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Peter R. Brown

Grant R. Singleton

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# IMPACTS OF HOUSE MICE ON CROPS IN AUSTRALIA – COSTS AND DAMAGE

PETER R. BROWN AND GRANT R. SINGLETON

**Abstract:** Rodents cause serious losses to crops in many different parts of the world. The house mouse (*Mus domesticus*, Schwarz and Schwarz 1943) is a serious pest to agriculture in Australia. The impacts of house mouse damage to crops in Australia were examined. Plagues of mice (>1,000 mice/ha) cause enormous economic and social stress to rural communities in Australia. The mouse plague in 1993/94 caused about US\$60 million in damage to crops, intensive livestock industries, and rural communities. The impact of mouse plagues is generally well understood, but there is a dearth of knowledge about the relationship between mouse densities and the degree of mouse damage to particular crops types. This paper examines the relationships between the abundance estimates of mice and the damage they cause to crops at sowing and prior to harvest. Crop types examined were wheat, flood irrigated rice, irrigated soybean, and maize. Estimates of damage were obtained by counting the number of tillers (or pods) that were damaged by mice. The results from two field seasons show that mouse population abundance was low (< 75 mice/ha) and the damage to crops was low also (generally < 5%). The positive relationship between damage and the abundance was weak for wheat crops prior to harvest, strong for damage to soybean crops, and unclear for rice and maize crops. More data are required over a wider range of mouse densities. The available data on the effectiveness and costs of mouse control were summarized. These data were used to build an economic model to provide better options for the management of mice. The model will be incorporated into a system for information transfer and decision support for the management of mouse plagues (Mouser CD-ROM).

**Key words:** abundance, Australia, benefit-cost analysis, break-even analysis, damage, density, economics, house mouse, mouse plague, *Mus domesticus*, New South Wales, rodent management, Victoria.

The house mouse (*Mus domesticus*) is a serious pest to agriculture in Australia. Mouse populations occasionally undergo widespread irruptions (= mouse plagues) in the grain-growing regions of Australia. In 1993-94, a mouse plague caused losses estimated at US\$60 million (Caughley et al. 1994). The impact of mouse plagues can be classified as off-farm and on-farm (Redhead 1988, Caughley et al. 1994). Off-farm impacts include mouse damage to stock, electrical equipment, and intensive animal holding facilities (insulation, electrics, other infra-structure); costs associated with labor for trapping and cleaning up after mice; and losses associated with consumption, spoiling, and contamination in premises of rural suppliers, food retail outlets, schools, hospitals, telephone exchanges, and accommodation venues. On-farm impacts include damage to crops (at sowing, tillering, and harvest), stored grain, and livestock (particularly in piggeries and poultry industries where mice contaminate feed and physically damage animals by gnawing them, causing reduced rates of production and increased risk of disease). Another form of impact is the stress to rural communities from sharing their living space with literally hundreds of mice and from the insidious effect of mice on their livelihood. This cost cannot be estimated.

Mouse plagues have been a feature in grain-growing regions of Australia since the first plague in 1904. They occur somewhere in Australia once every 4 years on average, but their frequency for any particular region is generally 1 year in 7 (Redhead and Singleton 1988, Singleton 1989, Mutze 1991). However, since 1980, the frequency of mouse plagues in some regions appears

to have increased to once every 3 years (Singleton and Brown 1999).

Mouse plagues occur when population densities are >1,000 mice/ha. Farmers generally do not perceive they have a mouse problem until densities are >200 mice/ha (Singleton and Brown unpublished data). Densities of mice have been recorded as high as 2,716 /ha (Saunders and Robards 1983) and >2,500 /ha (Boonstra and Redhead 1994). Mouse plagues develop in 4 stages (Singleton 1989). Stage 1 is the *low phase* where the abundance of mice is <10 mice/ha in all habitats, Stage 2 is the *increase phase* where the abundance of mice increases rapidly from 10 mice/ha to hundreds of mice/ha in all habitats, Stage 3 is the *peak stage* during winter when densities are highest (>1,000 mice/ha), and Stage 4 is the *decline phase* (crash) where the abundance of mice falls rapidly across all habitats to low densities (<1 mouse/ha). These low densities of mice persist for up to 2 years (Brown and Singleton 1999). The timing of high numbers of mice in relation to the stage of crop development is critical to the level of pre-harvest losses.

Mouse populations in Australia are similar in nature to microtine population cycles in temperate and Arctic regions of the northern hemisphere (Krebs et al. 1995). Microtine populations fluctuate in regular three- to four-year cycles (Krebs and Myers 1974), whereas mouse populations in southern Australia fluctuate, but not in regular 3- to 4-year cycles. Microtine species damage plants by girdling stems of cultivated plantation species, especially at the seedling stage, and damage plants in orchards (Myllymaki 1977). The level of

damage to plants by voles and lemmings can be up to 50% (Radvanyi 1980).

Management of mouse population problems in Australia generally has been reactive rather than palliative. During mouse plagues, large amounts of poisons are distributed to control mouse damage (see Singleton 2000 for review). In South Australia and Victoria during the 1993-94 mouse plague, 350,000 ha of crops were baited with strychnine (Mutze 1998). In Queensland in 1995, 250,000 ha were baited with strychnine (Fisher 1996), and in New South Wales in 1999, 500,000 ha were baited with zinc phosphide (David Croft, NSW Agriculture, personal communication). Current research is aimed at preventing the extensive spreading of poison by early preventive actions that confirm the concepts of ecologically based management (Singleton 1997, Singleton and Brown 1999).

Little is known about the relationship between the abundance of mice and the damage caused to agricultural crops in Australia. A summary of the data available from the few published studies is presented in Table 1. Not surprisingly, much of the information is associated with mouse plagues. Mouse densities are

highest in autumn and early winter. Therefore, damage is typically highest at the time of sowing of the winter cereals and, for summer crops, during the month prior to harvest. It is difficult to determine the effects of damage at sowing because of compensation by crops as they mature. Actual plant densities have been compared to potential plant densities based on sowing rates, assuming explicitly that the difference is attributable to mice. However, the relationship was inconsistent (Brown et al. 1997a).

The study reported here draws together data on the responses of populations of mice to farm management practices in Victoria and New South Wales, Australia. In each of these studies, mouse abundance was estimated using live-trapping techniques, and crop damage by mice was estimated from transect data. The costs associated with the respective control actions were recorded. The aims of this paper are as follows:

1. To describe and compare techniques for assessing mouse damage in different crop types;
2. To determine the relationships between abundance of mice and damage to wheat, rice, soybean and maize; and

**Table 1. Summary of published information on the damage caused by mice to agriculture in the main grain-growing regions of Australia.**

Date	Region <sup>A</sup>	Crop type/stage	Damage	Mouse abundance	Reference
Summer 1970	Murrumbidgee and Coleambally Irrigation Areas, southern NSW	All standing crops	15-25%	Unknown (plague abundance)	Ryan and Jones (1972)
Summer 1979/80	Murrumbidgee Irrigation Area, southern NSW	Flowering of sunflower	12.4% reduction in yield	2716 mice/ha	Saunders and Robards (1983)
Spring 1990	Mallee, SA	Maturing wheat	2-9% damage between flowering and harvest	70 mice/ha when treated with strychnine	Mutze (1993)
Summer 1989	Macquarie Valley, NSW	20 days before harvest of soybean	4-8.5% 20 days prior to harvest on unbaited sites	157 – 276 mice/ha	Singleton et al. (1991), Twigg et al. (1991)
Summer 1989	Macquarie, Namoi, and Gwydir Valleys, NSW	Soybean crops	2.9, 7.0 and 12.7%	Unknown – but high	Singleton et al. (1991)
Summer 1991	Macquarie Valley, NSW	Prior to harvest of soybean	0.56-2.58% prior to harvest on unbaited sites	Approximately 50-60 mice/ha (calculated from predicted numbers of mice in trap grid)	Kay et al. (1994)
Autumn 1993	Wimmera and Mallee Vic	Sowing of cereals, pulses and oil seed	30%	Unknown – but likely >1,000 mice/ha	Kearns (1993); Kearns (1994)
Autumn 1993	Mallee SA, Mallee and Wimmera Vic	All crops	Some areas required resowing	Unknown – but likely >1,000 mice/ha	Caughley et al. (1994)
Winter 1993	Many regions, SA	Winter cereal crops at sowing	Up to 100%	100-150 ATS (400-600 mice/ha based on a 5x5 grid)	Mutze (1998)
Autumn 1994	Mallee and Wimmera, Vic	Sowing of wheat	Unable to measure	200-650 and 15-250/ha	Brown et al. (1997b)
Autumn 1994	Murrumbidgee Irrigation Area, southern NSW	Rice, maize and soybean	6% (1-75%), 12% (1-75%) and 14% (2-100%)	Not measured	Caughley and Croft (1994), Croft and Caughley (1995)
Winter 1995	Darling Downs, Qld	Prior to harvest of winter cereals	Not measured, but perceived to be high	Unknown – but likely >1,000 mice/ha	Eldershaw (1996)

<sup>A</sup> Regions: SA = South Australia, Vic = Victoria, NSW = New South Wales, Qld = Queensland.

- To present data on the effectiveness and costs of control actions on mouse populations (for use in a CD-ROM decision support system "Mouser").

## STUDY AREAS

### Murrumbidgee Irrigation Area, Southern New South Wales

Population data were collected from 6 farms situated within 20 km of Coleambally, southern New South Wales (34°51'S, 146°05'E; altitude 126 m). The topography of the region is flat to mildly undulating. The soils are predominantly heavy gray-cracking clay soils. The climate is Mediterranean, with hot, dry summers and cool, wet winters. The average rainfall at Griffith (40 km north of Coleambally) is 406 mm per year.

The main crops grown in the region are winter cereals (wheat, barley, and oats, sown early winter, harvested mid-summer), flood irrigated rice (sown mid-spring, harvested mid-autumn), and pulse irrigated summer crops (maize, soybean, canola, and sunflower, sown mid-summer, harvested mid-autumn). Some paddocks were double-cropped with a winter cereal followed by a summer crop. The average farm size was 700 ha.

### Mallee, Victoria

Data were collected from 2 farms situated within 5 km of the Mallee research Station, Walpeup, Victoria (35°04'S, 142°19'E; altitude 115 m). The topography of the region is flat to mildly undulating. The soils are predominantly sandy loams. The climate is Mediterranean with hot, dry summers and cool, wet winters. The average annual rainfall is 340 mm.

The main crops grown are winter cereals (wheat, barley, oats, and rye). Crops are grown in a 2- or 3-year rotation with pasture and fallow periods. Each farm is generally > 1,000 ha in size.

### Wimmera, Victoria

Data were collected from 4 farms within 20 km north of Horsham, Victoria (36°43'S, 142°12'E; altitude 141 m). The topography of the region is flat to mildly undulating. The soils are predominantly heavy cracking clays. The climate is Mediterranean. The average annual rainfall is 452 mm.

Farmers generally implement a 2-year continuous cropping cycle, where cereal, legume (chickpea, field pea, faba bean, lupin, and vetch) and oil seed (canola) crops are grown in alternate years in a particular paddock. The average farm size is 750 ha.

### Mallee, South Australia

Data were collected from 2 sites, Lameroo (35°33'S, 140°52'E; altitude 99 m) and Loxton (34°43'S, 140°60'E; altitude 66 m). The topography and climate is similar to the Victorian Mallee. The average rainfall is 390 and 274 mm respectively.

The farming system is similar to the Victorian Mallee with winter cereals (wheat, barley, oats, and rye) grown in a 2- or 3-year rotation with pasture and fallow periods. Each farm is generally > 1,000 ha in size.

## METHODS

### Assessment of Crop Damage at Sowing

To determine the crop losses attributable to mice at sowing, the actual plant emergence was compared to the potential emergence based on information supplied by the farmers. Data were collected from the Victorian Wimmera after emergence of the 1996 winter cereal and pulse crops. Emergent plants were counted in all paddocks in which mouse populations were monitored regularly. The number of emerged plants were counted along crop rows for 1 meter, at random points along a random transect through the crop. The plant counts were made at 50 paired locations, thereby producing 100 counts. Sowing details were gathered from the individual farmers and the information was used in conjunction with the emergence counts to determine the crop losses that may be attributed to mice.

### Assessment of Crop Damage at Harvest

There are a number of techniques available to assess rodent damage to crops, particularly for rice crops in Asia (see Buckle 1994 for review). The method that seems to best describe damage to wheat crops by mice was modified from Rennison (1979).

$$\% \text{ cut tillers} = 100(a/b)$$

where:

a = number of cut tillers in sample;

b = total number of tillers in sample.

Mouse damage to crops was assessed 2 weeks prior to the farmer's intended date of harvest. Four transects were set through each crop. Each transect was separated by 20 m and was set at least 50 m from edges of crops (roads, fencelines etc.). On each transect, damage to plants was assessed at 5 distances into the crop: 10, 20, 50, 100 and 150 m. Ten plants were assessed at each distance. These plants were selected by choosing every second plant in a line perpendicular to the transect. The number of undamaged tillers and damaged tillers was recorded per plant as well as the number of plants damaged per sampling point.

This technique was used to assess mouse damage in winter cereal (primarily wheat), rice, soybean and maize crops. For cereals and rice, mouse damage was observed on heads and cut tillers. For soybean and maize, damage to pods and cobs was observed.

### Mouse Trapping - Southern New South Wales

Mouse abundance was monitored every 6-8 weeks using Longworth live-capture traps (Longworth Scientific, Abingdon, UK) baited with wheat. Wheat was used as a food source to maintain the animal until the traps could be checked. There is some evidence to suggest that the trappability of mice may be lower when there is abundant alternative food available (Krebs et al. 1994). Furthermore, it is not known whether there is any differential attractiveness of using wheat as bait in different crop types, therefore, this needs to be experimentally tested. All traps were placed at 10-m intervals. One grid (6 x 7) was set in cereal and soybean crops. Traps were placed 50 m from the edge of the crop. A line of 20 traps, with 2 traps at each trap station, was set along the edge of the crop along a fenceline or channel bank. In rice crops, 2 lines of 20 traps were set through internal banks and 1 line of 20 traps (2 traps per trap station) was set along the edge of the rice crop or channel bank. Traps were set for 2 consecutive nights giving 324 trap-nights per census. Trapping coincided with damage assessment (2 weeks prior to harvest).

Population abundance indices calculated were the trap success per 100 trap-nights adjusted by the frequency-density transformation (ATS%) (Caughley 1977) and the Petersen estimate (Caughley 1977). The frequency-density transformation is used because as traps are progressively filled, there are fewer traps available to other animals. Therefore, it represents the number of animals that would have been caught per trap if the traps were capable of multiple captures. The data used to calculate the adjusted trap success were from all the mice caught from grids and lines within a site. We determined the density of mice per hectare in wheat and soybean grids by multiplying the Petersen estimate by the assumed effective trapping area of the grid. The effective trapping area was grid area plus the additional area of one half trap interval width surrounding the grid (60 m x 70 m = 0.42 ha, so it was multiplied by 2.38).

### Mouse Trapping - Victoria and South Australia

The techniques for live-trapping mice in the Victorian Mallee and Wimmera were the same except for the number and arrangement of traps set. Traps were set at 2 grids and 2 lines at each site. The grids consisted of 7 x 7 traps set at 10-m intervals and placed 50 m from the edge of a paddock. A line of 20 traps, at 10-m intervals, was placed along a fenceline adjacent to the grids. At all sites, traps were set for 2 consecutive nights

and baited with wheat, giving 276 trap-nights per site per trap session.

At the South Australian sites (Lameroo and Loxton), traps were set in each of 2 paddocks for 3 consecutive nights in a 6 x 6 grid with 20 traps set along a fenceline adjacent to the grid, giving 336 trap nights per site.

### Relationship Between Abundance and Damage Prior to Harvest

In order to determine the relationship between the abundance of mice and damage to crops, we looked at the adjusted trap success and density of mice/ha from the grid in the crop, from traps on the edge of the crop and from all traps combined. These data were compared with the damage estimates using Pearson Correlations using untransformed data. Depending on the results obtained, only one measure of mouse abundance will be provided.

Where possible, published data were used to supplement our results. For soybeans, we used data from Singleton et al. (1991) and Twigg et al. (1991), and for maize, we used data from Parsons (2000). No comparable data existed for Australian wheat or rice crops.

### Cost of Mouse Control

Options for managing mouse populations were split into 2 categories: routine actions and preventive actions implemented only when mouse numbers were increasing. Data were gathered from farmers involved in studies of best farm management practices conducted in the Mallee and Wimmera regions of northeastern Victoria during 1995-1998, and from published studies. A list of mouse control actions was compiled and information was sought on the cost per hectare or kilometer for each mouse control action, the effectiveness (percentage reduction) of each action, and the effect on the available food supply (for example grain remaining on the ground after harvest).

## RESULTS

### Damage to Crops and the Abundance of Mice

*Damage at Sowing.* – The abundance of mice and damage caused to winter cereals and pulse crops in the Victorian Wimmera, July 1996, were moderately high (Table 2). The average density of mice in winter cereal crops was lower ( $219.5 \pm 16.5$  SE mice/ha) than in pulse crops ( $376.3 \pm 89.9$  SE mice/ha), but the adjusted trap success (ATS%) in winter cereals was higher ( $338.6\% \pm 124.0$  SE) than in pulse crops ( $176.7\% \pm 88.3$  SE) (Table 2). The average damage to winter cereals was 40% ( $\pm 3.7$  SE) and average damage to pulses was 31% ( $\pm 11.8$  SE).

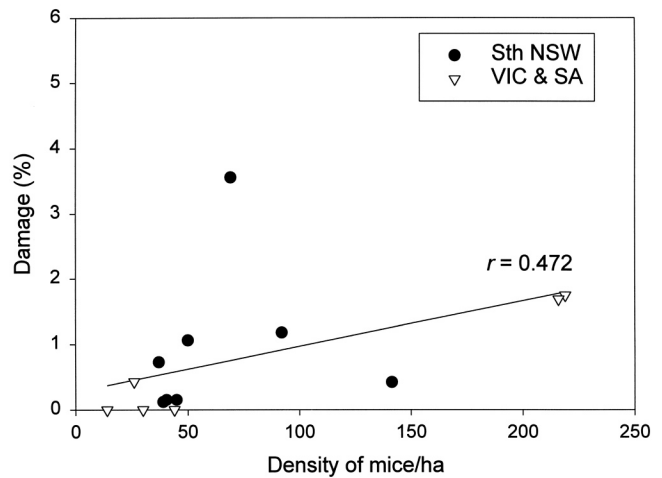
**Table 2. Mouse damage at emergence ( $\pm$  SE) of cereal and pulse crops, Wimmera, July 1996. The potential plant density was determined from sowing rates provided by farmers and assuming 100% germination of seeds planted. Mouse abundance shown as density/ha from Petersen estimates and adjusted trap success (ATS%, which represents the trap success per 100 trap nights adjusted by the frequency-density transformation [Caughley 1977]).**

Farm	Crop	Emergence plants/m	Plants/m <sup>2</sup>	Potential plant density/m <sup>2</sup>	Loss caused by mice (%)	Mouse density (mice/ha)	Mouse abundance (ATS%)
Mills	Wheat	29.7 ( $\pm$ 0.3)	85.4	175	51	209	132.5
Blair	Wheat	14.3 ( $\pm$ 0.3)	95.5	150	36	211	352.6
Walsgott	Wheat	17.3 ( $\pm$ 0.3)	96.0	150	36	191	422.0
McRae	Barley	17.0 ( $\pm$ 0.2)	95.6	153	37	267	147.6
Mills	Chickpeas	15.4 ( $\pm$ 0.2)	43.9	58	24	123	49.9
Blair	Chickpeas	3.6 ( $\pm$ 0.1)	24.1	30	20	413	185.6
Walsgott	Lentils	19.4 ( $\pm$ 0.3)	108.0	125	14	421	423.4
McRae	Field peas	2.9 ( $\pm$ 0.2)	16.1	48	66	548	47.8

*Damage Prior to Harvest.* - The results for damage prior to harvest have been combined across the different regions into the 4 crop types. The level of damage to crops at harvest was low: < 7% for wheat, < 3% for rice, and < 4% for soybean (Table 3). The damage to maize was relatively high (average = 11.8%, range = 0 to 30%). The abundance of mice was relatively low (range 17 to 141.5 mice/ha) in all crops.

**Relationship Between Abundance and Damage Prior to Harvest**

The relationship between the density of mice per hectare and damage to wheat crops was a weak positive correlation ( $r = 0.472$ ;  $P = 0.088$ ;  $n = 14$ ) (Fig. 1). The adjusted trap success did not correlate significantly with damage in rice ( $r = -0.443$ ;  $P = 0.149$ ;  $n = 12$ ) (Fig. 2). The relationship between density of mice/ha and damage to soybean was positive ( $r = 0.718$ ;  $P < 0.01$ ;  $n = 12$ ) (Fig. 3). Too few data were available for maize crops.

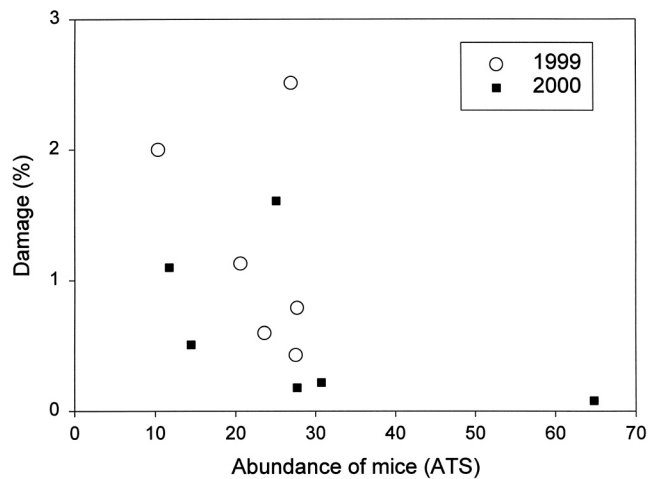


**Fig. 1. Relationship between population density of mice per hectare and damage to wheat crops (% damaged tillers) from the Southern New South Wales (Murrumbidgee Irrigation Area, MIA), Victoria and South Australia, 1999.**

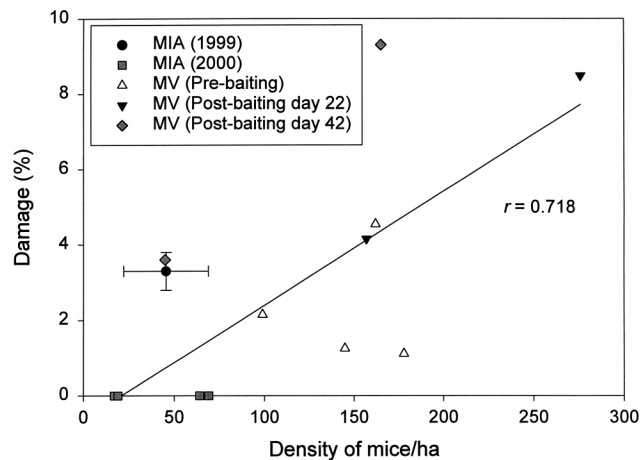
**Table 3. Summary of mouse abundance [density from Petersen estimates and % adjusted trap success (ATS%)] and damage to wheat, rice, soybean, and maize crops two weeks prior to harvest in New South Wales [Murrumbidgee Irrigation Area (MIA) and Macquarie Valley (MV)], Victoria (Mallee), and South Australia (Mallee). The mean, standard error and range of damage and mouse abundance are shown. Sample size (n) refers to number of sites. Trapping for the 1999 soybean crop was conducted on 3 farms within 20 km of the farms where damage was assessed. No data = unable to obtain density estimates on rice or maize crops.**

Region	Crop type (year)	Sample size (n)	Damage to tillers/pods (%)		Mouse density (mice/ha)		Mouse abundance (% ATS)	
			Mean ( $\pm$ SE)	Range	Mean ( $\pm$ SE)	Range	Mean ( $\pm$ SE)	Range
NSW (MIA)	Wheat (1998)	14	0.8 ( $\pm$ 0.2)	0.1 - 2.3	64.3 ( $\pm$ 12.9)	37.0 - 141.5	14.1 ( $\pm$ 2.0)	6.0 - 25.5
NSW (MIA)	Wheat (1999)	14	3.1 ( $\pm$ 0.5)	0.7 - 6.8	51.1 ( $\pm$ 7.5)	37.2 - 80.0	14.0 ( $\pm$ 1.4)	9.3 - 18.5
Vic (Mallee)	Wheat (1999)	2	0	0.0 - 0.0	22.0 ( $\pm$ 8.0)	14 - 30	Not calculated	Not calculated
SA (Mallee)	Wheat (1999)	4	1.0 ( $\pm$ 0.4)	0.0 - 1.8	126.3 ( $\pm$ 52.8)	26 - 219	Not calculated	Not calculated
NSW (MIA)	Rice (1999)	6	0.6 ( $\pm$ 0.3)	0.1 - 1.6	No data	No data	22.8 ( $\pm$ 2.7)	10.3 - 27.7
NSW (MIA)	Rice (2000)	10	1.5 ( $\pm$ 0.3)	0.6 - 2.8	No data	No data	29.1 ( $\pm$ 7.8)	11.7 - 64.8
NSW (MV)	Soybean (1989) <sup>A</sup>	8	4.3 ( $\pm$ 1.1)	1.1 - 9.3	153.4 ( $\pm$ 23.4)	45 - 276	120 ( $\pm$ 21.5)	42 - 240
NSW (MIA)	Soybean (1999)	4	3.3 ( $\pm$ 0.5)	2.0 - 4.0	45.5 ( $\pm$ 23.4)	2.4 - 83.0	10.5 ( $\pm$ 3.1)	4.6 - 15.2
NSW (MIA)	Soybean (2000)	6	0	0	42.5 ( $\pm$ 14.0)	17.0 - 69.0	13.9 ( $\pm$ 5.7)	4.4 - 30.4
NSW (MIA)	Maize (2000) <sup>B</sup>	6	11.8 ( $\pm$ 2.0)	0.0 - 30.0	No data	No data	22	12 - 35

<sup>A</sup> Twigg et al. (1991) and Singleton et al. (1991)    <sup>B</sup> Parsons (2000)



**Fig. 2.** Relationship between population density of mice per hectare and damage to flood irrigated rice (% damaged tillers), MIA 1999 and 2000. ATS represents the trap success per 100 trap nights adjusted by the frequency-density transformation (Caughley 1977).



**Fig. 3.** Relationship between damage to soybean crops (% damaged pods) and population density of mice per hectare, MIA 1999, and from Macquarie Valley (MV), NSW from published data by Twigg et al. (1991) and Singleton et al. (1991). Data presented for this study in 1999 were means and standard errors of damage and mouse density; trapping was conducted on three farms within 20 km of the farms where damage was assessed. Damage was assessed in MV prior to application of a rodenticide at 6 weeks prior to harvest (Pre-baiting), then at 3 weeks prior to harvest (Post-baiting day 22) and at 1 day prior to harvest (Post-baiting day 42).

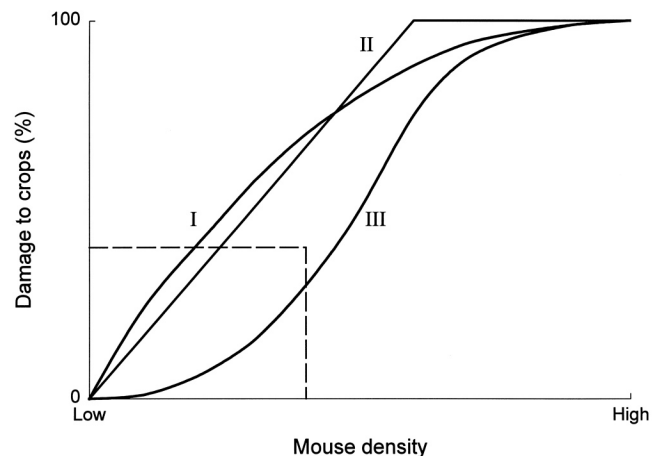
## Cost of Mouse Control

The costs and effectiveness of the routine and preventive mouse control actions are summarized in Table 4. There are some gaps in the available information, so the effect of some actions is unknown. Differences in the timing of some actions can lead to different effects on mouse populations. For example, crisis management using a broadscale application of an acute rodenticide in spring can result in an 80% reduction in mouse populations, whereas an application in autumn will result in a 42 to 66% reduction.

## DISCUSSION

The impact of mouse populations on agricultural crops in Australia is poorly understood. Most of the available information relates to estimates of damage caused by mice to farms during mouse plagues (as presented in Table 1). To understand the impact of mice, it is important to establish the relationship between the abundance of mice and the damage caused to agricultural crops. By understanding this relationship we can start to determine benefits and costs of management actions which will enable farmers to make more informed decisions about the management of mice on their farm.

Our review of the existing data from non-plague situations indicated that most of the data related to mouse densities <75/ha. At these densities, damage



**Fig. 4.** Potential relationships between mouse damage and mouse density in crops. These curves could be used to describe damage at sowing or prior to harvest. Type I shows a relationship where few mice can cause relatively high damage. Type II shows a linear relationship up to a point where 100% of the crop is damaged. Type III shows a response where relatively high densities of mice are required to cause low levels of damage to crops. The dashed box illustrates the extent of current data for the relationship between damage and abundance prior to harvest.

**Table 4. Cost and effectiveness of mouse control actions for Victorian Mallee wheatlands. Management types are classified as routine (should be conducted every year or if high mouse numbers are forecast) and crisis (when mouse plague has irrupted and damage is likely).**

Action	Timing	Effect on mouse population or available food supply	Cost (\$A)	Reference
<b>Routine Management Practices</b>				
Anticoagulant rodenticide in bait stations around perimeter of crop	Spring	40% reduction of mice	\$5.00/km (\$3.46/ha)	1
Anticoagulant rodenticide in bait stations around house and sheds <sup>A</sup>	Spring	Unknown	Unknown	-
Spray grasses and weeds along fencelines in early spring <sup>B</sup>	Spring	30% reduction of mice <sup>C</sup>	\$0.53/ha	1, 2
Slash grasses and weeds along fencelines in early spring <sup>B</sup>	Spring	30% reduction of mice <sup>C</sup>	\$0.53/ha	1, 2
Graze stubble immediately after harvest and at a high intensity	Summer	50% reduction in food	No cost if have sheep	1
Harvest as cleanly as practicable (set machinery to minimize losses)	Summer	Less food available	No cost; may take time	1
Clean up concentrated spillage of grain	Summer	Less food available	Time to do it	1
Clean up concentrated spillage of grain at sowing	Autumn	Less food available	Time to do it	1
Light cultivation after sowing to disguise seed	Autumn	Less food available	\$4.29/ha	1
Sow to even depth	Autumn	Less food available	Require new machinery	1
<b>Crisis Management Practices</b>				
Broadscale application of acute rodenticide	Spring	80% reduction of mice	\$15.00/ha	3
Broadscale application of acute rodenticide (zinc phosphide)	Autumn	42-66% reduction of mice	\$15.00/ha	4
Perimeter application of acute rodenticide	Autumn	20-30% reduction of mice	Unknown	4
Perimeter application of anticoagulant bait stations at sowing	Autumn	Unknown effect on mice	\$3.46 (\$3.75)/ha	1
Sow as deep as agronomically possible	Autumn	Less food available	\$0.35/ha	1
Sow at a higher rate	Autumn	Would enable crop to establish	Cost of additional seed	1
Consider changing crop rotation	Autumn	Unknown	Unknown	1

## References:

1. Brown et al. (1997a).
2. Brown et al. (1998).
3. Clare Dunn et al. (Personal Communication); P. Brown (Unpublished Data)
4. Brown et al. (2002)

## Notes:

<sup>A</sup> Will not affect mouse numbers in the field. Has not been fully examined.

<sup>B</sup> Action must be conducted prior to seed set of grasses and weeds.

<sup>C</sup> A 67% reduction of mice along fencelines, equates approximately to 30% reduction over whole farm.

levels to crops were generally low (<5% crop losses), the relationship between mouse abundance or density and mouse damage for wheat and soybean was positive, and the relationship for rice and maize was not clear. However, farmers generally do not notice damage or notice mice as being present on their farms when damage and mouse abundance are at these levels. Therefore, it is unwise to extend these conclusions given the lack of data from a wide range of mouse densities.

If we consider what possible form the damage/abundance function may take, we will see that our data so far are restricted to the area where there is low mouse densities and low damage (Fig. 4). There are too few data yet to test whether there is a threshold mouse density below which little damage occurs. Furthermore, we are not sure if the relationship is linear or curved.

There are few other examples of studies where the abundance of rodents and damage caused to crops has been examined. Lefebvre et al. (1989) found a strong relationship ( $r = 0.85$ ) between roof rat

population indices (from live trapping) and damage to sugarcane stalks in south Florida. Poché et al. (1982) looked at rodent damage to wheat fields in Bangladesh. Although they did not examine the relationship between rodent abundance and damage, they found greater damage in fields with a higher density of plants.

Furthermore, there are few published studies considering yield loss or damage to crops by small mammals other than rodents. Bell *et al.* (1998) found that by manipulating rabbit (*Oryctolagus cuniculus*) grazing pressure at different stages of winter cereal crop growth in experimental enclosures, that a threshold of rabbit damage occurred early in the growth of the crop. This contributed most to the yield loss. They suggested that it was important to protect the winter cereal crop early in its establishment stage. They did not relate density of rabbits to the level of damage.

The next step to better understand the relationship between damage and abundance would be to



develop a model of mouse damage using the functional response (the association between the amount of food available and the food eaten per animal). This information could then be incorporated into a model to examine whether there are density thresholds, linear relationships, etc. across the spectrum of rodent densities (Hone 1994).

### Damage at Sowing Versus Damage Prior to Harvest

Mice damage newly sown crops by digging up and eating seeds or by grazing newly emerged seedlings. When damage is patchy (1 or 2 plants missing or damaged intermittently), cereal and oilseed plants can compensate by improved tillering and branching because of reduced competition from surrounding plants. Pulse and canola plants are more limited in their ability to compensate in this manner. Pulses and oilseeds cannot compensate if the cotyledon and growing tip are destroyed. However, no crop can compensate after a certain stage of growth. For example, Mutze (1998) found that yield losses due to damage at flowering of wheat were almost directly proportional to the number of heads removed at that time.

In the present study, both the level of damage at emergence (14 to 66%) and the density of mice (123 to 548 mice/ha) were relatively high. However, these data were collected from only 8 sites (5 different crop types), so we cannot draw firm conclusions.

If we compare these results with other published data we see that conclusions are variable. Only 1 other study has looked at damage to winter cereal crops at sowing. Brown et al. (1997b) used potential plant density from sowing rates supplied by farmers and actual plant density from measurements of the number of plants per meter of row multiplied by the row width. They could not accurately gauge mouse damage to crops because in many cases measured plant density was higher than the potential plant density. Given that mouse numbers are generally highest in autumn, around sowing of winter crops, we would expect that mouse damage would be high at this time of year.

The technique we have described here for assessing damage at sowing requires modification. We are assuming 100% germination of sown seeds, no pre-existing bank of cropseed, and relying on accurate sowing rates from farmers. Two alternative methods could be considered for assessing damage at sowing. The first is to set up a number of small enclosures that prevent access by mice and compare emergence rates between enclosed and excluded areas of crop. The assumption here is that the enclosure does not change the emergence potential of the plants. A similar technique was used to determine damage by rats to rice plants in Indo-

nesia (Buckle 1988). The second technique involves sowing areas of crop by hand thereby knowing the sowing rate and attributing any difference in emergence to damage by mice. This also assumes 100% germination and no soil bank of crop seed. These techniques require further study.

If we do a simple sensitivity analysis on the basic assumption that there was 100% germination of seed, we can determine the relative effect on losses caused by mice. If the germination rate of seed was reduced to 95%, then there would be an average 8.1% reduction in loss for the winter cereals and 18.5% reduction in losses for pulses. Because the change in loss was larger than the reduction in sowing rate, it will be important to measure germination rate in any future studies.

Another unknown factor is the relationship between damage at sowing and the yields of the crop at harvest. This requires manipulative studies where damage is inflicted on crops at various periods during the growth of the crop and yields are assessed at harvest. This approach has been used in Hawaii to assess compensation by macadamia trees to rat damage (Tobin et al. 1997).

Accurate measurements of damage to crops by mice are required for benefit:cost assessments. Kay et al. (1994) found it difficult to establish the benefit-costs of mouse control actions because they needed better techniques for assessing crop damage and yield.

### Economics of Mouse Management

The development of an economics model for assisting with the management of mice requires the use of the best available information on the cost and benefits of mouse control actions and also having a reliable damage-abundance function. While we acknowledge that our understanding of the damage-abundance function is based on a small data set, we have good estimates of the effectiveness of particular control actions on mouse populations (Brown et al. 1997a; Brown et al. 1998; Brown et al. 2002) and also the cost of those controls.

In the development of an economics model for the Decision Support System "Mouser" (CD-ROM), the information provided in Table 4 was simplified. Four routine actions (rodenticide around perimeter of crop; spray or slash fencelines; reduce grain after harvest; sow to even depth) and four crisis management actions were used (broad-scale rodenticide use in spring; broad-scale rodenticide use in autumn; perimeter baiting at sowing; sowing at a higher rate than normal). These were selected because we wanted to combine a relatively simple model with realistic sets of actions so the end-users would be able to examine the effects of different types of control methods in isolation or in combination.

The economics model was built using an existing mouse population model. The population model was derived using the numerical response of mice over a 15-year period in the Victorian Mallee region (Pech et al. 1999). Abundance of mice was related to estimates of food availability from cereal crops and grazed pasture and a density-dependent factor representing the effects of predation, disease, and intrinsic regulatory processes.

The model operates by estimating mouse densities from April in the current year to April the next year and always runs 2 simulations: 1 with the mouse control that was specified by the user and one without mouse control options. The model requires estimates of rainfall to determine mouse densities and wheat yields, but the relationship between rainfall and mouse population dynamics is actually much more complex than is depicted in the model. A detailed explanation of an earlier version of the mouse population model can be found in Pech et al. (1999).

When control actions were invoked in the model, the numerical response of mice was affected. These actions have a cost that was then incorporated into the calculation of gross margins. The gross margins were determined using the farm gate price of wheat (tonnes/ha), area sown to wheat (ha), variable costs (\$/ha), an estimate of the wheat yield (based on the rainfall from April to October, Pech et al. 1999), and the cost of mouse control. The estimate of wheat yield was dependent on the population abundance of mice at harvest. As we have demonstrated above, more data are required to strengthen this relationship.

Results of the simulations provide a comparison of control with no control over a 12-month period. Graphs are used to show the effect on the response of the mouse population, gross margins, cost of control, and wheat yields. Much of the data used to generate the economics model have come from the Victorian Mallee, and so caution must be exercised when using the model in other agroecosystems.

Only a few studies have examined the benefit: costs of particular control actions, generally involving the use of a rodenticide (Saunders and Robards 1983, Mutze 1993, Twigg et al. 1991, Singleton et al. 1991, Kay et al. 1994, Brown et al. 1997b), but none have examined the effects of more than 1 action.

A study by Brown et al. (1997a) looked at a break-even analysis to determine the losses farmers would need to prevent in order to cover the costs of mouse control in the Mallee and Wimmera regions of Victoria, Australia. They showed that farmers in the Mallee would need to prevent losses of between 0.13 and 0.19 t/ha in cereal crops to cover the costs of mouse control. This figure represents between 8 and 12% of average

yields. In the Wimmera, the figures were between 0.19 and 0.23 t/ha for cereals (10 to 13% of average yields) and between 0.09 and 0.13 t/ha for pulses (8 to 11% of average yields). The total cost of implementing mouse control options over a 3-year period for the Mallee was \$17/ha for both cereals and pulses and for the Wimmera the total cost was \$29/ha and \$26/ha respectively for cereals and pulses.

## CONCLUSION

Information presented here shows that mice cause serious damage to agricultural crops in Australia during mouse plagues. With the available information, we examined the relationship between the abundance of mice and damage prior to harvest for 4 different crop types. The relationship was positive for wheat and soybean and not clear for rice or maize. More data are required to ascertain this relationship over a wider range of mouse densities, especially between 100 and 750 mice/ha. The technique for assessing damage at sowing requires further improvement to reduce the variation caused by assumed factors.

By gathering all the current information about the effectiveness and costs of mouse control actions, we were able to develop an economics model for the management of mice. The economics model is designed for use by farmers and agricultural extension officers to help provide better management options for the control of mice.

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