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

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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 management 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 in May, plus high rainfall and warm temperature, suppress the germination and growth of the grasses. 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 comparing 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 Mongolia grassland.

INTRODUCTION

B RANDT'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).

Table 1.

Species number, diversity and heterogeneity of plant and rodent communities in five types of steppe.
H is the Shannon-Wiener index: $H = -\Sigma Pi \ln Pi$, where *Pi* = proportion of *i* species in community. *J* is an index of evenness: J = H/ln S, where S = number of species in 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 a-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*			Season	Community	*Stipa grandis*		
		steppe					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

The changes in the α-diversity index of the plant community and rodent 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 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).
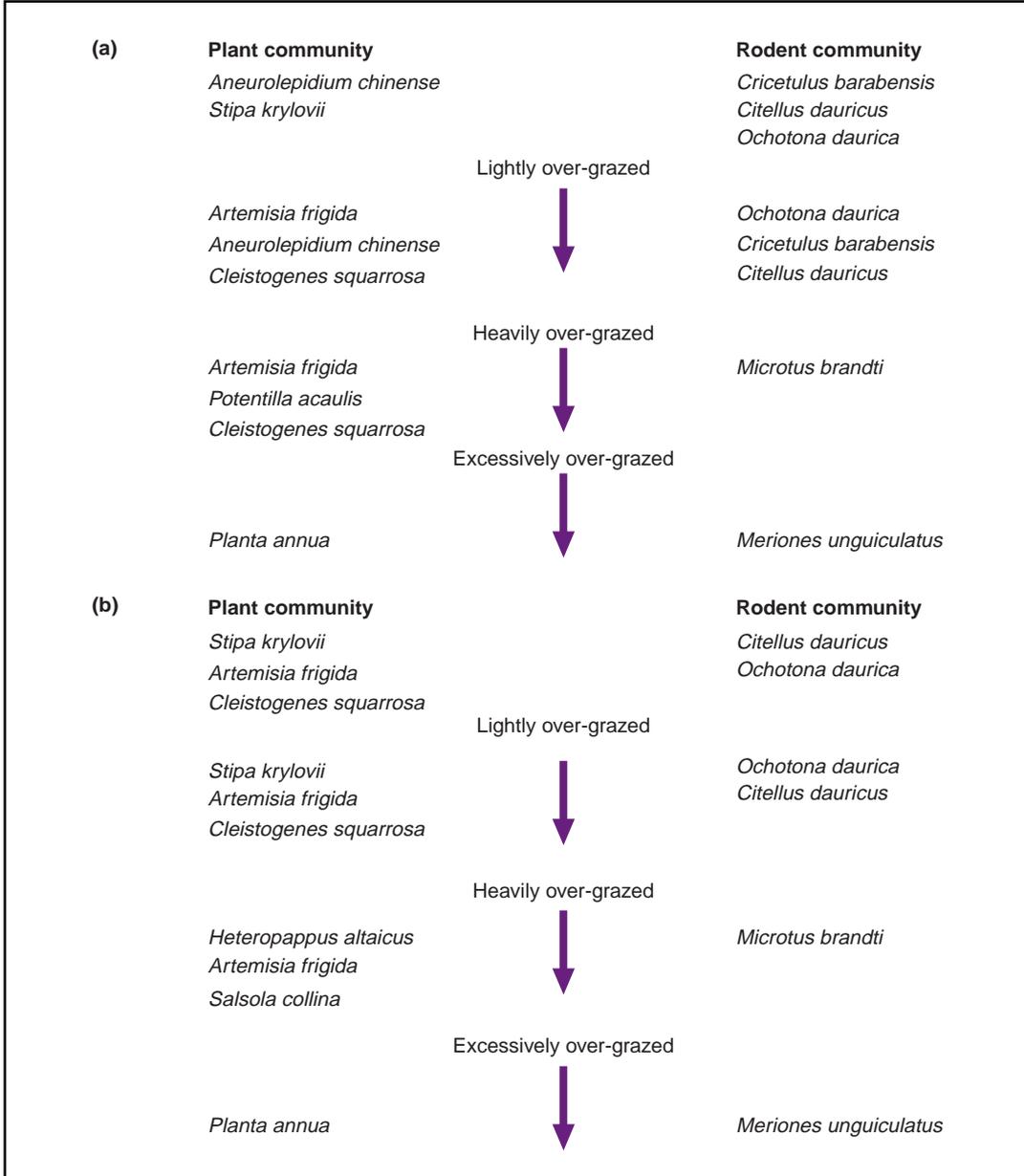
(a)

Plant community	Rodent community
Aneurolepidium chinense	*Cricetulus barabensis*
Stipa krylovii	*Citellus dauricus*
	Ochotona daurica

Lightly over-grazed

Artemisia frigida	*Ochotona daurica*
Aneurolepidium chinense	*Cricetulus barabensis*
Cleistogenes squarrosa	*Citellus dauricus*

Heavily over-grazed

Artemisia frigida	*Microtus brandti*
Potentilla acaulis	
Cleistogenes squarrosa	

Excessively over-grazed

Planta annua	*Meriones unguiculatus*

(b)

Plant community	Rodent community
Stipa krylovii	*Citellus dauricus*
Artemisia frigida	*Ochotona daurica*
Cleistogenes squarrosa	

Lightly over-grazed

Stipa krylovii	*Ochotona daurica*
Artemisia frigida	*Citellus dauricus*
Cleistogenes squarrosa	

Heavily over-grazed

Heteropappus altaicus	*Microtus brandti*
Artemisia frigida	
Salsola collina	

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) and (b) the Kelulun River (49°25'N, 116°42'E) 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 *Aneurolepidium chinense* and

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. We define the degree of degraded grassland using the botanists' standard, cover holes of Brandt's vole with soil, then check them 24 hours later, counting opened hole as active holes.

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

Allium aniso-podium, *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 exclosures 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* about 120 m, and *B* between *C* is 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

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 number of sample.

Study site	Density of voles	Vegetation			
		No. of species/m^2	Height (cm)	Cover (%)	Biomass (g/m^2)
	n = 6 $X \pm SE$	n = 20 $X \pm SE$	n = 5	n = 5	n = 5 $X \pm SE$
A. enclosure	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*	t-test
*(p < 0.01)	C<B#	C<B*		C<B*	C<B*
#(p < 0.05)	A<B*	A>B#		A>B*	A>B*

suggests that food is not the main factor influencing habitat selection by Brandt's vole. More important factors appear to be 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 choose 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 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 Xilin Geluo and Zhe Limo region in 1987, 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

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^{-1}) ($X \pm SE$)
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

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 ($r = -0.304$, $p > 0.05$). 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.

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					
		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		
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

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.

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 exclosure 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 I than in exclosure II, 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 I than II. 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 enclosure 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.

Table 9.
The impact of different grazing treatments on vegetation indices and the density of 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. (I) is the experimental exclosure, (II) is the control exclosure, and (III) is an unfenced grazing area.(Increase in the rate of vole density is calculated by: $r = ln(Nt+1/Nt)$ where Nt is the density of the population at time t .)

Treatment	Area (ha)	Vegetation in autumn			Density of Brandt's vole/ha)		Proportional 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 and n is the sample size.

Year	Study site	n	Vegetation in autumn Height (cm)	Cover (%)	Biomass (g/m^2)	n	Density of Brandt's vole/ha Spring	Autumn	Proportional 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 album Height (cm)	Biomass (g/m^2)	Aneurolepidium chinense Height (cm)	Biomass (g/m^2)	Biomass of other plants
Mosaic I (n = 5)	97.00 ± 1.22	85.52 ± 1.71	910.00 ± 85.58	45.72 ± 2.76	350.00 ± 41.76	530.00 ± 53.76
Mosaic II (n = 5)	94.00 ± 1.00	49.40 ± 2.77	94.00 ± 33.65	46.04 ± 1.04	970.00 ± 87.31	280.20 ± 89.96
No burrows (n = 30)	87.70 ± 1.37	0	0	27.59 ± 0.77	121.87 ± 11.72	664.00 ± 26.45

After ecological measurement, 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 was where a burrow system was abandoned during May or June in the current year and mosaic II was 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 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 are required to break this vicious cycle.
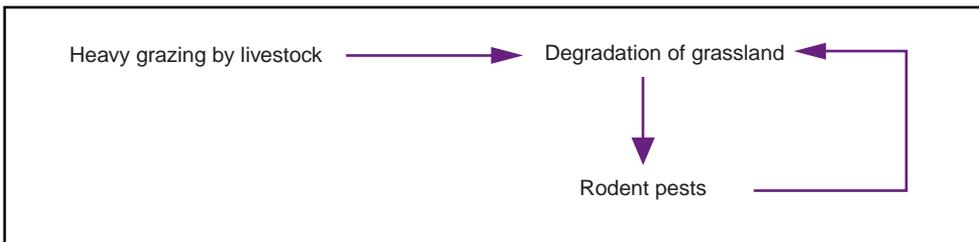

Figure 2.
Schematic diagram showing the interactions of livestock and rodents in grasslands. Overgrazing by livestock can degrade grasslands to a level that will be maintained indefinitely by rodent pests.

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.

Detail 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 remarkably suppress growth of rodent population (Zhong 1996).

We used exclosures to adjust the pressure and duration of grazing by livestock. This resulted in the recovery of degraded grassland and 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.

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