We have determined the ideal size range for a TBS for farmers (G.R. Singleton and Sudarmaji, unpublished data), but not the optimum spatial distribution of these in the landscape. Although there was much variation between seasons in the extent of the halo of protection provided to crops by a TBS+TC, we recommend that a 25 × 25 m TBS would significantly reduce rat damage in the surrounding 10–20 ha of rice crop. Therefore, at a village level we suggest that one TBS+TC would be sufficient for every 15 ha of rice crop. This recommendation has not been tested.

The spatial distribution of physical methods for controlling rat numbers is an important issue given the ability rats have to re-colonise areas where their densities have been reduced. In rice fields, rats move hundreds of metres in a night, especially once the developing crop reaches the booting stage (Singleton et al. 1994; P. Brown, pers. comm.). To reduce this ability of rats to compensate for control activities, management needs to be approached initially at the village level and then at the district level. A good extension program with strong grower participation is fundamental for a community-based control campaign to be successful (FAO 1997).

At the village level, the spatial distribution and number of TBS sites will not simply be determined by the area of land under rice production. Important considerations will be how rat populations respond to:

- the heterogeneity of the habitat (the seasonal dynamics in habitats where rats can take safe refuge and/or breed);
- the degree of asynchronous planting of rice crops; and
- the variety of other crops grown in the area.

This information requires detailed studies of the population ecology and behaviour of *Rattus argentiventer* and good documentation of farming practices. There are some data available on the first two dot points. For instance, banks along the margins of rice fields and the banks of the major irrigation canals provide important habitats for rats to take refuge in during non-breeding seasons, and for rats to nest and breed in after the crop reaches the maximum tillering stage (see Leung et al., Chapter 14). Also, the breeding season of *R. argentiventer* is linked to the reproductive stage of the rice crop (Lam 1983; Murakami et al. 1990). Therefore, asynchronous planting of neighbouring crops will extend the breeding season of rats. Although we require more detailed knowledge of the population ecology and biology of *R. argentiventer*, what we already know has had an important influence on the development of management strategies for this species. Our efforts to manage this species would be considerably strengthened if we had a better understanding of the processes that influenced whether a rat did or did not enter a trap of a TBS. Towards this end, we need to develop a better awareness of the behavioural responses of rats to a TBS+TC and of the factors that may influence this response.

Concluding Remarks

In closing, the biggest hurdle facing the successful use of physical methods for managing rodent pests is the ability of rodent populations to compensate for reductions in population size through immigration, increased survival and/or better breeding performance. The early studies of Davis (1953) clearly demonstrated the ability of rat populations to recover to original levels following poisoning operations. Similarly, H. Leirs (pers. comm.) has shown that a 50% reduction in a *Mastomys natalensis* population, through the use of chemical rodenticides, has little impact on the yield loss of crops. However, sustained harvesting of rats from a population can lead to the collapse of that population, presumably because of a decline in the age structure of the breeding population (Davis and Christian 1958). Together, these studies indicate that one-off uses of physical control, especially when rodent densities are high, may have little to no impact on rat populations. In contrast, sustained use of physical control methods over an appropriate spatial scale may be both cost effective and environmentally sustainable.

Two methods which warrant further study are the use of TBS+TC and the targeting of bounty seasons at appropriate times of the year. The timing of the latter needs to be dictated by our understanding of the population biology of the rat rather than the phenology of the crop. For both methods, success will revolve around coordinated, synchronised actions at a village or district level and their ability to be adopted as part of an integrated approach to rodent management (see Singleton 1997; Leung et al., Chapter 14, for discussion of other actions).

How the use of physical barriers plus traps has evolved in our endeavours to manage the rice-field rat highlights the imperative of having sound ecological studies in progress before embarking on broad scale management programs of a rodent pest (Leirs et al. 1996; Singleton 1997). Further population studies of rodent pests are planned for Indonesia, Vietnam and Lao PDR, and they will complement our progress towards optimising the use of trap barrier systems and trap crops.

Acknowledgments

The TBS studies in Indonesia and Vietnam were part of a multi-country study on the management of rodent pests in Southeast Asia, funded by the Australian Centre for International Agricultural Research (Project numbers AS1/9420 and AS1/9679). We acknowledge the efforts and commitment of the support staff from the Research Institute for Rice, Indonesia, and the Institute of Animal Sciences and National Institute of Plant Protection, Vietnam. We also thank Monica van Wensveen, Ms Rahmini, Ir Rochman, Nguyen Manh Hung, Nguyen Viet Quoc, Nguyen Phu Tuan, Lam Yuet Ming and Luke Leung for their support, input and ideas. We greatly appreciated the comments of David Freudenberger and Alan Buckle on an earlier draft of this chapter.

REFERENCES

Bell, A. 1998. Integrated rodent management in post-harvest systems. Eschborn, Germany, Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), leaflet, 8p.

Breckwoldt, R. 1988. A very elegant animal, the dingo. North Ryde, Australia, Angus and Robertson, 283p.

Brooks, J.E. and Rowe, F.P. 1979. Commensal rodent control. Geneva, World Health Organisation, WHO/VBC/79.726, 109p.

Brown, P.R. and Singleton, G.R. 1997. Review of rodent management for pig production units. Canberra, CSIRO Wildlife and Ecology, Report to the Pig Research and Development Corporation, 45p.

Brown, P.R., Singleton, G.R., Dunn, S.C. and Jones, D.A. 1998. The management of house mice in agricultural landscapes using farm management practices: an Australian perspective. In: Baker, R.O. and Crabb, A.C., ed., Proceedings of the 18th Vertebrate Pest Conference, Santa Clara, California, USA, 2–5 March 1998. Davis, University of California, 156–159.

Buckle, A.P. 1988. Integrated management of rice rats in Indonesia. FAO (Food and Agriculture Organization of theUnited Nations) Plant Protection Bulletin, 36, 111–118.

Caughley, G.C. 1977. Analysis of vertebrate populations. London, John Wiley and Sons, 234p.

Davis, D.E. 1953. The characteristics of rat populations. Quarterly Review of Biology, 28, 373–401.

Davis, D.E. and Christian, J.J. 1958. Population consequences of a sustained yield program for Norway rats. Ecology, 39, 217–222.

Elias, D.J. and Fall, M.W. 1988. The rodent problem in Latin America. In: Prakash, I., ed., Rodent pest management. Boca Raton, CRC, 13–28.

Emlem, J.T., Stokes, A.W. and Winsor, C.D. 1948. The rate of recovery of decimated populations of brown rats in nature. Ecology, 29, 133–145.

FAO 1997. Community based IPM case studies. Food and Agriculture Organization Intercountry Programme for the Development of Integrated Pest Management in Rice in South and Southeast Asia. FAO, Jakarta, 36p.

Halle, S. and Pelz, H.-J. 1990. On the efficiency of muskrat (*Ondatra zibethicus*) control from trapping data ascertained in Bremen. Zietschrift für angewandte Zoologie, 77, 205-218.

Hassall and Associates Pty Ltd 1998. Economic evaluation of the role of bounties in pest management. Unpublished report for the Bureau of Rural Sciences, Canberra.

Hone, J., O'Grady, J. and Pedersen, H. 1980. Decisions in the control of feral pig damage. NSW Agriculture Bulletin, 5.

Jenson, A.G. 1965. Proofing of buildings against rats and mice. Ministry of Agriculture, Fisheries and Food, Technical Bulletin No. 12, London, Her Majesty's Stationery Office, 18p.

Lam, Y.M. 1983. Reproduction in the rice field rat, *Rattus argentiventer*. Malayan Nature Journal, 36, 249–282.

Lam, Y.M. 1988. Rice as a trap crop for the rice field rat in Malaysia. In: Crabb, A.C. and Marsh, R.E., ed., Proceedings of the 13th Vertebrate Pest Conference, 123–128.

Lam, Y.M. and Mooi, K.C. 1994. TBS—an environmentally friendly system for the control of rodent pests of agriculture. Proceedings of the 4th International Conference on Plant Protection in the Tropics, 26–31 March, Kuala Lumpur, Malaysia, 159–160.

Lam, Y.M., Supaad, M.A., Chang, P.M., Mohamed, M.S., Goh, C.S. and Radzi, H. 1990. An innovative approach for protecting rice against severe rat depredation. Proceedings of the 3rd International Conference on Plant Protection in the Tropics, Genting Highlands, Malaysia, 20–23 March 1990, 1–23.

Leirs, H., Verhagen, R., Verheyen, W., Mwanjabe, P. and Mbise, P. 1996. Forecasting rodent outbreaks in Africa: an ecological basis for *Mastomys* control in Tanzania. Journal of Applied Ecology, 33, 937–943.

Mathur, R.P. 1997. Effectiveness of various rodent control measures in cereal crops and plantations in India. Belgium Journal of Zoology, 127, 137–144.

Meehan, A.P. 1984. Rats and mice. Their biology and control. Felcourt, East Grinstead, West Sussex, Rentokil Ltd, 383p.

Meyer, A.N. 1994. Rodent control in practice: food stores. In: Buckle, A.P. and Smith, R.H., ed., Rodent pests and their control. Cambridge, Cambridge University Press, 273–290.

Morley, G.E. and Humphries, J.R.O. 1976. Rodent damage to farm and village storage. In: Hopf, H.S., Morley, G.E.J. and Humphries, J.R.O., ed., Rodent damage to growing crops and to farm and village storage in tropical and subtropical regions. Southampton, United Kingdom, Centre for Overseas Pest Research and Tropical Products Institute, 61–87.

Murakami, O., Priyono, J. and Triastiani, H. 1990. Population management of the ricefield rat in Indonesia. In: Quick, G.R., ed., Rodents and rice—report and proceedings of an expert panel meeting on rice rodent control. Manila, Philippines, International Rice Research Institute, 49–54.

Posamentier, H. and van Elsen, A. 1984. Rodent pests—their biology and control in Bangladesh. Dhaka, Bangladesh, Department of Agriculture and Extension, 111p.

Prakash, I. and Mathur, R.P. 1988. Rodent problems in Asia. In: Prakash, I., ed., Rodent pest management. Boca Raton, CRC, 67–84.

Quick, G.R. and Manaligod, H.T. 1990. Some aspects of physical control of rice rodents. In: Quick, G.R., ed., Rodents and rice—report and proceedings of an expert panel meeting on rice rodent control. Manila, Philippines, International Rice Research Institute, 31–34.

Redhead, T.D. and Singleton, G.R. 1988. The PICA Strategy for the prevention of losses caused by plagues of *Mus domesticus* in rural Australia. EPPO Bulletin, 18, 237–248.

Singleton, G.R. 1997. Integrated management of rodents: a Southeast Asian and Australian perspective. Belgian Journal of Zoology, 127, 157–169.

Singleton, G.R., Chambers, L.K. and Quick, G.R. 1994. Assessment of the IRRI active barrier system (ABS) for rodent control. Canberra, Final Report to Australian Centre for International Agricultural Research, 50p.

Singleton, G.R. and Petch, D.A. 1994. A review of the biology and management of rodent pests in Southeast Asia. Canberra, Australian Centre for International Agricultural Research, Technical Reports, 30, 65p.

Singleton, G.R., Sudarmaji and Suriapermana, S. 1998. An experimental field study to evaluate a trap–barrier system and fumigation for controlling the rice field rat, *Rattus argentiventer*, in rice crops in West Java. Crop Protection, 17, 55–64.

9. Ecological Management of Brandt's Vole (*Microtus brandti*) in Inner Mongolia, China

Wenqin Zhong, Mengjun Wang and Xinrong Wan

Abstract

Brandt's vole (*Microtus brandti*) is a serious rodent pest in the grasslands of Inner Mongolia. Poison baiting is the traditional approach to controlling Brandt's vole in this region. Although this sharply reduces the density of voles, the remaining resident animals have high reproductive and survival rates, leading to rapid recovery of the population. Poison baiting also causes other problems such as environmental pollution and secondary poisoning of natural predators. Therefore, a new non-polluting, economically efficient technique, offering effective long-term control, is urgently required for the management of Brandt's vole. In this paper, we investigate the potential of an ecological strategy in managing Brandt's vole in the grassland of Inner Mongolia.

We found the main factor facilitating infestation by Brandt's vole in the grassland is overgrazing by livestock. The density and height of vegetation strongly influence the habitat selection of Brandt's vole. With heavier grazing pressure by livestock, the height and cover of vegetation are reduced and the plant composition is changed, resulting in high quality food and shelter for voles and consequent increases in their population densities. The density of voles was low where the height of vegetation was >190 mm but high where vegetation height was 30–130 mm. Fencing and pasture management could be used in some areas to reduce vole problems by increasing the height of grass.

In Inner Mongolia, local herdsmen fence pasture in June to increase herbage for harvesting in autumn or for grazing by livestock in winter. The grasses grow slowly and poorly under this traditional fencing management because extensive grazing suppresses the germination and growth of grasses that would otherwise occur due to high rainfall and warm temperatures in May. These grasslands then become more vulnerable to vole infestation. A new fencing management of removing livestock from pastures in the middle of May, rather than later in June, was examined using a series of experimental exclosures in Taipus Qi, Inner Mongolia, from 1986–1990. The densities of Brandt's vole populations in the experimental exclosures were reduced sharply and the grass yields increased greatly compared to the exclosures under the traditional fencing management. Over the next three years, the average investment:income ratio was 1:7. This new ecological management is very promising for solving the Brandt's vole problem in the Inner Mongolian grasslands.

Keywords

Brandt's vole, overgrazing, ecological management, Inner Mongolia

INTRODUCTION

BRANDT'S VOLE (*Microtus brandti*) is a major rodent pest in the grasslands of Inner Mongolia, especially in the typical steppe of the Xilin Gele region. It can cause problems in an area of up to 20 million ha or 75% of this region. The populations of Brandt's vole fluctuate remarkably, with positive feedback indicated by 2–3 years of low density after a period of high density. Each vole can eat 40 g of fresh plant material per day and in high-density years, with up to 1,384 individuals/ha, 15–44% of grass production can be consumed by voles (Zhang and Zhong 1981). The diet of Brandt's voles is similar to that of sheep and cattle (Wang et al. 1992), so it is an important competitor of livestock.

Brandt's voles live in social groups and dig complex burrow systems with up to approximately 5,616 holes/ha in high-density areas (Zhong et al. 1985b). Because voles excavate large amounts of soil, they accelerate erosion and desertification in grasslands.

Poison baiting is the traditional approach to controlling Brandt's vole in the Inner Mongolian grasslands. Although this sharply reduces the density of voles, the remaining resident animals have high survival rates because there are more resources available to them (Dong et al. 1991). The pregnancy rate increases and voles become mature earlier, leading to the rapid recovery of the Brandt's vole population (Yang et al. 1979; Zhou et al. 1992). Its relative abundance in the rodent community recovers within four months (Hou et al. 1993). Chemical control is applied nearly every year but pest problems also occur each year in a 'pest outbreak → chemical control → pest outbreak' cycle. This approach is not only expensive and fails to provide a long-term solution, but it also results in heavy environmental contamination. A new non-polluting, economically efficient technique, offering effective long-term control, is urgently required for the management of Brandt's vole. Major advances will depend on ecological studies (Barnett 1988).

The habitat of rodents is determined by many attributes of the plant community, such as the distribution and spatial pattern of plants, the proportions of edible and inedible plant species, and changes in phenology, biomass, cover and species composition. All of these influence the composition and dynamics of rodent communities. On the other hand, the animals' activities also change the vegetation.

We have investigated the number of species and the diversity and heterogeneity of plant and rodent communities in five types of steppe in the grassland of Inner Mongolia (Zhou et al. 1982). The results showed that the rodent and plant communities are closely connected (Table 1). The diversity index of the rodent community is correlated with the diversity index of the plant community ($r = 0.972$, $p < 0.01$) and that the heterogeneity index of the rodent community is also correlated with that of plants ($r = 0.905$, $p < 0.05$). Also, we have investigated the plant–rodent community in different stages of the same type of grassland (Wang et al. 1997; Table 2). The changes in the α-diversity index of the plant community and rodent

Table 1.
Species number, diversity and heterogeneity of plant and rodent communities in five types of steppe. *H* is the Shannon-Wiener index: $H = -\Sigma P_i \ln P_i$, where P_i = is the proportion of species *i* in the community. *J* is an index of evenness: $J = H/\ln S$, where *S* is the number of species in the community (Zhou et al. 1982).

Type	Rodent community			Plant community of steppe		
	No. of species	*H*	*J*	No. of species	*H*	*J*
1	7	0.9611	0.4939	39	1.7443	0.4761
2	6	1.2841	0.7167	37	2.2265	0.6166
3	9	1.4898	0.6780	40	2.4981	0.6772
4	8	1.6348	0.7862	26	2.5621	0.7864
5	5	0.8106	0.5037	26	1.8158	0.5573

Table 2.
Comparisons of the α-diversity index between plant and rodent communities along a grazing gradient in two types of steppe. The impacts of grazing were classified as: I = no grazing, II = moderately degraded pasture, and III = heavily degraded pasture. (From Wang et al. 1997.)

Season	Community	*Aneurolepidium chinense* steppe			Season	Community	*Stipa grandis* steppe		
		I	II	III			I	II	III
Spring	*Rodent*	0.2095	0.1515	0.0	Spring	*Rodent*	0.0	0.3909	0.4224
	Plant	1.2015	1.1638	1.0860		*Plant*	0.9798	1.0289	1.0410
Autumn	*Rodent*	0.3729	0.1682	0.1283	Autumn	*Rodent*	0.0	0.3195	0.3280
	Plant	1.3929	1.2290	1.1621		*Plant*	1.2238	1.2253	1.3524

community show the same trend. The diversity of plants reflects food availability for rodents, heterogeneity is a measure of the distribution of food, and height and cover are important spatial factors to which rodents are sensitive. The result is that changes in any of these plant community indices correspond to changes in the abundance and distribution of rodents.

In Inner Mongolia, the number of livestock has been increasing year by year. The number of livestock has increased 2.64 times in recent decades, with corresponding land degradation reaching 27.5% of all the Inner Mongolian grassland area (Ren et al. 1989). The pressure of grazing has resulted in degeneration and desertification of large areas of grassland as well as increasing salinity of soils. The plant community has responded with an increase in the proportion of dicotyledons and a general decrease in the production and biomass of vegetation. The successional changes in the plant community have been matched by changes in the composition of the rodent community.

Figure 1 summarises the sequence of changes in the plant–rodent community in degraded grassland in Inner Mongolia (Zhong et al. 1985a).

(a)

Plant community		Rodent community
Aneurolepidium chinense *Stipa krylovii*		*Cricetulus barabensis* *Citellus dauricus* *Ochotona daurica*
	Lightly over-grazed ↓	
Artemisia frigida *Aneurolepidium chinense* *Cleistogenes squarrosa*		*Ochotona daurica* *Cricetulus barabensis* *Citellus dauricus*
	Heavily over-grazed ↓	
Artemisia frigida *Potentilla acaulis* *Cleistogenes squarrosa*		*Microtus brandti*
	Excessively over-grazed ↓	
Planta annua		*Meriones unguiculatus*

(b)

Plant community		Rodent community
Stipa krylovii *Artemisia frigida* *Cleistogenes squarrosa*		*Citellus dauricus* *Ochotona daurica*
	Lightly over-grazed ↓	
Stipa krylovii *Artemisia frigida* *Cleistogenes squarrosa*		*Ochotona daurica* *Citellus dauricus*
	Heavily over-grazed ↓	
Heteropappus altaicus *Artemisia frigida* *Salsola collina*		*Microtus brandti*
	Excessively over-grazed ↓	
Planta annua		*Meriones unguiculatus*

Figure 1.
The impact of grazing by livestock on the plant–rodent communities at (a) Xilin Hot (43°25'N, 116°41'E; annual precipitation 350–400 mm) and (b) the Kelulun River (49°25'N, 116°42'E; annual precipitation 250–300 mm) in the typical steppe of Inner Mongolia (from Zhong et al. 1985a).

In degraded grasslands, the biomass of families in the Compositae, Rosaceae and Chenopodiaceae increase, all of which are the preferred food of the Daurian pika (*Ochotona daurica*) (Zhong et al. 1983). The vegetation of this stage also provides suitable cover and food for storage for the Daurian pika (Wang et al. 1998). With heavier grazing pressure, the height and cover of vegetation is reduced, the availability of food and shelter becomes unsuitable for the pika, its abundance decreases and its dominant position is taken by Brandt's vole. This degenerative stage is the preferred habitat of Brandt's vole and populations increase quickly and reach high densities (Zhong et al. 1985b). With excessive grazing, soil becomes susceptible to erosion and *Planta annua* becomes the main component of the plant community. Brandt's vole is displaced by the Mongolian gerbil (*Meriones unguiculatus*) and eruptions of this species can occur (Xia and Zhong 1966; Zhong et al. 1983).

Degradation of grassland is facilitated by the digging and feeding activities of Brandt's vole. Groups of voles occupy complex burrow systems. They often excavate soil when they repair their burrows, especially when constructing 3–4 storerooms per burrow system in autumn. As each storeroom is about 1.1 m long and 120 mm high, large volumes of new soil are mounded on the soil surface beside burrow entrances. Burrow systems can have up to 36 holes covering some 14 m^2, of which 9 m^2 can be covered by fresh soil (Zhang and Zhong 1981). Around the burrow systems, the production of fine-grazing grasses such as *Aneurolepidium chinense*, *Stipa grandis* and *Cleistogenes squarrosa* decreases by 20%, 86% and 83%, respectively, and *Artemisia scoparia*, *Artemisia frigida*, *Carex duriuscula* and *Keoleria cristata* increase to 60% of total plant production. The result is that Brandt's vole facilitates the degeneration of pasture for livestock.

HABITAT SELECTION OF BRANDT'S VOLE

There are no recorded cases of rodent pest problems in natural grassland or in areas subject to low grazing pressure. Outbreaks of Brandt's vole usually occur only in degraded pasture.

In natural pasture, the location of water sources, such as rivers, influences the grazing pressure of livestock. In one study (Zhong et al. 1985a) pasture within 3 km of a river suffered excessive grazing pressure. The area 3–8 km from the river showed moderate degradation, while the area 8–13 km from the river showed slight degradation. In the Kelulun River region, the production of herbs was 36% or 53% lower, and the density of Brandt's vole 3.6 or 0.9 times higher, in a heavily degraded area compared to a moderately degraded area (Zhong et al.1985a; Table 3).

Other research has reported a similar relationship between the density of Brandt's vole and the condition of the plant community (Liu 1979). A further investigation was conducted in a livestock resting site that was no longer used (Zhong et al. 1985b). Table 4 shows that in May 1974 low plant cover was associated with a high density of Brandt's vole, indexed by the number of holes/ha, whereas in August an increase in the height and cover of plants, mostly through rapid growth of *Aneuro-lepidium chinense* and *Allium anisopodium*,

Table 3.
The relationship between the density of Brandt's vole and the utilisation of the pasture in a terrace of the Kelulun River (Zhong et al. 1985a). The abundance of holes with signs of recent animal activity was used as an index of the density of voles. (Holes were covered with soil and checked 24 hours later. Re-opened holes were classified as active). The botanists' standard definitions were used for the degree of degradation.

Distance from river (km)	State of the pasture	Area of investigation (ha)	Density of Brandt's vole (active holes/ha)	
			June 1974	July 1975
1–3	Heavy degeneration	1.5	8.67	883.33
4–8	Medium degeneration	5.3	1.89	471.41
>20	Slight degeneration	4.0	0.0	0.0

Table 4.
Influence of vegetative change on the density of Brandt's vole at a resting site recently abandoned by livestock (Zhong et al. 1985b).

Time	Abandoned resting site			Normal grazing site		
	Vegetation			Vegetation		
	Height (cm)	Cover (%)	Voles active (holes/ha)	Height (cm)	Cover (%)	Voles active (holes/ha)
May	–	<5	972	–	10	204
August	40–50	95	0	15–20	30	84

A. bidentatum and *A. tenuissimum* after high summer rainfall, corresponded to a sharp decrease in the density of holes. Apparently, the low vegetative cover in May was due to grazing by voles, but by August voles would have dispersed to avoid high, dense vegetation.

Another study was carried out in 1982 by Zhong et al. (1985b). The vegetation and the density of holes used by Brandt's vole were monitored in a fenced area (*A*) that excluded livestock but allowed free access by rodents. The exclosure was compared to an area with normal grazing by livestock (*B*) and to a livestock resting site (C). The results are shown in Table 5. The density of Brandt's vole was inversely related to the height and cover of vegetation. The sites were ranked *A* > *B* > *C* for plant biomass and *A* < *B* < *C* for the relative density of voles. Parts of sites *A* and *B* were only 120 m apart, well within the range of movements of Brandt's vole, but the relative density of voles reached 5,616 holes/ha in C (Zhong et al. 1985b) and the density in *B* decreased by 33% to 84%. The distance from *A* to *B* was about 120 m, and from *B* to *C* about 500 m.

The biomass of *A. chinense*, which is Brandt's vole's preferred food (Wang et al. 1992), was higher in *A* than *B* and *C*. This suggests that food is not the main factor influencing habitat selection by Brandt's vole. More important factors appear to be

Table 5.
Comparisons of the density of Brandt's vole, indexed by the number of burrow holes/ha, and vegetation condition in areas with different use by livestock (Zhong et al. 1985b). Data are given as the mean (*X*) and the standard error (*SE*). *n* is the sample size.

Study site	Density of voles	Vegetation			
		No. of species/m^2	Height (cm)	Cover (%)	Biomass (g/m^2)
	n = 6 *X* ± *SE*	n = 20 *X* ± *SE*	n = 5	n = 5	n = 5 *X* ± *SE*
A. exclosure	700 ± 196	16.05 ± 0.47	30 – 35	57	190 ± 17
B. normal grazing	2063 ± 345	14.35 ± 0.51	13.6 – 16.4	46	102.9 ± 4.3
C. resting site	3661 ± 406	10.25 ± 0.51	5.4 – 7.4	33	53 ± 11
t-test	*A<C**	*A>C**	*A>C**	*A>C**	
*(*p* < 0.01)	*C<B#*	*C<B**		*C<B**	*C<B**
#(*p* < 0.05)	*A<B**	*A>B#*		*A>B**	*A>B**

the height and cover of vegetation, with voles preferring areas with sparse, low vegetation. It is likely that high, dense vegetation hinders the social behavior of Brandt's vole such as communication for feeding, mating and cooperative defense against predators (Xinrong Wan, unpublished data).

Although these studies indicate that both the height and cover of vegetation influence vole's habitat selection, it is not yet clear which one is the most restrictive factor. A study of the relationship between vegetation condition and the density of voles was carried in 1998. We chose 18 sites at random in Taipus Qi, Inner Mongolia, where we investigated the density of Brandt's vole and measured cover and height of vegetation at each site (Table 6). There was a significant negative correlation between the height of vegetation and the density of Brandt's vole ($r = -0.636$, $p < 0.01$), but there was no significant relationship between cover and the density of voles ($r = -0.128$, $p > 0.05$). These data suggest that there is an inverse relationship between the density of voles and the height of vegetation in areas where vegetation cover is in the range 28–75%.

Fenced areas were used to limit access by livestock in summer to allow recovery of pasture and the conservation of forage for winter grazing. Because the enclosures should improve the condition of vegetation, they should influence the density of Brandt's vole. This hypothesis was tested using five large enclosures in the Xilin Geluo and Zhe Limo region in 1987, with each enclosure more than 130 ha (Zhong et al. 1992). Table 7 indicates the condition of the vegetation and the density of voles inside and outside the exclosures during the course of the experiment.

The height of vegetation is significantly, negatively correlated with the density of Brandt's vole ($r = -0.708$, $n = 9$, $p < 0.01$) but there is no obvious relationship between plant cover and the density of voles

Table 6.
Comparison of the density of Brandt's vole and the vegetation conditions in its habitat. Data are given as the mean (*X*) and the standard error (*SE*).

Height of vegetation (cm) ($X \pm SE$)	Cover (%) ($X \pm SE$)	Density of Brandt's vole (Animals/ha) ($X \pm SE$)
12.92 ± 0.89	36.40 ± 2.11	308.31 ± 21.36
13.82 ± 0.95	52.00 ± 2.55	339.36 ± 23.31
10.95 ± 0.42	40.00 ± 2.24	396.85 ± 30.14
11.38 ± 0.61	53.00 ± 1.22	419.20 ± 13.29
16.52 ± 0.76	34.40 ± 2.20	193.80 ± 12.87
19.92 ± 1.29	70.00 ± 3.54	92.64 ± 10.86
11.99 ± 0.64	29.20 ± 1.48	233.60 ± 21.37
12.84 ± 0.69	61.00 ± 2.33	528.88 ± 24.22
68.84 ± 1.91	74.60 ± 3.26	2.40 ± 1.17
8.92 ± 0.58	36.00 ± 2.45	306.38 ± 12.46
3.62 ± 0.29	46.00 ± 1.87	464.56 ± 47.00
7.32 ± 0.47	30.00 ± 1.58	407.36 ± 26.37
4.68 ± 0.70	41.00 ± 2.45	577.60 ± 23.90
11.68 ± 0.37	28.20 ± 1.11	220.65 ± 21.79
7.72 ± 0.68	61.00 ± 1.87	191.04 ± 17.93
9.60 ± 0.28	29.20 ± 1.52	239.42 ± 16.93
7.53 ± 0.36	54.50 ± 1.89	585.44 ± 38.38
11.48 ± 1.10	66.00 ± 3.67	416.20 ± 35.04

($r = -0.304$, $p > 0.05$). This result is supported by the data in Table 8 which show the rate of change in the height of herbs (e.g. *A. chinense*) and the percentage changes in the density of voles.

There is a significant coefficient of correlation between these two variables of –0.917 indicating a very significant correlative relationship. The conclusion is that the density and height of vegetation in the habitat of Brandt's vole strongly influences its social behaviour; i.e. an increased height of vegetation decreases the fitness of Brandt's vole so that the population density of the vole decreases sharply. This suggests that fencing and pasture management could be used in some areas to reduce problems caused by Brandt's vole. As a guide, the density of voles was low where the height of vegetation was >190 mm but high where vegetation height was 30–130 mm.

The suppressive effect of vegetation growth on the abundance of Brandt's vole takes effect from spring to autumn. However the most important factor influencing the survival of voles in winter is their store of food (Zhong 1996). As *A. frigida* is the largest component (44–71%) of stored food (Zhou et al. 1988), pasture management such as fencing that diminishes production of *A. frigida*, will also reduce the over-winter survival of voles.

Table 7.

The density of Brandt's vole and the condition of vegetation inside and outside livestock enclosures (Zhong et al. 1992). Data are given as the mean ± the standard error, *n* is the sample size, and I and O indicate measurements inside and outside the exclosures, respectively.

Exclosure		Cover of vegetation (%)			Height of vegetation (cm)			Density (voles/ha)		
		n	I	O	*n*	I	O	*n*	I	O
A	June	5	36.40 ± 2.11	36.00 ± 2.45	5	12.92 ± 0.89	8.92 ± 0.58	6	308.31 ± 21.36	306.38 ± 12.46
	September	5	52.00 ± 2.55	46.00 ± 1.87	5	13.82 ± 0.95	3.62 ± 0.29	5	339.36 ± 23.31	464.56 ± 47.00
B	June	5	40.00 ± 2.24	30.00 ± 1.58	5	10.95 ± 0.42	7.32 ± 0.47	6	396.85 ± 30.14	407.36 ± 26.37
	September	5	53.00 ± 1.22	41.00 ± 2.45	5	11.38 ± 0.61	4.68 ± 0.70	5	419.20 ± 13.29	577.60 ± 23.90
C	June	5	34.40 ± 2.20	28.20 ± 1.11	5	16.52 ± 0.76	11.68 ± 0.37	6	193.80 ± 12.87	220.65 ± 21.79
	September	5	70.00 ± 3.54	61.00 ± 1.87	5	19.92 ± 1.29	7.72 ± 0.68	5	92.64 ± 10.86	191.04 ± 17.93
D	June	10	29.20 ± 1.48	29.20 ± 1.52	10	11.99 ± 0.64	9.60 ± 0.28	10	233.60 ± 21.37	239.42 ± 16.93
	September	10	61.00 ± 2.33	54.50 ± 1.89	10	12.84 ± 0.69	7.53 ± 0.36	10	528.88 ± 24.22	585.44 ± 38.38
E	August	5	74.60 ± 3.26	66.00 ± 3.67	5	68.84 ± 1.91	11.48 ± 1.10	4	2.40 ± 1.17	416.20 ± 35.04

Table 8.
The proportional change in the height of herbs and percentage decease of the vole population density in the exclosure in comparison to outside. From Zhong et al. 1992. Calculated from Table 7.

Exclosure	A		B		C		D		E
Time	June	September	June	September	June	September	June	September	August
	Times change in height of herbs								
	1.45	3.82	1.50	2.43	1.41	2.58	1.25	1.71	6.00
	% change in vole density								
	–0.63	26.95	2.58	27.42	12.17	51.51	2.43	9.66	99.42

Ecological Management of Brandt's Vole

In Inner Mongolia, local herdsmen fence off pasture in June to increase herbage for harvesting in autumn or for grazing by livestock in winter. However damage is still caused by Brandt's vole in some areas because fencing is not properly maintained to exclude livestock. High rainfall and warm temperatures in May can promote early pasture growth that may be useful in suppressing vole populations. The effect of removing livestock from pastures in the middle of May, rather than later in June, was examined using a series of experimental exclosures in Taipus Qi, from 1986–1990 (Zhong et al. 1991). Exclosure I was fenced from the middle of May, the control exclosure was fenced from June (according to the local custom) and a third area (III) remained unfenced throughout the experiment. Both fenced areas were opened to grazing from 3 September through to May (exclosure I) and June (exclosure II) of the following year. Sheep were stocked at 1.62 animals/ha during the grazing period. There were no differences between exclosures I, II and III in the vegetation and the density of Brandt's vole prior to the experiment.

In 1987 rainfall was 289.59 mm, 30% below average. In autumn, the height, cover and biomass of vegetation were higher in exclosure II than in exclosure I , and in the period from spring to autumn the rate of increase of the vole populations was 0.62 in exclosure I compared to 1.99 in exclosure II and 2.11 in exclosure III (Table 9). The autumn density of voles was 4.6 times higher in exclosure II than I. The experiment demonstrated that exclusion of livestock from pasture half a month earlier in mid-May increased biomass of grass by 40% and decreased the density of Brandt's vole by 78%. Comparing exclosure II and III, the increased grazing on the latter site resulted in the height, cover and biomass of vegetation being reduced by 70%, 12% and 55%, respectively, but there was no significant difference in the density of Brandt's vole. There appeared to be a significant threshold between 120 and 160 mm in the suppressive effect of vegetation height on the abundance of voles, and the traditional time of fencing in June was too late to allow vegetation to exceed this threshold.

The study was continued in 1988 and 1989 (Table 10). The year of 1988 was a wet year, with 339.8 mm of rainfall from May to August, 17.33% more than normal. The height, cover and biomass in the exclosure I were 95%, 10% and 80% higher than that outside exclosure, respectively. The density of Brandt's vole inside the exclosure was 2.24 times lower inside than outside the exclosure; the difference was significant ($p < 0.01$).

In 1989, 158.7 mm rain fell during the period from May to August, which was 45% less than average and the height, cover and biomass of vegetation was 35%, 22% and 139% higher in the exclosure than in the grazing area, respectively. Because of the aridity, the height of the main herb layer was about 144.2 mm, less than the critical value of 160 mm. The density of Brandt's vole in the exclosure was 16.85 animals/ha, not significantly different from the density of 33.74 animals/ha in the grazed area ($t = 1.68$, $p > 0.05$), and both were under the threshold for causing damage. Therefore, although no damage occurred in 1989, the data from the exclosure experiment in that year and from other years with different climatic conditions demonstrated the simultaneous effects of producing more grass and suppressing Brandt's vole.

After the ecological measurements, many colonies of Brandt's vole disappeared, their complex burrow systems were abandoned, and herbs grew quickly around these areas forming patches different from the surrounding area. These patches, or 'mosaics', were classified as two types: mosaic I where a burrow system was abandoned during May or June in the current year and mosaic II where the burrow system was abandoned in the previous year. Herbs growing in mosaics were big and tall (see Table 11). Vegetation cover in mosaics I and II was 1.1 and 1.07 times greater than in the non-burrow areas, respectively, and the

Table 9.

The impact of different grazing treatments on vegetation indices and the density of the Brandt's vole population. The experiment was conducted from spring to autumn in 1987 using three experimental areas: (I) livestock excluded from mid-May, (II) livestock excluded from June, and (III) free access to livestock (no fencing). Data are given as the mean ± the standard error and n is the sample size. The rate of increase of the vole population over the period from spring to autumn is calculated as $r = \ln(N_{t+1}/N_t)$ where N_t is the density at time t.

Treatment	Area (ha)	Vegetation in autumn			Density of Brandt's vole/ha		Rate of increase
		Height (cm)	Cover (%)	Above-ground biomass (g/m^2)	Spring	Autumn	
I	93	16.96 ± 0.43	73.50 ± 1.07	342.44 ± 16.42	63.00 ± 5.48	116.95 ± 36.32	0.62
		$n = 10$	$n = 10$	$n = 10$	$n = 10$	$n = 10$	
II	99	12.84 ± 0.69	61.00 ± 2.33	245.28 ± 12.12	73.41 ± 8.41	535.50 ± 25.43	1.99
		$n = 10$	$n = 10$	$n = 10$	$n = 8$	$n = 8$	
III	80	7.53 ± 0.36	54.50 ± 1.89	157.90 ± 6.00	69.39 ± 12.82	571.10 ± 38.32	2.11
		$n = 10$	$n = 10$	$n = 10$	$n = 8$	$n = 8$	

Table 10.

The impact of different grazing treatments on vegetation indices and the density of Brandt's vole population during 1998 and 1989. Data are given as the mean ± the standard error. *n* is the sample size and the rate of increase is calculated as in Table 9.

Year	Study site	Vegetation in autumn				Density of Brandt's vole/ha			
		n	Height (cm)	Cover (%)	Biomass (g/m^2)	*n*	Spring	Autumn	Rate of increase
1988	exclosure	30	27.59 ± 0.77	87.70 ± 1.37	785.87 ± 24.31	10	77.41 ± 4.40	38.04 ± 9.80	- 0.71
	unfenced	15	14.12 ± 0.64	80.13 ± 2.76	436.56 ± 26.22	10	99.97 ± 5.15	123.42 ± 12.46	0.21
1989	exclosure	30	14.42 ± 0.62	58.67 ± 1.24	129.23 ± 10.08	10	9.02 ± 2.08	16.85 ± 3.97	0.62
	unfenced	15	10.64 ± 0.44	47.67 ± 1.61	54.00 ± 5.74	10	14.00 ± 1.64	33.74 ± 9.25	0.88

Table 11.

Vegetation indices in mosaics I and II (see text) and in an area with no vole burrows. Data are given as the mean ± the standard error and *n* is the sample size.

Type	Cover of vegetation (%)	*Chenopodium aibum*		*Aneurolepidium chinense*		Biomass of other plants
		Height (cm)	Biomass (g/m^2)	Height (cm)	Biomass (g/m^2)	
Mosaic I	97.00 ± 1.22	85.52 ± 1.71	910.00 ± 85.58	45.72 ± 2.76	350.00 ± 41.76	530.00 ± 53.76
(*n* = 5)						
Mosaic II	94.00 ± 1.00	49.40 ± 2.77	94.00 ± 33.65	46.04 ± 1.04	970.00 ± 87.31	280.20 ± 89.96
(*n* = 5)						
No burrows	87.70 ± 1.37	0	0	27.59 ± 0.77	121.87 ± 11.72	664.00 ± 26.45
(*n* = 30)						

biomass of *A. chinense* in mosaics I and II was 2.87 times and 7.96 times that of the biomass in the non-burrow area, respectively. Productivity of a mosaic could exceed the productivity of the surrounding area in three months, with a considerable increase in the biomass of fine grazing grass such as *A. chinense* in the mosaics.

The ecological management of the vegetation was economically efficient with an increase of 530 kg/ha of dry matter produced in 1987 and an investment:income ratio of 1:7. 1988 was a wet year, with 1,753 kg/ha more dry herbs harvested, and the investment:income ratio was 1:8.8 (Zhong et al. 1991). By comparison, 1989 was the worst drought year in 29 years. Productivity was increased by 123 kg/ha at harvest that year and the investment:income ratio equaled 1:2.7. Over the three years from 1987–89, the average investment:income ratio was 1:7. In summary, good ecological management not only stopped the damage caused by Brandt's vole but also enhanced the productivity of the grassland.

Discussion

Heavy grazing pressure by livestock causes degradation of grassland in Inner Mongolia, with different rodent pests occurring at each different degenerative stage. At the same time, the rodents' devouring and digging activities aggravate the degradation of the grassland, i.e. there is positive feedback between damage caused by rodents and the degeneration of grassland that can lead ultimately to desertification (Figure 2). Coordinated management of livestock, grasses and rodents is required to break this vicious cycle.

The main aims of an ecological approach to controlling rodents in grasslands are economic benefits, minimal or no use of rodenticides to avoid chemical contamination of the environment, and a long-term solution brought about by decreasing the carrying capacity of rodents. To achieve this, we have studied the ecological management of both *M. brandti* and *O. daurica* simultaneously (Zhong 1996) from 1991 to 1996.

Detailed ecological studies of pest species are needed before ecological management is applied: the life history of a pest species must be understood for identifying weak links. For example, stored food is the most important factor influencing the survival of rodents during the long and cold winters in the grassland of Inner Mongolia. Decreasing the available storage food for rodents could

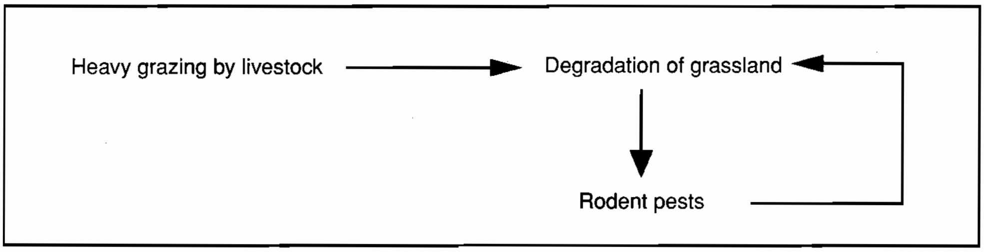

Figure 2.
Schematic diagram showing the interactions of livestock and rodents in grasslands. Overgrazing by livestock can degrade grasslands to a level that will be maintained indefinitely by rodent pests.

remarkably suppress the growth of rodent populations (Zhong 1996).

We used exclosures to adjust the pressure and duration of grazing by livestock. This resulted in the recovery of degraded grassland and a decline of the density of Brandt's vole. This result could be achieved in other ways. The cost of building fences could be saved by moving herds of livestock alternately between different areas based on well designed grazing plans, effectively employing 'formless exclosures'. As well, irrigation and the use of fertiliser are effective means of accelerating the recovery of degraded grassland (Zhong 1996). Rapid recovery of vegetation can quickly suppress Brandt's vole, preventing future degradation with economic savings in the long term.

The need for livestock to have access to water results in uneven grazing pressure and degradation of grassland near rivers. Grazing pressure near rivers can be reduced by digging wells to change the pattern of herding livestock and make full use of grass resources distant from rivers.

Dicotyledons are the main component of rodents' stored food for winter. Fencing to exclude livestock can decrease the biomass and proportion of dicotyledons in the plant community. In addition, we sowed monocotyledon seeds to increase the proportion of fine-grazing grass in fenced areas, with encouraging results (Zhong 1996). Another practice is to plough the grassland. Roots of *A. chinense* and *S. grandis* are extensive and easily cut to promote tillering. The result is an increase in the biomass and proportion of these fine-grazing grasses in the plant community (Zhong 1996).

Future research will be directed towards the strategy of ecological management at the landscape level. Myllymäki (1979) reviewed the landscape characteristics that could create conditions favourable for rodent plagues, and others that tend to prevent outbreaks. Some references suggest that characteristic changes of landscape would influence movement, competitive interaction, predation etc. of mammals in this habitat (Lidicker 1995).

Our approach to ecological management is not simply habitat modification. The main features of habitat modification are removal of basic life needs (food and water) from rodents and rodent proofing (Fitzwater 1988) using techniques such as clearing weeds quickly after crops are harvested, spraying 2,4-D herbicides to reduce pocket gopher's (*Thomoys talpoides*) favourite food and hence decrease their activity (Keith et al. 1959), planting buffer crops which pests prefer and setting up physical barriers. These techniques can eliminate rodent pests but may have deleterious effects on other vertebrate species that share the same habitat (Howard 1988), and they are usually expensive. Ecological management comes from systematic view, based on ecological studies, using natural forces to target weak links in the life history of a pest species. The aim is to take careful consideration of relationships with other species and the environment, while using existing equipment to save money and exploring new ways to enhance production.

Although we have achieved effective ways to manage Brandt's vole and the Daurian pika simultaneously (Zhong 1996), many improvements are still demanded.

Future study will continue to apply ecological principles to pest management.

Acknowledgments

We are very grateful to Dr Roger Pech for his tremendous help in improving the English writing of this paper and for his valuable comments for revising the original manuscript. This work is supported by the national rodent key project (96-005-01-06) and the Chinese Academy of Sciences key projects (KZ951-B1-106, KZ952-S1-107 and STZ-1-05).

References

Barnett, S.A. 1988. Ecology and economics of rodent pest management: the need for research. In: Prakash, I., ed., Rodent pest management. Boca Raton, Florida, CRC Press, 459–464.

Dong, W.H., Hou, X.X., Zhang, P.L., Zhou, Y.L., Yang, Y.P. and Xue X.P. 1991. Study on characteristics of population of Brandt's vole after rodent control. Acta Ecologica Sinica, 11, 274–279 (in Chinese).

Fitzwater, W.D. 1988. Non-lethal methods in rodent control. In: Prakash, I., ed., Rodent pest management. Boca Raton, Florida, CRC Press, 421–426.

Hou, X.X., Dong, W.H., Zhou, Y.L., Yang, Y.P., Zhang, Y.X. and Xue, X.P. 1993. A study on succession of rodent community in grassland after chemical control. Chinese Journal of Vector Biology and Control, 4, 271–274 (in Chinese).

Howard, W. E. 1988. Areas of further research. In: Prakash, I., ed., Rodent pest management. Boca Raton, Florida, CRC Press, 451–458.

Keith, J.O., Hansen, R, M. and Ward, A. L. 1959. Effect of 2,4-D on abundance and foods of pocket gophers. Journal of Wildlife Management, 23, 137–145.

Lidicker, W.Z. 1995. Landscape approaches in mammalian ecology and conservation. Minneapolis and London, University of Minnesota Press.

Liu, S.R. 1979. Basic study on relation between Brandt's vole and vegetation in Xinlin Guole region, Inner Mongolia. Chinese Grassland, 2, 27–31 (in Chinese).

Myllymäki, A. 1979. Importance of small mammals as pests in agriculture and stored products. In: Stoddart, D.M., ed., Ecology of small mammals. London, Chapman and Hall, 239–279.

Ren, J.Z., Ge, W.H. and Zhang, Z.H. 1989. The future of production of grassland. In: Grassland research group of the Chinese Academy of Sciences and the Agricultural Academy of Sciences, ed., Grassland science and development of China. Beijing, Science Press, 6–9 (in Chinese).

Wang, G.M, Zhou, Q.Q., Zhong, W.Q. and Wang, G.H. 1992. Food habits of Brandt's vole (*Microtus brandti*). Acta Theriologica Sinica, 2, 57–64 (in Chinese).

Wang, M.J., Zhong, W.Q., Wang, G.M. and Wang, G.H. 1997. Cooperative changes of plant–rodent communities in steppe on grazing gradient. Research on Grassland Ecosystem, 5, 32–42 (in Chinese).

Wang, M.J., Zhong, W.Q., Wan, X.R. and Wang, G.H. 1998. Habitat selection on dispersal of Daurian pika (*Ochotona daurica*). Acta Zoologica Sinica, 44, 398–405 (in Chinese).

Xia, W.P. and Zhong, W.Q. 1966. The successions and interactions of the rodent and plant communities of abandoned fields in desert steppe at Changan-Aobao, Inner Mongolia. Acta Zoologica Sinica, 18, 199–208 (in Chinese).

Yang, H.F., Zhou, Q.Q., Wang, S.Q., Zhong, W.Q. and Liu, B.Q. 1979. Investigations on population self-regulation in Brandt's vole—the relationships between population density, adrenal weight and gonadal weight. Acta Zoologica Sinica, 25, 154–168 (in Chinese).

Zhang, J. and Zhong, W.Q. 1981. On the colonial structure of Brandt's vole in burrow units. Acta Theriologica Sinica, 1, 51–56 (in Chinese).

Zhong, W.Q. 1996. Strategy of ecological management on rodent pest of grassland and research on pollution-free technology. Unpublished report to Chinese Academy of Science, 1–9.

Zhong, W.Q., Zhou, Q.Q. and Sun, C.L. 1983. Study on the food consumption of Daurian pika. Acta Ecologica Sinica, 3, 269–276 (in Chinese).

Zhong, W.Q., Zhou, Q.Q. and Sun, C.L. 1985a. The basic characteristics of the rodent pests on the pasture in Inner Mongolia and the ecological strategies of control. Acta Theriologica Sinica, 5, 241–249 (in Chinese).

Zhong, W.Q., Zhou, Q.Q. and Sun, C.L. 1985b. The vegetation and habitat selection by the Brandt's vole (*Microtus brandti*) in Inner Mongolia steppe. Research on Grassland Ecosystem, 1, 147–152.

Zhong, W.Q., Zhou, Q.Q., Sun, C.L., Wang, G.H., Zhou, P.Y., Liu, W.Z. and Jia, Y.P. 1991. The design for the ecological management of Brandt's vole pest and its application. Acta Theriologica Sinica, 11, 204–212 (in Chinese).

Zhong, W.Q., Zhou, Q.Q., Wang, G.H., Sun, C.L., Zhou, P.Y. and Liu, W.Z. 1992. Ecological effects of the measures for raising herbage in enclosure on Brandt's vole population. Research on Grassland Ecosystem, 4, 199–203 (in Chinese).

Zhou, Q.Q., Zhong, W.Q. and Sun, C.L. 1982. Study on species diversity of rodent communities in Baiyinxile typical steppe, Inner Mongolia. Acta Theriologica Sinica, 2, 90–94 (in Chinese).

Zhou, Q.Q., Zhong, W.Q. and Wang, G.M. 1988. Food store of Brandt's vole (*Microtus brandti*) and its ecological importance. Symposium of Asian–Pacific Mammalogy (Abstract), 77 (in Chinese).

Zhou, Q.Q., Zhong, W.Q. and Wang, G.H. 1992. Density factor in the regulation of Brandt's vole population. Acta Theriologica Sinica, 12, 49–56 (in Chinese).