*Animal Conservation* (1999) **2**, 235–240 © 1999 The Zoological Society of London Printed in the United Kingdom

# The plateau pika (*Ochotona curzoniae*) is a keystone species for biodiversity on the Tibetan plateau

Andrew T. Smith and J. Marc Foggin

Department of Biology, Box 871501, Arizona State University, Tempe, AZ 85287-1501, USA

*(Received 17 October 1998; accepted 19 December 1998)*

**Abstract**

It is necessary to look at the big picture when managing biological resources on the Qinghai–Xizang (Tibetan) plateau. Plateau pikas (*Ochotona curzoniae*) are poisoned widely across the plateau. Putative reasons for these control measures are that pika populations may reach high densities and correspondingly reduce forage for domestic livestock (yak, sheep, horses), and because they may be responsible for habitat degradation. In contrast, we highlight the important role the plateau pika plays as a keystone species in the Tibetan plateau ecosystem. The plateau pika is a keystone species because it: (i) makes burrows that are the primary homes to a wide variety of small birds and lizards; (ii) creates microhabitat disturbance that results in an increase in plant species richness; (iii) serves as the principal prey for nearly all of the plateau's predator species; (iv) contributes positively to ecosystem-level dynamics. The plateau pika should be managed in concert with other uses of the land to ensure preservation of China's native biodiversity, as well as long-term sustainable use of the pastureland by domestic livestock.

## INTRODUCTION

The Qinghai–Xizang (Tibetan) plateau occupies 2.5 million km$^2$, approximately 25% of the area of the People's Republic of China. An estimated 70% of the plateau is high altitude grassland, and Tibetan pastoralism is the primary sustainable use of this rangeland habitat (Ekvall, 1968; D. J. Miller, 1995; D. J. Miller & Craig, 1997). Although the plateau is not as biologically rich as some other areas in China, it contains a distinctive flora and fauna – much of which is endemic or endangered (MacKinnon *et al.*, 1996; Schaller, 1998).

Biodiversity conservation on an area as vast as the Tibetan plateau is a complex endeavour (CSCPRC, 1992; D. J. Miller, 1995, 1998; Schaller, 1998). Here we concentrate on one feature of this ecosystem and show its relevance to the overall biodiversity and ecosystem health on the plateau. We have investigated the role of the plateau pika (*Ochotona curzoniae*) as a keystone species in the Tibetan plateau ecosystem. In spite of the critical ecological role played by the plateau pika in this ecosystem, this species has been the target of widespread poisoning campaigns designed to control or eliminate it. We argue that an attempt to selectively poison the plateau pika is detrimental to the preservation of native biodiversity and the normal functioning of the Tibetan plateau ecosystem. If China is to implement successfully its forward policy of biodiversity conservation (Anonymous, 1994; MacKinnon *et al.*, 1996) on the Tibetan plateau (CCICED, 1996), the pika should be considered a positive element and widespread poisoning activities to kill pikas should be halted.

All correspondence to: Andrew T. Smith. Tel: xx.480.965.4024; Fax: xx.480.965.2519; E-mail: a.smith@asu.edu

## PIKAS AS A KEYSTONE SPECIES

A *keystone species* is one whose loss from an ecosystem would cause a greater than average change in other species' populations or ecosystem processes – one that has a disproportionately large effect on other species in a community (Heywood, 1995). The plateau pika is a keystone species because it: (i) makes burrows that are the primary homes to a wide variety of small birds and lizards; (ii) creates microhabitat disturbance that results in an increase in plant species diversity; (iii) serves as the main prey for most of the predatory animals on the plateau; (iv) contributes positively to ecosystem-level dynamics. The plateau pika, as a keystone species, closely resembles the prairie black-tailed dog (*Cynomys ludovicianus*) as a keystone species in the North American prairie ecosystem (Schaller, 1985; Hoogland, 1995; Kotliar *et al.*, 1999).

### Biodiversity of symbiotic animals

The Tibetan plateau is largely a treeless environment, and the open meadows that constitute the majority of the plateau ecosystem offer little protection for nesting animals. The burrows constructed by the plateau pika offer breeding habitat for many species. Hume's ground jay (*Pseudopodoces humilis*) and several species of snowfinch (*Montifringilla adamsi*, *M. blanfordi*, *M. davidiana*, *M. ruficollis*, *M. tacazanowski*) nest primarily in pika burrows (Prejevalski, 1876; Meyer de Schauensee, 1984; Feng, Cai & Zheng, 1986; Smith *et al*., 1990; Ma, 1995; Schaller, 1998). These birds are more abundant in areas inhabited by pikas (Ma, 1995). Similarly, Pere David's snow finches (*M. davidiana*) and Isabelline wheatears (*Oenanthe isabellina*) regularly nest in the holes of Daurian pikas (*O. daurica*), an ecologically similar species that also occupies portions of the plateau (Smith *et al*., 1990). In addition, native lizards (*Phrynocephalus vlangalii*, *Eremas multiocellata*) use pika burrows for cover and as breeding sites. Loss of pikas, and thus the burrows they create, negatively impacts many species and reduces native biodiversity on the Tibetan plateau (Li, 1989; pers. obs.).

## Increased plant species richness

Evidence for increased plant species richness caused by the burrowing activities of the plateau pika is indirect, because there are insufficient studies on this phenomenon in the Tibetan plateau ecosystem. However, a wide variety of studies on similar species on grasslands in other areas, including Asia, all indicate that the surface disturbance caused by burrowing animals commonly increases plant species richness compared to areas without burrowing animals (Formosov, 1928; Huntly & Reichman, 1994). Total plant species diversity on the American prairie is greatest in areas occupied by prairie dogs (Whicker & Detling, 1988; see also Stapp, 1998; Kotliar *et al*., 1999). On the Mongolian steppe local floral diversity is enhanced by the burrowing of Daurian pikas (some shrub plants only grow on pika burrows; Dmitriev, 1985; Smith *et al*., 1990). Certain plants (*Euphorbia altaica*, *Artemesia* spp. and some crucifers) grow only on the burrows of Pallas's pika (*O. pallasi pricei*; Smith *et al.,* 1990). At the International Symposium on the Qinghai–Tibet Plateau held in Xining in July 1998, the European Union-funded Qinghai Livestock Development Project stated clearly that more 'weeds' are present in areas with plateau pikas than in the surrounding grassland, thus indicating an increased plant diversity. However, it will take long-term controlled experiments in areas that are not overgrazed to evaluate the full relationship between plateau pikas and plant diversity (Stapp, 1998; Kotliar *et al*., 1999).

## Pikas serve as prey for many native wildlife species

Most predatory animals on the Tibetan plateau rely heavily on pikas in their diet (Prejevalski, 1876; Smith *et al*., 1990; Schaller, 1998). Across much of the plateau, the pika is the dominant small mammalian herbivore. Wooly hares (*Lepus oiostolus*) are encountered very rarely, and Himalayan marmots (*Marmota himalayana*) are scarce and patchily distributed. Only the fossorial zokor (*Myospalax baileyi*), a species also subject to control, can be found at high densities, but zokor colonies are also patchily distributed and encountered infrequently. Pikas are not only the most abundant source of food for predators during the summer, but as pikas do not hibernate, they become almost the sole source of food for many predatory species during winter. When pikas are exterminated regionally this important source of food disappears, starving predators and resulting in a loss of local biodiversity. We have driven across vast stretches of the plateau without seeing any raptors soaring in the sky – more often than not these are the areas void of pikas due to prior poisoning campaigns. Conversely, the presence of raptors generally indicates areas of healthy pika populations.

Populations of steppe polecat (*Mustela eversmanni*) on the plateau (like their counterpart in North America, the black-footed ferret (*M. nigripes*) which preys on prairie dogs) are linked to the dynamics of pika populations (Nekipelov, 1954; Schaller, 1985; Smith *et al*., 1990). In North America control of prairie dogs has resulted in the near extirpation of the black-footed ferret, which only now is being rescued from extinction using expensive intervention (B. Miller, Reading & Forrest, 1996). Similarly, other small mammals such as weasels (*Mustela altaica*, *M. eversmanni*), foxes (*Vulpes ferrilata*, *V. vulpes*), and Pallas's cat (*Otocolobus manul*) rely heavily on plateau pikas for food (Smith *et al*., 1990; Schaller, 1998).

Many larger mammalian predators such as wolves (*Canis lupis*), snow leopards (*Uncia uncia*) and brown bears (*Ursus arctos*) also prey on animals as small as the plateau pika (Schaller, 1998). Snow leopards largely specialize on big game, and pikas act only as a buffer species (Schaller, 1998). However, pikas comprise over 50% of the diet of wolves in some areas (Schaller, 1998), and brown bears appear to be particularly reliant on pikas for food. One study in the Chang Tang region found that almost 60% of the diet of brown bears was pikas (Schaller, 1998). During his 1893–1896 expedition to the Tibetan plateau, Kozlov found 25 pikas in the stomach of one bear, and when Przewalski secondarily defined the Tibetan form, he called it *U. lagomyiarius* or 'bear pika-eater' (Smith *et al*., 1990).

Most large predatory birds on the Tibetan plateau (golden eagles, *Aquila chrysaetos*; upland buzzards, *Buteo hemilasius*; saker falcons, *Falco cherrug;* goshawks, *Accipiter gentilis*; black kites, *Milvus migrans;* little owls, *Athene noctua*) depend upon pikas as a food source. Schaller (1998) determined that 90% of pellets under the nest of a saker falcon contained pika remains, as did all of the pellets beneath the nest of an upland buzzard. The similar Daurian pika has been shown to comprise the following percentages of the diet of avian predators in southeast Transbaikalia: steppe eagle (*Aquila nipalensis*), 62%; upland buzzard, 17%; eagle owl (*Bubo bubo*), 73%; and saker falcon, 22% (Peshikov, 1957, 1967).

### Contributions to ecosystem function

The plateau pika may contribute in many ways to enhanced functioning of the plateau ecosystem. Like fossorial animals in other ecosystems (including the prairie dog of North America) they may act to increase local primary plant productivity, aid in the formation, aeration and mixing of soil, and enhance infiltration of water into the soil (Grinnell, 1923; Whicker & Detling, 1988; Huntly & Reichman, 1994; Hoogland, 1995; Kotliar *et al*., 1999).

Jiang & Xia (1985, 1987) determined that the foraging of small and moderate populations of plateau pikas is selective and may play an important role in the stabilization of the alpine meadow vegetational community. Studies on the similar Daurian pika have shown that their digging activity loosens and improves the soil, and the accumulation of their excrement and leftover stores in the burrow system yields high levels of organic materials. Soil temperatures and humidity are higher, and concentrations of nitrogen, calcium and phosphorus are greater near burrow systems than in nearby areas without pika burrows. The result of these interactions is a greater biomass of roots, taller plants and increased density of plant cover near the burrow system than elsewhere; the overall biomass of plants growing over the burrow system of Daurian pikas is almost five times greater than in the surrounding steppe. In addition, spring phenology of plants growing over burrow systems is 10–15 days advanced over plants growing on areas of nearby steppe without pikas (Smith *et al*., 1990). Similar studies on the zokor have shown that aboveground biomass of plants on and surrounding zokor mounds was higher than in control areas, and the soil of fresh and old mounds was higher in available nitrogen and phosphorus content than randomly collected soil samples (Wang, Bian & Shi, 1993).

Our analysis of potential ecosystem services provided by plateau pikas is indirect. There is a pressing need for long-term studies to demonstrate how the poisoning of pikas (and zokors) has changed ecosystem functioning on the plateau (see Stapp, 1998; Kotliar *et al*., 1999).

## CONTROL OF PIKAS

### Background

In spite of these contributions of the plateau pika to the Tibetan plateau ecosystem, this species has been targeted for control (Liu, Zhang & Xin, 1980; Shen & Chen, 1984; Schaller, 1985; Zhong, Zhou & Sun, 1985; Fan *et al*., 1986; Smith *et al*., 1990; Ma, 1995; Zhang *et al.,* 1998). We define 'control' as the deliberate poisoning of a native species with the intent to reduce its density or eliminate it altogether from a geographic area. The plateau pika is the focus of this paper, but other species of pika (*O. daurica*, *O. pallasi*) and the zokor (*Myospalax* spp.) are also targets of control. Within China these activities are normally termed 'rodent control' – but as pikas are lagomorphs and not rodents, this is a misnomer (a better term would be small-mammal control; in this paper we simply use the term control). Most studies on plateau pikas have concentrated on those locations where they are found at very high densities (which may reach 300/ha; Liu *et al*., 1980; Shen & Chen, 1984; Smith *et al*., 1990). High densities normally occur at the end of summer when the pikas' normally high rate of reproduction has yielded its greatest population density and the meadow vegetation has begun to dry up.

Plateau pikas have been targeted for control primarily because they are believed to impact negatively on rangeland habitat and compete for forage that could otherwise be utilized by livestock. In addition, the many burrows constructed by pikas may be hazardous to individuals who ride horses across the grasslands (Prejevalski, 1876). These reasons are identical to those given in the USA to justify control of prairie dogs (Schaller, 1985; Whicker & Detling, 1988; Hoogland, 1995). A final possible reason for pika control efforts is more insidious: the practice may continue because of vested interests by those agencies responsible for control. In China (as in the USA and elsewhere), agencies and research institutions funded for small-mammal control might consider their funding jeopardized if they were to admit that some of their practices are outdated, unnecessary or counterproductive.

### Extent of control

Placing the blame on pikas for degraded rangelands on the Tibetan plateau is an old pursuit. Ekvall (1968), who worked in the Amdo region (present-day Qinghai province) during the 1930s, commented that pastoralists attributed areas of degraded pasture to the activities of pikas (see also Formosov, 1928). This observation predates the rangeland degradation that has occurred in the past four decades. Currently in Qinghai, it has been estimated that 'rodent' (namely pika or zokor) infested areas total 44 720 km$^2$ (Jing, 1986). Control is recommended when populations of these small mammal reach high densities.

Control of small mammal populations on the plateau began in 1958 with tests on the plateau pika. Large-scale control efforts were initiated in 1962, reached a peak between 1963 and 1965 (13 million ha poisoned; Smith *et al*., 1990) and continue on a reduced scale. Between 1986 and 1994 nearly 7.5 million ha of grassland in Qinghai were controlled to eradicate small mammals and, to a lesser degree, insects (QAHB, 1996). In 1997, we observed television programmes in Beijing extolling the virtues of control measures on the plateau. In the same year the programme officer for the Sino-German Poverty Alleviation programme informed us that they were engaged in an aggressive 'rodent control' programme in the area of Serxu, Sichuan Province, but simultaneously admitted that he knew it was ecologically 'the wrong thing to do'. The European Union-funded Qinghai Livestock Development Project lists their project objectives, and a primary goal is to '. . .reduce soil erosion caused by . . . rodent [sic] damage. . .' (ECDC, 1998). The continued emphasis on control programmes indicates that extremely large tracts of pastureland on the plateau have been poisoned to kill pikas and that this habitat remains at risk from these activities (Schaller, 1985, 1998; Smith *et al*., 1990; Ma, 1995).

An unfortunate consequence of these campaigns to kill the plateau (and Daurian and Pallas's) pika is that other pika species may inadvertently be targeted and killed. The IUCN/SSC Lagomorph Specialist Group recognizes several species and subspecies of pika in China (most inhabiting the high plateau country) as threatened (Chapman & Flux, 1990; Baillie & Groombridge, 1996; see also Ma, 1995). Most pikas look alike, thus many of these threatened forms may be poisoned. A recent expedition to the type locality of one of the rarest pikas, *O. koslowi*, failed to find any extant populations. Apparently, this species was poisoned in attempts to eradicate the plateau pika (N. Formozov, pers. comm.).

Because of the importance given to pest control in China, research on poisons has been well-funded, and almost all rodenticides have been tried. In the early years, when extensive control occurred, the main chemicals used were Compound 1080 and Fussol, applied from hand spreaders, tractors and often broadcast from aeroplanes. Application of Fussol was discontinued because of expense and environmental contamination from poisonous secondary derivatives. After it was understood that Compound 1080 killed pika predators as well as pikas, its use was discontinued in 1978 (Smith *et al*., 1990). Gophacide and Zinophos then became the primary control agents. Use of anti-coagulants is now popular because they avoid secondary by-products and damage to the environment. Anti-coagulants, however, are expensive and must be distributed in large quantities over several applications to be effective (Smith *et al*., 1990).

## Relationship of pikas and livestock

There is an apparent relationship between grazing of domestic animals and pika population density. When the combined grazing of yak, sheep and horses lower the degree of cover and the height of vegetation, plateau pikas may be found at greater densities than on natural meadows (Shi, 1983; Zhang *et al*., 1998). Similarly, Daurian pikas are more likely to contribute to the deterioration of rangelands that are already overgrazed (Zhong *et al*., 1985). The zokor, another species that is often held responsible for soil and vegetation degradation on the plateau, reportedly has a higher survival rate in heavily grazed sites (Cincotta, Zhang & Zhou, 1992). Apparently under conditions initiated by overgrazing, pikas and other small mammals on the plateau are in a position to do greater harm to the grassland environment. However, the question can be raised as to whether the high densities of pikas (and zokors) cause rangeland degradation, or are merely symptomatic of overgrazing by livestock (see also Cincotta *et al*., 1992). Shi (1983) concluded that the most effective way to control damage by pikas would be to improve the condition of the range, which presumably would mean reducing the intensity of grazing by domestic livestock.

Competition between plateau pikas and livestock is dependent on the density of pikas and the quality of the rangeland. The foraging of pikas at low and moderate densities is selective and overlaps little with the diet of domestic grazing animals; thus the pikas may play an important role in stabilization of the alpine meadow vegetational community (Jiang & Xia, 1985, 1987). However, the diet of pikas may overlap extensively with livestock when pika density is extremely high (such as is found in situations where rangelands are already heavily grazed; see above; Jiang & Xia, 1985, 1987). The situation is complicated further by the fact that overgrazing increases the proportion of plants that are unpalatable or poisonous to livestock (Lang, Huang & Wang, 1997), and pikas tend to eat those plants that livestock do not eat (*Stellaria*, *Ligularia*; Schaller, 1985, 1998). Schaller (1985, 1998) further suggested that by eating herbs, pikas may slow the spread of plants not palatable to livestock, and thus improve conditions of grasses and sedges preferred by livestock. Thus, pikas do not appear to compete with livestock for forage on well-managed ranges, and on degraded ranges, where pika densities are high and competition might exist, pikas still provide a beneficial service to livestock.

The alpine meadows of the Tibetan plateau contain areas of small depressions with steep edges and larger areas primarily devoid of vegetation, termed locally as 'black sands'. Areas of extensive black sands lack the deep sod base that is typical of alpine meadows, although on many of these areas a luxurious monoculture of mint (*Elscholtzia*) grows in late summer. Plateau pikas are thought to contribute to the origin of these areas, which are indicative of degraded rangeland. Since pikas have been observed frequently to utilize the edges of these depressions as cover and to eat plant roots there, it has been suggested that pikas may expand the extent of black sand areas (Schaller, 1998).

We have worked extensively with fully marked populations of the plateau pika, and one analysis directly addressed the issue of habitat utilization by pikas on the alpine meadow. Working on a 2 ha study area containing 26 pika families (about 40 breeding adults/ha), we identified three distinct habitat types: (i) meadow dominated by sedges (*Carex* spp., *Kobresia* spp.); (ii) small depressions (1–5 m across) in the sedge meadow; (iii) black sands. Although meadow accounted for 84% of the area, 47.4% of our 800 grid cells contained black sand habitat. We measured habitat edges, slope of the habitat, burrows ($n = 4056$) and 'duck holes' (burrows not linked to an underground burrow system; $n = 2054$). We examined the relationship of dispersal movements of marked individuals to determine if they favoured any of these components of the habitat. Although 192 correlational tests were run with both parametric and nonparametric procedures, we found that none of the family ranges of dispersing and philopatric pikas exhibited significant differences in any of the habitat characteristics (Dobson, Smith & Wang, 1998). Thus, although casual observations have suggested that pikas prefer the edges offered by depressions and black sands, our work does not confirm this conclusion; rather, it shows that pikas tend to utilize the alpine meadow randomly.

There are other hypotheses for the origin of black sand areas. One hypothesis is that trails cut on hillsides by overstocked livestock cause the compaction of soil and formation of erosion terraces – processes that may initiate the decline of a meadow and lead to a black sands situation (Ma, Lang & Li, 1997; Schaller, 1998). Another hypothesis is that anthropogenic activities, such as the cutting of sod by pastoralists to make walls and fireplaces, create clearings that expand into black sands. Finally, a demonstrable warming trend has been detected on the plateau (Miehe, 1988, 1996), and the resultant dessication may be changing the meadow into a semi-arid alpine steppe across much of the Tibetan plateau. These changes in climate may be upsetting the natural balance of the vegetational community leading to the formation of black sands.

## COMPREHENSIVE RANGELAND MANAGEMENT

The attempt to eliminate an ecological keystone species such as the plateau pika is a policy that operates in opposition to China's otherwise progressive policies concerning biodiversity conservation (CCICED, 1996; MacKinnon *et al*., 1996). Contravening policies are common in all countries, but they establish a situation that requires a close examination of the costs and benefits of each policy. On the Tibetan plateau, such an analysis must consider all potential uses of the grassland ecosystem – primarily its sustainable use for livestock grazing by pastoralists.

Poisoning pikas is expensive. We do not have hard figures on how much money has been spent or is being spent on pika control measures. However, a pika control expert has informed us that the application of such poisons is considered expensive by Chinese institutions (N. Fan, pers. comm.). Furthermore, the Sino-German Poverty Alleviation programme to control pikas mentioned above was cancelled recently because of its expense and its failure to achieve desired results.

Additionally, extermination of pikas in a region is based on the same premise as most control programmes: that controlling the plateau pika will yield positive benefits to economic utilization of the Tibetan grassland ecosystem. Massive control has taken place over the past three decades, and pikas have been eliminated over broad regions of the Tibetan plateau. Yet, in spite of the extent of control, productivity and health of livestock on the plateau has been declining. Livestock weight has declined by 3–4 kg per head of sheep and 10–15 kg per head of yak over the past three decades (QPCB, 1994). Animals are weak when entering the critical winter season and massive starvation of herds is becoming a more frequent event (namely in the Yushu and Guoluo regions in southern Qinghai during the winters of 1995–1996 and 1997–1998; Miller, 1998). The control policy has not improved the situation on the grasslands appreciably. Finally, as we have documented above, control of the pika poses serious negative impacts for the preservation and conservation of native biodiversity on the Tibetan plateau.

The implications of a cost–benefit analysis of the control of the plateau pika are obvious. Control is a lose–lose situation; costs are high and there are no demonstrable benefits. In this paper we have addressed a single component of the complex of factors governing the biodiversity and sustainable development of the alpine grasslands of the Tibetan plateau. We wish to stress that these rangeland resources must be viewed comprehensively. Just as campaigns to poison keystone species such as pikas and other small mammals in this ecosystem are short-sighted, so should we be skeptical of other apparent quick fixes to this ecosystem (such as planting grasses, fencing, winter housing, etc). Some of these approaches may be justified in a restricted geographical area, but the entire alpine grassland ecosystem on the Tibetan plateau is at risk (Miller, 1995, 1998; Lang *et al*., 1997; Schaller, 1998). What is needed are studies to evaluate the long-term sustainability of the ecosystem – studies that begin with the health of the alpine meadow which is the cornerstone for all biodiversity and pastoralist activity. We have shown that the plateau pika is a key element in this system and have argued that managing pika populations should be viewed as part of the solution, not part of the problem, for the restoration of Tibetan grasslands.

### Acknowledgements

We would like to thank IUCN (The World Conservation Union), the Biodiversity Working Group of the China Council for International Cooperation in Environment and Development, and the Center for Asian Studies at Arizona State University for their generous support of this endeavour. Harriet Smith and Stephen Dobson kindly read and commented on the manuscript.

## REFERENCES

Anonymous (1994). *China biodiversity conservation action plan*. Beijing: National Environmental Protection Agency.

Baillie, J. & Groombridge, B. (Eds) (1996). *1996 IUCN red list of threatened animals*. Gland, Switzerland: IUCN.

CCICED (China Council for International Cooperation on Environment and Development) (1996). *Proceedings of the fourth meeting of the China Council for International Cooperation on Environment and Development*. Beijing: China Council for International Cooperation on Environment and Development.

Chapman, J. A. & Flux, J. E. C. (Eds) (1990). *Rabbits, hares and pikas: status survey and conservation action plan*. Gland, Switzerland: IUCN.

Cincotta, R., Zhang, Y. & Zhou, X. (1992). Transhumant alpine pastoralism in northeastern Qinghai Province: an evaluation of livestock population response during China's agrarian reform. *Nomadic Peoples* **30**: 3–25.

CSCPRC (Committee on Scholarly Communication with the People's Republic of China) (1992). *Grasslands and grassland* *sciences in northern China.* Washington, DC: National Academy Press.

Dmitriev, P. P. (1985). The relationship between some shrubs of the Mongolian steppes and colonies of mammals. *Zh. Obshch. Biol*. **46**: 661–669.

Dobson, F. S., Smith, A. T. & Wang X. G. (1998). Social and ecological influences on dispersal and philopatry in the plateau pika (*Ochotona curzoniae*). *Behav. Ecol.* **9**: 622–635.

ECDC (European Commission Delegation in China) (1998). EU–China Qinghai livestock development program. URL: *http://www.ecd.org.cn/ecd/co/gingliv2.htm* Viewed: 24 August 1998.

Ekvall, R. B. (1968). *Fields on the hoof: nexus of Tibetan nomadic pastoralism.* Prospect Heights, IL: Waveland Press.

Fan, N., Jing, Z., Wang, Q. & Zhou, W. (1986). Studies on bromadiolone against the pika and the zokor. *Acta Theriol. Sin.* **6**: 211–217.

Feng, Z., Cai, G. & Zheng, C. (1986). *The mammals of Xizang*. Beijing: Science Press.

Formosov, A. N. (1928). Mammalia in the steppe biocenose. *Ecology* **9**: 449–460.

Grinnell, J. (1923). The burrowing rodents of California as agents in soil formation. *J. Mammal.* **4**: 137–149.

Heywood, V. H. (Ed.) (1995). *Global biodiversity assessment*. Cambridge: Cambridge University Press.

Hoogland, J. L. (1995). *The black-tailed prairie dog: social life of a burrowing mammal*. Chicago: Chicago University Press.

Huntly, N. & Reichman, O. J. (1994). Effect of subterranean mammalian herbivores on vegetation. *J. Mammal.* **75**: 852–859.

Jiang, Z. & Xia, W. (1985). Utilization of food resources by plateau pikas. *Acta Theriol. Sin.* **5**: 251–262.

Jiang, Z. & Xia, W. (1987). The niches of yaks, Tibetan sheep and plateau pikas in the alpine meadow ecosystem. *Acta Biol. Plat. Sin.* **6**: 115–146.

Jing, S. (1986). *The situation of Qinghai province*. Xining: Qinghai People's Publishing House.

Kotliar, N. B., Baker, B. W., Whicker, A. D. & Plumb, G. (1999). A critical review of assumptions about the prairie dog as a keystone species. *Environ. Mgmt.* (in press).

Lang, B. N., Huang, J. S. & Wang, H. Y. (1997). *Report on the pasture and livestock survey in Hainan IFAD Project Area*. Xining: International Funds for Agricultural Development.

Li, D. H. (Ed.) (1989). *Economically important vertebrates of Qinghai province*. Xining: Qinghai People's Publishing House.

Liu, J., Zhang, Y. & Xin, G. (1980). Relationship between numbers and degree of harmfulness of the plateau pika. *Acta Zool. Sin.* **26**: 378–385.

Ma, M. (1995). Suggestions for the protection of some pikas. *China Nature* **2**: 26.

Ma, Y., Lang, B. & Li, Q. (1997). Improve yak productivity through resuming 'black soil type' deteriorated grassland. In *Yak production in central Asian highlands:* 291–294. Yang, R., Han, X. & Luo, X. (Eds). Xining: Qinghai People's Publishing House.

MacKinnon, J., Sha, M., Cheung, C., Carey, G., Xiang, Z. & Melville, D. (1996). *A biodiversity review of China*. Hong Kong: World Wide Fund for Nature.

Meyer de Schauensee, R. (1984). *The birds of China*. Washington, DC: Smithsonian Institution Press.

Miehe, G. (1988). Geoecological reconnaissance in the alpine belt of southern Tibet. *GeoJournal* **17**: 635–648.

Miehe, G. (1996). On the connection of vegetation dynamics with climatic changes in High Asia. *Palaeogeog. Palaeoclim. Palaeoecol.* **120**: 5–24.

Miller, B., Reading, R. P. & Forrest, S. (1996). *Prairie night: black-footed ferrets and the recovery of endangered species.* Washington, DC: Smithsonian Institution Press.

Miller, D. J. (1995). *Herds on the move: winds of change among pastoralists in the Himalayas and on the Tibetan plateau.* Kathmandu, Nepal: International Centre for Integrated Mountain Development.

Miller, D. J. (1998). Hard times on the plateau. *Chinabrief* **1**: 17–22.

Miller, D. J. & Craig, S. R. (Eds). (1997). *Rangelands and pastoral development in the Hindu Kush–Himalayas*. Kathmandu, Nepal: International Centre for Integrated Mountain Development.

Nekipelov, N. V. (1954). Changes in numbers of the Daurian pika in southwest Transbaikalia. *Izv. Irkutsk. Nauchno-Issled. Protivochumnogo. Ins. Sib. Dal'nego Vost.* **12**: 171–180.

Peshikov, B. I. (1957). Data on numbers and diet of feathered predators of southeast Transbaikalia. *Izv. Irkutsk. Nauchno-Issled. Protivochumnogo. Ins. Sib. Dal'nego Vost.* **16**: 143–153.

Peshikov, B. I. (1967). On the biology of the upland buzzard. *Izv. Irkutsk. Nauchno-Issled. Protivochumnogo. Ins. Sib. Dal'nego Vost.* **27**: 167–174.

Prejevalski, N. (1876). *Mongolia, the Tanguat country, and the solitudes of northern Tibet*. London: Sampson Low, Marston, Searle & Rivington.

QAHB (Qinghai Animal Husbandry Bureau) (1996). *Summary of experiences, goal clarification and the promotion of animal husbandry: provincial animal husbandry development and its future tasks.* Xining: Qinghai Animal Husbandry Bureau.

QPCB (Qinghai Population Census Bureau) (1994). *Tibetan population in Qinghai*. Beijing: China Statistics Publishing House.

Schaller, G. B. (1985). Wildlife in the middle kingdom. *Defenders* **60**: 10–15.

Schaller, G. B. (1998). *Wildlife of the Tibetan steppe*. Chicago: University of Chicago Press.

Shen, S. & Chen, Y. (1984). Preliminary research on ecology of the plateau pika at the Dawu area, Guoluo, Qinghai province. *Acta Theriol. Sin.***4**: 107–115.

Shi, Y. (1983). On the influence of rangeland vegetation to the density of plateau pikas (*Ochotona curzoniae*). *Acta Theriol. Sin.* **3**: 181–187.

Smith, A. T., Formozov, A. N., Hoffmann, R. S., Zheng, C. & Erbajeva, M. A. (1990). The pikas. In *Rabbits, hares and pikas: status survey and conservation action plan:* 14–60. Chapman, J.A. & Flux, J.A.C. (Eds). Gland, Switzerland: IUCN.

Stapp, P. (1998). A re-evaluation of the role of prairie dogs in Great Plains grasslands. *Conserv. Biol.* **12**: 1253–1259.

Wang, Q., Bian, J. & Shi, Y. (1993). Influence of plateau zokor mounds on the vegetation and soil nutrients in an alpine meadow. *Acta Theriol. Sin.* **13**: 31–37.

Whicker, A. D. & Detling, J. K. (1988). Ecological consequences of prairie dog disturbances. *BioScience* **38**: 778–785.

Zhang, Y., Fan, N., Wang, Q. & Jing, Z. (1998). The changing ecological process of rodent communities during rodent pest managements in alpine meadow. *Acta Theriol. Sin.* **18**: 137–143.

Zhong, H., Zhou, Q. & Sun, C. (1985). The basic characteristics of the rodent pests on the pasture in Inner Mongolia and the ecological strategies of controlling. *Acta Theriol. Sin.* **5**: 241–249.