by the rat-like hamsters occurs to seeds during the sowing periods and to mature crops during the harvest periods. The rat-like hamster stores about 200 g of seed in both spring and summer, and much more in autumn ranging from 0.6–20.0 kg (n = 40) per hamster.

Peanuts, the favourite food of the rat-like hamster, suffer high levels of damage. In 1986, two enclosure experiments were conducted in Raoyang County, Hebei Province, on the depredations of the rat-like hamster to peanut crops. The first study was conducted in a 0.26 ha enclosure. At a capture success of 22%, the rat-like hamsters consumed 14.8% of the peanut crop. The second study was conducted in a 2 ha plot. At a capture success of 24%, the rat-like hamsters consumed 19.6% of the peanut crop (Zhang et al. 1998).

It is difficult to assign damage to particular species when the rodent population consists of a mix of several species. By employing multiple regression statistics, Wang et al. (1996) developed a model for estimating the damage to peanut crops by mixed populations of rodents during the sowing period (May) and the harvest period (September) in Shandong Province as below.

$$LS\% = 0.167 + 0.155D_{S1} + 0.260D_{S2} + 0.086D_{S3}\ (r = 0.981, F = 87.48, d.f. = 3,10, p < 0.001) \quad (1)$$

where $LS\%$ is the peanut loss at sowing caused by the striped hamster (D_{S1}), the rat-like hamster (D_{S2}) and the striped field mouse, *Apodemus agrarius* (D_{S3}). DS indicates the trap success (%) of the respective rodent populations in spring.

$$LA\% = 1.226 + 0.176D_{A1} + 0.456D_{A2} + 0.110D_{A3},\ r = 0.959, F = 22.98, d.f. = 3,6, p < 0.001) \quad (2)$$

where $LA\%$ is the peanut loss at harvest caused by the striped hamster (D_{A1}), rat-like hamster (D_{A2}) and striped field mouse (D_{A3}). DA indicates the trap success (%) of the respective rodent populations in autumn.

Population forecasting for management

Since the most serious damage occurs in autumn, and rodent control often begins in early spring, there is a strong need to be able to forecast the population of hamsters in autumn. Based on the monitoring data from 12 years in Raoyang County and Guan County, a short-term forecasting model for the rat-like hamster was established (Zhang et al. 1998):

$$Y_A = 0.98 + 8.66X_4\ (r = 0.96, p < 0.01)\ \text{when}\ X_4 \le 2.33 \quad (3)$$

$$Y_A = 18.43 - 2.14\,X_4\ (r = 0.89, p < 0.05)\ \text{when}\ X_4 > 2.33 \quad (4)$$

Using this model, where Y_A is the maximum trap success (%) in autumn (September, October or November), X_4 is the trap success (%) in April.

Although the autumn trap success of the rat-like hamster is highly correlated with its April trap success, the correlation is non-linear. There is a strong positive association when the April trap success is ≤ 2.3 and a strong negative association when the April trap success is > 2.3 (Figure 3).

Based on the above forecasting models, we successfully predicted the changes in population dynamics of the rat-like hamster in Raoyang County and Guan County in 1996 and 1997 (Table 3). The accuracy of prediction is defined as:

$$A = [1 - |P - O| / M] \times 100\% \quad (5)$$

where A is the accuracy of prediction, P is the predicted trap success, O is the observed trap success, and M is the maximum trap success ever observed. The accuracy of prediction in 1996 for Raoyang County and Guan County was 87% and 97.9%, respectively. In 1997 the accuracy of prediction for the same two counties was 95.2% and 90.7%, respectively.

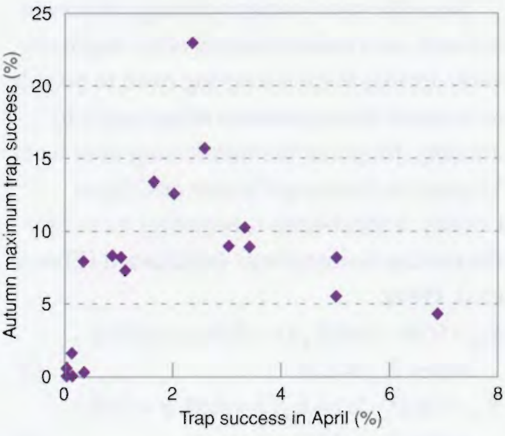

Figure 3.
The relationship between the autumn maximum trap success (%) and trap success in April (spring) in Hebei Province from 1984–1995.

Forecasting is an important step in deciding whether to launch a rodent control campaign in spring in this region. If the predicted autumn trap success is over 5%, a rodent campaign is necessary to reduce grain losses. We have observed that farmers pay less attention to damage when autumn trap success of the rat-like hamster is less than 5%. This trap success is equivalent to approximately 3–4% loss of the peanut crop.

Control techniques and strategies

The rat-like hamster is an important rodent pest in the North China Plain and farmers have developed several traditional methods of pest management. In autumn after harvest, farmers dig the rodent burrows to recover the grains stored by the rat-like hamster. Some farmers are extremely proficient at digging hamster burrows, recovering 100 kg of grain within 1–2 weeks.

The value of ploughing and irrigation is also well known by farmers for reducing hamster populations. It is common for farmers to directly kill hamsters during ploughing and irrigation.

During 1994–98, the negative impact of irrigation on the hamster population was clearly demonstrated in Shunyi District, Beijing. Shunyi used to irrigate its farmland in the traditional way, pumping water directly into farmland. This method wasted a lot of groundwater. In 1994, Shunyi swapped over from the old ditch irrigation to spray irrigation. The rodent community

Table 3.
Prediction of the population abundance of the rat-like hamster in Raoyang County and Guan County, Hebei Province, in 1996 and 1997 using the forecasting models described in the text (see also Zhang et al. 1998). *A* is the accuracy of prediction, *P* is the predicted trap success, and *O* is the observed trap success. The maximum trap success ever observed for this cropping system was 23.1

Place	1996			1997		
	P	O	A%	P	O	A%
Raoyang	7.73	8.21	97.9	7.68	5.52	90.7
Guan	12.0	9.0	87.0	9.4	8.3	95.2

changed suddenly from a striped field mouse dominant community into a rat-like hamster dominant one. The outbreak of rat-like hamster populations in Shunyi District occurred for several years after this change in irrigation system, and has resulted in tremendous losses in crop production.

In 1978, rural China experienced a reform from a community-based system to a family-based system in which each family rents a small area of land, and they decide what they plant. This has led to a patchy landscape consisting of a mosaic of different crops. This heterogeneous cropping system provides a favourable environment for hamsters by increasing their survival and breeding performance. Small plots of land in a patchy landscape are particularly vulnerable to attack by hamsters, especially those plots growing oil crops. Chemical control has little impact on rodent populations in such small plots of land because recolonisation by rats from the surrounding environment soon counteracts any local reductions in population density. In order to solve this problem, a new multiple-capture physical trap was invented (Zhang et al. 1996). The pitfall trap was designed with a magnetic trigger on its lid (Figure 4). One trap was set in each of two corn fields in Guan County in the summer of 1995. In eight days, both traps caught 20 hamsters. During the experiment, the capture success in snap-back traps of the rat-like hamster, striped hamster (*Cricetulus barabensis*) and house mouse (*Mus musculus*) was 21%, 1% and 0.3%, respectively.

Fresh wheat containing 0.005% bromadiolone (see Guo et al. 1997) was used in a rodent control campaign in Beijing. In 1997, more than 333,000 ha of farmland were treated with bromadiolone, achieving approximately a 92% kill rate (based on pre- versus post-treatment indices of abundance) in early spring. The capture success of hamster was maintained at a level less than 5% through the year, however the population recovered to its original density the next spring, and another chemical control campaign was launched in 1998 (Xihong Guo, pers. comm.).

In addition, a male chemosterilant, 1–2% α-chlorohydrin, has been tested for controlling the rat-like hamster (Zhang et al. 1997a,b). The chemosterilant was tested in Guan County, where bromadiolone only kills 70–80% of hamsters, enabling the populations to recover quickly from poisoning campaigns (Zhibin Zhang, unpublished data). Zhang (1995, 1996) suggested that a strategy of combining fertility control with chemical mortality might delay the recovery of hamster populations post-poisoning; male hamsters that do not die following the ingestion of bromadiolone would become sterile from the α-chlorohydrin.

In July of 1993 and in April of 1995, an experimental farmland site was treated with a wheat bait of 0.005% bromadiolone and 1% α-chlorohydrin. Similar surrounding farmland was selected as an untreated area. Ten days after treatment, 75% and 78% mortality were achieved in 1993 and 1995, respectively, on the experimental site. In 1994, no control measure was taken. Mortality control combined with sterilisation achieved good results. During 1995, the capture success of the rat-like hamsters on the experimental site was less than 5%, while eruptions of hamster populations occurred on the untreated site (Zhang et al. 1998; Figure 5).

Figure 4.
A new multiple pitfall trap with a magnetic trigger.

Recommended management strategies and research priorities

In the North China Plain, there are two strategies recommended for farmers to manage the rat-like hamster:

- If the hamster is causing localised problems within a farming system then the pitfall trap is recommended. One trap should be placed in the middle of a crop (in this region the average farm size is 0.25 to 0.5 ha).
- If the hamster is causing problems over a large area then broad-scale application of a wheat bait of 0.005% bromadiolone and 1% α-chlorohydrin is recommended.

Further research is required on the efficacy of bromadiolone with and without α-chlorohydrin, and on the social acceptance of using male sterility baits. Other research has begun on Chinese herbs for enhancing the effect of anticoagulants. In particular, is it possible to increase the susceptibility of hamster populations to bromadiolone and can the time until death be reduced (currently around 10 days for hamsters)?

Zokor management in the Northwest Loess Plateau

Agricultural system and environment

The Northwest Loess Plateau is one of the most undeveloped areas in China due to its harsh climate. This region has very limited

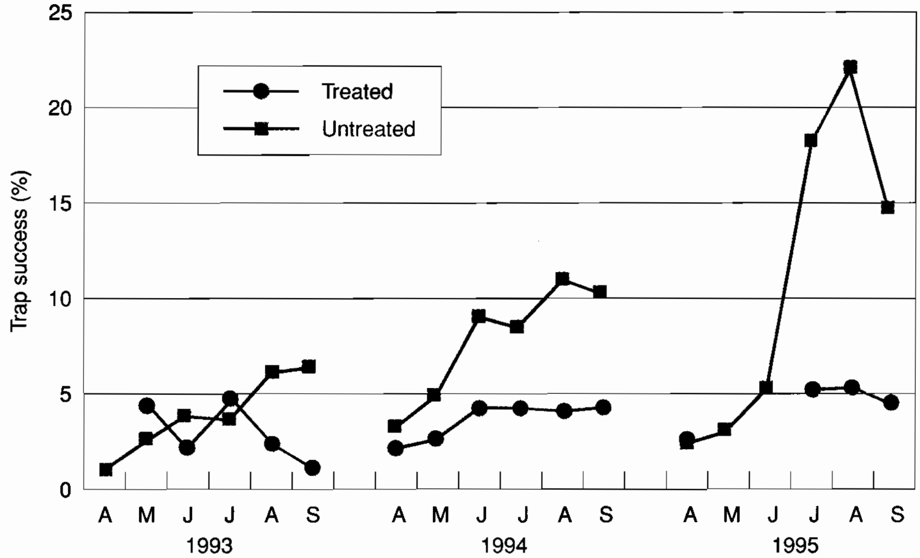

Figure 5.
Field trials of the effect of a-chlorohydrin combined with bromadiolone on the rat-like hamster population in Guan County, Hebei Province, from 1993–1995.

rainfall. Corn and wheat are commonly planted in the upper Yellow River regions. The grain production is seriously affected by rodents, particularly the Chinese zokor (*Myospalax fontanieri*). Rodent control is very important for reducing grain losses and increasing the income of farmers in this region.

Reproduction patterns and population dynamics

The Chinese zokor is a large rodent (300–650 g) that lives underground. The breeding season is from March to June, and adult females reproduce only once a year. The litter size ranges from 1–6, averaging 3.0 ± 0.4 (Zou et al. 1998). There is one annual peak in zokor numbers in June or July.

Damage and assessment

The burrowing activity of the Chinese zokor causes significant damage to crops. Zokors also take crop seedlings or seeds to their burrows for food. Winter wheat sustains high damage because zokor populations are short of other food sources during winter. Serious damage occurs to corn and sunflower seedlings in spring when zokors begin to breed and more extensive digging and burrowing take place. Zokors also horde food in autumn for over-wintering.

The degree of damage caused by zokors can be divided into five classes based on the proportion of seeds/seedlings eaten (Ning et al. 1994):

- no damage;
- proportion of seeds/seedlings eaten is 1–25%;
- proportion of seeds/seedlings eaten is 25–50%;
- proportion of seeds/seedlings eaten is 50–75%; and
- proportion of seeds/seedlings eaten is 75–100%.

The regression models between crop losses and density of zokor were established as follows (Ning et al. 1994; Chang et al. 1998):

$$L_W = -0.4462 + 0.9748X_6 \ (r = 0.9625, \ d.f. = 7, p < 0.01) \quad (6)$$

where LW is the proportion of wheat eaten by zokors (%) and X_6 is the density of the zokors in June (individuals/ha); and

$$L_C = -1.6427 + 1.1913X_9 \ (r = 0.9657, \ d.f. = 5, p < 0.01) \quad (7)$$

where L_C is the proportion of corn eaten by zokors (%) and X_9 is the density of zokors in September (individuals/ha).

Control techniques and strategies

Because zokors live underground and do not readily take baits or enter physical traps, routine techniques like rodenticides and physical trapping are inefficient for control. A fumigant, aluminium phosphide, is commonly used to kill zokors in this region. The burrow tunnel system is very complex, therefore it usually requires about 10 pieces of the fumigant (3.3 g) to effectively fumigate a burrow. The kill rate is approximately 80% (based on pre- versus post-treatment indices of active burrows) if conducted by experts, but is generally less than 70% when applied by farmers during a rodent control campaign.

A new technique was invented in 1986, called the 'explosive paper tube' (EPT) which is specialised for controlling underground rodents (Liu et al. 1991). The EPT contains explosives of dinitrodiazophenol or nickel nitrohydrazino, and is triggered via a battery. The EPT is 20–30 mm long, and its diameter is 3 mm (Figure 6). The EPT is waterproof, easy and safe to carry. EPT is also cost effective and available commercially in this region.

The kill rate with EPTs is over 95% for large-scale rodent control campaigns — much better than using rodenticides. The procedure for setting an EPT is simple and requires four steps: (1) select an active burrow tunnel; (2) dig into the tunnel to place an EPT there, bury it; (3) block the tunnel with a soil ball loosely; (4) connect the two wires with a small battery (1.5 V), making a trigger which will be touched by the falling soil ball. When a zokor pushes the soil ball which blocks its tunnel, the ball will touch the trigger, and the EPT will explode under the zokor body and kill it (Zou et al. 1998).

Recommended management strategies and research priorities

The EPT has been successfully commercialised and proven very efficient for zokor control in this region. However, the trigger system is still complex, and thus needs to be improved further. A trigger system is required that does not re-use the battery and the connecting wires. This would make it easier to set the EPT in the field.

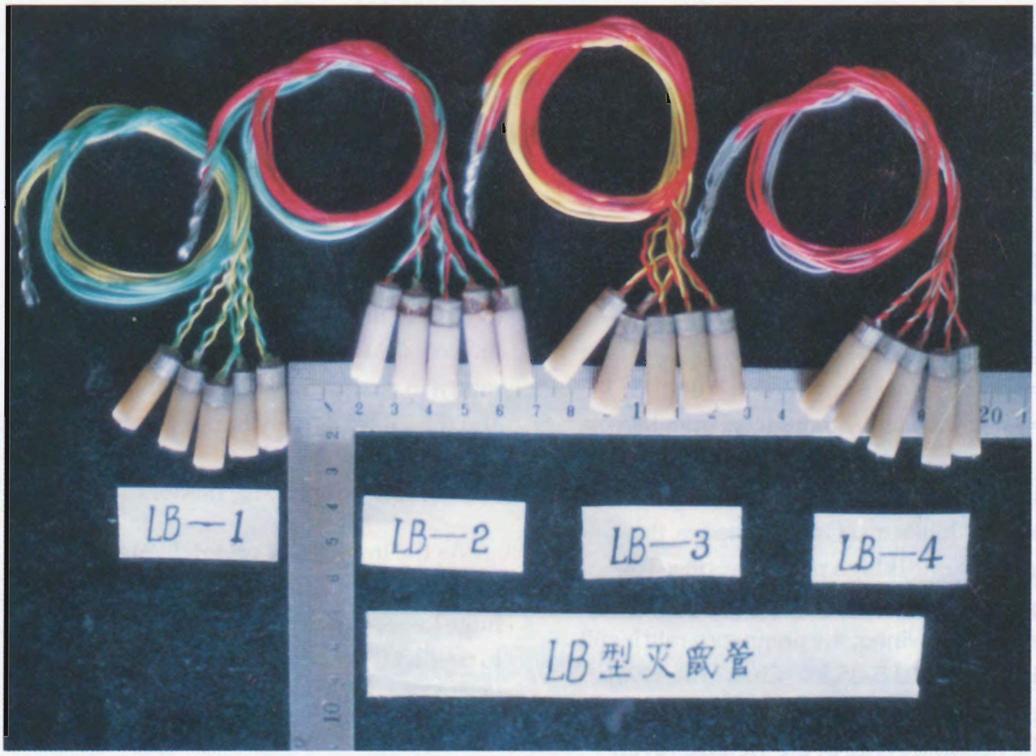

Figure 6.
The explosive paper tube (EPT) for controlling zokors.

The EPT occasionally only injures the zokor, and has potential risk to people, especially children. From the view of humaneness and public safety, alternative control techniques need to be considered for replacing the EPT for zokor control. Two research priorities are suggested. The first is to improve the acceptance of rodenticide bait by adding an attractant. This requires detailed study of zokor behaviour and their chemical communication. The second is to find an ecological management strategy for zokor control. The Chinese zokor's favourite food are the roots of grass and crops. The clearing of weeds using herbicides in non-crop lands has shown potential for reducing zokor populations (Zhengdong Ning, unpublished data). Also, planting toxic herbs in wastelands (non-crop habitats), banks and croplands could be effective in reducing the favourite grasses of zokors and in poisoning zokors when they eat the roots of the herbs.

Vole management in the South China Plain (Yangtze River region)

Agricultural system and environment

Dongting Lake is a very large lake located in the middle of the Yangtze River. It plays an important role in regulating floods of the Yangtze River during the rainy season. The oriental vole (*Microtus fortis*) is a rodent species well adapted to the environment of

Dongting Lake (Chen et al. 1995; Wu et al. 1996, 1998; Guo et al. 1997). The voles migrate back and forth between the beaches and islands of Dongting Lake and the surrounding rice fields as the floodwaters rise and recede (see below).

Reproduction patterns and population dynamics

The adult oriental vole weighs 59.5 ± 11.3 g (n = 378) for females, and 77.5 ± 15.0 g (n = 415) for males. Although the oriental vole can breed throughout the year at Dongting Lake, its breeding is much affected by flooding. Unlike most rodent species, the pregnancy rate is high prior to spring. The pregnancy rate from February to April is 64%. Even in deep winter, the pregnancy rate is still maintained at 23.5–35.3% (Chen et al. 1998). This reproductive strategy is clearly adapted to the flooding cycles of the Yangtze River. The beach and island habitat with grass in the lake is the optimal habitat for the herbivore voles in winter. During the flooding season these habitats are flooded. Just prior to flooding, oriental voles migrate in large swarms to the surrounding farmland where their breeding is greatly reduced (Table 4). During September and October, the flooding waters recede and the voles return to the beach and island habitats for the winter (Chen et al. 1995, 1996, 1998; Wu et al. 1996; Guo et al. 1997).

The seasonal population patterns of the oriental vole in rice fields and in the grass habitats on the islands and near the beaches of the lake are affected greatly by their migration between lake habitats and the rice fields. There is a population peak in summer in the rice fields following the migration of the voles. After October, voles begin to return to the beaches and ephemeral islands, and then their density in rice fields is low.

Population forecasting models

As the invasion of oriental voles into rice fields during the flooding season causes huge losses to rice production, it is necessary to predict these population changes. Chen et al. (1998) found that the trap success (%) of voles in farmland during the flooding season is mainly determined by the duration of breeding of the vole population living in beaches in the non-flooding season and the rainfall in March. The duration of breeding in lake beaches is strongly correlated with the period when the water level of Dongting Lake is below 27.5 m. The regression model was established as follows:

$Y = 0.0394X_1 - 0.0048X_2 - 5.02$ ($R = 0.957$, $d.f. = 9$, $F = 49.23$, $p < 0.0001$) (8)

Table 4.
Reproduction of oriental voles in flooding and non-flooding seasons (from Chen et al. 1998).

Habitat	Lake beaches	Rice fields
Duration	November to May	May to October
Season	Non-flooding season	Flooding season
Number of females	185	280
Pregnancy rate (%)	51.4	20.4
Litter size	5.06 ± 0.15	5.37 ± 0.25

where Y is the trap success of voles in rice fields during the next flooding season, X_1 is the duration of breeding in lake beaches and X_2 is the rainfall in March. In 1994 and 1996, this model was used with good accuracy for predicting the trap success of voles in rice fields during the next flooding season (Chen et al. 1998).

Damage and assessment

In 1986, in the Yueyang County, 5,213 ha of rice fields were damaged by voles with grain losses of 918 t. More than 50% of the surrounding trees were seriously chewed by voles (Chen et al. 1998).

The oriental vole also spreads a serious rodent-borne disease, leptospirosis, to farmers working in rice fields. In 1979, 527 people on one state farm were infected by leptospirosis and 214 of them were sent to hospital.

The regression model between rice loss (L%) and the trap success is established by Wang et al. (1997):

$$L = 0.0674X_1 + 0.0307X_2 - 0.1627\ (R = 0.83,\ d.f. = 2,10,\ F = 11.07,\ p < 0.01) \qquad (9)$$

where X_1 is the trap success of oriental voles, and X_2 is the trap success of the striped field mouse.

Control techniques and strategies

Based on the habits of migration of the oriental voles between beaches of the lake and rice fields during the flooding and non-flooding seasons, a new method for rodent control was invented in 1981 by the local farmers of Jingpen State Farm. They buried deep pots between fixed fences that were erected along the dyke surrounding the Dongting Lake. The plate fence was 500 mm high, and buried 50–100 mm into the soil to prevent immigration of voles from lake beaches to the rice fields. Pots which were 0.8 m deep and 0.3 m diameter were buried between two fences. The pots were located every 50 m along the fences. When the flooding season approached, the large swarm of voles was channelled into the pots en route to the surrounding rice fields. From 1981–1987, along the west bank of Dongting Lake (which covers two state farms and eight towns), 1,588 t of voles were captured along a total of 231 km of fence (Table 5).

Table 5.
The quantity (t) of voles captured by burying deep pots in the dyke along the west bank of Dongting Lake from 1981 to 1988 (from Chen et al. 1998).

Year	Barrier line (m)	Voles captured (t)
1981	3 050	11.00
1982	17 300	159.00
1983	43 200	58.55
1984	40 700	106.75
1985	35 450	240.50
1986	42 160	511.00
1987	47 200	501.2
1988	2 850	49.00
Total	**231 910**	**1 637**

Chen et al. (1998) later improved this technique by enclosing the banks of the dyke with a 0.5 m high brick wall at the top of the dyke, with a 80 mm overhang. This physical structure prevented the voles from entering the rice fields (Figure 7). The damage of this species has been well controlled since the construction of the rodent-proof wall. This is an example of successfully controlling rodents based on understanding their ecology, and without using chemical rodenticides.

Recommended management strategies and research priorities

The modified dyke-barrier is an efficient method for controlling voles in this region. This system also satisfies the demand for flood management, and is readily incorporated in the flood prevention program in the Dongting Lake region when the dyke needs repair. Therefore, it is important to maintain the dyke with the modified physical barrier system for vole control. Future study should focus on another pest species, the Norway rat (*Rattus norvegicus*), which causes damage in both fields and houses.

Rat management in the South China Plain (Pearl River Delta)

Agricultural system and environment

The climate in the Pearl River Delta is subtropical with an annual rainfall of 1500–2000 mm. Rice is the main crop in this region and it is planted twice a year. *Rattus rattoides* and *Bandicota indica* are two major rodent pests in the rice fields. In this region, the amount of arable land is decreasing because of industrialisation and this has created more wastelands (non-cultivated lands). In some areas, *B. indica* is becoming more abundant (He 1998).

Reproduction patterns and population dynamics

R. rattoides is a rodent of medium size. The adult body weight ranges from 100–200 g. It breeds through all seasons of the year, with two pregnancy peaks, one in June and the other in October. The pregnancy rates in January and December are very low, less than 0.6%. The average pregnancy rate ranged from 35.4–54.6% during 1987–1991 (Huang et al. 1994a). The litter size ranges from 2 to 14, averaging 6.78 ± 0.10.


Photo: Anguo Chen

Figure 7.
The modified dyke-barrier system for controlling oriental voles.

R. rattoides displays seasonal movements between different crop fields. During the growing seasons for rice (April to July; August to November) they invade rice fields. After the harvest of rice they migrate into orange and banana plantations, where they over-winter.

In winter, the average densities of rats in orange and banana plantations are 13.6% and 13.7%, respectively, while the average densities in rice fields surrounding orange and banana plantations are only 6.2% and 7.1%, respectively (Feng et al. 1990a).

Population recovery of *R. rattoides* after chemical control

The population recovery of *R. rattoides* after chemical control has been well studied in 1987 by Feng et al. (1990b). The experimental area of each treatment was 27 ha without replicates. Twenty days after use of diphacinone rodenticides in the middle of January, February, March or April, the kill rates (based on pre- versus post-treatment abundance indices) of rats were 78.5%, 91.2%, 94.8% and 70%, respectively. In the experimental area treated in mid-January, the rat population had recovered to or surpassed its original level by early July. In the other experimental areas treated either in the middle of February, March or April, the rat populations also had recovered to their original levels by July (Figure 8). Therefore, even if the kill rate during the first half-year was over 90%, populations of *R. rattoides* recovered so rapidly that another chemical control campaign was necessary to protect the autumn rice crop. Rodenticides were applied in August to protect the autumn crop, however heavy rain, strong winds and thick ground weed cover resulted in a much lower kill rate than in the first half-year. Following an August baiting campaign, populations of rats recovered to the original level, or even higher, by November (Figure 8) (Feng et al. 1990b).

Damage and assessment

In the Pearl River Delta, rice, orange, bananas and vegetable crops suffer great losses from *R. rattoides*. Rice that ripens early suffers more damage than rice that ripens later. The levels of rat damage to early, medium and late ripening rice are 5.3%, 1.5% and 0.6%, respectively. Huang et al. (1990a) reported that an adult *R. rattoides* could cause losses amounting to 3,150 g of rice in one year. Huang et al. (1990b,c) established a regression model between infestation rate of rice (L, %) and the trap success of *R. rattoides* (X, %) in 1987:

$$L = -0.27 + 0.29X \ (d.f. = 3, r = 0.998) \quad (10)$$

For assessing damage caused by a mixture of populations of several rodent species, Feng et al. (1995) established two regression models between the loss rate (%) of rice and rodent densities in 1992:

$$L_1 = -0.0990 + 0.3367X_1 + 1.4578X_2 + 0.0361X_3 \ (R = 0.976, d.f. = 5, F = 73.22) \quad (11)$$

$$L_2 = -0.4250 + 0.3781X_1 + 1.4523X_2 + 0.6639X_3 \ (R = 0.904, d.f. = 5, F = 122.24) \quad (12)$$

where L_1 and L_2 represent the loss rate (%) of early ripening rice and late ripening rice and X_1, X_2, and X_3 are the trap success (%) of *R. rattoides*, *B. indica* and the house mouse, respectively.

Control techniques and strategies

Since the 1980s, coumatetralyl and diphacinone have been widely used for controlling *R. rattoides*. Two separate chemical control campaigns are needed

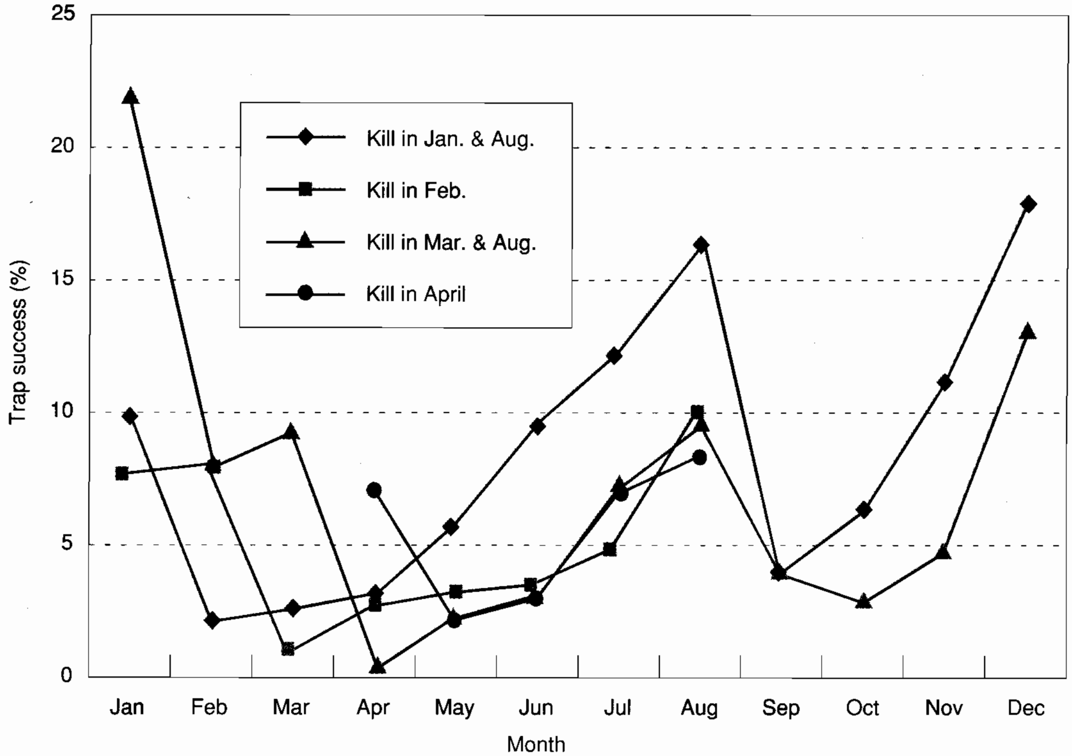

Figure 8.
Population recovery dynamics of *Rattus rattoides* after chemical control (from Feng et al. 1990b).

every year in this region in order to reduce rat damage to rice because of the rapid recovery of the rodent populations after chemical control. Therefore ecologically-based management is urgently needed as an alternative method.

R. rattoides depends much upon the ground vegetation cover in the orange groves, banana plantations, wastelands and banks of rice fields. When the ground vegetation cover in orange or banana plantations is over 60% with dry biomass of 766 g/m^2, the number of active burrow holes of *R. rattoides* is 48 ± 4.7 holes/100 m (estimated using a line transect method); when the ground vegetation cover in these plantations is less than 20% with dry biomass of 369.5 g/m^2, the number of active burrow holes of *R. rattoides* is only 2.4 ± 0.3 holes/100 m (Feng et al. 1996). Therefore, the clearing of weeds in the orange groves, banana plantations, wastelands and banks of rice fields is important for reducing the density of rat populations. Huang et al. (1994b) demonstrated that the density of *R. rattoides* was reduced from 52.0 ± 5.5 holes/100 m to 5.0 ± 1.1 holes/100 m after the clearing of weeds in rice fields and in the optimal habitats surrounding the rice fields.

Feng et al. (1996) examined whether planting some economic fruit trees with thick branches and leaves such as lychee, mango and longan in the wastelands or at the edge of rice fields could greatly reduce the weed cover, and thence reduce the rat density. After planting such evergreen fruit trees, weed biomass was reduced by 62.5–79.5% and the rat density was reduced by 77.3–89.1% (Table 6).

Recommended management strategies and research priorities

This study clearly indicates that chemical control is not a solution for sustainable management of rodent pests in this region. We recommend the strategy of combining chemical control with ecological management. In regions with high rat density, rodenticides should be used in February or March, followed by clearing of weeds in the wastelands and/or fruit tree plantations, and modifying these habitats by planting trees with thick leaves, such as lychee, mango or longan. The latter would be a more promising method of management because it not only reduces the population density of rats by reducing weed cover and their damage to crops, but also provides additional economic income for the farmers.

Problems and Possible Solutions

Since the 1980s, China has achieved promising advances in rodent pest management in agricultural systems (Zhang and Wan 1997). Firstly, acute poisons were replaced with anticoagulants. This alleviated the environmental pollution and secondary poisoning of natural predators and increased public safety.

Secondly, population ecology has been considered more than before as a basis for developing strategies for rodent pest management. Prediction of population increases and data on damage assessment have been listed as important aspects for the development of cost-effective and environmentally sensitive rodent control. The concept of ecological management is becoming much more accepted by people, even by those who were strong proponents of pure chemical control. For some of the major rodent pest species, reliable prediction models and sound damage assessment models have been established. These provide important information on when,

Table 6.
Changes in weed biomass and rat density (active holes/100 m) after planting fruit trees on the river dyke and waste hill lands in Pear River Delta. Control plots were not planted with any fruit trees (from Feng et al. 1996).

Habitat	Fruit tree type	Plots	Weeds biomass (g/m^2)	Rat density (active holes/100 m)
River dyke	Lychee	10	299.3 ± 21.5	36.3 ± 4.4
	Orange	10	354.1 ± 27.9	39.9 ± 4.1
	Control	10	945.2 ± 58.2	175.6 ± 12.0
Hill lands	Lychee	10	120.6 ± 35.9	14.7 ± 3.2
	Orange	10	187.3 ± 29.6	23.5 ± 2.7
	Control	10	589.4 ± 37.3	135.2 ± 19.3

where and how to manage rodents before launching a control campaign.

Thirdly, some new techniques for managing target rodent pests have been developed and proven effective. For example, the EPTs for managing zokors in the Northwest Loess Plateau, the multiple magnet-triggered traps for managing rat-like hamsters in the North Plain, the dyke-barrier system for managing oriental voles at Dongting Lake and habitat modification for managing rats in the Pearl River Delta. These advances depend heavily on understanding the behaviour of the target species, in particular how they respond to and use their environment. Therefore, ecologically-based rodent management must focus on detailed research of the biology, ecology and behaviour of the target species as well as the surrounding environment, instead of looking for a popular generic recipe applicable for managing all rodent pest species.

Despite this promising progress, rodent control in China still faces many problems. One problem is that the role of government in rodent control has been recently reduced under the new policy of relieving the economic burden on farmers. China used to manage rodent problems in farmland by launching state-level or provincial-level rodent control campaigns, with strict coordination of rodenticide use, baiting methods and public education. Farmers paid part of the cost for rodent control on their own land under the campaigns organised by government. Without the coordination by government, rodent control by farmers is conducted sporadically and not concurrently. As indicated in this chapter, chemical control with a kill rate of less than 90% or with a higher kill rate but only in a small area is not effective. In some instances the problem worsens following application of chemical control. Therefore, government involvement —through training farmers and coordinating the timing of their control actions—needs to occur for there to be effective rodent control in agricultural systems.

A second problem is that farmers have strong reservations about the effectiveness of anticoagulants. Farmers seldom buy anticoagulants in markets because these chemicals kill rodents too slowly. The resistance of rodents to anticoagulants could be another reason for their poor acceptance. This would be likely if they have been used in the same region for many years. Although public education is necessary, it is also important to improve the present anticoagulants to give a shorter kill time, and make them more acceptable to farmers.

A third problem is that population recovery by rodents after chemical control is too fast to achieve sustainable control. Many studies have indicated that the response of rodent populations after chemical control is non-linear (Liang 1982; Liang et al. 1984; Zhang 1996; Huang and Feng 1998; Qi et al. 1998). Killing some individuals may reduce the population numbers initially, but the remaining animals have less competition for food and nesting sites, and less social stress. Therefore, the surviving animals have higher productivity and higher survival rates than untreated populations. Re-invasion is another factor resulting in populations returning quickly to pre-control densities. This is illustrated by the results of a field experiment on Mongolian gerbils (*Meriones unguiculatus*). When 88% of the population was removed, the body mass of pregnant females was reduced from 58 g to

35–50 g (Wang et al. 1998). Dong et al. (1991) reported that, comparing with an untreated area, the litter size and pregnancy rate of Brandt's vole (*Microtus brandti*) increased after 75–83% population was reduced by using warfarin in Inner Mongolia. This compensation in fecundity after chemical control resulted in the population returning quickly to its pre-poisoning density. In the Pearl River Delta, chemical control, even with >90% kill rate, only was effective for less than six months (Huang and Feng 1998). To overcome this problem of population compensation, it is important to follow up chemical control with other control methods such as ecological or physical control.

Fertility control, as a sustainable and environmentally benign control technique (see Chambers et al., Chapter 10), is a promising alternative control method. By using mathematical models, Zhang (1995, 1996) demonstrated that fertility control has an extra effect in keeping rodent populations at a lower level, mostly due to the mating interference by sterilised males or females (Figure 9). Mating interference is largest when there is a mating system involving one male with one female, or one male with multiple females. Other mating systems, such as polygamy, decrease the effect of mating interference. The greater the number of females per male, the lower the level of interference. Experimental studies are urgently needed to test this hypothesis.

Rodent control in China is now facing new challenges. The first challenge is the likely escalation of rodent problems in the coming century. For example, climate change, especially warmer winters and heavy droughts in North China, has been

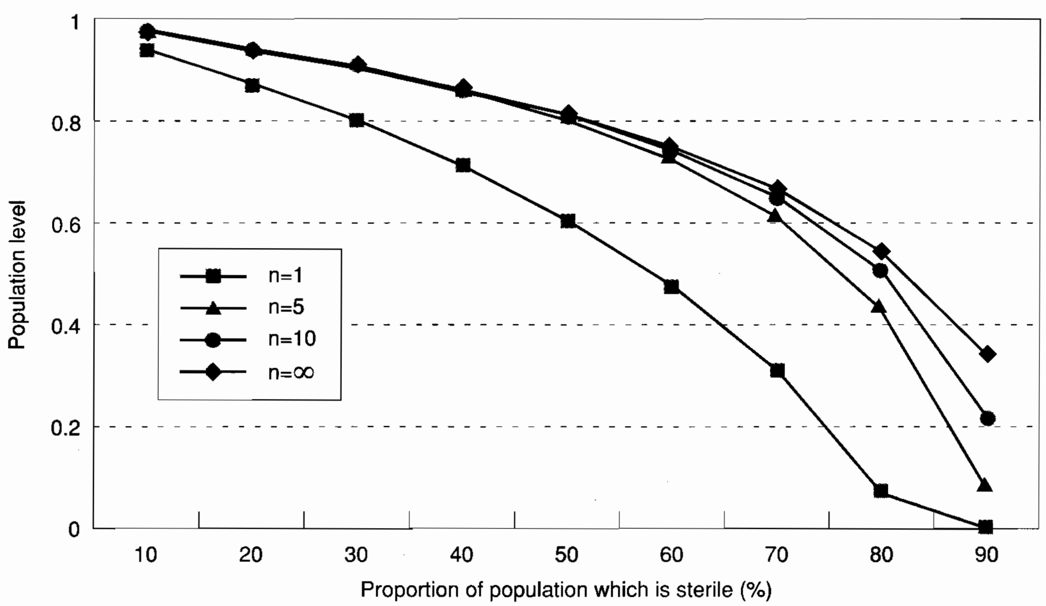

Figure 9.
The effect on the rodent population of mating interference caused by fertility control; *n* is the number of female partners per male (from Zhang 1995).

implicated in causing serious rodent problems. The second challenge comes from the changes in the agricultural system with new technologies being adopted for ploughing, planting and irrigation. Many studies have shown that traditional deep ploughing, canal irrigation, and plantations over a large area are important factors in limiting the carrying capacity of rodent populations (Zhao 1996; Zhang et al. 1997a). In Shanxi Province, it was estimated that 14.9 million Daure ground squirrels were killed from 1985–1987 following canal irrigation of 467,000 ha of arable land (Zhao 1996). In an experiment in Zhang Bei County of Hebei Province, the density of ground squirrels in an arable land area of 20 ha was reduced from 1.05 individuals/ha to 0.3 individual/ha, 10 days after irrigation. In another study, in June of 1964 in Inner Mongolia, the rodent density in ploughed wheat lands, wastelands and banks was 2, 84, and 312 individuals/ha, respectively, which indicated how ploughing affects the rodent population. Unfortunately, with the introduction of new agricultural technology like minimum tillage and drip irrigation or spray irrigation, as well as more diversified and patchy plantations, the negative effect on rodents of traditional agricultural systems is diminishing. The outbreaks of rat-like hamsters and community changes of rodent species in Shunyi District, Beijing, appear to be related to the adoption of these new farming systems. New efforts are needed to deal with these new challenges.

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

Naichang Fan, Wenyang Zhou, Wanhong Wei, Quanye Wang and Yongjin Jiang

Abstract

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

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

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

Keywords

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

INTRODUCTION

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

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

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

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