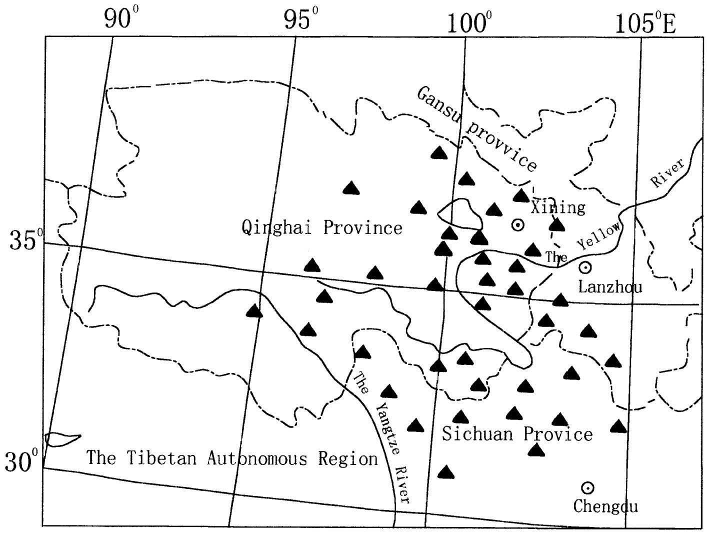

Fig. 1. The geographical distribution of plateau zokors in Qinghai, Gansu, Sichuan provinces and The Tibetan Autonomous Region, People's Republic of China in 1980.

Table 1. The characteristics of soil in plateau zokor mounds and the surrounding soil measured in August (mean ± standard error)

Soil character	Mounds emerged in April	Mounds emerged the previous October	Surrounding soil
Hardness (kg/m^3)	1.14 ± 0.13	2.11 ± 0.91	10.02 ± 4.49
Moisture (%)	20.89 ± 0.82	23.47 ± 0.68	29.40 ± 0.91
Organic matter (%)	15.67 ± 0.25	14.83 ± 0.46	17.92 ± 0.59

Table 2. The contents of available nitrogen (N), available phosphorus (P), and available potassium (K) in the soil of plateau zokor mounds measured in July (Wang *et al.*, 1993)

Item	Control	Mounds emerging in April	*T*-test	Mounds emerged in previous October	*T*-test
N (p.p.m)	50.9	78.8	$P < 0.01$	69.3	$P < 0.05$
P (p.p.m)	12.2	18.2	$P < 0.05$	14.7	$P < 0.05$
K (p.p.m)	179.9	192.8	$P > 0.05$	182.7	$P > 0.05$

EFFECTS ON SOIL AND PLANT DIVERSITY

As with other fossorial herbivores (Andersen, 1987; Nevo, 1979), the most conspicuous effects of plateau zokors on soil arise from the mounds and earth cores that they produce while enlarging and maintaining their tunnel systems. It is estimated that a plateau zokor deposits at least 1024 kg/year at the soil surface of alpine meadows (Wang & Fan, 1987). The soil in zokor mounds frequently differs in hardness, moisture and organic matter from the surrounding undisturbed soil (Table 1). Similarly, levels of soil nutrients, including nitrogen and phosphorus vary significantly among zokor mounds of differing ages and from undisturbed soil. Studies conducted at the Haibei Research Station (Menyuan County, Qinghai Province) have shown that the soil of fresh mounds was higher in available nitrogen and phosphorus content than in randomly collected soil samples (Table 2). The effect of plateau zokors on soil nutrients results from the manner in which zokors forage and from the vertical distribution of nutrients in the soil. Nitrogen and phosphorus content of alpine meadow soils drops rapidly with increasing depth (Le *et al.*, 1989), thus zokors deposit mounds of nutrient-poor soil on the ground surface when excavating their foraging tunnels (Wang, Bian & Shi, 1993; Zhang, 2000). However, once at the surface the temperature of soil found in fresh mounds increases – leading to concomitant promotion of mineralization of organic phosphorus and nitrogen, and increases in the abundance of soil micro-organisms (Li, Yang & Zhu, 1989). Over time, however, the soil of old mounds becomes significantly lower in available nitrogen and phosphorus content (Zhang, 2000).

Huntly & Inouye (1988) suggest that the changes subterranean herbivores make in the vertical and horizontal distribution of the physical and chemical characteristics of soil can affect the resources available to plants in several ways: (i) the average level of nutrients is changed; (ii) the spatial pattern of soil nutrients is changed – soil nutrients becomes more heterogeneous; and (iii) the relationship between soil nutrients and light, another resource that limits plant growth, is altered. In undisturbed vegetation more soil nitrogen results in more plant growth and thus in higher plant biomass; therefore, light penetration through the plant canopy is reduced. As a result, the availability of light of sub-canopy plants is inversely related to the availability of nutrient. Zokors tend to uncouple these two resources by creating patches of bare or less densely vegetated ground. In the presence of zokors, light availability is more variable and, on average, higher; nitrogen availability is more variable and, on average, higher; and the negative correlation between the availabilities of nitrogen and light that exists in undisturbed vegetation is relaxed. These changes produce a far greater range of resource conditions for plants. Therefore, in the presence of zokors a higher diversity of plants should coexist, if plants differ in their relative competitive abilities for nutrient and light.

Creation of mounds changes soil nutrients and surface light, thus affecting plant biomass and species composition. The above-ground biomass of plants surrounding zokor mounds was higher than in control areas (Table 3; Wang *et al.*, 1993). The flora of zokor mounds typically differs from the surrounding vegetation (Wang & Du, 1990; Bian, Wang & Shi, 1991; Zhang, Zhou & Cincotta, 1994; Zhang, 2000). Frequently, forbs are more abundant on mounds (Bian *et al.*, 1991; Zhang *et al.*, 1994). Mounds of gophers have been assumed to affect plant community diversity and species composition simply by providing space for colonization by so-called fugitive plant species that are competitively eliminated over time by more advanced successional species (McDonough, 1974; Hobbs & Hobbs, 1987; Hobbs *et al.*, 1988). Many studies about zokors show the competitive relations of plants can be changed by creating mounds and the consumption of plants (Wang & Du, 1990; Zhang *et al.*, 1994).

Plateau zokors can also have long-term effects on plant biomass and species composition. Our study results at Haibei Research Station indicate that above- and below-ground biomass,

Table 3. The comparison of above-ground biomass of plants (g/m^2) between the soil in the immediate vicinity of zokor mounds and in the soil further away, measured in July (Wang *et al.*, 1993)

	Above-ground biomass		
Plant group	Near zokor mounds	Away from zokor mounds	*T*-test
Grasses	53.0	33.1	$P > 0.05$
Sedges	47.4	29.7	$P > 0.05$
Forbs	228.0	142.0	$P > 0.05$
Total	328.4	204.8	$P < 0.05$

Table 4. Number of plant species sampled, plant species diversity (H'), cover, height of vegetation, and above- and below-ground biomass measured in August in three zones of alpine meadows with varying zokor activity (Zhang & Liu, 2003)

Vegetation characteristics	Treatment: Occupied by zokors for >10 years	Abandoned by zokors for 5 years	Unoccupied by zokors
Number of plant species			
Monocotyledon	3	5	10
Dicotyledon	21	19	32
All species	24	24	42
Species diversity (H')			
Monocotyledon	0.606 ± 0.156	1.029 ± 0.125	1.824 ± 0.081
Dicotyledon	2.357 ± 0.033	1.931 ± 0.076	2.701 ± 0.049
All species	2.520 ± 0.037	2.280 ± 0.052	2.892 ± 0.034
Cover (%)	19.2 ± 2.4	47.1 ± 4.8	81.2 ± 3.5
Height (cm)	9.7 ± 1.4	23.8 ± 3.2	42.2 ± 3.4
Above-ground biomass (g/m^2)	170.2 ± 8.7	238.8 ± 22.2	413.6 ± 36.0
Below-ground biomass (g/m^2)	489.1 ± 13.2	1546.6 ± 19.36	2450.4 ± 16.3

height and cover of vegetation significantly decreased in a habitat occupied by plateau zokors over 10 years (Table 4). The growth and development of monocotyledons was restrained. Long-term colonization by the zokors resulted in fewer plant species and lower plant species diversity (Table 4; Zhang & Liu, 2003), while the community on the occupied sites became dominated by those plants containing secondary chemical compounds such as *Ajania tenuifolia* containing monoterpenes and *Elsholtzia calycocarpa* containing pennyroyals (Yang, 1991). There are many differences in the dominant species among mounds, arising from different patterns of age and habitat colonization. The spatial and temporal patterning in soil nutrient and plant composition may contribute to large-scale vegetational diversity and increase the complexity of landscape (Zhang, 2000).

Many studies on pocket gophers indicate that soil-moving activities of gophers increase the abundance of plants that gophers prefer to eat. Annuals, short-lived perennials, and forbs tend to be more abundant where gophers are active (Turner *et al.*, 1973; Laycock & Richardson, 1975; Tilman, 1983; Williams *et al.*, 1986; Inouye *et al.*, 1987; Hobbs *et al.*, 1988). Tilman (1983) suggested that early successional plants are preferred by pocket gophers. However, in the alpine meadows of the Tibetan plateau, several early successional plants on mounds such as *Ajania tenuifolia*, *Eeontopodium nanum*, *Anaphalis lacteal*, and *Aster flaccidus* are not preferred by plateau zokors (Wang & Du, 1990; Zhang *et al.*, 1994; Zhang, 2000). Pocket gophers' activities slow down the rate of succession at Cedar Creek (Inouye *et al.*, 1987; Huntly & Inouye, 1988). Similarly, Xiao *et al.* (1981) and Fan *et al.* (1989) also considered that plateau zokor activity slowed the succession of vegetation in alpine meadows because where zokors were active, forbs that were not preferred as food were more common. Our results suggest that forbs that live in areas of high zokor activity, especially those forbs containing secondary chemical compounds, can effectively prevent these landscapes from being over grazed by livestock. Thus a secondary benefit of zokors is that they provide a mechanism of plant protection that restricts the process of over grazing.

THE EFFECT OF PLATEAU ZOKORS ON OTHER ANIMALS

Burrows that are created by zokors become significant breeding habitat for native amphibians, reptiles, birds and other small mammals (Fan *et al.*, 1990; Smith & Foggin, 1999). There also is intense competition between plateau zokors and plateau pikas for space (Zong, Xia & Sun, 1986; Fan *et al*., 1990; Zhang *et al*., 1998). Thus, where these two species are sympatric, this interaction limits each species from extreme increases in density (Zong *et al*., 1986; Zhang *et al*., 1998). Abandoned zokor burrows often are colonized by root voles *Microtus oeconomus* and Gansu pikas *O. cansus* as nests for breeding and protection from predators. Many birds depend on the burrows that are constructed by plateau zokors for nesting and to reduce the risk of predators. Hume's ground jay *Pseufopodoces humilis* and several species of snow finch *Montifringilla adamsi*, *M. blanfordi*, *M. davidiana*, *M. ruficollis*, *M. tacazanowski* nest primarily in pika or zokor burrows (Zhang, 1982; Smith *et al*., 1990; Smith & Foggin, 1999).

PLATEAU ZOKORS AS PREY FOR NATIVE WILDLIFE

Across much of the plateau, the plateau pika and zokor are the dominant small mammalian herbivore. Other species, such as woolly hares *Lepus oiostolus*, Himalayan marmots *Marmota himalayana*, Gansu pika, Daurian pika *Ochotona dauurica*, root vole, Qinghai vole *Microtus fuscus* are scarce and patchily distributed. Most predatory animals living on the Tibetan plateau, including: Eurasian ferrets *Mustela nigripes*, foxes *Vulpes ferrilata* and *V. vulpes*, steppe polecats *Mustela eversmanni*, Chinese mountain cats *Felis bieti*, Pallas's cat *Otocolobus manul* and Eurasian lynx *Lynx lynx*, rely mainly on the abundant plateau pikas in their diet (Smith *et al*., 1990; Zhou & Dou, 1990; Zhou, Wei & Biggins, 1994a; Zhou, Wei & Biggins, 1994b; Zhou, Wei & Biggins, 1995; Schaller, 1998; Smith & Foggin, 1999). However, populations of plateau pika are heavily influenced by the plateau climate, and their density plummets regionally when there are atypical heavy snowstorms in winter. During these times, plateau zokors become the primary food resource for many predators. Steppe polecats, Chinese mountain cats, Pallas's cat and Eurasian lynx rely heavily on plateau zokors for food (Li *et al*., 1989). Eurasian polecats, foxes and many raptor species also rely at least partly on plateau zokors on food. Many large mammalian predators such as wolves *Canis lupus* and brown bears *Ursus arctos* also prey on animals as small as the plateau pikas and zokors (Li *et al*., 1989; Schaller, 1998). Thus, plateau zokors act as an alternative food source for many carnivores in the plateau ecosystem (Li *et al*., 1989; Zhou *et al*., 1994a, 1994b, 1995; Wei *et al*., 1996).

It had been generally assumed (Li *et al*., 1989) that most large predatory birds on the Tibetan plateau, such as golden eagles *Aquila chrysaetos*, upland buzzards *Buteo hemilasius*, saker falcons *Falco cherrug*, goshawks *Accipiter gentilis*, black kites *Milvus migrans*, and little owls *Athene noctua*, depended primarily upon plateau pikas as a food resouce. Recently, however, Su (2001) determined that a significant amount of pellets found under nests of upland buzzards, saker falcons, and little owls contained zokor remains. This result shows that zokors are also an important component in the diet of avian predators on the plateau.

RELATIONSHIPS BETWEEN PLATEAU ZOKORS AND LIVESTOCK

Species diversity and species number of small herbivorous mammals show significantly positive correlations with grazing intensity of livestock, while there is an insignificantly positive correlation between rodent species evenness and grazing intensity (Liu *et al*., 1991). The combined grazing of yaks, sheep and horses lowers the degree of cover and the height of vegetation, plateau zokors occur at greater densities than on natural meadows (Liu *et al*., 1991; Bian *et al*., 1994; Zhang *et al*., 1998).

The diversity of mammal species was also related to grazing-induced changes in vegetative structure. The diversity of plants and that of the herbivorous small mammals within various levels of grazing intensity indicated a significantly positive correlation, and the evenness of community structure also showed a significantly positive correlation with plant evenness (Liu *et al.*, 1991). However, there was no relationship between the species richness of plants and species richness of herbivorous small mammals. Furthermore, species diversity was negatively correlated to the height of plants and vegetative cover level. The small herbivore community in alpine meadows is determined primarily by the structural attributes of the habitat, which in turn is largely a function of the intensity of grazing by livestock.

In most cases, the degraded vegetation resulting from over grazing provides an advantageous ecological condition for the formation and spread of high-density populations of plateau zokors and pikas (Shi, 1983; Liu *et al.*, 1991; Bian *et al.*, 1994; Su, 2001). Zokors, along with pikas, are more likely to accelerate the deterioration of rangelands that are already overgrazed. Thus, the most effective way to control damage by small mammals on the high alpine grasslands of the Tibetan plateau would be to improve the grazing system.

CONTROL AND EXPLOITATION OF PLATEAU ZOKORS

In spite of the important role played by the plateau zokor in the alpine meadow ecosystem, this species has been targeted for intensive control measures using poison baits for the past two decades. Other species, such as the plateau pika, Daurian pika and Qinghai vole are also targets of control (Fan *et al.*, 1990; Jing *et al.*, 1991; Zhang *et al.*, 1998; Smith & Foggin, 1999). These control activities have been carried out every year because local governments and residents believe these small mammals have a negative impact on rangeland habitats, compete for forage that could otherwise be utilized by livestock, and create mounds that can cover vegetation and reduce primary productivity.

Since the 1990s, the bones of plateau zokors have been used as a material in traditional Chinese medicine. As a result of this commercial value, zokors were killed and captured intensively across the plateau. More than 20 000 km of zokor bone were produced each year for medicinal purposes, and millions of plateau zokors over large areas have been killed annually. This harvest appears unsustainable, and it is difficult to find active mounds. In spite of this intensive killing and capture of zokors, many farmers still used traditional methods to poison the zokors every year. The culmination of these activities has been the near extirpation of plateau zokors across much of the plateau.

COMPREHENSIVE RANGELAND MANAGEMENT

Many scientists have realized that the attempt to eliminate native species such as the plateau pika and the plateau zokor on the Tibetan plateau is 'the wrong thing to do'. The idea that small mammals cause rangeland degradation across the plateau has lost favour among scientists though is still a common perception among land owners and managers. However, we believe that the current poisoning campaign will have disastrous consequences for many avian and mammalian predators in this region that are secondarily poisoned by eating dead and moribund small mammals. A large number of studies on small mammal population dynamics indicate that there are significant positive correlations between grazing intensity and populations of plateau pikas and plateau zokors. Research conducted at the Haibei Alpine Meadow Ecosystem Station shows that plateau zokor populations can remain stable over a period of more than 10 years in the absence of livestock grazing (Zhang *et al.*, 1991). High densities can only be found in abandoned fields, overgrazed grasslands, or abandoned farmland that is reverting to grasslands. Obviously, overgrazing and improper rangeland management causes the plateau zokor population to increase and exacerbates the perception of their 'rodent pest' status. The results of many studies in other regions indicate that zokors never reach high densities or appear to be 'rodent pests' where grazing intensity is kept light and the stocking rate is moderate (Liu *et al*., 1991). Many scientists in China now conclude that rodents become harmful to rangeland only when overgrazing is so extremely heavy that it causes small mammal populations artificially to increase (Liu *et al*., 1991).

The idea of a comprehensive rangeland management policy has been gradually accepted by local government and stakeholders to overcome the negative effects on the environment and biodiversity of 'pest control' directed at native mammal species. This understanding, based on the concept of ecological equilibrium, has been endorsed and put into practice across grassland habitats throughout western China (Zhong, Zhou & Sun, 1985; Jing *et al*., 1991; Zhong *et al*., 1991).

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