HOUSE MOUSE

House mouse (*Mus domesticus*) in Queensland

PEST STATUS REVIEW SERIES - LAND PROTECTION

by
J.A.Caughley

Queensland Government
Natural Resources and Mines

Acknowledgements

The author wishes to thank the many people who provided information for this assessment. In
particular the Bureau of Resouce Sciences, Grains Research and Development Corporation, Mary Bomford, Bob Parker, Ron Sinclair, John Griffths and Dana Kelly who supported or produced the B RS Managing Vertebrate Pests – Rodents publication from which much of this information is derived

Cover and contents design:
Grant Flockhart and Sonia Jordan

Photographic credits:
Natural Resources and Mines staff

ISBN 0 7242 7258 5
Published by the Department of Natural Resources and Mines, Qld.

Land Protection
Department of Natural Resources and Mines
Locked Bag 40, Coorparoo Delivery Centre, Q, 4151

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1.0 Summary

Mice cause serious damage to Queensland grain crops during mouse plagues. The problem is most severe on the Darling Downs where plagues are more frequent but major crop damage has also occurred in recent years in the Dawson and Callide catchments and around Goondiwindi. Mice are a problem in other crops as well, especially vegetable crops, and on pig and poultry farms within these regions.

Mice are also a serious nuisance in homes and buildings during a plague. They contaminate foodstuffs, destroy paper and cloth goods, and gnaw on electrical equipment and other possessions. Because they can transmit *Salmonella* (which causes food poisoning), they constitute a potential health hazard if they are in food preparation areas.

Control of mice is usually achieved by trapping and poisoning. Trapping is effective in buildings that can largely be made ‘mouse-proof’ by blocking all holes and placing sealing strips on doors. The few mice that enter are easily removed by trapping. Where buildings cannot be rodent-proofed (e.g. sheds), a number of rodenticides are available for use.

No rodenticide is currently registered for broadacre use, although zinc phosphide bait is presently under consideration by the National Registration Authority for Agricultural and Veterinary Chemicals (NRA). If it receives registration, strategic baiting will then be an option available to farmers. At present, their management options are restricted to habitat manipulation, except during major plagues, when the NRA provides temporary registration of a rodenticide for in-crop control.

Plagues vary in timing and location within a district according to the degree to which on-farm environmental factors are conducive to a build up in mouse numbers. For this reason each farmer needs to monitor mouse numbers on their farm at regular intervals so they can take appropriate management actions to control mice when their numbers are building up and thus restrict the amount of crop damage. Tracking mouse numbers through time can provide an advance warning of a plague.

Regular broadscale monitoring is undertaken on the Darling Downs each year (in June, September, October and November) by the Department of Natural Resources and Mines. A one per cent trap success or greater (that is, 9 or more mice caught in 940 traps) in spring is considered the commencement of the increase phase. Conversely, a plague is not expected if the September trap return is lower than one per cent.

Mice are not a declared pest under the *Rural Lands Protection Act 1985* so there is no legal requirement that they be controlled. The Queensland Department of Natural Resources and Mines’ policy on mice includes provision for the department to monitor rodent populations on the Central Darling Downs and provide short and long term predictions on the potential for plague development.

2.0 History

House mice (*Mus domesticus*) are introduced pests probably arriving in Australia at the time of European settlement (Singleton and Redhead 1989). They are now distributed throughout the continent and are ubiquitous in agricultural areas where they are usually found in areas of long grass (e.g. along fencelines), within crops and stubble, and around sheds and houses. At most times, their numbers are low but when seasonal conditions are favourable, their numbers can increase to such a level that they become a serious pest, causing damage to crops, stored products and equipment. These events are called mouse plagues.

The earliest reported plague of mice in Queensland was in 1917 on the Darling Downs. From then until 1980, plagues occurred on average once every 10 years, but since 1980 the incidence of plagues has increased (Singleton and Brown 1998). Between 1980 and 1995, a plague has occurred on the Darling Downs on average every three years. This increase in frequency of plagues has been attributed to the progressive adoption in recent years of conservation farming practices such as stubble retention that provides undisturbed habitat for mice for long periods of the year (Singleton and Brown 1998).

The trigger for a mouse plague is considered to be above-average autumn rainfall—particularly if the rain follows one or two years of drought. Saunders and Giles (1977) suggested that this relationship arises because populations of mice and their natural predators, pathogens and parasites decline during a drought, and then when conditions again become favourable, mouse populations reach plague proportions before these normal agents of mortality are re-established. However Redhead *et al.* (1985) proposed that drought-breaking rain, rather than drought *per se,* was the important factor, as it ensured a good growth of grasses in the following spring when the breeding season of mice begins. If conditions continue to be favourable, breeding continues through summer and, by autumn, mice can be in plague proportions (Redhead and Singleton 1988; Singleton 1989).

3.0 Current and Predicted Distribution

Although mice are found throughout Queensland, plagues of mice occur primarily in the grain-growing areas (Fig. 1). It appears from a questionnaire sent to members of the Queensland Grain Growers Association in 1997 that the frequency of plagues varies between grain-growing areas. For example, the questionnaire returns indicated that four plagues had occurred on the Darling Downs between 1992 and 1997. In contrast only one plague occurred in Goondiwindi and South West Queensland (in 1995), and one in the Dawson and Callide Valley regions (in 1997). Very few problems were experienced with mice in the Lockyer, Burnett and Emerald regions over the five years.

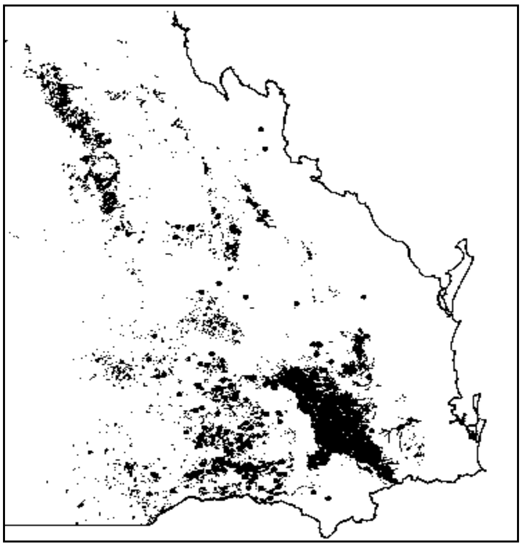

Figure 1. Map of grain-growing areas in Queensland The extent and frequency of plagues also varied between farms within each region. Although the Darling Downs had experienced four plagues between 1992 and 1997, the majority of farmers experienced only one plague within this time interval (Table 1).

Table 1. Number of plagues experienced between 1992 and 1997 by Darling Downs respondents (*n*=204) to a questionnaire (from Donkin and Caughley 1998).

No. of plagues experienced	% of respondents
0	22
1	53
2	23
3	2

These results show how spatially and temporally variable plagues can be. A farmer will experience a mouse plague according to the degree to which on-farm environmental factors are conducive to a build up in mouse numbers. For this reason farmers need to monitor mouse numbers on their farms at regular intervals to detect the onset of a plague. They will then be able to take appropriate management actions to control mice at that time and thus restrict the amount of crop damage.

Regular broadscale monitoring can track mouse numbers through time to provide an advance warning of a plague. Such monitoring is undertaken by the Department of

Natural Resources and Mines on the Darling Downs and the data collected are entered into a model that predicts the probability of a plague at least six months in advance.

3.1 Monitoring Methods

3.1.1 Trap Lines

The monitoring on the central Darling Downs by the Department of Natural Resources and Mines is undertaken each year in June, September, October and November. Forty-seven trap lines with 20 break-back traps in each (total of 940 traps) are set for one night. The number of mice caught is entered into a model developed by the Queensland University of Technology that predicts the probability of plague the following autumn. For example, a one per cent trap success or greater (that is, 9 or more mice caught in 940 traps) in September is considered the commencement of an increase phase that will lead to a plague the following autumn. Conversely, a plague is not expected if the September trap return is lower than one per cent.

Lines of break-back traps in different habitats could also be used by farmers for on-farm monitoring. The method gives a good indication of abundance and provides a cheap, simple and effective means of keeping track of mouse numbers over time.

3.1.2 Bait Cards

Bait cards have been introduced recently as a technique for estimating the likely effectiveness of crop baiting. Bait cards are 10cm x 10cm square pieces of white paper that are soaked in canola oil and pegged out overnight in a crop or other habitat. To obtain a reasonable estimate, at least five cards should be placed 5-10 metres apart at each site.

The bait card technique is a less reliable indicator of mouse numbers. The amount of a card eaten is largely a reflection of the numbers of mice and the availability of food for the mice rather than the numbers of mice present *per se*. When food is plentiful, the cards may be largely untouched even when mouse numbers are high. However, if bait card take is greater than 10%, it indicates (i) that mouse numbers are high and (ii) the mice will readily take the bait and cost-effective control will be achieved.

3.1.3 Visible Sightings

There are a number of visual sighting techniques available to farmers. The presence of burrows or of worn paths between cracks on the cracking clay soils of the Darling Downs are good indicators that mice are present. The number of burrow entrances counted per unit area in crops, contour banks and along grass verges and fencelines gives an indication of mouse activity. Freshly dug soil at the entrance to a burrow indicates that the burrow is active.

Counting numbers of mice seen on a road regularly travelled at night can provide an indicator of mouse abundance. Another visual method can be the number of mice seen in a one minute period after switching on a light in a shed.

3.1.4 Rate of Bait Removal

The rate of removal of baits placed in sheds and around grain stores is a good indicator of whether mouse numbers are increasing or decreasing.

3.1.5 Crop Damage

Crop damage from mice is not a good indicator of mouse numbers as it is often unnoticed until it is severe. Signs of high mouse activity include chewed stems or damage to seed heads. Debris such as seed husks at the base of plants suggests the damage to seed heads has been caused by mice rather than insects or birds.

4.0 Estimates of Current and Potential Impact

The impact of mice on various primary industries and on rural communities has been quantified for other states. Few hard data exist for the Queensland situation but some of the data from other states can be used to gain an appreciation of the scale of the impact mice have on all of these areas.

4.1 Impact on Primary Production

Mice can have a serious economic impact on a range of farming enterprises. The principal enterprise affected is grain growing, but vegetable growers, orchardists, graziers and intensive livestock producers can also suffer significant losses during a plague. In addition to production losses, farmers incur damage to machinery and vehicles, insulation in ceilings and walls of buildings, electrical equipment and fittings, and to household items and personal possessions.

The impact varies considerably between enterprises and between years. In most years mouse numbers are low and the damage they cause is unnoticeable, but when their numbers irrupt to plague densities in grain-growing areas, the damage on farms in the affected areas and in adjacent rural townships is measured in millions of dollars (Caughley *et al.* 1994).

4.1.1 Impact on grain growers

Mice can damage grain crops at all stages of growth (Redhead and Singleton 1988). Generally, plagues irrupt in autumn at the end of a protracted breeding season and thus in Queensland the potential for damage is greatest to maturing summer crops. Mouse numbers usually decline over winter but the timing of the decline varies. If survival is high early in winter, mice can also cause severe damage to winter crops through attacking the embryonic seed heads within the tillers.

Following the 1997 Central Queensland mouse plague and baiting program a questionnaire was sent to graingrowers involved in the baiting program Caughley *et al* (1998b). For the landholders who responded, the winter crop losses prior to baiting were between 0-$100,000+; they estimated that baiting prevented further crop losses of between $1,000-$100,000+. If the estimates of the landholders who responded were typical for all landholders who baited, the total crop losses prior to baiting would have been in the order of $2.8 million, and baiting would have prevented a further $4.8 million of damage.[1] The average cost of baiting per landholder was $2,800, which provides an average cost benefit ratio of 12:1 (range 2:1 to 48:1).

In 1995, a major mouse plague was experienced on the Darling Downs and around Goondiwindi. As in 1997, a questionnaire was sent to farmers at the end of the plague. From the responses, the estimated damage to crops prior to the baiting campaign (in this case the poison used was strychnine) was in the order of $18 million; the damage prevented was estimated to be in the order of $45 million (Miller 1996). The average loss per respondent was $27,000 (range $0–$400,000), and the damage prevented $65,000 (range $0–$1,125,000). The average cost of baiting to the farmer was $1,750. No estimates of other on-farm losses and costs were made in either 1995 or 1997.

[1] The total figures are estimates for all landholders who baited, and do not include other landholders who may have suffered damage but did not bait.

The economic impact of a plague in Victoria in 1993 was evaluated by Caughley *et al.* (1994) from data gathered from 257 farmers who responded to a phone-in. In this plague, the average crop loss of the respondents was $51,100 (Table 2). Other economic losses were experienced from damage to machinery, stores, and household goods but these were small by comparison with the loss in crop production (Table 2).

Table 2. Average amount lost per grain-grower, based on information provided by those who responded to the phone-in during the 1993 mouse plague in Victoria (from Caughley *et al.* 1994).

Estimated losses in crop production	$51,000
Resowing costs	$ 2,900
Baiting costs	$ 760
Damage to sheds, machinery, household goods	$ 1,360
Total	**$56,120**

The total loss reported by the respondents was $14.4 million. The response came from 7% of the farmers in the affected shires in Victoria, but how many more farmers experienced damage in the region is unknown. In South Australia, damage from mice was also widespread in 1993. The Department of Primary Industries, South Australia estimated the losses to grain-growers in that State was in the vicinity of $46 million (Caughley *et al.* 1994).

Various estimates of crop losses have been made in other plagues. Saunders (1987) reported that a plague in 1969–70 cost grain growers in southern New South Wales, Victoria and South Australia in the order of $14 million (NPV $117 million). In 1979–80, losses in Victoria were in the order of $15–20 million (NPV $46–61 million) (Redhead 1988). In 1984, surveys conducted by Government agencies in South Australia, Victoria and New South Wales placed losses in excess of $13 million (NPV $22 million).

Damage is recorded in localised areas in years between major plagues. For example, a plague in the Murrumbidgee Irrigation Area in 1994 caused an estimated $8 million of damage (Croft and Caughley 1995). Over the past 30 years, the average *annual* impact of mice on the Australian grain-growing industry was conservatively placed at $8 million by Caughley *et al*. (1994). Not surprisingly, the increasing incidence of mouse plagues (Singleton and Brown 1998) is deemed a matter of considerable concern both in Queensland and nationally.

4.1.2 Impact on sheep and cattle graziers

No value has been placed on losses experienced by graziers during mouse plagues. In Victoria in 1993, farmers reported severe depletion of medic pastures and a resultant loss in stock condition, especially in ewes and lambs (Caughley *et al.* 1994). Other losses experienced by graziers were damage to stored hay and wool bales. As with all other farmers in affected regions, graziers would have also suffered losses from damage to sheds, equipment and household goods, to which needs to be added the cost of bait to control the numbers of mice.

4.1.3 Impact on horticulturalists

Mice cause damage to a range of horticultural crops during plagues. Vegetable growers report losses in broccoli, tomatoes, capsicum, chilli, garlic, pumpkins and melons. Grapes, apples and other soft fruit are also damaged and serious losses can occur in almond and pistachio orchards. In the 1984 plague, losses to vegetable growers were placed at $100,000 (NPV $162,000) in Victoria (Redhead 1988). No estimates are available for other areas or plagues but losses are likely to be significant.

4.1.4 Impact on intensive livestock producers

Pig and poultry farmers in plague-affected areas can sustain major losses in livestock production, arising from stress (pigs in particular are highly stress-labile) and from direct physical attacks by mice upon the animals themselves (Table 3). Feed costs also increase. During the 1993 plague in Victoria, producers reported feed costs rose by up to 50%. Mice also block feed lines, gnaw on electrical wiring in air conditioners and waste disposal units, and cause damage to sheds (particularly the insulation in the walls). The losses experienced by intensive livestock producers during the 1993 plague were in the order of $530,000 in the worst affected area in north-western Victoria (Caughley *et al.* 1994).

Table 3. Losses experienced by pig and poultry producers in Victoria during the 1993 plague (from Caughley *et al.* 1994).

Pigs		Poultry	
Sows		**Layers**	
Conception rate		Weight	Down 30-50%
Litter size	Down 20-50%	Mortality	Up 15%
Litter mortality	Down 20-30%		
Baconers	Up	**Eggs**	
Growth rate		Number	Down 20%
Mortality	Down 20%	Size and quality	Down
Carcase quality	Up		
	Down 10%		

4.1.5 Off-farm impact

During plagues, mice often cause damage in rural townships. The types of off-farm impacts on rural businesses include:

- Damage to plant and equipment (particularly electrical appliances);
- Spoiling and consumption of perishables intended for sale;
- Lost business opportunity from not stocking, and therefore not selling, products considered at risk (e.g. packet foods); and
- Cost of redirected time and effort spent trapping and cleaning to protect goods and maintain health and hygiene standards.

Businesses where there are few food resources for mice (e.g. banks, machinery sales or fuel distributors) are not affected to the same extent as those that stock perishable goods. However, in all businesses, electrical and electronic equipment is at risk.

Only one detailed assessment of the off-farm economic cost of a mouse plague to townspeople has been conducted. During the 1993 plague, rural townspeople were interviewed across a broad spectrum of retail businesses and community services in South Australia[2] (Caughley *et al.* 1994). Everyone interviewed indicated that their most significant cost was the time required to mouse-proof, bait, trap, clean, and search for and dispose of carcasses; in many instances, these costs were incurred every day for the duration of the plague (in this case, for four months). For the purposes of their assessment, Caughley *et al.* (1994) costed all such time at $10 per hour.

Apart from time, the losses incurred were principally from damage to goods and electrical equipment. Three factors determined the extent of damage experienced: type of business, its location and type of construction. Retail outlets with large quantities of feed or foodstuffs, such as rural suppliers, grocers, supermarkets and bakeries, suffered more than other businesses. Secondly, those situated on the edges of town had more problems than similar businesses located centrally. Thirdly, the age and construction of the business premises determined how easy it was to exclude mice. Rural suppliers recorded the highest losses (Table 4). Their businesses were usually located on the edges of towns, their stock included large amounts of produce palatable to mice (e.g. grain and seed supplies, organic fertilisers and pet foods), and their premises were often open sheds that were impossible to mouse-proof. Food retailers, hotels and motels also experienced high costs. Goods and equipment were damaged and high labour costs were incurred in cleaning premises to the standard required by council health regulations. Schools and hospitals incurred similar costs in maintaining standards of hygiene.

Table 4. Average costs to retailers, community services and residents interviewed in plague-affected regions of South Australia, 1993, and some extrapolated estimates for the region (data from Caughley *et al.* 1994).

Service or business	No. sampled	Average cost	No. in plague area	Estimated total (South Aust.)
Retailers				
Rural suppliers	9	$7,451	45	$335,295
Food retailers	33	$2,304	100	$230,400
Hotels and motels	13	$2,496	82	$204,672
Other (e.g. finance)	72	$ 778		
Community services				
Schools	9	$2,734	24	$65,616
Hospitals	7	$2,107	36	$75,852
Councils, postal and emergency services	14	$ 814		
Households*	48	$ 280		

* Household costs do not include a costed labour component.

Telephone communications can be vulnerable to damage during mouse plagues. Not surprisingly, automatic exchanges in plague-prone areas are constructed to be mouse-proof and they are regularly checked by technicians who lay rodenticide baits as an extra precaution. Despite this state of preparedness, mice gained access to

[2]Note: the estimates were of costs incurred up to the time of the survey. No flow-on costs beyond the duration of the plague nor costs incurred prior to the plague (for example, construction costs in making buildings mouse-proof) were included. Some of the costs identified by a business or individual would have come from the sale of goods or services by another, but no method was available to balance the ledger.

one exchange in South Australia during the 1993 plague. It cost $30,000 to replace the damaged equipment; after parts were replaced, mouse-proofing the building cost a further $600.

Another enterprise that is highly vulnerable during mouse plagues is grain handling. Losses to grain stored in vertical silos are small since the structures are essentially mouse-proof. However, some grain is still stored in horizontal sheds on the Eyre Peninsula in South Australia and during the 1993 plague, mice caused considerable, though uncosted, losses in these sheds. In Victoria, in addition to silos, grain is stored in horizontal sheds and covered bunkers. With the onset of the plague in 1993, the Victorian grain-handling authorities instituted specific measures to limit losses; these included increased vigilance (bunker covers were checked weekly for holes or other signs of mouse infestation); the removal of grain from districts where the plague was severe; and the increased use of rodenticides around horizontal storage sheds. Between April and October, $12,000 was spent on bait. South Australian grain handling authorities spent $25,000 on bait over the same period. No estimates of losses to stored grain have been made in Queensland where grain is stored in similar ways to other states.

Many other off-farm costs of mouse plagues are intangible. For example, redirection of State Government staff to managing mouse plagues is usually uncosted. The one exception is for the 1995 plague on the Darling Downs where Fisher (1996) estimated that the cost to Queensland Government Departments of the strychnine baiting campaign was $311,000.

4.2 Impact on the Environment

The impact of mice on the environment has not been researched. Potential impacts could be:

- Competition with native fauna for food resources;
- Depletion of seed banks in pastures and native vegetation;
- Increased risk of soil erosion through the consequent reduction of ground cover;
- Increased predator pressure on native species at the end of a plague if predator numbers have increased in response to availability of mice during the plague; and
- Transmission of disease to other fauna.

Another important potential environmental impact is non-target mortalities arising from poisons used to control mice. Several rodenticides may legally be used around sheds and buildings, the most commonly used products being the anticoagulants brodifacoum (Talon™) and bromadiolone (Bromakil™). These baits take several days to kill and, as a consequence, can indirectly kill predators that feed on mice that have consumed poisoned bait. Carcasses of Australian kestrels (*Falco cenchroides*) are not infrequently seen around grain handling facilities.

Non-target mortality also occurs during broadacre baiting campaigns. Monitoring during the strychnine baiting campaign in Queensland in 1995 found approximately 120 birds that were considered to have died from strychnine poisoning (Lundie-Jenkins and Brown, 1996). After the same baiting campaign, landholders reported over 300 bird carcasses of a variety of species found after the baiting campaign, but the cause of death could not be confidently attributed to the strychnine baiting (Miller 1996). Strychnine was detected in carcasses of the following species: apostle bird, cockatiel, crested pigeon, feral pigeon, galah, sulphur crested cockatoo, Australian kestrel, black-shouldered kite, letter-wing kite, crow, emu, magpie and magpie lark. The greatest proportion of the bird deaths came from a single site where the bait had been distributed 10 m beyond a fenceline into bordering woodland. By comparison, the effect of the baiting campaign on populations of non-target species had been minimal when bait had been distributed according to the established protocols.

Monitoring during the strychnine baiting campaign in 1993 in South Australia found 665 birds believed to have been killed by strychnine (Bird 1995). Most were granivores (67% of species and 98% of individuals found) and the commonest species killed were crested pigeons and feral pigeons.

In contrast, non-target mortalities recorded during the zinc phosphide baiting campaign in Central Queensland in 1997 were very few (Caughley *et al*.1998). The only species whose carcasses were found and tested positive for phosphine were Torresian crow (*n=4*) and Australian magpie (*n=1*). Similar low non-target mortality has been reported with zinc phosphide baits in the United States (Ramey and Sterner 1995; Parker and Hannan-Jones 1996). However, native rodents may have been poisoned if they were present in the areas baited. None were found dead during monitoring but they are known to occur at very low densities in crops and grassy habitats in Central Queensland.

The environmental fate of poisons not consumed has received some attention. Strychnine is gradually adsorbed onto soil particles where, in soils with high clay content, it breaks down within 45 days (Kookana *et al.* 1997). No evidence of crop uptake or of movement into water bodies has been recorded. Studies in the United States have also shown that zinc phosphide breaks down rapidly and its use does not lead to contamination of soils or water bodies (Parker and Hannan-Jones 1996).

5.0 Biology and Ecology

Three salient aspects of the biology of mice explain their pest status. The first is their diet, the second their propensity for gnawing, and the third is their reproductive capacity.

5.1 Diet

Mice are highly opportunistic feeders. They predominantly feed on grass seeds but also eat invertebrates and other plant material. They are cannibalistic during plagues.

In the laboratory, a mouse consumes 3–4 grams of food per day. Saunders (1987) calculated that during a plague in a sunflower crop mice were eating around 12 kg of sunflower seeds per hectare per day. If numbers remained high up to harvest, more than half a tonne would have been consumed per hectare, reducing the yield by some 29%. However, mice often eat only part of a seed so calculations such as these can underestimate the true level of damage.

5.2 Gnawing behaviour

The upper and lower incisors of all rodents grow continuously and are constantly ground down by grinding or by gnawing. Mice frequently gnaw on any hard surface. They are notorious for the damage they cause by gnawing on plastic. Telephone cables and electrical wiring are particularly susceptible. In addition to the direct damage, the gnawing on wiring can cause fires, set off alarms and disrupt telecommunications.

5.3 Reproductive Capacity and Population Dynamics

Mice living in buildings may breed throughout the year but in the field breeding is mostly in spring and early summer. The start of breeding is usually triggered by the increase in seed and insect availability in spring (Bomford 1987; Tann *et al.* 1991). The proportion of females breeding at any time is a function of the quality of the food as well as the quantity (Bomford and Redhead 1987), both of which are largely determined by rainfall. If the summer is hot and dry, reproduction ceases, but if conditions are favourable, mice will continue to breed through into autumn.

Mice are highly fecund (Table 5). The young grow rapidly and reach sexual maturity early. They are also good dispersers and quickly colonise new areas when conditions are favourable. Conversely, mortality is often high and the life span short.

Table 5. Reproductive potential of the house mouse (*Mus domesticus*) (from Caughley *et al*. 1998b).

Breeding season	From spring to autumn, depending on seasonal conditions (can breed throughout the year)
Mean litter size	6 (range 1-10; nipples 10)
Post partum oestrus	Yes
Gestation	19-20 days (although delayed implantation of up to two weeks has been reported)
Weaned at	18-21 days
Age at 1st breeding	5 weeks

Female mice can produce a litter each month during the breeding season. If the breeding season extends well into summer and the number of females participating remains high, then the doubling time for a population can be as short as three to four weeks and a plague may develop. In Fig. 2, the solid line shows the growth of a mouse population leading to a plague. Plotted on the same graph is population growth (the dotted line) that does not result in a plague. The principal differences between the two curves are: (i) starting density (i.e. number of mice at the start of the breeding season and (ii) the length of the breeding season. Quite small differences in population dynamics can produce large differences in abundance.

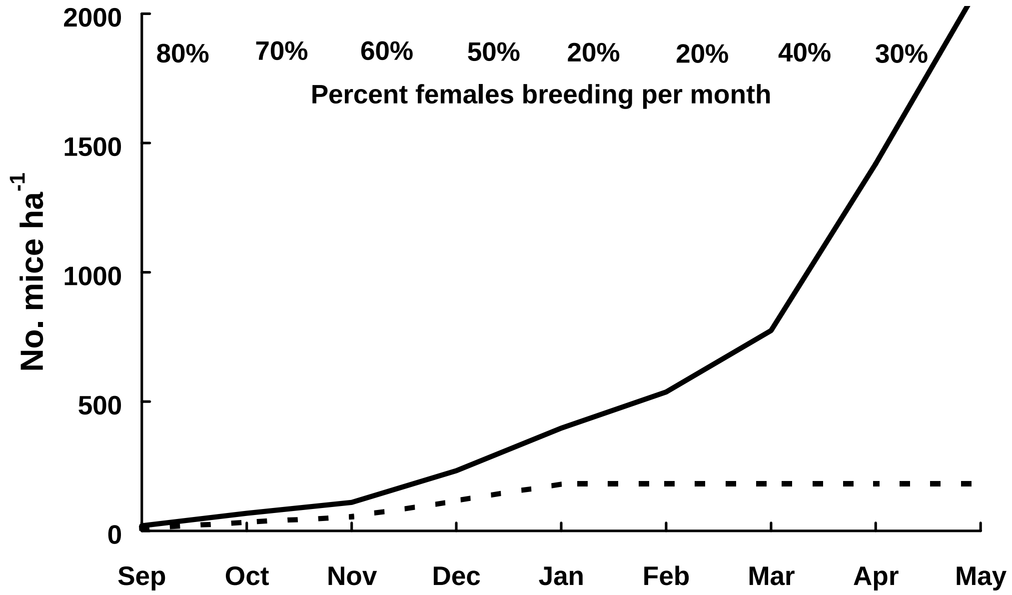

Figure 2. **Mouse Population Trends** The solid line represents the growth of a hypothetical mouse population where the starting density is 20 mice per hectare and breeding extends over eight months of the year, the proportion of females breeding each month between September and April as shown. The dotted line presents for comparison the trend in numbers of a population where the starting density is 10 mice per hectare, the breeding season is only four months long (September to December), and 80%, 70%, 60% and 40% of females participate in breeding in each of these months respectively.
Note: In both curves, litter size is set at six young per female, the sex ratio at birth at 1:1 and the age at first breeding in females at 2 months. No mortality is factored in.

This graph clearly indicates the potential for mouse populations to increase from very low numbers to large numbers in a relatively short period ie 8-9 months. The graph also shows (dotted line) that if only half the original population is present and if the breeding season is reduced then the population will not increase as dramatically.

5.4 Other Behavioural Characteristics

Mice are primarily nocturnal although they are often seen during the day when numbers are high. Mostly they spend the day in nests they have created in natural cavities or in shallow burrows e.g. in cracked soils. They tend to live in small colonies that are probably groups of related individuals. Burrows used by each group are clumped and distinct runways may be visible between their entrances. When populations are high, these runways become more obvious from their frequent use.

5.4.1 Feeding behaviour

Laboratory studies show that mice may feed from up to 20-30 different sites each night, eating only a little at each location. Consequently, the optimal baiting strategy recommended for mice is to offer a small amount of bait at a large number of sites (MacDonald and Fenn 1994).

5.4.2 Sensory capabilities

Mice have poor sight but very acute senses of smell, hearing, touch and taste. Odours are produced by specific glands and are present in urine and faeces (MacDonald and Fenn 1994). All mice mark extensively with urine, creating a network of odours on every object in their environment. They recognise other members of the group and negotiate in total darkness by these odours.

Because mice have an acute sense of smell, a number of chemical repellents have been tested as a means for excluding mice. None of the repellents has been successful for more than a short time (Smith 1994). Ultrasonic devices similarly repel for little more than a day or two (Kaukeinen 1994).

6.0 Efficacy of Current Control Methods

Management of mouse plagues at the farm level has largely been directed towards reducing mouse numbers after farmers notice damage to their crops. The reduction is usually attempted by the use of poisons.

6.1 Poisoning

6.1.1 In crops

In the past, a multitude of chemicals has been used in and around the perimeter of crops during mouse plagues. For example, during the 1970 plague in New South Wales, the chemicals[3] used included strychnine, arsenic, phosphorus, 1080, the organochlorines DDT, Dieldrin and Endrin, the organophosphates Parathion, Phosdrin and Lucijet, the fungicide Thiram and the anticoagulants Ratsak and Racumin (Ryan and Jones 1972).

Because of its effectiveness, strychnine has been the most widely used chemical but its availability has been progressively restricted since the 1980's because of its toxicity. Nonetheless, during the 1993–94 plague, it was given temporary registration by the National Registration Authority for Agricultural and Veterinary Chemicals (NRA) for broadacre distribution in South Australia and Victoria, and again during the mouse plague in southern Queensland and northern New South Wales in 1995.

However, the use of strychnine as an in-crop rodenticide was finally banned in 1997, not because of its dangers but because of Australia's need to meet international residue standards for exported products. No maximum permissible residue level (MRL) has been assigned for strychnine by the International Codex Committees on Pesticide Residues and Residues of Veterinary Drugs in Food. When no MRL is assigned, it is by default set at zero. It is impossible to prove zero residues because all assay techniques have a lower limit of detection.

Consequently, when mouse plagues irrupted in several areas of Australia in 1997, temporary registration was given by NRA to a bait formulation containing zinc phosphide. Zinc phosphide baits are widely used overseas as in-crop rodenticides and an MRL exists for the bait's breakdown product, phosphine. Good results were achieved with the bait, and the Victorian manufacturing company has applied to the NRA for registration of its product. In the interim, a minor off label permit has been issued by the NRA to allow use of the bait where and when necessary, which is valid until 30 June 1999.

Value of baiting during mouse plagues

Several studies have attempted to estimate the cost/benefits of baiting mice in crops. The first study was during a plague in the Murrumbidgee Irrigation Area in 1979–80 when Saunders (1986) baited a sunflower crop with strychnine and achieved a 90% reduction in mouse numbers. He calculated that, had the mice not been killed, they would have eaten 3.4g per mouse per day over the seven weeks remaining to harvest, equivalent to 29% of the yield. The cost of baiting (excluding labour) was \$8/ha; the value of the crop was \$640/ha. Baiting may thus have prevented a loss of \$130/ha, giving a benefit/cost ratio of 16:1. The calculation presumes neither re-

[3] Most of these chemicals are now banned or are not registered for use on rodents.

invasion of the baited crop by mice from unbaited areas nearby, nor the possibility of a natural decline in mouse numbers over the time between baiting and harvest.

A study by Singleton *et al.* (1991) evaluated the cost/benefit of baiting with bromadiolone in summer soybean crops in the Namoi Valley using responses to a questionnaire sent to farmers. At baiting costs[4] of $45/ha and a crop value $400/ha, they estimated that the break-even point would have been when crop damage was around 11%. The extent of crop damage varied considerably between farms and between areas but on average, the damage exceeded 11%. Therefore, for more than half the respondents, the benefit of baiting would have exceeded the cost.

Mutze (1993) conducted an economic assessment of strychnine baiting in a wheat crop at the time of flowering in 1987. The baiting reduced mouse numbers by 46%. Although by the time of harvest two months later, densities were similar to pre-baiting levels, Mutze found baiting had reduced the level of damage to the grain heads by 81%. Mouse numbers were only around 50 per ha at the time of the study so the actual tonnage lost was small, approximating a 2% reduction in yield. Mutze concluded that even at those relatively low densities the cost of baiting was close to the gain in yield.

No studies have been conducted on the effectiveness of perimeter baiting but Kay *et al.* (1994a) evaluated the effect of baiting refuge habitats around irrigated soybeans with bromadiolone. They found that baiting significantly reduced the number of mice inhabiting the refuge habitat and reduced the rate at which mice invaded and colonised the adjacent crops. No significant reductions in crop damage were detected because mouse numbers overall were low.

6.1.2 Around buildings

Poisons are also widely used to control mice around buildings. Several rodenticides are registered for use in and around buildings (see Appendix B).

6.2 Trapping

Break-back traps are commonly used around houses and sheds. Trapping is preferable to baiting in these areas since:

- There is no danger of accidental poisoning of children and pets; and
- Mice do not die (and smell) in wall cavities and other inaccessible nooks and crannies.

During plagues, farmers also often use water traps where a greased bottle with a food attractant in the neck is balanced over a bucket of water. Mice fall into the water when trying to reach the food. There are numerous variations on trap designs used by farmers. If a record of the number of mice caught is kept, all of these trapping methods can provide an index of mouse numbers and allow a farmer to judge the size of the mouse problem at any given time.

Trapping is also used for monitoring mouse numbers over time in fields. For example, multiple catch traps are used in broccoli crops by the landholder on ‘Wando’ on the Darling Downs, and break-back traps are used by the Queensland

[4] Comprising cost of bait and grain ($4.20); cost of bait stations ($20) (which could be re-used) and cost of labour ($21) (1989$ values) (Singleton *et al.* 1991).

Department of Natural Resources and Mines personnel to follow trends in mouse numbers over transects in grain-growing areas.

6.3 Exclusion

Exclusion is a highly successful way of reducing the damage caused by mice in buildings. Houses and storages are made rodent-proof by sealing all holes, keeping doors closed, fitting traps to drains, screening all vents, etc. Barrier fencing in doorways is successfully used to exclude mice in some businesses in Queensland (e.g. seed merchants, peanut processors). Two major types of barriers are used: electric pads and counter-levered fences made of steel that allow access of machinery but prevent the entry of mice.

6.4 Habitat Modification

Undisturbed areas such as roadside verges and fencelines can act as refuge habitat for mice (Mutze 1991; Chambers *et al.* 1996). Other refuge habitats are areas where weeds or rubbish is allowed to accumulate (Singleton 1989). Reducing mice by habitat modification involves removing weeds and debris around crops, buildings and storages and controlling growth of grasses and weeds along fencelines and roads by ploughing, burning, grazing or applying herbicides. These methods are used variously by farmers throughout plague-prone areas. Other forms of habitat modification widely used are slashing and working stubble. Some of these methods may however conflict with soil conservation principles and practices, and so need to be carefully considered as part of a holistic approach to on-farm management.

6.5 Other Control Measures

6.5.1 Use of raptor perches

An option that has been researched both in Australia and overseas is the placement of raptor perches in or at the margins of crops to increase the level of predation (Howard *et al*. 1985; Kay *et al*. 1994b). While it is recognised that birds of prey cannot eat enough mice to prevent a plague (Sinclair *et al*. 1990), they can slow the rate of plague formation by several weeks.

6.5.2 Chemical repellents

Because mice have an acute sense of smell, chemical repellents have been tested as a means of control. However, as noted earlier, research has shown that the repellent effect tends to be short-lived.

6.5.3 Ultrasonic devices

Similarly, studies have shown that ultrasonic devices are unsuccessful as a practical means of rodent control (Meehan 1984; Howard and Marsh 1985). Although the animals initially withdraw from a loud new ultrasonic noise, they start to ignore it within a few days. As Smith (1994) commented, 'behavioural modification is only effective if the animal can choose a more attractive alternative. If food or harbourage is short, or population density is high, methods that do not exclude absolutely may be overcome because the animal perceives that the alternatives are worse'.

6.5.4 Biological Control

The potential for a parasitic nematode, *Capillaria hepatica*, to control mouse populations was investigated in Australia by Singleton and his co-workers (Singleton and McCallum 1990). If mice infected with the parasite have less frequent litters, population growth rate would be slowed and plagues would be prevented. Field trials on the Darling Downs and in the Mallee in Victoria, however, failed to demonstrate any decline in breeding by mouse populations that were experimentally infected with *C. hepatica* (Singleton *et al*. 1995; Singleton and Chambers 1996) and the research has been discontinued.

Singleton and his co-workers at the Cooperative Research Centre for Biological Control have now directed their research towards immunocontraception using a mouse-specific virus[5] that is present in nearly all Australian mouse populations (Chambers *et al*. 1997). Laboratory trials to date have shown that the virus will carry foreign material and that the modified virus will replicate in mice. The next step in the research is to identify an appropriate fertility blocking protein to attach to the virus and to study the behaviour and epidemiology of this modified virus.

[5] Murine Cytomegalovirus (MCMV)

7.0 Human and Animal Welfare Considerations

7.1 Disease

Rodents are vectors of a number of diseases that affect humans and livestock. In Australia, most of these pathogens are absent or rare but there are a few that cause problems. Perhaps the commonest are *Salmonella* bacteria that can be spread by a range of animal species (including humans). The bacteria are usually transmitted to people through food contaminated with infected urine or droppings, and can cause acute gastroenteritis (Stevenson and Hughes 1988).

Another known pathogen in mice in Australia is *Streptobacillus moniliformis* that causes rat bite fever in people and other animals (Taylor *et al.* 1994). During plagues, mice are caught occasionally with polyarthritis or abscesses (‘lumpy tail’) that are caused by the pathogen. Although no transmission to humans from infected mice has been recorded, one person in Australia has died from the pathogen following a bite from a wild rat (Taylor *et al*. 1994).

The best means of limiting the risk to humans from these pathogens is to exclude mice from foodstuffs and to maintain high standards of cleanliness in food preparation and eating areas. Protection of feed storages and good shed hygiene are likewise important in intensive livestock operations.

For livestock, the most serious disease that mice may transmit is swine encephalo-myocarditis that led to substantial pig mortalities on some properties in New South Wales during the mouse plagues of 1970 and 1984 (Acland and Littlejohns 1975; Seaman *et al.* 1986). Intensive livestock farmers also reported an increase in the incidence of other infectious diseases during mouse plagues. Scouring is a frequent problem in pig herds during plagues with mice aiding the transfer of bacteria between pens. During the 1984 NSW and 1993 SA plagues, infection with *Erysipelas* was reported in some herds.

7.2 Other health risks

7.2.1 Risk of poisoning

During a mouse outbreak, people take risks with poisons, using them in ways that they would not normally countenance. No poisoning of humans has been attributed to rodent baits during mouse plagues in Australia but accidental poisoning of domestic pets occurs quite frequently. During the 1993 mouse plague in South Australia, one veterinarian treated 40 dogs that according to their owners had eaten rodent bait (Caughley *et al.* 1994).

As a part of any education program prior to mouse plagues, town residents must be alerted to the dangers to pets of accidental poisoning and offered advice on how to prepare baits in bait stations or to lay them in places inaccessible to dogs.

7.2.2 Risk of fire

Mice gnawing on electrical wiring can cause fires in homes and other buildings. For intensive livestock farmers, the risk is magnified if their sheds are lined with polyurtheane insulation since it gives off cyanide gases when it burns which is lethal to both livestock and firefighters.

7.3 Animal Welfare Issues

7.3.1 Impact of mice on livestock

During the 1993 SA plague, mice caused considerable damage to penned animals (Caughley *et al.* 1994). Poultry had their feet gnawed and, as a direct result of stress and stress-related injuries, the birds lost condition, egg production declined and mortality increased. In piggeries, breeding sows and piglets were the most seriously affected and badly gnawed animals had to be destroyed to end their suffering.

Destocking is one option available to intensive livestock producers during a mouse plague but the costs of destocking and restocking are high. Farmers usually choose to persist with baiting and the constant care of their animals.

7.3.2 Humane control of mice

With regard to mice, the primary animal welfare issue is that the control methods selected are those that cause the minimal pain, distress and discomfort to the animals being controlled. Measurements of the humaneness of rodenticides are largely subjective, but in animal welfare terms, a poison, which acts quickly to kill or leave an animal unconscious, is better than one that takes a considerable time to act.

8.0 Legislation and Policy

8.1 Legislative Status of Mice in Queensland

Mice are not a declared pest under the *Rural Lands Protection Act 1985* so there is no legal requirement that they be controlled. As the house mouse is not a native species there are no laws governing their control other than the *Animals Protection Act 1925* and *via* health regulations[6].

The use of chemical poisons is constrained by Government regulations in Queensland. A number of rodenticide poisons are registered (see Appendix B) and may be used in and around buildings, animals sheds and storage facilities. No rodenticide is registered for use in grain crops although temporary registration has been given for the broadacre distribution of strychnine and zinc phosphide during the 1995 and 1997 mouse plagues respectively.

8.2 Queensland Department of Natural Resources and Mines' Policy on Mice

The Queensland Department of Natural Resources and Mines' does not have any legislative responsibility to control or enforce the control of the house mouse but has assumed a coordination role for non-urban situations. The departments' exact role is outlined in the policy on rodents that states.

"The Department of Natural Resources and Mines will:

(a) Monitor rodent populations on the Central Darling Downs and provide short and long term predictions on the potential for plague development;
(b) Provide graingrowers with technical advice on available mouse control strategies;
(c) Undertake research to support the registration of a rodenticide suitable for incrop baiting of mice;
(d) Undertake research into integrated long term management strategies for the control of mice in farming areas;
(e) Accept responsibility for coordinating large scale emergency mouse control operations;
(f) Collaborate with industry (eg GrainGrowers Association), State Departments (Primary Industries, Environment and Health), interstate counterparts and research and development organisations, including CSIRO, as necessary to satisfy Queensland's requirements for mouse control consistent with national standards;
(g) Cooperate with industry and other organisations in the development of control options for other rodent species, subject to availability of funding.

The Department of Natural Resources and Mines will not:

(a) Declare any rodent species."

[6] An authorised health officer may give 'reasonable directions' to the owner or occupier of premises to destroy any rats and mice on those premises or to rectify conditions that are conducive to their breeding.

9.0 Recommended Management and Control Practices

The Queensland Department of Natural Resources and Mines and Mines advocates the following management and control practices.

9.1 Managing Mice around Buildings

Controlling mice in and around buildings is important for all people living in plague-prone areas. In homes, trapping is recommended, rather than the use of poisons, to avoid accidental poisoning of children or pets and to prevent the unpleasant smell of decaying mice if they die in wall cavities and inaccessible areas.

Good hygiene is very important. Because mice can carry a number of diseases, washing hands with soap and water after handling dead mice, and washing food preparation surfaces, plates, utensils, etc. before use, are strongly recommended.

If possible, houses should be made ‘mouse-proof’ by locating the routes mice are using to enter the house, blocking holes with steel wool, and placing sealing strips on doors. Foodstuffs and precious items should be stored in mouse-proof containers.

In sheds, a combination of trapping, baiting and storing goods in rodent-proof containers or on rodent-proof stands is recommended measures. Baits should be used according to directions on the manufacturer’s label. Bait blocks and pellets should be laid in bait stations to prevent mice from scattering the bait and to guard against the accidental poisoning of children and pets. The simplest design is a small plastic container with a lid, with small holes cut in the sides to give mice access to the bait.

Grassy areas around sheds and homes should be kept mown, building materials stored upright and piles of rubble or other material removed.

9.2 Managing Mice on Farms

A number of agronomic practices are available to broadacre farmers to limit the impact of mice. The best forms of defence are methods that reduce the amount of shelter and food available to mice. General farm hygiene is important - that is, cleaning up piles of rubbish and any spilt grain, and keeping grass down by slashing or spraying along roads and around verges, haystacks, etc. Minimising grain spill at harvest is also very important.

Slashing, working or burning stubble reduces both the availability of food and shelter for mice, but stubble retention is an important method for controlling soil erosion and retaining soil moisture. Controlling mice by stubble management needs to be balanced against the benefits of its retention. To optimise stubble management practices, farmers should assess the number of mice in the stubble and make their decision accordingly.

Monitoring

Regular monitoring of mouse numbers enables farmers to undertake management actions to control mice before they begin to damage crops. In order to prevent mouse damage to crops, the most important times to check mouse numbers are prior to flowering for each winter and summer crop, checking both within crops and within adjacent stubble on each occasion.

There are two principal means of monitoring. The first is break-back traps which can be set out overnight in crops, stubbles and other habitats in a line of 20 or so traps. These traps are a cheap, simple and effective means of keeping track of mouse numbers over time.

The second method is to use bait cards that are 10cm x 10cm square pieces of white paper that are soaked in canola oil and pegged out overnight in crops and in other habitats. The amount of card eaten serves as an index of mouse numbers. To obtain a reasonable estimate, at least five cards should be placed 5-10 metres apart in each habitat.

The bait card technique is a less reliable indicator of mouse numbers than break-back traps, since the amount of a card eaten is largely a reflection of the paucity of food available for the mice rather than the numbers of mice present. When food is plentiful, the cards may be relatively untouched even when mouse numbers are high. However, if bait card take is greater than 10%, it indicates (i) that mouse numbers are high and (ii) the mice will readily take the bait and cost-effective control will be achieved.

Baiting

At present, no rodenticide is registered for in-crop mouse control although an application for the registration of zinc phosphide bait is currently before the National Registration Authority for Agricultural and Veterinary Chemicals. If it receives approval, baiting crop and stubble areas will be an option available to farmers. Research has shown that the best results will be achieved by baiting when alternative food is scarce (for example, in crops before flowering commences and in stubble about one month after harvest). Recommended strategies for use of bait will be published by the Department when the product receives registration.

10. References

Acland, H.M. and Littlejohns, I.R. 1975. Encephalomyocarditis virus infection of pigs. I. An outbreak in New South Wales. *Australian Veterinary Journal* 51: 409–415.

Bird, P. 1995. Off-target mortalities due to strychnine baiting during the 1993 mouse plague in South Australia. *Proceedings of the 10th Australian Vertebrate Pest Control Conference*, pp. 188–191.

Bomford, M. 1987. Food and reproduction of wild house mice. I. Diet and breeding seasons in various habitats on irrigated cereal farms in New South Wales. *Australian Wildlife Research* 14: 183–196.

Bomford, M. and Redhead, T. 1987. A field experiment to examine the effects of food quality and population density on reproduction of wild house mice. *Oikos* 48: 304–311.

Caughley, J., Monamy, V. and Heiden, K. 1994. Impact of the 1993 mouse plague. *Occasional Paper Series No. 7*. Grains Research and Development Corporation, Canberra.

Caughley, J., Strong, K. and Donkin, C. 1998a. Managing mouse plagues in rural Australia. *Proceedings 18th Vertebrate Pest Conference*, 2–5 March 1998, Costa Mesa, California (in press).

Caughley, J., Strong, K. and Hinchcliffe, P. 1998b. Report on the Zinc Phosphide Baiting Program to Control Mice in Central Queensland in 1997. Queensland Department of Natural Resources and Mines, Brisbane.

Caughley, J., Bomford, M., Parker, R. , Sinclair, R., Griffiths, J. and Kelly, D. 1998b. *Managing Vertebrate Pests: Rodents*. Bureau of Resource Sciences and Grains Research and Development Corporation, Canberra.

Chambers, L.K., Singleton, G.R. and van Wensveen, M. 1996. Spatial heterogeneity in wild populations of house mice (*Mus domesticus*) on the Darling Downs, south-eastern Queensland. *Wildlife Research* 23: 23–38.

Chambers, L. K., Singleton, G. R., and Hood, G. M. 1997. Immunocontraception as a potential control method of wild rodent populations. *Belgian Journal of Zoology* 127 (Suppl. 1): 145–156.

Croft, D. and Caughley, J. 1995. A survey of the MIA mouse plague — at what cost? *Farmers' Newsletter* 145: 40–41.

Donkin, C., and Caughley, J. 1998. Are mouse plagues increasing in frequency in Queensland? *Proceedings of the 11th Australian Vertebrate Pest Conference*, Bunbury, May 1998.

Fisher. G. 1996. Resourcing the operation. Pp. 25–28 in: V. Eldershaw (ed.) *Report on Aerial Baiting with Strychnine during the 1995 Mouse Plague in the Dalby-Goondiwindi Area, Queensland*. Queensland Department of Natural Resources and Mines, Brisbane.

Howard, W.E. and Marsh, R.E. 1985. Ultrasonics and electromagnetic control of rodents. *Acta Zoologica Fennica* 173: 187–189.

Howard, W.E., Marsh, R.E. and Corbett, C.W. 1985. Raptor perches: their influence on crop protection. *Acta Zoologica Fennica* 173: 191–192.

Kaukeinen, D. 1994. Rodent control in practice: householders, pest control authorities and municipal authorities. Pp. 249–271 in: A.P. Buckle and R.H. Smith (eds) *Rodent Pests and their Control.* CAB International, Wallingford, Oxford.

Kay, B.J., Twigg, L.E. and Nicol, H.I. 1994a. The strategic use of rodenticides against house mice (*Mus domesticus*) prior to crop invasion. *Wildlife Research* 21: 11–19.

Kay, B.J., Twigg, L.E., Korn, T.J. and Nicol, H.I. 1994b. The use of artificial perches to increase predation on house mice (*Mus domesticus*) by raptors. *Wildlife Research* 21: 95–106.

Kookana, R.S., Rogers, S.L. and Oliver, D.P. 1997. Sorption and desorption behaviour of strychnine rodenticide in soils. *Australian Journal of Soil Research* 35:491–502.

Lundie-Jenkins, G. and Brown, P. 1996. Monitoring of non-target species. Pp. 160–164 in: V. Eldershaw (ed.) *Report on Aerial Baiting with Strychnine during the 1995 Mouse Plague in the Dalby-Goondiwindi Area, Queensland*. Queensland Department of Natural Resources and Mines, Brisbane.

Macdonald, D.W. and Fenn, M.G.P. 1994. The natural history of rodents: preadaptations to pestilence. Pp. 1–21 in: A.P. Buckle and R.H. Smith (eds) *Rodent Pests and their Control*. CAB International, Wallingford.

Meehan, A.P. 1984. *Rats and Mice: their Biology and Control*. Rentokil, East Grinstead, United Kingdom.

Miller, E. 1996. Landholder survey after mouse plague. Pp. 29–48 in: V. Eldershaw (ed.) *Report on Aerial Baiting with Strychnine during the 1995 Mouse Plague in the Dalby-Goondiwindi Area, Queensland*. Queensland Department of Natural Resources and Mines, Brisbane.

Mutze, G. 1991. Mouse plagues in South Australian cereal-growing areas. III. Changes in mouse abundance during plague and non-plague years, and the role of refugia. *Wildlife Research* 18: 593–604.

Mutze, G.J. 1993. Cost-effectiveness of poison bait trails for control of house mice in Mallee cereal crops. *Wildlife Research* 20: 445–456.

Parker, R. and Hannan-Jones, M. 1996. The Potential of Zinc Phosphide for Mouse Plague Control in Australia. Queensland Department of Natural Resources and Mines, Brisbane.

Ramey, C.A. and Sterner, R.T. 1995. Mortality of gallinaceous birds associated with 2% zinc phosphide baits for control of voles in alfalfa. *International Biodeterioration and Degradation* 1995: 51–64.

Redhead, T.D. 1988. Prevention of plagues of house mice in rural Australia. Pp. 191–205 in: I. Prakash (ed.) *Rodent Pest Management*. CRC Press, Baton Rouge.

Redhead, T. and Singleton, G. 1988. An examination of the PICA strategy for the prevention of losses caused by plagues of house mice *Mus domesticus* in rural Australia. Pp. 18–37 in: G.A. Norton and R.P. Pech (eds) *Vertebrate Pest Management in Australia: A Decision Analysis/Systems Analysis Approach*. Project Report No. 5, CSIRO Division of Wildlife and Ecology, Melbourne.

Redhead, T.D., Enright, N. and Newsome, A.E. 1985. Causes and predictions of outbreaks of *Mus musculus* in irrigated and non-irrigated cereal farms. *Acta Zoologica Fennica* 173: 123–127.

Ryan, G.E. and Jones, E.L. 1972. A report on the mouse plague in the Murrumbidgee and Coleambally Irrigation Areas, 1970. New South Wales Agriculture, Orange.

Saunders, G. 1986. Research into the ecology and control of the house mouse and other rodents. Agdex 672. Miscellaneous Bulletin 15. New South Wales Agriculture, Orange.

Saunders, G.R. and Giles, J.R. 1977. A relationship between plagues of the house mouse, *Mus musculus* (Rodentia: Muridae) and prolonged periods of dry weather in south-eastern Australia. *Australian Wildlife Research* 4: 241–247.

Seaman, J.T., Boulton, J.G. and Carrigan, M.J. 1986. Encephalomyocarditis virus disease of pigs associated with a plague of rodents. *Australian Veterinary Journal* 63: 292–294.

Sinclair, A.R.E., Olsen, P.D. and Redhead, T.D. 1990. Can predators regulate small mammal populations? Evidence from house mouse outbreaks in Australia. *Oikos* 59: 382–392.

Singleton, G.R. 1989. Population dynamics of an outbreak of house mice (*Mus domesticus*) in the Mallee wheatlands of Australia—hypothesis of plague formation. *London Journal of Zoology* 219: 495–515.

Singleton, G. and Brown, P. 1998. Management of mouse plagues in Australia: integration of population ecology, bio-control and best farm practice. In: D.P. Cowan and C.J. Feare (eds) *Advances in Vertebrate Pest Management.* Zoological Library Vol. 7 (in press).

Singleton, G.R. and Chambers, L.K. 1996. A large scale manipulative field study of the effect of *Capillaria hepatica* on wild mouse populations in southern Australia. *International Journal for Parasitology* 26: 383–398.

Singleton, G.R. and McCallum, H.I. 1990. The potential of *Capillaria hepatica* to control mouse plagues. *Parasitology Today* 6: 190–193.

Singleton, G.R. and Redhead, T.D. 1989. House mouse plagues. Pp. 418–433 in: J.C. Noble and R.A. Bradstock (eds) *Mediterranean Landscapes in Australia. Mallee Ecosystems and their Management*. CSIRO, Melbourne.

Singleton, G.R., Chambers, L.K. and Spratt, D.M. 1995. An experimental field study to examine whether *Capillaria hepatica* (Nematoda) can limit house mouse populations in eastern Australia. *Wildlife Research* 22: 31–53.

Singleton, G.R., Twigg, L.E., Weaver, K.E. and Kay, B.J. 1991. Evaluation of bromadiolone against house mouse (*Mus domesticus*) populations in irrigated soybean crops. II. Economics. *Wildlife Research* 18: 275–283.

Smith, R.H. 1994. Control methods: non-chemical and non-lethal chemical. Pp. 109–125 in: A.P. Buckle and R.H. Smith (eds) *Rodent Pests and their Control*. CAB International, Wallingford, Oxford.

Stevenson, W.J. and Hughes, K.L. 1988. *Synopsis of Zoonoses in Australia* (2nd edition). Australian Government Publishing Service, Canberra.

Tann, C.R., Singleton, G.R. and Coman, B.J. 1991. Diet of the house mouse, *Mus domesticus*, in the Mallee wheatlands of North-western Victoria. *Wildlife Research* 18: 1–12.

Taylor, J.D., Stephens, C.P., Duncan, R.G. and Singleton, G.R. 1994. Polyarthritis in wild mice (*Mus musculus*) caused by *Streptobacillus moniliformis*. *Australian Veterinary Journal* 71: 143–145.

Appendix 1. A Summary of the Biology and Ecology of the House Mouse

Scientific name: *Mus domesticus*
Common name: House mouse (*also* Field mouse)

Size
- Head/body length 55-100 mm
- Tail length 75-100 mm
- Weight 10-25 g

Description
- Brown, grey or black above; white, pale yellow or grey below. Fur soft, short. Distinguished from similar species by notched upper incisors and musty smell.

Reproductive characteristics

Breeding season	Mostly between spring and autumn, but can breed throughout the year
Mean litter size	6 (range 1-10; nipples 10)
Post partum oestrus	Yes
Gestation	19-20 days (although delayed implantation of up to two weeks has been reported)
Weaned at	18-21 days
Age at 1st breeding	5 weeks

Diet
- Principally seeds but omnivorous and highly opportunistic.

Behaviour
- Predominantly nocturnal except when population density is high.
- Social, living in small groups of related individuals, usually with in a home range that appears to be defended at certain times or at certain population densities. Most young disperse on reaching adulthood.
- Burrows are often complex with interconnecting tunnels. Usually shallow (less than 20 cm below the surface) but in light soils can be 100 cm or more deep. Stores of seed can sometimes be found in burrows. Also nests in natural cavities, e.g. in wood piles, back of stoves, between walls.

Appendix 2: Rodenticides that are registered for use in Qld

Department of Natural Resources and Mines

RODENTICIDES REGISTERED FOR USE IN QUEENSLAND			
Product Name	**Active Ingredient**	**Pack Sizes**	**Registered Usage Area**
Ditrac All Weather Blox Rodenticide	Brodifacoum	1.8 kg, 4 kg, 8 kg, 10 kg	Commercial/Industrial Buildings Domestic Buildings Farm/Agricultural Buildings
Ditrac Rodenticide	Brodifacoum	2 kg, 5 kg, 10 kg	Unspecified Perimeter baiting adjacent to crops
Farmoz Rodex B Rat Blocks	Brodifacoum	2 kg, 5 kg	Commercial/Industrial Buildings Domestic Buildings Public Services
Farmoz Rodex B Rodenticide Pellets	Brodifacoum	300 g, 5 kg	Commercial/Industrial Buildings Domestic Buildings Farm/Agricultural Buildings Public Services Perimeter baiting adjacent to crops
Hortico Ratsack 1 Shot Rat and Mouse Bait	Brodifacoum	150 g (2 x 75g)	Unspecified
Klerat Rodenticide Wax Blocks	Brodifacoum	10 kg	Sugarcane
Mortein Rat Kill, Rat & Mouse Killer	Brodifacoum	150 g (4 x 37.5g), 450 g (12 x 37.5g)	Unspecified
Oztec Ratal Rodenticide Pellets	Brodifacoum	200 g, 1 kg, 10 kg, 140 kg	Commercial/Industrial Buildings Domestic Buildings Farm/Agricultural Buildings Public Services Perimeter baiting adjacent to crops
Talon Rodenticide All Weather Rodenticide Wax Blocks	Brodifacoum	75 g, 1 kg, 2.4 kg, 10 kg	Commercial/Industrial Buildings Domestic Buildings Farm/Agricultural Buildings Public Services
Talon Rodenticide Pellets	Brodifacoum	50 g, 200 g, 1 kg, 10 kg	Commercial/Industrial Buildings Domestic Buildings Farm/Agricultural Buildings Public Services Perimeter baiting adjacent to crops
Bromakil Super Rat Bait	Bromadiolone	500 g, 2 kg, 5 kg, 15 kg	Commercial/Industrial Buildings Domestic Buildings Public Services Perimeter baiting adjacent to crops
Bromakil Super Rat Blocks	Bromadiolone	1.4 kg	Commercial/Industrial Buildings Domestic Buildings Public Services
Bromakil Super Rat Drink Concentrate	Bromadiolone	500 mL	Commercial/Industrial Buildings Domestic Buildings Public Services
Contrac Blox	Bromadiolone	1.8 kg, 8 kg, 9 kg	Commercial/Industrial Buildings Domestic Buildings Public Services
Contrac Rat and Mouse Bait	Bromadiolone	5 kg (100 x	Commercial/Industrial Buildings

		50g), 10 kg	Domestic Buildings Public Services Perimeter baiting adjacent to crops
Contrac Rodenticide	Bromadiolone	5 kg, 10 kg	Commercial/Industrial Buildings Domestic Buildings Public Services Perimeter baiting adjacent to crops
Country Di-O-Lone Super Rat Grain Bait	Bromadiolone	500 g, 1 kg, 2 kg, 5 kg, 10 kg, 20 kg	Commercial/Industrial Buildings Domestic Buildings Farm/Agricultural Buildings Perimeter baiting adjacent to crops
Rattex Bromablock	Bromadiolone	5 kg	Buildings Sewers/Drains
Rattex Grain Bait	Bromadiolone	5 kg	Commercial/Industrial Buildings Domestic Buildings Farm/Agricultural Buildings Perimeter baiting adjacent to crops
Rentokil Bromakil Bait for Rats and Mice	Bromadiolone	200 g	Domestic Buildings
Rentokil Bromakil Mouse Mix	Bromadiolone	750 g, 3 kg, 10 kg	Commercial/Industrial Buildings Domestic Buildings Farm/Agricultural Buildings Public Services Perimeter baiting adjacent to crops
Rentokil Bromakil Rodenticide Concentrate	Bromadiolone	1 L, 5 L, 20 L	Commercial/Industrial Buildings Domestic Buildings Public Services
Rentokil Bromakil Super Rat Bait Sachets	Bromadiolone	2.5 kg (100 x 25 g)	Domestic Buildings
Rentokil Bromakil Super Rat Blocks	Bromadiolone	500 g, 2 kg, 5 kg, 10 kg	Commercial/Industrial Buildings Domestic Buildings Public Services
Rentokil Bromakil Super Rat Drink	Bromadiolone	500 mL	Commercial/Industrial Buildings Domestic Buildings Public Services
Rentokil Bromakil Super Rat Grain Bait	Bromadiolone	2 kg, 4 kg, 15 kg	Commercial/Industrial Buildings Domestic Buildings Farm/Agricultural Buildings Perimeter baiting adjacent to crops
Rentokil Bromakil Super Rodent Blocks Rodenticide	Bromadiolone	140 g	Commercial/Industrial Buildings Domestic Buildings Farm/Agricultural Buildings
Rentokil Bromakil-P Rodenticide Pellets	Bromadiolone	200 g, 1 kg, 10 kg	Commercial/Industrial Buildings Domestic Buildings Perimeter baiting adjacent to crops
Tomcat All-Weather Blox	Bromadiolone	112 g, 224 g, 784 g, 900 g, 1.8 kg, 4 kg, 8 kg, 9 kg	Commercial/Industrial Buildings Domestic Buildings Public Services
Tomcat Rat and Mouse Bait	Bromadiolone	50 g, 200 g, 300 g, 500 g, 1.75 kg, 2.5 kg, 3.5 kg, 5 kg, 10 kg	Commercial/Industrial Buildings Domestic Buildings Public Services Perimeter baiting adjacent to crops
Yates Mouser One Shot Mouse Bait	Bromadiolone	33 g	Domestic Buildings
Yates Rat Attack One Shot Rodenticide	Bromadiolone	200 g (4 x 50 g)	Commercial/Industrial Buildings Domestic Buildings
* Rampage Rat and Mouse Bait	Cholecalciferol	1 kg, 1.5 kg	Commercial/Industrial Buildings Domestic Buildings Farm/Agricultural Buildings
Barmac Racupak Ready to use Rodenticide	Coumatetralyl	100 g	Industrial Sites/Factories
Racumin 8 Bayer Rat and	Coumatetralyl	1 kg, 10 kg	Commercial/Industrial Buildings

Mouse Rodenticide Bait Concentrate and Tracking Powder			Domestic Buildings Farm/Agricultural Buildings Meatworks (non-product areas) Wharves
Racumin Domestic Mouse and Rat Bait	Coumatetralyl	150 g	Commercial/Industrial Buildings Domestic Buildings Farm/Agricultural Buildings Meatworks (non-product areas) Wharves
Racumin Mouse and Rat Blocks Ready to use Bait Blocks	Coumatetralyl	1440 g	Commercial/Industrial Buildings Domestic Buildings Farm/Agricultural Buildings Meatworks (non-product areas) Wharves
Racumin Mouse and Rat Bait Pelleted Bait - ready to use	Coumatetralyl	1.5 kg, 15 kg	Commercial/Industrial Buildings Domestic Buildings Farm/Agricultural Buildings Meatworks (non-product areas) Wharves
Ratex Mouse and Rat Bait	Coumatetralyl	1 kg, 5 kg, 15 kg	Commercial/Industrial Buildings Domestic Buildings Farm/Agricultural Buildings Meatworks (non-product areas) Wharves
Hortico Double Strength Ratsak Ready to use Rat Bait	Warfarin	250 g, 350 g, 1 kg, 2.5 kg	Unspecified
* Rattex Gel	Warfarin	500 g	Commercial/Industrial Buildings
* Rattex Tracking Powder	Warfarin	5 kg	Commercial/Industrial Buildings Domestic Buildings
RCI Ratblitz Bait	Warfarin	3 kg, 13 kg	Unspecified
Terminator Mouse and Rat Bait	Warfarin	300 g, 1.5 kg, 8 kg	Commercial/Industrial Buildings Domestic Buildings Farm/Agricultural Buildings
Storm Wax Block Rodenticide	Flocoumafen	500 g, 3 kg, 10 kg	Commercial/Industrial Buildings Domestic Buildings Farm/Agricultural Buildings

* Supply/use restricted to licensed Pest Control Operators

Prepared by Officers of - Land Protection
Department of Natural Resources and Mines and Mines

Chemical Services
Department of Primary Industries

4 June 1998

Pest Status Reviews

Others in the series:

Prickly acacia in Queensland

Rubber vine in Queensland

Mesquite in Queensland

Cabomba in Queensland

Sicklepod in Queensland

Veterbrate Pests of Built-up areas

Hymenachne in Queensland

Bellyache bush in Queensland

Feral pigs in Queensland

Feral Goat in Queensland

For further information contact:

C.S. Walton,
Land Protection,
Natural Resources and Mines.
Phone: (07) 3406 2879.